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1. Curriculum Vitae

1.1 Personal Data

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1.2 Education and degrees

Ph.D. Degree : December 2006

Institute of Physics, Polish Academy of Sciences, Warsaw (Poland)

Division of Solid State Spectroscopy

Dissertation entitled "*The 3d states in the electronic structure of GaN surface modified with layers containing transition metals*"

Supervisor: Prof. dr hab. Bogdan Kowalski

M.Sc. Degree: September 2001

Department of Physics, Warsaw University (Poland)

Institute of Experimental Physics, Particles and Fundamental Interactions Division

Dissertation entitled "*Detection of muons in the Backing Calorimeter (experiment ZEUS at the accelerator HERA)*"

Supervisor: Prof. dr hab. Jacek Ciborowski

Bachelor's Degree: September 1999

Department of Physics, Warsaw University (Poland)

Institute of Experimental Physics, Solid State Physics Division

Specialization: Solid State Physics

Dissertation entitled "*Morphology of GaN surface studied by AFM*"

Supervisor: Prof. dr hab. Jacek Baranowski

1.3 Employment history

Since the 1st of January 2016 till present: Assistant at the Institute of Physics, Polish Academy of Sciences, Division of Physics and Technology of Wide-Band-Gap Semiconductor Nanostructures, Al. Lotników 32/46, 02-668 Warsaw, Poland;

Since the 1st of January 2007 till the 31st of December 2015: Assistant Professor at the Institute of Physics, Polish Academy of Sciences, Division of Physics and Technology of Wide-Band-Gap Semiconductor Nanostructures, Al. Lotników 32/46, 02-668 Warsaw, Poland;

Since the 15th of October 2007 till the 15th of January 2009: on an "on leave" status, as a postdoctoral researcher at the MAX-lab synchrotron laboratory, Lund University, Box 118, SE-221 00 Lund, Sweden;

Since the 1st of October 2001 till the 31st of December 2006: PhD student at the Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland;

1.4 Bibliometric data according to the Web of Science (Google Scholar) database

Total Impact Factor of scientific publications as given by Journal Citation Reports (JCR) according to publication year: 64.062

Impact Factor of the publications within the habilitation topic: 31.993

Impact Factor of other publications published after finishing PhD studies (not included in the habilitation topic): 16,853

Impact Factor of the publications published during PhD studies: 15.216

Sum of the citation as given by Web of Science (Google Scholar): 332 (451)

Sum of citation of the publications within the habilitation topic: 59 (77)

Sum of citation of the publications published after finishing PhD studies (not included in the habilitation topic): 236 (325)

Sum of citation of the publications published during PhD studies: 37 (49)

Sum of citation without self-citations: 308

Hirsch index as given by Web of Science: 9

2. Scientific achievements forming the basis for the habilitation application

List of scientific publications included in the habilitation:

“Element specific magnetism and electronic structure of selected functional spintronic materials”

- H1. *Description of the new I1011 beamline for magnetic measurements using synchrotron radiation at MAX-lab*
I. A. Kowalik, G. Öhrwall, B. N. Jensen, R. Sankari, E. Wallén, U. Johansson, O. Karis and D. Arvanitis
Journal of Physics: Conference Series 211, 012030 (2010) (*Proceedings Paper*)
- H2. *Element specific magnetometry combining X-ray Circular with Linear Dichroism: fundamentals and applications*
I. A. Kowalik
Acta Phys. Pol. A 127, 831 (2015)
- H3. *Element specific characterization of heterogeneous magnetism in (Ga,Fe)N films*
I. A. Kowalik, A. Persson, M. Á. Niño, A. Navarro-Quezada, B. Faina, A. Bonanni, T. Dietl, D. Arvanitis
Physical Review B 85, 184411 (2012)
- H4. *Role of interface in ferromagnetism of (Zn,Co)O films*
M. Godlewski, E. Guzewicz, M. I. Łukasiewicz, **I. A. Kowalik**, M. Sawicki, B.S. Witkowski, R. Jakiela, W. Lisowski, J.W. Sobczak, M. Krawczyk
Physica Status Solidi B 248, 1596 (2011)
- H5. *Homogenous and heterogeneous magnetism in (Zn,Co)O: from a random antiferromagnet to a dipolar superferromagnet by changing the growth temperature*
M. Sawicki, E. Guzewicz, M. I. Łukasiewicz, O. Proselkov, **I. A. Kowalik**, W. Lisowski, P. Dłużewski, A. Wittlin, M. Jaworski, A. Wolska, W. Paszkowicz, R. Jakiela, B. S. Witkowski, L. Wachnicki, M. T. Klepka, F. J. Luque, D. Arvanitis, J. W. Sobczak, M. Krawczyk, A. Jablonski, W. Stefanowicz, D. Sztenkiel, M. Godlewski, and T. Dietl
Phys. Rev. B 88, 085204 (2013)
- H6. *Soft x-ray absorption spectroscopy on Co doped ZnO: structural distortions and electronic structure*
I. A. Kowalik, E. Guzewicz, M. Godlewski, D. Arvanitis
Journal of Physics: Conference Series 712, 012104 (2016) (*Proceedings Paper*)
- H7. *Towards a new class of heavy ion doped magnetic semiconductors for room temperature applications*

J.W. Lee*, N.G. Subramaniam*, **I.A. Kowalik***, J. Nisar, J.C. Lee, Y.H. Kwon, J. Choon Lee, T.W. Kang, X. Peng, D. Arvanitis, R. Ahuja
Scientific Reports 5, 17053 (2015), * equal authors

- H8. *Enantiospecific spin polarization of electrons photoemitted through layers of homochiral organic molecules*
M.Á. Niño, **I.A. Kowalik**, F.J. Luque, D. Arvanitis, R. Miranda, J.J. de Miguel
Advanced Materials 26, 7474 (2014)

- H9. *Electron Spin Filter*
J.J. de Miguel, F.J. Luque, M.A. Nino, R. Miranda, **I.A. Kowalik**, D. Arvanitis
Publication no. US2016057859, *United States Patent and Trademark Office* (publication related to Patent Application no. 14/830239)
<https://portal.uspto.gov/pair/PublicPair>
https://worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20160225&DB=EPODOC&locale=en_EP&C=US&NR=2016057859A1&KC=A1&ND=5#
The publication material has been examined by the US Patent and Trademark Office prior to publication.

2.1 Short summary of the scientific activities during the PhD studies

The topic of my PhD thesis was the characterisation and investigation of the impact of the 3d shell of transition metals (TM) on the electronic structure of the TM/GaN system, in the few atomic layers range. The GaN(000 $\bar{1}$) surface of GaN was chosen for the investigations. I did focus my study on the valence band of the TM/GaN system and the shallow Ga 3d core levels. The goal of the work was to identify processes taking place at the interface and characterise the compounds forming there. Within this work, studies of the electronic structure of TM/GaN (TM = Ti, Mn, Co) and MnAs/GaN were done, by means of resonant and angle-resolved photoemission spectroscopy, during *in situ* stepwise deposition of the films and after annealing of the system. The specific transition metals were chosen in such a way, as to study the electronic structure while varying the occupation of the open d shell, moving through the TM series. The technique used, based on the Fano effect, did allow to select and study the contribution of the TM 3d states to the electronic structure of the GaN valence band. I did quantify the modifications of the density of states energy distribution function versus the thickness of the deposited film. The photoemission study results were complemented by *ex situ* studies of the sample surface morphology by means of Atomic Force Microscopy (AFM), the chemical composition by means of Secondary Ion Mass Spectrometry (SIMS) and the magnetic properties by means of SQUID magnetometry. The results of the thesis were compared with theoretical calculations of the electronic structure and other experimental results from the literature.

2.2 Scientific activities after the PhD studies, not included within the habilitation topic

After finishing my PhD studies for about one year I have been working in the area of Atomic Layer Deposition (ALD) technology, which at that time was a relatively new technique for the growth of thin films at the IF PAN. I did work on the optimisation of the growth parameters of ZnO thin films. I did characterise the structure, crystallographic orientation and quality of the films by x-ray diffraction (XRD), AFM, and their optical properties by means of photoluminescence (PL). I did optimise the growth parameters such as temperature, pulsing and purging times of the precursors. I also did perform measurements by means of Scanning Electron Microscopy (SEM). The electronic structure and magnetic properties of this type of ZnO films, ALD grown and doped with magnetic ions, I did characterise by means of x-ray absorption spectroscopy within my habilitation topic.

2.3 Introduction to the results obtained within the habilitation topic:

“Element specific magnetism and electronic structure of selected functional spintronic materials”

2.3.1 Introduction and motivation of the chosen topic

During my PhD studies I have been investigating the electronic structure of semiconductor surfaces by means of Photo-Emission Spectroscopy (PES). These surface science PES experiments were performed using synchrotron radiation to obtain the photons necessary for the photoelectron excitation. After my PhD Thesis defence, in December 2006, I did

modify the direction of my research in order to investigate not only the electronic structure, but also the magnetic properties of novel materials. At the time, a mainstream problem which was discussed in the solid state physics literature in the area of semiconductors was the possibility of inducing a magnetic response in known semiconductor materials. Important efforts were devoted to include various dopant elements into the ZnO and GaN lattice in a substitutional form, these materials being prominent in the field of Dilute Magnetic Semiconductors (DMS). Specific dopants were expected to modify the electronic structure of the host lattice in such a way as to induce in particular a ferromagnetic response, in some cases well above room temperature, leading to a new class of ferromagnetic materials. DMS materials would be based on known semiconductors, which would acquire by means of doping and elemental substitution in random lattice sites, specific magnetic properties, increasing the field of possible applications for semiconductor materials. In view of doping with one more element, characterisation techniques possessing elemental contrast were in demand allowing also for a measure of the magnetic moment on an element specific basis.

Based on these needs in the DMS field, requiring also a magnetic characterisation of semiconductors, I did extend my scientific profile by means of new analysis techniques as discussed in **H[1]** and **H[2]**. Having already the required background in the topic of semiconductor physics, I decided to exploit the possibilities offered by synchrotron radiation in the area of DMS suitable for spintronics applications. I focused on GaN **H[2]**, **H[3]** and ZnO **H[4]**, **H[5]**, **H[6]**, **H[7]** wide band gap semiconductors, doped both with magnetic 3d element ions, but also diamagnetic 6p element ions of high atomic number. Looking for alternative ways to induce a magnetic response and spin sensitivity to an otherwise non ferromagnetic material, I investigated also a new idea opening up new possibilities for spintronics going beyond the traditional semiconducting materials. I did investigate the spin filtering induced by chiral organic molecules in **H[8]**, **H[9]**. Chiral organic semiconductors appear in this context as new interesting materials for spintronic applications. The present collection of papers proposes new physical mechanisms to exploit, in the search for new spintronic materials. Doping with p element ions allows to reveal the importance of p symmetry electronic states in ZnO **H[7]**. Doping with heavy elements allows to introduce sites of high spin-orbit energy in the host lattice helping to stabilise the ferromagnetic response in DMS materials **H[7]**. In a different direction I did study the use of chiral organic molecules as efficient spin filters at the single molecule level **H[8]**, **H[9]**. To study the above mentioned new materials I decided to complement my PES expertise learning to use X-ray Absorption Spectroscopy (XAS). I chose to focus on XAS and X-ray Magnetic Circular Dichroism (XMCD) experiments in the XAS mode in the soft x-ray range, which covers the L-edges of the 3d transition elements **H[2]**. These absorption edges are important for magnetism applications. XMCD allows for the determination of magnetic moments in an elementally and electron shell resolved manner in magnetic systems. I also added to my previous knowledge of PES, spin analysis. These techniques form a comprehensive and valuable complement to my previous experience in photoemission spectroscopy in the spectroscopic characterisation of magnetic materials in general and more specifically also DMS materials. They allow for magnetism and electronic structure studies with elemental sensitivity of several new classes of functional spintronic materials, which I chose as the topic of my habilitation. Given the fact that the dopant dilution level is often high in typical DMS materials, several time consuming experimental innovations were needed in the course of this work, as described in **H[1]** and **H[2]**. The result of this investment is more than satisfactory. As discussed in this summary and collection of papers, given the high experimental accuracy reached, combined with the multitude of synchrotron radiation

based techniques applied, it is possible to propose two new physical mechanisms to obtain new families of materials for spintronic applications **H[7],H[8]**.

I used the opportunity offered by the construction and commissioning of a new high brilliance beam line in the soft x-ray range for x-rays of variable polarisation, to gain developer expertise in the photo-absorption spectroscopy technique. I did start my habilitation work by taking part in the completion, commissioning and managing of the early user operation of the new soft x-ray beam-line I1011 at MAX-lab (Lund, Sweden) during my two-year post-doctoral fellowship in this Swedish national laboratory **H[1]**. As a result in my habilitation work I could exploit fully the possibilities of XMCD/XAS for the obtention of unusually weak magnetic signatures, as I not only did use but also did design and commission several underlying tools for x-ray absorption for a state the art beam-line in this area. As I discuss in the habilitation papers, I not only characterise existing families of spintronic materials, but I also provide new physical mechanisms to design new ones. I demonstrate in few selected cases that the best insight in the electronic structure origins of the magnetic response can only be obtained by the combination of XMCD, XAS and PES probing several core levels and using x-rays of variable polarisation.

The habilitation topic aims to develop and characterise new functional materials for applications in spintronics using the possibilities offered by spectroscopy, exploiting in particular resonant excitation. It targets magnetic properties and electronic structure studies of three families of materials. Two of them, wide band gap GaN and ZnO semiconductors, are broadly studied not only for magnetism related, but also energy saving and optical applications. For GaN and ZnO based DMS materials, the present collection of papers uses the possibility to measure the contribution to the magnetic response of the N(2p) **H[3]** and O(2p) **H[7]** states. Experiments at a synchrotron radiation facility are necessary in this context, given the tunability of the photon source excitation, which allows to obtain element and electron shell specific information. Going one step further, to allow for a spin resolved characterisation of the electronic states, control of the polarisation state of the exciting radiation is also extensively used in this paper collection, both in the soft x-ray, as well as the vacuum-ultraviolet (VUV) spectral ranges. Finally, a spin polarisation analysis of the photoemitted electrons allows, when appropriate, to reveal not only the spin of electronic states, but also the impact of molecular orbitals on the spin of transmitted electron beams **H[8] H[9]**.

2.3.2 Novel families and applications of functional spintronic materials using spectroscopy and resonant photon excitation

With the ever-increasing use of sensors, microprocessors and other types of telecommunication and information devices, their energy consumption becomes an important society issue. It constitutes a limiting factor for further increases in performance and limits the use of mobile devices. Even more important is the impact of the energy consumption of information and communication technologies on climate change. Several approaches are explored trying to find a new paradigm in semiconductor technology to address these problems and open new opportunities for growth in the information and communication technology area. In one of these approaches, spintronics constitutes one of the possible solutions to limit energy consumption. Spintronic devices are designed for the use of the electronic spin rather than its charge as the carrier of information in electronic devices.

On general grounds, despite continuous efforts by many research groups during the last decade, for a better control and understanding of DMS materials, several basic questions remain open, making the DMS field still challenging. DMS based on ZnO and GaN doped

with transition metal (TM) atoms have been intensively investigated as previous works indicate the existence of ferromagnetism, even in some cases above room temperature [10, 11]. However, the understanding of the magnetic properties at the atomic level, for magnetically doped nitrides and oxides, is still an open problem. For these samples some groups detect only a paramagnetic response [12–14], while others find the ferromagnetism to persist up to well above room temperature for, nominally, the same system [15]. Hole mediated ferromagnetism of p-type was originally suggested for ZnO:TM systems [16]. However, in several experimental studies RT ferromagnetism was found for n-type materials [17]. Therefore the origin of ferromagnetism for ZnO:TM can be considered to be still not fully clarified.

ZnO and GaN based spintronic materials: status when this work started. The limited solubility of transition metals in semiconductors leading to chemical phase separation (spinoidal decomposition) of the alloy into nanoscale regions containing a high concentration of the magnetic constituent embedded coherently in a non ferromagnetic host, can be viewed as a new possibility to grow in a controlled way nano crystals of ferromagnetic and antiferromagnetic phases, such as Fe_xN nanocrystals in GaN. It has been found, that due to a significant contribution of highly lying open d orbitals to the bonding energy, the magnetic elements, instead of assuming random positions over the cation lattice sites, tend to aggregate during the epitaxy. Embedded nanocrystals are formed, which either preserve the host structure (chemical decomposition) or give rise to precipitates (crystallographic nanodecomposition) [18, 19]. Owing to a large concentration of the magnetic constituent, these nanocrystals exhibit high ordering and blocking temperatures, typically above room temperature and, therefore, control the magnetic properties of the system. At first, lots of attention were paid to ZnO and GaN doped with Mn. In many cases, the ferromagnetism of ZnO doped with Mn caused by the presence of ferromagnetic precipitates of different phases of Mn oxides was observed, while homogeneous material ZnMnO showed no clear ferromagnetic response [12]. The study of the ZnCoO films in recent years shows that the magnetic signal of this material is superparamagnetic in nature and comes from small antiferromagnetic Co precipitations [20], while the uniformly diluted material is paramagnetic. Once it appears that it is possible with the present day samples to easily form secondary phases, an important issue concerning DMS is the formation of ferromagnetic clusters. Given the existence of clusters or nanocrystals in established DMS materials, efforts has been devoted to explore their possible functionalities for spintronic applications [21]. Thin layers of epitaxial (Ga,Fe)N are investigated because of their magnetic properties: the transition temperature, T_C , is higher than room temperature, even at relatively low concentrations of Fe, up to a few percent **H[3]**. Dilute (Ga,Fe)N layers proved to be ideal material to study the size of the exchange integrals of the interactions responsible for the magnetic response of doped semiconductors with transition metals [16, 19]. As a result of a comprehensive electric, structural, magnetic and optical characterisation of the materials under investigation [22, 23], the probable reason for the magnetic response has been identified, namely - depending on the fabrication parameters: (A) the presence of incoherent ferromagnetic Fe-rich nanocrystals of a crystallographic phase other than the matrix (like Fe nitrides) embedded in the paramagnetic host lattice, or (B) chemical phase separation leading to the formation of coherent Fe-rich regions in the GaN lattice [22, 23].

We can minimize the problem of the formation of magnetic precipitations by doping with a non ferro- or non ferrimagnetic element in its bulk and oxide forms **H[7]**. In such a case the formation of precipitates or clusters is less likely to contribute to the ferromagnetic response of the material. In recent years, Cu-doped ZnO has attracted increasing

attention as a promising model DMS material, free of ferromagnetic precipitates. Cu is a potential magnetic ion in the 2^+ state, so only due to substitution of Cu on Zn sites ZnCuO may exhibit magnetic properties. Ferromagnetism cannot arise from the metallic Cu or secondary magnetic phases of Cu because its oxides (CuO and Cu₂O) are non ferromagnetic at 300 K [24]. Despite the above interest, the ZnCuO is not beyond controversies. There are contradicting reports where the authors have confirmed the occurrence of ferromagnetism [25–27] in this material while others have ruled it out [28].

Proposing new directions of research for spintronic materials: doping ZnO with Bi.

It is observed that the generation of holes in the system can stabilize ferromagnetism in the ground state of a DMS material [29]. Ferromagnetic stability of non-TM doped system depends on the concentration of holes and the exchange splitting of the dopant gap states [29, 30]. It is also demonstrated that ferromagnetism could originate within a semiconductor by means of the introduction of free carriers in the system, using anion doping, such as N and C [31, 32]. Focusing on non-TM ions as doping elements, in an itinerant picture of the electronic structure, the choice of heavy non ferromagnetic elements presents the advantage of stabilizing the ferromagnetic response. This is due to the stronger spin-orbit energy associated with the ion cores of heavy elements, linking the magnetic moments with the lattice. It also allows to highlight the impact of electronic states other than the ones of d -symmetry on the mediation of the ferromagnetic interaction. As our model system we choose Bi doped ZnO **H[7]**. A p -element doping by means of lighter atoms, as for example B in ZnO, leads also to a ferromagnetic phase of this material, however in this case the occurrence of ferromagnetism is related to defect formation [33]. In contrast, doping with a heavy p element, such as Bi, leads to $p - p$ interactions related itinerant ferromagnetism, not defect related. This finding strongly suggests that the spin-orbit coupling is indeed a key component to favour itinerant magnetism in ZnO. To my knowledge, we report for the first time on ferromagnetism in a p -metal doped semiconductor **H[7]**. It is well known that doping with a heavy element leads to an increase of the magnetic anisotropy and ultimately the magnetisation for metallic systems, even in the presence of disorder. Thus, non-TM and non ferromagnetic heavy ion doped DMS materials may yield a radically new direction in the search for novel spintronic materials. Most of the magnetic studies of ZnO and GaN systems are done by means of SQUID magnetometry. However, as pointed out by Ando [34]. SQUID magnetometry is necessary but not sufficient to reveal intrinsic ferromagnetism. Thus, a complementary study with an element-specific, magnetism sensitive spectroscopic probe such as a soft x-ray magnetic circular dichroism measurement is needed for this class of materials.

Using chiral organic molecules for spintronic applications. The control of the magnetic properties of established DMS materials, using $3d$ TMs for doping, has proven to be challenging. These difficulties are forming the basis for the search of new families of spintronic materials, with a high degree of flexibility and the potential to be easily integrated in real devices. In this work I do already propose doping ZnO with heavy non-TM ions, in order to take advantage of the possibility of $p - p$ electron state ferromagnetism **H[7]**. Here the spin orbit energy allows to efficiently couple the electron spin to the host lattice and stabilise ferromagnetism. Another alternative is to look for new physical properties to obtain different families of spintronic materials, a theme followed throughout the habilitation papers. I propose that it is still possible to exploit the chirality of organic molecules in order to couple the electron spin to the lattice **H[8]**. The successful development of carbon based

spintronics could represent a technological breakthrough for electronic and optoelectronic applications from several points of view. In the first place, the longer coherence length and smaller probability of scattering of the electron spins during their transport [35] should result in higher carrier velocities and lower energy consumption for devices. The use of molecules and organic materials for the construction of electronic devices has already been actively pursued in the past. Molecular electronics [36] attempts to reach the ultimate stage of miniaturisation and take full advantage of the immense versatility and superior degree of control and reproducibility in the synthesis of the molecular building blocks that can be achieved by the methods of organic chemistry. However, the same features that favour easy spin transport with low scattering also constitute a drawback for the production of spin polarised currents: the weak spin orbit coupling makes spin separation difficult. In many cases thus it has been necessary to resort to traditional magnetic materials as the source of spin polarised currents. Here a new idea is explored to overcome these difficulties: to use purely organic, chiral molecules to generate spin polarisation. Some recent results [37], demonstrate that electrons transmitted through long chiral molecular media acquire a spin polarisation at room temperature comparable to that furnished by conventional ferromagnets. In our work we demonstrate that this process takes place even at the level of a single molecular layer **H**[8], thus allowing for new possibilities for an efficient miniaturisation of molecular spintronic components, once the appropriate chiral molecular layer has been successfully incorporated in an organic spintronic device. An interesting implication of this research in this context, given the fact that in living organisms there is unequal abundance of enantiomers, is the fact that spin scattering may play an important role in the chemistry of life.

Chiral molecules appear in different configurations that are mirror images of each other, called enantiomers. A long-standing mystery of nature is the unequal abundance of enantiomers that was detected first within all living beings on earth and later throughout the universe. The spin-resolved photoemission experiments reported in this work reveal a peculiar relationship between the molecular chirality and the electron spin. Our measurements demonstrate that electron currents photoemitted from films of different enantiomers of the same molecule produce macroscopic spin polarisations oriented along different directions in space. This effect can be observed at room temperature and at the single monolayer scale, even using linearly polarized exciting radiation **H**[8]. Besides setting the basis for the possible use of these carbon-based, low spin-orbit coupling materials as efficient and versatile spin filters for spintronics applications, this first observation of an enantio-sensitive response of the adsorbed chiral films to irradiation can provide some clues on the origin of this puzzling phenomenon.

Already Louis Pasteur, right after his discovery of molecular chirality based on molecular optical activity [38], speculated about a possible connection with magnetism. Although the existence of a relationship between these two effects was later ruled out by Lord Kelvin based on symmetry arguments [39], an increasing amount of evidence has accumulated in recent times strongly suggesting that both fields are indeed related. The asymmetric absorption of photons by chiral media depending on their propagation direction with respect to an applied magnetic field was first predicted theoretically [40] and later confirmed by experiments [41]. This so-called *magnetochiral dichroism* effect [42] has played an important role in the reawakening of the interest on this highly suggestive area of research, culminating in the recent spectacular finding of up to 60% spin polarisation of electrons originating right below the Fermi level of Au substrates and transmitted through layers of chiral double-stranded DNA [37]. Our present results confirm and go beyond the findings

of that pioneering work. In our experiments we have been able to study the effect of the two chiral enantiomers of one molecule, designated as *R* (“*Rectus*”) and *S* (“*Sinister*”). We thus demonstrate that substituting one enantiomer by its specular image does not simply revert the sign of the spin polarisation of the transmitted electrons but rather can rotate the spatial orientation of that polarisation **H[8]**. We also show that strong spin asymmetries, comparable at least to those offered by a typical ferromagnet, can be obtained with films of single molecular thickness at room temperature and without the need for a high degree of long-range structural order within it.

Summary and conclusion. In conclusion, during the present study I did characterize three classes of new materials for spintronic applications by means of a combination of synchrotron radiation based spectroscopies. In two of these material classes the existence of an intrinsic spin polarisation in the valence electronic states was investigated **H[2]**, **H[3]**, **H[4]**, **H[5]**, **H[6]**, **H[7]**. In the third case the lowering of spatial symmetry was found to be at the origin of an induced spin polarisation in electron beams **H[8]**. In the case of chiral molecules and ZnO, the use of the spectroscopy tools was crucial in order to introduce two new classes of spintronic materials.

Early in this study, I found that upon doping GaN with Fe, to obtain iron nitride nanocrystals in the GaN matrix, the N(2p) states of the N atoms clearly contribute to the magnetism, highlighting the importance of the *p*-symmetry states for DMS materials **H[3]**. The ideas on studying the *p*-symmetry state spin polarisation and related analysis tools developed during the work on this system, were expanded, and as a result, it has been possible to also record the O(2p) magnetism upon doping ZnO with the heavy diamagnetic *p*-metal B **H[7]**. I did develop the analysis tools stemming from the work on this system one step further, and as a result, it has been possible to also record the O(2p) magnetism upon doping ZnO with the heavy diamagnetic *p*-metal Bi **H[7]**. In the DMS field, almost all studies did focus on doping with *d*-metals, mostly from the transition metal series, such as Mn, Cr, Fe, Co, Ni, Cu. In contrast, doping with a non ferromagnetic *p*-metal allows to characterise the importance of the *p* – *p* electron interaction for a DMS system. Bi doped ZnO is found to be ferromagnetic at room temperature, this system constituting a good example of a novel type of a DMS material. Furthermore, the large spin orbit energy of the Bi atoms is found to stabilise the ferromagnetic phase, in analogy to what is also known for metallic systems **H[7]**. In this work I did examine the model Co doped ZnO DMS system **H[4]**, **H[5]**, **H[6]**. It has been possible to further elucidate the origin of the ferromagnetic response and link it to the Co(3d) states, for the Co atoms at the inner interface for thin films grown by means of Atomic Layer Deposition (ALD) **H[4]**, **H[5]**.

The third family of materials, based on chiral organic molecules, is new in the literature. Despite the fact that the impact of chiral molecules on the polarisation state of the light is known since 1848, the use of chiral molecules as new spintronic media was neglected in magnetism oriented research till very recently. In this work I characterise in a spin resolved manner, the structure of the relevant electronic states carrying the chiral information, for a model system consisting of ultra thin enantiospecific molecular layers on a surface. It is found that even a single enantiospecific molecular layer acts as a perfect spin polariser at the single molecule level **H[8]**. Overall, on all the three categories of materials I investigate, I present synchrotron radiation based spectroscopy results, opening possibilities for new applications or new families of spintronic materials.

Importantly, the instrument with which I did perform these studies, the beam line I1011 operating at the MAX II storage ring **H[1]**, **H[2]**. is relocated to Poland and scheduled to

start operation at the new Solaris storage ring, following the built up of a new 3 GeV storage ring in Sweden, a development not allowing for its continued operation there without major investments. It is to hope that the present collection of papers will motivate more studies in this thematic area in Poland, and will inspire new users in the DMS research area to use core level spectroscopy tools to advance the understanding in this challenging and rich in applications solid state physics topic.

2.4 Topical introduction to the habilitation publications

2.4.1 XMCD as a tool for element specific magnetometry H[1], H[2]

Motivation, experimental challenges and general importance. A large part of the results presented here were obtained at beamline I1011 at MAX-lab. The beamline is dedicated to XAS, XMCD and X-ray Linear Magnetic Dichroism (XLMD) as well as X-ray Resonant Magnetic Reflectivity (XRMS) studies. During my post-doctoral fellowship, together with staff of MAX-lab, I was responsible for the characterisation and calibration of the various beam line components. I introduced and coordinated the implementation of all needed modifications in the hardware and software, together with the staff of MAX-lab, preparing the beamline for regular user operation.

I was in charge for the characterisation of the operation of the Elliptically Polarizing Undulator (EPU), in particular for the control of the degree of circular polarisation of the various undulator harmonics. I did design and develop several magnetic standards for that purpose. For some of the measurements it was necessary to grow the magnetic standards *in situ*. In other cases it was sufficient to use *ex situ* grown magnetic standards H[1],H[2]. I have participated with the staff of MAX-lab to the beam line alignment and characterized its impact on the degree of circular polarisation of the x-ray beam. I have participated in the design, buildup and characterisation of several components used in the beam line's end stations, including several detectors and the associated electronics. It has been possible to progressively increase the signal to background and signal to noise ratio for the measured core level spectra and reach surface sensitivity in the range of a small fraction of a submonolayer on a surface H[2]. This part of the work has been time consuming but necessary as the XMCD response of DMS systems can be very weak depending on the absorption edges probed. For work at the O and N K-edges of ZnO and GaN at I1011 the level of accuracy has reached the level of 10^{-4} of the atomic absorption cross section even in cases of high dilution in DMS materials H[3],H[7]. This level of sensitivity is outstanding for a soft x-ray beam line based on operation using the third undulator harmonic, given that the energy of the MAX II storage ring was set to 1.5 GeV. Core level spectra of quality comparable to the ones obtained at 3 GeV storage rings, where work with the first undulator harmonic is possible, have been obtained H[1],H[2],H[3],H[4],H[5],H[6],H[7]. Noteworthy to mention, that not only the electron yield signal has been detected but also the weak fluorescence yield signal which allows for the depth profiling of DMS materials H[7].

Selected results placed in the context of the habilitation topic. The experimental layout of I1011 beamline of the MAX II (1.5 GeV) storage ring at the MAX IV synchrotron laboratory is shown in Fig. 1. To reveal the spin-dependence of the x-ray absorption process, best is to use an x-ray light source capable of delivering variable polarisation. In particular, the XMCD and XLMD techniques requires the full control of polarisation over the whole energy range covering the absorption edges of all relevant elements, in combina-

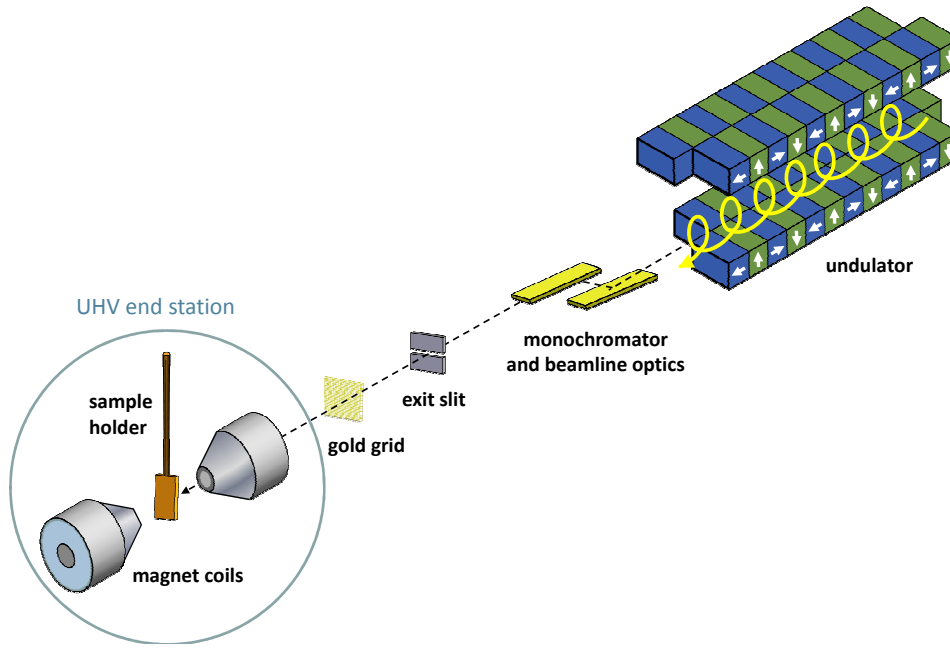


Figure 1: Simple schematic representation of the I1011 beam line at the MAX-IV synchrotron facility in Lund (Sweden) dedicated to XAS/XMCD measurements in the soft x-ray range. The beam line is equipped with an Elliptically Polarizing Undulator (EPU), allowing for full control of the polarisation state of the light. A collimated Plane Grating Monochromator (cPGM from the BESTEC company) provides the high flux ($10^{11} - 10^{12}$ photons/sec) x-ray beam within the energy range of 0.1 - 1.7 keV. The reference signal I_0 is measured in the TEY mode using a gold mesh located between the exit slit and the end station **H[2]**.

tion with good photon energy resolution and sufficient photon flux. This beamline is using an Elliptically Polarizing Undulator (EPU) source producing soft x-rays of a variable polarisation state: linear (vertical and horizontal) to circular, with sufficient flux and brilliance over the important energy range, 0.1-1.7 keV. The high photon flux (as characterised in Fig. 2) makes possible to measure even dilute magnetic samples and nanostructures. The third harmonic of the undulator radiation covers the full range of the L-edges of the 3d transition metal series, allowing for element specific investigations of most technologically important materials.

To optimize the photon flux and resolving power, the collimated Plane Grating Monochromator (cPGM) is used. The cPGM covers under high photon flux and good energy resolution, the energy range of 0.1 -1.7 keV. It contains three blazed gratings, which can be exchanged in vacuum: 336, 1221, or 1400 l/mm. A plane grating solution is used for the x-ray monochromatization, which maintains the polarisation state over the whole energy range covered by the monochromator. The possibility of selecting the so-called c_{ff} parameter allows balancing between energy resolution, photon flux or higher order suppression [43, 44]. The energy resolution was characterized using a gas cell, by measuring the photo ion yield. Various gases were used to cover the energy range of about 0.2 to 1 keV. In Fig. 3 we show the case of Ne gas using the 1221 l/mm grating. The energy range probed using the K-edge of Ne is close to the Co L-edge and characteristic of the performance of the I1011 BL for the late 3d series ferromagnets. The cPGM is designed to deliver a resolution of 10 000 over the whole energy range of operation but even with rather relaxed conditions

($c_{ff} = 4.5$, slit $30 \mu\text{m}$), the resolving power which we reached is more than 9000 for N_2 and 6000 for Ne gas, while the flux at the sample is about 10^{11} photons/sec. The flux, within an order of magnitude, is estimated using the photocurrent from a fine electroformed Au mesh in the beam path.

I participated in the assembly, component design and commissioning of two different custom-made end stations, which can be exchanged, depending on the conditions needed for certain experiments. As an example in Fig. 4(a) the “octupole” magnetic Ultra High Vacuum (UHV) end station is shown. The “octupole” end station has been specially engineered to solve the problem of the limited optical access typically arising from magnetic measurements using synchrotron radiation [45]. The name of the station finds its origin from the eight water-cooled electromagnets, spaced equidistantly over the surface of a sphere of the UHV chamber, which allows the application of the magnetic field in any direction. This solution, together with the possibility to rotate the whole chamber around the beam axis, allows to measure the magnetic properties with a variable geometry of applied magnetic field, electromagnetic radiation and sample orientation. These high current electromagnets (100 A each) generate a field in the sample space of up to 1 T. Such possibilities allow to optimize the measuring conditions for various magnetic systems studied by the XMCD and XLMD method. In another end station dedicated to surface science experiments, a rotatable set of coils has been installed. Here the applied magnetic field can only be rotated in the horizontal plane, by rotating the coils independently of the sample rotation. This system can be routinely baked, allowing for surface science work in ultra-high vacuum (Fig. 4(b)). Only smaller magnetic field values can be reached, given

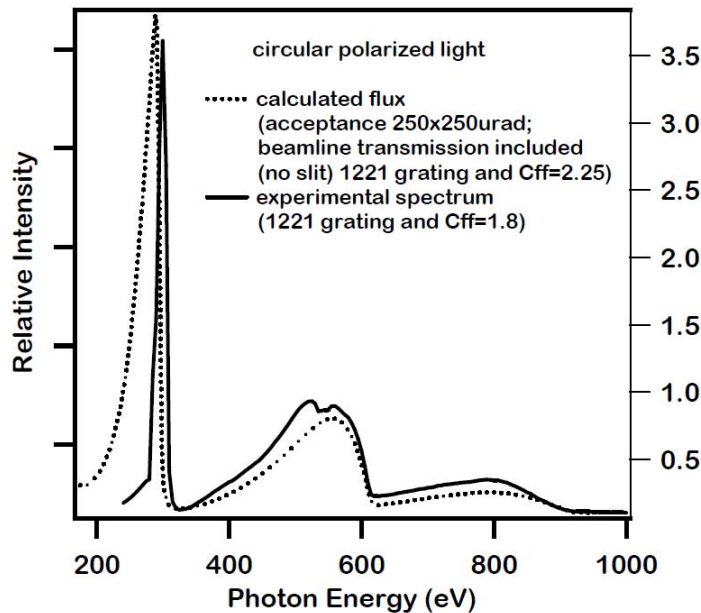


Figure 2: The I_0 photocurrent measured from a Au mesh with the 1221 1/mm grating compared with theoretical predictions for circularly polarized light. The 1st and 2nd harmonics are clearly visible. The minimum in the measured spectrum around 530 eV, is due to oxygen contamination of the optical elements of the beamline. The carbon minima can also be observed, here not so clearly, as they are located in the low energy side of the first harmonic peak. These features can be normalized out in the measured spectra using the I_0 flux reference monitor of the beamline **H**[1].

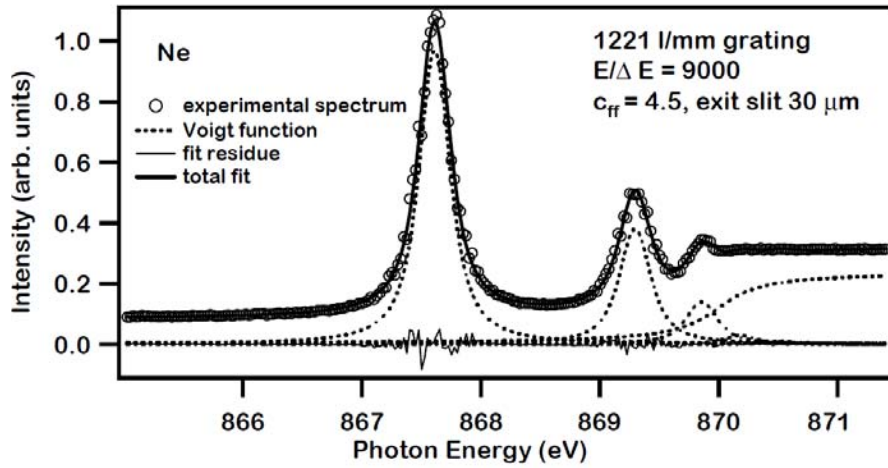


Figure 3: Photo ion yield spectrum recorded at Ne 1s ionization threshold. The spectrum is dominated by the 1s to 3p absorption peak, between 867 and 868 eV. A Voigt profile analysis is shown; the instrumental width corresponds to the resolving power of 6000 **H**[1].

the size limitations of the coils.

Future opportunities opened up by this study, impact for the research area.

Such possibilities allow to optimize the measuring conditions for various magnetic systems studied by the XMCD method [46]. XMCD relies on spin selective photo excitation of the $2p_{3/2}$, $2p_{1/2}$ electrons to the empty $3d$ band, the case of the $3d$ transition metals. Circularly polarised light transfers its angular momentum $+\hbar$ for right handed (σ^+) and $-\hbar$ for left handed (σ^-) to a spin-orbit split core electron states. This process leads to spin selectivity in the XAS using for example the $2p_{3/2}$ and $2p_{1/2}$ electron states. By applying the magneto optical sum rules the orbital (m_l) and spin (m_s) moments can be determined directly from the experimental XMCD signal [47]. We find that the amount of depolarized x-ray light is negligible. The experiments can be carried out both in remanence and under magnetic field, in particular with a constant applied magnetic field (DC mode). Another method available at the “octupole” end station is XRMS known also as resonant x-ray reflectivity. A photodiode detector travels along a ± 90 deg arc perpendicular to the beam axis. This motion, coupled with the entire system rotation of ± 90 deg and incoming light polarisation allows for the diode to be placed anywhere on a hemisphere perpendicular to the beam for any light polarisation. The XMCD or XRMS experiments can be combined with element specific magnetic hysteresis loops taken in total electron yield mode or using the photodiode. This allows for a full magnetic characterisation of the specimen (measurements of saturation moment, coercive force, magnetic anisotropy) in an elementally resolved manner. A cryogenically cooled rod allows the XMCD and XRMS signals to be measured as a function of temperature - down to 20 K.

As a means to perform a characterisation of the degree of circular polarisation of the EPU x-rays, we perform XMCD measurements of magnetic standards **H**[2]. I give as an example data obtained for a thick *bcc* Fe film, exhibiting high degree of crystal order and purity (Fig. 5). The Fe film is protected from oxidation by means of a protective cap layer. The x-ray absorption spectroscopy can be measured in different ways, using various secondary channels. Of importance is to stay in such conditions that the signal chosen is proportional to the absorption coefficient. Here we use the photocurrent of the

sample and work in the Total Electron Yield (TEY) mode. To limit the uncertainties in magnetic moment determination we repeat the same XMCD measurement by varying the different control parameters, which the experiment provides. The dichroic XMCD pair shown in Fig. 5(a,b) is taken by keeping the magnetic state of the sample identical and reverting the light helicity (σ^+ versus σ^-) (by means of reverting the phase of the EPU) and in Fig. 5(c,d) the equivalent result is obtained by keeping fixed the light helicity and reverting the magnetisation direction. We cover the photon energies around the Fe L-edges with the 1221 l/mm grating. We measure the difference in absorption of circularly polarized x-rays between parallel and anti-parallel orientation of the photon spin in the TEY mode.

The angle of x-ray incidence is 45° to avoid saturation effects in the secondary channel. The data are taken in the remanent magnetic state after a 0.2 T magnetic field pulse was applied along the magnetic easy direction. The data can be analyzed using the magneto-optic sum rules, which allows in particular to determine the orbital and spin magnetic

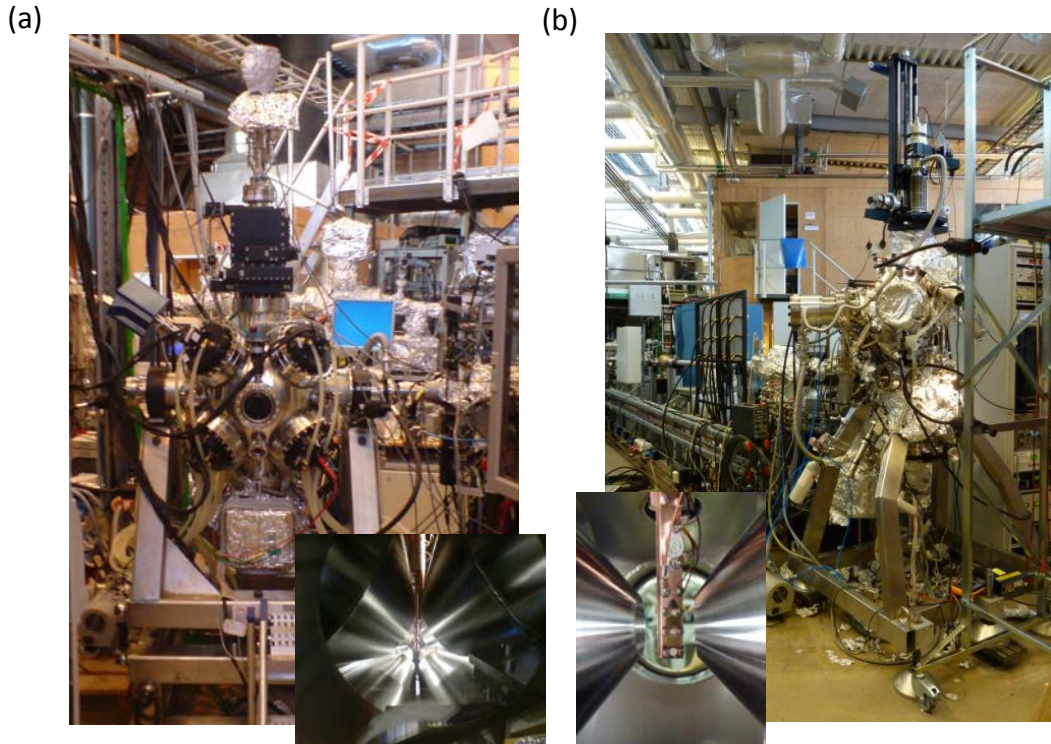


Figure 4: Photographs of the Ultra High Vacuum (UHV) end stations located at the I1011 beam line at the MAX-IV synchrotron facility (Lund, Sweden). The “octupole” UHV chamber is equipped with eight water cooled electromagnets generating a magnetic field in the sample space of up to 1 T (a). The sample positioned in the center between the electromagnets can be rotated around the polar axis (insert of figure (a)). The whole chamber can be rotated around the beam axis by $\pm 90^\circ$, what allows to measure the magnetic properties with a variable geometry of applied magnetic field, electromagnetic radiation and sample orientation, also for the reflected x-ray beam from the sample at grazing x-ray angles. In the end station dedicated to surface science experiments (b), a rotatable set of coils has been installed (insert of figure (b)). Here the applied magnetic field can only be rotated in the horizontal plane, by rotating the coils independently of the sample rotation.

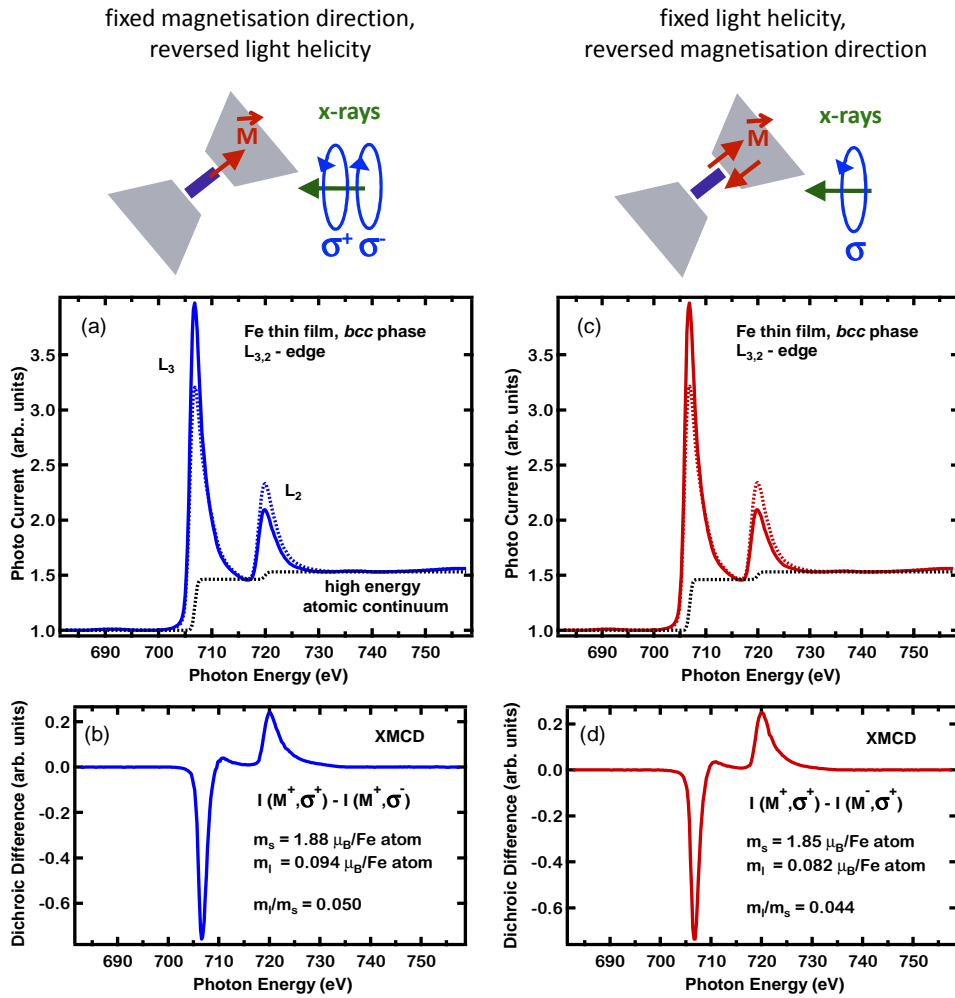


Figure 5: XAS spectra (a,c) and their XMCD difference (b,d) at the $L_{3,2}$ -edges of Fe, for a metallic film of *bcc* Fe. Here are shown two equivalent approaches to measure the XMCD effect. Both methods give the same result within the experimental error. As illustrated in the schematic graphs above, the XMCD measurement can be done by applying two different experimental geometries: fixed magnetisation direction and reversing the light helicity (a,b) or for a fixed light helicity and reversing the magnetisation direction (c,d) **H[2]**.

moments, on a per atom basis. Here we focus on the spin moment by assuming the known number of holes for bulk Fe (3.8) and neglecting the dipole term, which is small for the Fe bulk. Knowing the experimental geometry and assuming that the remanent magnetisation is to a good approximation equal to the full saturation magnetisation, the degree of circular polarisation can be deduced: we obtain a value of 0.9(1). This is close to the predicted value for the 3rd EPU harmonic for the chosen beamline acceptance angle.

Most of the scientific problems included in the habilitation topic and published in the series of articles (page 3-4) were solved by performing experiments at the I1011 beamline at MAX-lab **H[1]**. These results, depending on the need, were completed by means of other techniques as photoelectron emission microscopy (PEEM) **H[3]**, **H[2]** and magnetic PEEM (XMCD-PEEM) **H[2]** or spin and angle-resolved photoemission spectroscopy (ARUPS) **H[8]**.

The overview of the use of the XAS technique to characterise the magnetic properties

for technologically important, low dimensional magnetic materials is given in monography **H[2]**. This article contains the description of both experimental hardware, measurements and data analysis of the spectra.

2.4.2 The magnetic response of Fe_xN nanocrystals: the Fe and N atom contribution **H[3],H[2]**

Motivation, experimental challenges and general importance. Various functionalities have already been demonstrated for semiconductors containing a layer of quantum dots. As reviewed elsewhere, striking electronic, optical, thermoelectric, and magnetic properties have already been observed and proposed for semiconductors with buried metallic and/or magnetic nanocrystals [48, 49].

The experimental study of magnetic nanocrystals embedded in a host lattice requires the combination of several analytical techniques. First of all the nanocrystals should be visualised, and if possible their composition, structure and crystalline order assessed. As a second step the magnetic response of the nanocrystals needs to be recorded and analysed. Using inductive magnetometry, the magnetic response of the material can be typically split up between several contributions, and eventually each one of them can be assigned to a specific sample component. The MOCVD technique has been used by the group in Linz (Austria) to grow Fe rich Fe_xN nanocrystals embedded in GaN. Using SIMS, electron microscopy, XRD, and hard x-ray EXAFS it has been possible to indeed trace the existence of Fe_xN nanocrystals in the GaN lattice [22, 23]. Several Fe_xN nanocrystal phases do appear to co-exist, making this particular system challenging to characterise. SQUID magnetometry did indicate that the magnetic response as a function of temperature and magnetic field is a superposition of several contributions, of which the ferromagnetic and the paramagnetic ones appear to be the most reliable to analyse. These results did motivate the study of these samples in the soft x-ray domain. The spectral region of 0.1-1.7 keV allows for element specific excitation at several core levels of Ga, N and Fe, which allows for information related to each element separately. The N K-edge as well as the Fe and Ga L-edges, do allow to characterise the local electronic and magnetic state of all of the constituent atoms. In particular the Fe L-edges allow for the determination of the orbital and spin moments due to the Fe(3d) electron states of the Fe atoms, the N K-edge allows for the characterisation of the N(2p) states and to probe their possible participation to the magnetic response **H[3]**. Due to the high degree of dilution of the Fe atoms, the spectral intensity relating with the Fe atoms is expected to be weak, and in particular the dichroic response based on spectral differences, challenging to measure with high accuracy.

This was the available context when the soft x-ray spectroscopy and microscopy measurements reported in this paper summary did start. The measurements of the samples do require supplementary care versus the hard x-ray measurements performed earlier, due to the smaller penetration of the soft x-rays in the samples and the limited possibility to use fluorescence yield for recording the XAFS spectra with a high signal to noise ratio using soft x-rays. Fluorescence yield is straightforward to implement for hard x-rays and is routinely available at various beam lines based on commercial detectors. Here the fluorescence yield, only of order of 10^{-3} for the Fe L_3 edge and 10^{-4} for the N K-edge per core hole, does not allow for spectra with a very high signal to noise ratio in the case of dilute magnetic semiconductor samples, as the ones investigated here. Furthermore, the shallow penetration of the soft x-ray fluorescence, in combination with the ultra high vacuum used in this spectral domain, makes the use of soft x-ray fluorescence yield detectors technically

challenging. The dominant de-excitation channel after core hole excitation, allowing to dramatically improve the signal to noise ratio of the spectra in the soft x-ray domain, is the Auger de-excitation channel. High quality spectra, allowing for a good analysis of the small signal originating from the nanocrystals can be obtained therefore in the electron yield mode. Choosing electron yield detection makes that the samples do require surface preparation. The total electron yield signal which was used, allows to characterise the near surface region of the samples, it has a probing depth for the core levels probed here of order of 5 nm. The study of the GaN samples was performed therefore using custom made surface science analytical equipment adapted to magnetism studies. Several problems needed to be addressed, such as the sample surface cleanness and order as well the careful characterisation of possible charging effects in the near surface region of the samples.

The results which were obtained fully justified the investments in operating in ultra high vacuum, fine tuning the detection tools at synchrotron radiation facilities and characterising the status of the sample surface. It has been possible to measure not only the spin moment of the Fe atoms in the Fe_xN nanocrystals, but also their orbital moment. A direct visualisation of the Fe_xN nanocrystals has been possible, with both elemental as well as magnetic contrast. The magnetic domain structure of the nanocrystals has also been recorded. For larger but even for smaller nanocrystals, down to a typical size of order 40 nm, a magnetic multi domain structure was recorded **H[2]**. The level of accuracy of the measurements has allowed to also measure the magnetic response of the N atoms at the N K-edge, despite the fact that at K-edges the dichroic contrast is weak **H[3]**. Finally, it has been also possible to record the XLMD response of the Fe atoms. The XLMD response per photo-excited atom is much smaller as compared to the XMCD response and much harder to record. The importance of this result lies in the future opportunities it opens, as it allows to record the magnetic response of the non ferromagnetic nanocrystals in the GaN matrix.

Selected results placed in the context of the habilitation topic. By exploiting x-ray absorption spectroscopy and related techniques we obtain information on the local electronic and magnetic state of Fe-doped GaN, whose previous structural and magnetisation studies pointed to a highly non uniform Fe distribution and complex macroscopic magnetic properties [22, 23, 50–52]. In particular, by x-ray photoemission electron microscopy (XPEEM), performed at the the Nanospectroscopy beam line at the Elettra Synchrotron facility in Trieste (Italy), we directly demonstrate the existence of Fe-rich nano scale regions residing close to the surface of (Ga,Fe)N epitaxial films. We characterise the distribution, chemical state and magnetism of Fe_xN nanocrystals aggregating in a self-organized manner in epitaxial layers of (Ga,Fe)N **H[2],H[3]**. We demonstrate that Fe_xN nanocrystals embedded in the GaN matrix stabilise the ferromagnetism of (Ga,Fe)N at 300 K **H[3]**. We establish this finding both by means of XMCD-PEEM measurements (dichroic micrographs), as well as by spatially integrated XAS and XMCD measurements. These nanocrystals are characterised by various degrees of nitridation. We quantify the impact of the degree of nitridation on the orbital moment and the stability of ferromagnetism at 300 K.

By means of XPEEM in the XAS mode we do visualise the distribution of nanocrystals and characterise their chemical composition. We also quantify the amount of substitutional Fe diluted in the GaN lattice. By setting the photon energy at the L_3 Fe edge white line, we increase the reliability of the spatially resolved XAS and can also be sensitive to the regions of the samples with the least Fe concentration. In Fig. 6 an example is given, of XPEEM

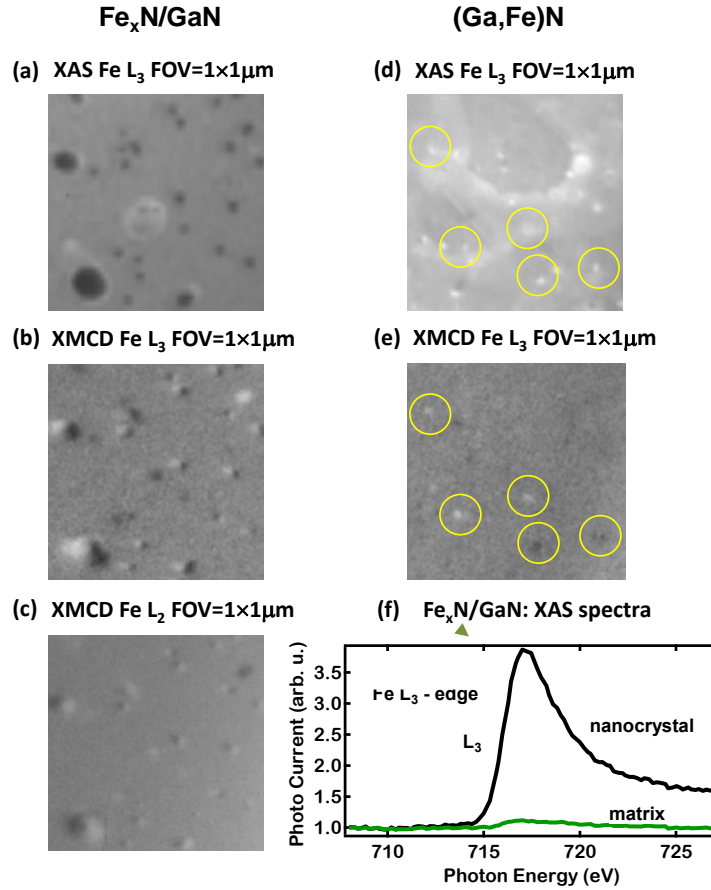


Figure 6: PEEM micrographs measured at the “Nanospectroscopy” beam line at Elettra for a nano-structured $\text{Fe}_x\text{N}/\text{GaN}$ and $(\text{Ga},\text{Fe})\text{N}$ thin film. The Field Of View (FOV) is given for each panel. The microscope operates at grazing x-ray incidence so that only the in plane component of the magnetisation primarily in a specific direction is seen. The micrograph in panels (a) and (d) were obtained in the XAS mode, it allows to visualise the Fe-rich nanocrystals at GaN surface and in the $(\text{Ga},\text{Fe})\text{N}$ surface region, seen as islands of darker contrast. The micrograph in panels (b), (c) and (e) show the XMCD signal at the L_3 ((b) and (e)) and L_2 (c) edges. The XAS spectra shown in panel (f) prove that for $\text{Fe}_x\text{N}/\text{GaN}$ sample almost all the Fe is distributed within the nanocrystals. The contrast is magnetic as it reverts between the two panels ((b) and (c)), an important experimental check. In the case of the larger nanocrystals, the characteristic magnetic contrast of a magnetic “vortex” is seen. For $(\text{Ga},\text{Fe})\text{N}$ film the remaining regions are not entirely dark, indicating that Fe is also dissolved in the lattice. The micrograph (d) and (e) visualises that not all the nanocrystals show ferromagnetic contrast. Data partly presented in **H[2]**.

micrographs for selected samples: Fe_xN nanocrystals grown on the GaN surface (sample number s1311 (a)) and Fe_xN nanocrystals embedded in the $(\text{Ga},\text{Fe})\text{N}$ lattice (sample number s988 (d)) **H[2]**. The micrographs establish the presence of iron rich nanocrystals with sizes of the order of 40 to 150 nm (a) and 30 to 50 nm (d). The nanocrystals are visualised with either a dark or bright contrast versus the GaN matrix. The dark contrast on the micrograph (a) visualises the Fe-rich nanocrystals, a very small amount of iron is also em-

bedded in the GaN matrix. This fact is confirmed by the absorption spectra obtained from the area of a single nanocrystal and the doped GaN matrix (f). Due to the geometry of the measurement, in which x-rays are incident on the surface of the material at an angle of 16° grazing, the contrast is the result of the magnetisation component in the plane of the sample. In the case of (Ga,Fe)N samples, the concentration of magnetic ions is confirmed to be non homogeneous and in the regions where the distance between the Fe-rich nanocrystals is reduced, a bright halo is found connecting the structures **H[3]**. These results correlate the overall magnetisation in terms of contributions from dilute paramagnetic Fe ions and ferromagnetic high-Fe density nanocrystals with the sample topography [23].

The measurements of the Fe_xN nanocrystals grown on the GaN surface are taken at room temperature in the magnetic virgin state of the sample for both Fe edges, L_3 and L_2 . Their magnetic contrast is presented respectively in the (b) and (c) micrographs. The reversed contrast between panels (b) and (c) confirms the magnetic origin of the micrograph contrast. All nanocrystals, regardless of their size, are magnetically live, while the matrix on which they are grown does not show dichroic contrast. Some of the smallest nanocrystals are single domain. The micrograph contrast is indeed reversed when the energy of the photons is tuned from the L_3 to the L_2 -edge. Other nanocrystals have a domain structure in the form of a “vortex” **H[2]**. This structure arises when the formation of a ferromagnetic domain wall becomes a disadvantage in terms of magnetostatic energy. By means of the XMCD-PEEM measurements for nanocrystals embedded in the GaN matrix we find that the nanocrystals for this series of samples are single domain, however not all of them show ferromagnetic contrast (Fig. 6 (e)). The nanocrystals giving no ferromagnetic contrast can be antiferromagnetic or paramagnetic.

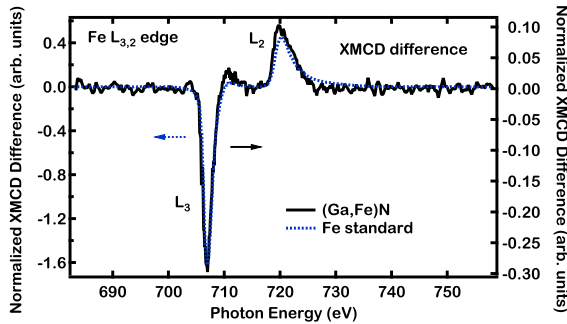


Figure 7: XMCD difference absorption spectra for the Fe L-edges. The XMCD signal is normalised on a *per atom* basis. A strong similarity is observed between a bcc Fe thin film and the Fe in the (Ga,Fe)N sample. The strength of the magnetic response for the (Ga,Fe)N sample is only of order 20% of the bcc Fe film.

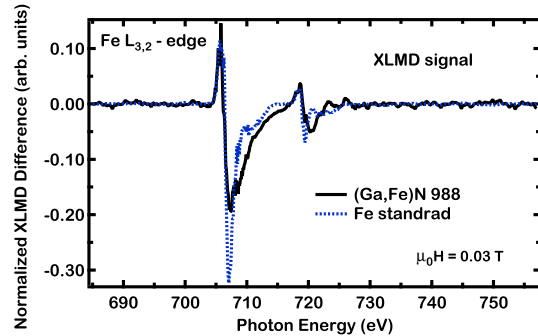


Figure 8: XLMD difference absorption spectra for the Fe L-edges. The XLMD signal is normalised on a *per atom* basis. In contrast to the circular dichroism case there are noticeable differences in the spectral shape of the linear dichroism response of the Fe atoms in the (Ga,Fe)N sample. The XLMD signal strength for the (Ga,Fe)N sample, is comparable to the one for the bcc Fe film, indicating that a considerable amount of Fe atoms are in a non ferromagnetic state.

The magnetic response of the nano crystals which contribute to the existence of a finite magnetisation was studied by using laterally integrating XMCD measurements at the Fe L-edges **H[3]**. An example of a typical XMCD spectrum is shown in Fig. 7. Here the magnetic response of the sample is not fully saturated and depends on the value of the applied

magnetic field. A detailed account of the XMCD analysis of the (Ga,Fe)N samples is presented by Kowalik et al. **H[3]**. Figure 8 illustrates that it is possible to characterise further the magnetic response of these samples using x-ray linear magnetic dichroism (XLMD). For the XLMD measurements, the x-ray absorption coefficient is measured with the electric field direction of the incident x-rays, parallel and perpendicular to the direction of the magnetisation of the sample. The XLMD signal is much smaller than the XMCD signal, but clearly measurable at the I1011 beam line **H[2]**. It is importantly non zero for both ferromagnetic and antiferromagnetic arrangements of the atomic magnetic moments [53]. The XLMD difference of Fig. 8 confirms that a large number of magnetic nano crystals is in a non ferromagnetic state. In contrast to the XMCD signal of the Fe_xN nano crystals of Fig. 7 which is only about 20% of the normalised ferromagnetic response of bcc Fe on a per atom basis, the XLMD response is comparable, illustrating that indeed a strong fraction of the Fe_xN nano crystals, has the moments of the Fe atoms in a non-parallel arrangement. This result is consistent with the XMCD-PEEM results of Fig. 6, where only about 50% of the Fe rich nanocrystals do exhibit XMCD contrast.

The XMCD signal in Fig. 9 appears to consist of two contributions: an oscillatory part is superimposed to broader $\text{N}(2p)$ localised features, re-emphasising the presence of different magnetic phases. Following earlier work [54] we also plot the second derivative of the XAS spectrum. Agreement is observed with the oscillatory part of the XMCD signal, suggesting that the probed final states possess a considerable degree of itinerant character. One determines from the spectra of Fig. 9 an exchange splitting energy of about 0.9 eV that falls within the expected range for itinerant magnetism. The observed band character suggests that the Fe_xN nanocrystals polarise also atoms in their near vicinity. This polarisation explains the large XMCD signal and its sizeable angle dependence. The angular dependence of the N K-edge XMCD signal, which follows distinct spectral features, attributed to $\text{N}(2p)$ states, is an additional indication that the spin polarisation of N atoms is induced by exchange couplings to neighbour Fe atoms. In order to gain further quantitative insight into our experimental XAS and XMCD spectra, we compare our data with theoretical spectra **H[3]**. We use the FEFF package, which is an *ab initio*, self-consistent, multiple scattering code for simultaneous calculations of excitation spectra and electronic structure. In this work, we model also the magnetic part of the absorption coefficient. The accuracy of the experimental data reaches the value of the order of 10^{-3} of the atomic cross section at the N K-edge (Fig. 9), making necessary a high level of accuracy in the theoretical calculations. We use the possibilities of this code, for the calculation of the spectra of clusters of atoms [55, 56]. A GaN cluster in the wurzite crystal structure with a radius of 12 Å (638 atoms) around the photo-excited N atom is used for the calculations. Systematic calculations were performed, varying the radius of the atom cluster around the photo-excited atom, to probe the convergence of the self consistent potential calculations in the full multiple scattering mode.

We reproduce the intensity variations of the various spectral features relative to each other and versus the high energy atomic continuum step, and discuss the origin and symmetries of the various spectral features and N K-edge core level dichroism effects. Our results are consistent with these earlier FEFF calculations, where no angle dependence in the XAS spectra was discussed or any magnetic effects [57]. For the XAS of pure GaN. good agreement is found over the whole photon energy range available between theory and experiment, in particular the edge energy in the theoretical spectra is found to agree with the experiment within 0.5 eV corresponding to a level of relative accuracy of 0.12% **H[3]**. The theoretical spectra indicate that the wurzite hexagonal plane for the GaN lattice, lies

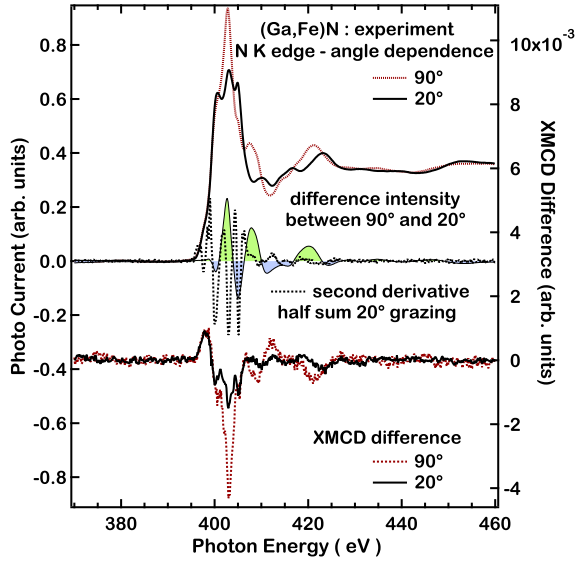


Figure 9: N K-edge for the (Ga,Fe)N sample s300 (left scale), with the constant pre-edge signal 1.0 subtracted, taken with linear x-rays at normal (90°) and grazing (20°) x-ray incidence *versus* the film plane. The corresponding difference spectra are shown: negative peaks (left scale) indicates $s \rightarrow p_z$ states, positive peaks - $s \rightarrow p_x, p_y$. Also shown is the XMCD difference, taken with circular x-rays, for spectra at normal and grazing x-ray incidence (right scale) under an applied field of ± 80 mT. The second derivative of the N XAS spectrum at grazing incidence is shown, as it reproduces the oscillatory part of the XMCD signal, pointing to some itinerant character of the final states **H[3]**.

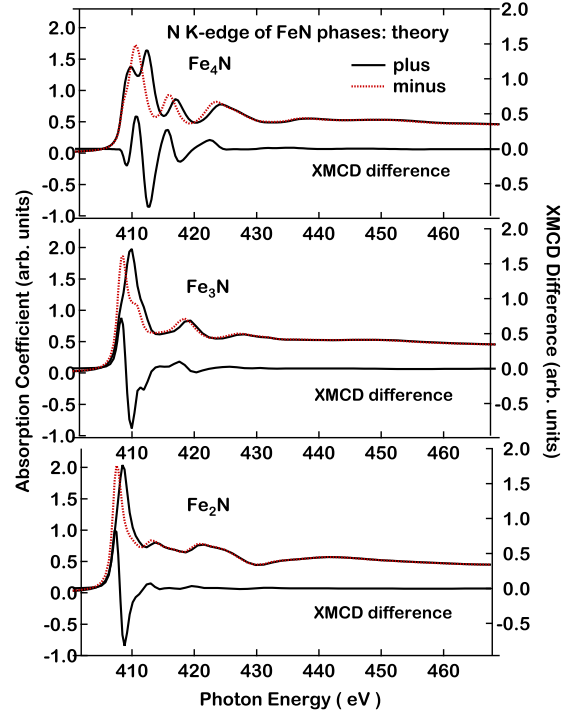


Figure 10: Calculated N K-edge XAS and XMCD spectra *versus* photon energy using the FEFF code for γ -Fe₄N, ϵ -Fe₃N, and ζ -Fe₂N. The XAS spectra (full line and dotted lines, left scale) correspond to full circular x-ray polarisation. The corresponding XMCD difference spectrum is shown in each case (right scale). For γ -Fe₄N, ϵ -Fe₃N the XMCD difference to the stable ferromagnetic state is calculated (full lines for the XMCD, right scale). For ζ -Fe₂N a ferromagnetic state is assumed (full line for the XMCD) **H[3]**.

within the surface plane of the sample. The most intensive spectral feature around 400 eV both in Fig. 9 and Fig. 10 is therefore seen with the electric field vector in the hexagonal plane corresponding to normal incidence **H[3]**.

Having achieved a reasonable agreement for the near edge N K-edge spectral features and their angular dependence between theory and experiment we used the possibility of the FEFF code for the calculation of XMCD difference spectra. The experimental XMCD N K-edge difference consists of a strong oscillation very close to the edge, and is then much weaker at higher photon energies. These weaker oscillations are seen in particular for the experiment using the wave vector of the circular x-ray beam along the surface plane, at grazing x-ray incidence, corresponding to the hexagonal plane of the wurzite unit cell for GaN. The existence of oscillations in the measured XMCD difference is indicative of the existence of itinerant character for the final p states which are probed here **H[3]**.

Focusing on the origin of the XMCD signal at the N K-edge we present here the outcome of computations for γ -Fe₄N, ϵ -Fe₃N, and ζ -Fe₂N, employing experimental values of the lattice parameters.[58, 59] It is observed that also here the XMCD signal contains an oscillatory part and for Fe₃N and Fe₂N it is strongest close to the absorption edge. This allows to conclude that Fe₄N and Fe₃N nanocrystals with a ferromagnetic ground state do contribute to the measured XMCD signal. We use the magnetic structure for these nitride phases previously discussed in the literature [60, 61]. The results, presented in Fig. 10, lead to two conclusions. First, the computed magnitude of normalized XMCD signals is about a factor of 120 larger than the experimental values (Fig. 9). This is an expected magnitude as the Fe concentration is in a 5% range and there are 2 to 4 Fe ions per N in the Fe_xN nanocrystals. Second, any of the computed XMCD spectra presents some similarities to the experimental XMCD results, but cannot fully reproduce the experimental XMCD signals as a function of the photon energy. On the other hand, it appears very likely, that a weighted combination of the computed XMCD data can provide a proper description of the experimental spectra, an interpretation supported by the energy dependence of the second derivatives of the XAS spectra. It is expected that ϵ -Fe₃N, and ζ -Fe₂N nano crystals are the dominant phases [23].

The fact that the XMCD signal exhibits angular dependence, can be explained if a sufficient number of Fe rich nano crystals follow a crystal orientation imposed by the GaN lattice. Such observations have been indeed made earlier, by means of electron microscopy on these samples [23].

Future opportunities opened up by this study, impact for the research area.

The results presented in this section and in the publications by I. Kowalik et al. **H[3]** and by I. Kowalik **H[2]** open up new opportunities for the use of (Ga,Fe)N and in the whole field of DMS in general. Concerning the (Ga,Fe)N system it has been demonstrated that through the careful application of specialised synchrotron radiation based spectro-microscopy tools combined with surface science techniques *it is possible to not only directly image the nanocrystals but also disentangle their magnetic state*. We have been able to fully exploit the XMCD technique to measure the Fe atom spin and orbital moment of the (Ga,Fe)N samples at the Fe L-edges. Furthermore, going beyond the customary analysis *we have been able to record and analyse* (using *ab-initio* calculations) *the magnetism of the N atoms*, to characterise the magnetic contribution of the N(2*p*) states **H[3]**. The fact that we have been able to push the accuracy of the XAFS technique in the soft x-ray range to determine small dichroic differences in the 10⁻⁵ range of the absorption coefficient is allowing to tackle the magnetic response of the light atoms of the second period in the periodic table, which are present in typical wide band semiconductor DMS compounds. We have successfully implemented *ab initio* spin resolved calculations modelling the measured spectra, which explain the observed results. The results of this study *have already been incorporated in a recent textbook in the area of synchrotron radiation and magnetism*, using our spectra and the FEFF code analysis as basic educational material in this area [62]. Finally, *we have resolved basic issues in the detection of the XLMD and have been able to demonstrate its use* **H[2]**. In the context of the (Ga,Fe)N this is an important milestone, allowing to directly probe the antiferromagnetic response of the (Ga,Fe)N samples.

2.4.3 Magnetism and structure in doped ZnO thin films: the impact of d and p symmetry electronic states H[2], H[4], H[5], H[6], H[7]

Motivation, experimental challenges and general importance. Since the theoretical suggestion by *ab initio* computations that (Zn,Co)O can be intrinsically ferromagnetic [29], and the subsequent experimental observation of high-temperature ferromagnetism [15], this compound did reach the status of a model system for a broad class of dilute magnetic oxides [63–65]. However, over the recent years it has become more and more obvious that the understanding of these ferromagnets requires the use of advanced nano-characterisation tools in order to assess how magnetic impurities are actually incorporated and distributed depending on the growth conditions and co-doping [18]. In many studies of (Zn,Mn)O [12, 13] and of (Zn,Co)O [13, 14] only a paramagnetic response has been observed, affected actually by antiferromagnetic coupling between neighbouring spins [14, 66, 67]. At the same time, it has been argued that the abundant observations of high-temperature ferromagnetism in dilute magnetic oxides, if not originating from experimental artefacts, are brought about by a highly nonrandom distribution of TM ions, introduced to the sample either purposely or via contamination [18]. There are many theoretical [65] and experimental [18, 68] studies on DMS in which the cations are partially substituted with transition metal ions to achieve ferromagnetism above room temperature. However, an undesirable phase separation can occur and constitutes a problem in the TM doped DMS, often hindering its practical applications. Moreover, transition metal oxide inclusions may be ferromagnetic themselves, giving rise to doubts on the intrinsic origin of the ferromagnetism in transition metal doped oxide and nitride semiconductors and causing complications for the growth of practical DMS materials.

This is the general context in which the present study was initiated. Given that the soft x-ray domain presents advantages for probing magnetism in an elementally resolved manner for TM ion doped DMSs and dilute magnetic oxides, the present work focused on two possible tracks from the materials point of view using ZnO as the host matrix. In the first case the system of choice was ZnO:Co, and a series of ZnO:Co samples was investigated H[4],H[5],H[6]. Here the possibilities of soft x-ray spectroscopy were used to better understand the origin of the ferromagnetic response observed for some of the samples by means of inductive magnetometry H[5]. In the second case the possibilities of the soft x-ray domain and the very high sensitivity of the detection tools which were developed, was used to propose a solution for the practical use of ZnO indeed as a DMS material. In this work the oxygen specific magnetic response of Bi doped ZnO was measured, using the O(2p) levels H[7]. This study has been challenging due to the fact that dichroic signals at K-edges are weak. For the ZnO:Bi based samples to ensure that the observed magnetism is indeed an intrinsic property as predicted by ground state theory, experimental improvements were made in the detection of the x-ray absorption spectra. Measurements were performed under fields of 0.5 T using simultaneously, both total electron yield (TEY) and fluorescence yield (FY) detection H[7]. The FY probing depth is much longer in ZnO, of order 100 nm, for photon energies close to the the O K-edge, and allows to obtain information from the bulk of the thin films which were investigated. Simultaneously the TEY allows to investigate the near surface region. The data analysis involved the use of the FEFF code to better quantify the experimental results and bridge the gap to the *ab initio* electronic and magnetic structure calculations. In the course of these studies the full available energy range in the soft x-ray domain was exploited. The L-edge magnetic circular dichroism for the Co ions in ZnO:Co was analysed H[2],H[5]. Doping with Bi leads to p-p related itinerant ferromagnetism, as could be directly probed using the O

K-edge to probe the dichroism of the O(2p) states **H[7]**. Modelling the XAS spectra with the FEFF code, allowed to compare the real space and electronic structure of doped ZnO in the near surface region versus the bulk **H[7]**. Small but significant differences are found. For the ZnO:Co system, intensity variations in the XAS spectra were measured in the O K-edge, Co L-edge and Zn L-edges which could be traced to small structural effects **H[6]**. Small variations of the real space structure may have a strong impact on the occurrence of ferromagnetism and could improve the agreement between theory and experiment for ZnO based DMS systems.

More specifically, concerning the ZnO:Co system, a series of ZnO:Co thin film samples, with Co diluted in the 10% range, were grown. SQUID magnetometry indicated either a paramagnetic or a ferromagnetic response **H[5]**. Attempting to isolate the origin of the magnetic response, special samples ZnO:Co were prepared, by sputtering away the ZnO material from a region of the sample, creating a crater, where the interface to the Si is exposed. XPS results did indicate that within the crater metallic Co was present **H[4],H[5]**. TEM electron microscopy gave also evidence of the existence of Co rich inclusions close to the Si interface for this series of samples. In this context, given the tools previously developed at MAX-lab **H[1]**, soft x-ray Co L-edge XAS and XMCD studies were started with this series of samples. Laterally integrating XAS and XMCD have been performed using *in situ* surface science tools, as well as XPEEM spectro-microscopy **H[5]**. These studies were performed both probing the near surface region of the ZnO:Co thin film samples, as well as the Si interface of the samples. Our results present evidence that it is possible to control the electronic state of the Co atoms, upon a specific choice of the growth parameters **H[6]**. We correlate the electronic state of the Co ionic cores with variations observed in the electronic structure and local environment of the host lattice atoms, characterised by means of x-ray absorption spectra at the O K-edge and Zn L-edges **H[6]**. The XAS results allow us to discuss the choice of ALD growth parameters in order to influence specific sample properties.

Concerning the novel idea to use ZnO:Bi, we note that with Bi we can minimise the problem of the formation of magnetic precipitations by doping with a non ferro- or non ferrimagnetic element in its bulk and oxide forms **H[7]**. DMS materials with a Curie temperature, T_C , above 300 K can be synthesised by doping with non-TM atoms to substitute for the anions in the semiconductors **H[7]**. Focusing on non-TM ions as doping elements, in an itinerant picture of the electronic structure, the choice of heavy elements presents the advantage of stabilising the ferromagnetic response due to the stronger spin-orbit energy associated with the ion cores of heavy atoms. It also allows to highlight the impact of electronic states other than the ones of d-symmetry on the mediation of the ferromagnetic interaction. We find that doping with a heavy *p* element, such as Bi, leads to *p* – *p* related itinerant ferromagnetism, highlighting that the spin-orbit coupling is indeed a key component to favour itinerant magnetism in ZnO **H[7]**. Non-TM and non ferromagnetic heavy ion doped DMS materials may yield a radically new direction in the search for novel spintronic materials.

Selected results concerning ZnO:Co placed in context. A series of ZnO:Co thin film samples, with Co diluted in the 10% range, have been grown by means of the Atomic Layer Deposition (ALD) technique on Si substrates at temperatures 160 – 300 °C. Table 1 summarises some of the growth parameters **H[6]**. The samples were characterised by means of Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), Secondary Ion Mass Spectrometry (SIMS), X-ray Photoelectron

Sample	T_g [°C]	ZnO:CoO $m:n$	t [nm]	x_{Co} [%]
F179	160	2:1	140	15(8.9)
F213	300	8:1	130	8.8
F254	160	8:1	70	18-36
F279	300	8:1	1280	5.9
F307	200	2:1	250	8
F328	200	2:1	60	11.4

Table 1: List of the samples investigated in this study. We indicate the growth temperature, the ZnO to CoO cycles ratio, thicknesses, and the Co concentrations obtained from SIMS. Data partly presented in **H[6]**. For samples F179 and F254 SIMS indicates an inhomogenous doping by Co.

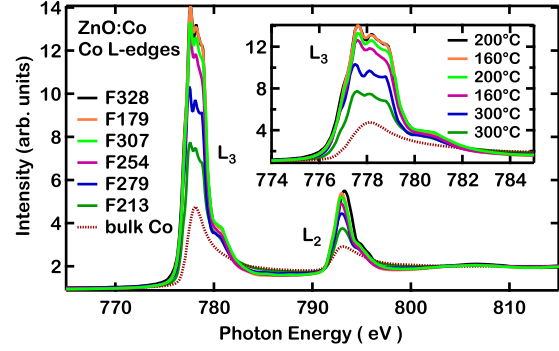


Figure 11: Co L-edge XAS spectra. White line intensity variations are found as a function of the growth parameters. A correlation with the growth temperature (see insert) is found. Data partly presented in **H[6]**.

Spectroscopy (XPS), High Resolution Transmission Electron Microscopy (HR-TEM) and SQUID magnetometry to quantify the surface topography, crystal grain size, phase purity, atom composition and magnetic response of the samples for the samples discussed here **H[4],H[5]**.

We observe systematic variations of the Co L-edge white line intensity and multiplet features for this series of samples **H[6]**. We document sizeable differences in the electronic state of the Co ionic cores, as well as in the local environment of the host lattice atoms, characterised by means of x-ray absorption spectra at the O K-edge and Zn L-edges. Model calculations allow to assign the observed effects to small structural distortions of the ZnO lattice **H[6]**. Guided by the results of the XPS and HR-TEM studies, we employ XMCD to investigate with elemental selectivity the properties of the Co nanocrystals located at the layer/substrate interface **H[2],H[4],H[5]**. The XAS and XMCD measurements are performed in the TEY mode by measuring the photocurrent of the sample, meaning that only about a 5 nm thick zone located just below the illuminated surface of the layer is probed. This is highly advantageous here, as we can investigate separately the near surface region of the ZnO layer, and compare with the bottom interface with the substrate in the crater **H[2],H[4],H[5]**. In Fig. 11, Fig. 12 and Fig. 13 TEY results are shown at normal x-ray incidence, using linearly polarised x-rays. All XAS spectra are normalised to the atomic continuum on a *per atom* basis to allow for a meaningful comparison. To allow for a determination of the electronic state of the Co atoms, spectra were taken also for a reference metallic Co sample using a thin film grown and characterised *in situ* **H[2]**.

The Co L-edges of the ZnO:Co films do indeed exhibit the typical multiplet shapes observed earlier on ZnO:Co magnetically dilute samples [69, 70]. We denominate the samples using a growth sequence number, such as F328 (Table 1, Fig. 11). We observe in the data presented in Fig. 11 a strong increase of the white lines intensity, versus the Co bulk **H[2],H[5],H[6]**. The white line area is proportional to the number of empty Co(3d) final states. We observe also a decrease of intensity in the spectral regions following the white lines (782-790 eV and 796-802 eV). These spectral areas correspond to Co(4s) final states. The data of Table 1 indicate that the spectral area variations correlate best with the growth temperature. Growth at low temperatures leads to higher white line intensities. The variations observed at the Co L-edge are of the order of several 10% of the XAS

intensity, at the Zn L-edge they are of order few %, in particular in the region close to the edge **H**[6]. Even if in terms of absolute intensity these can be considered small, their relative intensity variation cannot be neglected. The data of Fig. 13 indicate that intensity variations at the O K-edge can be very strong close to the edge, comparable in strength to the intensity variations of the Co data (around 530 eV). It can be seen from the data of Fig. 11, Fig. 12 and Fig. 13 that in cases where the Co white lines are strongest and of comparable intensity, such as in the case of samples F254 and F328, still sizeable intensity variations are observed at the Zn L-edge and O K-edge. In Fig. 11 the XAS intensity variations at the Co L-edges indicates the existence of more empty Co(3d) states and of less Co(4s) empty states, versus metallic Co. A similar result is found for the case of controlled oxidation of ultra thin Ni films for the Ni(3d) and Ni(4s) states [71]. For the Ni films these intensity variations were found to correlate with the decrease of the ferromagnetic response [71]. As each Ni atom is losing first neighbour Ni atoms and acquiring as first neighbour O atoms, the alignment of the magnetic moment of the Ni atoms tends to switch from parallel to antiparallel versus the closest Ni neighbour atoms. A similar effect can be expected here with the Co atoms. The strong variations of spectral intensities for the Co atoms can be understood assuming the existence of Co rich clusters within the ZnO lattice, as suggested earlier [20, 72]. Stronger L-edge white lines allow to conclude, assuming Co clusters are present within the ZnO lattice, either that they are less numerous leading to more substitutional Co, or smaller in size, or possibly incorporating more O atoms. Given the fact that Co is diluted in the ZnO lattice with the concentration in the 10% range, the variations in intensity at the Zn and O edges indicate that the stronger variations observed at the Co-edges correspond to small structural distortions relating with the ZnO lattice. Strain is indeed expected within the ZnO lattice if Co clusters are present, with Co not fully substituting the Zn atoms. It is furthermore observed that the multiplet fine structure at the Co L-edge presents small differences in energy and relative intensities of the features observed, indicating that at least some of the Co atoms, are located in an environment of different crystal symmetry. To elucidate the origin of the spectral variations we use theoretical model spectra where structural distortions are introduced in the ZnO lattice **H**[6].

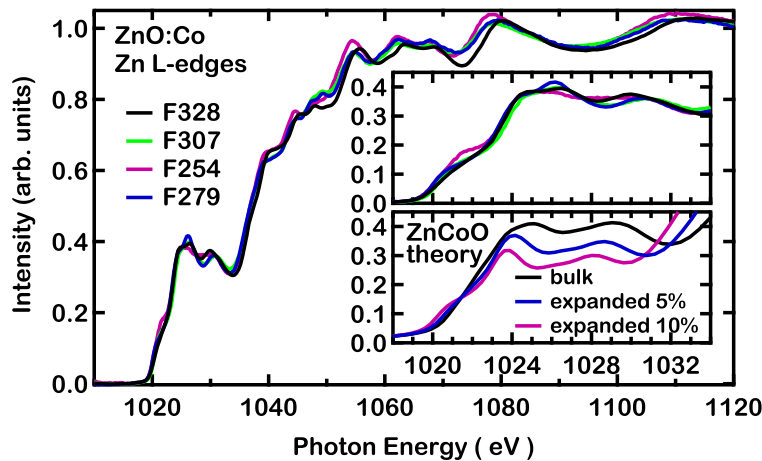


Figure 12: XAS spectra for the Zn L-edges. In the insert the experimental spectra are shown, as well as two model calculations. Data partly presented in **H**[6].

We perform the XAS calculations for the O K-edge and Zn L_3 -edge using the FEFF code, and compare these theoretical model spectra with our experimental results. To

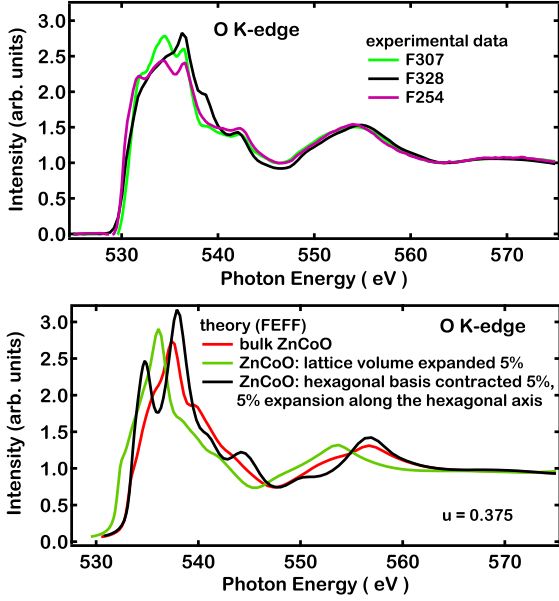


Figure 13: XAS O K-edge experimental and theoretical spectra for ZnO:Co thin film samples. For theory the Co content is 4% **H**[6].

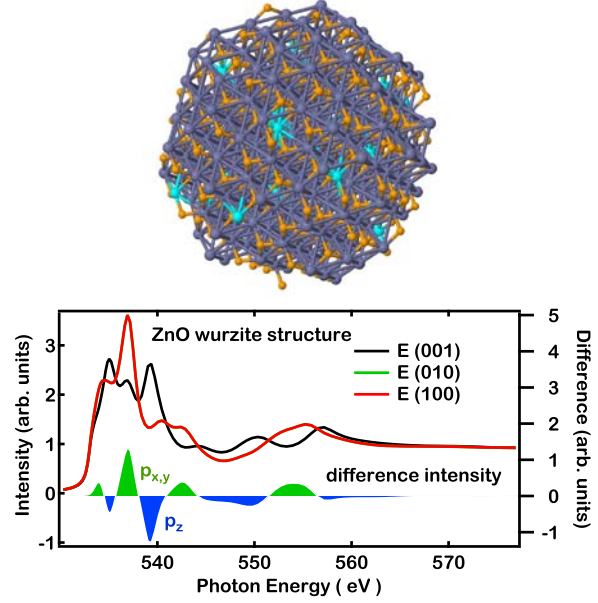


Figure 14: Visualization of the cluster used in the calculations and XAS O K-edge theoretical spectra for ZnO:Co samples. Data partly presented in **H**[6].

calculate the XAS spectra we use the FEFF9 version of the *ab initio* FEFF code [56, 73]. For the present calculations a ZnO cluster with a radius of 12 Å (608 atoms) is used, around the photo-excited O atom, in the wurtzite crystal structure. The calculations of Fig. 13 are performed with unpolarized light given the random granular growth. Linearly polarized light is used for calculations shown in Fig. 14, to explore the angle dependence in the wurtzite structure and assign the various spectral features [6]. The Co atoms occupy Zn sites and are randomly distributed (Fig. 14). Several different Co atom configurations have been considered, the results being similar to better than 2% in spectral intensity.

It is found that it is possible to reproduce the order of magnitude of the difference of spectral shapes of samples F307 and F254 versus F328 by considering small structural distortions of order of 5% of the lattice constant **H**[6]. We are able to reproduce in particular the strong variations at the edge, around 530 eV in the experimental data. The samples exhibit granular growth, with a typical grain size of order 4-5 nm and it is probable that a broadening of the absorption edge should be observed, as can be reproduced by the calculations, due to small structural distortions for each grain as presented in Fig. 13. Fig. 14 shows the symmetry assignment of the various spectral features at the O K-edge. The hexagonal *c*-axis is probed by orienting the electric field along the (001) direction. Focusing on the Zn *L*₃-edge data of Fig. 12, we also find that it is possible to reproduce the observed intensity variations with a ZnO lattice expansion of the 5-10% range. The existence of structural distortions for ZnO:Co constitutes an important result for magnetism applications. It has been proposed that structural distortions in ZnO:Co affect the magnetic properties. A decrease in the lattice constant of the order of 5% contribute to an increase in the Curie temperature of the order of 100 K in theoretical models [74].

As mentioned in the introduction to this section, specially tailored samples were used, allowing to study also the real space and electronic structure of the surface versus interface regions of these thin films, under the same experimental conditions **H**[5]. The surface and

interface regions are marked as B and A, respectively, in Fig. 15 and Fig. 16. First, by using the elemental specificity of XAS the composition of the ZnO:Co samples is probed at location A and B. The resonant character of the excitation makes XAS a more sensitive tool than the laboratory non-resonant XPS or Auger-ES for checking the presence of impurities in small concentrations. We do not find any trace of Ti, V, Mn, Cr, Fe atoms in these samples. The contents of Co in the “bulk” part of sample F328 is 6% on average. However, the distribution of Co is not homogeneous within the layer. For sample F328 the highest amount of Co is about 14%, which is close to the value obtained from the analysis of hard x-ray XANES data on this family of samples **H[5]**.

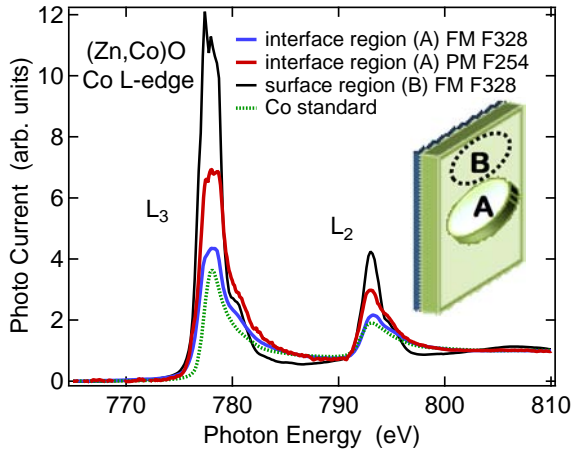


Figure 15: L-edge x-ray absorption spectra versus photon energy for ferromagnetic (Zn,Co)O sample F328 from the interface region (region A, in the crater) and from the surface region (region B of the film). The interface region (region A) is also shown for the paramagnetic (Zn,Co)O sample, F254. The Co L-edge data are taken at normal x-ray incidence (a 90° angle between the x-ray propagation direction and the film surface plane) in the total electron yield mode and normalised to the atomic continuum at high photon energies Data partly presented in **H[5]**.

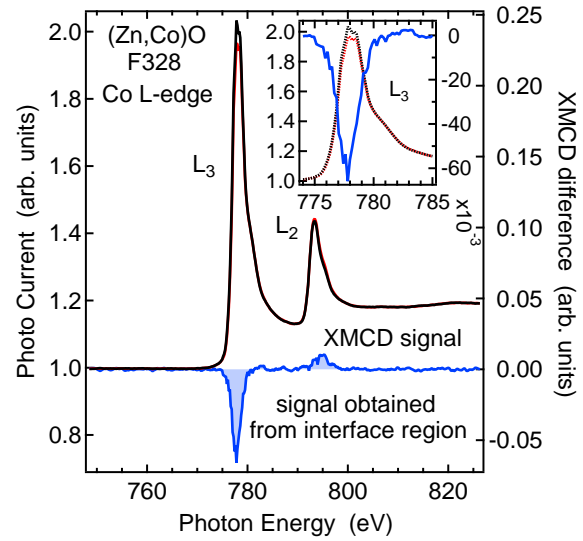


Figure 16: XAS (left scale) and XMCD (right scale) spectra in the total electron yield mode versus photon energy. Measurements are performed at room temperature under an applied magnetic field of $H = 35$ mT. The XAS spectra are obtained with nearly fully circularly polarized light (a light helicity of 0.85); a 40° x-ray incidence angle is employed. The insert shows an enlarged view of the L_3 edge of the XAS and XMCD spectra **H[5]**.

We find sizable differences in the fine structure of the Co white lines measured for the surface and the interface regions (see Fig. 15) **H[5]**. The Co L-edge and O K-edges measured within the crater indicate a different chemical composition and electronic state for the O and Co ion cores probed by XAS. More in detail, the inter-peak continuum of final states (of s symmetry) for the Co spectra is more intense in the crater. Since the magnitude of final states continuum is a direct probe of the degree of metallic character, we are driven to the conclusion that Co may form either a continuous ultrathin film or a layer of nanocrystals at the interface. The shape of XAS spectra obtained for Co L-edge

indicates that in the interface region the metallic Co is the dominant phase but not the only one. We observe a superposition with a small amount of CoO [75]. The difference of the electronic state of the Co atoms at the surface versus the interface region manifests itself also in the big difference in the number of holes of Co atoms in these two regions of the sample, illustrated as difference in the area under L_3 line (Fig. 15). The white line area for the Co atoms in the surface region is up to 2.5 times larger versus metallic Co, for the Co atoms in the crater it is 1.25 times larger (Fig. 15). A larger white line intensity indicates that the number of $3d$ holes for the Co atoms in the surface and within the crater is larger versus the metallic state. Given these numbers, the spectra for the interface are mostly metallic in nature as only a 25% increase in white line intensity is observed. It is not clear that this increase is due exclusively to Co^{2+} atoms, but if we assume this is indeed the case the data of Fig. 15 would indicate that 17% of the Co atoms of the inner interface region are in a 2^+ state. This result confirms the difference in the hybridization of Co with neighboring atoms. To conclude this part, we add that a certain amount of Zn has also been found on the interface, strongly indicating a lack of a continuous Co layer there.

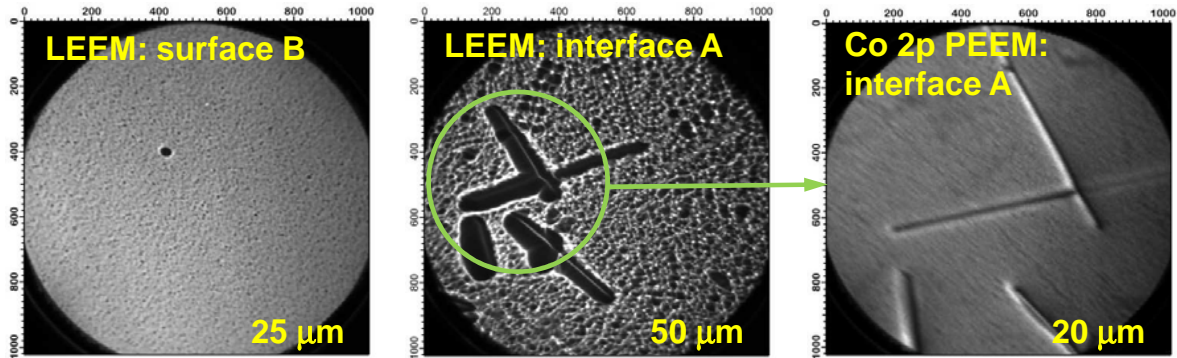


Figure 17: LEEM micrograph obtained in the mirror mode visualising the topography of surface (left panel) and interface region (middle panel). The PEEM micrograph visualising the Co distribution in the interface region was obtained as the difference of intensity between 62 eV and 56 eV (right panel). The field of view for each micrograph is indicated.

The possible existence of x-ray magnetic circular dichroism was probed at the Co L -edges. No measurable XMCD was found in the TEY mode from the surface region, for magnetic fields up to 0.5 T at 300 K. The absence of ferromagnetism at 300 K for the near surface region is in agreement with previous observations [69]. A small XMCD dichroic signal is seen in the interface region (inside the crater, Fig. 16) at room temperature, when the magnetic field of 35 mT is applied in the surface plane **H**[2], **H**[5]. For this family of samples, also a ferromagnetic response is observed in several cases by means of SQUID magnetometry **H**[5]. The dichroic response is much more pronounced at the L_3 white line indicating that the orbital moment carried by the Co atoms at the interface is much stronger than that for bulk Co. The magnitude of m_l/m_s obtained by employing the magneto-optical “sum rules” for (Zn,Co)O is 0.31(7), whereas for metallic Co the typical value is about 0.08 **H**[2]. If we refer to the XMCD analysis of metallic Co, in a system where a strong magnetic anisotropy has been found and the associated effect of the T_z term is documented on the spin moment determination [76], we would expect related errors of the order of 12%. It is not clear that the T_z term of the Co atoms within the high symmetry local environment we are dealing with here would be that important. A higher m_l/m_s

value versus the Co bulk value is possible if the Co atoms agglomerate in the form of small crystals with a metallic Co core [77, 78]. Alternatively, a very rough Co film in the crater with metallic patches is also consistent with our measured values.

The overall value of the magnetic moment within the crater at 300 K is for the spin moment of $0.21(4) \mu_B$ per Co atom, after correcting for the angle of x-ray incidence and the helicity of the x-rays. This value is of the order of 13% of the spin moment for Co. We note in this context that a continuous film of only 2-3 atomic layers of Co should yield the full magnetic moment at 300 K, under the conditions of the present experiment. The low value of the magnetic moment which we obtain here is a further hint of stronger finite size effects than in the case of a thin film, indicating eventually Co nanocrystal formation. The values of the magnetic moments determined here are significantly different from those found in ZnO containing Co nanocrystals of about 5 nm in diameter dispersed in the bulk of the films [79]. This difference illustrates the fact that the precise size, form and geometric shape of inclusions play a crucial role here and determine the outcome of an experiment. Conversely, an accumulated data base of such studies on well structurally characterized systems may later prove invaluable in the identification of the phases present in the investigated samples. We conclude that both the high orbital to spin moment ratio obtained from the inner interface as well as the low value of the magnetic moment after the application of the magneto-optic sum rules indicate the presence of Co nanocrystals or a discontinuous Co film in the interface region **H[5]**. The X-PEEM measurements performed at I311 beamline at MAX-lab confirm that the ZnCoO film is homogenous (Fig. 17 left panel) except for the inner interface region where the nanocrystals are clearly visible (Fig. 17 middle panel). The Co distribution was visualised at the difference micrograph shown in right panel of Fig. 17 and indicates that indeed the precipitations which are directly visualised do contain Co atoms.

Selected results concerning ZnO:Bi placed in context. The previous section highlights in detail the complexity, and some of the complications that do arise from the use of the ZnO:Co system for DMS applications. Here an alternative route is explored for the doping of the ZnO in view of DMS applications, by doping ZnO with the heavy element Bi by means of Pulsed Laser Deposition (PLD). We employ x-ray absorption spectroscopy to characterise the magnetism of $\text{ZnBi}_x\text{O}_{1-x}$ films grown by PLD at the atomic level **H[7]**. To probe for O(2p) electron related magnetism linked with the Bi doping, we use circular x-rays at the I1011 beam line of MAX-lab to excite the O(1s) core electrons, leading to dipole transitions to the O(2p) states. To revert the magnetic moment of the O atoms we apply a magnetic field of 0.5 T *in situ*. In Fig. 18 O K-edge XAS spectra are shown, taken with circular x-rays. The characteristic intensity variations close to the O K-edge, are due to transitions to O(2p) final states. The observation of O K-edge XMCD is direct evidence that the O atoms carry a magnetic moment. In general, K-edges lead to rather small XMCD effects. Nevertheless, we observe a clear XMCD response from the O atoms under the applied magnetic field of 0.5 T. The XMCD response at the O K-edge highlights that the O(2p) states carry considerable spin polarisation, in agreement with the previous *ab initio* theory results and the SQUID magnetisation measurements performed for these samples. We observe that the Total Electron Yield (TEY) and Total Fluorescence Yield (TFY) detection channels lead to strong differences in spectral features as observed earlier in ZnO thin films [80]. Differences in the TEY versus TFY spectra highlight the possibility for a different electronic and real space structure of the near surface region of the film versus the film interior.

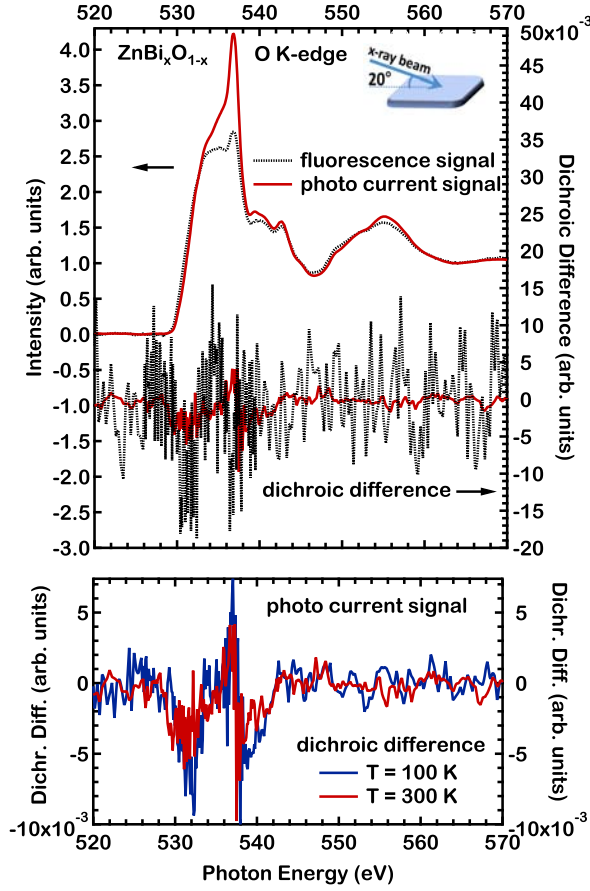


Figure 18: Experimental XAS and XMCD spectra are shown, taken with close to circular x-rays for a $\text{ZnBi}_x\text{O}_{1-x}$ ($x=4\%$) thin film. Grazing x-rays are used at 20° from the surface plane. The dichroic (XMCD) signal is taken by reverting the applied magnetic field. The XMCD difference is stronger for TFY **H**[7].

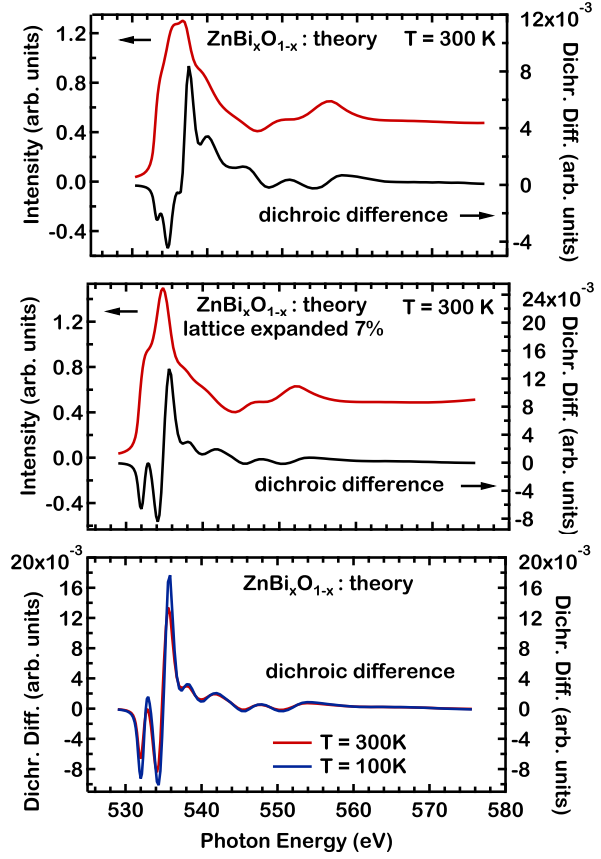


Figure 19: Theoretical XAS and XMCD spectra are shown for $\text{ZnBi}_x\text{O}_{1-x}$ ($x=3\%$) which are calculated with the FEFF code. Close to circular light is used, with the same degree of circularity as for the experiment. The Bi doped ZnO spectra using the known bulk values for the ZnO lattice describe well the experimental TFY spectra. The TEY spectra, are best described, by means of an expanded ZnO lattice, here a calculation with an expansion of 7% is shown. The TEY channel is sensitive to the near surface region of the $\text{ZnBi}_x\text{O}_{1-x}$ film, only with TFY the bulk of the $\text{ZnBi}_x\text{O}_{1-x}$ film is probed. The thermal disorder on the XAS and XMCD spectra is introduced using the correlated Debye model **H**[7].

In order to gain further quantitative insight into our experimental XAS and XMCD spectra, we compare our data with theoretical spectra **H**[7]. We use again the FEFF code [55, 56]. Here we work with its real space option, suitable for precise calculations also at higher energies above the edge. We discuss a wider energy range (529-570 eV) for both XAS and XMCD spectra, given the intensity variations observed in our experimental results. We now turn to the results of our FEFF calculations for the XAS of $\text{ZnBi}_x\text{O}_{1-x}$ shown in Fig. 19. To simplify the calculation, the ZnO crystalline structure is used, without

static disorder or defects. To obtain the characteristic shape of the XAS features in the TEY spectra where the signal to noise ratio is much higher, a lattice expansion is found necessary. A volume lattice expansion, for the surface region, by 8(2)% yields much better agreement to the TEY spectra. The TFY spectrum appears to be consistent with a superposition of a theoretical spectrum corresponding to the bulk values of the ZnO lattice together with spectra corresponding to an expanded lattice. The Bi atoms are randomly substituted to 3% at the O sites, for these calculations. The theoretical spectra indicate that the wurzite hexagonal plane for the ZnO lattice, lies within the surface plane of the sample. The dominant spectral features seen in the experiment can be reproduced by the theory, both in terms of energy and relative intensity, if the existence of a lattice relaxation is assumed for the near surface region probed by TEY. We now turn to the possibility of the FEFF code, for the calculation of XMCD difference spectra. Focusing on the origin of the XMCD signal at the O K-edge we present results of two limiting cases relating with the present experimental material. We calculate the XMCD of a volume expanded ZnO lattice by 7% to model the film surface region probed by TEY and also the bulk ZnO structure, a contribution to the signal which should be present in the TFY results. The data of Fig. 19 show theoretical $\text{ZnBi}_x\text{O}_{1-x}$ XMCD difference spectra for the expanded ZnO lattice. The spin is reversed and the two obtained spectra are then subtracted to obtain the XMCD difference shown in Fig. 19. The spin values used for the O, Zn and Bi atoms are the ones obtained from *ab initio* ground state theory, namely for the O atoms a spin moment of $0.022 \mu_B/\text{atom}$, for Zn $0.033 \mu_B/\text{atom}$ and for Bi $0.26 \mu_B/\text{atom}$ **H[7]**.

The result of the spin dependent calculations of Fig. 19 reproduce fairly well the strength of the experimental XMCD difference in Fig. 18 for grazing x-ray incidence **H[7]**. The experimental O K-edge XMCD difference consists of oscillations versus the photon energy, strong very close to the edge, which become weaker as the photon energy increases. Also the calculated XMCD consists of fast oscillations. We find the amplitude of the calculated XMCD signal to be within a factor of 2 from the one observed in the experiment in Fig. 18 (right Figure axis), using the theoretical magnetic moments for the Zn, O and Bi atoms. The XMCD signal, as predicted by theory, starts at the absorption edge by transitions to delocalised final states exhibiting O(2p) character. This appears to be a general feature of Bi doped ZnO. Expanding the lattice and superimposing XMCD oscillations with slightly different phase for each lattice value, leads then to average XMCD oscillations which will tend to cancel out with increasing photoelectron kinetic energy, as observed in the experiment. This is due to the fact that these oscillations start in phase at the absorption edge but have a different phase, leading to destructive interference at higher photoelectron kinetic energies. The discrepancy of the theoretical XMCD signal versus the experimental one, may be also due to the existence of structural disorder, in particular for the TEY in the near surface region. Also the magnetic response for various ZnO lattice constants is varying strongly, as shown in Fig. 19. The XMCD signal for the TFY channel, will be also a superposition of several contributions due to the finite probing depth, still tending to lower the overall signal amplitude. Overall the fact that the FEFF code reproduces several characteristics of the XMCD signal, strongly supports the values of the magnetic moments as determined by the theory. We have been able to identify a plausible reason for the discrepancy of the XAS data between the TEY and TFY channels, namely an expansion of the lattice. Modelling of the XMCD would require not only the use of the *ab initio* FEFF code for a variety of geometries, but also a weighted average of these results using the TEY probing depth into the surface, taking into account the roughness of the surface, increasing the number of free parameters. The FEFF results describe correctly a negative

dichroic signal directly at the absorption edge. They fail however to yield a negative signal at higher energies. Possible reasons for this discrepancy, beyond structural disorder and surface relaxation may lie in the presence of an orbital moment contribution, which is not addressed here. The possible presence of an orbital moment for the O atoms is consistent with the strong spin orbit energy of the Bi atoms.

Future opportunities opened up by this study, impact for the research area.

We document intensity variations at the core level edges of all constituent atoms for ALD grown ZnO:Co samples, correlating with the sample growth temperature **H[6]**. The observed effects at the Co L-edges support that small Co rich clusters exist within the ZnO lattice **H[4],H[5]**. Co clusters are expected to induce local strain within the host lattice. Control of the local strain in the ZnO lattice is important, as theoretical work has established that structural distortions in DMS materials do affect the magnetic properties [74]. *Modelling of the O K-edge and Zn L-edges*, using the FEFF *ab initio* code *supports that small structural variations* of the ZnO lattice constitute a possible explanation for the observed spectral intensity variations **H[6]**. We conclude that *through the combined use of ALD and XAS it is possible to influence specific properties of the samples, such as the occurrence of ferromagnetism in ZnO:Co*.

This study presents, using Bi doped ZnO, an example of *a novel type of DMS materials based on a heavy ion doped oxide semiconductor*, highlighting *a novel p-symmetry interaction of the electronic states to stabilise ferromagnetism* **H[7]**. The study includes both *ab initio* ground state electronic structure theory and experiments, which yield clear evidence for above room temperature ferromagnetism. ZnBi_xO_{1-x} thin films are grown using the pulsed laser deposition technique. *The room temperature ferromagnetism finds its origin in the holes introduced by the Bi doping and the p-p coupling between Bi and the host atoms*. A sizeable magnetic moment is measured by means of x-ray magnetic circular dichroism at the O K-edge, probing directly the spin polarisation of the O(2p) states. This result is in agreement with the theoretical predictions and inductive magnetometry measurements. *Ab initio* calculations of the electronic and magnetic structure of ZnBi_xO_{1-x} at various doping levels allow to trace the origin of the ferromagnetic character of this material. It appears, that *the spin-orbit energy of the heavy ion Bi stabilises the ferromagnetic phase* **H[7]**. Thus, ZnBi_xO_{1-x} doped with a heavy non ferromagnetic element, is a credible example of a candidate material for a new class of compounds for spintronics applications, based on the spin polarisation of the *p* states.

In summary, our experimental findings and *ab initio* calculations reveal that *Bi doped ZnO is a potential prototype system for a novel class of dilute magnetic semiconductor materials, which are ferromagnetic at room temperature* **H[7]**. Free carriers in the system are found to play an important role in the electronic and magnetic properties of anion doped DMS. The origin of ferromagnetism in ZnBi_xO_{1-x} can be traced to the *p – p* coupling interaction between Bi, Zn and O atoms. Doping with Bi, a heavy *p* element, leads to itinerant ferromagnetism which is not defect related. In contrast, doping with B, a light *p* element, does not lead to a stable itinerant ferromagnetic phase. Our findings strongly suggest that the *p – p* type of interaction, in combination with the spin-orbit coupling, are key ingredients the doping atom has to introduce into the ZnO lattice, to stabilise itinerant ferromagnetism **H[7]**. The results presented for ZnBi_xO_{1-x} are valid for materials such as GaAs, GaN and TiO₂. Further efforts should be put forward, using doping with heavy elements which favour a *p*-symmetry coupling, and stabilise itinerant

ferromagnetism through enhanced spin-orbit coupling.

2.4.4 Chiral molecules for spin filtering applications H[8], H[9]

Motivation, experimental challenges and general importance. One of the main problems that need to be solved for a successful development of spintronics is the production and detection of spin-polarised currents. The typical source of spin polarisation in ferromagnetic materials is the spin-orbit coupling, which generates an energy contribution that splits electronic levels with different spin components allowing for their easier separation. However, this same spin-orbit coupling also favours spin scattering and spin-flip processes, thus limiting the carrier's coherence length and hence the distance over which the information can be effectively transmitted.

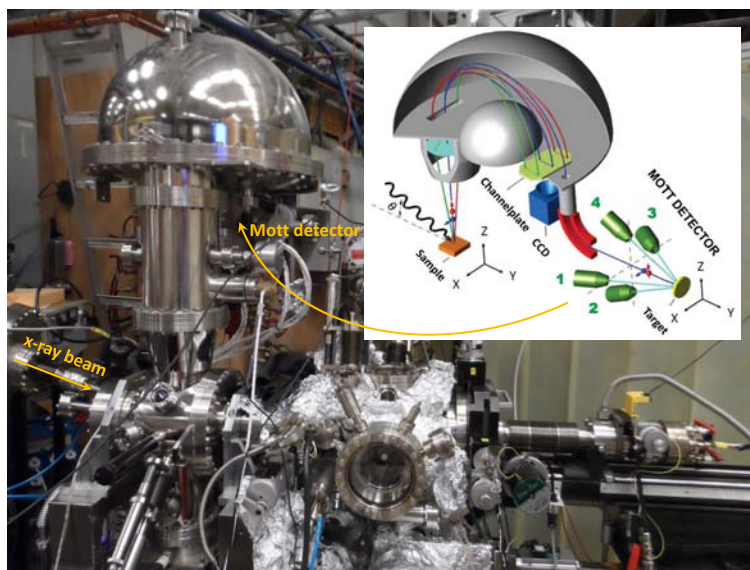


Figure 20: Photo and schematic representation of the spin-resolved photoemission experiment. The energy analysis of the photoelectrons is performed by a Scienta SES 200 electron analyser. The analyser is fitted by a Mott detector stage for performing the spin analysis. The photoelectrons are accelerated towards a Th target. In the inset the Mott detector geometry is shown. The spin polarisation can be measured in two orthogonal directions, in the surface plane of the sample and along the normal to the sample surface.

In previous chapters of this work, state of the art spectroscopy tools were applied to characterise the magnetism and electronic structure of well established semiconductor systems, such as GaN and ZnO, doped with 3d transition metal atoms to explore their suitability for spintronic applications. In the case of ZnO a novel approach to exploit the spin-orbit coupling was explored, and also for the first time a non ferromagnetic *p*-element, such as Bi, was used for the doping. The heavy element Bi has allowed for a one of the highest possible values of the spin-orbit energy within the *p*-block elements. Still the question at this stage remains open if it is possible to obtain spintronic materials in the weak spin-orbit coupling limit, suitable for applications.

In this context, another long-term objective actively pursued nowadays is the use of organic molecules in electronic devices. Molecular electronics attempts to reach the ultimate stage of miniaturisation and take full advantage of the versatility, control and reproducibility in the synthesis of molecular building blocks that can be achieved by the methods of

organic chemistry. The use of molecules as building blocks, in complex structures, favouring the conduction of spin currents is particularly interesting because the weak spin-orbit coupling and hyperfine interaction of carbon-based materials greatly reduces spin scattering and favours coherent spin transport over large distances. The main drawback in this case is exactly the opposite as in the previous one, namely that the small atomic masses of the elements usually found in organic materials account for a weak spin-orbit coupling thus making spin separation difficult. Recent experimental and theoretical results, during the course of this work did indicate that strong spin polarisation can be obtained upon electron emission or transmission in layers of large chiral organic molecules, such as DNA, adsorbed in an ordered manner on Au. These findings can represent a major breakthrough in the efforts to develop a microelectronics technology based on the use of the electron spin rather than its charge as the carrier of information. The physical origin of the spin polarisation observed for chiral molecules, is not yet fully understood, and more work is needed in order to turn this emerging knowledge into usable technological developments. In this work an important step was taken using a state of the art combination of spectroscopic techniques. Efficient spin filtering can occur at a very short length of the order of one molecular layer, of small organic molecules **H[8]**. Till the results of this work were obtained, it was accepted that long helical structures were necessary, in order to effectively spin polarise electrons.

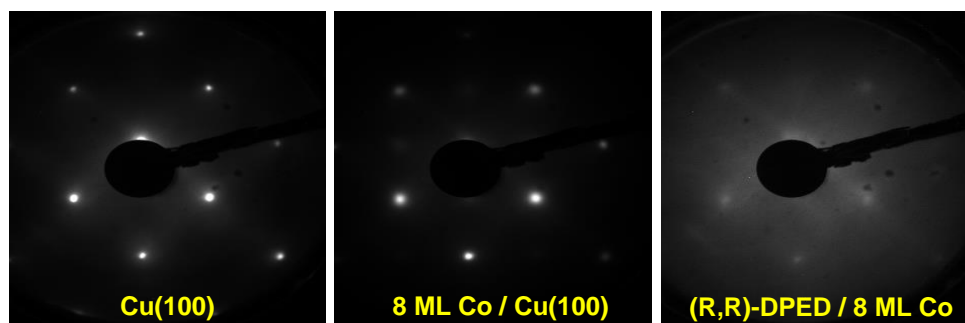


Figure 21: LEED patterns obtained at an incident electron energy of 133 eV at 300K. Both DPED enantiomers form a disordered monolayer on the Co surface, leading to an increase of the background on the LEED pattern and no extra intensity spots. Here the (R,R)-DPED enantiomer pattern is shown.

We have followed a step by step systematic approach in the growth and characterisation of a simple model chiral molecule on well characterised surfaces. The simple 1,2-diphenyl-1,2-ethanediol (DPED) molecule was chosen to study the impact of a single molecular layer on the electron spin scattering **H[8]**. The combination of *in situ* surface science growth and characterisation with spectroscopy tools at MAX-lab did allow to control molecular adsorption on both a Cu(100) surface as well as on *in situ* grown Co layers on the Cu(100) surface. Co/Cu(100) is a model system in the field of thin film magnetism. The Co layers do grow epitaxially on the Cu(100) surface. The Co layers grow on Cu(100) in a face centred tetragonal (fct) phase and adopt a small tetragonal distortion, to match the Cu lattice constant along the Cu surface plane. Such a Co ultrathin film in the few monolayer range forms a well studied magnetic monodomain which can be used as a close to ideal source of spin polarised electrons. Adsorbing the DPED molecules on such a Co layer on a weakly chemisorbed state, and detecting the electrons transmitted through the DPED layer by means of a Mott detector in a classical photoemission experiment, allows to determine

the efficiency of a single chiral molecular layer on the spin filtering of photoelectrons of a well determined kinetic energy, under close to ideal conditions.

Figure 20 shows the experimental end station at the I3 beam line of the MAX III storage ring at MAX-lab. The Cu(100) single crystal surface is prepared by sputtering and annealing cycles to 900 K. The Cu(100) surface is first characterised by means of LEED as shown in Fig. 21 and then by means of ARUPS. Then the Co layers are evaporated *in situ*. LEED and ARUPS allow to check the sample again, using in particular the spin analysis stage. The Co layers are remanently magnetised *in situ* by means of a permanent magnet, mounted in the preparation chamber. The existence of a remanent magnetisation can be probed *in situ* by means of the spin analysis using the Mott detector stage at the hemispherical electron analyser (Fig. 20). Once it is checked that the Co layers exhibit the wished properties the DPED molecules are evaporated on the Co(100) surface. ARUPS allows under these conditions to characterise the spin of the spin polarised photoelectrons produced by the Co(100) surface, as they propagate through the molecular monolayer.

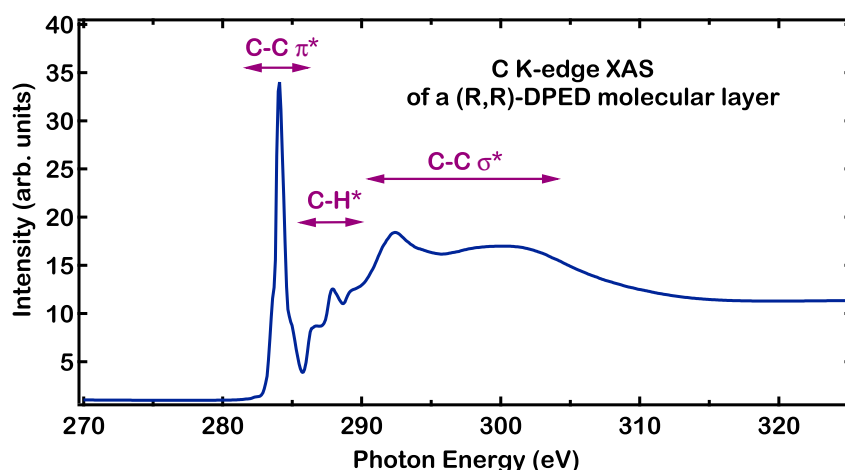


Figure 22: The C K-edge XAS of a (R,R)-DPED molecular layer is shown. Here the XAS is taken at 150 K with the molecules adsorbed directly at the Cu(100) surface. The angle of x-ray incidence is 22° versus the sample surface.

The ARUPS experiments described here, follow a series of XAS and XMCD experiments at the I1011 beam line of MAX-lab. It has been established that the molecules adsorb in a weakly chemisorbed state. C K-edge XAS allows to follow the electronic state of the DPED molecules. Both the molecular monolayer regime was characterised on the Co(100) surface at 300K as well as the adsorption on the Cu(100) surface at 150 K. At 150 K a multilayer of the DPED molecules can be obtained. The XAS spectrum of Fig. 22 can be used to identify the various molecular resonances. Around 284 eV photon energy the lowest unoccupied molecular orbitals of π symmetry can be seen. This sharp resonance corresponding to π -levels have predominantly a C-C character. These are followed by molecular unoccupied levels of C-H character around 286-290 eV. Finally, at higher photon energies, the broader shape resonances can be identified. These have a strong C-C character and are of σ -symmetry. The assignments of the molecular resonances are following the results of the StoBe package. They are in agreement with the assignment of C K-edge XAS spectra in the literature. The XAS experiments allow to establish that the molecules both on Cu(100) as well as on Co(100) adsorb in a molecular form.

Selected results placed in the context of the habilitation topic. To investigate spin polarisation effects in chiral layers we have used the 1,2-diphenyl-1,2-ethanediol (DPED) molecule. This compound possesses two chiral centers, located at the two C atoms of the ethane chain. We have studied the two chiral enantiomers with (R,R) and (S,S) configurations, which are shown in Fig. 23a and Fig. 23b, respectively. Ultrathin Co films epitaxially grown on a Cu(001) single crystal were chosen as the substrate for the adsorption of the enantio-pure chiral molecular layers for several reasons. Co/Cu(001) has been extensively studied in the past as a model system for two-dimensional magnetism [81]. Since its spin-resolved band structure has been determined in photoemission experiments analogous to ours [82, 83], a measurement of the spin polarisation of our Co films serves both as a calibration of the spin detector and as an *in situ* reference for the magnitude of the polarisation induced by the chiral molecular layers. Besides, the use of a single-crystal substrate allows us to precisely control the magnetic anisotropy axes within the Co film [84], which is important in order to have the film magnetisation properly aligned with respect to the Mott detector. And finally the DPED molecules, which show negligible adhesion at room temperature on clean Cu, rapidly stick to the Co forming a stable layer of single molecular thickness, thus allowing us to easily obtain reproducible samples.

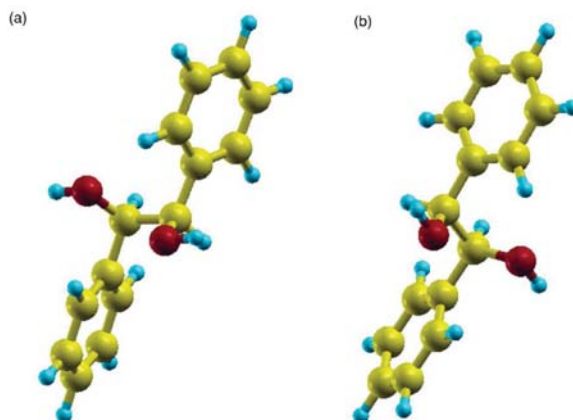


Figure 23: The molecular configurations of the two enantiomers used in this study: (a) (R,R)-(+)-DPED and (b) (S,S)-(-)-DPED, as derived from DFT calculations using the StoBe theory package.

The results of our measurements on an 8-ML-thick Co film on Cu(001) are summarized in Fig. 25 for the in plane direction $\mathbf{H}[8]$. The LEED pattern displayed in the middle panel of Fig. 21, with sharp spots and low background, demonstrates that the Co films grow pseudomorphically on Cu(001) with good crystallinity and low roughness, as expected [85]. The Co film was magnetized parallel to the surface before starting the experiment. An in-plane spin polarisation of up to 20% can be detected in the d bands of the Co right below E_F (Rys. 25). No significant spin polarisation appears perpendicular to the surface $\mathbf{H}[8]$, also according to the expectations [82, 83].

Having characterised our substrate we proceed to study the influence of the adsorption of the chiral molecules on the electronic spin. A layer of the pure (R,R)-(+)-DPED enantiomer was adsorbed at 300 K on an 8 ML Co/Cu(001) substrate analogous to the one described above. The weak (1×1) LEED pattern with high diffuse background depicted in the right panel of Fig. 21 reveals laterally disordered growth. In Fig. 24 the peak close to the Fermi level corresponds to the Co d band. The peaks at 3.7 and 6.5 eV binding energy correspond to the HOMO and HOMO+1 of (R,R)-(+)-DPED. The corresponding

ARUPS and spin-polarisation results are shown in Fig. 24. For this sample we find a roughly constant polarisation within the surface plane with negligible values for the perpendicular direction. Our lower bound estimate for the spin polarisation induced by the chiral layer in this case is about 5% at 300 K and for a single adsorbed molecular layer. The real value, however, could be larger because our measurement only probes the in-plane projection of the spins along the Y axis, as schematically indicated in Fig. 20; the spin components parallel to the X direction are not detected in this experiment. In any case the spin polarisation presented in Fig. 24 is rather distinct from the case of the clean Co film. The in plane spin polarisation expected from the magnetized Co film in the absence of adsorbed molecules, is now much smaller close to the Fermi level and embedded within the energy-independent signal created by the chiral film **H[8]**.

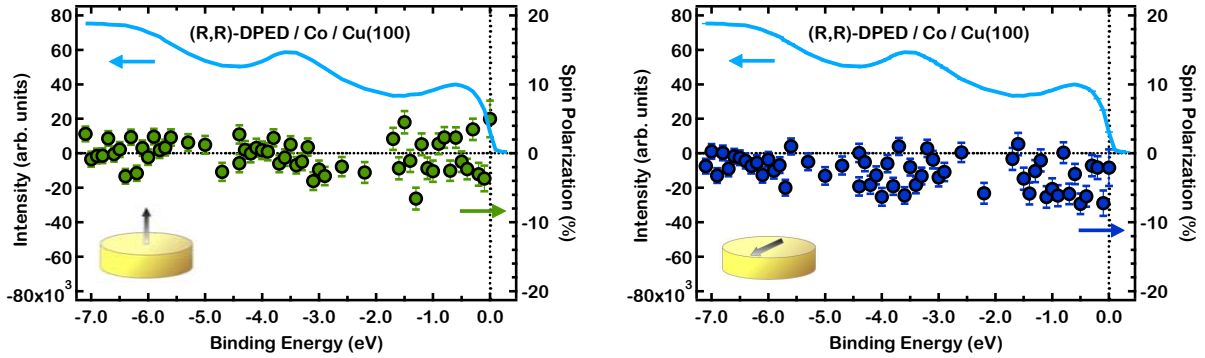


Figure 24: In-plane and out-of-plane spin polarisation spectra at $k_{\parallel} = 0$ and 300 K, with the sample magnetized in-plane. An approximately energy-independent, in-plane spin polarisation can be observed **H[8]**.

The data presented in Fig. 24 thus apparently confirm the basic findings by Göhler *et al* [37]. Nevertheless, the effect of substituting one enantiomer by its mirror counterpart could not be directly tested by these authors since they employed chiral double-stranded DNA chains with a single handedness. Although it seemed reasonable to expect that the sign of the spin polarisation might be reversed, a direct proof of this hypothesis has been lacking so far. In this work we have tried to answer this question by depositing analogous films of the other chiral enantiomer, (S,S)-(-)-DPED on the same substrate, Co/Cu(001), and directly measuring the resulting spin polarisation **H[8]**.

These films were grown on similar 8 ML Co/Cu(001) substrates as for the previous enantiomer, and also at 300 K. The LEED pattern reveals an analogous degree of structural disorder within the molecular layer as for (R,R)-(+)-DPED. The features appearing in the ARPES spectrum are also practically identical to those for that enantiomer. However, the spin analysis presented in the Fig. 25 reveals a totally unexpected effect: rather than a simple inversion of the sign of the spins what we find is a rotation of their direction, yielding a practically constant polarisation of about 8% perpendicular to the surface throughout the whole energy range probed in our experiment. At the same time, and what appears even more surprising, the in-plane spin polarisation of the Co *d*-electrons is still clearly visible close to the Fermi level. Again in this case the magnitude of the spin polarisation induced by the chiral layer can best be evaluated by comparing it with the one stemming from the underlying Co film. The smaller value of this latter when compared to the uncovered Co sample presented in Fig. 25 suggests that the adsorption of the (S,S)-(-)-DPED layer may have altered the coercivity and, consequently, also the domain structure

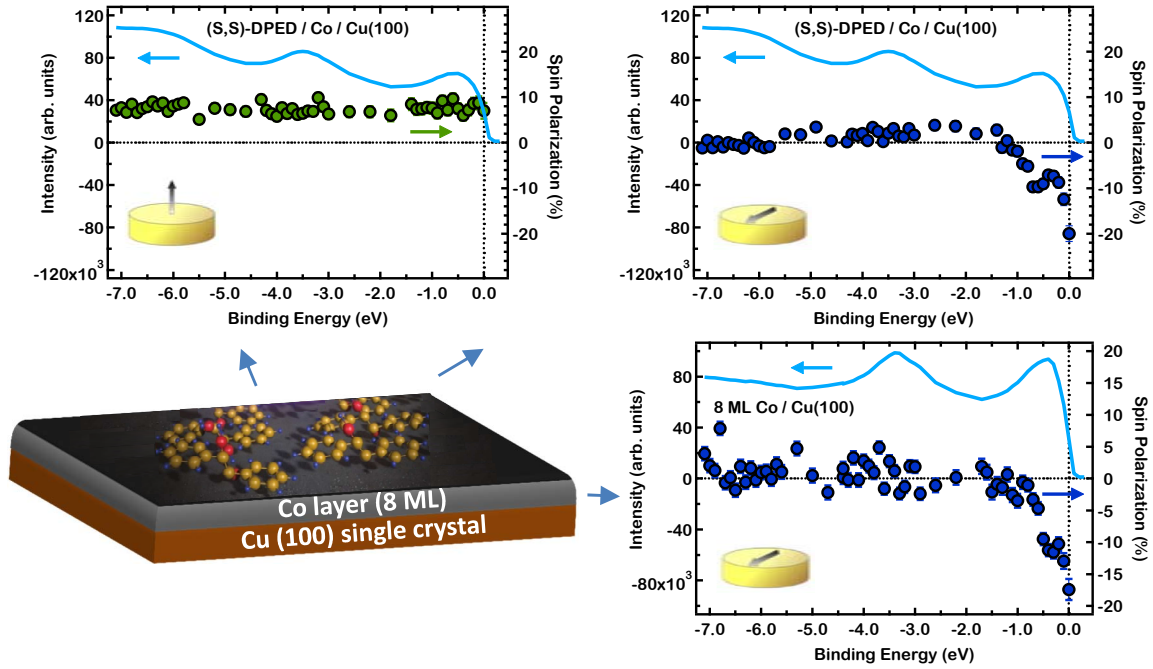


Figure 25: In-plane and out-of-plane spin polarisation spectra at $k_{\parallel} = 0$ and 300 K. In spite of having the sample magnetized in-plane as in the previous experiment with (S,S)-(+)-DPED, the photoemitted electrons are spin-polarized out-of-plane in this case, with a magnitude also independent of their binding energy; the Co d -electrons maintain their in-plane polarisation though. Spin polarisation data presented in **H[8]**.

of the ferromagnetic Co film, thus reducing its remanent magnetisation. A modification of the Co magnetic moments associated to the charge transfer between the adsorbed molecules and the substrate should not be excluded, either.

The asymmetric inner potentials created by strain-induced deformations in graphene sheets are predicted to create pseudo-magnetic fields more intense than 300 T [86]. It appears that this latter effect might be involved in the origin of the electron spin polarisation in chiral molecules. The electron spin polarisation, according to some recent publications, might be caused by the effective magnetic field felt by the electrons as they propagate through the helicoidal electronic potential created by the chiral media [87–89]. Our results lend some support to these models, since the magnitude of the polarisation measured in our experiments is practically constant in the whole energy range explored and therefore it does not seem to be related to any particular electronic state either from the substrate or within the molecular layer. Growing the molecular films on a ferromagnetic surface, beyond its usefulness for self-calibration purposes, it also helps to reveal the potential chiral molecules do possess, for the rotation of the spin polarisation direction. The spectra of Fig. 25 demonstrate that the effect induced by the chiral layer is the same for all the electrons analysed, independently of their origin (the Co d -band or the molecular orbitals) and their initial polarisation state.

The observation that the diverse enantiomers of a same molecule can react differently to radiation is reported here for the first time. Our results suggest strong differences in the ability of the two enantiomers to filter and rotate the two spin components **H[8]**. We suggest that this behaviour may be related to differences in the structure of the adsorbed films. Since the chiral enantiomers have different spatial configurations, it is conceivable

that upon their adsorption on a solid surface, an environment where spatial inversion symmetry is broken, the arrangement and relative alignment of the enantiomers may also be different.

Our findings are important for several reasons. In the first place, they may add considerable flexibility for practical applications such as the fabrication of spin filters for detectors or for use in spintronics devices [35, 90, 91]. But also they can shed some light onto the basic questions about the origin of the chiral asymmetry in the universe [92, 93]. The organic molecules detected in outer space are found mostly adsorbed at the surface of interstellar dust and are subject to the effect of electromagnetic radiation. An enantio-selective enhancement of reaction rates induced by spin polarized secondary electrons has recently been proposed as the possible source of enantiomeric excesses [94]. Our work now provides the first direct proof that the enantio-selective response of adsorbed chiral molecules to irradiation could be a general phenomenon, even without the need to use circularly polarized light. This observation might be key to unveil the mechanisms responsible for the appearance of chiral asymmetry throughout the Universe. We expect that our results will motivate further work along this line.

Future opportunities opened up by this study, impact for the research area.

Spintronics is a promising field of research involving both the disciplines of solid state physics and materials science. In a spintronic device, one tries to use the electron spin rather than the electron electric charge as the information carrier in electronic devices. In such a device, one hopes for a longer coherence length and smaller probability of scattering of the electron spins during their transport, leading to higher carrier velocities and low energy consumption. The implementation of spintronic based technology on a large scale will allow not only for significant energy savings but also for improvements of the performance of mobile electronic devices. As an example, carbon-based spintronics could lead to technological improvements for optoelectronic applications. Research has already been done on organic light emitting diodes for practical applications in flexible displays and luminescent devices controlled by external magnetic fields. The efficiency of organic light emitting diodes is limited by the conversion process. Electron-hole pairs are formed when current circulates through a donor-acceptor junction. These can be in either a spin singlet or spin triplet configuration. Singlets are more efficient for light emission versus triplet states which favour transitions producing heat. Improvements in the performance of optoelectronic devices can be attained by appropriate spin filtering of the injected charge carriers [95].

One of the central issues to be addressed for the development of spintronic devices is the efficient obtention and detection of spin polarised electrons. Traditionally, spin-polarised electron currents have been produced by optical excitation of semiconducting (e.g., GaAs) photocathodes with circularly polarised light. This method remains still in use today because of the high polarisations which can be achieved, with values up to 92%. However, the efficiency remains low (about 0.5%) and the current intensities are very weak. The spin selective detection of electron currents suffers also from similar limitations. Traditional Mott detectors are based on the effect of spin-orbit coupling (SOC) and typically derive the magnitude of spin polarisation from the asymmetry in the scattering of electrons at the surface of some heavy element such as tungsten (W) or gold (Au). This type of set-up requires high accelerating voltages (around 30-40 keV) to achieve efficiencies only of the order of 10^{-4} . Other detection schemes are based on the use of spin filters. The first realisations of such devices made use of the Giant Magneto-Resistance

effect in multilayers of magnetic transition metals. Recently the focus for efficient spin filtering shifted to magnetic tunnelling junctions. Devices based on magnetic tunnelling junctions, are expected to be more efficient as the tunnelling process is elastic and conserves the spin orientation.

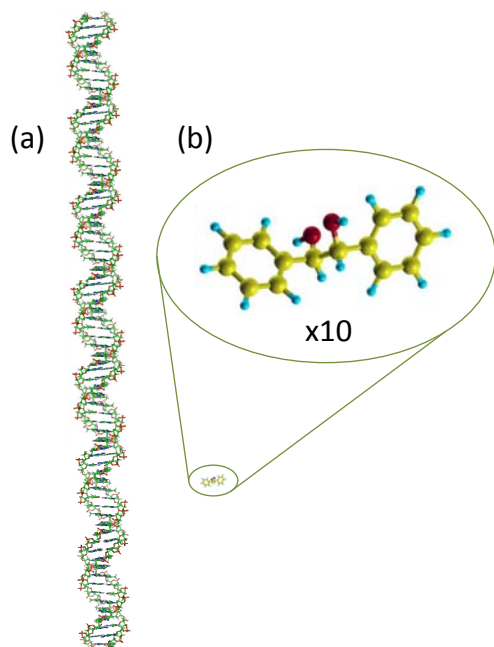


Figure 26: In (a) a long DNA chain is shown, the length of the DNA chain is based on electron transmission experiments to obtain a large spin polarisation [37]. In our work, a strong spin polarisation is observed with the electrons being transmitted only through a monolayer of enantio-specific DPED molecules, as shown in scale in (b).

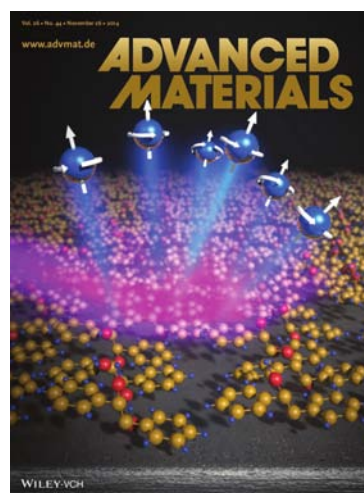


Figure 27: An illustration of our spin-resolved photoemission experiment on a monolayer of enantio-pure DPED molecules adsorbed on an ultrathin film of ferromagnetic Co on Cu(001), used as a cover by Advanced Materials. The DPED molecules not only filter the spin polarised photoelectrons but also act as spin polarisers \mathbf{H} [8].

The approach which was used here, to exploit chiral organic molecules for spin filtering, has appeared only recently. The basic idea has been originally to use the chiral symmetry possessed by certain types of organic molecules to reorient the spin of electrons transmitted across them. Since these molecules only contain light atoms, their spin-orbit coupling is negligible and the spin coherence length can be extremely long. The origin of the spin polarisation was proposed to be related to the effective magnetic field that appears within the molecules due to the helical symmetry of their inner potential [96]. A pioneering work has demonstrated that spin polarisation as high as 60% can be obtained using chiral chains of double-stranded DNA arranged on a metallic (Au) substrate [37, 96].

The published work on DNA [37] and the accompanying patent (EP 2 492 984) are based on a comparison of the results of the spin polarisation measured on two systems, namely single- and double-stranded DNA chains, with a single helicity. The former molecules form disordered layers whereas the latter ones display a high degree of spatial order. From these experimental data it is concluded that the ordered arrangement of the chiral molecules

on the solid substrate is an essential requirement for the achievement of spin polarisation. This restriction seriously limits the applicability of this technique for practical purposes, since the number of combinations substrate/molecule satisfying that requirement might be very small, and the preparation conditions needed to obtain stable, well-ordered arrangement of the molecules are difficult and costly to determine. Furthermore, although the experiments were carried out with molecules with a single helicity, it has been assumed without demonstration that the sign of the spin polarisation will be reversed by using the opposite enantiomer. If this were the case, this fact would also represent a limitation for the possible combination of these spin-filtering molecular films with other spin-polarised materials such as ferromagnetic metals. ***The results presented here, obtained on both enantiomers, did allow to establish that a similarly strong spin polarisation can be achieved already in the monolayer range by enantio-specific chiral molecules H[8].*** This result already lifts the condition of long, spatially oriented, chiral symmetry chains, allowing for more flexibility and higher efficiency towards new spin filter devices. Fig. 26 illustrates the significant gains achieved in creating efficient spin filters based on chiral organic molecules. Until our experiments, the propagation of electrons through long helical symmetry structures was assumed to be necessary to generate sizable spin filtering effects. In the present work, a similarly strong spin polarisation was observed with the electrons being transmitted only through 1-2 monolayers of enantio-specific DPED molecules, as shown in scale in Fig. 26 (b), over a much shorter path **H[8]**. A pictorial representation of the photoemission experiment is shown in Fig. 27. ***Furthermore, the present results illustrate that chiral molecules may act on the electrons also as spin polarisers rather than as spin filters, with the choice of enantiomer being crucial, not only reverting the spin polarisation of the electron beam but allowing to obtain a spin polarisation in a different direction of space H[8].*** Given their importance for the field of carbon based molecular spintronics, the results of this work have been the basis of the Patent application “Electron Spin Filter” with the USA Patent and Trademark Office (EFS ID 23253609 and PCT international number 14/830239) **H[9]**. The importance and technological potential of our findings was realised by the editors of the scientific journal of Advanced Materials, who asked for a pictorial representation of our experiment as cover material for their magazine, as shown in Fig. 27. The results of **H[8]** and **H[9]** have been presented at several international conferences and workshops. Their significance and potential of simple chiral molecules for magnetism applications has been also recognised recently by many established research groups within several EU member states. This allowed creating new links with research groups across the EU. The rich potential of the results of **H[8]** and **H[9]** for applications in the area of molecular spintronics, has recently led my participation to a network proposal to the EC within the Horizon2020 Marie Skłodowska-Curie Innovative Training Network program. The proposal title for an EU ITN network is “CHiral MEdia for carbon-based molecular Spintronics” (CHIMES, under proposal number 765096). I do act as the CHIMES network coordinator. Eight academic Institutions and two companies from six EU member states did join the CHIMES network proposal.

Acknowledgements

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3. Description of research not included in the habilitation topic

3.1 List of scientific publications included in the Journal Citation Reports database

A) Published after the end of PhD studies (since January 2007)

1. *Gd and Sm on clean semiconductor surfaces - resonant photoemission studies*
E. Guziewicz, B.A. Orlowski, B.J. Kowalski, I.A. Kowalik, A. Reszka, L. Wachnicki, S. Gieraltowska, M. Godlewski, R.L. Johnson
Applied Surface Science 282, 326 (2013)
2. *Growth of SiC by PVT method in the presence of cerium dopant*
K. Racka, E. Tymicki, K. Graszka, I.A. Kowalik, D. Arvanitis, M. Pisarek, K. Kosciwicz, R. Jakiela, B. Surma, R. Diduszko, D. Teklinska, J. Mierczyk, J. Krupka
Journal of Crystal Growth 377, 88 (2013)
3. *Magneto-optical Properties of (Ga,Fe)N Layers*
J. Papierska, J.-G. Rousset, W. Pacuski, P. Kossacki, A. Golnik, M. Nawrocki, J.A. Gaj, J. Suffczynski, I. Kowalik, W. Stefanowicz, M. Sawicki, T. Dietl, A. Navarro-Quezada, B. Faina, T. Li, A. Bonanni
Acta Physica Polonica A 120, 921 (2011)
4. *ZnCoO films by Atomic Layer Deposition – influence of a growth temperature on uniformity of cobalt distribution*
M. Łukasiewicz, B. Witkowski, M. Godlewski, E. Guziewicz, M. Sawicki, W. Paszkowicz, E. Łusakowska, R. Jakiela, T. Krajewski, I.A. Kowalik, B.J. Kowalski
Acta Physica Polonica A 116, 921 (2009) (*Proceedings Paper*)
5. *Microscopic (AFM) and resonant photoemission study of Gd/Si(111) interface*
B.A. Orlowski, B.J. Kowalski, E. Guziewicz, E. Łusakowska, V. Osinniy, I.A. Kowalik, M.A. Pietrzyk, E. Nossarzewska-Orłowska, R.L. Johnson
Radiation Physics and Chemistry 78, S22 (2009) (*Proceedings Paper*)
6. *Electronic structure of bulk ferromagnetic $\text{Ge}_{0.86}\text{Mn}_{0.14}\text{Te}$*
M.A. Pietrzyk, B.J. Kowalski, B.A. Orlowski, P. Dziawa, W. Knoff, V. Osinniy, I.A. Kowalik, W. Dobrowolski, V.E. Slynko, E.I. Slynko, R.L. Johnson
Radiation Physics and Chemistry 78, S17 (2009) (*Proceedings Paper*)
7. *Structural and optical properties of low-temperature ZnO films grown by atomic layer deposition with diethylzinc and water precursors*
I.A. Kowalik, E. Guziewicz, K. Kopalko, S. Yatsunenko, A. Wojcik-Głodowska, M. Godlewski, P. Dłuzewski, E. Łusakowska, W. Paszkowicz
Journal of Crystal Growth 311, 1096 (2009)
8. *The influence of growth temperature and precursors' doses on electrical parameters of ZnO thin films grown by atomic layer deposition technique*
T. Krajewski, E. Guziewicz, M. Godlewski, L. Wachnicki, I.A. Kowalik, A. Wojcik-Głodowska, M. Łukasiewicz, K. Kopalko, V. Osinniy, M. Guziewicz
Microelectronics Journal 40, 293 (2009)
9. *Extra-Low Temperature Growth of ZnO Thin Films by Atomic Layer Deposition*
E. Guziewicz, M. Godlewski, K. Kopalko, I.A. Kowalik, S. Yatsunenko, V. Osinniy, W. Paszkowicz, E. Łusakowska, P. Dłuzewski
Journal of the Korean Physical Society 53, 2880 (2008) (*Proceedings Paper*)
10. *Extremely low temperature growth of ZnO by atomic layer deposition*
E. Guziewicz, I.A. Kowalik, M. Godlewski, K. Kopalko, V. Osinniy, A. Wojcik, S. Yatsunenko, E. Łusakowska, W. Paszkowicz, M. Guziewicz

Journal of Applied Physics 103, 033515 (2008)

11. *Photoemission study of Mn 3d electrons in the valence band of Mn/GeMnTe*
M.A. Pietrzyk, B.J. Kowalski, B.A. Orlowski, W. Knoff, V. Osinniy, I.A. Kowalik, T. Story
Acta Physica Polonica A 112, 275 (2007) (*Proceedings Paper*)
12. *Extra-low temperature growth of ZnO by atomic layer deposition with diethylzinc precursor*
I.A. Kowalik, E. Guzewicz, K. Kopalko, S. Yatsunenkov, M. Godlewski, A. Wojcik, V. Osinniy, T. Krajewski, T. Story, E. Lusakowska, W. Paszkowicz
Acta Physica Polonica A 112, 401 (2007) (*Proceedings Paper*)
13. *MnAs dots grown on GaN(0001)-(1x1) surface*
I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, K. Kopalko, E. Lusakowska, M. Sawicki, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
Physical Review B 75, 235303 (2007)
14. *Resonant photoemission study of TM/GaN (TM = Mn, Ti, Co) interface formation*
I.A. Kowalik, B.J. Kowalski, B.A. Orlowski, P. Kaczor, P. Dziawa, E. Lusakowska, S. Mickevicius, R.L. Johnson, J. Brison, L. Houssiau, I. Grzegory, S. Porowski
Journal of Electron Spectroscopy and Related Phenomena 156, LXXXI (2007) (*Proceedings Paper*)
15. *MnAs dots on GaN(0001) surface - Growth process and electronic structure*
B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, K. Kopalko, E. Lusakowska, M. Sawicki, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
Physics of Semiconductors, Pts A and B 893, 113 (2007) (*Proceedings Paper*)

B) Published during the PhD studies (till December 2006)

16. *GaN(0001) surface doped with Fe atoms*
B.A. Orlowski, I.A. Kowalik, B.J. Kowalski, N. Barrett, I. Grzegory, S. Porowski
J. Alloys and Comp. 423, 136 (2006)
17. *Resonant photoemission study of Ti interaction with GaN surface*
I.A. Kowalik, B.J. Kowalski, P. Kaczor, B.A. Orlowski, E. Lusakowska, R.L. Johnson, L. Houssiau, J. Brison, I. Grzegory, S. Porowski
Surface Science 600, 873 (2006)
18. *Resonant photoemission study of $\text{Eu}_{1-x}\text{Gd}_x\text{Te}$ layers*
B.A. Orlowski, P. Dziawa, B. Kowalski, I. Kowalik, M. Pietrzyk, V. Osinniy, T. Story, S. Mickievicius, R. Johnson
Applied Surface Science 252, 5379 (2006)
19. *Surface and electronic structure of $\text{Ga}_{0.92}\text{In}_{0.08}\text{N}$ thin film investigated by photoelectron spectroscopy*
B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, J. Sadowski, J. Kanski, B.A. Orlowski, J. Ghijsen, F. Mirabella, E. Lusakowska, P. Perlin, S. Porowski, I. Grzegory, M. Leszczynski
Thin Solid Films 476, 396 (2005)
20. *Fano resonance of Eu^{2+} and Eu^{3+} in (Eu,Gd)Te MBE layers*
B.A. Orlowski, B.J. Kowalski, P. Dziawa, M. Pietrzyk, S. Mickievicius, I.A. Kowalik, V. Osinniy, B. Taliashvili, T. Story, R.L. Johnson
Acta Phys. Pol. A 108, 803 (2005)
21. *Electronic structure of GaN(0001)-(1x1) surface*
B.J. Kowalski, R.J. Iwanowski, J. Sadowski, I.A. Kowalik, J. Kanski, I. Grzegory, S. Porowski
Surface Science 548, 220 (2004)

22. *Interaction between Sm and GaN - a photoemission study*

E. Guziewicz, B.J. Kowalski, B.A. Orlowski, A. Szczepanska, Z. Golacki, I.A. Kowalik, I. Grzegory, S. Porowski, R.L. Johnson
Surface Science 551, 132 (2004)

23. *Photoemission study of Mn/GaN*

I.A. Kowalik, B.J. Kowalski, B.A. Orlowski, E. Lusakowska, S. Mickevičius, R.L. Johnson, I. Grzegory, S. Porowski
Surface Science 566, 457 (2004)

24. *MnAs overlayer on GaN(0001)-(1×1) – it's growth, morphology and electronic structure*

B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, E. Lusakowska, M. Sawicki, J. Sadowski, I. Grzegory, S. Porowski
Acta Physica Polonica A 105, 645 (2004)

25. *Mn doped ZnTe (110) surface in Resonant Photoemission study*

B.A. Orlowski, S. Mickevičius, B.J. Kowalski, I.A. Kowalik, K. Kopalko, A. Mycielski, R.L. Johnson
J. Alloys and Compounds 382, 218 (2004)

26. *Differential Reflectivity and photoemission study of ZnTe and CdTe (110) Surface*

B.A. Orlowski, I.A. Kowalik, B.J. Kowalski, M. Suffczynski, A. Mycielski, S. Colonna, C. Ottaviani, F. Ronci, A. Cricenti
J. Alloys and Compounds 382, 224 (2004)

3.2 List of scientific publications not included in the Journal Citation Reports database

A) International synchrotron radiation facilities activity reports

1. *Investigating the surface and interface of (Zn,Co)O thin films by XAS and XMCD*

I.A. Kowalik, F. J. Luque, E. Guziewicz, M. Godlewski, D. Arvanitis
MAX IV Activity Report vol. 2013, 2 strony (2014)

2. *Enantiospecific Spin Polarisation of Electrons Photoemitted through Layers of Homochiral Organic Molecules*

M. Á. Niño, I. A. Kowalik, F. J. Luque, D. Arvanitis, R. Miranda, J. J. de Miguel
MAX IV Activity Report vol. 2013, 2 strony (2014)

3. *Heterogeneous magnetism in (Ga,Fe)N films: experiment and theory at the N K-edge*

I.A. Kowalik, A. Persson, M. Á. Niño, A. Navarro-Quezada, B. Faina, A. Bonanni, T. Dietl, D. Arvanitis
MAX IV Activity Report vol. 2012, 2 strony (2013)

4. *X-ray Absorption of doped ZnO thin films: surface and subsurface material chemistry*

N.G. Subramainam, I. Kowalik, R. Sudar Kodi, S. Senthil Kumar, Juwon Lee, Jaechul Lee, Tae Won Kang, B. Johansson, R. Ahuja, D. Arvanitis
MAX IV Activity Report vol. 2012, 2 strony (2013)

5. *Surface versus interface composition by element specific microscopy: Co doped ZnO*

I.A. Kowalik, M.A. Niño, M. Łukasiewicz, A.A. Zakharov, E. Guziewicz, M. Godlewski, T. Dietl, D. Arvanitis
MAX-lab Activity Report vol. 2010, 142-143 (2011)

6. *Extended X-ray Absorption Fine Structure of Prussian blue analogues*

I.A. Kowalik, F. J. Luque, H. Prima García, J. P. Prieto, F. Romero, M. Makarewicz, J. J. de Miguel, R. Miranda, E. Coronado, and D. Arvanitis
MAX-lab Activity Report vol. 2010, 314-315 (2011)

7. *X-ray absorption and magnetic circular dichroism on Prussian blue analogues*

I.A. Kowalik, F.J. Luque, H. Prima Garcia, J.P. Prieto, F. Romero, M. Makarewicz, D. Arvanitis, J.J. de Miguel, R. Miranda, E. Coronado
MAX-lab Activity Report vol. 2010, 450-451 (2011)

8. *Linear x-ray dichroism at BL I1011: first results on bcc Fe*
I.A. Kowalik, F. Luque, D. Arvanitis
MAX-lab Activity Report vol. 2010, 452-453 (2011)
9. *Interfacial effects in the magnetism of metastable fcc FeCu alloy thin films*
F.J. Luque, M. Á. Niño, A. Persson, I. Kowalik, D. Arvanitis, R. Miranda, J.J. de Miguel
MAX-lab Activity Report vol. 2010, 454-455 (2011)
10. *Element specific characterization of (Ga,Fe)N: magnetism and structure*
I.A. Kowalik, A. Persson, A. Bonanni, T. Dietl, D. Arvanitis
MAX-lab Activity Report vol. 2009, 394-395 (2010)
11. *X-ray Absorption and Magnetic Circular Dichroism on a Prussian blue analogue: first results*
I.A. Kowalik, H. Prima Garcia, J.P. Prieto, F. Romero, E. Jiménez, J. Camarero, M. Makarewicz, D. Arvanitis, R. Miranda, and E. Coronado
MAX-lab Activity Report vol. 2009, 424-425 (2010)
12. *On the electronic structure and magnetic properties of GeMnTe versus GeMnEuTe: XAS and XMCD results*
I.A. Kowalik, A. Wolska, A. Persson, D. Arvanitis, V.E. Slynko, E.I. Slynko
MAX-lab Activity Report vol. 2008, 432-433 (2009)
13. *Commissioning of beamline I1011 – First results*
I.A. Kowalik, G. Öhrwall, B.N. Jensen, E. Wallén, U. Johansson, O. Karis, D. Arvanitis
MAX-lab Activity Report vol. 2008, 456-457 (2009)
14. *MnSb and MnAs quantum dots grown by MBE on GaN(0001) surface - resonant photoemission study*
I.A. Kowalik, B.J. Kowalski, M. Sawicki, M. Pietrzyk, J. Sadowski, E. Łusakowska, I. Grzegory, S. Porowski
MAX-lab Activity Report vol. 2007, 92-93 (2008)
15. *Co-layer formation on GaN - a resonant photoemission study*
I.A. Kowalik, B.J. Kowalski, B.A. Orłowski, P. Dziawa, R.L. Johnson, I. Grzegory, S. Porowski
Hasylab Annual Report vol. 2005, 729-730 (2006)
16. *MnAs dots on GaN(0001)-(1x1)*
B. Kowalski, I.A. Kowalik, R. Iwanowski, K. Kopalko, E. Łusakowska, M. Sawicki, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
MAX-lab Activity Report vol. 2004, 104-105 (2005)
17. *Photoemission study of Mn/GaN*
I.A. Kowalik, B. Kowalski, B. Orłowski, E. Łusakowska, S. Mickievicius, R.L. Johnson, I. Grzegory, S. Porowski
Hasylab Annual Report vol. 2003, 779-780 (2004)
18. *Ti on GaN surface - a resonant photoemission study*
B. Kowalski, I.A. Kowalik, P. Kaczor, R.L. Johnson, I. Grzegory, S. Porowski
Hasylab Annual Report vol. 2003, 805-806 (2004)
19. *Mn doped ZnTe(110)(1x1) surface in resonant photoemission study*
B. Orłowski, S. Mickievicius, B. Kowalski, I.A. Kowalik, K. Kopalko, A. Mycielski, R.L. Johnson
Hasylab Annual Report vol. 2003, 383-384 (2004)
20. *Photoemission study of MnAs deposited on GaN(0001)-(1x1)*
B. Kowalski, R. Iwanowski, E. Łusakowska, I.A. Kowalik, M. Sawicki, J. Sadowski, I. Grzegory, S. Porowski
MAX-lab Activity Report vol. 2003, 116-117 (2004)
21. *Mn on GaN – a resonant photoemission study*
I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, J. Sadowski, J. Kanski, I. Grzegory, S. Porowski
MAX-lab Activity Report vol. 2002, 94-95 (2003)

22. *Photoemission study of Sm/GaN(0001) interface formation*
B. Orłowski, B. Kowalski, E. Guziewicz, I.A. Kowalik, A. Szczepańska, S. Mickevicius, I. Grzegory, S. Porowski, Ł. Pluciński, R.L. Johnson
Hasylab Annual Report vol. 2001, 291-292 (2002)
23. *Photoemission studies of Ga_{1-x}In_xN and GaN epitaxial layers*
I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, J. Sadowski, J. Kanski, P. Perlin, S. Porowski, I. Grzegory, M. Leszczyński
MAX-lab Activity Report vol. 2001, 106-107 (2002)

B) Proceedings and extended abstracts

24. *Resonant photoemission of 4f electrons on clean semiconductor surfaces*
E. Guziewicz, B.A. Orłowski, A. Reszka, L. Wachnicki, S. Gieraltowska, M. Godlewski, I.A. Kowalik, B.J. Kowalski, R.L. Johnson
Bull. Polish Synchr. Rad. Soc. 11, 69-70 (2012)
25. *Electronic structure and magnetic properties of self-organized MnSb and MnAs dots grown by MBE on GaN surface*
I.A. Kowalik, B.J. Kowalski, M. Sawicki, M. Pietrzyk, J. Sadowski, E. Łusakowska, I. Grzegory, and S. Porowski
Bull. Polish Synchr. Rad. Soc. 7, 77 (2008)
26. *Microscopic and resonant photoemission study of Si/Gd*
B.A. Orłowski, B.J. Kowalski, E. Łusakowska, I.A. Kowalik, M.A. Pietrzyk, E. Guziewicz, E. Nossarzewska-Orłowska, R.L. Johnson
Bull. Polish Synchr. Rad. Soc. 7, 129-130 (2008)
27. *MnAs dots on GaN(0001) surface – growth proces and electronic structure*
B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, K. Kopalko, E. Łusakowska, M. Sawicki, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
AIP Conf. Proc. 893, 113 (2007)
28. *Laser-induced band bending variation for ZnTe(110) 1x1 surface*
S.D. Thorpe, S. Colonna, F. Ronci, A. Cricenti, B.A. Orłowski, I.A. Kowalik, B.J. Kowalski
Epiopics-8 Proc., 187 (2006)
29. *Localized 3d states in spintronic materials - studies with use of synchrotron radiation*
B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, E. Łusakowska, K. Kopalko, M. Sawicki, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
Bull. Polish Synchr. Rad. Soc. 4, 8-9 (2005)
30. *A resonant photoemission study of Co/GaN system*
I.A. Kowalik, B.J. Kowalski, B.A. Orłowski, P. Dziawa, E. Łusakowska, R.L. Johnson, J. Brison, L. Houssiau, I. Grzegory, S. Porowski
Bull. Polish Synchr. Rad. Soc. 4, 14-15 (2005)
31. *Photoemission studies of Ga_{0.92}In_{0.08}N(0001) and GaN(0001)*
B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, B.A. Orłowski, E. Łusakowska, J. Sadowski, J. Kanski, J. Ghijsen, F. Mirabella, P. Perlin, S. Porowski, I. Grzegory, M. Leszczyński
Bull. Polish Synchr. Rad. Soc. 3, 80-81 (2004)
32. *Mn, GaMn and MnAs on GaN(0001)-(1x1) surface*
I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, E. Łusakowska, J. Sadowski, I. Grzegory, S. Porowski
Bull. Polish Synchr. Rad. Soc. 3, 78-79 (2004)
33. *Ti interaction with GaN surface - a resonant photoemission study*

I.A. Kowalik, B.J. Kowalski, P. Kaczor, B.A. Orlowski, E. Lusakowska, R.L. Johnson, L. Houssian, J. Brison, I. Grzegory, S. Porowski
Bull. Polish Synchr. Rad. Soc. 3, 58-59 (2004)

34. *Electronic structure of GaN(0001)-(1x1) surface - an angle resolved photoemission study*
B. Kowalski, R. Iwanowski, J. Sadowski, I.A. Kowalik, J. Kanski, I. Grzegory, S. Porowski
Inst. Phys. Conf. Ser. vol. 171, C4.5 (1-8) (2003)

4. Scientific Conference Presentations “Abstract only”

4.1 Invited lectures

1. *Soft x-ray spectroscopy and spectro-microscopy on ZnO thin films: tracing the origin of ferromagnetism upon Co doping*
I.A. Kowalik, M.I. Łukasiewicz, E. Guzewicz, M. Godlewski, F.J. Luque, M.A. Nino, A. Zakharov, D. Arvanitis
International Conference Spin Physics, Spin Chemistry and Spin Technology, 1-5.06.2015 St. Petersburg (Russian Federation)
Conference Programme 13 (2015);
2. *Circular, Linear and Natural Dichroism at MAX IV-lab: challenges and perspectives*
I.A. Kowalik
User Meeting, MAX IV, Session “Solid State, Structure and Surface”, 21-23.09.2015 Lund, (Sweden)
Program on line: https://www.maxiv.se/files/Parallel_session_4S_UM15.pdf ;
3. *Soft x-ray spectroscopy and spectro-microscopy on (Ga,Fe)N films*
I.A. Kowalik, M. Á. Niño, F. J. Luque, A. Locatelli, T. Onur Montes, A. Bonanni, T. Dietl, D. Arvanitis
The joint STINT Workshop on functional materials and minerals, 10-11.06.2013 Uppsala (Sweden);
4. *Soft x-ray spectroscopy and microscopy on functionalized Diluted Magnetic Semiconductor films*
I.A. Kowalik, M.A. Niño, A. Locatelli, T. Onur Montes, A. Bonanni, T. Dietl, D. Arvanitis
European Materials Research Society (E-MRS), Symposium H “Novel Materials for Electronics, Optoelectronics, Photovoltaics and Energy Saving Applications”, 19-23.09.2011 Warsaw (Poland)
Book of Abstracts H III-2 (2011);
5. *Magnetyczna spektroskopia i spektro-mikroskopia na materiałach spintronicznych*
I.A. Kowalik, M.A. Niño, A. Locatelli, T. Onur Menteş, A. Bonanni, T. Dietl, D. Arvanitis
IX Krajowe Sympozjum Użytkowników Promieniowania Synchrotronowego, 26-27.09.2011 Warsaw (Poland);
Bull. Polish Synchr. Rad. Soc. 10, 42 (2011)
6. *Electronic structure and magnetic properties of self-organized MnSb and MnAs dots grown by MBE on GaN surface*
I.A. Kowalik, B.J. Kowalski, M. Sawicki, M. Pietrzyk, J. Sadowski, E. Lusakowska, I. Grzegory, S. Porowski
9th International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS 2008), 15-20.06.2008 Ameliówka (Poland);
Bull. Polish Synchr. Rad. Soc. 7, 77 (2008)

Invited lectures given by co-authors

7. *Element Specific Magnetism and Structure of Functional Magnets: Prussian Blue Derivatives*
D. Arvanitis, I.A. Kowalik, F.J. Luque, M.Á. Niño, J.J. de Miguel, R. Miranda, H. Prima García, J. P. Prieto, F. Romero, M. Makarewicz, E. Coronado
The joint STINT Workshop on functional materials and minerals, 10-11.06.2013 Uppsala (Sweden);
8. *II-VI based DMS materials- from materials properties to magnetic properties*
M. Godlewski, M.I. Łukasiewicz, A. Wójcik-Głodowska, I. Kowalik, E. Guzewicz
EMN Fall Meeting – Energy, Materials, Nanotechnology, 7-10.12.2013 Orlando FL (USA);

9. *Resonant photoemission of 4f electrons on clean semiconductor surfaces*
E. Guzewicz, B.A. Orlowski, A. Reszka, L. Wachnicki, S. Gieraltowska, M. Godlewski, I.A. Kowalik, B.J. Kowalski, R.L. Johnson
11th International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS 2012), 20-25.05.2012 Tyniec, Karków (Poland);
Bull. Polish Synchr. Rad. Soc. 11, 69 (2012)
10. *Homogenous and Heterogeneous Magnetism in (Zn,Co)O*
M. Sawicki, E. Guzewicz, M. I. Lukasiewicz, O. Proselkov, I.A. Kowalik, P. Dłuzewski, W. Paszkowicz, R. Jakiela, B.S. Witkowski, L. Wachnicki, W. Stefanowicz, D. Sztienkiel, M. Godlewski and T. Dietl
International Conference on Oxide Materials for Electronic Engineering – fabrication, properties and applications OMEE-2012, 3–7.09.2012 Lviv (Ukraine);
11. *XPS studies of (Zn,Co)O/Si interfaces*
E. Guzewicz, M. Godlewski, M.I. Lukasiewicz, W. Lisowski, M. Krawczyk, J.W. Sobczak, A. Jablonski, M. Sawicki, I.A. Kowalik, D. Arvanitis, F.J. Luque, P. Dłuzewski, T. Dietl
Joint Polish-Japanese Workshop “Spintronics – from new materials to applications”, 15-18.11.2011 Warsaw (Poland);
12. *Wide band-gap II-VI semiconductors for optoelectronic applications*
E. Guzewicz, M. Godlewski, K. Kopalko, A. Szczerbakow, I.A. Kowalik, A. Wójcik, S. Yatsunencko, W. Paszkowicz, E. Łusakowska
European Materials Research Society Fall Meeting (E-MRS 2007), Symposium C “Atomic Layer Deposition”, 17-21.09.2007 Warsaw (Poland)
Scientific Programme and Book of Abstracts 89 (2007);
13. *Localized 3d states in spintronic materials - studies with use of synchrotron radiation*
B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, E. Łusakowska, K. Kopalko, M. Sawicki, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
6th Polish Meeting of Synchrotron Radiation Users (KSUPS), 8-9.09.2005 Warsaw (Poland);
Bull. Polish Synchr. Rad. Soc. 4, 8-9 (2005)
14. Gallium nitride surface formation and modification by Mn deposition – photoemission studies with use of synchrotron radiation
B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, B.A. Orlowski, E. Łusakowska, J. Sadowski, R.L. Johnson, I. Grzegory, S. Porowski
European Materials Research Society (EMRS), Symposium B “Development of Methods for Characterizing the Microstructure of Novel Materials”, 14-18.09.2003 Warsaw (Poland)
Program of EMRS Fall Meeting 28 (2003);

4.2 Regular talks

1. *Towards single molecule spin filters: organic chiral molecules on metal surfaces*
I.A. Kowalik, M. Á. Niño, F. J. Luque, D. Arvanitis, J. J. de Miguel
First European Conference on Molecular Spintronics (ECMoIS), 15-18.11.2016 Bologna (Italy);
Abstract accepted as regular talk;
2. *X-ray absorption and photoemission spectroscopy of organic chiral molecules on metal surfaces*
I.A. Kowalik, M. Á. Niño, F. J. Luque, D. Arvanitis, R. Miranda, J. J. de Miguel
Joint European Magnetic Symposia (JEMS), 21-26.08.2016 Glasgow (UK);
Book of Abstracts (2016);
3. *Soft x-ray absorption spectroscopy on Atomic Layer Deposition grown ZnO films*
I.A. Kowalik, M.I. Łukasiewicz, E. Guzewicz, M. Godlewski, D. Arvanitis
International Conference on X-ray Absorption Fine Structure, 23-28.08.2015 Karlsruhe (Germany);
Book of Abstracts 64 (2015);

4. *Combining linear and circular L-edge x-ray dichroism: identification of magnetic phases in (Ga,Fe)N*
I.A. Kowalik, A. Locatelli, T. Onur Montes, F. Luque, B. Faina, A. Bonanni, T. Dietl and D. Arvanitis
European Materials Research Society Fall Meeting E-MRS, Symposium X "Antiferromagnetic spintronics: materials, characterization, functionalities", 15-19.09.2014 Warsaw (Poland);
Book of Abstracts 366 (2014);
5. *X-ray absorption and photoemission spectroscopy on chiral DPED molecules on Cu(100) and Co/Cu(100)*
F. J. Luque, I. A. Kowalik, M. Á. Niño, D. Arvanitis, R. Miranda, J. J. de Miguel
European Materials Research Society Fall Meeting E-MRS, Symposium H "Organic and Carbon based Spintronics: materials and device trends", 16-20.09.2013, Warsaw (Poland);
Book of Abstracts 172 (2013);
6. *Soft x-ray spectroscopy and microscopy on Co doped ZnO films*
I.A. Kowalik, M.I. Lukaszewicz, E. Guziewicz, M. Godlewski, F. Luque, M.A. Nino, A. Zakharov, D. Arvanitis
European Materials Research Society Fall Meeting E-MRS, Symposium F "Novel materials for electronic, optoelectronic, photovoltaic and energy saving applications", 16-20.09.2013, Warsaw (Poland);
Book of Abstracts 110 (2013);
7. *Nano magnetism in functional dilute magnetic semiconductors: (Ga,Fe)N films*
I.A. Kowalik, M.A. Niño, A. Locatelli, T. Onur Montes, A. Bonanni, T. Dietl and D. Arvanitis
TEAM workshop "Atomic and molecular level devising of functional nanostructures for magnetic and catalytic applications", 12-16.04.2011 Zakopane (Poland);
8. *Soft x-ray absorption on (Ga,Fe)N films: magnetism and structure*
I.A. Kowalik, A. Persson, A. Bonanni, T. Dietl, D. Arvanitis
23rd General Conference of the Condensed Matter Division of the European Physical Society, 30.08-03.09.2010 Warsaw (Poland)
Book of Abstracts 53 (2010);
9. *Element specific characterization of (Ga,Fe)N: XMCD and XPEEM*
I.A. Kowalik, A. Persson, M.A. Niño, A. Bonanni, T. Dietl, D. Arvanitis
European Materials Research Society E-MRS, 13-17.09.2010 Warsaw (Poland);
10. *A resonant photoemission study of Co/GaN system*
I.A. Kowalik, B.J. Kowalski, B.A. Orlowski, P. Dziawa, E. Łusakowska, R.L. Johnson, J. Brison, L. Houssiau, I. Grzegory, S. Porowski
6th Polish Meeting of Synchrotron Radiation Users (KSUPS), 08-09.09.2005 Warsaw (Poland);
Bull. Polish Synchr. Rad. Soc. 4, 14-15 (2005)
11. *Ti interaction with GaN surface - a resonant photoemission study*
I.A. Kowalik, B.J. Kowalski, P. Kaczor, B.A. Orlowski, E. Łusakowska, R.L. Johnson, L. Houssiau, J. Brison, I. Grzegory, S. Porowski
VIIth International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS), 8-13.06.2004 Zakopane (Poland)
Bull. Polish Synchr. Rad. Soc. 3, 58-59 (2004);

Regular talks given by co-authors

12. *Adsorption of homochiral organic molecules on metal surfaces: Structure and enantiospecific photoelectron spin polarization*
M. Á. Niño, R. Palacios, F. J. Luque, I. A. Kowalik, S. Matencio, E. Barrena, D. Arvanitis, C. Ocal, J. J. de Miguel
31st European Conference on Surface Science, 31.08-04.09.2015 Barcelona (Hiszpania);
13. *Enantiospecific spin polarization from adsorbed organic chiral molecules*
J. J. de Miguel, M. A. Nino, R. Palacios, F. J. Luque, I. A. Kowalik, S. Matencio, E. Barrena, D. Arvanitis, C. Ocal

Chirality at the Nanoscale, 03.11-06.11.2015 Leuven (Belgium);

14. *Enantiospecific spin polarisation of electrons photoemitted through layers of homochiral organic molecules*
M. Á. Niño, I. A. Kowalik, F. J. Luque, D. Arvanitis, R. Miranda, J. J. de Miguel
30th European Conference on Surface Science (ECOSS-30), 31.08.-05.09.2014 Antalya (Turkey);
15. *Enantiospecific spin polarization of electrons photoemitted through layers of homochiral molecules*
J. J. De Miguel, M. Á. Niño, I. A. Kowalik, F. J. Luque, D. Arvanitis, R. Miranda
Workshop on "Electronic and Magnetic Properties of Chiral Structures and their Assemblies", 30.06.-04.07.2014 Telluride, CO (USA);
16. *Nanospectroscopy On FeCu Magnetic Alloy Films: Electronic Interface Effects In Organic-Metal Films*
M. A. Niño, F. J. Luque, P. Perna, I. O. Kowalik, T. O. Montes, A. Locatelli, L. Aballe, D. Arvanitis, R. Miranda, J. J. de Miguel
12th European Conference on Molecular Electronics (ECME-2013), 03-07.09.2013, London (U. K.);
17. *Nanospectroscopy on FeCu magnetic alloy films: electronic interface effects in organic-metal films*
M. A. Niño, F. J. Luque, P. Perna, I. O. Kowalik, T. O. Montes, A. Locatelli, L. Aballe, D. Arvanitis, R. Miranda, J. J. de Miguel
19th International Vacuum Congress (IVC-19), International Conference on Nanoscience and Technology (ICN+T) and 15th International Conference on Solid Surfaces (ICSS-15), 09-13.09.2013, Paris (France);
18. *Atomic Layer Deposition – a growth method for novel spintronics materials*
M.I. Łukasiewicz, M. Godlewski, E. Guzewicz, A. Wojcik-Głodowska, K. Kopalko, A. Wolska, M. Klepka, B.S. Witkowski, R. Jakiela, I.A. Kowalik
13th International Conference on Atomic Layer Deposition, 28-31.07.2013 San Diego (USA);
19. *X-ray circular dichroism in chemisorbed chiral molecules*
F. J. Luque, I. A. Kowalik, M. Á. Niño, D. Arvanitis, R. Miranda, J. J. de Miguel
29th European Conference on Surface Science (ECOSS-29), 03-05.09.2012 Edinburgh (U. K.);
20. *Circular dichroism of chemisorbed DPED chiral molecule film*
M. A. Niño, F.J. Luque, I. Kowalik, D. Arvanitis, R. Miranda, J.J. de Miguel
Multifunctional Hybrids and Organics Conference (MAMA-Hybrids), 22-24.10.2012, Ischia (Italy);
21. *Electronic interface effects in FeCu alloy films grown on self-assembled Pb islands*
F. J. Luque, I. A. Kowalik, T. O. Montes, A. Locatelli, R. Miranda, J. J. de Miguel, D. Arvanitis, M. Á. Niño
29th European Conference on Surface Science (ECOSS-29), 03-05.09.2012 Edinburgh (U. K.);
22. *XPS studies of (Zn,Co)O/Si interfaces*
E. Guzewicz, M. Godlewski, M.I. Łukasiewicz, W. Lisowski, M. Krawczyk, J. W. Sobczak, M. Sawicki, I. A. Kowalik, D. Arvanitis, F. Luque, P. Dłuzewski
International Conference on the Formation of Semiconductor Interfaces (13th ICFSI), 3-8.07.2011 Prague (Czech Republic);
23. *Interfacial effects in the magnetism of metastable fcc FeCu alloys*
M. Á. Niño, F. J. Luque, T. O. Montes, I. A. Kowalik, A. Locatelli, D. Arvanitis, R. Miranda, J. J. de Miguel
28th European Conference on Surface Science (ECOSS-28), 28.08-02.09.2011 Wrocław (Poland);
24. *Extra-low temperature growth of ZnO thin films by Atomic Layer Deposition*
E. Guzewicz, M. Godlewski, K. Kopalko, I.A. Kowalik, A. Wojcik, S. Yatsunenko, V. Osinnyi, W. Paszkowicz, E. Łusakowska
The 13th International Conference on II-VI Compounds, 10-14.09.2007 Jeju (Korea);
25. *MnAs grown on GaN(0001)-(1×1) surface*
B. Kowalski, R. Iwanowski, E. Łusakowska, I.A. Kowalik, M. Sawicki, J. Sadowski, I. Grzegory, S. Porowski
13th International Congress on Thin Films (ICTF 13), 8th International Conference on Atomically Controlled Surfaces, Interfaces and Nanostructures (ACSIN 8), 19-23.06.2005 Stockholm (Sweden)

Book of Abstracts 30 (2005);

26. *Gallium nitride surface formation and modification by Mn deposition - photoemission studies with use of synchrotron radiation*

B. Kowalski, I.A. Kowalik, R. Iwanowski, B. Orłowski, E. Łusakowska, J. Sadowski, R.L. Johnson, I. Grzegory, S. Porowski

E-MRS 2003 Fall Meeting: Symposium B, 15-19.09.2003 Warsaw (Poland);

4.3 Poster presentations

1. *Linear and circular Fe L-edge x-ray dichroism on (Ga,Fe)N: element specific magnetometry including the antiferromagnetic components*

I.A. Kowalik, N. Gonzalez Szwacki, M.A. Niño, A. Locatelli, T. Onur Montes, F. Luque, A. Navarro-Quezada, B. Faina, T. Dietl, A. Bonanni, and D. Arvanitis

Joint European Magnetic Symposia (JEMS), 21-26.08.2016 Glasgow (UK);

Book of Abstracts (2016);

2. *Spin-sensitive spectroscopy studies of chiral molecules adsorbed at surfaces*

I.A. Kowalik, J. J. de Miguel, M. Á. Niño, F. J. Luque, D. Arvanitis

The Future of X-ray and Electron Spectroscopy, 15-17.06.2016 Uppsala (Szwecja)

Book of Abstracts (2016);

3. *X-ray spectro-microscopy on ZnO thin films: tracing the origin of ferromagnetism upon Co doping*

I.A. Kowalik, M.I. Łukasiewicz, E. Guzewicz, M. Godlewski, F.J. Luque, M.A. Nino, A. Zakharov, D. Arvanitis

International Conference on X-ray Absorption Fine Structure, 23-28.08.2015 Karlsruhe (Germany)

Book of Abstracts 131 (2015);

4. *Nano magnetism by means of core level dichroism in a functional dilute magnetic semiconductor: (Ga,Fe)N films*

I.A. Kowalik, M.A. Nino, A. Locatelli, T.O. Montes, F.J. Luque, A. Navarro-Quezada, B. Faina, A. Bonanni, T. Dietl, D. Arvanitis

IEEE International Magnetism Conference (INTERMAG), 04-08.05.2014 Dresden (Germany)

Book of Abstracts 254 (2014);

5. *Large x-ray circular dichroism in adsorbed films of homochiral organic molecules*

F. J. Luque, I. A. Kowalik, M. Á. Niño, D. Arvanitis, R. Miranda, J. J. de Miguel

30th European Conference on Surface Science (ECOSS-30), 31.08.-05.09.2014 Antalya (Turkey);

6. *Spin polarization of electrons photoemitted through layers of homochiral organic molecules*

M Á Niño, I A Kowalik, F J Luque, D Arvanitis, R Miranda, J. J. de Miguel

International Symposium on Spin-Polarized Electron Physics and Nanomagnetism, 10-13.07.2014 Halle (Germany);

7. *Structural and electronic characterization of adsorber layers of chiral molecules by x-ray absorption*

F. J. Luque, M. Á. Niño, I. A. Kowalik, D. Arvanitis, R. Miranda, J. J. de Miguel

Workshop on "Electronic and Magnetic Properties of Chiral Structures and their Assemblies", 30.06.-04.07.2014 Telluride, CO (USA);

8. *Magnetic Microspectroscopy and Dichroic Effects in X-Ray Absorption by Adsorbed Thin Films of Chiral Molecules*

M.A. Nino, F.J. Luque, J.J. de Miguel, P. Perna, R. Miranda, I. Kowalik, L. Aballe, M. Foerster, D. Arvanitis

Workshop on "Electronic and Magnetic Properties of Chiral Structures and their Assemblies", 30.06.-04.07.2014 Telluride, CO (USA);

9. *Synchrotron radiation for study Fano type photoemission resonances in rare earth atoms*

B.A. Orłowski, B.J. Kowalski, E. Guzewicz, I. Kowalik, M. Pietrzyk, A. Reszka

10th National Meeting of Synchrotron Radiation Users (KSUPS-10), 09-11.09.2013 Stalowa Wola (Poland)

Bull. Polish Synchr. Rad. Soc. 12, 47 (2013);

10. *Soft x-ray spectroscopy and microscopy on ZnO films: the importance of the inner interface*

I.A. Kowalik, M.I. Lukaszewicz, E. Guziejewicz, M. Godlewski, F. J. Luque, M. Á . Niño, A. Zakharov, D. Arvanitis
3rd European Workshop on Self Organized Nanomagnets, 16-20.04.2012 Guadarrama, Madrid (Spain)
Book of Abstracts 126 (2012);

11. *Electronic interface effects in FeCu alloy films grown on self-assembled Pb islands*

F. J. Luque, I. A. Kowalik, T. O. Montes, A. Locatelli, R. Miranda, J. J. De Miguel, D. Arvanitis, M. Á . Niño
3rd European Workshop on Self Organized Nanomagnets, 16-20.04.2012 Guadarrama, Madrid (Spain)
Book of Abstracts 130 (2012);

12. *Synchrotron radiation-based studies of Prussian Blue derivatives*

I.A. Kowalik, F. J. Luque, H. Prima García, J. P. Prieto, M. Á . Niño, F. Romero, M. Makarewicz, J. J. de Miguel, R. Miranda, E. Coronado, D. Arvanitis
3rd European Workshop on Self Organized Nanomagnets, 16-20.04.2012 Guadarrama, Madrid (Spain)
Book of Abstracts 168 (2012);

13. *Circular dichroism in chemisorbed chiral molecules*

F. J. Luque, I. A. Kowalik, M. Á . Niño, D. Arvanitis, R. Miranda, J. J. de Miguel
3rd European Workshop on Self Organized Nanomagnets, 16-20.04.2012, Guadarrama, Madrid (Spain)
Book of Abstracts 174 (2012);

14. *Electronic structure and magnetism of (Zn,Co)O films: A soft x-ray spectroscopy study*

I.A. Kowalik, M.I. Lukaszewicz, E. Guziejewicz, M. Godlewski, F.J. Luque, M.A. Nino, A. Zakharov, D. Arvanitis
11th International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS 2012), 20-25.05.2012 Tyniec, Karków (Poland)
Bull. Polish Synchr. Rad. Soc. 11, 108 (2012);

15. *Soft x-ray spectroscopy and spectro-microscopy on Co doped ZnO films*

I.A. Kowalik, M.I. Lukaszewicz, E. Guziejewicz, M. Godlewski, F.J. Luque, M.A. Nino, A. Zakharov, D. Arvanitis
International Workshop on Zinc Oxide and Related Materials, 11-14.09.2012 Nicea (France);

16. *Room temperature nano-magnetism of (Ga,Fe)N films: element specific spectroscopy and microscopy*

I.A. Kowalik, M.A. Niño, A. Locatelli, T. Onur Montes, A. Navarro-Quezada, Mauro Rovezzi, A. Bonanni, T. Dietl and D. Arvanitis
40th "Jaszowiec" International School and Conference on the Physics of Semiconductors, 25.06-01.07.2011 Krynica-Zdrój (Poland)
Book of Abstracts 213 (2011);

17. *Magneto-optical properties of (Ga,Fe)N layers*

J. Papierska, J.-G. Rousset, A. Golnik, W. Pacuski, M. Nawrocki, J. A. Gaj, J. Suffczyński, I. Kowalik, W. Stefanowicz, M. Sawicki, T. Dietl, A. Navarro-Quezada, B. Faina, Tian Li, A. Bonanni
40th "Jaszowiec" International School and Conference on the Physics of Semiconductors, 25.06-01.07.2011 Krynica-Zdrój (Poland)
Book of Abstracts 229 (2011);

18. *Natural x-ray dichroism in chemisorbed films of chiral molecules*

F. J. Luque, M. Á . Niño, I. A. Kowalik, D. Arvanitis, R. Miranda, J. J. de Miguel
28th European Conference on Surface Science (ECOSS-28), 28.08-02.09.2011 Wrocław (Poland);

19. *ZnCoO Films by Atomic Layer Deposition – structural and magnetic properties*

M. Łukaszewicz, M. Godlewski, E. Guziejewicz, M. Sawicki, W. Paszkowicz, E. Łusakowska, R. Jakiela, T. Krajewski, I.A. Kowalik, B.J. Kowalski, B. Witkowski
Fifth International School and Conference on Spintronics and Quantum Information Technology (Spintech 5), 07-11.06.2009 Cracow (Poland)
Program and abstracts 206 (2009);

20. *ZnCoO Films by Atomic Layer Deposition – optimization of a growth parameters to obtain uniform cobalt distribution*

M. Łukasiewicz, B. Witkowski, M. Godlewski, E. Guziewicz, M. Sawicki, W. Paszkowicz, E. Łusakowska, R. Jakiela, T. Krajewski, I.A. Kowalik, B.J. Kowalski
The Baltic ALD conference (BALD 2009), 15-16.06.2009 Uppsala (Sweden);

21. *The new I1011 beam line for magnetism work at MAX-lab: description and first results*

I.A. Kowalik, G. Öhrwall, B. N. Jensen, E. Wallén, U. Johansson, O. Karis, D.Arvanitis
International Conference on Magnetism (ICM), 26-31.07.2009 Karlsruhe (Germany)
Program and Abstracts 238 (2009);

22. *The new I1011 beamline for magnetic measurements at MAX-lab*

I.A. Kowalik, G. Öhrwall, B. N. Jensen, E. Wallén, U. Johansson, O. Karis, D.Arvanitis
Polarized Neutrons and Synchrotron X-rays for Magnetism (PNSXM), 02-05.08.2009 Bonn (Germany);

23. *Commissioning of beamline I1011 at MAX-lab – First results*

I.A. Kowalik, G. Öhrwall, B. N. Jensen, E. Wallén, U. Johansson, O. Karis, D.Arvanitis
The 10th International Conference on Synchrotron Instrumentation (SRI 2009), 27.09-02.10.2009 Malbourne (Australia);

24. *ZnCoO Films by Atomic Layer Deposition – influence of a growth temperature on uniformity of cobalt distribution*

M. Łukasiewicz, B. Witkowski, M. Godlewski, E. Guziewicz, M. Sawicki, W. Paszkowicz, E. Łusakowska, R. Jakiela, T. Krajewski, I.A. Kowalik, B.J. Kowalski
XXXVIII International School and Conference on the Physics of Semiconductors, 19-26.06.2009 Krynica-Zdrój (Poland)
Book of Abstracts 121 (2009);

25. *The influence of growth temperature and precursors' doses on electric parameters of ZnO thin films*

T. Krajewski, E. Guziewicz, M. Godlewski, Ł. Wachnicki, I.A. Kowalik, K. Kopalko, A. Wójcik, V. Osinniy, M. Guziewicz
European Material Research Conference March Meeting 2008, 26-30.05.2008 Strassbourg (France);

26. *Self-Organized MnSb and MnAs Dots Grown by MBE on GaN(0001) Surface – Comparison of Electronic Structure and Magnetic Properties*

I.A. Kowalik, B.J. Kowalski, M. Sawicki, M. Pietrzyk, J. Sadowski, E. Łusakowska, I. Grzegory, S. Porowski
XXXVII International School on the Physics of Semiconducting Compounds, 7-13.06.2008 Ustroń-Jaszowiec (Poland)
Book of Abstracts 106 (2008);

27. *Reactivity of Gd on Si(111) surface*

B.A. Orlowski, E. Łusakowska, I.A. Kowalik, M.A. Pietrzyk, B.J. Kowalski, E. Guziewicz, E. Nossarzewska-Orłowska, R.L. Johnson
XXXVII International School on the Physics of Semiconducting Compounds, 7-13.06.2008 Ustroń-Jaszowiec (Poland)
Book of Abstracts 112 (2008);

28. *Electronic Structure of Mn deposited ZnMnO films grown by ALD technique – resonant photoemission study*

I.A. Kowalik, E. Guziewicz, Ł. Wachnicki, K. Kopalko, E. Łusakowska, W. Paszkowicz, M. Godlewski
9th International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS 2008), 15-20.06.2008, Ameliówka (Poland)
Bull. Polish Synchr. Rad. Soc. 7, 112 (2008);

29. *Microscopic and resonant photoemission study of Gd/Si*

B.A. Orlowski, B.J. Kowalski, E. Guziewicz, E. Łusakowska, V. Osinniy, I.A. Kowalik, M.A. Pietrzyk, E. Nossarzewska-Orłowska, R.L. Johnson
9th International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS-9), 15-20.06.2008, Ameliówka (Poland)
Bull. Polish Synchr. Rad. Soc. 7, 129-130 (2008);

30. *Photoemission Study of Mn 3d Electrons in the valence band of Mn/GeMnTe*

M.A. Pietrzyk, B.J. Kowalski, B.A. Orlowski, W. Knoff, V. Osinniy, I.A. Kowalik, T. Story, R.L. Johnson
XXXVI International School on the Physics of Semiconducting Compounds, 9-15.06.2007 Jaszowiec (Poland)

Book of Abstracts 44 (2007);

31. *Extra-low temperature growth of ZnO by ALD with diethylzinc precursor*

I.A. Kowalik, E. Guzewicz, K. Kopalko, S. Yatsunenko, M. Godlewski, A. Wójcik, V. Osinniy, T. Krajewski, T. Story, E. Łusakowska, W. Paszkowicz

XXXVI International School on the Physics of Semiconducting Compounds, 9-15.06.2007 Jaszowiec (Poland)

Book of Abstracts 70 (2007);

32. *Gd 4f electrons contribution to Si/Gd valence band*

B.A. Orlowski, B.J. Kowalski, E. Guzewicz, E. Łusakowska, V. Osinniy, I.A. Kowalik, M.A. Pietrzyk, E. Nossarzewska-Orłowska, A. Bukowski, L. Johnson

7th Polish Meeting of Synchrotron Radiation Users (KSUPS-7), 24-26.09.2007 Poznań (Poland)

Bull. Polish Synchr. Rad. Soc. 6, 55 (2007);

33. *Mn 3d contribution to the valence band of Mn/GeMnTe*

M.A. Pietrzyk, B.J. Kowalski, B.A. Orlowski, W. Knoff, V. Osinniy, I.A. Kowalik, T. Story, R.L. Johnson

7th Polish Meeting of Synchrotron Radiation Users (KSUPS-7), 24-26.09.2007 Poznań (Poland)

Bull. Polish Synchr. Rad. Soc. 6, 62 (2007);

34. *ZnO thin films for organic/inorganic heterojunctions*

I.A. Kowalik, Ł. Wachnicki, E. Guzewicz, K. Kopalko, S. Yatsunenko, M. Godlewski, A. Wójcik, V. Osinniy, T. Krajewski, T. Story, E. Łusakowska, W. Paszkowicz

European Materials Research Society Fall Meeting (E-MRS 2007), Acta Materialia Gold Medal Workshop, 17-21.09.2007 Warsaw (Poland)

Scientific Programme and Book of Abstracts 309 (2007);

35. *Mn 3d electrons in the valence band of Mn/Ge_{0.9}Mn_{0.1}Te – a resonant photoemission study*

M. Pietrzyk, B.J. Kowalski, B.A. Orlowski, W. Knoff, V. Osinniy, I.A. Kowalik, T. Story, R.L. Johnson,

European Materials Research Society Fall Meeting (E-MRS 2007), Symposium I “New opportunities and challenges in material research using synchrotron and free electron laser sources”, 17-21.09.2007 Warsaw (Poland)

Scientific Programme and Book of Abstracts 235 (2007);

36. *Gd atoms on Si (111) surface – AFM and photoemission study*

B.A. Orlowski, B.J. Kowalski, E. Guzewicz, E. Łusakowska, V. Osinniy, I.A. Kowalik, M.A. Pietrzyk, E. Nossarzewska-Orłowska, A. Bukowski, R. L. Johnson

European Materials Research Society Fall Meeting (E-MRS 2007), Symposium I “New opportunities and challenges in material research using synchrotron and free electron laser sources”, 17-21.09.2007 Warsaw (Poland)

Scientific Programme and Book of Abstracts 234 (2007);

37. *Mn 3d electrons in the valence band of Mn/GeMnTe-a photoemission study*

M.A. Pietrzyk, B.J. Kowalski, B.A. Orlowski, W. Knoff, V. Osinniy, I.A. Kowalik, T. Story, R.L. Johnson,

IVC-17/ICSS-13 and ICN+T 2007 Co-Organised with NCSS-6/NSM-22/SVM-4, 02-06.07.2007 Stockholm (Sweden);

38. *Effect of annealing on electrical properties of low temperature ZnO films*

I.A. Kowalik, E. Guzewicz, K. Kopalko, M. Godlewski, A. Wójcik, V. Osinniy, T. Krajewski, T. Story

5th International Conference on Solid State Crystals (ICSSC-5) and 8th Polish Conference on Crystal Growth (PCCG-8), 20-24.05.2007, Zakopane (Poland)

Book of Abstracts 22 (2007);

39. *MnAs dots on GaN(0001) surface – growth process and electronic structure*

B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, K. Kopalko, E. Łusakowska, M. Sawicki, J. Sadowski, M. Adell, I. Grzegory, S. Porowski,

28th International Conference on the Physics of Semiconductors, 24-28.07.2006, Vienna (Austria);

40. *Resonant Photoemission Studies of the Electronic Structure of MnAs Dots on GaN*

I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, K. Kopalko, M. Sawicki, E. Łusakowska, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
VIIIth International School and Symposium on Synchrotron Radiation in Natural Sciences (ISSRNS-8), 12-17.06.2006 Zakopane (Poland)
Bull. Polish Synchr. Rad. Soc. 5, 69 (2006);

41. *The electronic structure of MnAs dots on GaN – a resonant photoemission studies*

I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, K. Kopalko, M. Sawicki, E. Łusakowska, J. Sadowski, M. Adell, I. Grzegory, S. Porowski
XXXIII International School on the Physics of Semiconducting Compounds, 17-23.06.2006 Jaszowiec (Poland)
Program & Abstracts 181 (2006);

42. *Resonant photoemission study of TM/GaN (Tm=Mn, Ti, Co) interface formation*

I.A. Kowalik, B.J. Kowalski, B.A. Orłowski, P. Kaczor, P. Dziawa, E. Łusakowska, S. Mickevicius, R.L. Johnson, J. Brison, L. Houssiau, I. Grzegory, S. Porowski
International Conference on Electronic Spectroscopy and Structure (ICESS), 28.08-01.09.2006 Foz do Iguaçu (Brazil);

43. *Co/GaN interface formation - a resonant photoemission study*

I.A. Kowalik, B. Kowalski, B. Orłowski, P. Dziawa, E. Łusakowska, R.L. Johnson, J. Brison, L. Houssian, I. Grzegory, S. Porowski
XXXIV International School on the Physics of Semiconducting Compounds, 04-10.06.2005 Jaszowiec (Poland)
Program & Abstracts 183 (2005);

44. *Resonant photoemission study of Ti/GaN interface formation*

I.A. Kowalik, B.J. Kowalski, P. Kaczor, B.A. Orłowski, E. Łusakowska, R. Johnson, L. Houssian, J. Brison, I. Grzegory, S. Porowski
13th International Congress on Thin Films (ICTF 13), 8th International Conference on Atomically Controlled Surfaces, Interfaces and Nanostructures (ACSIN 8), 19-23.06.2005 Stockholm (Sweden)
Book of Abstracts 88 (2005);

45. *Resonant photoemission study of Eu(1-x)Gd(x)Te layers*

B.A. Orłowski, P. Dziawa, B.J. Kowalski, I.A. Kowalik, M. Pietrzyk, V. Osinniy, T. Story, S. Mickevicius, R. Johnson
13th International Congress on Thin Films (ICTF 13), 8th International Conference on Atomically Controlled Surfaces, Interfaces and Nanostructures (ACSIN 8), 19-23.06.2005 Stockholm (Sweden)
Book of Abstracts 82 (2005);

46. *Study of Eu valence in (Eu,Gd)Te by means of photoemission spectroscopy*

M. Pietrzyk, B.A. Orłowski, B.J. Kowalski, P. Dziawa, S. Mickevicius, V. Osinniy, B. Taliashvili, I.A. Kowalik, T. Story, R.L. Johnson
6th Polish Meeting of Synchrotron Radiation Users (KSUPS), 08-09.09.2005 Warsaw (Poland)
Bull. Polish Synchr. Rad. Soc. 4, 61 (2005);

47. *Interaction of Mn and Ti atoms with GaN surface – a resonant photoemission study*

I.A. Kowalik, B.J. Kowalski, B.A. Orłowski, P. Kaczor, E. Łusakowska, S. Mickevicius, R.L. Johnson, L. Houssian, J. Brison, I. Grzegory, S. Porowski
European Materials Research Society (EMRS) Fall Meeting, Symposium C “Science and Technology of Nitrides and Related Materials” 06-10.09.2004 Warsaw (Poland)
Book of Abstracts 100 (2004);

48. *A resonant photoemission study of Ti/GaN*

I.A. Kowalik, B. Kowalski, P. Kaczor, B. Orłowski, E. Łusakowska, R.L. Johnson, L. Houssian, J. Brison, I. Grzegory, S. Porowski
XXXIII International School on the Physics of Semiconducting Compounds, 29.05-04.06.2004 Jaszowiec (Poland)
Program & Abstracts 123 (2004);

49. *Photoemission study of GaN(0001) surface Fe doped*

B.A. Orłowski, I.A. Kowalik, B.J. Kowalski, N. Barrett, I. Grzegory, S. Porowski

XXXIII International School on the Physics of Semiconducting Compounds, 29.05-04.06.2004 Jaszowiec (Poland)
Program & Abstracts 122 (2004);

50. *MnAs layer on GaN(0001)-(1×1) – its growth, morphology and electronic structure*

B.J. Kowalski, R.J. Iwanowski, E. Łusakowska, I.A. Kowalik

XXXIII International School on the Physics of Semiconducting Compounds, 29.05-04.06.2004 Jaszowiec (Poland)
Program & Abstracts 90 (2004);

51. *Photoemission study of Fe/GaN(0001) surface*

B.A. Orlowski, I.A. Kowalik, B.J. Kowalski, N. Barrett, I. Grzegory, S. Porowski

VIIth International School and Symposium on Synchrotron Radiation in Natural Science (ISSNRS), 08-13.06.2004
Zakopane (Poland)

Bull. Polish Synchr. Rad. Soc. 3, 102 (2004);

52. *Photoemission studies of Ga_{0.92}In_{0.08}N(0001) and GaN(0001)*

B.J. Kowalski, I.A. Kowalik, R.J. Iwanowski, B.A. Orlowski, E. Łusakowska, J. Sadowski, J. Kanski, J. Ghijsen, F. Mirabella, P. Perlin, S. Porowski, I. Grzegory, M. Leszczynski

VIIth International School and Symposium on Synchrotron Radiation in Natural Science (ISSNRS), 08-13.06.2004
Zakopane (Poland)

Bull. Polish Synchr. Rad. Soc. 3, 80-81 (2004);

53. *Mn, GaMn and MnAs on GaN(0001)-(1×1) surface*

I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, E. Łusakowska, J. Sadowski, I. Grzegory, S. Porowski

VIIth International School and Symposium on Synchrotron Radiation in Natural Science (ISSNRS), 08-13.06.2004
Zakopane (Poland)

Bull. Polish Synchr. Rad. Soc. 3, 78-79 (2004);

54. *Photoemission studies of (0001)-(1×1) surfaces of Ga_{1-x}In_xN and GaN epitaxial layers*

B. Kowalski, I.A. Kowalik, R. Iwanowski, B. Orlowski, E. Łusakowska, J. Sadowski

22nd European Conf. on Surface Science (ECOSS-22), 07-12.09.2003 Prague (Czech Republic);

55. *Synchrotron radiation study of Mn/GaN*

I.A. Kowalik, B. Kowalski, B. Orlowski, E. Łusakowska, S. Mickevicius, R.L. Johnson, I. Grzegory, S. Porowski

XXXII International School on the Physics of Semiconducting Compounds, 30.05-06.06.2003 Jaszowiec (Poland)
Program & Abstracts 155 (2003);

56. *Mn doped ZnTe(110) (1×1) surface in resonant photoemission study*

B.A. Orlowski, S. Mickevicius, B.J. Kowalski, I.A. Kowalik, K. Kopalko, A. Mycielski, R.L. Johnson

European Materials Research Society (EMRS), Symposium C “Development of Methods for Characterizing the
Microstructure of Novel Materials”, 14-18.09.2003 Warsaw (Poland)

Program of EMRS Fall Meeting 24 (2003);

57. *Differential reflectivity and photoemission study of ZnTe and CdTe(110) surface*

B.A. Orlowski, I.A. Kowalik, B.J. Kowalski, M. Suffczynski, A. Mycielski, S. Colonna, C. Ottaviani, F. Ronci, A. Cricenti

European Materials Research Society (EMRS), Symposium C “Development of Methods for Characterizing the
Microstructure of Novel Materials”, 14-18.09.2003 Warsaw (Poland)

Program of EMRS Fall Meeting 24 (2003);

58. *Franz-Keldish effect on ZnTe(110) surface by means of Surface Differential Reflectivity method*

B. Orlowski, I.A. Kowalik, B. Kowalski, A. Mycielski, S. Colonna, C. Ottaviani, A. Cricenti

XXXII International School on the Physics of Semiconducting Compounds, 30.05-06.06.2003 Jaszowiec (Poland)
Program & Abstracts 152 (2003);

59. *Photoemission study of the ZnTe (110) (1×1) surface doped by deposited Mn atoms*

B. Orlowski, S. Mickevicius, B. Kowalski, I.A. Kowalik, A. Mycielski, R.L. Johnson

XXXII International School on the Physics of Semiconducting Compounds, 30.05-06.06.2003 Jaszowiec (Poland)
Program & Abstracts 92 (2003);

60. *Photoemission Study of the Valence band Electronic Structure of $Ga_{1-x}In_xN$ and GaN*

I.A. Kowalik, B.J. Kowalski, R.J. Iwanowski, J. Sadowski, P. Perlin, S. Porowski, I. Grzegory, M. Leszczynski, J. Kanski
XXXI International School on the Physics of Semiconducting Compounds, 7-14.06.2002 Ustroń-Jaszowiec (Poland)
Program & Abstracts 86 (2002);

61. *Valence band of Sm/GaN(0001) surface*

B. Orlowski, E. Guziewicz, B. Kowalski, K. Kopalko, I.A. Kowalik, E. Łusakowska, A. Szczepańska, S. Mickevicius, I. Grzegory, S. Porowski, Ł. Pluciński, R.L. Johnson
XXXI International School on the Physics of Semiconducting Compounds, 7-14.06.2002 Ustroń-Jaszowiec (Poland)
Program & Abstracts 133 (2002);

62. *Samarium on clean semiconductor surface - a photoemission study*

E. Guziewicz, B.A. Orlowski, B.J. Kowalski, I.A. Kowalik, S. Mickievicius, A. Szczepanska, Z. Golacki, I. Grzegory, S. Porowski, and R.L. Johnson
6th International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS), 17-22.06.2002 Jaszowiec (Poland)
Bull. Polish Synchr. Rad. Soc. 1, 57 (2002);

63. *Photoemission studies of $Ga_{1-x}In_xN$ epitaxial layers*

I.A. Kowalik, B.J. Kowalski, B.A. Orlowski, R.J. Iwanowski, E. Łusakowska, J. Ghijsen, F. Mirabella, J. Sadowski, J. Kanski, P. Perlin, S. Porowski, I. Grzegory, and M. Leszczynski
6th International School and Symposium on Synchrotron Radiation in Natural Science (ISSRNS), 17-22.06.2002 Jaszowiec (Poland)
Bull. Polish Synchr. Rad. Soc. 1, 50 (2002);

5. Other scientific activities

5.1 Supervision

I have been in charge of the user operation at BL I1011, during the last year of my stay at MAX-lab (Lund University). In this role I introduced the beamline users to the operation of the experimental equipment and when needed I also supervised the operation. The users of BL I1011 did include scientists at the senior level as well as PhD students. Several research groups (of the order of 15) did perform measurements at BL I1011 during the time I had this responsibility. The typical duration of such a beamtime is one or two weeks and a research team typically consists of 3 scientists.

As a beam line scientist of the I1011, XMCD beam line at MAX-lab, during the practical sessions of the "Nordic and European Summer school in Synchrotron Radiation Science" organized by MAX-lab, I was in charge of organizing "hands on" full day sessions for PhD students and young researchers at the I1011 beamline to illustrate magnetism research based on synchrotron radiation. For these specialization days to dichroic spectroscopies, I did conceive and prepare various didactic XAS and XMCD experiments that groups of 3-4 students had to perform under my supervision for about half a day. I did introduce these young researchers to the experimental equipment available.

I have acted as the coordinator for a Marie-Curie research and training network application (CHIMES European Training Network, application submitted January 2017). The CHIMES network focuses on the education of young researchers in the area of new spintronic materials based on organic compounds. The research and education plan of 14 PhD students was developed together with the scientists in charge of the 10 participating universities, research centers and companies in several EU member states. This educational and research plan had to take into account the various educational models followed by the participating institutions and companies. During the period of September 2016-January 2017, I did develop together with the scientists in charge a comprehensive educational package for these 14 young researchers including yearly specialization schools, a specialized course curriculum and company training, following the directives given by the European Commission.

5.2 Outreach activities

As a beam line manager at MAX-lab I have been active in the organization and interaction with the general public visiting MAX-lab, presenting to the general public the magnetism research performed by the various user groups. I have also explained and demonstrated the use of the I1011 beamline during high school visits as well as during the

“Open Door days” of MAX-lab, open to the general public. Every year about 10-20 high school visits took place at MAX-lab. The high success and good publicity in the general press generated by these events, and their large impact locally, contributed via the support of the region of Skåne (south Sweden), among others, to the upgrade of the MAX II and MAX III storage rings. The region of Skåne is taking a substantial part of the costs for the new MAX IV laboratory.

I acted as the scientific secretary of the 41st International School & Conference on the Physics of Semiconductors in 2012, since 29th of June 2011 till 3rd of November 2011. During that time I was responsible for the correspondence with the members of the Scientific and Advisory Committees. I did organise and perform the vote for the invited speakers. Finally, I did prepare the homepage of the conference and kept it updated till November.

In 2013 I was participating in the organization of 17th Science Picnic (15.06.2013), the biggest open-air event in Europe popularizing science. I was presenting experiments in the field of the “Physics of Low Temperature”.

I am a member of the Polish Synchrotron Radiation Society since 2002. The society's goal is the scientific and educational activity, in particular the promotion of the development of research making use of synchrotron radiation and the popularization of this type of research in Poland.

Seminars given in Poland and abroad:

12.02.2015 Institute of Physics PAS, “Polaryzacja spinowa elektronów emitowanych poprzez warstwę homochiralnych cząsteczek organicznych” – chosen among most important achievements of IP PAS in 2014

18.03.2014 Division of Physics and Technology of Wide-Band-Gap Semiconductor Nanostructures, IP PAS, “X-ray absorption and photoemission spectroscopy on chiral DPED molecules on Cu(100) and Co/Cu(100)”

11.03.2013 CELLS-ALBA synchrotron facility, Balcelona (Spain), “On the EAgLE project related science within the Institute of Physics PAS in Warsaw: selected examples”

05.11.2013 Laboratory of Cryogenic and Spintronic Research, IP PAS, “Element specificity using core level excitation at a synchrotron”

16.10.2012 Seminar of the Condensed Matter Physics, IP PAS, „Niskowymiarowe materiały magnetyczne badane z zastosowaniem spektroskopii i spektro-mikroskopii poziomów rdzeniowych”

11.09.2012 Laboratory of Cryogenic and Spintronic Research, IP PAS, “Zastosowanie dichroicznej spektroskopii poziomów rdzeniowych do badań struktury elektronowej cząsteczek chiralnych adsorbowanych na powierzchni Cu(100) oraz w fazie gazowej”

21.01.2011 FunDMS/SemiSpinNet meeting and Workshop, Linz (Austria), “(Ga,Fe)N studied by x-ray absorption”

08.02.2010 HASYLAB DESY, Hamburg (Germany), “Soft X-ray Absorption Spectroscopy at MAX-lab: towards novel magnetic semiconductor materials”

10.02.2009 Division of Physics and Technology of Wide-Band-Gap Semiconductor Nanostructures, IP PAS, “Rentgenowski magnetyczny dichroizm kołowy (XMCD) – selektywna metoda wyznaczania własności jonów magnetycznych”

05.12.2006 Division of Solid State Spectroscopy, IP PAS, „Stany 3d w strukturze elektronowej powierzchni GaN modyfikowanej warstwami zawierającymi metale przejściowe”

2006 MAX-lab synchrotron facility, Lund (Sweden), “The 3d states in electronic structure of GaN surface modified with layers containing transition metals”

11.04.2006 Division of Solid State Spectroscopy, IP PAS, “Fotoemisyjne badania struktury elektronowej Mn/GaN i MnAs/GaN” part 2

07.03.2006 Division of Solid State Spectroscopy, IP PAS, “Fotoemisyjne badania struktury elektronowej Mn/GaN i MnAs/GaN” part 1

05.04.2005 Division of Solid State Spectroscopy, IP PAS, "Fotoemisyjne badania procesu formowania interfejsu Co/GaN"

15.03.2005 Division of Solid State Spectroscopy, IP PAS, "Rezonansowe badania fotoemisyjne powierzchni Mn/GaN i GaMnN"

06.04.2004 Division of Solid State Spectroscopy, IP PAS, "Badania fotoemisyjne Ti/GaN"

2002 Division of Solid State Spectroscopy, IP PAS, "Morfologia powierzchni warstw GaN"

The articles in press concerning the research performed within the habilitation topic:

"Científicos desentrañan el enigma de la asimetría quiral" at elEconomista.es (15.12.2014 Spain)
<http://ecodiario.economista.es/ciencia/noticias/6327927/12/14/Cientificos-desentranan-el-enigma-de-la-asimetria-quiral.html#.Kku8ltF1wVAhx00>

"Científicos desentrañan el enigma de la asimetría quiral" at [Cienciaplus.com](http://www.europapress.es/ciencia/laboratorio/noticia-cientificos-desentranan-enigma-asimetria-quiral-20141215140153.html) (15.12.2014 Spain)
<http://www.europapress.es/ciencia/laboratorio/noticia-cientificos-desentranan-enigma-asimetria-quiral-20141215140153.html>

Data used in:

Figure 3.6 in "Real-Space Multiple-Scattering Theory of X-Ray Spectra", J.J. Kas, J. Jorisson and J.J. Rehr, in 'X-Ray Absorption and X-Ray Emission Spectroscopy: Theory and Applications', edited by J.A. van Bokhoven & C. Lamberti, Wiley UK, © 2016, 9781118844236

BOREAS News "BL29-CIRCE, Resonant Absorption and Scattering"
ALBA Newsletter 35, 10 (April 2013)

5.3 International Cooperation

1. *Dr. B. Norsk, Dr. G. Ohrwall, Prof R. Nyholm. MAX-laboratory, Lund University, Sweden.*

Having spent in a post-doctoral position two years at MAX-lab, the National Swedish synchrotron radiation laboratory, I continued to collaborate with various of the MAX-lab staff, since my stay there. These contacts often concerned technical issues on synchrotron radiation equipment, involving equipment modifications in view of upcoming experiments. The contact was maintained during several experiments per year at MAX-lab at various beamlines during the habilitation period.

2. *Dr. A. Grigoriev, Prof. R. Ahuja, Prof. B. Johansson the KTH Royal Institute of Technology, Stockholm, Sweden and Uppsala University (Physics and Astronomy, Materials theory), Uppsala, Sweden.*

This is an ongoing longstanding collaboration. These researchers lead a materials science theory group, which uses ab initio calculations, characterizing the electronic structure and magnetic properties of spintronic materials. This group performed calculations on the Bi doped ZnO system based on the experiments I performed in collaboration at MAX-lab. At present, calculations are being done on the geometry and electronic structure of chiral molecules on metal surfaces based on the experimental results I did obtain in collaboration at MAX-lab.

3. *Prof. J. E. Rubensson, Prof. D. Arvanitis, Prof. N. Mårtensson, Uppsala University (Physics and Astronomy, Molecular and Condensed Matter Physics).*

This is an actual collaboration running since several years. The Division of Molecular and Condensed Matter Physics has been a partner in several projects and has common interests in the area of x-ray based spectroscopies for the characterization of surfaces and interfaces. D. Arvanitis is co-applicant at the NCN Grant Nr DEC-2011/03/D/ST3/02654, where I am the project leader. He participated in several experiments at synchrotron radiation facilities investigating spintronic materials relating with the NCN grant Nr DEC-2011/03/D/ST3/02654, which I lead.

4. *Prof. J. J. de Miguel, Universidad Autonoma de Madrid.*

This is a collaboration taking place during the entire time of the Habilitation involving joint experiments on chiral molecules adsorbed on ferromagnetic and non-ferromagnetic surfaces at MAX-lab and at the ALBA synchrotron

radiation laboratories. This is an ongoing collaboration, with J. J. de Miguel being co-applicant in the NCN Grant Nr DEC-2011/03/D/ST3/02654, where I am the project leader.

5. *Dr. M. A Nino, the IMDEA Nanoscience Institute, Madrid, Spain.*

This collaboration is focusing on nano-spectroscopy. Joint experiments were performed at the Elettra and ALBA synchrotrons on spintronic relevant materials. This is an ongoing collaboration.

6. *Dr. J. W. Lee, Prof. N. G. Subramaniam, Prof. T. W. Kang, The Quantum Functional Semiconductor Research Centre, Dongguk University, Seoul, Republic of Korea.*

This collaboration is focusing on the growth and characterization of ZnO based spintronic materials. An active and ongoing collaboration, with the Dongguk University team providing state of the art ZnO based DMS materials.

5.4 Refereeing

Radiation Physics and Chemistry

Journal of X-ray Spectrometry

Cogent Physics

Acta Physica Polonica

Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms (NIMB)

5.5 Scientific grant management

1. Project Nr: 2011/03/D/ST3/02654, financed by the Polish National Science Centre (NCN)
Magnetic spectroscopy and spectro-microscopy of the low-dimensional magnetic structures
Duration: 07.08.2012-06.08.2016
Project leader
2. Polish-Austrian Bilateral Co-operation Project (004/2012/2013/2014 8564/R 12/R 14)
Condensed and dilute magnetic nitrides: pinning the fundamental exchange interactions and the pathway to spintronic functionalities
Duration: 2012-2013
Polish Project coordinator
3. Project Nr: 1 P03B 116 28 funded by State Committee for Scientific Research (KBN), Ministry of Science and Higher Education
Struktura elektronowa warstw MnAs osadzonych techniką MBE na powierzchni GaN (0001)-(1x1)
Duration: 04.03.2005 – 03.09.2006
Main Investigator
4. Project Nr CTS 14:32, funded by Carl Tryggers Foundation for Scientific Research (Sweden)
Synchrotron radiation based studies of functional magnetic materials
Duration: 2015-2016
Co-applicant
5. Project Nr CTS 10-22, funded by Carl Tryggers Foundation for Scientific Research (Sweden)
Magnetic nano-inclusions and dots: element specific magnetometry
Duration: 2011-2013
Co-applicant
6. Functionalisation of Diluted Magnetic Semiconductors (FunDMS)
Project Nr: ERC-2008-AdG-227690 financed by European Research Council, Advanced Grants
Duration: 2008-2013
Investigator

I did coordinate during the Autumn of 2016 the drafting of the project "CHIMES" in the European Commission call: Marie-Curie Innovative Training Networks (HORIZON 2020). I did submit the final version of this project in January of 2017. The proposal was developed jointly with partners in 8 different academic institutions and 2 companies in different EU member states. This European Training Network has a total budget of 3.5 MEuro and proposes the training of 14 young researchers over a period of 4 years.

Projects at the Large Scale Facilities for science financed within EU Transnational Access Programs like CALIPSO (Coordinated Access to Lightsources to Promote Standards and Optimization, 2012-2015), ELISA (European Light Sources Activities - Synchrotrons and Free Electron Lasers, 2009-2011) and Baltic Science Link project financed by Swedish Research Council, VR (2012-2014).

As a Project Leader

1. Project Nr: 20140382, *Magnetism and local structure of nanostructured ZnO doped with rare earth and metal elements*
Co-applicants: Ganapathisubramaniam Nagarajan (Principal Investigator), Dongguk University, Quantum-functional Semiconductor Research Center, Dimitri Arvanitis, Dept. of Physics and Astronomy, Uppsala University, Elżbieta Guzewicz, Institute of Physics, Polish Academy of Sciences
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2014)
2. Project Nr: 20130281, *XAS and XMCD on magnetic functional semiconductors*
Co-applicants: Dimitri Arvanitis, Dept. of Physics and Astronomy, Uppsala University, Elżbieta Guzewicz, Institute of Physics, Polish Academy of Sciences
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2013)
3. Project Nr: 2012010194, *Dilute magnetic semiconductors – high field XMCD and XLMD on GaN and ZnO based materials*
Co-applicants: Dimitri Arvanitis, Uppsala University, Physics and Astronomy, Molecular and Condensed Matter Physics, Miguel Angel Niño, IMDEA Nanociencia, Microscopia de Superficies, Madrid, Juan José de Miguel, University Autonoma Madrid, Física de la Materia Condensada, Faculty of Sciences, Madrid, Tomasz Dietl, IF PAS, Warsaw, Alberta Bonanni, JKU, Semiconductor and Solid State Physics, Linz, Paolo Perna, IMDEA Nanociencia, Microscopia de Superficies, Madrid
ALBA, Barcelona, Spain, BL BOREAS, 1 week (2012)
4. Project Nr: I1011-045 (20110223), *Element specific magnetometry of Fe_xN , FeGa_3 and GaFe_3N nanocrystals embedded in GaFeN matrix: XAS, XMCD and XLMD*
Co-applicants: Dimitri Arvanitis, Dept. of Physics and Astronomy, Uppsala University, Tomasz Dietl, Institute of Physics, Polish Academy of Sciences, Alberta Bonanni, Inst. for Semicond. and Solid State Phys., Johannes Kepler Univer. (Linz), Miguel Angel Nino Orti, IMDEA, Facultad de Ciencias Módulo C-IX, Madrid
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2011)
5. Project Nr: I3-052 (20110240), *The topological surface states of HgTe : spin-resolved ARPES*
Co-applicants: Tomasz Dietl, Institute of Physics, Polish Academy of Sciences, Dimitri Arvanitis, Dept. of Physics and Astronomy, Uppsala University, Łukasz Cywiński, Institute of Physics, Polish Academy of Sciences, Mats Leandersson, MAX-lab, Lund, Sweden
MAX-lab, Lund, Sweden, BL I3, 1 week (2011)
6. Project Nr: 311-PEEM-033, *Probing spinodal decomposition by element specific means: Co doped ZnO*
Co-applicants: Tomasz Dietl, Institute of Physics, Polish Academy of Sciences, Marek Godlewski, Institute of Physics, Polish Academy of Sciences, Dimitri Arvanitis, Dept. of Physics and Astronomy, Uppsala University, Miguel Angel Nino Orti, IMDEA, Facultad de Ciencias Módulo C-IX, Madrid
MAX-lab, Lund, Sweden, BL I311-PEEM, 2 days (2010)
7. Project Nr: I1011-028, *Element specific magnetism of $(\text{Ga},\text{Fe})\text{N}$ and $(\text{Ga},\text{Mn})\text{N}$: XMCD and XRMS*
Co-applicants: Tomasz Dietl, Maciej Sawicki, Dimitri Arvanitis, Alberta Bonanni, Juan J. de Miguel
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2010)
8. Project Nr: I1011-012, *Element specific magnetism of $(\text{Ga},\text{Fe})\text{N}$, GaFe:N and $(\text{Ga},\text{Fe})\text{N}$ co-doped with Si and Mg: XMCD and XRMS*

Co-applicants: Tomasz Dietl, Maciej Sawicki, Alberta Bonanni, Andrea Navarro-Quezada, Dimitri Arvanitis, Viktor Stefanowicz
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2009)

9. Project Nr: I1011-013, *XMCD and XRMS measurements of $Fe_{(1+y)}Te_{(x)}Se_{(1-x)}$*
Co-applicants: Dimitri Arvanitis, Dimitri, Roman Puźniak, Tomasz Dietl, Andrzej Wiśniewski, Jarosław Pietosa, Dariusz Gawryluk
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2009)
10. Project Nr: 1011-238, *Magnetic properties of MnSb dots studied by XMCD*
Co-applicants: Bogdan Kowalski, Anna Wolska
MAX-lab, Lund, Sweden, BL D1011, 1 week (2008)
11. *XMCD analysis of the magnetic properties of (Ga,Fe)N, GaFe:N and (Ga,Fe)N co-doped with Si and Mg*
Co-applicants: Tomasz Dietl, Alberta Bonanni, Maciej Sawicki
MAX-lab, Lund, Sweden, BL D1011, 1 week (2008)
12. Project Nr: 41-237, *ZnMnO and Mn/ZnO resonant photoemission spectroscopy*
Co-applicants: Elżbieta Guzewicz, Krzysztof Kopalko
MAX-lab, Lund, Sweden, BL 41, 2 weeks (2007)

As Co-applicant

13. Proposal Nr 20160581, *RIXS applied to a new class of heavy-ion doped magnetic semiconductors*.
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
SOLEIL synchrotron, Paris, France, BL SEXTANTS, 1 week (2017)
14. Proposal Nr 20160307, *Study of the spin polarization and spin filtering by adsorbed films of chiral organic molecules*
Main applicant: Juan J. de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
SOLEIL synchrotron, Paris, France, BL CASSIOPEE, 1 week (2017)
15. Project Nr: 2016021627, *Spin selective charge transfer in thin films of chiral organic molecules*.
Main applicant: Miguel Angel Niño, IMDEA Nanociencia, Microscopia de Superficies, Madrid (Spain)
ALBA, Barcelona, Spain, BL BOREAS, 1 week (2016)
16. Project Nr: 2013100599, *Enantioselective chemistry at magnetic and non-magnetic surfaces*
Main applicant: Juan J. de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
ALBA, Barcelona, Spain, BL CIRCE, 1 week (2014)
17. *RIXS characterization of doped ZnO and TiO₂ thin films and nanowires*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL SPECIES (RIXS), 1 week (2014)
18. Project Nr: 20140102, *Study of spin polarization in electron emission from chiral molecular layers*
Main applicant: Juan J. de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
MAX-lab, Lund, Sweden, BL I3, 2 weeks (2014)
19. Project Nr: 20140289, *Depth resolved characterization of doped ZnO thin films: element specific magnetism and electronic structure*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2014)
20. Project Nr: 20130134, *Depth resolved characterization of doped ZnO and TiO₂ thin films and nanowires: element specific magnetism and electronic structure*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2013)

21. Project Nr: 20120156, *Angle- and spin-resolved photoemission study of adsorbed chiral molecules*
Main applicant: Juan J. de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
MAX-lab, Lund, Sweden, BL I3, 2 weeks (2012)
22. Project Nr: 20120289, *Magnetism and local structure of nanostructured ZnO doped with rare earth and metal elements*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2012)
23. Project Nr: 2011120036, *Influence of DPED on Fe spin polarization*
Main applicant: Miguel Angel Niño, IMDEA Nanociencia, Microscopia de Superficies, Madrid (Spain)
ALBA, Barcelona, Spain, BL CIRCE (Photoemission Spectroscopy and Microscopy), 1 week (2012)
24. Project Nr: I1011-038 (20110216), *Element specific magnetism of functional dilute magnetic semiconductors*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I1011, 1 week (2011)
25. Project Nr: I1011-041 (20110219), *Dichroism in thin magnetic films covered with a chiral molecular layer*
Main applicant: Juan José de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
MAX-lab, Lund, Sweden, BL I1011, 1 week (2011)
26. Project Nr: 811-224 (20110123), *XAFS on Prussian Blue analogues: structure and photomagnetism*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I811, 3 days (2011)
27. Project Nr: 2011120036, *Influence of DPED on Fe spin polarization*
Main applicant: Miguel Angel Niño, IMDEA Nanociencia, Microscopia de Superficies, Madrid (Spain)
ALBA, Barcelona, Spain, BL CIRCE (Photoemission Spectroscopy and Microscopy), 1 week (2011)
28. Project Nr: I1011-048 (20110226), *Magnetism of the surface alloying in Fe thin films on copper substrate*
Main applicant: Miguel Angel Niño, IMDEA Nanociencia, Microscopia de Superficies, Madrid (Spain)
MAX-lab, Lund, Sweden, BL I1011, 1 week (2011)
29. Project Nr: 20105171, *Semiconductor nano-magnetism by phase separation: (Ga,Fe)N and (Ga,Mn)N*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
Elettra, Trieste, Italy, BL Nanospectroscopy (PEEM), 1 week (2011)
30. Project Nr: I1011-021, *Magneto-chiral dichroism in adsorbed molecules on magnetic substrates*
Main applicant: Juan J. de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
MAX-lab, Lund, Sweden, BL I1011, 1 week (2010)
31. Project Nr.: I1011-030, *Surfactant assisted growth of metastable magnetic FeCu alloy thin films*
Main applicant: Miguel Angel Niño, IMDEA Nanociencia, Microscopia de Superficies, Madrid (Spain)
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2010)
32. Project Nr.: 811-154, *Correlating magnetism with local structure in nano dots and nano inclusions*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I811, 1 week (2009)
33. Project Nr: I1011-009, *Magnetic anisotropy and spin reorientation transitions in nanomagnet arrays*
Main applicant: Juan J. de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2009)
34. Project Nr: I1011-004, *XAFS at BL I1011: quantitative intensity analysis and the transverse source coherence*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2009)

35. Project Nr: 1011-223, *Orbital moment anisotropy and the spin reorientation for Au/Co/Au*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I1011, 2 weeks (2008)
36. *Magnetic anisotropy at the nanoscale*
Main applicant: Juan J. de Miguel, Física de la Materia Condensada, Faculty of Sciences, Universidad Autonoma de Madrid (Spain)
MAX-lab, Lund, Sweden, D1011, 2 weeks (2008)
37. Project Nr: I811-112, *Correlating magnetism and structure for nano-dot arrays and thin films*
Main applicant: Dimitri Arvanitis, Physics and Astronomy, Uppsala University (Sweden)
MAX-lab, Lund, Sweden, BL I811, 1 week (2008)
38. Project Nr: 41-238, *Electronic structure of $\text{Ge}_{1-x}\text{Mn}_x\text{Te}$ and $\text{Ge}_{1-x-y}\text{Mn}_x\text{Eu}_y\text{Te}$ epilayers*
Main applicant: Bogdan Kowalski, Institute of Physics PAS, Warsaw (Poland)
MAX-lab, Lund, Sweden, BL 41, 18 days (2007)
39. Project Nr: II-04-008 EC, *TM in III-V, II-IV-V2 and I-III-VI2 crystals*
Main applicant: Bogdan Kowalski, Institute of Physics PAS, Warsaw (Poland)
HASYLAB at DESY, Hamburg, Germany, BL E1, 2 weeks (2004)
40. Project Nr: 41-214, *Photoemission investigation of electronic structure of MnAs deposited on GaN*
Main applicant: Bogdan Kowalski, Institute of Physics PAS, Warsaw (Poland)
MAX-lab, Lund, Sweden, BL 41, 2 weeks (2004)
41. Project Nr: I-03-008, *Ti interaction with GaN surface*
Main applicant: Bogdan Kowalski, Institute of Physics PAS, Warsaw (Poland)
HASYLAB at DESY, Hamburg, Germany, BL E1, 2 weeks (2003)
42. Project Nr: 41-207, *Photoemission investigations of MnGa and MnAs layers deposited on GaN*
Main applicant: Bogdan Kowalski, Institute of Physics PAS, Warsaw (Poland)
MAX-lab, Lund, Sweden, BL 41, 2 weeks (2003)
43. Project Nr: 41-198, *Surface and bulk electronic band structure of GaN crystals*
Main applicant: Bogdan Kowalski, Institute of Physics PAS, Warsaw (Poland)
MAX-lab, Lund, Sweden, BL 41, 2 weeks (2002)

5.6 Awards and honorable distinctions

Honorable distinction as the second best PhD thesis of the 2006 year in the area of vacuum physics, obtained in the competition for the Groszkowski's Award organized by the Polish Vacuum Society in 2007.

Publication **H8** was chosen as one of the most important scientific achievements of the Institute of Physics PAS in 2014.

5.7 Buildup of unique research equipment

During my postdoctoral stay at MAX-lab as a postdoctoral fellow, together with the staff of MAX-lab, I took part in the final stage of the installation of the new I1011 beam line, which was equipped with two custom made end stations operating in ultra high vacuum. I was responsible for the design, characterization and calibration of several components of the measuring equipment and of I1011 the beam line. In cooperation with colleagues at MAX-lab I introduced and coordinated the implementation of necessary modifications in equipment and software, preparing the I1011 beam line for its regular user operation (Section 2.4.1).

Using my own NCN Grant money I have collected the necessary portable equipment suitable for x-ray absorption measurements at synchrotron radiation facilities. This includes necessary components for the photocurrent measurements, as well as the surface preparation of the samples (Ar ion sputtering, LEED). This equipment has been

used during the last few years for experiments at synchrotron radiation facilities in combination with the equipment made available by these laboratories.

5.8 Long scientific visits abroad

Since the 15th of October 2007 till the 15th of January 2009: I was working, as a postdoctoral researcher at the MAX-lab synchrotron laboratory, Lund University in Sweden. I did participate in the commissioning and calibration of the new I1011 beam line which is dedicated for XAS, XMCD, XLMD and XRMS measurements in the soft x-ray range (Section 2.4.1). I have also been responsible for the technical and scientific support of the users at the I1011 beam line during regular user operation.

5.9 Short scientific visits for experiments at synchrotron radiation facilities

1. *Spin selective charge transfer in thin films of chiral organic molecules* (Project Nr: 2016021627)
ALBA synchrotron radiation laboratory, Barcelona, Spain, BL BOREAS
26.06.2016-01.07.2016, 1 week (2016)
2. *RIXS characterization of doped ZnO and TiO₂ thin films and nanowires*
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL SPECIES (RIXS)
28.09.2015-05.10.2015, 1 week (2015)
3. *Depth resolved characterization of doped ZnO thin films: element specific magnetism and electronic structure* (Project Nr: 20140289)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
08.06.2015-22.06.2015, 2 weeks (2015)
4. *Magnetism and local structure of nanostructured ZnO doped with rare earth and metal elements* (Project Nr: 20140382)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
10.05.2015-18.05.2015, 1 week (2015)
5. *Study of spin polarization in electron emission from chiral molecular layers* (Project Nr: 20140102)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I3
26.01.2015-09.02.2015, 2 weeks (2015)
6. *Magnetism and local structure of nanostructured ZnO doped with rare earth and metal elements* (Project Nr: 20140382)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
18.01.2015-26.01.2015, 1 week (2015)
7. *Enantioselective chemistry at magnetic and non-magnetic surfaces* (Project Nr: 2013100599)
ALBA synchrotron radiation laboratory, Barcelona, Spain, BL CIRCE (Photoemission Spectroscopy and Microscopy)
23.11.2014-29.11.2014, 1 week (2014)
8. *Depth resolved characterization of doped ZnO and TiO₂ thin films and nanowires: element specific magnetism and electronic structure* (Project Nr: 20130134)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
15.06.2014-30.06.2014, 2 weeks (2014)
9. *XAS and XMCD on magnetic functional semiconductors* (Project Nr: 20130281)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
19.01.2014-03.02.2014, 2 weeks (2014)
10. *Influence of DPED on Fe spin polarization* (Project Nr: 2011120036)
ALBA synchrotron radiation laboratory, Barcelona, Spain, BL CIRCE (Photoemission Spectroscopy and Microscopy)
12.03.2013-19.03.2013, 1 week (2013)
11. *Dilute magnetic semiconductors – high field XMCD and XLMD on GaN and ZnO based materials* (Project Nr: 2012010194)

- ALBA synchrotron radiation laboratory, Barcelona, Spain, BL BOREAS
10.03.2013-17.03.2013, 1 week (2013)
12. *Angle- and spin-resolved photoemission study of adsorbed chiral molecules* (Project Nr: 20120156)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I3
22.02.2013-04.03.2013, 2 weeks (2013)
13. *Magnetism and local structure of nanostructured ZnO doped with rare earth and metal elements* (Project Nr: 20120289)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011,
20.01.2013-28.01.2013, 1 week (2013)
14. *Magnetism and local structure of nanostructured ZnO doped with rare earth and metal elements* (Project Nr: 20120289)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011,
08.11.2012-19.11.2012, 1 week (2012)
15. *Element specific magnetism of functional dilute magnetic semiconductors* (Project Nr: I1011-038 (20110216))
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
17.06.2012-25.06.2012, 1 week (2012)
16. *The topological surface states of HgTe: spin-resolved ARPES* (Project Nr: I3-052 (20110240))
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I3
18.03.2012-26.03.2012, 1 week (2012)
17. *XAFS on Prussian Blue analogues: structure and photomagnetism* (Project Nr: 811-224 (20110123))
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I811
21.02.2012-26.02.2012, 1 week (2012)
18. *Element specific magnetometry of Fe_xN , FeGa_3 and GaFe_3N nanocrystals embedded in GaFeN matrix: XAS, XMCD and XLMD* (Project Nr: I1011-045 (20110223))
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
13.02.2012-26.02.2012, 2 weeks (2012)
19. *Magnetism of the surface alloying in Fe thin films on copper substrate* (Project Nr: I1011-048 (20110226))
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
06.02.2012-13.02.2012, 1 week (2012)
20. *Dichroism in thin magnetic films covered with a chiral molecular layer* (Project Nr: I1011-041 (20110219))
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
29.01.2012-06.02.2012, 1 week (2012)
21. *Element specific magnetism of $(\text{Ga,Fe})\text{N}$ and $(\text{Ga,Mn})\text{N}$: XMCD and XRRS* (Project Nr: I1011-028)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011
08.05.2011-23.05.2011, 2 weeks (2011)
22. *Semiconductor nano-magnetism by phase separation: $(\text{Ga,Fe})\text{N}$ and $(\text{Ga,Mn})\text{N}$* (Project Nr: 20105171)
Elettra synchrotron radiation laboratory, Trieste, Italy, BL Nanospectroscopy (PEEM)
03.03.2011-14.03.2011, 1 week (2011)
23. *Correlating magnetism with local structure in nano dots and nano inclusions* (Project Nr.: 811-154)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I811
14.02.2011-21.02.2011, 1 week (2011)
24. *Probing spinodal decomposition by element specific means: Co doped ZnO* (Project Nr: 311-PEEM-033)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I311-PEEM
06.02.2011-13.02.2011, 4 days (2011)
25. *Surfactant assisted growth of metastable magnetic FeCu alloy thin films* (Project Nr.: I1011-030)
MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011

31.01.2011-13.02.2011, 2 weeks (2011)

26. *Magneto-chiral dichroism in adsorbed molecules on magnetic substrates* (Project Nr: I1011-021)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011

25.01.2011-30.01.2011, 1 week (2011)

27. *XAFS at BL I1011: quantitative intensity analysis and the transverse source coherence* (Project Nr: I1011-004)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011

21.06.2010-05.07.2010, 2 weeks (2010)

28. *Element specific magnetism of (Ga,Fe)N, GaFe:N and (Ga,Fe)N co-doped with Si and Mg: XMCD and XRMS* (Project Nr: I1011-012)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011

06.06.2010-20.06.2010, 2 weeks (2010)

29. *XMCD and XRMS measurements of $Fe_{(1+y)}Te_{(x)}Se_{(1-x)}$* (Project Nr: I1011-013)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011

14.02.2010-01.03.2010, 2 weeks (2010)

44. *Magnetic anisotropy and spin reorientation transitions in nanomagnet arrays* (Project Nr: I1011-009)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I1011

30.11.2009-14.12.2009, 2 weeks (2009)

45. *XMCD analysis of the magnetic properties of (Ga,Fe)N, GaFe:N and (Ga,Fe)N co-doped with Si and Mg*

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL D1011

01.06.2009-08.06.2009, 1 week (2009)

46. *Orbital moment anisotropy and the spin reorientation for Au/Co/Au* (Project Nr: 1011-223)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL D1011

18.05.2009-31.05.2009, 2 weeks (2009)

47. *Magnetic anisotropy at the nanoscale*

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL D1011

23.02.2009-09.03.2009, 2 weeks (2009)

48. *Correlating magnetism and structure for nano-dot arrays and thin films* (Project Nr: I811-112)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL I811

11.11.2008-16.11.2008, 22.06.2009-29.06.2009, 2 weeks (2009)

49. *Magnetic properties of MnSb dots studied by XMCD* (Project Nr: 1011-238)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL D1011

20.10.2008-27.10.2008, 1 week (2008)

50. *ZnMnO and Mn/ZnO resonant photoemission spectroscopy* (Project Nr: 41-237)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL 41

02.12.2007-14.12.2007, 2 weeks (2007)

30. *Electronic structure of $Ge_{1-x}Mn_xTe$ and $Ge_{1-x-y}Mn_xEu_yTe$ epilayers* (Project Nr: 41-238)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL 41

29.04.2007-14.05.2007, 18 days (2007)

31. *Electronic structure of IV-VI-based ferromagnetic semiconductors* (Project Nr: II-20060146 EC)

HASYLAB at DESY, Hamburg, Germany, BL E1

18.03.2007-02.04.2007, 2 weeks (2007)

32. *Magnetic semiconductors surface and interface* (Project Nr: II-20060116 EC)

HASYLAB at DESY, Hamburg, Germany, BL E1

24.09.2006-09.10.2006, 2 weeks (2006)

33. *Photoemission investigation of electronic structure of MnAs deposited on GaN* (Project Nr: 41-214)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL 41
10.04.2005-25.04.2005, 2 weeks (2005)

34. *Investigation of the composition of semimagnetic semiconductor surface region using "SCIENTA"*

LISE, Facultés Universitaires Notre-Dame de la Paix a Namur (FUNDP), University of Namur, Belgium
09.01.2005-22.01.2005, 2 weeks (2005)

35. *TM in III-V, II-IV-V2 and I-III-VI2 crystals* (Project Nr: II-04-008 EC)

Magnetic Semiconductors (Project Nr: II-04-048 EC)

HASYLAB at DESY, Hamburg, Germany, BL E1

01.12.2004-23.12.2004, 3 weeks (2004)

36. *Investigation of the composition of semimagnetic semiconductor surface region using "SCIENTA"*

LISE, Facultés Universitaires Notre-Dame de la Paix a Namur (FUNDP), University of Namur, Belgium

11.01.2004-23.01.2004, 2 weeks (2004)

37. *Ti interaction with GaN surface* (Project Nr: I-03-008)

HASYLAB at DESY, Hamburg, Germany, BL E1

23.11.2003-08.12.2003, 2 weeks (2003)

38. *EuTe/PbTe superstructures* (Project Nr: I-03-063 EC)

HASYLAB at DESY, Hamburg, Germany, BL E1

03.11.2003-16.11.2003, 2 weeks (2003)

39. *Badania struktury elektronowej przy użyciu promieniowania synchrotronowego*

Laboratoire pour l'Utilisation du Rayonnement Electromagnetique LURE, Uniwersytet Paryski IX, Orsay, France

01.09.2003-12.09.2003, 2 weeks (2003)

40. *Surface and bulk electronic band structure of GaN crystals* (Project Nr: 41-198)

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL 41

19.05.2003-02.06.2003, 2 weeks (2003)

41. *EuS/PbS superstructures* (Project Nr: I-02-062)

HASYLAB at DESY, Hamburg, Germany, BL E1

18.11.2002-02.12.2002, 2 weeks (2002)

42. *Differential Reflectivity and Photoemission study of ZnTe and CdTe(110) surface*

Istituto di Struttura della Materia, Consiglio Nazionale delle Ricerche, Rome, Italy

05.10.2002-14.10.2002, 9 days (2002)

43. *Doped surfaces of semimagnetic semiconductors*

Laboratoire pour l'Utilisation du Rayonnement Electromagnetique, Uniwersytet Paryski IX, Orsay, France

07.04.2002-20.04.2002, 2 weeks (2002)

44. *Photoemission studies of Ga_{1-x}In_xN epitaxial layers*

MAX-lab synchrotron radiation laboratory, Lund, Sweden, BL 41

24.02.2002-11.03.2002, 2 weeks (2002)

5.10 Patent application

US patent application:

„*Electron Spin Filter*” U.S Patent Application Number 62/040038 (2014) 14/830239 (2015), US20160057859A1

Inventor(s): Spain: J.J. de Miguel, F.J Luque, M.A. Nino, R. Miranda

Poland: **I.A. Kowalik**

Sweden: D. Arvanitis

United States Patent and Trademark Office, Patent Application no. 14/830239, Publication no. US2016057859

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<http://appft1.uspto.gov/netacgi/nph->

<Parser?Sect1=PTO1&Sect2=HITOFF&d=PG01&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&s1=20160057859.PGNR.&OS=DN/20160057859&RS=DN/20160057859>

I. Kowalik