Załącznik nr 3 w postępowaniu habilitacyjnym – Autoreferat w wersji angielskiej

Self–Report

Impact of spin and spin-orbit interaction on transport properties of strongly correlated complex oxides and topological crystalline insulators

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1 Education and degrees

- 1985, M.Sc. in Physics, University of Warsaw, Faculty of Physics, Warsaw, Poland. thesis: *Landau levels emission in narrow-gap semiconductors*, Advisor: prof. dr hab. Marian Grynberg, co–advisor: mgr Wojciech Knap
- 1996, Ph.D. in Physics, Institute of Physics, Polish Academy of Sciences, Warsaw, Poland. thesis: *Electron transport properties of semimagnetic semiconductors based on iron*, Advisor: prof. dr hab. Andrzej Mycielski

2 Employment history

09/1985 – present: Institute of Physics, Polish Academy of Sciences, Warsaw, Poland. (excluding period: 11/1998 - 06/2000 , scientific co-worker, contract within European Community TMR project, Leoben University, Austria.)

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3 Scientific achievement being the basis of the habilitation procedure

The scientific achievement, in accordance with the art. 16 paragraph 2 of the Act of March 14th, 2003, concerning the scientific degrees and titles (Dz. U. no. 65, item 595, as amended), is the series of publications on common topic entitled:

Impact of spin and spin-orbit interaction on transport properties of strongly correlated complex oxides and topological crystalline insulators

3.1 Authors, titles of publication, journal, publication year

[H1] **K. Dybko**, P. Aleshkevych, M. Sawicki, and P. Przyslupski. Magnetic and magnetotransport characterization of $La_{0.7}Sr_{0.3}MnO_3$/YBCO/$La_{0.7}Sr_{0.3}MnO_3$/YBCO spin valve. *Journal of Magnetism and Magnetic Materials*, 373:48, 2015.

[H2] **K. Dybko**, P. Aleshkevych, M. Sawicki, W. Paszkowicz, and P. Przyslupski. The onset of ferromagnetism and superconductivity in [$La_{0.7}Sr_{0.3}MnO_3$ (n u.c.)/$YBa_2Cu_3O_7$(2 u.c.)]$_{20}$ superlattices. *Journal of Physics - Condensed Matter*, 25:376001, 2013.

[H3] P. Aleshkevych, **K. Dybko**, P. Dluzewski, E. Dynowska, L. Gladczuk, K. Lasek, and P. Przyslupski. Magnetic and magnetotransport properties of epitaxial $La_{0.7}Sr_{0.3}MnO_3$/$SrIrO_3$/$La_{0.7}Sr_{0.3}MnO_3$ spin valves. *Journal of Physics D-Applied Physics*, 51:385002, 2018.

[H4] **K. Dybko**, P. Pfeffer, M. Szot, A. Szczerbakow, A. Reszka, T. Story, and W. Zawadzki. Nernst-Ettingshausen effect at the trivial–nontrivial band ordering in topological crystalline insulator $Pb_{1-x}Sn_xSe$. *New Journal of Physics*, 18:013047, 2016.

[H5] **K. Dybko**, M. Szot, A. Szczerbakow, M. U. Gutowska, T. Zajarniuk, J. Z. Domagala, A. Szewczyk, T. Story, and W. Zawadzki. Experimental evidence for topological surface states wrapping around a bulk SnTe crystal. *Physical Review B*, 96:205129, 2017.

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3.2 Description of scientific achievement

At the beginning of XXI-st century I was involved in European Community program called Centre of Excellence for Low Dimensional Structures - CELDIS and national special research project "Spin Electronics". We were actively looking for all–semiconductor structures displaying new optical and transport spintronic effects brought about by ferromagnetic constituent of heterointerface in PbS/EuS/PbS structures. The tunneling magnetoresistance in mentioned structures should depend strongly on temperature because below ferromagnetic Curie temperature of EuS, the large exchange splitting of the conduction band influences the tunnel barrier for tunneling electrons. To cope with a problem, I have developed sensitive bridge–like apparatus which enabled differential measurements dI/dV or dV/dI vs DC voltage or current. It occurred that parasitic pinholes in the EuS barrier make shortage in tunnel resistance thus hindering the effect we were looking for [Z1]. Being in position that tunneling magnetoresistance and spin filtering effects were out of my reach, I turned my attention to strongly correlated systems (perovskite oxides) comprised of strong metallic ferromagnets (manganites) and superconductors (cuprates). These materials possess very intriguing physical properties due to simultaneous presence of various interactions including charge, spin, spin–orbital and lattice distortion, which are responsible for such properties as colossal magnetoresistance [1], superconductivity [2], ferroelectricity and multiferroicity [3], ferromagnetism,[4] metal-insulator transition [5], not to mention wide band gaps range suitable for photovoltaics [6]. The heterostuctures build of manganite $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) and high temperature superconductor $YBa_2Cu_3O_7$ (YBCO) materials were routinely grown in Professor Przyslupski's laboratory. The LSMO is half-metallic compound, with nearly 100% spin polarization at low temperatures, and will be employed as a ferromagnetic electrodes (F) in our heterostructures, while YBCO will constitute the superconducting interlayer (S). The investigations of perovskite based F/S heterostructures can reveal the nature of coexisting competitive orders: ferromagnetism and superconductivity. Moreover, they can be regarded even as magnetic superconductor as proposed in Ref.[7].

From the other point of view in the F/S/F trilayer heterostructures the possibility of indirect exchange coupling between F layers without destruction of superconductivity in S layer was theoretically considered in [8]. Even earlier proposition by Tagirov [9] was devoted to multilayer spin valve-like structure (antiferromagnet/ferromagnet/super-

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conductor/ferromagnet) coined the name superconducting spin switch, due to the effect of switching the supercurrent by rotation of the magnetization of top (unpinned) magnetic layer. The existing observations in metallic layers reported the change in the critical temperature between anti-parallel and parallel magnetizations on the order of several tens of milliKelvin. In 2008, we have succeeded with our first device of mentioned type (F1/S/F2) based on LSMO and YBCO. The highest enhancement of the transition temperature, relative to zero magnetic field, was found to be 1.6 K [Z2]. In this paper, among the other explanations, we first signaled the possibility of the spin triplet phase to be responsible for the critical temperature enhancement with raising magnetic field. It was based on the theoretical paper by Kirkpatrick et al [10].

In the follow up paper [Z3], we have studied more thoroughly similar sample LSMO(16nm)/YBCO(21nm)/LSMO(22nm) of F1/S/F2 type. We have confirmed the enhancement of the critical temperature of the device, but this time we studied both geometries: current in plane (CIP) and current perpendicular to plane (CPP). It was possible because the step-like structure was grown with an open access to bottom ferromagnetic electrode. By performing the dynamical conductance measurements at various temperatures and in broad range of magnetic field, we got the information about the superconducting pairing symmetry of the order parameter and the spin-dependent sub-gap transport. In both configurations we observed zero bias conductance peak. It was very sharp in CIP configuration, while very broad and not pronounced in CPP configuration. Exactly such a scenario was predicted in theoretical paper by Tanaka and Kashiwaya for spin triplet superconductor (p-wave type) junctions and YBCO (d-wave type) junctions respectively [11]. Therefore, by dynamical conductance spectroscopy we obtained an additional confirmation of the possibility of the spin triplet phase in our F1/S/F2 trilayers. In this situation, we even put this finding into the title: "Possible spin-triplet superconducting phase in the $La_{0.7}Sr_{0.3}MnO_3/YBa_2Cu_3O_7/La_{0.7}Sr_{0.3}MnO_3$ trilayer". This topics was very timely, because at the same time the group from Madrid has confirmed our finding about the occurrence of the spin-triplet superconducting phase in manganite/cuprate heterostructures by the use of the angular magnetoresistance measurements [12].

In the subsequent paper [H1], we have also investigated the possibility of spin triplet phase occurence, but this time in F1/F2/S spin valve structure realized in LSMO(13.5 nm)/YBCO(3.6nm)/LSMO(27nm)/YBCO (42nm). The 3.6 nm thick

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YBCO in this was not superconducting due to charge transfer effects and thus served us as an insulating layer separating two LSMO ferromagnetic layers. Because of different thicknesses of LSMO, their magnetic moments and coercive fields are also different. Effectively our structure is analogous to F1/F2/S considered theoretically in Ref. [13]. The measurements of ferromagnetic resonance revealed two lines which confirmed the existence of two components of structure (F1 and F2). The whole structure exhibited sharp peaks of magnetoresistance (MR) at coercive field which indicated spin valve effect. It occurred that the magnitude of the MR peak depends on in-plane magnetic field rotation. The studies of angular dependence of critical temperature (defined as three orders drop of resistance) in constant magnetic field H=450 Oe revealed non-monotonous and asymmetric behaviour with respect to 90 degree. This fact is again in agreement with theoretical prediction of generation of the superconducting long-range triplet component in system where minimal critical temperature corresponds to noncollinear alignment of magnetizations F1/F2 [13].

The paper [H2] is devoted to more fundamental/practical issue: we asked what is the onset of magnetism and superconductivity in systems comprising of ultra thin LSMO and YBCO layers. The samples were grown on (100) $LaAlO_3$ substrate in the form of superlattices with varying number of manganite layers n, $[\text{LSMO n u.c./YBCO 2 u.c.}]_{20}$. We made first approach with one by one superlattice $[\text{LSMO 1 u.c./YBCO 1 u.c.}]_{20}$, but unfortunately it was not superconducting. Therefore, we fixed the thickness of YBCO to 2 unit cells and varied LSMO layer from 1 to 4 unit cells. The superconducting behaviour was observed for n=1 and 2 u.c. of LSMO as an onset in temperature dependence of resistance. On the other hand, the ferromagnetism appears for n=4 superlattice. The paramagnetic behaviour of superlattines with $n \leqslant 3$ is due to hole charge transfer from YBCO to LSMO layer as we earlier confirmed in nuclear magnetic resonance studies of trilayers [Z3].

In the next paper [H3], we have combined two perovskites, one well known ferromagnetic LSMO posessing 100% spin polarization and $SrIrO_3$ being a paramagnetic metal which hosts 5d electrons with strong spin-orbit coupling. Our aim was to study the influence of $SrIrO_3$ on the transport properties of the spin valve based on this material and LSMO. We fixed the LSMO layers to 19 nm and 12 nm and varied the thickness of inner $SrIrO_3$ spacer layer between 0.4 nm to 2.4 nm. The ferromagnetic resonance spectra demonstrate 90 degree magnetic moment alignment of the bottom

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and the top LSMO layer in epitaxial LSMO/$SrIrO_3$/LSMO trilayers. Magnetotransport measurements exhibit standard and inverse spin valve effect, depending on the orientation of magnetic field to the current. Such behavior may result from the influence of spin filtering by the $SrIrO_3$ spacing layer on transport current. However, it is worth to mention that overall change in observed magnetoresistance is extremely small (of the order of tens of ppm).

In parallel to other studies, I was also involved in discovery of the first topological crystalline insulators (TCI) based on IV-VI compounds [Z4]. As opposed to bismuth based topological insulators, these new states of topological matter are topologically protected by specific crystalline symmetry. In the case of TCI, it is mirror symmetry of unit cell [14, 15]. And again, as the consequence of this unique protection, the protected surface states are located only on certain crystallographic planes: (001), (110), (111). Therefore, all the TCI samples suitable for experiments have to be cleaved along mentioned crystallographic planes. In our paper [Z4], the results of the whole transport measurements were moved to supplementary information, because of lack of clear evidence for topological surface states in high field magnetotransport experiments. The Shubnikov - de Haas quantum oscillations observed at helium temperatures did not reveal any angular dependence what pointed to their trivial 3Dim origin. It was confirmed by the electron density obtained from low field Hall measurements and its agreement with density obtained from the period of Shubnikov - de Haas effect.

Having all above mentioned complications in mind, we did not expect the signatures of topological surface states in thermoelectric Nernst - Ettingshausen (N–E) effect measured on TCI $Pb_{1-x}Sn_xSe$ crystals [H4]. We were rather inspired by Ref.[16], where authors claimed that the change of the sign in Nernst - Ettingshausen coefficient as a function of temperature corresponds to the band inversion point. It is, the temperature and composition where energy gap is zero and band structure changes from trivial to non-trivial (inverted band structure). This observation was only supported by single sample measurements ($Pb_{1-x}Sn_xSe$, x=0.23). Here, in Ref.[H4] we collected the data of N-E coefficients for the whole solubility range of compositions within topologically non-trivial case: x=0.25, 0.277, 0.325, 0.39 as well as the trivial PbSe sample. Our work shows unambiguously that N-E coefficient exhibits maximum when transition to topological phase takes place. The trivial sample - PbSe does not show any temperature dependence of N-E coefficient. Moreover, our experimental findings have been also

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confirmed in the theoretical model, which reproduced the experimental results almost quantitatively.

The transport observation of topological surface states in 3Dim TCI like prototypical SnTe seems to be very unlikely because of high bulk hole density on the order of 10^{20} cm^{-3}. It is true unless one observes both trivial-bulk contribution and topological-surface contribution. We showed it occured in our SnTe samples of exceptional crystallographic quality grown by self selective vapour growth method [H5]. We studied quantum transport at low temperatures. We measured Shubnikov - de Haas effect, de Haas - van Alphen effect and prerequisites of quantum Hall effect. The angular dependence measurements enabled us to distinguish between two-dimensional and bulk three-dimensional contributions. By careful determination of the π Berry phase, we proved that the two-dimensional oscillations are due to the topological surface states. Moreover, we showed that the parallelpiped sample with (001) equivalent planes is wrapped around by these topological surface states. We also succeeded with theoretical modeling of the oscillatory magnetization data (de Haas-van Alphen effect). The model relied on assumption that bulk SnTe reservoir of carriers pins the Fermi energy of the whole system [17].

Summary of the main achievements

- New evidence for long – range triplet superconductivity, one of the most important subjects in condensed matter physics. We experimentally confirmed theoretical prediction concerning superconducting triplet spin valve with noncollinear magnetic moments, by the observation of nonmonotonic dependence of superconducting transition temperature, while rotating the sample in parallel magnetic field [H1].

- We employed superlattices made of ultra thin (few unit cells) layers of manganite and cuprate for determination of the onset of two mutually competing orders ferromagnetism and superconductivity [H2].

- We demonstrated normal spin valve as well as inverse spin valve effects in the system build of manganite and new highly spin-orbital material $SrIrO_3$ [H3].

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- We proved experimentally and theoretically that the thermoelectric Nernst–Ettingshausen effect may be used for determination of the topological properties of matter. Our experimental and theoretical findings show that topological phase transition driven by band inversion occurs when Nernst–Ettingshausen coefficient reaches maximal value [H4].

- First, experimentally consistent, transport detection of topological surface states wrapping around bulk SnTe single crystal. Both contributions, bulk and topological, were naturally resolved in quantum oscillatory phenomena Shubnikov – de Haas and de Haas – van Alphen. The latter effect found its theoretical description assuming pinning of Fermi energy by highly degenerate bulk SnTe reservoir [H5].

Publications Related to Habilitation but not assigned to main achievement

[Z1] S. Wrotek, K. Dybko, A. Morawski, A. Makosa, T. Wosiński, T. Figielski, Z. Tkaczyk, E. Łusakowska, T. Story, A.Yu. Sipatov, A. Szczerbakow, K. Grasza, J. Wróbel, and W. Palosz. Vertical electron transport through PbS-EuS structures. *Acta Phys. Pol. A*, 103(6), 2003.

[Z2] K. Dybko, K. Werner-Malento, M. Sawicki, and P. Przyslupski. Enhancement of the superconducting transition temperature by an external magnetic field parallel to the plane of $La_{0.7}Sr_{0.3}MnO_3/YBa_2Cu_3O_7/La_{0.7}Sr_{0.3}MnO_3$ trilayers. *EPL (Europhysics Lett.)*, 85:57010, 2009.

[Z3] K. Dybko, K. Werner-Malento, P. Aleshkevych, M. Wojcik, M. Sawicki, and P. Przyslupski. Possible spin-triplet superconducting phase in the $La_{0.7}Sr_{0.3}MnO_3/YBa_2Cu_3O_7/La_{0.7}Sr_{0.3}MnO_3$ trilayer. *Phys. Rev. B*, 80:144504, 2009.

[Z4] P. Dziawa, B. J. Kowalski, K. Dybko, R. Buczko, A. Szczerbakow, M. Szot, E. Łusakowska, T. Balasubramanian, B. M. Wojek, M. H. Berntsen, O. Tjernberg, and T. Story. Topological crystalline insulator states in $Pb_{1-x}Sn_xSe$. *Nat. Mater.*, 11:1023–1027, 2012.

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Referencies

[1] R. von Helmolt, J. Wecker, B. Holzapfel, L. Schultz, and K. Samwer. Giant negative magnetoresistance in perovskitelike $La_{2/3}Ba_{1/3}MnO_x$. *Phys. Rev. Lett.*, 71(14):2331–2333, 1993.

[2] J. G. Bednorz and K. A. Müller. Possible high Tc superconductivity in the Ba-La-Cu-O system. *Zeitschrift für Phys. B Condens. Matter*, 64(2):189–193, 1986.

[3] H Béa, M Gajek, M Bibes, and A Barthélémy. Spintronics with multiferroics. *Journal of Physics: Condensed Matter*, 20(43):434221, 2008.

[4] Fumihiko Fukunaga and Nobuo Tsuda. On the Magnetism and Electronic Conduction of Itinerant Magnetic System $Ca_{1-x}Sr_xRuO_3$. *J. Phys. Soc. Japan*, 63(10):3798–3807, 1994.

[5] Masatoshi Imada, Atsushi Fujimori, and Yoshinori Tokura. Metal-insulator transitions. *Rev. Mod. Phys.*, 70:1039–1263, 1998.

[6] Olga Malinkiewicz, Aswani Yella, Yong Hui Lee, Guillermo Mínguez Espallargas, Michael Graetzel, Mohammad K. Nazeeruddin, and Henk J. Bolink. Perovskite solar cells employing organic charge-transport layers. *Nat. Photonics*, 8(2):128–132, 2014.

[7] H.-U. Habermeier, G. Cristiani, R.K. Kremer, O. Lebedev, and G. van Tendeloo. Cuprate/manganite superlattices: A model system for a bulk ferromagnetic superconductor. *Physica C: Superconductivity and its Applications*, 364-365:298 – 304, 2001.

[8] C.A.R. Sá de Melo. Interplay of magnetism and superconductivity at the nanometer scale: the case of complex oxide heterostructures. *Physica C: Superconductivity*, 387:17 – 25, 2003.

[9] L. R. Tagirov. Low-field superconducting spin switch based on a superconductor /ferromagnet multilayer. *Phys. Rev. Lett.*, 83:2058–2061, 1999.

[10] T. R. Kirkpatrick, D. Belitz, Thomas Vojta, and R. Narayanan. Strong enhancement of superconducting T_c in ferromagnetic phases. *Phys. Rev. Lett.*, 87:127003, 2001.

[11] Y. Tanaka and S. Kashiwaya. Anomalous charge transport in triplet superconductor junctions. *Phys. Rev. B*, 70:012507, 2004.

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[12] T. Hu, H. Xiao, C. Visani, Z. Sefrioui, J. Santamaria, and C. C. Almasan. Evidence from magnetoresistance measurements for an induced triplet superconducting state in $La_{0.7}Ca_{0.3}MnO_3/YBa_2Cu_3O_{7-\delta}$ multilayers . *Phys. Rev. B*, 80:060506, 2009.

[13] Ya. V. Fominov, A. A. Golubov, T. Yu. Karminskaya, M. Yu. Kupriyanov, R. G. Deminov, and L. R. Tagirov. Superconducting triplet spin valve. *JETP Lett.*, 91:308–313, 2010.

[14] Liang Fu. Topological Crystalline Insulators. *Phys. Rev. Let.*, 106:106802, 2011.

[15] Timothy H Hsieh, Hsin Lin, Junwei Liu, Wenhui Duan, Arun Bansil, and Liang Fu. Topological crystalline insulators in the SnTe material class. *Nat. Commun.*, 3:982, 2012.

[16] Tian Liang, Quinn Gibson, Jun Xiong, Max Hirschberger, Sunanda P. Koduvayur, R. J. Cava, and N. P. Ong. Evidence for massive bulk Dirac fermions in Pb(1-x)SnxSe from Nernst and thermopower experiments. *Nat. Commun.*, 4:3696, 2013.

[17] W. Zawadzki, A. Raymond, and Kubisa M. Reservoir model for two-dimensional electron gases in quantizing magnetic fields: A review. *Phys. Status Solidi.*, 251:247–262, 2014.

4 Remaining scientific activity

During my research stay in Austria (1998/2000 European Community TMR project) I had an unique opportunity to work with moderate mobility two-dimensional electron gas in GaAs/AlGaAs heterostructures. The samples studied were all in the integer quantum Hall regime at low temperatures. It was already known that the plateau-plateau transitions in quantum Hall effect can be treated, from theoretical point of view, as a zero temperature quantum phase transitions. Our task was to obtain various types of scaling exponents related to system size, temperature and frequency [A1-A4]. Therefore we measured the width of plateau-plateau transitions with DC transport and AC transport in broad frequency range (20-60 GHz). The joint publication with Professor Haug group from Hannover was the culmination of our two years studies [A5].

(A1) R Meisels, F Kuchar, and K Dybko. Temperature and frequency scaling of the quantum Hall effect. ANNALEN DER PHYSIK, 8:609, 1999.

(A2) F Kuchar, R Meisels, K Dybko, and B Kramer. DC- and AC-scaling of the integer quantum Hall effect in the presence of interactions. EUROPHYSICS LETTERS, 49:480, 2000.

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(A3) K Dybko, R Meisels, F Kuchar, G Hein, and K Pierz. Dynamic scaling of the IQHE: evidence from millimeter wave experiments. In Miura, N and Ando, T, editor, PROCEEDINGS OF THE 25TH INTERNATIONAL CONFERENCE ON THE PHYSICS OF SEMICONDUCTORS, PTS I AND II, volume 87 of SPRINGER PROCEEDINGS IN PHYSICS, pages 915. 25th International Conference on the Physics of Semiconductors (ICPS25), OSAKA, JAPAN, SEP 17-22, 2000.

(A4) R Meisels, K Dybko, F Ziouzia, F Kuchar, R Deutschmann, G Abstreiter, G Hein, and K Pierz. Millimeter wave and DC investigations of spin effects in the 2DES of AlGaAs/GaAs. PHYSICA E, 10:57, 2001.

(A5) F Hohls, U Zeitler, RJ Haug, R Meisels, K Dybko, and F Kuchar. Dynamical scaling of the quantum Hall plateau transition. PHYSICAL REVIEW LETTERS, 89, 276801, 2002.

(A6) F Hohls, U Zeitler, RJ Haug, R Meisels, K Dybko, and F Kuchar. A generalized treatment of the dynamical scaling of the quantum Hall plateau transition. PHYSICA E-LOW-DIMENSIONAL SYSTEMS & NANOSTRUCTURES, 16:10, 2003.

From the very beginning I started the scientific cooperation with MBE group at the Institute of High Pressure of the Polish Academy of Sciences led by Professor Czesław Skierbiszewski. My area of interest covers classical transport and quantum transport properties of two-dimensional electron gas in GaN/AlGaN heterostructures. In the first paper [B1] we achieved (and hold for about two month) the world record high electron mobility in GaN/AlGaN heterostructure (110 000 cm^2/Vs at liquid helium temperature). This sample exhibited also very pronounced integer quantum Hall effect at 0.3 K. This and similar high quality samples served us for activation measurements in quantum Hall regime, which provided the data about renormalization of the effective mass and effective g-factor due to electron–electron interaction [B4]. In the paper [B3] I found explanation of the observed resonances in standard ESR spectrometry as being caused by coupled plasmon–cyclotron modes. We showed also that this fact provides easy method for contactless characterization of two–dimensional systems. The other joint papers are listed below:

(B1) C Skierbiszewski, K Dybko, W Knap, M Siekacz, W Krupczynski, G Nowak, M Bockowski, J Lusakowski, ZR Wasilewski, D Maude, T Suski, and S Porowski. High mobility two-dimensional electron gas in AlGaN/GaN heterostructures grown on bulk GaN by plasma assisted molecular beam epitaxy. APPLIED PHYSICS LETTERS, 86, 102106, 2005.

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(B2) W Knap, C Skierbiszewski, K Dybko, J Lusakowski, M Siekacz, I Grzegory, and S Porowski. Influence of dislocation and ionized impurity scattering on the electron mobility in GaN/AlGaN heterostructures. JOURNAL OF CRYSTAL GROWTH, 281, 194, 2005.

(B3) Agnieszka Wolos, Wolfgang Jantsch, Krzysztof Dybko, Zbyslaw Wilamowski, and Czeslaw Skierbiszewski. Plasmon-cyclotron resonance in two-dimensional electron gas confined at the $GaN/Al_xGa_{1-x}N$ interface. PHYSICAL REVIEW B 76, 045301, 2007.

(B4) M. Siekacz, K. Dybko, D. Maude, M. Potemski, W. Knap, and C. Skierbiszewski. Electron-electron interaction effects in quantum hall regime of GaN/AlGaN heterostructures. ACTA PHYSICA POLONICA A, 112, 269, 2007.

(B5) K. Dybko, M. Siekacz, and C. Skierbiszewski. Zero Field Spin Splitting in GaN/AlGaN Heterostructures Probed by the Weak Antilocalization. ACTA PHYSICA POLONICA A, 114, 1109, 2008.

(B6) M. Czapkiewicz, G. Cywinski, K. Dybko, M. Siekacz, P. Wolny, S. Gieraltowska, E. Guziewicz, C. Skierbiszewski, and J. Wrobel. Electrostatic Gates for GaN/AlGaN Quantum Point Contacts. ACTA PHYSICA POLONICA A, 122, 1026, 2012.

(B7) Henryk Turski, Grzegorz Muziol, Marcin Siekacz, Pawel Wolny, Krzesimir Szkudlarek, Anna Feduniewicz-Zmuda, Krzysztof Dybko, and Czeslaw Skierbiszewski. Growth rate independence of Mg doping in GaN grown by plasma-assisted MBE. JOURNAL OF CRYSTAL GROWTH, 482, 56, 2018.

The other area of my research activity is associated with thermoelectric properties of condensed matter. I have developed methodology and build necessary experimental setup for direct determination of crucial for thermoelectricity parameter, figure of merit ZT. It relies on measurements of DC and AC resistivity at given temperature and on proper account for radiation looses of studied sample. It is so called Harman method [C1]. In our group we already used this method in studies of p–n (Pb,Mn)Te and (Pb,Cd)Te materials. These were basic tasks realized in POIG project "Novel Materials and Innovative Methods for Energy Conversion and Monitoring" in years 2009-2014. These experimental setups will also serve as a basic thermoelectric characterization tools in a new project obtained by Institute of Physics PAS in 2019 from the National Centre for Research and Development.

(C1) K. Dybko, M. Szot, A. Mycielski, A. Szczerbakow, P. Dziawa, M. Guziewicz, W. Knoff, E. Lusakowska, and T. Story. Effcient thermoelectric energy conversion in $Pb_{0.95}Mn_{0.05}Te$ p-n couple. APPLIED PHYSICS LETTERS, 108, 133902, 2016.

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(C2) Michal Szot, Krzysztof Dybko, Piotr Dziawa, Leszek Kowalczyk, Viktor Domukhovski, Badri Taliashvili, Anna Reszka, Bogdan Kowalski, Piotr Dluzewski, Maciej Wiater, Tomasz Wojtowicz, and Tomasz Story. Electric and thermoelectric properties of CdTe/PbTe epitaxial nanocomposite. FUNCTIONAL MATERIALS LETTERS, 7, 1440007, 2014.

(C3) Michal Szot, Krzysztof Dybko, Piotr Dziawa, Leszek Kowalczyk, Ewa Smajek, Viktor Domukhovski, Badri Taliashvili, Piotr Dluzewski, Anna Reszka, Bogdan J. Kowalski, Maciej Wiater, Tomasz Wojtowicz, and Tomasz Story. Epitaxial Zinc-Blende CdTe Antidots in Rock-Salt PbTe Semiconductor Thermoelectric Matrix. CRYSTAL GROWTH & DESIGN, 11, 4794, 2011.

(C4) V Osinniy, A Jedrzejczak, W Domuchowski, K Dybko, B Witkowska, and T Story. $Pb_{1-x}Mn_xTe$ crystals as a new thermoelectric material. ACTA PHYSICA POLONICA A, 108, 809, 2005.

(C5) P Lazarczyk, MV Radchenko, GV Lashkarev, T Story, K Dybko, and RR Galazka. Determination of the band structure of $Pb_{1-x-y}Sn_yMn_xTe$ semimagnetic semiconductors from thermoelectric power studies. SEMICONDUCTOR SCIENCE AND TECHNOLOGY, 13, 989,1998.

K. Dybko