Warsaw, March 6th, 2012

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SELF REPORT

Table of Contents

1. Personal Data

Agata Kamińska
[redacted]

PESEL:

2. Education and Degrees

Ph.D. in Physics 2001 - Institute of Physics, Polish Academy of Sciences, Warsaw, specialization: Solid State Physics
thesis topic: *The High Pressure Studies of Electronic Structure of Chromium Dopant in the Laser Materials,* Ph.D. Advisor: prof, dr hab. Andrzej Suchocki

M.Sc. in Physics 1988 - Faculty of Mathematics and Physics, Jagiellonian University, Cracow specialization: Medical Physics
thesis topic: *The Influence of Paramagnetic Centers on Proton Relaxation in the Solutions of Various Compositions,* supervisor: prof, dr hab. Stanisław Lukiewicz,

- ***diploma with honors,***
- ***Award of the Deputy Prime Minister of December 1st, 1988,***
- ***Scholarship of the Chairman of the Committee for Youth Affairs and Physical Culture, for the period 1.XI.1988-31.X.1989***

Secondary Education 1983 - High School No. 1 im. M. Kromera, Gorlice, province Małopolska, mathematics and physics profile

Primary Education 1979 - Primary School No. 4 im. Bohaterów Westerplatte, Gorlice, province Małopolska,

- ***first place in the Regional Olympiad in Physics for Primary Schools***

3. Information on Previous Employment

2002 - : Research Associate, ON-4, Institute of Physics, Polish Academy of Sciences, Warsaw

2000 - 2001 : Research Assistant, ON-4, Institute of Physics, PAS, Warsaw 1995 -

2000: Ph.D. student, ON-4, Institute of Physics, PAS, Warsaw

1988 - 1995: Research Assistant, Department of Biophysics, Institute of Molecular Biology, Jagiellonian University, Cracow

4. Information on Published Scientific Papers and Creative Professional Works

4.1. Total Number of Publications = **52,** including **45** after obtaining a Ph.D. degree in Physics. The papers were published in peer-reviewed journals having high international reputation, such as:

- **Physical Rewiev B** - 12 articles, including 10 published after obtaining a Ph.D. degree in Physics,
- **Applied Physics Letters** - 6 articles, all published after obtaining a Ph.D. degree in Physics,
- **New Journal of Physics** - 1 article, published after obtaining a Ph.D. degree in Physics,
- **Journal of Physics: Condensed Matter** - 4 articles, all published after obtaining a Ph.D. degree in Physics,
- **Journal of Applied Physics** - 5 articles, including 4 published after obtaining a Ph.D. degree in Physics.

In the Web of Science base (WoS) **42** publications are included.

4.2. Total *Impact Factor* of publications after the Journal Citation Reports (JCR), according to year of publication = **102,409.**

4.3. Total citation number of publications after the WoS base, of 27.11.2012 = **278.** Hirsch Index of publications after the WoS base, of 27.11.2012 = **10.**

4.4. Other Creative Professional Works:

- co-author of 1 manual for students, published before obtaining a Ph.D. degree in Physics,
- 94 conference presentations, including:
  a) 18 invited lectures (10 presented personally), all presented after obtaining a Ph.D. degree in Physics,
  b) 33 oral presentations (9 presented personally), including 27 after obtaining a Ph.D. degree in Physics (6 presented personally),
  c) 43 posters, including 38 after obtaining a Ph.D. degree in Physics,
- popular-scientific lecture presented at the Festival of Science 2007, entitled: *Journey to the Center of the Earth - high pressure in nature and research,*
- total number of seminars delivered =11, including 8 after obtaining a Ph.D. degree in Physics.

5. Managing and Participation in Domestic or International Research Projects

5.A. Research projects performed before obtaining a Ph.D. degree in Physics

1988 - 1990 **investigator** in the government project CPBP 01-12-9-27, topic managed by prof, dr h ab. S . Lukiewicz, performed in the Department of Biophysics, Institute of Molecular Biology, Jagiellonian University, Cracow;

1997 _ 1999 **investigator** in the research project of the State Committee for Scientific Research No. 8T11B 052 13 entitled: „ *The study of defects in oxide single crystals of ABO 3 type"*, performed in the Institute of Physics, Polish Academy of Sciences, Warsaw; project terminated 31. XII. 1999;

2000-2001: **main investigator** in the Ph.D. project No. 8T11B 048 19 entitled: *„ Identification of* Cr^{3+} *centers and study of their energetic structure by means of high-pressure spectroscopy in selected laser crystals"*, performed in the Institute of Physics, Polish Academy of Sciences, Warsaw from 1. VIII. 2000 to 31.X. 2001.

5.B. Research projects performed after obtaining a Ph.D. degree in Physics

2003-2005: **principal investigator** in the research project of the State Committee for Scientific Research No. 2P03B 054 24 entitled: „ The study of defect structure *of* $LiNbO_3$*:Cr,MgO crystals"*, performed in the Institute of Physics, Polish Academy of Sciences, Warsaw from 20. III. 2003 to 19. III. 2005;

2006-2008: **investigator** in the research project MNiSW No. 1 P03B 021 29 entitled: *Mechanisms of carrier localization determining the electrical and optical properties of InGaN layers and quantum structures"*, performed in the Institute of High Pressure Physics, Polish Academy of Sciences, Warsaw; project terminated 23. V. 2008;

2006-2009: **investigator** in the research project MNiSW No. 1 P03B 100 30 entitled: *,flanocrystalline and monocrystalline yttrium aluminium garnets doped with manganese for photonics and thermoluminescence dosimetry"*, performed in the Institute of Physics, Polish Academy of Sciences, Warsaw; project terminated 29. III. 2009;

2007 - 2011 : **investigator** in the research project MNiSW No. N202 046 32/1179 entitled: *influence of high hydrostatic pressure on the optical properties of CdTe/ZnTe quantum dots grown by MBE method'*, performed in the Institute of Physics, Polish Academy of Sciences, Warsaw; project terminated 17. IV. 2011;

since 2007: **investigator** in the key project POIG 01.01.02-00-008/08 entitled: „ *Quantum semiconductor nanostructures for applications in biology and medicin€* (NANOBIOM), performed in the framework of the Operational Programme Innovative Economy by Institute of Physics, Polish Academy of Sciences, Warsaw in years 2007 - 2013;

2008 - 2010: **principal investigator** in the research project MNiSW No. N N202 203734 entitled: *„The study of the influence of crystalline environment on the* *probabilities of intraconfigurational transitions of selected rare earth dopants"*, performed in the Institute of Physics, Polish Academy of Sciences, Warsaw from 9. V. 2008 to 8. XI. 2010;

2009: **investigator** in the project POIG 01.01.02-00-108/09 entitled: *"**Advanced^** Materials and Innovative Methods for Energy Processing and Monitoring"* (MIME), performed in the framework of the Operational Programme Innovative Economy by Institute of Physics, Polish Academy of Sciences, Warsaw in years 2009 - 2014;

2010: **principal investigator** in the habilitation research project MNiSW No. N N202 203838 entitled: *„The pressure study of radiative recombination processes in selected structures of nitride semoconductors and in dielectrics doped with rare earth ions"*, performed in the Institute of Physics, Polish Academy of Sciences, Warsaw from 30. IV. 2010 to 29. IV. 2012.

6. List of Invited Lectures Presented at International or Domestic Thematic Conferences

All invited lectures were presented after obtaining a Ph.D. degree in Physics.

1 A. Kamińska, T. Suski, G. Franssen, H. Teisseyre, P. Perlin, A. Suchocki, N. Grandjean, *Localized excitons and the radiative recombination mechanism in InGaN/GaN quantum structures,* 11th International Conference on High Pressure Semiconductor Physics, San Francisco, USA, 2-5 August 2004;

2. A. Kamińska, A. Mycielski, S. Trushkin, A. Suchocki, *ZnO crystals obtained with the chemical vapour transport method - properties and applications,* The 2n Workshop on Physics of Semiconductor Science, Lattakia, Syria, 24 -26 April 2005;

3 A. Kamińska, G. Franssen, T. Suski, A. Suchocki, K. Kazlauskas, G. Tamulaitis, A. Żukauskas, H. Teisseyre, P. Perlin, N. Grandjean, *Growth and spectroscopic studies of localization effects in InGaN/GaN quantum structures,* The 2n Workshop on Physics of Semiconductor Science, Lattakia, Syria, 24 -26 April 2005;

4 A Kamińska, *Photoluminescence Studies of TM and RE Doped Oxides Using Diamond Anvil Cell*, The 2nd ASPECT Workshop on Advanced Spectroscopy, Kazimierz Dolny, Poland, 29 September - 2 October 2005;

5 A Kamińska *The study of internal electric fields in lattice-matched GaN/AlInN quantum structures*, New materials and sensors for optoelectronics, informatics and medicine, Będlewo, Poland, 26-28 April 2008;

6 A Kamińska, G. Franssen, T. Suski, E. Feltin, N. Grandjean, High-pressure photoluminescence studies of near-lattice-matched GaN/AlInN quantum wells, 13 International Conference on High Pressure Semiconductor Physics (HPSP-13), Fortal eza, Brazi 1, 22 - 25 Jul y 2008;

7. A. Kamińska, G. Franssen, T. Suski, I. Gorczyca, H. Teisseyre, A. Suchocki, *Study of radiative recombination mechanisms in nitride semiconductors using high hydrostatic pressure,* The 6th Workshop on Physics of Semiconductor Sciences and Lasers, Lattakia, Syria, 24 -26 May 2009;

8 A Kamińska, *Optical properties of rare earth doped wide band-gap materials under hydrostatic pressure,* The Third International Workshop on Advanced Spectroscopy and Optical Materials (I WASOM'11), Gdańsk, Poland, 17-22 July 2011;

9. A. Kamińska, C.-G. Ma, M.G. Brik, A. Kozanecki, A. Suchocki, *Electronic structure of Yb^{3+} dopant in III-V semiconductors: experimental and crystal field studies,* E-MRS Fall Meeting, Warsaw, Poland, 19-23 September 2011;

10 A Kamińska, *Radiative recombination mechanisms in nitride semiconductor structures revealed by high-pressure studies,* XIX Ural International Winter School on the Physics of Semiconductors (UIWSPS), Ekaterinburg, Russia, February 20 - 25 2012.

7. List of Published the Series of Articles Constituting the Scientific Achievement, in accordance with the Art. 16 Paragraph 2 of the Act of March 14th, 2003 (Dz. U. No. 65, item 595, as amended)

Subject of publications:

HIGH-PRESSURE STUDIES OF RADIATIVE RECOMBINATION PROCESSES IN NITRIDE SEMICONDUCTOR STRUCTURES AND RARE EARTH IONS DOPED MATERIALS

A. **Nitride Semiconductor Structures**

HI. G. Franssen, A. **Kamińska,** T. Suski, A. Suchocki, K. Kazlauskas, G. Tamulaitis, A. Żukauskas, R. Czernecki, H. Teisseyre, P. Perlin, M. Leszczyński, M. Boćkowski, I. Grzegory, N. Grandjean, *Observation of localization effects in InGaN/GaN quantum structures by means of application of hydrostatic pressure,* Phys. Stat. Sol. (b) **241,** 3285 (2004).

My contribution to this publication consisted of performing of all pressure measurements, processing the obtained results, and participation in the preparation of the manuscript. I estimate my contribution to the 40%.

H2. A. **Kamińska,** G. Franssen, T. Suski, I. Gorczyca, N.E. Christensen, A. Svane, A. Suchocki, H. Lu, W.J. Schaff, E. Dimakis, A. Georgakilas, *Role of conduction-band filling in the dependence of InNphotoluminescence on hydrostatic pressure,* Phys. Rev. B **76,** 075203 (2007).

My contribution to this publication consisted of performing of all measurements, processing the obtained results, and participation in their anaysis as well as in the preparation of the manuscript. I estimate my contribution to the 50%.

H3. A. **Kamińska,** G. Franssen, T. Suski, E. Feltin, N. Grandjean, *Pressure-induced piezoelectric effects in near-lattice-matched GaN/AUnN quantum wells,* J. Appl. Phys. **104,** 063505 (2008).

My contribution to this publication consisted of performing of all measurements, processing the obtained results, participation in their anaysis and on the preparation of the manuscript. I estimate my contribution to the 70%. **H4.** I. Gorczyca, T. Suski, A. **Kamińska,** G. Staszczak, H.P.D. Schenk, N. Christensen, A. Svane, *In-clustering effects in InAIN and InGaN revealed by high pressure studies,* Phys. Stat. Sol. (a), **207,** 1369 (2010).

My contribution to this publication consisted of participation in the measurements, processing the obtained results, and participation in the preparation of the manuscript. I estimate my contribution to the 40%.

H5. I Gorczyca, A. **Kamińska,** G. Staszczak, R. Czernecki, S.P. Łepkowski, T. Suski, H.P.D. Schenk, M. Glauser, R. Butté, J.-F. Carlin, E. Feltin, N. Grandjean, N. E. Christensen, A. Svane, *Anomalous composition dependence of the band gap pressure coefficients in In-containing nitride semiconductors,* Phys. Rev. B **81,** 235206 (2010).

My contribution to this publication consisted of participation in the measurements, processing the obtained results, and participation in the preparation of the manuscript. I estimate my contribution to the 40%.

B. Rare Earth Ions Doped Materials

H6. A. **Kamińska,** S. Biernacki, S. Kobyakov, A. Suchocki, G. Boulon, M. O. Ramirez, L. Bausa, *Probability of Yb^{3+} 4f-4f transitions in Gadolinium Gallium Garnet Crystals at High Hydrostatic Pressures,* Phys. Rev. B **75,** 174111 (2007).

My contribution to this publication consisted of performing of all measurements, processing the obtained results, and participation in the preparation of the manuscript. I estimate my contribution to the 50‰.

H7. A. **Kamińska,** A. Duzynska, A. Suchocki, M. Bettinelli, *Spectroscopy of f-f radiative transitions of Yb^{3+} ions in ytterbium doped orthophosphates at ambient and high hydrostatic pressures,* J. Phys.: Condens. Matter **22,** 225902 (2010). My contribution to this publication consisted of guidance of measurements, performing of all pressure measurements, processing and analyzing the obtained results, and the preparation of the manuscript. I estimate my contribution to the 70%.

H8. A. **Kamińska,** A. Kozanecki, S. Trushkin, A. Suchocki, *Spectroscopy of ytterbium doped InP under high hydrostatic pressure,* Phys. Rev. B **81,** 165209 (2010).

My contribution to this publication consisted of performing of all pressure measurements and processing the obtained results, as well as the participation in their analysis and the preparation of the manuscript. I estimate my contribution to the 60%.

H9. A. **Kamińska,** R. Buczko, W. Paszkowicz, H. Przybylinska, E. Werner-Malento, A. Suchocki, M. Brik, A. Durygin, V. Drozd, S. Saxena, *Merging of the $^4F_{3/2}$ level states of Nd^{3+} ions in the photoluminescence spectra of gadolinium-gallium garnet under high pressure,* Phys. Rev. B **84,** 075483 (2011).

My contribution to this publication consisted of performing of all optical measurements, processing the obtained results, and the participation in the preparation of the manuscript. I estimate my contribution to the 40%.

H10. A. **Kamińska,** C.-G. Ma, M .G. Brik, A. Kozanecki, M. Boćkowski, E. Alves, A. Suchocki, *Electronic structure of ytterbium-implanted GaN at ambient and high pressure: experimental and crystal field studies,* J. Phys.: Condens. Matter, **24,** 095803 (2012).

My contribution to this publication consisted of performing of all measurements, processing the obtained results, and the preparation of the manuscript. I estimate my contribution to the 60%.

The statements of the co-authors, specifying their individual contribution to the publications, are attached in alphabetical order in the annex No. 8 entitled: „The co-authors statements". The statement of prof. W. J. Schaff concerning the publication No. 2 is not attached due to the lack of contact with this co-author, and the statement of doc. dr hab. S Biernacki, concerning the publication No. 6 - due to his death in 2007.

The contribution of prof. W. J. Schaff to the publication No. 2 is analogous, as the contribution described in the statement of prof. H.Lu, who then worked in the same group ir the Department of Electrical and Computer Engineering, Cornell University (USA) - i.e. i consisted of MBE *(molecular beam epitaxy)* growth of InN films.

The contribution of theoretician physicist doc. dr hab. S Biernacki, who at that tim< was my colleague working in the same group of Division of Solid State Spectroscopy of II PAS, consisted of theoretical analysis of obtained experimental results.

8. The Course of Scientific Work

8.1 Scientific Work before Obtaining a Ph.D. Degree in Physics

After graduation and defending my M.Sc. thesis in June the 14^{th}, 1988, I was employed in the Department of Biophysics of the Institute of Molecular Biology at the Jagiellonian University in Cracow, initially as an investigator in the government project CPBP 01-12-9-27, and since October the 1^{st}, 1988 - as a trainee assistant. After the training I was employed in the Department of Biophysics as a research assistant. My scientific supervisor was prof, dr hab. S. Lukiewicz. Then my activities consisted of:

1) study of the problems related to the diagnostics and therapy of cancer, e.g. contrast agents for NMR *(nuclear magnetic resonance)* tomography - the results of this study were presented at the conference Seventh Annual Meeting of Society of Magnetic Resonance in Medicine in San Francisco, USA, 1988,
2) work on problems concerning electron paramegnetic resonance (EPR) imaging and EPR study of nitric oxide, released by living organisms as a result of an immune response,
3) organising and conducting students laboratory in physics for students of biology in the years 1989-1992: this work resulted in the edition of the manual for students in 1999, entitled *"Biophysics: exercises and seminars'"*, which I am the co-author (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 2).

After moving to Warsaw, during my parental leave, and then unpaid leave at the Jagiellonian University, on the 1st of October 1995 I began my Ph.D. studies at the Institute of Physics of Polish Academy of Sciences. The advisor of my Ph.D. was prof, dr hab. Andrzej Suchocki. My contract of employment at the Jagiellonian University I terminated finally in November 1997, when I was the third year student of Ph.D. studies at the Institute of Physics, PAS in Warsaw.

I was the Ph.D. student at the IP PAS in the years 1995 - 2000. Initially, I participated in the study of the origin of the yellow luminescence in gallium nitride and in the study of Auger effect in $CdF_2:Mn^{2+}$, using optical and magneto-optical spectroscopy. The results of these studies were published in my first papers *(Materials Science Forum,* **258-263,** 1149 (1997), *Acta Physica Polonica,* **92,** 815 (1997) and *Journal of Applied Physics,* **84,** 6753 (1998)), and they were also presented as my first oral presentation at the XXV International School on the Physics of Semiconducting Compounds, Jaszowiec 1997.

Next I started the study of optical properties of laser materials doped with Cr^{3+} ions and their temperature and pressure dependencies. This subject, related to high-pressure studies of electronic structure of chromium dopant in the selected laser materials, became finally the subject of my Ph.D. dissertation. I performed the measurements of absorption, excitation, and luminescence spectra, as well as decay kinetics of luminescence as a function of temperature and hydrostatic pressure, generated by using diamond anvil cell (DAC). The high-pressure spectroscopy became an essential tool used by me in these studies. This technique turned out to be an effective and efficient tool for investigations of radiative processes. It facilitated the determination of important parameters, which are in many cases unavailable or difficult to obtain in another way. Despite its efficiency and apparent simplicity, the high-pressure spectroscopy is used in a few laboratories only. This is caused by many conditions that must be satisfied simultaneously to enable perform this kind of research. Apart from the full equipment for optical measurements, the possibility of work at low temperature and possession of an appropriate designed DAC, the proper use of this technique requires some skills to manage with quite sophisticated procedure of sample preparation and high-pressure measurements. In Poland, besides IP PAS, the high-pressure technique is used currently in two other research centers: in the Institute of High Pressure Physics PAS „ ni ress" in Warsaw, in the group of prof. T. Suski, and in the Institute of Experimental Physics of Gdansk niversity, in the grou of rof. M. Grinberg.

Studying the chromium-doped oxide materials I collaborated with prof. Luis Arizmendi from Universidad Autónoma de Madrid in Spain, where I had a few scientific-research visits in the years 1997-2000, and with prof. Marek Grinberg, then the employee of the Faculty of Physics, Astronomy and Informatics of Nicolaus Copernicus University in Toruń, with whom I discussed the obtained results and their compatibility with theoretical model developed by prof. Grinberg. The application of this model for analysis of my experimental data enabled the determination of important spectroscopic parameters characterizing the chromium centers in the investigated materials, as the strength of the crystal field influencing the chromium ions, the electron-phonon coupling (Huang-Rhys parameter), and the value of the spin-orbit interaction. The obtained results were published in the years 1999 - 2002 in five ariticles, in the journals cited in the Journal Citation Reports (JCR) database, including three articles in Physical Review B.

During my Ph.D. study I participated in five international and one domestic conferences, where I presented three orals and two posters. I was also the co-author of two more orals and three posters. Moreover, I gave three seminars at the Seminar on

Semiconductor Physics at the Institute of Physisc PAS. I also participated in two projects of the State Committee for Scientific Research: the research project entitled „ The study of *defects in oxide single crystals of*$AB0_3$ type", and the Ph.D. project entitled „ *Identification of* Cr^{3+} *centers and study of their energetic structure by means of high-pressure spectroscopy in* selected laser crystals", where I was the main investigator.

In addition, in the years 1996/97 and 1997/98 I conducted students' laboratory in physics for students of School of Science (at present the department of Cardinal S. Wyszyński University) in Warsaw.

In November 2001 I defended my Ph.D. thesis entitled „ *The High Pressure Studies of Electronic Structure of Chromium Dopant in the Laser Materials".*

The complete list of publications, presentations and seminars delivered in this period can be found in the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works".

8.2 Scientific Work after Obtaining a Ph.D. Degree in Physics

From October the 1st, 2000, to December the 31st, 2001 I was employed as a research assistant at the Institute of Physics, PAS. From January 2002 up today I am employed at the same Institute as a research associate.

Initially after my Ph.D. defense I was dealing mainly with the study of defect structure of $LiNb0_3$:Cr,MgO crystals, using absorption and luminescence measurements, high-pressure luminescence measurements and magneto-optical measurements. For this research I received funding as a research project of the State Committee for Scientific Research No. 2P03B 054 24. During the execution of the project I studied temperature and pressure dependencies of luminescence and luminescence decays at the IP PAS, and I performed also absorption measurements at the Universidad Autónoma de Madrid in Spain, hi 2003 I was there on one month research stay. The magneto-optical measurements at high magnetic fields I performed during my two research stays in Grenoble High Magnetic Field Laboratory, CNRS, France in 2004 and 2005. For these stays I received funds through the support of the European Community from the contract No. RITA-CT-2003-505474. These studies resulted in four publications in prestigious journals [1-4] and five presentations at international conferences (E-MRS Fall Meeting, Warsaw 2003; International Workshop on Lithium Niobate from material do device, from device to system Metz, France 2005; ICL'05, Beijing, China 2005; Polish-French Workshop "High Magnetic Fields in Semiconductor Physics", Warsaw 2006). Furthermore, I gave two seminars on topics related to the investigated problems, including the seminar at the Universidad Autonoma de Madrid in Spain (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 4, ref. 4, 5).

In 2003 I began to participate in the studies of semiconductor materials: bulk ZnO crystals grown in the laboratory of prof, dr hab. A. Mycidski in IP PAS, and nitride semiconductors structures, which I investigated in close cooperation with a group of prof, dr hab. T. Suski from the Institute of High Pressure Physics PAS Unipress". In the frame of these collaborations I took part e.g. in the study of the influence of oxygen annealing of ZnO crystals on their optical properties, and in the study of electric fields in quaternary nitride heterostructures (InAlGaN). These investigations resulted in two publications [5, 6] and five conference presentations, including one invited lecture, which was given by me (see - the anne o. entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 22), as well as one my seminar (see - annex No. 6, sect. 4, ref. 6).

8.2.1 Scientific Achievement Being the Subject of Habilitation - the Series of Publications Entitled:

TTiph-Pressure Studies of Radiative Recombination Processes in Nitride Semiconductor Structures and Rare Earth Ions Doped Materials

In subsequent years, developing and improving the high-pressure measurements technique, I got involved in the study of radiative recombination processes in various materials, whose existing and potential applications in efficiently emitting optical and optoelectronic devices, and also in solar cells, stimulate intensive research since several years. The aim of this work is:

1) improving the efficiency and stability of existing devices (blue and violet light emitters based on nitride semiconductor structures);
2) extension of the spectral range of light emitting diodes (LEDs) and nitride-based semiconductor lasers into the green-red spectral region;
3) construction of more and more efficient solid-state compact lasers, operating at different required wavelengths, built of rare earths doped dielectrics, which can compete in some applications with semiconductor lasers due to the higher mode quality and stability of frequency;
4) obtaining new devices with unique optical and electrical properties, based on rare earths doped semiconductors.

Realization of these application goals requires e.g. more complete understanding of radiative mechanisms and energy transfer processes occurring in luminescent materials, their dependence on the material composition, material defect structure, as well as the strength and symmetry of crystalline environment of radiative recombination centers. The high-pressure spectroscopy suits very well for this type of investigations, as changing the hydrostatic pressure acting on the material under study, and hence - changing the ion-ion distances and the crystal field strength generated by the ions, we can change in the controlled and smooth way both the energetic structure of the band states of the investigated crystal, and the energy levels of dopants introduced into the crystal.

The materials, which I have investigated in this regard, can be divided into two groups:

A) layers and quantum heterostructures of nitride semiconductors;
B) dielectrics and semiconductors doped with rare earth ions.

Due to the valuable results obtained by using high-pressure spectroscopy as a main research tool, this part of my scientific work, concerning the **high-pressure studies of radiative recombination processes in nitride semiconductor structures and rare earth ions doped materials** described in the present chapter, is in my opinion the most important achievement after obtaining my Ph.D. degree in physics. Therefore I consider it to be a basis to apply for the habilitation degree. The series of publications, in which results on this subject are presented, shows that using high hydrostatic pressures generated in DAC allows for obtaining unique informations on local structure and symmetry of the investigated system, as well as involved energetic relationships influencing the efficiency and properties of the occurring radiative processes.

Publications constituting this appointed part of my work are cited according to their list, and their full texts can be found in the annex No. 4 entitled: he texts of the published series of articles considered as a scientific achievement".

8.2.I.A. Layers and Quantum Heterostructures of Nitride Semiconductors

Since 2003 I have carried on spectroscopic studies of films and quantum heterostructures of nitride semiconductors. The direct energy gap *(E_G)* of nitride semiconductors (Ga,In,Al)N covers a very wide spectral range, from the infrared (£$_G$(InN) = 0.65 eV at room temperature) to the ultraviolet (£$_G$(A1N) = 6.04 eV), engendered the hope for the construction of optoelectronic devices with efficient luminescence, operating a different spectral ranges. Nitride quantum structures are currently commonly used in blue and violet light emitters. They are also considered for use in solar cells and transistors. Anyhow, in spite of intense research, mechanisms of radiative and non-radiative recombination in nitrides are still under debate, however the progress made in recent years in the growth techniques of high-quality structures has enabled their more detailed investigation and better control of their properties.

My study of phenomena influencing the light emission efficiency and carrier transport in these materials, were related to:

1) the problems of indium seggregation and resulting processes of carriers (excitons) locatisation in indium containing alloys (InGaN, InAIN),

3) effects associated with built-in electric fields in quantum structures of GaN/AlInN, a consequence of a spontaneous polarization, characteristic for materials crystallizing in wurtzite structures, and piezoelectric polarization resulting from the differences in quantum wells and barriers lattice parameters.

Ad. 1).

The importance of carrier localization mechanisms in In_xGai-_xN ternary alloys for $0 < x < 0.2$ have been widely discussed since the first quantum structure-based LEDs *(light emitting diodes)* and LDs *(laser diodes)* appeared, constructed on nitrides with an active InGaN region. They exhibited excellent luminescence efficiency in spite of such unfavourable features like very high defect densities up to 10^{10} cm"[1], created mainly by dislocations acting as a non-radiative recombination centers [8]. According to a model proposed first by Chichibu et al. [9], the radiative recombination centers arise from the presence of spatial fluctuations of the InGaN valence- and conduction-band potential profile, caused by indium segregation. The potential fluctuations result in strong, short-range carriers localization, and consequently -carriers are trapped and isolated from non-radiative recombination centers. Further studies confirmed the validity of this model [10, 11]. It clarifies why despite the high dislocations density the efficient radiative recombination occurs, and explains the existence of Stokes shift (i.e. the energetic difference between the absorption edge and luminescence maximum), frequently observed in optical measurements. The energetic position of the absorption edge is defined by the average value of the energy gap (average indium content), whereas the photoluminescence occurs due to radiative transitions between the local conduction band minima and valence band maxima, so it arises from the regions, when the bandgap is lower, and the local indium concentration is larger.

Because of the close relation between indium content fluctuations and optical properties of the $In_xGai\_{_x}N$/GaN heterostuctures, the proper assessment of the degree of exciton localization in the InGaN alloys is essential for optimization of the device design. The measure of the degree of localization is the Stokes shift value. It can be determined by the absorption and luminescence measurements. The measurement of the absorption edge in $In_xGai\_{_x}N$/GaN structures is not straightforward, therefore finding the alternative tool for the evaluation of the degree of carrier localization has been considered for very useful.

The aim of my study was to examine the possibility of using high-pressure spectroscopy for solving the above problem. Due to the differences in the InN and GaN pressure dependence of the photoluminescence peak energy (referred to as the pressure

1phenomena associated with conduction band filling and non-parabolicity effects in InN, which e.g. occurred to be responsible for an overestimation of the energy gap value of this material; this value has been verified only in the last decade [7], coefficient of photoluminescence $dE_{PI}/dp)$ we can expect that the values of the pressure coefficients may reflect the degree of carrier localization. Indeed, as *dEpJdp* (InN) ~ 25 meV/GPa [12], dE_{PI}/dp (GaN) ~ 40 meV/GPa [13], and higher degree of localization means higher indium content, the pressure coefficient of luminescence can be expected to be lower for radiative transitions associated with carriers with a higher degree of localization.

I performed the temperature measurements of photoluminescence pressure coefficients of In_xGai_$_x$N/GaN structures. Then the pressure coefficients were compared with the relevant results of Stokes shift measurements, where the absorption edge was evaluated by our coworkers from Vilnius University: at temperatures exceeding 200 K it was done by means of photoferlectance spectroscopy, whereas at temperatures below 200 K - using a specially developed theoretical model, i.e. an exciton hopping model [14]. In this model hopping of excitons is assumed to occur in a double-scaled potential profile: through localized states formed as a result of potential fluctuations distributed on a 16 meV energy scale within the In-rich clusters, and between these clusters - with the presumption that dispersion of the distribution in average localization energy of the clusters is of order 42 meV [14]. The obtained results showed the existence of the expected correlation between these parameters. The details of this study have been described in the paper **[HI],** and subsequent investigations have confirmed that the high-pressure spectroscopy can be used for the evaluation of localization phenomena in InGaN/GaN quantum structures [15 - 17]. The results concerning this subject have been published in total in four articles **[HI,** 15 - 17], and have been also presented at six international conferences, including two invited lectures given by me (see -the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 18 and 23).

Continuing the study of the indium segregation problem and the resulting carrier localization, I performed in subsequent years the measurements of series In_xGai_$_x$N and In_xAli_$_x$N layers in cooperation with the Institute of High Pressure Physics PAS „Unipress". Theoretical calculations of the electronic band structures of In_xGai.$_x$N and In_xAli_$_x$N alloys carried out by Gorczyca et al. for 32-atom wurtzite supercell showed strong dependence of the alloys' bandgaps and the bandgaps pressure coefficients (for a fixed indium content x, $0 < x < 1$) on the degree of indium segregation in the material [18, **H5].** Taking into account segregation effect causes a strong decrease in energy gap of such a supercell and even much more pronounced decrease in the bandgap pressure coefficient with respect to material with uniformly distributed indium atoms. My experimental results, published in two articles **[H4,**

H5], have confirmed these predictions, pointing to the possibility of identifying short-range indium clustering in the alloy by measuring its bandgap pressure coefficient, and hence - the correlation of indium segregation effects with growth conditions of $In_xGai\_{x}N$ and $In_xAli\_{x}N$ layers. My research on this subject was presented in the form of three presentations at international conferences (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 67, 68 and 73). A part of these studies was also the subject of the M.Sc. thesis e ntitled " *Optical Spectroscopy of Nitride Semiconductor Layers Grown by MBE and MOVPE techniques"* (2011), made under my supervision. The results of this work, after a slight experimental complement, will be written and published in the near future. The author of that work, M.Sc. P. Nowakowski, is currently a first year Ph.D. student at my Institute.

Ad. 2).

Another problem related to the semiconductors, which I studied, was connected with the effects of conduction-band filling and non-parabolicity in indium nitride. Recent progress in the growth of high-quality InN films has enabled obtaining samples with good structural properties and low electron concentrations. High electron concentrations were associated with the high defect densities of formerly grown layers. The study of high-quality InN layers with low electron concentrations allowed e.g. the verification of the value of the energy gap of this material, which until recently was regarded to be equal to about 2 eV. Now there is a common agreement among researchers that the value of the energy gap in InN at room temperature does not exceed 0.65 eV, and its previous overestimation was mainly due to Burstein-Moss effect caused by very high intrinsic electrons concentration in the strongly defected samples [7].

The narrow bandgap also has implications for the basic properties of InN. It leads to an increased interaction across the bandgap between the conduction band and the valence band states, giving rise to a relatively low value of effective mass m*. For example, in InN it is approximately equal to $0,05m_0$ (where m_0 signifies the free-electron mass), in contrast with about *0,23mo* for GaN, whose energy gap E_G at room temperature is equal to 3.43 eV, and about $0,3m_0$ for A1N (E_G (295 K) = 6.04 eV) [19]. A low effective mass value induces an efficient conduction band filling, i.e. a fast blue shift of the Fermi level with increasing electron concentration, which is reflected in luminescence measurements by the blue shift of the maximun of luminescence line and increasing its half-width **[H2].**

The application of hydrostatic pressure leads to the increase in the direct bandgap of InN, and therefore to the increasing effective mass of electrons. As a result, the observed luminescence pressure coefficient dE_{PL}/dp may differ from the energy gap pressure coefficient dE_G/dp, and this difference depends on the electrons concentration in the sample. I performed high-pressure luminescence study of a series of InN samples with different electrons concentration, which have shown the predicted influence of conduction-band rilling effect in indium nitride on the pressure coefficient of photoluminescence peak. Furthermore, the fit of the theoretical model to the experimental data indicated a significant role of InN conduction-band non-parabolicity in the luminescence process of this material. Taking into account this effect in performed *ab-initio* calculations (LDA - *local density approximation)* occured to be necessary to receive the proper accordance of the model with the experimental data **[H2,** 20]. These results and conclusions have been published in one paper **[H2],** and have been also presented at two international conferences (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 43 and 47).

Ad. 3).

The problem of electric fields in nitride semiconductor quantum structures is associated with the fact that nitrides crystallize in hexagonal wurtzite structure. The characteristic feature of nitride based quantum heterostructures grown along the (0001) crystallographic axis is the presence of a strong internal electric field, caused by the spontaneous polarization resulting from from the lack of inversion symmetry of the wurtzite structure, and piezoelectric polarization, which is the result of a lattice mismatch of wells and barriers.

Strong built-in electric fields in quantum wells result in the so-called quantum confined Stark effect, causing the spatial separation of the electrons and holes inside the quantum wells region, leading to a reduction of radiative transition probability, which is very disadvantageous from the point of view of potential optoelectronic applications. An additional effect associated with the bands inclination due to internal electric fields is the red-shift of luminescence energy, increasing with the quantum well width, and the dependence of the luminescence energy on excitation power.

One of the methods of overcoming the electric fields problem in nitride heterostructures is using the lattice-matched wells and barriers, enabling the minimizing the piezoelectric polarization. Such a possibility has appared in recent years, due to the progress in the growth techniqe of GaN/AlInN quantum structures. An important feature of the $Ali_{-x}In_xN$ alloy is the possibility to grow epitaxial layers which are lattice-matched to GaN at an indium content x of about 0.17 [21]. Lattice matching of quantum wells and barriers enables to avoid the strain (and thereby cracking and/or dislocation formation), and minimizing the piezoelectric polarization. In addition, it allows the study of spontaneous polarization only, usually difficult to separate from piezoelectric polarization.

To analyze the problem of electric fields in near-lattice-matched GaN/AlInN quantum structures, I performed in collaboration with the group of prof. T. Suski from Unipress the study of the series of unique GaN quantum wells with $Al_{0.88}In_{0.12}N$ barriers of different thicknesses, grown by our collaborators from École Polytechnique Fédérale in Lausanne [22, **H3]**. The main goal of this work was the determination of the built-in electric field value in such heterostructures, its dependence on hydrostatic pressure, as well as the infuence of pressure on both spontaneous and piezoelectric polarization. The performed measurements enabled the determination of ambient-pressure internal electric field value in the investigated structures and its pressure dependence. The drastic variation of the photoluminescence energy pressure coefficient (dE_{PL}/dp) with the quantum well width has been observed. We have shown that this effect is connected with the pressure increase in internal electric field. Using a common method for finding the values of this electric field, relying on comparing a plot of the photoluminescence peak energy as a function of quantum well width with theoretical predictions for different electric field values, we have found that the built-in electric field increases with pressure with the "internal electric field pressure coefficient" equal to 0.29 MV/(cm-GPa). This result is qualitatively consistent with the estimated theoretical value. The results of these studies have been published **[H3]** and presented in the form of three presentations at international conferences and one presentation at domestic conference, including two invited lectures, which were given by me (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 49 and 53).

In summary, the result of the studies of nitride semiconductor structures presented above is so far my co-authorship in ten articles with good citations, published in the years 2004 - 2010 in world-wide scientific journals (e.g. one in Applied Physisc Letters, two in Physical Revew B, one in Journal of Applied Physics), of which in five my role was leading in collecting and analyzing experimental data, as well as in preparing the publications. The conclusions of the succesive stages of research, covering the investigated problems of nitride semiconductors an their structures as a whole, were presented in the form of twenty presentations at international and domestic conferences, including eight invited lectures (six given by me: see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 18, 23, 49, 53, 59 and 94), 6 oral presentations. I also gave two seminars: at the Institute of Physics PAS in Warsaw and at the Institute of Experimental Physics, University of Gdańsk (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 4, ref. 7 and 8). Furthermore, I was a supervisor of one M.Sc. thesis related to this issue.

8.2.l.B. Dielectrics and semiconductors doped with rare earth ions

Since 2004, in addition to problems related to nitride structures, I have been dealing in parallel with the study of properties of rare earth dopants in dielectrics and semiconductors. Rare earths doped materials are nowadays attracting a lot of attention in solid state physics and are very intensively studied for fundamental studies as well as for their applications as a laser materials and/or efficient light sources. Rare earth ions are important optically active dopants both in semiconductors matrices and in dielectrics due to the wide potential applications in efficient laser materials, fluorescent lamps, colourfull electroluminescent panels, X-ray enhancing screens for and in photonics, e.g. for the generation of entangled photon pairs [23]. In particular, the growing interest in the Yb^{3+}-doped crystals is caused by their bright luminescence at the wavelengths of around 1 urn, associated with the intraconfigurational transitions within the 4/-shell of trivalent ytterbium ion $({}^2F_{5/2} \rightarrow {}^2F_{7/2})$. Due to the development of high brightness InGaAs-based laser diodes emitting near 980 nm, where the Yb^{3+} has a strong absorption peak, this ion may compete with Nd^{3+} as an active lasing center emitting in the same range of emission wavelength, because ytterbium ions have many advantages, which do not have the neodymium ions [24].

In cooperation with prof. L. Arizmendi and the research group of prof. L. Bausafrom Universidad Autonoma de Madrid we initially took up the research of ytterbium-doped dielectrics with ferroelectric properties, i.e. ytterbium-doped lithium niobate and strontium barium niobate. The obtained results quickly led to two articles published in Physical Review B [25, 26] and they turned out to be so interesting that encouraged me to stronger involvement in the problems associated with optical properties of rare earth dopants. They pointed to the significant influence of symmetry and strength of the crystal field acting on the dopant, the energy distance between 4/and *5d* states, as well as charge transfer-type transitions on the probabilities of intraconfigurational transitions of 4/-shell electrons. The electric-dipole (ED) transitions within the pure 4f configuration are parity forbidden, while the much weaker magnetic dipole transitions are allowed. Inpractice, however, i t turns out that in the observed intraconfigurational emission electric-dipole transitions are often dominant, si nee even a smal I admixture with uneven symmetry to the electronic wave function of 4f shell can cause significant changes in transition probabilities. This admixture can be changed by applying pressure, because it causes the change of energy distance between *4f* and *5d* states, and may also result in a change of host crystal symmetry (e.g. changes of the *cla* lattice parameters ratio, often observed in rhombohedral crystals), causing changes in the admixture coefficient of the odd-parity components of crystal field potential. If in addition the host crystal is a semiconductor, where the valence band or conduction band may be in a relatively small energetic distance from the energy levels of rare earth ion dopant, the transition probabilities can be also influenced by energy transfer processes between the band states and the dopant states.

A more detailed study of this issue was enabled by the support of the Polish Ministry of Science and Higher Education as a reserach project No. N N202 203734 entitled *„The study of the influence of crystalline environment on the probabilities of intraconflgurational transitions of selected rare earth dopants"*, in which I was a principal investigator.

The using of high pressure allows a continuous change of the ion-ion distances in the compressed crystal, and in this way - changes of the crystal field strength experienced by the dopant ion. Besides, applying pressure induces a continuous change of interaction of dopant energy levels with the conduction or valence bands, whose energies shift with pressure much stronger not only than the energy levels of the electrons of the well shielded 4f-shell, but also than the energy levels of the electrons of the much more environment-sensitive 5d-shell [27, 28]. In order to study the influence of the $4f^{n-1}5d$ configuration, the symmetry of rare earth ion dopant surrounding, and the possible effect of interactions between dopant states and band states on 4f - 4f intraconflgurational transition intensities and probabilities I investigated materials, in which the dopant ions were in different symmetries of ligand crystal fields and different bandgap energies. Generally they can be divided into two groups

1) rare earth ions doped dielectrics,
2) rare earth ions doped semiconductors.

Ad.l).

I performed the series of measurements of temperature and/or pressure dependence of absorption, luminescence and luminescence decay times on a group of several types of crystals containing the Yb^{3+} dopant with the $4f^{13}$ electronic configuration of the ground state, and on a gadolinium gallium garnet crystal $Gd_3Ga_50i_2$ (GGG) containing Nd^{3+} dopant with the$4f^4$ electronic configuration of the ground state. The ytterbium-doped materials were the following: gadolinium gallium garnet crystal $Gd_3Ga50i_{2>}$ lanthanide orthophosphate crystals: $YP0_4$, $GdP0_4$ and $LaP0_4$, and ternary lanthanum chloride K_2LaCl_5 in a powder form. In GGG the dopant ions are in the crystal field of dodecahedral symmetry, close to the cubic symmetry: they are surrounded by eight O^{2}" I igands forming a slightly twisted cube with D_2 local symmetry. Among the phosphates $YP0_4$ crystallizes in zircon structure, whereas $LaP0_4$ and $GdP0_4$ crystallizein monazite structure. The dopant ionsin $YP0_4$ are surrounded by eight O^{2}" I igands forming a dodecahedron with $D_{2c}i$ local symmetry, whereas in $LaP0_4$ and $GdP0_4$ the dopant ions are surrounded by nine O^{2}" I igands with Ci local symmetry. As the $LaP0_4$ and $GdP0_4$ crystals have the same crystal structure, I performed the pressure measurements of luminescence and luminescence decay times on $GdP0_4$:Yb and $YP0_4$:Yb only.

The ternary lanthanum chloride K_2LaCl_5 is a powder in which the dopant ions are surrounded by seven Cl" I igands forming a distorted mono-capped trigonal prism with Cs local symmetry. In spite of the interesting results of the dependence of luminescence efficiency and its thermal stability on the ytterbium ions concentration in K_2LaCls powder, I was not able to observe the luminescence of this material after inserting in diamond anvil cell, which is an interesting and worth a thorough examination effect in itself.

High-pressure studies of the luminescence associated with the $^2F_{5/2}$ -» $^2F_{7/2}$ transitions of Yb^{3+} and the decay times of this luminescence in dielectrics revealed the expected very weak pressure dependence of the transition energies accompanied by a much stronger dependence of radiative transitions probabilities, whose pressure dependence was different in different crystals. Theoretical analysis of the obtained results, performed by S. Biernacki for GGG:Yb **[H6],** and previously also for $LiNb0_3$:Yb [25] showed that the observed changes in radiative trasition probabilities are caused by pressure-induced changes of non-centrosymmetric admixture to the electronic wave function that may originate from two sources: approaching the energy of *5d* state to the energy of *4f* state, and the crystal lattice symmetry changes (modification of the crystal lattice distortion and the appearance of the non-centrosymmetric component of crystal field potential). The increase in the non-centrosymmetric admixture to the electronic wave function causes increasing the electric di pol e transi ti ons probabi l i ti es.

The results collected in years 2007 - 2011 for the Yb^{3+} dopant in dielectrics have been published in four articles, in which I am the first author **[H6, H7,** 29, 30]. In my opinion the most interesting and providing much new and important information results are contained in the papers **[H6]** and **[H7].**

In the paper **[H6]** we analyzed the influence of pressure on the energies and probabilities of radiative transitions of Yb^{3+} dopant in GGG. The observed nonmonotonic changes of luminescence decay times in this material we interpreted as the consequence of pressure changes of local symmetry of dopant ion environment, which has a tendency towards cubic symmetry with pressure increasing up to about 70 kbar, and then the symmetry is lowered again if this pressure is exceeded. These changes are accompanied obviously by the continuous pressure decrease in the *5d* configuration energy. Assuming of such a model allowed the theoretical description of the observed phenomena. In order to investigate this problem in more detail I performed pressure measurements of Nd^{3+} dopant in the same crystal matrix, because this ion is known as a symmetry gauge in garnets due to the fact that the number of its luminescence lines depends on the local symmetry of the ion [31].

The splitting of the excited state of the $^4F_{3/2}$ configuration of Nd^{3+} dopant depends on garnet lattice distortion and it disappears in the ideal cubic lattice. As a result, in garnets with perfect cubic local symmetry of the Nd^{3+} ion only three luminescence lines should be observed - i.e. three single lines associated with the transitions from the degenerate excited $^4F_{3/2}$ energy level to each of the three partially degenerate energy levels of the ground $^4I_{9/2}$ configuration [32]. Instead, in the garnets of lower symmetry up to ten luminescence lines are observed - i.e. five doublets associated with the transitions from the split excited $^4F_{3/2}$ energy levels to each of the five lenergy levels of the ground $^4I_{9/2}$ configuration. Indeed, pressure measurements of Nd^{3+} luminescence in GGG showed the disappearance of the luminescence lines splitting at pressures corresponding to the observed maximium of luminescence decay times of the Yb^{3+} ions in this garnet, indicating a change in the crystal symmetry. However, further detailed high-pressure crystallographic studies carried out through collaboration with the group of dr. S. Saxena from Florida International University in Miami and *ab initio* calculations revealed that although the distances between the central Gd^{3+} ion and all surrounding eight O^{2-} ions creating the dodecahedron become approximately equal to each other at pressures about 10 - 12 GPa, the surrounding of the ion is still not cubic. Therefore the local symmetry of the Gd^{3+} ion and the local symmetries of all dopants substituting this ion does not change and still remains the D_2 -type symmetry. These results have been published in Physical Review B **[H9].**

In the paper **[H7]** we described the measurements of temperature and pressure dependencies of luminescence and luminescence decay kinetics in lanthanide orthophosphates, where as already mentioned, the dopant ion can be surrounded by eight O^{2-} ligandsforming a dodecahedron with D_{2d} local symmetry (YPO_4), or by nine O^{2-} ligandswith

Ci local symmetry ($LaP0_4$ i GdPCU). Rare earth orthophosphates, due to their advantageous optical properties and the possibility of relatively easy and cheap growth techniques, have gained increasing attention from the point of view of possible applications of these materials in efficient lighting devices as well as for fundamental studies. The results of my research pointed to the importance of local symmetry of dopant on radiative transitions probabilities. They revealed that more efficient luminescence is obtained by using host crystals with possible high local symmetry of dopant and weak crystal field strength. Both these factors result in lengthening the decay times of the *4f* intraconfigurational transitions, which allows the reduction of optical pumping threshold.

The temperature studies of rare earth phosphates at ambient pressure were part of the M.Sc. thesis entitled *"The study of optical properties of Yb^{3+} dopant in selected rare earth phosphates"* (2009), which I was a supervisor. The results of this thesis obtained by M.Sc. A. Duzyhska have been included in the publication **[H7].**

The results of research on rare earth dopants in dielectrics have been published in total in eight articles and were also presented in the form of sixteen presentations at international conferences, including four invited lectures (two were given by me: see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 31 and 89). Furthermore, they were the main topic of the seminar delivered by me at the Institue of Physics of University of Tartu in Estonia, and also were part of the seminar, which I have presented at the Faculty of Physics of University of Warsaw (see - the annex No. 6, sect. 4, ref. 10 and 11).

Ad.2).

Rare earth ions doped semiconductors are the subject of research due to the unique combination of their optical and electrical properties providing high potential of these materials in new optoelectronic device applications. They are interesting as well from the point of view of fundamental studies. The selection of semiconductors with proper energy gap value and the use of high hydrostatic pressure allows for a kind of controlled "programming" of the rare earth ion interaction with the host band states and thus for the investigations of both the influence of the band states, and the symmetry of the crystalline environment on the dopant ion. Despite the rapid development in this research area, so far there were very few significant publications on this topic [33, 34].

My research on this issue includes two types of $A^{m}B^{v}$ semiconductors doped with the Yb^{3+}ions:

- indium phosphide (InP); the cubic, narrow bandgap and direct bandgap semiconductor (**E_G(1** atm, **300** K) = **1.34** eV), in which the dopant ions are surrounded by four P^{3-} anions forming a tetrahedron with T_d local symmetry; the proximity of the conduction band causes si gni f i cant changes i n the radi ati ve transi ti ons probabi l i ti es, as we! l as an ef f ecti ve thermal quenching due to the „back transfer" type transitions and Auger effect [35, 36, **H8];**
- gallium nitride (GaN); the hexagonal, wide bandgap and direct bandgap semiconductor (**EQ(1** atm, **300** K) = **3.45** eV), in which the dopant ions are surrounded by four N^{3-} anions forming a distorted tetrahedron with $C3_V$ local symmetry; the wider bandgap results in a weaker temperature quenching and obtaining efficient luminescence even at room temperature [37, **H10].**

Performing high-pressure studies of the luminescence and the probabilities of intraconfigurational transitions of the Yb^{3+} ions in indium phosphide matrix I observed surprisingly strong pressure dependence of transition energies in the pressure raised from ambient up to about 6 GPa, accompanied by the increasing luminescence decay time from 10 us to 16 us. The decay time of Yb^{3+} luminescence in InP is much shorter than that observed usually in ionic materials, where they are in the range of 500 - 2500 us [24, 38]. The fit of the theoretical model to the experimental results, described in the paper **[H8]** revealed that the pressure dependence of luminescence up to 6 GPa is determined by the increase in the spin-orbit interaction caused by the pressure-enhanced covalency effects, i. e. the mixing of the Yb^{3+} wavefunctions with those of the surrounding P^{3-} ions.

With further increasing pressure above 6 GPa I observed a distinct reduction in the pressure coefficient and increasing radiative transitions probabilities. In order to explain this effect, additional measurements of pressure dependence of InP absorption edge were carried out, which enabled the determination of the pressure coefficients of conduction band minimum and valence band maximum. The obtained results indicated that the decrease in the pressure dependence of luminescence lines energy above 6 GPa can be explained in terms of an effect of interaction of Yb^{3+} acceptor level with the top of the InP valence band, which approach each other at pressure of approximately 6 GPa. These conclusions were confirmed by *ab initio* calculations using the density functional theory (DFT), carried out within the framework of the cooperation established with theoretical physicist dr M. Brik from Institue of Physics of University of Tartu in Estonia. They have been published in the paper [39].

In comparison to narrow bandgap InP, wide bandgap GaN doped with Yb^{3+} showed relatively stable and efficient luminescence up to room temperature. The high-quality semiinsulating bulk GaN:Mg crystal used for this investigation was grown by dr. M. Bockowski from Unipress using high nitrogen pressure solution (HNPS) method, next implanted in Instituto Tecnológico e Nuclear in Sacavém, Portugal by dr. E. Alves, and then annealed at nitrogen overpressure by dr. M. Bockowski. As a result of such a procedure, we received a sample of high-quality and high-efficiency lighting. The studies of the pressure dependence of luminescence lines energies revealed that both the signs and the values of pressure coefficients were different from those observed in InP:Yb, which is consistent with the expected weak dependence due to the strong screening of the $4f^3$ subshell of the Yb^{3+} ion by its outer filled $5s^2 5p^6$ subshells. Theoretical analysis of the experimental results performed within the crystal field theory by my collaborators from University of Tartu, with fitting the parameters of trigonal crystal field Hamiltonian to the experimental data allowed the determination of the ambient pressure values and pressure dependencies of the Yb^{3+} energy levels, the spin-orbit parameter and crystal field parameters in gallium nitride host crystal. The results of the studies on ytterbium ion doped semiconductors have been published as yet in three publications **[H8, H10,** 39] and presented in the form of ten conference presentations, including two invited lectures (one given by me, see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 91).They were also the main topic of the seminar delivered by me at my home Institue of Physics PAS, and were part of the seminar, which I have presented at the Faculty of Physics of University of Warsaw (see - the annex No. 6, sect. 4, ref. 9 and 11).

During my investigations of properties of rare earth ions doped materials I established a very interesting scientific cooperations with several scientific centers in Poland and abroad, e.g. the collaboration with the group of prof. E. Zych from the Faculty of Chemistry of University of Wroclaw and with the group of prof. M. Bettinelli from Universita Degli Studi di Verona in Italy, who provided me with many interesting crystalline and powder samples, the collaboration with dr E. Alves from Instituto Tecnológico e Nuclear, Sacavem in Portugal, where the implantation of crystals was carried out, and also the collaboration with theoretician dr M. Brik from Institue of Physics of University of Tartu in Estonia, who helped me to carry out a consistent theoretical analysis of my results. On the materials under study I have performed a series of different measurements, such as absorption, luminescence, high-pressure measurements of luminescence and decay kinetics of luminescence, and Raman spectra measurements. All the measurements were performed in the Institue of Physics PAS in Warsaw. In order to measure the absorption spectra of powder samples at ambient pressure and temperature we started a new measurement technique, where the samples were squeezed into the form of parallel flat tablets. The optical absorption spectra were obtained from the scattered transmittance, measured with the use of the special integrating sphere integrated with the spectrophotometer. Another newly used measuring method were high-pressure absorption measurements with use of so called double gasket technique (i.e. steel gasket with a hole drilled, placed between the compressed diamonds, forming a chamber for the sample and pressure gauge). In the case of high-pressure absorption measurements such a gasket consists of two steel layers with coaxial holes of different diameters. The sample of appropriate size is located in the larger hole, while covering the smaller hole into the rear thin gasket, so it can be illuminated via an optical fiber coupled to a broadband light source and the spectra of transmitted light can be collected.

The result of my work on the problem of lanthanide doped materials consists in total of eleven articles published in years 2005 - 2011, where in eight of them I am the first author (including five in Physical Revew B, three in Journal of Physics - Condensed Matter, and one in Journal of Applied Physics), and twenty six conference presentations, including seven invited lectures (three given by me, see - the a nnex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 31, 89 and 91), ten oral presentations and nine posters. Besides I gave three seminars on this subject, including one given abroad (see - the annex No. 6, sect. 4, ref. 9 - 11). I was also the supervisor of one related M.Sc. thesis.

8.2.2 Activity in Other Research Areas

In addition to my research of polar structures of nitride semiconductors I also participated in the study of optical properties of non-polar structures. In collaboration with dr H. Teisseyre from the Institute of High Pressure Physics PAS „Unipress" in W arsaw I performed a series of comparative measurements of GaN/AlGaN quantum wells grown along polar or non-polar crystallographic directions. The results of this interesting study were published in Journal of Applied Physics [40], and they were also presented as the posters at two international conferences (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 52 and 55).

Moreover, beside the main topics of my research concerning structures of nitride semiconductors and rare earths doped materials, I am involved from several years in the studies of other group of wide bandgap semiconductors, namely, zinc and magnesium oxides and their alloys.

Zinc oxide, similarly like gallium nitride, is a promising semiconductor for potential applications in optoelectronic devices working in the blue and ultraviolet spectral range. Many research groups are currently working on optimizing growth techniques of this material, both in the form of bulk crystals, and films or powders, including nanopowders. In addition, a very important issue in designing modern optoelectronic devices is the possibility of growing structures with desired properties, and hence - with controlled parameters of quantum wells and barriers in these structures. For this reason it is important to know and to controll the properties of ZnMgO alloys, which constitute the natural material to obtain barriers for ZnO-based quantum wells.

For these reasons, the study of ZnO and its magnesium alloys, in which I take an active part, can be divided into two main groups:

1) optical studies (pressure and temperature dependencies) and crystallographic studies (pressure studies of structural phase transitions) of pure ZnO bulk crystals, films and powders in order to understand the dependence of their properties on the crystalline form and related strain; the aim of these studies is to compare the stability, bulk moduli and optical properties of different crystalline forms of zinc oxide;
2) optical studies (pressure and temperature dependencies) of films and quantum structures of ZnO/ZnMgO, carried out in collaboration with prof. M. Eickhoff from Justus-Liebig-Universität Giessen and MSc. B. Laumer from Walter Schottky Institut, Technische Universität München in Germany, who grow high-quality ZnO/ZnMgO structures as well

as ZnMgO layers with different magnesium concentrations, up to a content of about 35% of Mg (and higher), when the phase transition occurs from wurtzite structure of ZnO to cubic rock salt structure specific to MgO crystals, and in cooperation with Assoc. Eng. R. Kudrawiec from Wroclaw University of Technology, who performs the measurements of photoreflectance and contactless electroreflectance on these samples, enabling to estimate the absorption edge. The aim of these studies is, apart from determining the composition dependence of ZnMgO energy gap, also to investigate the effects associated with built-in electric fields in ZnO/ZnMgO quantum structures, a consequence of a spontaneous polarization and piezoelectric polarization resulting from the differences in quantum wells and barriers lattice constatns - the phenomena analogous to those observed in the alike wurtzite nitride structures. Analysis of the results of measurements of ZnO/ZnMgO quantum structures will allow for the estimation of influence of internal electric fields on optical properties of structures based on zinc oxide and its alloys with magnesium. In combination with the results of previous studies of nitride structures it will enable to compare the properties of these highly interesting and important materials. These studies are still in progress - so far their results were published in one article [41] and presented at six conferences as three oral presentations and four posters (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 74 - 77, 82, 84 and 90). Recently the next article entitled *„The high-pressure structural* properties of ZnO bulk crystals and nanopowder", authors R. Hrubiak, V. Drozd, A. Duzyhska, H. Teisseyre, W. Paszkowicz, A. Reszka, A. Kamihska, A. Durygin, S. Saxena, J. D. Fidelus, J. Grabis, C Monty, A Suchocki, has been submitted for publication.

Further research problems, in which I have been also involved in recent years, are:

1) high-pressure study of Mn^{4+} dopant in $YA10_3$ perovskite, considered for applications in thermoluminescent dosimetry in the temperature range from 90 to 420 K (results published in Journal of Physics - Condensed Matter in 2006 [42]), and in GGG garnet -presented in the form of the oral presentation (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 19);
2) optical properties of $A^{n}B^{VI}$ -type crystals (ZnS, ZnSe, ZnTe) doped with Cr^{2+} ions, JahnTeller effect observed in these crystals, and the dependence of spin-orbit interaction parameter on the pressure and the type of ligands surrounding the dopant; results of these studies have been published in New Journal of Physics [43], and also presented at five international conferences in the form of one oral presentation and four posters (see - the

annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 30, 37, 38, 54 and 63);

3) studies related to serching for new pressure sensors in the infrared spectral range: good candidates for such sensors occurred to be InAsP/InP quantum structures and yttrium aluminium garnet crystal doped with neodymium ions ($Y_3Al_5O_{12}:Nd^{3+}$). Both these materials revealed very efficient luminescence consisting of narrow lines, which is a very advantageous feature because of the lower probability of overlap the luminescence of materials studied with the used pressure sensor luminescence. The results of these studies were published in one article [44], and also were presented at two international conferences (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 41 and 56);
4) optical properties of CdTe and CdMnTe quantum dots in ZnTe matrix and their pressure dependence: these structures are very interesting both for fundamental studies (interesting and new physics of occurring effects), and with recpect to their existing and potential applications (in optical filters, high efficiency lasers, inorganic fluorescent markers for applications in biology and medicine). The obtained results have been published so far in one article [45] and presented as two conference posters (see - the annex No. 6 entitled: "List of Published Scientific Papers and Creative Professional Works", sect. 3, ref. 64, 86 and 87).

8.2.3 The Other Achievements

Apart from research activities, in the years 2005 and 2006 I participated in the organization of two serial conferences "XXXIV International School on the Physics of Semiconducting Compounds - Jaszowiec 2005" and "XXXV International School on the Physics of Semiconducting Compounds - Jaszowiec 2006", which I was the secretary. The institutions co-organizing these conferences were: the Institute of Physics PAS, the Faculty of Physics of Warsaw Univeristy, the Committee on Physics PAS, the Institute of High Pressure Physics PAS "Unipress", and the Foundation "Pro Physica". They have been held annually in Ustroń-Jaszowiec (in recent years - in Krynica-Zdrój), and for many years they have been the most important meeting of physicists and engineers involved in the solid state physics in Poland, and from at least several years they have been also one of the most important scientific events gathering semiconductor physics community from the countries of the Central and Eastern Europe and from many other countries. At the conferences co-organized by me attended over 230 participants from several countries worldwide each time. The conference proceedings containing the texts of invited papers and and original works have been published in the four numbers of *Acta Physica Polonica A,* which I was co-editor.

Moreover, in 2007 I took part in XIth Warsaw Festival of Science, the annual event held in September, aiming to popularization of science in the society. At this Festival I presented a popular scientific lecture entitled *"Journey to the Center of the Earth or High Pressure in Nature and Scientific Research".*

Since 2007 I have led students' laboratory as a second lab for fourth year students of the Faculty of Mathematics and Natural Sciences of Cardinal S. Wyszyński University. Two of those students afterwards have prepared and defended their M.Sc. theses under my supervision.

8.3. Summary

My several years of involvement in research carried out in the Group of High Pressure Spectroscopy (up to January 2012: Group of Spectroscopy and Non-Linear Optics) of Division of Physics and Technology of Wide-Band-Gap Semiconductor Nanostructures (up to January 2012: Division of Solid State Spectroscopy) of Institute of Physics PAS, led to many interesting scientific results, which have been published in 52 publications, including 45 in peer-reviewed journals from the JCR list. They were also presented in the form of 94 presentations at numerous scientific conferences in Poland and abroad.

Obtaining these often unique results was made possible by:

a) access to high-quality samples grown straightway in the Institute of Physics PAS in Warsaw (prof. M. Berkowski, prof. A. Mycielski, prof. G. Karczewski) or received within the established domestic collaborations (the Institute of High Pressure Physics PAS "Unipress" and a number of foreign institutions cooperating with "Unipress", the Faculty of Chemistry of University of Wroclaw), as well as foreign cooperation (Universidad Autónoma de Madrid, Spain, Universita Degli Studi di Verona, Italy, Walter Schottky Institut, Technische Universität München, Germany),

b) learning and development of various optical measurement techniques (temperature measurements of absorption, luminescence and luminescence decay kinetics - IP PAS in Warsaw), magneto-optical measurement technique (Grenoble High Magnetic Field Laboratory, France), with particular emphasis on diamond anvil cell technique, enabling high-pressure measurements of absorption, luminescence and luminescence decay kinetics at temperatures from 10 K to 300 K. At the beginning of my PhD study in the former laboratory of the Group of Spectroscopy and Non-Linear Optics, there was the only one DAC, allowing for achieving pressures up to approximately 18 GPa, and besides dr. J. Dmochowski, who left the work about the year 2000,1 was the only person dealing with this type of measurements. Currently, in the same laboratory there are three DACs for measurements at pressures up to about 35 GPa. Apart from my PhD thesis, using this technique two further PhD theses have been executed, and two another are currently in progress. The advisor of all of these theses was prof, dr hab. A. Suchocki, however all the PhD students learned the high-pressure measurements technique with my help. Recently we are also working on running high-pressure transport measurements - this work is currently nearing completion,

c) modeling and theoretical analysis of obtained experimantal data, possible to perform to a large extent through collaboration with theoreticians from IP PAS (dr hab. S. W. Biernacki, prof. R. Buczko), as well as with theoreticians from other scientific centers in Poland (prof. I. Gorczyca, prof. M. Grinberg) and abroad (prof. N. E. Christensen, dr A. Svane, dr. M. G. Brik).

All these collaborations are still maintained and allow for hope for the continuing development of research topics, as well as getting further interesting and precious scientific results.

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