Department of Experimental Physics

Faculty of Fundamental Problems of Technology

Wroclaw University of Science and Technology

Dr. Marcin Syperek

AUTOREFERAT

PREPARED FOR THE PURPOSE OF OBTAINING THE HABILITATION DEGREE.

Table of contents

1 Characteristic of Candidate

1.1 Name

Marcin Syperek

Date of Birth: 11th February 1979

1.2 Scientific and professional titles and degrees

2008.09	Ph. D. in physics, Wroclaw University of Science and Technology Thesis: “Electron and hole spin coherence in confined semiconductor structures.” 1st Advisor: Prof. Dr. hab. Jan Misiewicz (WrUST) 2nd Advisor: Prof. Manfred Bayer (TU Dortmund)
2004.10	M. Sc. Eng. Solid State Physics, Wroclaw University of Science and Technology. Thesis “Spektroskopia fotoodbiciowa warstw epitaksialnych GaN, AlGaN oraz heterostruktur AlGaN/GaN” (“Photoreflectance spectroscopy of GaN, AlGaN and AlGaN heterostructure epitaxial layers”) Supervisor: Prof. Dr. Hab. Jan Misiewicz

1.3 Course of employment during professional career

2011.09 – present	Assistant Professor at Faculty of Fundamental Problems of Technology, Department of Experimental Physics, WrUST;
2008.09-2011.09	Scientific-didactic Assistant at Faculty of Fundamental Problems of Technology, Department of Experimental Physics, WrUST;
2008.10-2011.08	Assistant at Faculty of Microsystem Electronics and Photonics employed for the purpose of POIG project;
2005.01-2008.08	Internship at Technical University Dortmund (Germany) in Experimentalle Physik II group of Prof. Manfred Bayer;

1.4 Bibliometric data regarding scientific achievements as per 17.06.2018

Data from Web of Science Core Collection database.

Number of publications: **71**

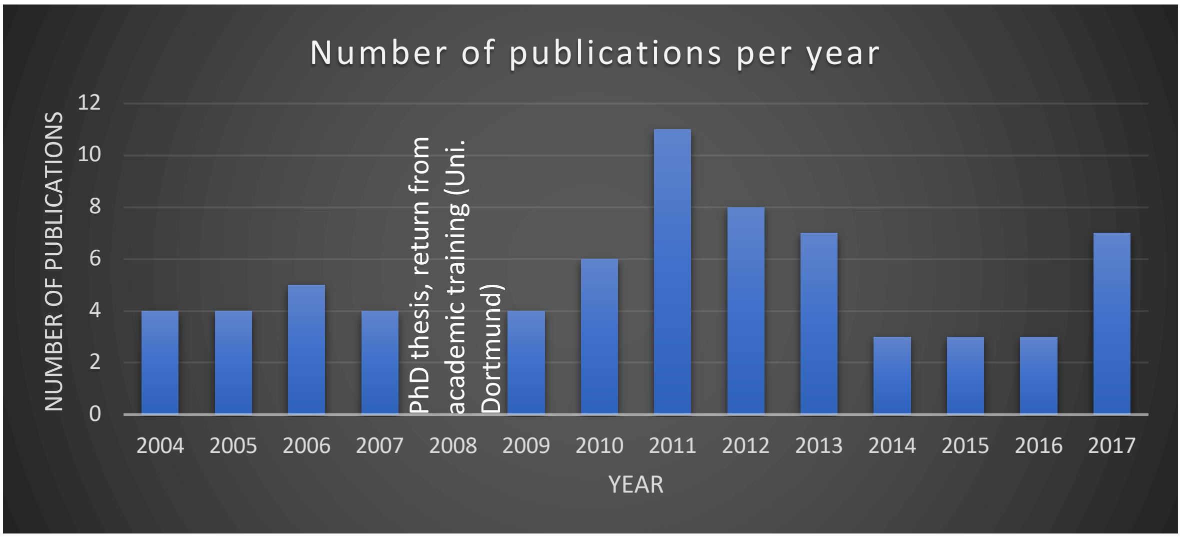
Number of citations: **609**

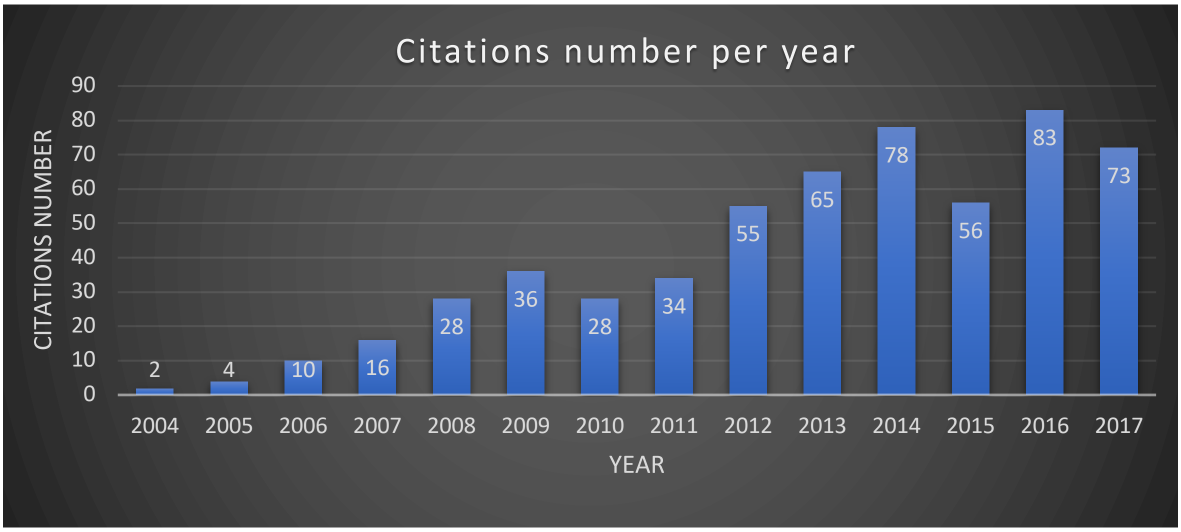
Number of citations without selfcitations: **537**

Average citation per article: **8.58**

Total *Impact Factor* according to Journal Scitation Reports (JCR): 159.693[1*)]

Hirsch Index: **14**





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[1] *) As in the year of publication.

2 Summary of scientific achievements (according to requirements of art. 16 sec. 2 act of 14 march 2003 on scientific degrees and the scientific title and on degrees and the title in the field of art (Dz. U. 2016 r. poz. 882 ze zm. w Dz. U. z 2016 r, poz. 1311.)

2.1 Title of scientific achievement

The scientific achievement, as mentioned in art. 16 sec. 2 of the Act, is series of 9 publication under joint title:

“Dynamics of inter- and intraband relaxation of charge and spin in quasi-zero-dimensional III-V semiconductor compounds”

2.2 List of publications forming the scientific achievement

<table>
<tr><th>#</th><th>Authors, title, journal, year of publication</th><th>Input</th><th>IF[1]</th><th>Ministry points</th></tr>
<tr><td>[H1]</td><td>M. Syperek, Ł. Dusanowski, J. Andrzejewski, W. Rudno-Rudziński, G. Sęk, J. Misiewicz, and F. Lelarge <i>„Carrier relaxation dynamics in InAs/GaInAsP/InP(001) quantum dashes emitting near 1.55 µm”</i> Applied Physics Letters 103, 083104 (2013).</td><td>55%</td><td>3.515</td><td>40</td></tr>
<tr><td colspan="5">My input in [H1] was planning spectroscopic studies, performing measurements of transition reflectivity, participation in the interpretation of data, and writing the first version of the manuscript.</td></tr>
<tr><td>[H2]</td><td>M Syperek, Ł. Dusanowski, M. Gawełczyk, G. Sęk, A. Somers, J. P. Reithmaier, S. Höfling, J. Misiewicz <i>“Exciton spin relaxation in InAs/InGaAlAs/InP (001) quantum dashes emitting near 1.55 µm”</i> Applied Physics Letters 109, 193108 (2016).</td><td>50%</td><td>3.124</td><td>40</td></tr>
<tr><td colspan="5">My input in [H2] was planning of the experimental part of spectroscopic studies, in part measuring of carrier and spin dynamics, preliminary interpretation of the results, and writing the first version of the manuscript.</td></tr>
<tr><td>[H3]</td><td>M. Gawełczyk, M. Syperek, A. Maryński, P. Mrowiński, Ł. Dusanowski, K. Gawarecki, J. Misiewicz, A. Somers, J. P. Reithmaier, S Höfling, and G. Sęk <i>”Exciton lifetime and emission polarization dispersion in strongly in-plain asymmetric nanostructures”</i> Physical Review B 96, 245425 (2017).</td><td>35%</td><td>3.736</td><td>35</td></tr>
<tr><td colspan="5">My input in [H3] was planning spectroscopic experiments, measuring time-resolved dynamics, preliminary interpretation of the results, and writing the very first version of the manuscript.</td></tr>
<tr><td>[H4]</td><td>M. Syperek, J. Andrzejewski, E. Rogowicz, J. Misiewicz, S. Bauer, V. I. Sichkovskyi, J. P. Reithmaier, and G. Sęk <i>”Carrier relaxation bottleneck in type-II InAs/InGaAlAs/InP(001) coupled quantum dots-quantum well structure emitting at 1.55 µm”</i> Applied Physics Letters (2018).</td><td>60%</td><td>3.411</td><td>40</td></tr>
<tr><td colspan="5">My input in [H4] was planning spectroscopic experiments, measuring time-resolved dynamics, participating in interpretation of the results, and writing the first version of the manuscript.</td></tr>
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[1] IF – Impact Factor in the year of the publication

[H5]	**M. Syperek**, R. Kudrawiec, M. Baranowski, G. Sęk, J. Misiewicz, D. Bisping, B. Marquardt, A. Forchel, and M.Fischer, *„Time resolved photoluminescence of In(N)As quantum dots embedded in GaIn(N)As/GaAs quantum well”*, Applied Physics Letters **96**, 041911 (2010).	48%	3.82	40
My input in [H5] was planning spectroscopic experiments, measuring time-resolved dynamics, participating in interpretation of the results, and writing the first version of the manuscript.				
[H6]	**M. Syperek**, P. Leszczyński, J. Misiewicz, E. M. Pavelescu, C. Gilfert, D. Bisping, and J. P. Reithmaier *„Time-resolved photoluminescence spectroscopy of an InGaAs/GaAs quantum well-quantum dots tunnel injection structure”*, Applied Physics Letters **96**, 011901 (2010).	65%	3.82	40
My input in [H6] was planning and performing all optical spectroscopy experiments, proposing the first theoretical concept for interpretation of the results and writing the first version of the manuscript.				
[H7]	**M. Syperek**, M. Baranowski, G. Sęk, J. Misiewicz, A. Löffler, S. Höfling, S. Reitzenstein, M. Kamp, and A. Forchel *“Impact of wetting-layer density of states on the carrier relaxation process in low indium content self-assembled (In,Ga)As/GaAs quantum dots”* Physical Review B **87**, 125305 (2013).	54%	3.664	35
My input in [H7] was planning and performing all optical spectroscopy experiments, proposing the theoretical concept for interpretation of the results and writing the first version of the manuscript.				
[H8]	**M. Syperek**, D. R. Yakovlev, I. A. Yugova, J. Misiewicz, M. Jetter, M. Schulz, P. Michler, and M. Bayer *„Electron and hole spins in InP/(Ga,In)P self-assembled quantum dots”* Physical Review B **86**, 125320 (2012).	50%	3.767	35
My input in [H8] was performing all experiments, participating in interpretation of the results, and summarising them in the preliminary version of the manuscript.				
[H9]	**M. Syperek**, J. Andrzejewski, W. Rudno-Rudziński, G. Sęk, J. Misiewicz, E. M. Pavelescu, C. Gilfert, and J. P. Reithmaier *„Influence of electronic coupling on the radiative lifetime in the (In,Ga)As/GaAs quantum dot–quantum well system”* Physical Review B **85**, 125311 (2012).	52%	3.767	35
My input in [H9] was planning and performing all experiments, except for modulated reflectivity, proposing the theoretical concept for interpretation of the results, and writing the first version of the manuscript.				

2.3 Description of the purpose of scientific achievement, the most important results, and determination of their significance for development of the discipline and knowledge

In order to perform research specified in the scientific achievement, it was necessary to create a set of experimental tools, which was not earlier available in the Laboratory for Optical Spectroscopy of Nanostructures (LOSN) at the Faculty of Fundamental Problems of Technology (FFPT) at Wroclaw University of Science and Technology (WrUST), where the research took place. Four measurement setups (**U1-U4**) have been installed for the purpose of research on time-resolved and time-integrated emission and absorption in the 0.27-3.5 μm spectral range. The central part of all setups is a set of pulse lasers able to generate ~140 fs or 2-5 ps long optical pulses, with the repetition frequency of ~76 MHz or lower:

- **U1.** Setup for time-resolved and time-integrated photoluminescence measurements with detection based on a streak camera apparatus with the S20 photocathode in the spectral range of 0.2-0.85 μm and with the maximum time resolution of ~2 ps;
- **U2.** Setup for time-resolved and time-integrated photoluminescence measurements with detection based on a streak camera apparatus with the S1 photocathode in the spectral range of 0.3-1.6 μm, with quantum efficiency optimised for the 0.3-1.1 μm spectral range, with the maximum time resolution of ~2 ps;
- **U3.** Setup for time-resolved and time-integrated photoluminescence measurements based on a prototype device with the InP/InGaAs photocathode cooled down to -100 °C, with quantum efficiency optimised for the near infrared spectral range 1-1.65 μm and the maximum time resolution of ~20 ps;

U4. Setup for time-resolved (transient) reflectivity/transmission in the pump-probe configuration operating in the near- and mid-infrared range (0.4-3.5 μm) with a temporal resolution limited by the pulse duration.

Setups **U1** and **U2** at the time of their launch (2009) were unique in the scale of the country due to application of streak cameras. Setup **U3** consists of a prototype device (streak camera) with the exceptional spectral range of 1.00-1.65 μm. The special feature of the **U4** setup is high sensitivity for registered signals of transient reflectivity ($\Delta R/R \sim 10^{-4}$-10^{-5}) and transmission in the near- and mid-infrared spectral range ($\lambda > 1$ μm), which is an advantage due to a typically low intensity of measured signal. As far as the **U1** to **U4** setups are currently part of experimental equipment of the LOSN (http://osn.pwr.edu.pl), the **U5** setup described below has been adapted from the existing setup for time-resolved Kerr rotation and prepared to perform experiments in the spectral range between 500 nm and 700 nm. The **U5** setup was based on similar components as the **U4** setup and was located in the laboratory of Prof. Manfred Bayer - Experimentalle Physik II at Technical University Dortmund, where the author was performing experiments during an internship in 2011.

Application of the specified spectroscopic tools, especially time-resolved spectroscopy experiments, alongside with spectroscopic data obtained by other optical methods and theoretical modelling allowed achieving **the main goal of the research work related to determination of kinetics of optical processes in considered quantum nanostructures, but also allowed finding the character of interactions accompanying optical excitation modified by spatial confinement and ambient conditions.**

Research was performed on epitaxial quasi-zero-dimensional objects called quantum dots (QDs), in which the electrostatically-(Coulomb-)correlated electron and hole pair (an exciton) is bound in a three-dimensional confining potential determined by material properties of an object, its physical dimensions and the closest surrounding. Ever since the beginning of nanostructure manufacturing, there is need to search for specific physical and chemical parameters of QDs with regard to their device application, as well as towards the observation of specific phenomena, which are impossible to observe in more typical and commonly examined nanostructures. This research may lead to intentional and unintentional modification of QDs and their environment, which may determine observed relaxation dynamics of the charge and spin state.

In subsection 2.3.1 there are shown the results of research on interband exciton relaxation in InAs QDs, strongly elongated in one of the in-plane spatial direction, embedded in InAlGaAs or InGaAsP matrices, and grown by molecular beam epitaxy on InP(001) substrates **[H1, H2, H3]**. Quantum objects elongated in the growth plane are, due to their shape, often called quantum dashes (QDashes). They are used as a gain medium in lasers and optical amplifiers [1-3], as well as single photon sources for quantum cryptography in schemes of quantum information processing [4, 5, 6, 7]. These objects show specific properties of emission kinetics related to the energy structure of strongly elongated QDs and Coulomb correlations between an electron and a hole. In order to reveal the influence of these correlations, e.g. on intraband carrier relaxation, the research results will be discussed with correspondence to other, obtained for a classical system consisted of more "typical" self-assembled (In,Ga)As **[H6, H9]** or InAs **[H5]** QDs embedded in the GaAs matrix, and further compared with the results of experiments performed on nearly symmetrical in the growth plane InAs QDs **[H4]** embedded in the InAlGaAs matrix, grown on an InP(001) substrate.

Modification of the QD band structure, leading to the change of spatial confinement, may also influence intraband relaxation of an excitation. Key results of research regarding this issue for strongly elongated InAs QDs embedded in InAlGaAs or InGaAsP barriers have been presented in **subsection 2.3.2.** The parameters of intraband carrier relaxation in these quantum objects **[H1]** were compared to those obtained for symmetrical InAs QDs embedded in InAlGaAs matrices, grown on an InP(001) substrate **[H4]**, on which there is almost no available literature data.

The intraband carrier relaxation does not need to be determined solely by parameters related to the quantisation of energy levels in confining potential of a quasi-zero-dimensional object. Such relaxation can also be defined by local and non-intentional surrounding of QDs. **In subsection 2.3.3** there are discussed research results on intraband exciton relaxation in strongly elongated (In,Ga)As QDs embedded in the GaAs matrix **[H7]**. These objects have been designed for obtaining strong light-matter coupling in optical microcavities.[20] Optimisation of (In,Ga)As/GaAs QDs parameters for the purpose of reaching the strong coupling regime has resulted in creation of objects in which the exciton is weakly confined in quantum dot's potential (the range of weak spatial confinement), but also in non-intentional generation of trap states in the wetting layer (WL), on which the dots are naturally deposited in the Stranski-Krastanow growth mode. Quasi-discrete character of density of states of this nominally two-dimensional (2D) WL significantly modifies relaxation of an excitation to quantum dots, as well as the interband carrier relaxation itself, and this dependence is strongly related to the temperature and the ratio between the density of localised states in the WL to the density of QDs.

The unintentional modification of QDs' surrounding is usually an undesired effect because of its weak control, however, the intentional modification may lead to interesting phenomena, such as resonant or non-resonant carrier transfer between neighbouring potentials. **In subsection 2.3.4** there are shown results of research on intra- and interband carrier relaxation in the system of InAs/GaAs QDs coupled to an (In,Ga)As QW by a thin GaAs barrier **[H6, H9]** and intraband carrier relaxation for a system of InAs/InAlGaAs QDs coupled to an (In,Ga)As QW **[H4]**. It turns out that in the mentioned prototype system already proposed for the active area of fast modulated QD-based lasers, presence of a QW may cause change in the character of the fundamental transition of the entire system. The observed emission kinetics leads to a conclusion that for defined parameters of the coupled system, the fundamental electron state can be strongly decoupled from the QD potential. Moreover, coupling between the QW and QDs may significantly modify parameters of intraband carrier relaxation and lead to its slow down as compared to the relaxation in a system consisted of QDs only.

In subsection 2.3.5 there are described research results on coherent relaxation of spin excitation in InP/(Ga,In)P QDs **[H8],** in which holes are only weakly spatially confined in a dot, and InAs/InAlGaAs QDashes **[H2],** in which the spin excitation is formed in the regime of intermediate spatial confinement for an exciton (between strong and weak). In the case of QDs, there is shown how important is the role of the lack of isolation of a spin state on the coherent dynamics of the hole spin. In the case of QDashes, the importance of initialisation of a spin state on the spin memory effect and its subsequent evolution is raised.

2.3.1 Interband relaxation of an exciton in strongly elongated, asymmetric InAs quantum dots on InP(001) substrate

Strongly elongated, asymmetric in the growth plane, quantum dots made of the InAs/InP(001) material system are a competitive solution to QWs in the active area of semiconductor lasers and optical amplifiers operating in the second (1.26-1.36 µm), third (~1.53-1.565 µm), and fourth (1.565-1.625 µm) transmission window of silica fibres. Moreover, the range of applications of these objects can be expanded to single photon [4, 5, 6] and polarisation-entangled photons pair [7] sources, which are of the key importance for developing of quantum-secured communication in silica-fibre-based systems [8, 9] It has been thought that physics of well-known QDs made of InAs and/or GaAs can be directly translated, by many analogies, to the system of InAs QDs grown on InP. The results of research proved otherwise, mainly because of significant differences, e.g. in size of objects, their symmetries, and existing strain (Fig. 2.1). Self-assembled InAs QDs grown by Stranski-Krastanow method on the GaAs substrate are small and almost symmetric in the growth plane because of high strain (~7% difference in the lattice constant between InAs and GaAs). For combination of InAs and InP materials, and by using InP lattice-matched multi-compound barrier materials (InAlGaAs, InGaAsP, InAlAs) maximal difference in the lattice constants is ~3%. Strain relaxation together with anisotropy of atom diffusion on the surface leads to growth of large and often highly asymmetric objects in the Molecular Beam Epitaxy (MBE) or Metalorganic Vapour Phase Epitaxy (MOVPE) growth technology (compare Fig. 2.1).

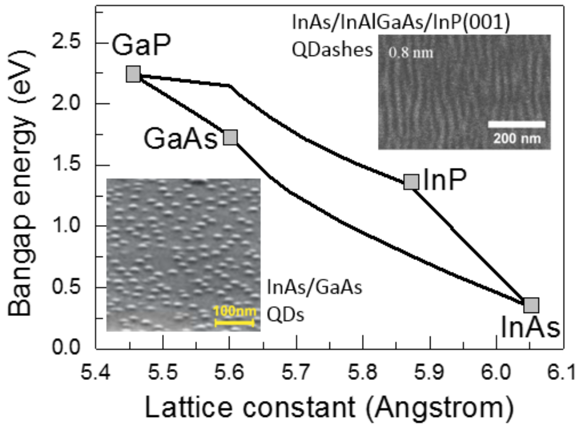


Figure 2.1. Lattice constants of III-V materials and images of surfaces illustrating typical quantum objects manufactured in the epitaxial process – InAs QDs on GaAs substrate (bottom) **[H5,H6]** and strongly elongated InAs QDs (top) on the InAlGaAs barrier matched to InP(001) **[H2,H3]**.

Differences between InAs/GaAs **[H5, H6]** and InAs/InP **[H1, H2, H3]** material systems are not limited to geometry and size of quantum objects. While band discontinuity of the InAs/GaAs material system provides deep binding potential for an electron, in the InAs on InP it usually depends on the selection of a suitable barrier material lattice-matched to InP. These factors shift the correlations within the electron-hole pair in the InAs/GaAs QD and InAs/InP QD towards completely different regimes of spatial confinement [10]. Subsequently, it leads to modification of parameters such as a dipole moment of optical transition, polarisation of emitted photons, and the oscillator strength, and so the lifetime of an electron-hole pair. **[H2, H3]** The latter issue, i.e. parameters of radiative interband recombination in strongly elongated InAs/InP QDs had not been earlier thoroughly researched, which was an inspiration for undertaking efforts and research projects in this area.

Research on interband exciton relaxation in these objects, emitting in the third telecommunication window, began in 2013 **[H1]**. Structures for the research, consisting of strongly elongated InAs/$Ga_{0.2}In_{0.8}As_{0.4}P_{0.6}$/InP(001) QDs, were supplied by Dr. Francois Lelarge from III-V Lab in Marcoussis in France. The experiment required building of the new setup **U4** and modification of the **U3** setup by adding state-of-the-art detectors based on a superconductor, capable of registering single photons and applying the time-correlated single photon counting technique. One of the results of performed experimental work was the first determination of value of the *effective radiative recombination lifetime of an exciton* confined in the ground state of asymmetric $InAs/Ga_{0.2}In_{0.8}As_{0.4}P_{0.6}/InP(001)$ QD of nearly 1.75 ns at ~1.55 µm emission wavelength. This parameter was obtained in the pump-probe experiment using transient reflectivity with the resonant optical pumping. The parameters of interband exciton relaxation have been confirmed in time-resolved photoluminescence (Fig. 2.2.). Correspondence of results of both experiments suggested that effects of intraband relaxation and non-radiative transitions do not influence significantly the obtained parameters of interband transitions and these values can be identified as a radiative lifetime of a neutral exciton in the ground state of the system.

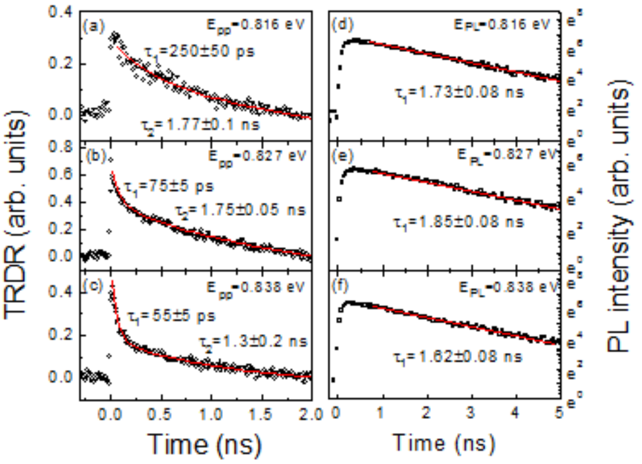


Figure 2.2. (a)-(c) Dynamics of intra- and interband relaxation measured on a set of strongly asymmetric $InAs/Ga_{0.2}In_{0.8}As_{0.4}P_{0.6}/InP(001)$ quantum dots in a pump-probe experiment using time-resolved reflectance for different detection energy (E_{pp}). **(d)-(f)** Dynamics of interband relaxation measured in time-resolved photoluminescence in configuration with time correlated single photon counting **[H1].**

From the viewpoint of system engineering of highly asymmetric QDs, the value of obtained interband relaxation is of the key importance for the laser device and is especially important for proper modelling of laser parameters based on such solution in their active area. Among important laser parameters, which are determined by the lifetime of an electron-hole pair, are threshold current density, and characteristic temperature [28, 29, 30]. Until now, little was known about the actual meaning of experimentally obtained interband relaxation time, where it comes from, and how the exciton lifetime depends on the size of the object, and what its characteristic spectral (energy) dispersion is.

In the year 2016 in **[H2]** results have been shown, which shed some light on physical processes of observed interband exciton relaxation in strongly elongated InAs quantum nanostructures grown on InP. The main subject was examining such system towards its application in an optically addressed spin memory (discussed in subsection 2.3.5). Also, the time evolution of emission from exciton states has been investigated. Spatial anisotropy of exciton confining potential, resulting from the object's shape, and additional anisotropies resulting from distribution of strain, chemical content, or existence of asymmetry of an elementary cell of the crystal lattice, cause the four-fold degeneracy of an exciton ground state. The two of these four new states, so called bright states, are possible to observe in emission experiments. In the system of certain anisotropy, these two bright excitonic states should result in generation of photons of linear light polarisation, but perpendicular to each other. In the experiment performed on a single QDash it has been observed [4, 5] that polarisation of these two states is not strictly linear, but rather elliptical, which in consequence gives non-zero degree of linear polarisation reaching up to a few dozen of percent.**[H2]** The reason for observing elliptical polarisation (significant value of linear polarisation) lies in the structure of the valence band (mixing of heavy and light hole states) influencing parameters of the exciton transition. Because of dense ladder of states in the valence band in strongly elongated QDs **[H1, H3]** the wavefunction of an exciton does not consist solely of electron and heavy hole wavefunctions, but also comprises little, but significant, admixture of the light hole state. In typical, “small” and almost symmetric InAs/GaAs QDs, the heavy and light holes are strongly separated in energy, and the exciton can be described as a heavy-hole-like. The consequence of hole states mixing in the valence band in a strongly asymmetric QD at its ground state is observation of two separated exciton states not only of elliptical polarisation, but also of different oscillator strengths, having two different exciton lifetimes. This effect, for the discussed strongly elongated QDs, was observed and published for the first time in **[H2]**. The results pave the way for further research on this topic, which in consequence led to publication of **[H3]**.

In **[H3]** there has been shown a theoretical model regarding polarisation properties and exciton lifetimes for strongly elongated InAs/$Al_{0.24}Ga_{0.23}In_{0.53}As$/InP(001) QDs. This model has been confronted with experimental data obtained in the **U3** setup regarding degree of polarisation and emission lifetimes registered for strongly asymmetric nanostructures. These nanostructures have been supplied by technological partner from University of Würzburg in Germany (Laboratory of Prof. Sven Höfling) and were able to emit, dependent on the sample and mean size of the quantum object, in a broad spectrum range between 1.2-1.6 μm, which gave possibility of observation of spectral dispersion of polarisation and exciton lifetimes. Analysis of experimental data has shown that emission from the ground state of the quantum objects has two components, which closely match theoretical predictions. One of the components has a characteristic decay time nearly 1 ns and has weak energy dispersion, while the second one has almost 2.5 times longer lifetime, and its value changes with lowering of energy of the ground state in quantum dashes (Fig. 2.4). The results have been confirmed by the candidate on other structures, also characterized by the strong shape asymmetry, with different morphology, and originating from different suppliers, with which the candidate is collaborating (Prof. J. Faist, ETH Zurich, Prof. J. P. Reithmaier, University of Kassel).

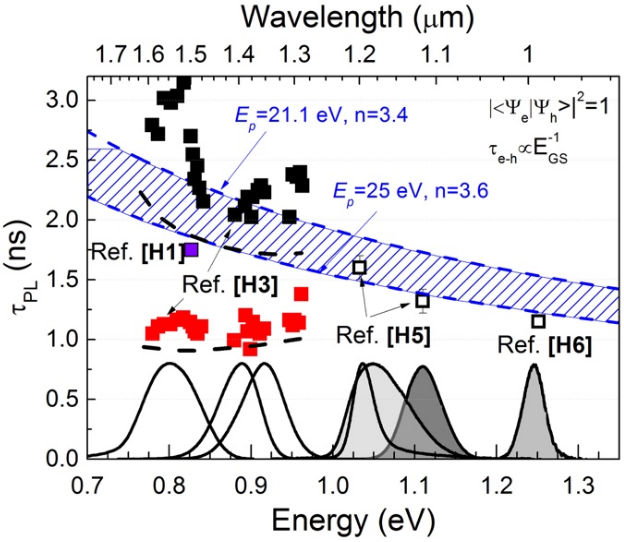


Figure 2.4. Dispersion of interband exciton relaxation (τ_{PL}) as a function of the emission energy for InAs/GaAs QDs (open points) **[H5, H6]**, and InAs/InAlGaAs/InP(001) QDashes (red and black points) **[H3]** and InAs/InGaAsP/InP(001) QDashes (violet point) **[H1]**. Blue dashed area is a range of τ_{PL} parameters for an exciton in the strong confinement regime. Dashed black lines represent dispersion of τ_{PL} parameters for QDashes, where the exciton is in the intermediate confinement regime.

The results published in **[H3]** have more general implications, which was noticed by the reviewers, as well as editorial team of Physical Review B, where the article received the „Editors’ Suggestions” distinction. The results are important for understanding exciton dynamic and character of the emission process for interband transitions in quantum objects characterized by the intermediate confinement regime. Generally, the observed effect should be visible for QDs not only made of III-V elements, but also from different material groups, where an exciton is in the intermediate confinement regime, and where the exciton wavefunction is affected by the intermixed hole states. Asymmetry of confining potential of a quantum object may lead to enhancement of the effect. Existence of said effect had been signalled earlier in the four wave mixing experiment in

(In,Ga)As/GaAs[31] and InAs/InP(311)B QDs[32]. However, such significant effect observed in the time-resolved photoluminescence experiment for asymmetric InAs/InP(001) QDashes had been observed for the first time. It is worth mentioning that for symmetric in growth plane and smaller InAs QDs grown on the InP substrate emitting at 1.55 µm range **[H4]**, no similar emission from recombination of exciton state has been found, which seems to be typical only for relatively large quantum objects, often with asymmetry of confinement potential.

Apart from fundamental physical value, examination of interband relaxation in large and asymmetric InAs nanostructures grown on InP substrate is of great importance for applications of these quantum objects in lasers and optical amplifiers working in the ranges of the second, third and fourth telecommunication windows. Demonstration of the character of the ground state as a combination of two states of different emission parameters creates significant complications for designing and modelling devices based on such objects, but also gives possibilities of omitting technological problems resulting from this fact. For example, above mentioned technology group from University of Kassel, while manufacturing and characterising lasers and optical amplifiers, has observed anisotropy of device parameters, such as threshold current, or modulation speed as a function of geometry of layout of quantum dashes within the resonance cavity, which partially can be explained by observed effects being results of research of the candidate. Such effects can also have significant relevance for application of a QDash in a single-photon generators. Proper layout of emitter geometry regarding the cavity mode can lead to strengthening or weakening of Purcell effect, and therefore let control speed of single-photon emission.

2.3.2 Intraband relaxation of an electron and a hole in nearly symmetric and strongly elongated InAs quantum dots on InP(001) substrate

Intraband carrier relaxation is an important element determining the efficiency of filling the ground state with carriers. For QDs made of the InAs/InP material system, it is especially important from the viewpoint of modulation frequency of lasers and optical amplifiers dedicated for mid- and long-range silica-fibre-based communication.[28, 29, 30] Knowledge on intraband carrier relaxation in strongly elongated QDs can be crucial for understanding of relaxation mechanisms in quasi-zero-dimensional potentials in general. In literature parameters of intraband carrier relaxation in InAs QDashes embedded in the InGaAsP barrier and InAs QDs immersed in the InGaAlAs barrier, both grown on the InP(001) substrate, had not been determined. In the case of applying ultrafast optical spectroscopy for obtaining parameters of intraband carrier relaxation in such objects, the main difficulty is the spectral range (near infrared), required temporal resolution (<1 ps), and low nominal signals of optical response.

Examining intraband carrier relaxation in InAs QDs grown on the InP(001) substrate gives general argument to the discussion on mechanisms and relaxation kinetics in self-assembled QDs. In the literature, despite a few decades for which QDs have been manufactured, relaxation mechanisms are still not well known. Based on present literature data, it is still difficult to obtain a coherent image of carrier relaxation. In this context there is still unclear e.g. the role of phonon mechanism and controversies with existence, or not, of so called phonon bottleneck, heavily related to intraband quantisation in QDs.

In the candidate research on intraband carrier relaxation, the main experimental method which was used is that based on measurement of time-varying reflectivity in the pump-probe setup configuration scheme (the **U4** setup). The results have been partially shown in figure 2.2 (a)-(c) **[H1].** In the experiment, photon energy in pump and probe pulses were equal. Therefore, the process of photo-creation of electron-hole pairs in a given state in a QDash was instantaneous, and depopulation of addressed state, as a result of existence of intra- and interband relaxation, is visible in time decay of the probe beam intensity. During the experiment it was possible to register interband relaxation time, characterized by the time constant of ~1.75 ns, as mentioned in the subsection 2.3.1. However, there was also a second, short living component of the transient reflectivity signal, ascribed to the process of intraband relaxation. Moreover, the time constant characterizing this component changes from 40 ps for the high photon energy in the pulse, to almost 250 ps when the lower energy states in QDash were addressed.

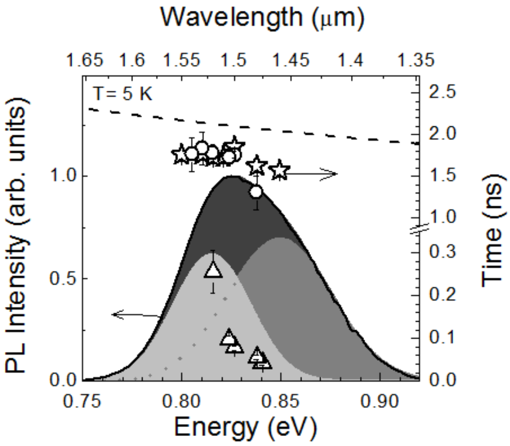


Figure 2.5. The photoluminescence emission band from strongly elongated InAs/$Ga_{0.2}In_{0.8}As_{0.4}P_{0.6}$/InP(001) QDs (grey colour). Parameters related to the intraband relaxation process are marked as triangles, whereas those related to interband relaxation are depicted as stars. (stars - time-resolved photoluminescence, circles and triangles – transient reflectivity experiment). **[H1]**

So called dispersion of effective intraband carrier relaxation had not been reported prior. Strongly elongated QDs, due to of their sizes and asymmetry, are characterised by a lower quantisation energy as compared to more symmetric and typically smaller QDs made of the same material system. Results of calculation of the band structure for elongated dots **[H1]** have shown that the value of quantisation energy in the conduction band can be significantly lower than the energy of an optical phonon (33-36 meV), and in the valence band it is just a few meV. If one assumes that the most effective process of energy dissipation by an electron is related to its interaction with optical phonons, then in the case of examined structures this assumption cannot be fulfilled, and in the relaxation process low-energy phonon excitations (acoustic phonons) must play the leading role, effectively slowing down the overall relaxation. In the experiment realization there has been selected a range of addressed states, so intraband relaxation was only between the ground state and the first excited state of a dash. Moreover, if the photon energy in the pump/probe pulse changes toward its lower values it should result in selection of larger QDashes, for which intraband quantisation is lower than for those on the higher energy side of the scanning range. This may lead to the observation of theoretically predicted[11] characteristic dispersion of relaxation time related to selection of low-energy phonon excitations that participate in the process of energy dissipation between higher state and the ground state in the nanostructure.

For comparison, in the year 2018, the measurements of intraband relaxation in almost symmetrical and small InAs/$In_{0.53}Ga_{0.23}Al_{0.24}As$/InP(001) QDs have been performed using the modified **U4** setup. The measurements of intraband relaxation have been performed by tracking the evolution of an intensity of the probe beam reflected off the examined structure after its non-resonant excitation by a train of pump pulses. For the examined objects intraband quantisation is similar to the energy of an optical phonon in InAs (~32-36 meV) **[H4]**. Therefore, intraband relaxation can be determined solely by interaction of charge carriers with optical phonons, which leads to effective filling of the ground state of a QD. It worth mentioning that intraband carrier relaxation in QDs made of considered material composition has never been researched. Existing information mainly regarded standard InAs/GaAs QDs [12, 13, 14, 15, 16] and to some extent InAs/InAlAs/InP(001)[17] or InAs/InP(331)B QDs[18, 19], in which intraband relaxation was established in between 1 ps and 40 ps. The candidate's research has shown that intraband relaxation in InAs/InAlGaAs/InP(001) QDs may occur in time of 8 ps **[H4]**, that is four times shorter than observed in strongly elongated InAs/InGaAsP/InP(001) nanostructures **[H4]**, confirming earlier hypotheses.

Collected research results regarding intraband relaxation in InAs/InGaAsP/InP(001) QDashes and InAs/InAlGaAs/InP(001) QDs, both emitting around the third telecom window, showed how deep the relaxation mechanisms can be modified when the excitation is out of the standard regime defined by the strong electron-hole confinement in a dot. The latter is characterised by a high energy of intraband quantisation for an electron and a hole, opposite to the weaker confinement regime where the quantization is lowered either for electron or for holes, like in a QDash. This postulate, resulting from the analysis of experimental data, has not yet found proof in theoretical works, and mechanisms of relaxation as such, generally still remain the important element of research and vigorous discussion in literature. In typical quantum dots the polaron relaxation mechanism or Coulomb scattering may play dominant role in the intraband relaxation process for high density of non-equilibrium carriers generated in a system[16]. Achieved results suggest that in the case of objects surpassing in size a typical quantum dot, carrier-low-energy-phonon scattering processes may be more relevant for intraband relaxation, which also can lead to significant prolongation of relaxation time.

Research carried out by the candidate, apart from fundamental insight, have great importance for technological applications. The intraband relaxation time strongly determines device parameters such as differential gain in an optical amplifier, or modulation frequency in a laser. In this matter, quantum dots seem to be more effective. As a result of the research it was possible to introduce important parameters of intraband relaxation in InAs/InAlGaAs/InP(001) QDs and InAs/InGaAsP/InP(001) QDashes, which fill the gap of knowledge related to these nanoobjects.

2.3.3 Impact of unintentional surrounding on relaxation of exciton in strongly elongated (In, Ga)As quantum dots on GaAs substrate

Searching for new technological solution based on QDs can lead to significant modification, intentional or not, of both the QD, as well as its surrounding. The consequence can be the substantial modification of relaxation processes in such a system. An example of such solution can be QDs designed for the effect of strong coupling of an emitting dipole (exciton) with an optical cavity mode. Among many important parameters, such dots should be characterised by a large oscillator strength and low surface density for the coupling of only a single emitter with the small volume cavity mode.[20, 21, 22] In the InAs/InP materials combination, partially discussed in subsections 2.3.1 and 2.3.2, it is very difficult to manufacture a monolithic cavity based on Bragg reflectors and characterised by a high quality factor (Q factor) due to low contrast of refraction index η of materials lattice-matched to InP (e.g.: $\eta = 0.2$ for cavities made of InP and InGaAsP).

The problem of a monolithic cavity system is less critical in the case of Bragg mirrors made of AlAs/GaAs material composition, lattice-matched to GaAs, where just a few layers of AlAs/GaAs can lead to the Q factor reaching from a few thousands to a few hundred thousand. [20, 23] In order to obtain QDs with a high oscillator strength in the (In,Ga)As/GaAs material system, it is necessary to lower the indium content to approx. 30%. In this case QDs nucleation in the Stranski-Krastanow mode on a two-dimensional wetting layer (2D WL) occurs at different strain conditions than for typical InAs/GaAs QDs[24] and results in **[H7]**: (a) appearing of the WL with a high density of zero-dimensional states (0D WL) (analogy of a quantum well with additional lateral confining potential caused by fluctuations of the well/barrier material composition and well width) and (b) creation of strongly elongated QDs of ~25 nm in width, a few nanometres in height, and length of about 100 nm, and with shallow confining potential, and (c) appearing of a low surface density of dots, as shown in Fig. 2.6.

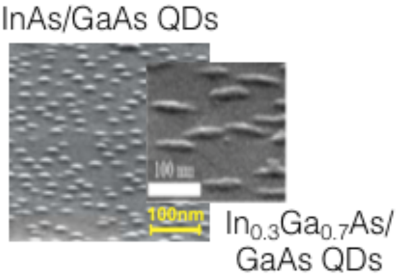


Figure 2.6. Images from a scanning electron microscope showing surfaces with typical InAs/GaAs and modified $In_{0.3}Ga_{0.7}As$/GaAs QDs. Compare **[H5]** and **[H7]**.

Structures containing QDs used in the research were manufactured at University of Würzburg in Germany (Laboratory of Prof. A. Forchel). Performed spectroscopic studies [25] indicated presence of a quasi-zero-dimensional density of states in the wetting layer (0D WL) along with quantum dots. It appears that the presence of the 0D WL, alongside with large $In_{0.3}Ga_{0.7}As$/GaAs quantum dots of a shallow confining potential and low surface density, leads to surprising, temperature-activated, intraband relaxation, after non-resonant excitation of the system above the WL. The results of experiments regarding this subject has been published in **[H7]**.

At low temperature (~10 K) and at low density of photo-injected carrier population in GaAs, intraband carrier relaxation ends up within the 0D WL density of states, and carriers cannot be effectively captured by QDs. After elevating the temperature, carriers initially localised in 0D WL states, are thermally activated to 2D states of the WL that form the mobility edge, from which they supply states in $In_{0.3}Ga_{0.7}As$/GaAs QDs. It has been shown that this process has its own particular kinetics (Fig. 2.7), which is related to the ratio between non-intentionally introduced density of localized states in the WL and the surface density of QDs.

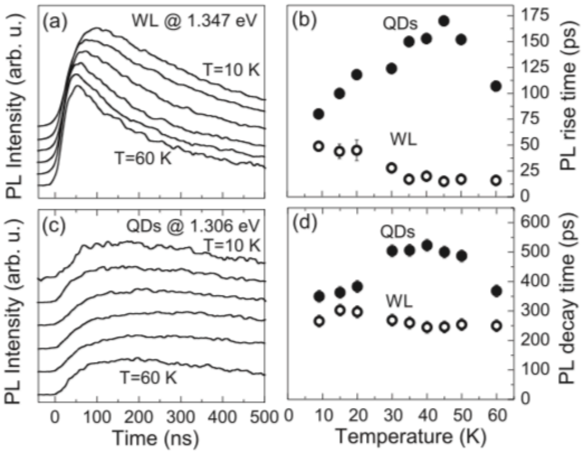


Figure 2.7. (a) Kinetics of the emission process in the WL area, (b) PL rise_time as a function of temperature in $In_{0.3}Ga_{0.7}As$/GaAs QDs, and the WL, (c) kinetics of the PL emission process for $In_{0.3}Ga_{0.7}As$/GaAs QDs, (d) The PL decay as a function of temperature for $In_{0.3}Ga_{0.7}As$/GaAs QDs, and the WL. **[H7]**

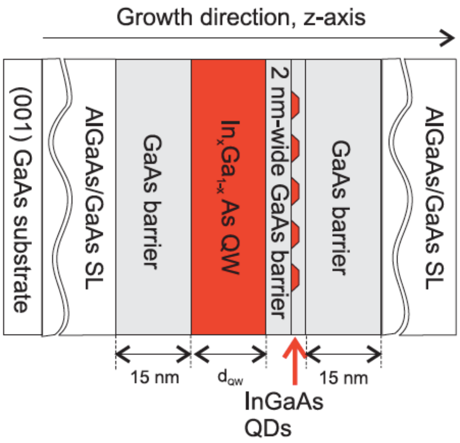
In typical QDs, made within the Stranski-Krastanow growth method, where QDs are formed on the 2D WL, it is very difficult to observe the effect related to slow down of intraband carrier relaxation from the WL to the QDs after photo-excitation into the QDs barrier. **[H4, H5, H6]** Nevertheless, in the WL area there can be formed a density of states characterised by three-dimensional confining potential for electrons and holes. Such potentials are sometimes called natural quantum dots.[26, 27] The increase in the population of states able to spatially localize carriers in the WL can lead to a significant increase in the intraband relaxation time with rising temperature (Fig. 2.7 (b)). Research summarised in **[H7]** showed that this effect cannot be explained only by the process of retarded, temperature-controlled, carrier releasing from the 0D WL. In the proposed model of this phenomenon it has been shown that the ratio between the density of 0D WL states to the density of epitaxial

QDs is of key significance. This parameter determines time of carrier migration in the WL area before they are effectively captured by confining potential of QDs. Within the assumption, the model qualitatively reconstruct observed carrier dynamics.

Research results published in **[H7]** are important for understanding intraband relaxation kinetics in two coupled systems characterised by a degree of quasi-zero-dimensional localisation of carriers. It introduces a significant argument in the form of the ratio between concentrations of 0D states in both subsystem, which can substantially modify observer carrier relaxation kinetics.

2.3.4 Importance of intentionally modified surrounding on inter- and intraband relaxation in InAs/GaAs quantum dots coupled to (In,Ga)As/GaAs quantum well and InAs/InAlGaAs/InP(001) quantum dots coupled to (In, Ga)As/InAlGaAs/InP(001) quantum well

In some cases, quantum dots cannot be treated as isolated from their surroundings. Moreover, their coupling to environment is an important factor in many application, such as schemes of quantum information processing based on charge or spin excitation.[33, 34] As it has been shown in the previous subsection, QDs can interact with other carriers localized in the vicinity of quantum dot potential and with other dots. On one hand, the interaction leads to modification of excitation properties in QDs, including changes in observed carrier kinetics. On the other hand, observation of excitation kinetics can give information on the character of the excitation, as for the systems described below, where QDs are intentionally coupled to QW states. Such QDs-QW coupled system was initially proposed for realisation of carrier injection from their large reservoir within density of states of the well to quantum dots. The concept, with certain modifications, has been utilised in single-electron transistor [35, 36], lasers with tunnel injections [37-43] and with memories based on quantum dots [44].



Schemat 2.8. The layer layout in a coupled structure with InGaAs/GaAs quantum dots and an In$_x$Ga$_{1-x}$A/GaAs quantum well separated by a 2 nm barrier made of GaAs. Structure grown on GaAs substrate by the MBE method. (Figure from work **[H9]**)

In application of quantum dots in the active part of lasers, the concept of carrier injection from the adjacent quantum well is aimed to: (i) increase collection of carriers to the ground state of dots, and by that omitting the problems of hot carriers at upper levels and in the barrier; (ii) accelerate the intraband relaxation by preliminary "cooling" of carriers inside the quantum well injector, and then injecting them to the quantum dots ground state via the effective carrier interaction with optic phonons, or within an electron-hole plasma (Auger processes). However interesting the concept may seem, understanding of such a hybrid quantum system was scarce. Among others, there had been unclear: the energy structure of states in the coupled system, intra- and interband carrier relaxation in the system, as well as mechanism of carrier transfer between well and quantum dots. Literature projections of the coupled system, as composed of two subsystems of different dimensionalities, obscured correct interpretation of experimental data. Work **[H6]** gave one of the first impulses to change of viewpoint on such systems. In this case, $In_{0.5}Ga_{0.5}As$ quantum dots embedded in the GaAs matrix, separated by a 2 nm barrier made of GaAs from a 7 nm-wide $In_{0.3}Ga_{0.7}As$ quantum well, were examined (Figure 2.8).

The (In,Ga)As/GaAs material system has been used for coupled structures because of their well controllable manufacturing process (MBE), which results in structures of a very good crystallographic quality. Investigated systems were provided by a partner from Institute of Analytical Technologies and Nanostructures, University of Kassel (Laboratory of Prof. J.P. Reithmaier), which is an European leader in manufacturing and research on semiconductor quantum dots-based lasers. In the time-resolved photoluminescence experiment there have been noticed differences between PL decays from the ground state of the reference structure composed of only quantum dots and the examined coupled structure (Figure 2.9). While in the first structure the PL rise time occurred with the average time constant of 28 ps (limited by the setup resolution), for the coupled structure it was about 150 ps.

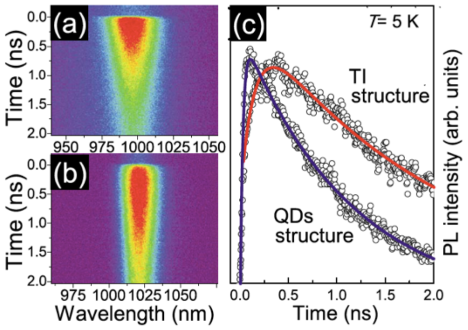


Figure 2.9 (a) The spectral map of PL evolution registered for the ground state in QDs, and **(b)** in the coupled system, **(c)** PL decay profiles for reference quantum dots and the coupled system. (Figure from **[H6]**).

Relevant differences between both structures were also observed for average times of photoluminescence decay. For the structure with quantum dots only the decay time was ~1.1 ns, which is close to theoretical predictions for excitation in the strong confinement regime for an (In, Ga)As/GaAs quantum dot. For the coupled structure this time constant was estimated to ~2 ns. These results clearly show that intra- and interband relaxation in the coupled system must be determined by existing quantum coupling between subsystems. In the first proposed interpretation, slow down of intraband relaxation, seen as elongated photoluminescence rise time, will cause change in the population kinetics of the coupled system ground state and lead to observation of prolonged emission. Such a hypothesis confirmed the model proposed in **[H6]** and presented in Figure 2.10

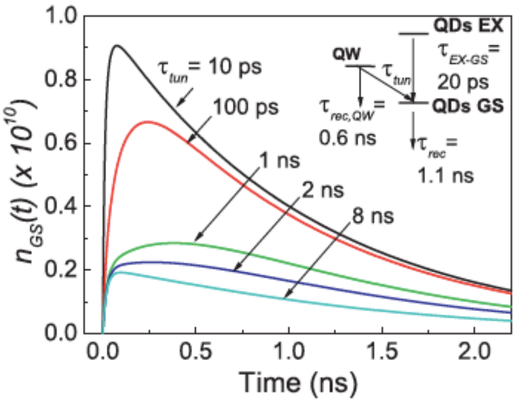


Figure 2.10. Model of carrier relaxation in the coupled quantum well- quantum dots system with simulated population kinetics at the ground state of the system. Model assumes a change in parameter which is time of carrier transfer (τ_{tun}) between a quantum well and a quantum dot (Figure from **[H6]**).

Observed elongation of the emission process from the ground state of the coupled system could indicated another possible scenario. As mentioned earlier, the presence of quantum well potential near spatially localised quantum dot must influence confined states in a common (hybrid) potential, as for e.g. in superlattices with quantum wells. As for the higher states in the coupled system, it is easy to imagine the existence of such hybrid states, for the ground state such possibility had not been explicitly considered. Vision of a common ground state was in contradiction to the idea of a laser with the active medium consisting of quantum dots, which uses the concept of tunnelling, but the lasing state is still strongly localised inside the quantum dot. Results summarised in **[H9]** confirmed the concept of a common ground state in the system of coupled QDs and a QW. It has been noticed that for a coupled system made of (In,Ga)As/GaAs, the increase in potential depth in the well caused by the increase in the indium content, leads to monotonic elongation of observed emission time from the ground state, which was assumed to be purely dot-like, and therefore have emission time of ~1.1 ns (Figure 2.11).

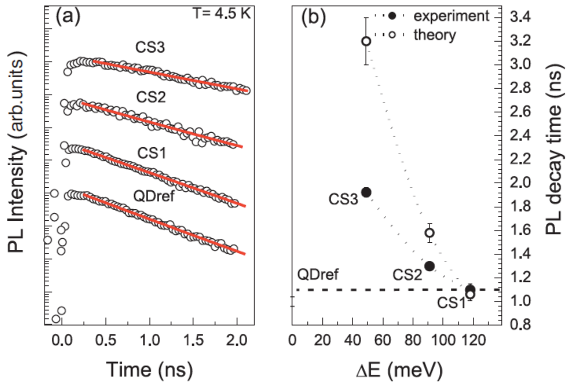


Figure 2.11 (a) PL evolution at the coupled system ground state (CS1-CS3) and quantum dots (QDref). **(b)** The PL decay time constant obtained for ground state emission (filled points) and theoretically calculated (open points). (Figure from **[H9]**).

As it has been shown in **[H6]**, elongation of emission time at the ground state of the coupled system can be caused not only by the process of state filling, but also because of the change of the character of optical transition. Interband, fundamental optical transition in a coupled system can occur between hole (electron) state localised in a quantum dot and common for the well and the dot electron (hole) state, as shown in fig. 2.12. Such optical transition will be indirect in the real space and will lead to longer emission time.

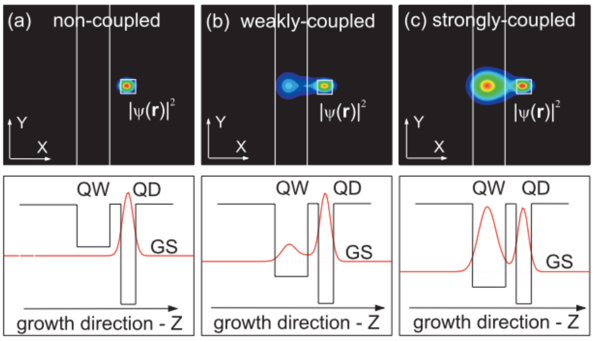


Figure 2.12. The concept of coupling of the ground state in a dot-well system. **(a)** a non-coupled system with the probability density function for the electron/hole localised in a quantum dot, **(b)** a weakly coupled system with the probability density for the electron/hole blurred between the dot and the well, **(c)** a strongly coupled system. (Figure from **[H9]**).

Proposed hypothesis have been verified and confirmed in theoretical calculation of coupled systems **[H9]**. Calculations have shown that for coupled systems of (In,Ga)As/GaAs materials there can be strong decoupling of fundamental electron level of the QD form the QW potential, where fundamental level of holes remains strongly coupled in QD potential (Fig. 2.13). In general, this effect leads to longer observed lifetime of electron-hole pair in the ground state of the coupled system.

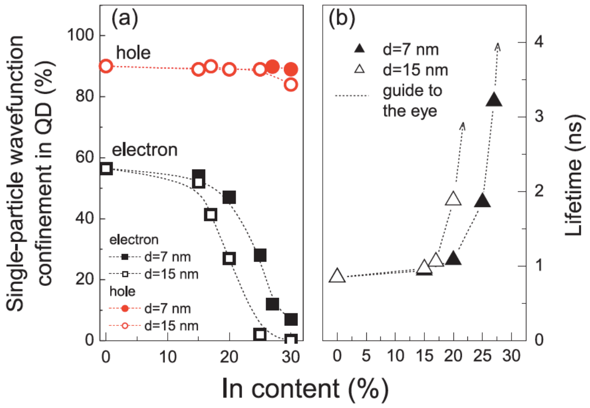


Figure 2.13. (a) Calculations of the spatial confinement of an electron and a hole at the ground state of a coupled QDs-QW system as a function of indium concentration in the well and its thickness. **(b)** Calculated radiative lifetime of an electron-hole pair at the ground state of the coupled system. (Figure taken from **[H9]**).

A few years later, the candidate started research on the coupled system, in which the active medium were InAs/$In_{0.53}Ga_{0.23}Al_{0.24}As$ quantum dots lattice matched to InP(001) separated by a 4 nm-width $In_{0.53}Ga_{0.23}Al_{0.24}As$ barrier from a strained, 5 nm-width $In_{0.64}Ga_{0.36}As$ quantum well with an $In_{0.53}Ga_{0.23}Al_{0.24}As$ barrier. These structure also come from University of Kassel (Laboratory of prof. J.P. Reithmaier). The main purpose of the research was comparing intraband carrier relaxation in the coupled system and in a system containing only of InAs/$In_{0.53}Ga_{0.23}Al_{0.24}As$/InP(001) quantum dots. That time, instead of time-resolved photoluminescence, as in **[H6]**, the two-colour pump-probe experiment with high time resolution (0.3 ps) was used (modified **U4** setup). Thanks to the possibility of independent tuning of the photon energy in the pump and probe pulses, it was possible to examine kinetics of the intraband carrier relaxation process in different parts of density of state of the coupled system. In **[H4]** it has been shown that intraband relaxation in the coupled system, in the area of hybridised density of states of QW and QDs, can be faster than in the case of sole quantum dots (~4 ps vs. ~8 ps) (Fig. 2.14) and is similar to that observed in quantum wells (~0.1-1 ps).

It has been proven that in the coupled system there is an effect of significant slowdown of intraband relaxation (from ~4 ps to ~45 ps), exactly as previously observed in time-resolved PL for the (In, Ga)As/GaAs based coupled system. The effect is probably related with significant "inconsistence" of an initial and a final state, where the initial state is of the quantum well character (confined in the area of the well), whereas the final state is of a dot character (confined in the QD with a considered blurring of the state onto the well).

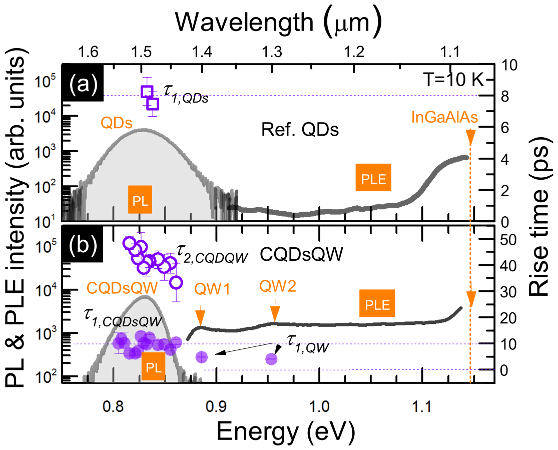


Figure 2.14 (a) photoluminescence (grey area), photoluminescence excitation (black curve), time of intraband relaxation (open violet points) for InAs/$In_{0.53}Ga_{0.23}Al_{0.24}As$/InP(001) quantum dots. **(b)** photoluminescence (grey area), photoluminescence excitation (black curve), time of intraband relaxation (open and fileld points) in system of QDs as in (a) coupled to $In_{0.64}Ga_{0.36}As$/$In_{0.53}Ga_{0.23}Al_{0.24}As$ quantum well. (Figure form **[H4]**).

Results of experiments on coupled quantum dots-quantum well structures allowed better understanding of kinetics of intra- and interband carrier relaxation in such system based on InGaAs/GaAs as well as **[H4]** InAs/InAlGaAs/InP(001) material systems **[H6]**. The most important conclusions are:

(a) intraband carrier relaxation in the coupled system can be a few times slower than in sole quantum dots;

(b) kinetics of emission of at ground state in the coupled system is determined by two factors: (i) intraband carrier relaxation, and (ii) the character of fundamental optical transition in the real space;

(c) modification of the coupled structure by changing parameters of the QW may leads to de-coupling of a fundamental electron/hole state from its strong localized potential in a dot;

Those results are of significant importance for designing systems based on InGaAs/GaAs and InAs/InAlGaAs/InP(001) quantum dots for applications in telecom lasers, where coupling of a quantum well to quantum dots is relevant from the viewpoint of both physics of such systems, as well as their applications. They show that the concept of analysis of separated subsystems and their parameters is controversial. Moreover, literature results for QD lasers based on a tunnel injection concept should be verified because of the fact that the ground state of the coupled system often is not a state purely confined in a QD, but it is rather a hybrid state made of mixed zero- and two- dimensional states. Only proper engineering of the band structure with application of different semiconductor materials can lead to achieving specification needed in context of expected action of a device based on the coupled system – this issue will require further research.

2.3.5 Initialisation of a spin state and control of its evolution in InAs/InAlGaAs/InP quantum dashes and InP/(Ga,In)P quantum dots

Spin excitation in quantum dots is still less known and less frequently researched than charge excitation. Current knowledge is limited almost exclusively to spin excitation in (In,Ga)As/GaAs dots, where the electron/hole/exciton is in the so called strong confinement regime. In such a case, properties of the electron/hole/exciton weakly depend on QD surrounding and the structure of states within the dot. In a system being in a weaker spatial confinement regime, spin properties may significantly differ from those in known systems with the strong confinement regime. That is why, in the above mentioned context, research of two different nanostructures has been conducted: InP/(Ga,In)P QDs **[H8]** and InAs/InAlGaAs/InP QDashes **[H2]**.

Structures with self-assembled InP QDs embedded in $Ga_{0.51}In_{0.49}P$ matrix had been manufactured on a GaAs substrate in the MOVPE technique in the laboratory of Prof. P. Michler at University of Stuttgart, Germany. These dots are characterised by peculiar properties in terms of spatial confinement. On one hand, confining potential in the conduction band makes an electron strongly confined in the dot. On the other hand, for holes, band discontinuity between InP and $Ga_{0.51}In_{0.49}P$ is negative and reaches -45 meV, which makes a hole be always outside the dot.[45] Strain modifies this situation, changing band discontinuity towards positive values. In spite of the fact that the hole becomes confined in a dot potential, i.e. in a dot material, the confining energy is still small. Additionally, the electrostatic potential of an electron strongly localised inside the dot can have a significant influence on the confinement of the hole in the InP/(Ga,In)P QD.[45, 46, 47, 48] In work **[H8]** there has been summarised research on effect of such limitation on coherent dynamics of spin of both an electron and a hole. Work uses time-resolved Kerr rotation[49], in which dynamics of change of magnetisation of a medium, induced by a circularly polarised laser pump pulse, is probed by rotation angle of the polarisation plane of a linearly polarised probe pulse (setup **U5**). Dynamics of magnetisation of a medium is related to complex evolution of a spin state of an electron or a hole, which is subjected to the Larmor precession in external magnetic field applied perpendicularly to the growth direction of a QD. Kinetics of Kerr rotation signal from examined InP/(Ga,In)P quantum dots as a function of magnetic field is shown in figure 2.15. Fig. 2.15 (a) shows that signal consist of two characteristic components, which was confirmed by Fourier analysis of measured Kerr rotation signal (Fig. 2.15 (b)).

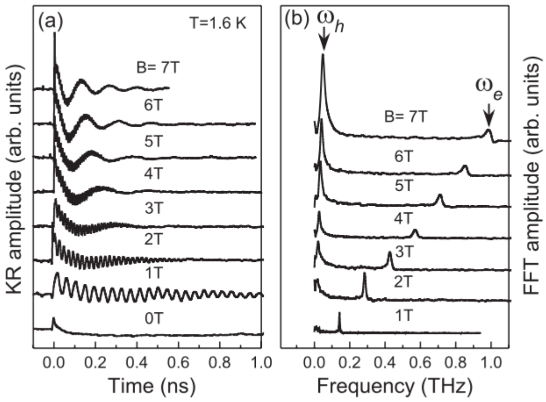


Figure 2.15 (a) Kerr rotation traces for InP/(Ga,In)P quantum dots, **(b)** Fourier analysis (FFT) of oscillations in Kerr signal showing presence of two components related to the Larmor precession of a hole (ω_h) and an electron (ω_e) spin in external magnetic field B at T=4.2 K. (Figure from **[H8]**)

First of these components, characterised by higher frequency of the Larmor precession (ω_e), is related to coherent evolution of an electron spin due to the expected high Zeeman splitting ($g_e \approx 1.6$), while the other component (ω_h), of much lower frequency of the Larmor precession, is connected to the precession of a hole spin. In this way information was obtained on the Zeeman spliting between two eigenstates of a hole spin with its characteristic g-factor of $g_h \approx 0.07$. It was the first observation of a coherent hole spin evolution for InP/(Ga,In)P QDs.

Additional information could be obtained by analysis of anisotropy of in-plane g factors. Due to the s-type symmetry of orbitals creating the conduction band in InP (material of a quantum dot), it is expected that g_e will have an isotropic character. However, for a hole spin and its g_h factor it should be different, owing to p-type symmetry of orbitals creating the valence band of a dot. This effect had been shown prior for typical (In,Ga)As/GaAs quantum dots, in which the hole remains strongly confined in (In,Ga)As, and the anisotropy of g_h was up to 50%.[50, 51] The lack of g_h anisotropy shown in figure 2.16 (d) for InP/(Ga,In)P QDs suggests that a hole is in the weak spatial confinement regime. Similarly as for elongated quantum dots described in subsections 2.3.1 and 2.3.2, the hole state being in the weak confinement regime is contributed by other states confined in the dot and the barrier material, which weakens the anisotropic character of the g-factor of the hole.

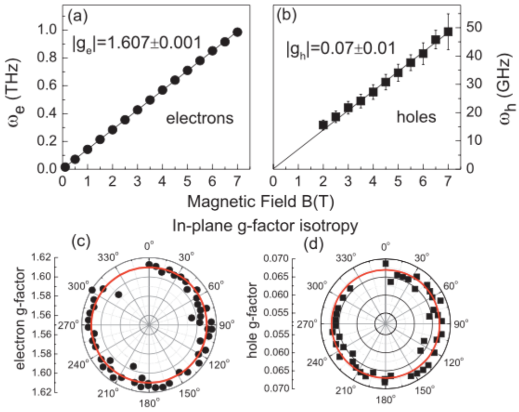


Figure 2.16 (a), (b) In-plane magnetic field dependence of the Larmor precession frequency for electron (ω_e) and hole (ω_h) spins in InP/(Ga,In)P QDs. **(c), (d)** The in-plane isotropic character of the g-factor of an electron and a hole. (Figure from **[H8]**)

Beside information on the Larmor precession of an electron and a hole spin and values of the g-factor of Zeeman splitting, the envelope of the Kerr rotation gives information on dephasing time of the spin state (T_2^*) in non-uniform set of spin states. For the electron spin this time ($T_2^* \approx 3ns$ for $B = 0.1\ T$) turned out to be comparable to values obtained for similar InAs/(Ga,In)P quantum dots.[52] Moreover, it turned out to be also comparable with similar times for the electron spin in (In,Ga)As/GaAs quantum dot ($T_2^* \approx 2ns$ for $B = 0.25\ T$) [53] and CdSe/(Zn,S)Se ($T_2^* \approx 5.6\ ns$ for $B = 0.25\ T$) [54]. Observed dephasing time of the electron spin state is significantly higher than the electron-hole pair lifetime in InP/(Ga,In)P QDs (the latter was measured to be 320 ps in the time-resolved PL experiment). This results suggest that in the Kerr rotation experiment, the component of signal associated with the electron spin comes from a negatively charged exciton, in which after annihilation of an electron-hole pair there is still visible coherent evolution of a resident electron spin in the dot. The character of the dephasing process, described as coming mainly from inhomogeneity in a set of tested spins, which may be parameterised by dispersion of the g-factor ($\Delta g_e \approx 0.018$), and was confirmed by showing characteristic dependence of dephasing time as a function of magnetic field ($T_2^* \propto 1/B$), as shown in figure 2.17 (a). The same cannot be said about the hole spin state. Dephasing time for hole spin as presented in fig. 2.17 (b) is approximately constant at the level of ~100 ps in the whole range of applied magnetic fields. This time is significantly shorter than observed lifetime of an electron-hole pair. It is worth mentioning that observed Kerr rotation for a hole comes from a photo-induced state, and therefore in general the coherent precession time of the hole spin should be close to the lifetime of an electron-hole pair. There is a hypothesis that this experimental observation is associated with the existence of a strong mechanism for spin relaxation of a hole, leading to loss of spin coherence in a shorter time scale, which is connected with the loss of isolation of the hole spin state in a dot.

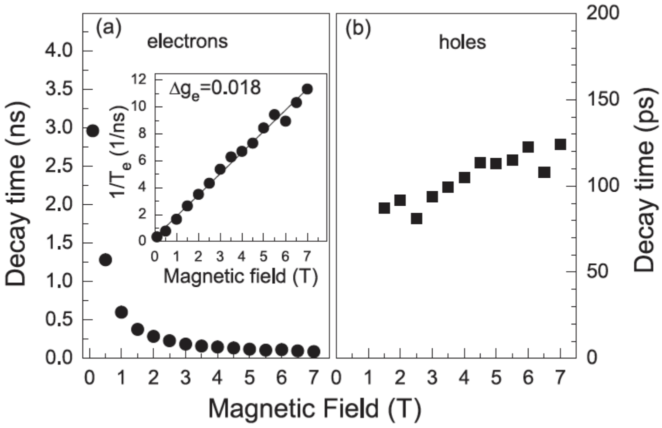


Figure 2.17 (a) Magnetic field dependence of dephasing time for an electron, **(b)** magnetic field dependence of dephasing time for a hole. (Figure from **[H8]**)

Results of research on electron and hole coherent spin dynamics in InP/(Ga,In)P quantum dots allowed better understanding of the process of loss of spin coherence in this material system, where electron remains strongly confined to the dot, contrary to hole remaining in the weak spatial confinement regime, determined by conditions of confining potential in a strained InP/(Ga,In)P material system. The most important conclusion from this work are:

(a) Dephasing time of a resident electron spin is compared to the one observed in the time-resolved Faraday and Kerr rotation for (In,Ga)As/GaAs and CdSe/(Zn,S)Se quantum dots;

(b) For the first time the dephasing time for a hole spin and the hole g-factor has been measured in InP/(Ga,In)P quantum dots;

(c) short dephasing time of a hole spin of approx. 100 ps is related to allowing extra processes of spin state decoherence due to weakening of isolation of a hole state in QD potential;

Presented results of the research made important contribution to the discussion on mechanisms of spin decoherence in quantum dots. In this context it seems surprising that dephasing time for an electron spin in InP/(Ga,In)P, (In,Ga)As/GaAs and CdSe/(Zn,S)Se quantum dots is similar. It is still believed that one of the most important mechanisms of the spin state decoherence in quantum dots is interaction with a spin of an atom nuclei (*hyperfine interaction*). If so, then the isotopic composition of quantum dots should determine the coupling strength between the nuclei spin and the electron spin. The candidate has investigated this aspect. In work [54] it has been shown that for quantum dots made of stable isotopes of indium and phosphorus the coupling should be greater than for those made of (In,Ga)As and CdSe. Experimental results suggests, however, that perhaps it is better to search for different mechanisms of the electron spin state decoherence, which would allow better understanding and order published literature results. In the context of an interaction between nuclei and hole spins, this mechanism, theoretically leading to strong decoherence of an electron spin state, should be ineffective for the hole spin, because a hole wavefunction is mainly made of p type orbitals in III-V semiconductor compounds. It is worth noticing, however, that the p-type symmetry of a hole wavefunction can be observer virtually for the case of its strong isolation in confining potential of a QD. In the case of lowering of spatial confinement, this symmetry may by significantly changed by admixing higher-order states of different symmetries, including s-type, into the ground state of a hole. In this way it may lead to effective spin relaxation in the discussed type of dephasing mechanism. In the extreme case of lowering of spatial confinement observed for discussed InP/(Ga,In)P QDs, decoherence mechanism typical for bulk materials should be considered.

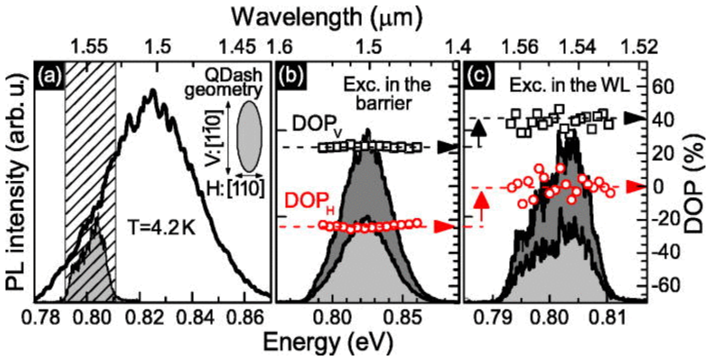


Figure 2.18 (a) Emission band from a set of InAs/InAlGaAs/InP(001) quantum dashes, **(b)** degree of linear polarisation of emission from dashes during spin initialisation in the barrier or **(c),** in the wetting layer. (Figure from **[H2]**).

While InP/(Ga,In)P quantum dots are interesting mainly because of fundamental research point of view due to the peculiar character of spatial confinement of an electron and a hole, strongly elongated and asymmetric InAs/In$_{0.53}$Ga$_{0.23}$Al$_{0.24}$As/InP(001) quantum dots discussed in subsections 2.3.2 and 2.3.3 may have significant application meaning in the telecom range, also in the context of spin excitation. Quantum communication can be based on single photon transmission, where the information is encoded in a polarisation state of a photon. Appropriately polarised photon state, absorbed at the ground state of a quantum dot, will generate a spin state of an electron/exciton, which can be processed in more sophisticated systems, with possibility of later conversion of the spin state back to the photon state and sending it further. This type of interface is especially important in long-range quantum telecommunication, which requires use of so called quantum repeater, for which it is necessary to store in a memory the entangled state of one of the two entangle photons.[55, 56] In work **[H2]** it has been summarised the results of research on possibility of initialization, storage, and read-out of a photon state in strongly asymmetric quantum dots, also in the context of search for possibilities of generation of polarisation-entangled pairs of photons from such a dot emitting in the third telecom window.[7]

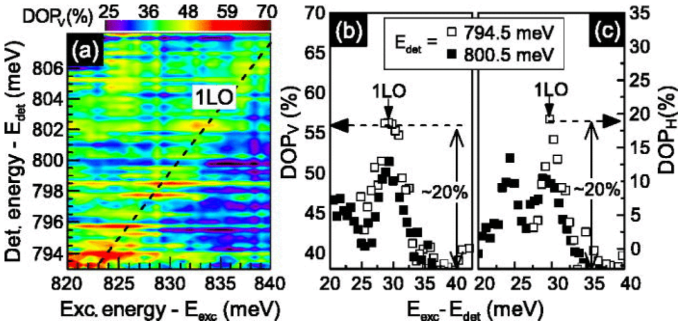


Figure 2.19 (a) Spectral map of registered degree of polarisation in the excitation scheme utilizing an optical phonon, **(b)** selected profiles of the spectral map from (a) showing amplification of observed degree of polarisation of emission. (Figure from **[H2])**

Results of experiments have shown that in the case of quantum dashes, process with non-resonant conversion of photon polarisation to the exciton state and back is inefficient. Polarisation is rapidly lost due to effective relaxation of spin excitation during its transfer from the InAlGaAs barrier to the ground state in quantum dashes. Moreover, it has been shown that for the quantum dashes the resulting polarisation of emission must be measured on the background of so called built-in polarisation (Fig. 2.18 (a)), resulting from anisotropic properties of confining potential of the quantum dash. This issue was discussed in subsection 2.3.2.

In **[H2]** it has been shown that the problem of spin relaxation during initialization of a spin state in the InAlGaAs barrier can be partially omitted by applying spin initialisation in the wetting layer for self-assembled object grown in the Stranski-Krastanow mode in the epitaxial process. In such a case an increase of resultant degree of polarisation of over a dozen percent above degree of natural (built-in) polarisation it is observed, which indicates existence of spin memory in considered objects. However, the observed contrast of degree of polarisation was not satisfactory. Only the proposal with initialisation of a spin state by quasi-resonant pumping of the quantum dot ground state using a coherent interaction with optical phonons turned out to be the most efficient method of increasing the contrast of observed resultant polarisation. Achieved degree of polarisation in the above-mentioned scheme of spin initialization (Fig. 2.19) was almost 20% higher than in the case of excitation with spin initialization in the wetting layer.

Ultimately, it has been shown that InAs/InAlGaAs/InP quantum dashes, with the use of a proper scheme of spin initialization, can be an element of a spin memory dedicated for information processing in the third telecom window. It has been also shown that InAs/InAlGaAs/InP quantum dashes have significant limitation in this context regarding properties of confining potential for an electron and a hole. Due to the intermediate confinement regime for an excitation, and taking into account strong anisotropy of the confinement potential, a strong polarization background related to high degree of linear polarisation of emission is observed. Those factors make the observation of spin polarisation very limited in time, to only over a dozen of nanoseconds in the cryogenic temperature range, even with the use the spin initialisation scheme, when the spin excitation is initialized at the ground state using the coherent interaction with optical phonons.

2.4 Summary

The candidate's scientific achievement **„Dynamics of intra- and interband relaxation of charge and spin excitation in quasi-zero-dimensional semiconductor structures of III-V compounds„** comprises of two parts:

I. Creating experimental workshop from the scratch, in some sense unique in the country;

II. Research on dynamics of intra- and interband relaxation of charge and spin excitation in quasi-zero-dimensional semiconductor structures of III-V compounds;

The most important results of the research are:

(a) Determination of an effective parameter of interband radiative recombination of an exciton in strongly elongated in the growth plane InAs/InGaAsP/InP(001) quantum dots;

(b) Determination of dynamics of interband relaxation in quantum dots, where the Coulomb-bound electron-hole pair is in the regime of intermediate confinement;

(c) Determination of energetic dispersion of interband recombination time in strongly elongated, asymmetric InAs/InAlGaAs/InP(001) quantum dots;

(d) Determination of intraband relaxation parameters for carriers confined in InAs/InGaAsP/InP(001) quantum dots with low energy level quantisation, in which predicted mechanisms of energy dissipation are most-likely related to acoustic phonons;

(e) Determination of intraband relaxation parameters for carriers confined in nearly-symmetrical InAs/InAlGaAs/InP(001) quantum dots with high energy level quantisation, in which predicted mechanism of energy dissipation is most-likely related to optical phonons;

(f) Showing the influence of non-intentional QDs surrounding on temperature-controlled intraband relaxation in strongly elongated (In,Ga)As/GaAs quantum dots. Showing that relaxation between two sets of quasi-zero-dimensional states distributed in space depends on their mutual spatial density;

(g) Assessment of the type of interband transition in the coupled quantum dots-quantum well made of InAs/GaAs and InAs/InP materials composition and observing the effect of slowdown of intraband carrier relaxation in the coupled system;

(h) Determination of parameters of coherent electron and spin relaxation in InP/(Ga,In)P quantum dots characterised by shallow confinement potential for holes, and observation of electron and hole spin coherence in the dots as a function of temperature and external magnetic field;

(i) Determination of efficiency of the spin initialisation processes in a system comprising of strongly elongated, asymmetric InAs/InAlGaAs/InP(001) quantum dots;

These results extends knowledge on relaxation processes of charge and spin carriers in quasi-zero-dimensional quantum objects, for which the fundamental excitation (charge or spin) is not in the range of strong spatial confinement. It has been shown that it may strongly determine both physical mechanisms accompanying relaxation of excitation, as well as parameters of relaxation. Obtained knowledge is significant not only because of fundamental research value, but also can be used for modelling and constructing of quantum dot-based devices.

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3 Information about candidate's other achievements

3.1 List of scientific publications not being a part of the habilitation

3.1.1 Publications after receiving Ph.D. degree

Other than research directly related with topic of habilitation, the candidate undertakes series of scientific activities in many fields regarding condensed matter physics. Particularly, those interest concern:

- *kinetics of polariton fluids and interactions of propagating polaritons in semiconductor structures of quantum wells in a microcavity;* **[A4, A10]**
- *search for quantum sources of single photons and polarisation-entangled photons utilising quasi-zero-dimensional epitaxial nanostructures like quantum dashes and dots;* **[A3, A8, A11, A12-A13, A18-A20, A37]**
- *effects related to localisation of charge carriers in quasi-zero-dimensional confining potential in bulk systems (3D) and in quantum wells with crystal lattice nonuniformities generated during growth of those materials;* **[A14-A15, A17, A21-A25, A29, A30, A33, A41]**
- *effects related to carrier kinetics and kinetics of a band structure in quantum wells systems with spatial separation of charge carriers* **[A9, A24, A29]**

#	Authors, title, journal , year of publication	IF	Ministrypoints
	2018		
[A1]	W. Rudno-Rudziński, **M. Syperek**, A. Maryński, J. Andrzejewski, J. Misiewicz, S. Bauer, V. I. Sichkovskyi, J. P. Reithmaier, M. Schowalter, B. Gerken, A. Rosenauer, G. Sęk *"Control of Dynamic Properties of InAs/InAlGaAs/InP Hybrid Quantum Well-Quantum Dot Structures Designed as Active Parts of 1.55 1.55 µm Emitting Lasers"* Phys. Stat. Sol. A 215, 1700455(2018). *My input in creating this paper was preparing concepts of experiments related to kinetics of optical processes in quantum well – quantum dots coupled systems. I estimate my input at 5%.*	1.775	25
	2017		
[A2]	W. Rundo-Rudziński, **M. Syperek**, J. Andrzejewski, A. Maryński, J. Misiewicz, A. Somers, S. Höfling, J. P. Reithmaier, and G. Sęk *"Carrier delocalization in InAs/InGaAlAs/InP quantum-dash-based tunnel injection system for 1.55 µm emission"* AIP Advances 7, 015117 (2017). *My input in creating this paper was preparing concepts of experiments related to kinetics of optical processes in quantum well – quantum dots coupled systems. I estimate my input at 5%.*	1.43	25
[A3]	Ł. Dusanowski, P. Mrowiński, **M. Syperek**, J. Misiewicz, A. Somers, S. Höfling, J. P. Reithmaier, and G. Sęk, *"Confinement regime in self-assembled InAs/InAlGaAs/InP quantum dashes determined from exciton and biexciton recombination kinetics"* Appl. Phys. Lett. 111, 253106 (2017).	3.411	40

	My input in creating this paper was a participation in the data interpretation process related to exciton and biexciton dynamics in quantum dashes and preparing final version of the manuscript. I estimate my input at 5%.		
[A4]	M. Pieczarka, **M. Syperek**, Ł. Dusanowski, A. Opala, F. Langer, C. Schneider, S. Höfling, and G. Sęk *"Relaxation Oscillations and Ultrafast Emission Pulses in a Disordered Expanding Polariton Condensate"* Sci. Rep. 7, 7094 (2017). *My input in this paper was performing time-resolved photoluminescence experiments and taking part in the discussion of the results. I estimate my input at 6%.*	4.847	40
[A5]	M. Pieczarka, **M. Syperek**, D. Biegańska, C. Gilfert, E. M. Pavelescu, J. P. Reithmaier, J. Misiewicz, and G. Sęk *"Lateral carrier diffusion in InGaAs/GaAs coupled quantum dot-quantum well system"* Appl. Phys. Lett. 110, 221104 (2017). *My input in this paper was helping in interpretation of experimental data and preparing the manuscript. I estimate my input at 5%.*	3.411	40
[A6]	A. Maryński, **M. Syperek**, M. Pieczarka, M. Gawełczyk, J. Misiewicz, V. Liverini, M. Beck, J. Faist, and G. Sęk *"Lateral interdot coupling among dense ensemble of InAs quantum dots grown on InP substrate observed at cryogenic temperatures"* Journal of Physics: Conf. Series 906, 012008 (2017). *My input in this paper was interpretation of experimental data and preparing the manuscript. I estimate my input at 8%.*		Conf.
[A7]	**M. Syperek**, J. Andrzejewski, W. Rudno-Rudziński, A. Maryński, G. Sęk, J. Misiewicz, J. P. Reithmaier, A. Somers, S. Höfling, *"The issue of 0D-like ground state isolation in GaAs- and InP-based coupled quantum dots-quantum well systems"* Journal of Physics: Conf. Series 906, 012019 (2017). *My input in this paper was interpretation of experimental data, performing measurements of interband relaxtion dynamics and preparing the manuscript. I estimate my input at 45%.*		Conf.
	2016		
[A8]	Ł. Dusanowski, **M. Syperek**, J. Misiewicz, J. Misiewicz, A. Somers, S. Höfling, M. Kamp, A. Kavokin, J. P. Reithmaier, and G. Sęk *„Single photon emission of InAs/InP quantum dashes at 1.55 µm and temperature up to 80 K"* Applied Physics Letter 108, 163108 (2016). *My input in this paper was supervising conducted experiments, participating in interpretation of experiments results and co-preparing the manuscript text. I estimate my input at 10%.*	3.142	45
[A9]	**M. Syperek**, K. Ryczko, M. Dallner, M. Dyksik, M. Motyka, M. Kamp , S. Höfling, J. Misiewicz, G. Sęk *"Room temperature carrier kinetics in the W-type GaInAsSb/InAs/AlSb quantum well structure emitting in mid-infrared spectra range"* Acta. Phys. Polonica A 130 1224 (2016). *My input in this paper was preparing the concept of experiments of ultrafast processes regarding kinetics of charge carriers in semiconductor structures emitting in the mid-infrared spectral range, performing the pump-probe experiments, preparing experimental data, interpretation and writing the first version of manuscript. I estimate my input at 70%.*	0.525	15
	2015		
[A10]	M. Pieczarka, **M. Syperek**, Ł. Dusanowski, J. Misiewicz, F. Langer, A. Forchel, M. Kamp, C. Schneider, S. Höfling, A. Kavokin, and G. Sęk *„Ghost branch photoluminescence from a polariton fluid under nonresonant excitation"* Physical Review Letters 186401, 115 (2015). *My input in this paper was performing time-resolved measurements of dissolving polariton condensate, participation in interpretation of experimental results, co-preparing the manuscript and discussion with reviewers. I estimate my input at 12%.*	7.645	45
[A11]	Ł. Dusanowski, **M. Syperek**, A. Maryński, H. L. H. Li, J. Misiewicz, S. Höfling, M. Kamp, A. Fiore, and G. Sęk *"Single photon emission up to liquid nitrogen temperature from charged excitons confined in GaAs-based epitaxial nanostructures"* Applied Physics Letters 106, 233107 (2015). *My input in this paper was proposing the idea of applying columnar quantum dots as single photon emitters in the visible spectral range, supervising of performed experiments and co-preparing of the manuscript. I estimate my input at 15%.*	3.142	40
[A12]	P. Mrowiński, A. Musiał, A. Maryński, **M. Syperek**, J. Misiewicz, A. Somers, J. P. Reithmaier, S. Höfling and G. Sęk *„Magnetic field control of the neutral and charged exciton fine structure in single quantum dashes emitting at 1.55 µm"* Applied Physics Letters 106, 053114 (2015).	3.142	40

	My input in this paper was taking part in interpretation experiment results regarding excitonic complexes in magnetic field and co-preparing manuscript. I estimate my input at 5%.		
	2014		
[A13]	Ł. Dusanowski, **M. Syperek**, P. Mrowiński, W. Rudno-Rudziński, J. Misiewicz, A. Somers, S. Höfling, M. Kamp, J. P. Reithmaier and G. Sęk *"Single photon emission at 1.55 μm from charged and neutral exciton confined in a single quantum dash"* Appl. Phys. Lett. **105**, 021909 (2014). *My input in this paper was supervising conducted experiments, participating in interpretation of experiment results and co-preparing the manuscript. I estimate my input at 8%.*	3.302	40
[A14]	M. Gładysiewicz, R. Kudrawiec, **M. Syperek**, J. Misiewicz, M. Siekacz, G. Cywiński, A. Khachapuridze, T. Suski, C. Skierbiszewski *„Influence of quantum well inhomogeneities on absorption, spontaneous emission, photoluminescence decay time, and lasing in polar InGaN quantum wells emitting in the blue-green spectral region"* Applied Physics A 115, 1015 (2014). *My input in this paper was measuring time-resolved photoluminescence spectra for InGaN quantum wells and discussing obtained results with co-authors of the manuscript. I estimate my input at 5%.*	1.704	25
[A15]	M. Baranowski, R. Kudrawiec, **M. Syperek**, J. Misiewicz, T. Sermiento, and J. S. Harris *„Time-resolved photoluminescence studies of annealed 1.3 μm GaInNAsSb quantum wells"* Nanoscale Research Letters 9, 81(2014). *My input in this paper was supervising conducted experiments in measuring time-resolved photoluminescence spectra and participating in interpretation of experiment results. I estimate my input at 5%.*	2.779	35
	2013		
[A16]	J. Kutrowska, P. Bugajny, M. Baranowski, L. Bryja, **M. Syperek**, A. Wójs, J. Misiewicz, M. Wiater, G. Karczewski, T. Wojtowicz *„Time Resolved Photoluminescence Study of the Wide (Cd,Mn)Te/(Cd,Mg)Te Quantum Well"* Acta Physica Polonica 124, 895 (2013). *My input in this paper was preparing the concept of conducted experiments, performing 80% of experiments, interpretation of the results and writing the manuscript. I estimate my input at 70%.*	0.604	15
[A17]	M. Baranowski, R. Kudrawiec, M. Latkowska, **M. Syperek**, J. Misiewicz, T. Sarmiento, and J. S. Harris *„Enhancement of photoluminescence from GaInNAsSb quantum wells upon annealing: improvement of material quality and carrier collection by the quantum well"* *J. Phys.: Condens. Matter* 25, 065801 (2013). *My input in this paper was supervising conducted experiments in time-resolved spectroscopy and participating in interpretation of experiment results. I estimate my input at 5%.*	2.223	30
[A18]	Ł. Dusanowski, **M. Syperek**, W. Rudno-Rudziński, P. Mrowiński, G. Sęk, J. Misiewicz, A. Somers, J.P. Reithmaier, S. Hofling, A. Forchel *„Exciton and biexciton dynamics in single self-assembled InAs/InGaAlAs/InP quantum dash emitting near 1.55 μm"* Appl. Phys. Lett. 103, 253113 (2013). *My input in this paper was supervising conducted experiments in time-resolved spectroscopy and participating in interpretation of experiment results and co-preparing the manuscript. I estimate my input at 12%.*	3.515	40
[A19]	Ł. Dusanowski, A. Golnik, M. Syperek, J. Sufczyński, M. Nawrocki, G. Sęk, J. Misiewicz, T. W. Schleretch, C. Schneider, S. Höfling, M. Kamp, and A. Forchel *„Properties of InGaAlAs/AlGaAs quantum dots for single photon emission in the near infrared and visible spectral range"* AIP Conf. Proc. 1566, 540 (2013). *My input in this paper was proposing the idea of using InGaAlAs/AlGaAs quantum dots as a single photon source and planning experimental steps towards confirming assumed theses. I estimate my input at 6%.*		Conf.
	2012		
[A20]	Ł. Dusanowski, A. Golnik, **M. Syperek**, M. Nawrocki, G. Sęk, J. Misiewicz, T. W. Schlereth, C. Schneider, S. Höfling, M. Kamp, and A. Forchel *„Single photon*	3.794	40

	emission in the red spectra range from a GaAs-based self-assembled quantum dots" Appl. Phys. Lett. 101, 103108 (2012). *My input in this paper was proposing the idea of using InGaAlAs/AlGaAs quantum dots as a single photon source and planning experimental steps towards confirming assumed thesis. I estimate my input at 6%.*		
[A21]	M. Baranowski, R. Kudrawiec, M. Latkowska, **M. Syperek**, J. Misiewicz, and J. A. Gupta *„Dynamics of localized excitons in $Ga_{0.69}In_{0.31}N_{0.015}As_{0.985}$/GaAs quantum well: Experimental studies and Monte-Carlo simulations"* Appl. Phys. Lett. 100, 202105 (2012). *My input in this paper was supervising conducted experiments in time-resolved spectroscopy and participating in interpretation of experiment results. I estimate my input at 4%.*	3.794	40
[A22]	M. Baranowski, M. Latkowska, R. Kudrawiec, **M. Syperek**, J. Misiewicz, K. Giri Sadasivam, J. Shim, and J. K. Lee *„Time-resolved photoluminescence studies of the optical quality of InGaN/GaN quantum well grown by MOCVD—antimony surfactant effect"* Semicond. Sci. Technol. 27 105027 (2012). *My input in this paper was supervising conducted experiments in time-resolved spectroscopy and participating in interpretation of experiment results. I estimate my input at 5%.*	1.921	30
[A23]	M. Baranowski, R. Kudrawiec, M. Latkowska, **M. Syperek**, J. Misiewicz *„Monte Carlo Simulations of the Influence of Localization Centers on Carrier Dynamics in GaInNAs Quantum Wells"* Act. Phys. Polonica A 122, 1022 (2012). *My input in this paper was supervising conducted experiments in time-resolved spectroscopy and participating in discussion on theoretical background of the work. I estimate my input at 4%.*	0.531	15
[A24]	M. Baranowski, **M. Syperek**, R. Kudrawiec, J. Misiewicz, J. A. Gupta, X. Wu, and R. Wang *„Carrier dynamics in type-II GaAsSb/GaAs quantum Wells"* *J. Phys.: Condens. Matter* 24 185801(2012). *My input in this paper was proposing concept of research on type-II quantum wells using time-spectral tomography, supervising conducted experiments, participating in interpretation of results and preparing the first version of manuscript. I estimate my input at 12%.*	2.355	30
[A25]	R. Kudrawiec, **M. Syperek**, M. Latkowska, J. Misiewicz, V.-M. Korpijärvi, P. Laukkanen, J. Pakarinen, M. Dumitrescu, M. Guina, and M. Pessa *„Influence of non-radiative recombination on photoluminescence decay time in GaInNAs quantum wells with Ga- and In-rich environments of nitrogen atoms"* J. Appl. Phys. 111, 063514 (2012). *My input in this paper was preparing concept of experiments on kinetics of relaxation processes in GaInNAs quantum wells, performing measurements of time-resolved photoluminescence, preparing the results of experiments. I estimate my input at15%.*	2.21	30
	2011		
[A26]	**M. Syperek**, D. R. Yakovlev, I. A. Yugova, J. Misiewicz, I. V. Sedova, S. V. Sorokin, A. A. Toropov, S. V. Ivanov, M. Bayer, *„Long-lived elektron spin coherence in CdSe/Zn(S,Se) self-assembled quantum dots*" Physical Review B 84, 085304 (2011). *My input in this paper was preparing the experimental setup, performing all of the experiments, preparing results of the experiments and their preliminary interpretation, and writing the first version of manuscript. I estimate my input at 55%.*	3.691	35
[A27]	J. Akhtar, M. Afzaal, M. Banski, A. Podhorodecki, **M. Syperek**, J. Misiewicz, U. Bangert, S.J.O. Hardman, D.M. Graham, W.R. Flavell, D.J. Binks, S. Gardonio, P. O'Brien, *„Controlled Synthesis of Tuned Bandgap Nanodimensional Alloys of PbS(x)Se(1-x)"*, Journal of the American Chemical Society. 133, 5602 (2011). *My input in this paper was preparing concept of experiments on photoluminescence dynamics in examined structures, conducting experiments, and preparing the results with their preliminary interpretation. I estimate my input at 5%.*	9.907	40
[A28]	M. Siekacz, M. Sawicka, H. Turski, G. Cywiński, A. Khachapuridze, P. Perlin, T. Suski, M. Boćkowski, J. W. Smalec-Koziorowska, M. Kryśko, R. Kudrawiec, **M. Syperek**, J. Misiewicz, Z. R. Wasilewski, S. Porowski, C. Skierbiszewski, *„Optically pumped 500 nm InGaN green lasers grown by Plasma-Assisted Molecular Beam Epitaxy"* J. Appl. Phys. 110, (2011).	2.168	30

	My input in this paper was performing experiments in measuring kinetics of photoluminescence from InGaN quantum wells and preparing results of experiments. I estimate my input at 2%.		
[A29]	M. Baranowski, **M. Syperek**, R. Kudrawiec, J. Misiewicz, J. A. Gupta, X. Wu, and R. Wang, "*Carrier dynamics between delocalized and localized states in type-II GaAsSb/GaAs quantum wells*" Appl. Phys. Lett. 98, 061910 (2011). *My input in this paper was proposing the concept of research on type II-quantum wells using time-spectral tomography, supervising conducted experiments, participating in interpretation of results and preparing the first version of manuscript. I estimate my input at 15%*	3.844	40
[A30]	Baranowski. M, Kudrawiec. **Syperek. M**, Misiewicz J, Zhao .H, Sadeghi. M ,Wang S.M. "*Contactless electroreflectance, photoluminescence and time resolved photoluminescence of GaInNAs quantum wells obtained by the MBE method with N-irradiation*", Semiconductor Science and Technology 26, 045012 (2011). *My input in this paper was preparing the concept of experiments on kinetics of relaxation processes in GaInNAs quantum wells, supervising measurements of time-resolved photoluminescence, and participating in data interpretation. I estimate my input at 5%.*	1.723	30
[A31]	A. Podhorodecki, P. Gluchowski, G. Zatryb, **M. Syperek**, J. Misiewicz, W. Lojkowski, W. Stręk, "*Influence of Pressure-Induced Transition from Nanocrystals to Nanoceramic Form on Optical Properties of Ce-Doped Y3Al5O12*" J. Am. Ceram. Soc. B 1-6 (2011). *My input in this paper was preparing the concept of experiments on photoluminescence dynamics in examined structures, conducting experiments, and preparing the results with their preliminary interpretation. I estimate my input at 5%.*	2.272	45
[A33]	C. Boney, I. Hernandez, R. Pillai, D. Starikov, A. Bensasoula, M. Henini, **M. Syperek**, J. Misiewicz, and R. Kudrawiec *"Growth and characterization of InGaN for photovoltaic devices"* Phys. Stat. Sol. C 8, 2460 (2011). *My input in this paper was preparing the concept of experiments on photoluminescence dynamics in examined structures, conducting experiments, and preparing the results with their preliminary interpretation. I estimate my input at 2%.*		Conf.
[A33]	M. Gładysiewicz, R. Kudrawiec, **M. Syperek**, J. Misiewicz, M. Siekacz, G. Cywiński, C. Skierbiszewski, T. Suski *"Theoretical simulations of radiative recombination time in polar InGaN quantum wells"* Phys. Stat. Sol. C 8, 2273 (2011). *My input in this paper was preparing the concept of experiments on photoluminescence dynamics in examined structures, conducting experiments, and preparing the results with their preliminary interpretation. I estimate my input at 5%.*		Conf.
[A34]	**M. Syperek**, A. Musiał, G. Sęk, P. Podemski, J. Misiewicz, A. Löffler, S. Höfling, L. Worschech, and A. Forchel *"Impact of the localized wetting layer states on carrier relaxation processes in GaAs-based quantum dash structures"* AIP Conf. Proc. 1399, 563 (2011). *My input in this paper was preparing concept of experiments on InAs/GaAs quantum dashes in recognition of charge/exciton dynamics, performing experiments, giving preliminary interpretation of the results, and writing the first version of manuscript. I estimate my input at 54%.*		Conf.
	2010		
[A35]	G. Sęk, A. Musiał, P. Podemski, **M. Syperek**, J. Misiewicz , A. Löffler, S. Höfling, L. Worschech and A. Forchel, *"Exciton kinetics and a few particle effects in self-assembled GaAs-based quantum dashes"* J. Appl. Phys. 107,096106 (2010). *My input in this paper was discussion on experimental results and participating in data interpretation. I estimate my input at 5%.*	2.064	30
[A36]	C. Boney, I. Hernandez, R. Pillai, D. Starikov, A. Bensaoula, M. Henini, **M. Syperek**, J. Misiewicz, and R. Kudrawiec *"Growth and characterizarion of InGaN for photovoltaic devices"* 35th IEEE Photovoltaic Specialists Conference 3316 (2010). *My input in this paper was preparing the concept of experiments on photoluminescence dynamics in examined structures, conducting experiments, and preparing the results with their preliminary data interpretation. I estimate my input at 2%.*		Conf.

[A37]	A. Musiał, G. Sęk, P. Podemski, **M. Syperek**, J. Misiewicz, A. Löffler, S. Höfling ,and A. Forchel *“Excitonic complexes in InGaAs/GaAs quantum dash structures”* J. Phys.: Conf. Series 245, 012054 (2010). *My input in this paper was discussion of experimental results and participating in interpretation of data. I estimate my input at 4%.*		Conf.
[A38]	W. Rudno-Rudziński, J. Andrzejewski, G. Sęk, **M. Syperek**, J. Misiewicz, E. M. Pavelescu, C. Gilfert, and J. P. Reithmaier *“Tunnel injection structures based on InGaAs/GaAs quantum dots: optical properties and energy structure”* J. Phys.: Conf. Series 245, 012047 (2010). *My input in this paper was discussion of experimental results and participating in the data interpretation process. I estimate my input at 5%.*		Conf.
	2009		
[A39]	W. Rudno-Rudziski, G. Sęk, K. Ryczko, **M. Syperek**, J. Misiewicz, E. S. Semenova, A. Lemaitre, A. Ramdane *„Optical properties and energy transfer in InGaAsN quantum well - InAs quantum dots tunnel injection structures for 1.3 μm emission”* Phys. Stat. Sol. A 206, 826 (2009). *My input in this paper was discussion of experimental results and participating in the data interpretation process. I estimate my input at 5%.*	1.228	25
[A40]	W. Rudno-Rudziński, G. Sęk, K. Ryczko, **M. Syperek**, J. Misiewicz, E. S. Semenova, A. Lemaitre, and A.Ramdane *„Room temperature free carrier tunneling in dilute nitride based quantum well - quantum dot tunnel injection system for 1.3 μm”* Appl. Phys. Lett. 94, 171906 (2009). *My input in this paper was preparing the concept of experiments on photoluminescence dynamics in tunnel structures, conducting experiments, preparing the data, and participating in the interpretation of the results. I estimate my input at 5%.*	3.554	40
[A41]	R. Kudrawiec, **M. Syperek**, P. Poloczek, J. Misiewicz, R. H. Mari, M. Shafi, M. Henini, Y. Galvão Gobato, S. V.Novikov, J. Ibáñez, M. Schmidbauer, and S. I. Molina *“Carrier localization in GaBiAs probed by photomodulated transmittance and photoluminescence”* J. Appl. Phys. 106, 023518 (2009). *My input in this paper was preparing the concept of experiments on photoluminescence dynamics in GaBiAs layers, conducting experiments, preparing the data, and participating in the interpretation of the results. I estimate my input at 12%.*	2.072	30
[A42]	W. Rudno-Rudziński, K. Ryczko, G. Sęk, **M. Syperek**, J. Misiewicz, E. M. Pavelescu, C. Gilfert, J. P. Reithmaier *“Optical methods used to optimize of semiconductor laser structures with tunnel injection from quantum well to InGaAs/GaAs quantum dots”* Optica Applicata 39, 923 (2009). *My input in this paper was discussion of experimental results and participating in the data interpretation process. I estimate my input at 5%.*	0.358	15

3.1.2 Publications before receiving Ph.D. degree

Before obtaining Ph.D. the candidate had been undertaking efforts focused on two topics:

- Optical properties of structures based on wide-bandgap materials GaN, AlGaN, AlN and their heterostructures;
- coherent spin dynamics of an electron and a hole in GaAs and CdTe based quantum wells.

#	Authors, title, journal , year of publication	IF	Ministry Points
	2007		
[B1]	**M. Syperek**, D. R. Yakovlev, A. Greilich, J. Misiewicz, M. Bayer, D. Reuter, and A. Wieck *“Spin coherence of holes in GaAs/AlGaAs quantum wells”*, Phys. Rev. Lett. 99, 187401 (2007). *My input was preparing the experimental setup, performing all experiments, preparing results of experiments and their preliminary interpretation, and writing the first version of manuscript. I estimate my input at 60%.*	6.994	45

[B2]	M. Motyka, R. Kudrawiec, **M. Syperek**, J. Misiewicz, M. Rudziński, P.R. Hageman and P.K. Larsen, *"Screening effect in contactless electroreflectance spectroscopy observed for AlGaN/GaN heterostructures with two dimensional electron gas",* Thin Solid Films 515, 4662-4665 (2007). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 10%.*	1.693	30
[B3]	**M. Syperek**, M. Motyka, R. Kudrawiec, J. Misiewicz, M. Rudziński, P. R. Hageman, and P. K. Larsen *"Investigation of built-in electric fields in AlGaN/GaN heterostructures grown on misoriented 4H-SiC substrate by contactless electroreflectance"* Phys. Stat. Sol C 4, 366 (2007). *My input was preparing the experimental setup, performing experiments, preparing results of experiments and their preliminary interpretation, and writing the first version of manuscript. I estimate my input at 40%.*		Conf.
[B4]	**M. Syperek**, D. R. Yakovlev, A. Greilich, M. Bayer, J. Misiewicz, D. Reuter, and A. Wieck *"Spin coherence of holes in GaAs/AlGaAs quantum wells"* AIP. Conf. Proc. 893, 1303 (2007). *My input was preparing the experimental setup, performing all experiments, preparing results of experiments and their preliminary interpretation, and writing the first version of manuscript. I estimate my input at 60%.*		Conf.
	2006		
[B5]	M. Motyka, **M. Syperek**, R. Kudrawiec and J. Misiewicz, M. Rudzinski, P. R. Hageman, P. K. Larsen, *"Investigation of GaN surface quantum well in AlGaN/GaN transistor heterostructures by contactless electroreflectance spectroscopy"*, Appl. Phys. Lett. 89, 231912 (2006). *My input in this paper was performing photoreflectance and photoluminesce spectra, interpretation of the results of experiments, introducing the concept of surface GaN/AlGaN quantum well and writing the first version of manuscript. I estimate my input at 35 %.*	3.977	40
[B6]	R. Kudrawiec, **M. Syperek**, M. Motyka, and J. Misiewicz, R. Paszkiewicz, B. Paszkiewicz, and M. Tłaczała, *„Contactless electromodulation Spectroscopy of AlGaN/GaN heterostructures with a two dimensional elektron gas: a comparision of photoreflectance and contactless electroreflectance"* J. App. Phys. 100 , 013501 (2006). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 24%.*	2.316	30
[B7]	R. Kudrawiec, M. Nyk, **M. Syperek**, A. Podhorodecki, J. Misiewicz, and W. Stręk, *„Photoluminescence from GaN nanopowder: The size effect associated with the surface-to-volume ratio"* Appl. Phys. Lett. 88, 181916 (2006). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 20%.*	3.977	40
[B8]	B. Paszkiewicz, R. Paszkiewicz, A. Szyszka, M. Wośko, W. Macherzyński, M. Tłaczała, R. Kudrawiec, **M. Syperek**, J. Misiewicz, E. Dumiszewska, and W. Strupiński *"Study of activation process of Mg dopant in GaN:Mg layers"* Phys. Stat. Sol. C 3, 579 (2006). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 2%.*		Konf.
[B9]	R. Kudrawiec, **M. Syperek**, J. Misiewicz, M. Rudziński, A. P. Grzegorczyk, P. R. Hageman, and P. K. Larsen *"Below bandgap transitions in an AlGaN/GaN transistor heterostructure observed by photoreflectance spectroscopy"* Phys. Stat. Sol. C 3, 2117 (2006). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 25%.*		Konf.
	2005		
[B10]	R. Kudrawiec, **M. Syperek**, J. Misiewicz, M. Rudziński, AP Grzegorczyk, P.R. Hageman,P.K. Larsen *„Photoreflectance investigations of a donor-related transition in AlGaN/GaN transistor structures",* App. Phys. Lett. 87, 153502 (2005). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 25%.*	4.127	40

[B11]	**M. Syperek,** R. Kudrawiec, J. Misiewicz, R. Korbutowicz, R. Tłaczała, *„Photereflectance investigation of trick GaN layers prepared by HVPE technique”,* Optica Applicata 35, 529(2005). *My input was performing photoreflectance spectra, preparing the results and their interpretation as well as preparing the first version of manuscript. I estimate my input at 40%.*	0.459	15
[B12]	J. Misiewicz, R. Kudrawiec, **M. Syperek**, R. Paszkiewicz, B. Paszkiewicz and M. Tłaczała *„Investigations of AlGaN/GaN field-effect transistor structures by photoreflectance spectroscopy”,* Microelectronics Journal 36, 442 (2005). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 12%.*	0.836	20
[B13]	R. Kudrawiec, **M. Syperek**, J. Misiewicz, R. Paszkiewicz, B. Paszkiewicz, M. Tłaczała *“Photoreflectance studies of undoped and Si-doped AlGaN/GaN heterostructures with a two-dimensional electron gas“* AIP Conf. Proc. 772, 417 (2005). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 20%.*		Konf.
	2004		
[B14]	R. Kudrawiec, **M. Syperek**, J. Misiewicz, R. Paszkiewicz, B. Paszkiewicz, M. Tłaczała *"Photoreflectance Investigations of AlGaN/GaN heterostructures with a two dimensional elektron gas"* Superlattices and Microstructures, vol. 36, pp. 633-641 (2004). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 20%.*	2.097	25
[B15]	R. Kudrawiec, **M. Syperek**, J. Misiewicz, R. Paszkiewicz, B. Paszkiewicz, M.Tłaczała *"Photoreflectance study of p-type GaN layers"* Superlattices and Microstructures, vol. 36, pp. 643-649 (2004). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 20%.*	2.097	25
[B16]	R. Kudrawiec, R. Korbutowicz, R. Paszkiewicz, **M. Syperek** and J. Misiewicz *„Photoreflectance and photoluminescence of thick GaN layers gron by HVPE”* Opto-Electronics Review 12(4), 435-439 (2004). *My input was performing photoreflectance spectra, preparing the results and their preliminary interpretation. I estimate my input at 20%.*	1.413	20

3.2 List of domestic and international scientific projects in which the candidate was a project leader

#	Duration	Founder/country of realisation	Title	Place of realisation
1	2007/06/01-2007/11/30	DAAD/Germany	Dynamics of optical coherent processes in (In,Ga)As-based quantum dots and quantum wells	TU Dortmund, Germany
2	2011/04/20-2013/12/19	MNiSW/NCN/ Poland **N N515 496640**	Dynamics of radiative and non-radiative recombination in semuconductor structures with quantum dashes on InP(001) substrate for lasers and optic amplifiers in near infrared (Dynamika procesów relaksacji promienistej i bezpromienistej w strukturach półprzewodnikowych z kreskami kwantowymi na podłożu InP(001) przewidzianych na lasery i wzmacniacze optyczne pracujące w zakresie bliskiej podczerwieni)	Wroclaw University of Science and Technology, LOSN
3	2012/06/11-2014/06/10	MNiSW/NCN/ Poland **IP2011053371**	Dynamics of charge carriers and excitons in quaternary InAlGaAs quantum dots on GaAs substrate for laser applications (Dynamika nośników ładunku oraz ekscytonów w czteroskładnikowych kropkach kwantowych InAlGaAs na podłożu z GaAs przeznaczonych do zastosowań laserowych)	Wroclaw University of Science and Technology, LOSN

3.3 List of domestic and international projects in which the candidate was a main contractor or a contractor

List of projects comprises of 16 positions. Vast majority is realised in international collaboration.

#	Duration	Founder/country of realisation	Title	Place of realisation
1	2008/09/01-2012/07/31	7 Framework UE/International project	Development of low-cost technologies for the fabrication of high-performance telecommunication lasers (DeLight)	Wroclaw University of Science and Technology/ LOSN
2	01.04.2015-31.03.2018	UE "Horizon 2020"/International project	In-line Cascade Laser Spectrometer for Process Control (iCSpec)	Wroclaw University of Science and Technology/ LOSN
3	01/04/2016-31/03/2019	NCBiR/ 2/POLBER-2/2016/Polish-German project	Semiconductor single photon source for quantum secured communication in the 1.3 µm spectral range (Półprzewodnikowe źródło pojedynczych fotonów do bezpiecznej światłowodowej komunikacji kwantowej w zakresie 1.3 µm)	Wroclaw University of Science and Technology/LOSN
4	2011/02/03-2014/08/27	MNiSW, NCN, DFG/Polish-German project	Emiters of infrared radiation using polaritonic effect for applications in fiber-based telecommunication (Emitery promieniowania podczerwonego wykorzystujące efekt polarytonowy przeznaczone do zastosowań w telekomunikacji światłowodowej)	Wroclaw University of Science and Technology/ LOSN
5	09/06/2014-08/01/2018	NCN "Harmonia 6" UMO-2013/10/M/ST3/00636/Polish-German project	Research on fundamental properties of coupled quantum well – quantum dots systems emitting in the 1.3 – 1.5 micrometer range (Badania własności podstawowych sprzężonych systemów typu studnia kwantowa-kropki kwantowe emitujących w zakresie spektralnym 1.3-1.55 mikrometra)	Wroclaw University of Science and Technology/ LOSN
6	02/06/2015-01/06/2018	NCN "Harmonia 6" UMO-2014/14/N/ST3/00821/Polish-German project	Single photon emitter at 1.55 µm using a quantum dot in a microcavity architecture (Pojedynczy emiter fotonów na dł. fali 1.55 mikrometra wykorzystujący architecture kropki kwanowej w mikrownęce)	Wroclaw University of Science and Technology/ LOSN
7	29/01/2015-28/01/2018	NCN "Opus" P. Machnikowski UMP-2014/13/B/ST5/04603/Domestic project	Dynamics and optical control of spin in coupled nanostructures systems (Dynamika i optyczna kontrola spinu w układach sprzężonych nanostruktur)	Wroclaw University of Science and Technology/ LOSN
8	22.09.2015-21.09.2018	NCN "Opus" Motyka, UMP-2014/15/B/ST7/04663/	Examining energy band structure and carrier dynamics in type-II semiconductor nanostructures for emission and detection in the 3-10 µm	Wroclaw University of Science and Technology/

			range (Zbadanie struktury energetycznej oraz dynamiki nośników ładunku w półprzewodnikowych strukturach niskowymiarowych typu drugiego przeznaczonych do emisji lub detekcji promieniowania z zakresu 3-10 mikrometrów)	LOSN
9	2013/01/01-2015/12/31	FNP “Mistrz” Prof. A. Wójs	Magneto-optics of semiconductor nanostructures with carriers of 3/2 spin for application in processing of quantum information (Magneto-optyka nanostruktur półprzewodnikowych z nośnikami o spinie 3/2 pod kątem zastosowań w przetwarzaniu informacji kwantowej)	Wroclaw University of Science and Technology/ LOSN
10	27/04/2012-27/04/2017	NCN “Maestro” Prof. J. Misiewicz UMO-2011/02/A/ST3/00152	New epitaxial semiconductor nanostructures: optical properties and applications (Nowe epitaksjalne nanostruktury półprzewodnikowe: własności optyczne i aplikacje)	Wroclaw University of Science and Technology/ LOSN[2]
11	2010/04/06-2012/04/05	MNiSW/NCN NN202179538	Magnetooopic research on electron dynamic properties of quantum fluids with spin (Badania magnetooptycze własności dynamicznych elektronów cieczy kwantowych ze spinem)	Wroclaw University of Science and Technology/ LOSN[2]
12	2010/09/27-2012/09/26	MNiSW/NCN NN202258339	Processes of radiative and non-radiative recombination in III-V compounds and structures containing Nitrogen (Procesy rekombinacji promienistej i niepromienistej w związkach i strukturach półprzewodnikowych III-V z azotem)	Wroclaw University of Science and Technology/ LOSN[2]
13	2010/04/06-2012/04/05	MNiSW/NCN NN202181238	Optical properties of epitaxial nanostructures with strong shape asymmetry (Własności optyczne nanostruktur epitaksjalnych o silnej asymetrii kształtu)	Wroclaw University of Science and Technology/ LOSN[6]
14	2010/04/08-2012/04/07	MNiSW/NCN NN515518338	Research on optical properties of quantum well – quantum dot tunnel structures for applications in telecommunication lasers (Badania własności optycznych struktur tunelowych typu studnia-kropka kwantowa pod kątem zastosować w laserach telekomunikacyjnych)	Wroclaw University of Science and Technology/ LOSN[2]
15	01/05/2008-30/09/2013	EU Structure Fund POIG 01.01.02-00-008-00	Quantum semiconductor structures for applications in biology and medicine – development and commercialisation of new generation of molecular diagnostic devices based on novel Polish semiconductor devices (Kwantowe struktury półprzewodnikowe do zastosowań w biologii i medycynie – rozwój i komercjalizacja nowej generacji urządzeń diagnostyki molekularnej opartych o nowe polskie przyrządy półprzewodnikowe)	Wroclaw University of Science and Technology/ LOSN

16	10/10/2009-30/06/2013	EU Structure Fund POIG. 02.02.00-00-003/08	National Laboratory of Quantum Technologies	Wroclaw University of Science and Technology/ LOSN

3.4 List of invited talks at domestic and international scientific conferences

#	Author(s) of lecture	Year of presentation	Title	Name and place of conference
1	**M. Syperek**	2018/02/14-16	Optical properties and carrier dynamics in InAs/InP(001) quantum dashes/dots	International Workshop on the Optical Properties of Nanostructures, Munster, Germany
2	**M. Syperek**	2017/05/5-7	Exciton dynamics in quasi-0D semiconductor nanostructures beyond the strong confinement regime	VI NANOIN Student Conference, Szklarska Poręba, Poland
3	**M. Syperek**	2015/06/25-27	Ultrafast carrier relaxation processes in semiconductor nanostructures	VII Polish Conference on Nanotechnology, Poznań, Poland
4	**M. Syperek**	2013/02/13-15	Carrer relaxation process in low-indium content, self-assembled (In,Ga)As/GaAs quantum dots	International Workshop on the Optical Properties of Nanostructures, Bayreuth, Germany
5	**M. Syperek**	2013/07/9-12	Nanosecond and sub-nanosecond time-resolved spectroscopy of low-dimensional quantum structures	VI Polish Conference on Nanotechnology, Szczecin, Polska
6	**M. Syperek**	2012/11/27	Time-resolved photoluminescence spectroscopy: Introduction and applications	International Meeting on Spectroscopy of Semiconductors, Departament of Electronic Engineering, National Taiwan University, Taiwan
7	**M. Syperek**	2011/03/05	Dynamics of charge carriers, excitons and spin in semiconductor nanostructures using tools of ultrafast optical spectroscopy (Dynamika nośników ładunku, ekscytonów i spinu w nanostrukturach półprzewodnikowych z wykorzystaniem narzędzi ultraszybkiej spektroskopii optycznej)	Conference of National Laboratory of Quantum Technologies, Warszawa, Polska

3.5 List of other conference talks

#	Author(s) of lecture	Year of presentation	Title	Name and place of conference
1	**M. Syperek** , Ł. Dusanowski, J. Misiewicz, A. Somers, J. P. Reithmaier, S. Höfling, G. Sęk	2016/06/18-24	On the spin memory effect in InAs quantum dash emitting at 1.55 µm	45th “Jaszowiec” International School and Conference on the Physics of Semiconductors, Szczyrk, Polska
2	**M. Syperek**, Ł. Dusanowski, J. Misiewicz, A. Somers, J. P. Reithmaier, S. Höfling, G. Sęk	2016/02/17–19	Exciton spin relaxation in InAs/InP(001) quantum dashes emitting at 1.55 µm	4th International Workshop on the Optical Properties of Nanostructures, Wrocław, Polska

3	**M. Syperek**	Wroclaw, 2013	Carrier relaxation processes in low-indium content, self-assembled (In,Ga)As/GaAs quantum dots	16th Conference on Modulated Semiconductor Structures (MSS-16)
4	**M. Syperek**, P. Leszczyński, W. Rudno-Rudziński, G. Sęk, A. Andrzejewski, J. Misiewicz, E. M. Pavelescu, C.Gilfert, and J. P. Reithmaier	7-8.10.2010	Carrier dynamics in GaAs-based quantum dot– quantum well tunnel injection structures	International Workshop on the high speed semiconductor lasers
5	**M. Syperek**	14-16.02. 2011	Photoluminescence dynamics in coupled (In,Ga)As/GaAs quantum well-quantum dots system	POLISH-GERMAN WORKSHOP ON THE OPTICAL PROPERTIES OF NANOSTRUCTURES
6	**M. Syperek**	27.06.2011-01.07.2011	Ultrafast carrier dynamics of charge carriers in semiconductor coupled quantum structures of quantum well – quantum dot type (Ultraszybka dynamika nośników ładunku w półprzewodnikowych kwantowych strukturach sprzężonych typu studnia kwantowa-kropki kwantowe)	II Polish Optic Conference, Międzyzdroje
7	**M. Syperek**	4-6.03.2011	Photoluminescence dynamics in the (In,Ga)As/GaAs coupled quantum well-quantum dot system	Conference "Quantum Technology 2011"
8	**M. Syperek**, W. Rudno-Rudziński, G. Sęk, K. Ryczko, J. Andrzejewski, J.Misiewicz, E. S. Semenova, A. Lemaitre, A. Ramdane	19-26.06. 2009	Time-resolved photoluminescence of a coupled quantum well - quantum dots system: inelastic electron-electron scattering as a main mechanism of tunneling process	XXXVIII International School and Conference on the Physics of Semiconductors, Jaszowiec
9	**M. Syperek**, W. Rudno-Rudziński, G. Sęk, K. Ryczko, J. Andrzejewski, J.Misiewicz, E. S. Semenova, A. Lemaitre, A. Ramdane	06. 2009	Carrier dynamics and optical properties of coupled structures with tunnelling between quantum well and quantum dots for application in active area of lasers for telecommunication range 1.3 µm (Dynamika ładunku i własności optyczne w sprzężonych strukturach z tunelowaniem typu studnia kwantowa-kropka kwantowa przeznaczonych na obszar aktywny laserów telekomunikacyjnych przeznaczonych na 1,3 mikro-m)	XI Seminar "Surface and Thin Film Structures" Szklarska Poręba, Poland
10	**M. Syperek**, D. R. Yakovlev, A. Greilich, J. Misiewicz, M. Bayer, D. Reuter, and A. Wieck	27.08– 8.09, 2007	"Spin coherence of holes in GaAs/AlGaAs quantum wells"	Magnetic Fields for Science. Cargese, Corsica, France

3.6 List of domestic and foreign organizations and societies with which the candidate is cooperating

Member of Academy of Young Scientists and Artists.

Member of Polish Physical Society.

Member of Deutscher Akademischer Austausch Dienst (DAAD).

3.7 Didactic activity

3.7.1 Role as an auxiliary advisor in doctoral thesis

Dr. Łukasz Dusanowski

Thesis: "Dynamics of carriers, statistics of photon emission and phonon decoherence in single quantum dashes emitting in near infrared range." (*"Dynamika nośników, statystyka emisji fotonów oraz dekoherencja fononowa w pojedynczych kreskach kwantowych emitujących w zakresie bliskiej podczerwieni"*).

Doctorate finished – Thesis realised at Wroclaw University of Science and Technology, Faculty of Fundamental Problems of Technology, Laboratory of Optical Spectroscopy of Nanostructures from 03.12.2013 to 28.09.2016.

3.7.2 Supervision of M.Sc. and B.Sc. theses

Total of 13 M.Sc. Theses have been realised.

name	Semester	Title
mgr. inż. Joanna Kita	*Summer and winter 2016/2017*	Measurements of picosecond optical pulses in infrared using two photon absorption method in an InGaAs detector (Pomiar pikosekundowych impulsów optycznych w podczerwieni w metodzie z dwu-fotonową absorpcją w detektorze InGaAs)
mgr inż. Ernest Rogowicz	*Summer and winter 2016/2017*	Kinetics of charge carriers in semiconductor quantum wells emitting in mid infrared range (Kinetyka nośników ładunku w półprzewodnikowych studniach kwantowych emitujących w zakresie średniej podczerwieni)
mgr inż. Kajetan Fijałkowski	*Summer and winter 2014/2015*	Dynamics of charge and spin carriers in coupled (In,Ga)As/GaAs structures (Dynamika nośników ładunku i spinu w strukturach sprzężonych (In,Ga)As/GaAs)
mgr inż. Anna Kubiak	*Summer and winter 2014/2015*	Research of optical properties and charge carrier dynamics in epitaxial InGaAsN layers (Badanie własności optycznych i dynamiki nośników ładunku w warstwach epitaksjalnych InGaAsN przeznaczonych na ogniwa słoneczne)
mgr inż. Albert Ratajczak	*Summer and winter 2013/2014*	Dynamics of exciton in group of (In,Ga)As/GaAs quantum columns (Dynamika ekscytonu w zespole słupków kwantowych (In,Ga)As/GaAs)
mgr. Michał Studniarek	*Summer and winter 2012/2013*	Multifunctional Molecular Spintronics
Alex Sohrab	*Winter 2012/2013*	Photoluminiscence Dynamics of Non-polar AlGaN/GaN Superlattices Grown on m-plane GaN

mgr inż. Łukasz Dusanowski	*Summer and winter 2011/2012*	(Multi-excitonic emission from single and elongated (In, Ga)As/GaAs quantum dots) Emisja multiekscytonowa z pojedynczych wydłużonych kropek kwantowych (In, Ga)As/GaAs
mgr inż. Michał Studniarek	*Summer and winter 2011/2012*	Dynamics of photoluminescence of InAlGaAs quantum dots with AlGaAs barrier on GaAs surface (Dynamika fotoluminescencji kropek kwantowych InAlGaAs z barierą z AlGaAs na podłożu z GaAs)
mgr inż. Ugo Chapet	*Summer 2010/2011*	Carrier dynamics in tunel injection structures
mgr inż. Przymysław Leszczyński	*Summer and winter 2009/2010*	Photoluminescence spectroscopy and time-resolved spectroscopy of coupled structures with quantum well – quantum dots tunnelling structures (Spektroskopia fotoluminescencyjna oraz rozdzielona w czasie fotoluminescencja sprzężonych struktur z tunelowaniem typustudnia kwantowa-kropki kwantowe)
mgr inż. Jacek Sajkowski	*Summer and winter 2009/2010*	Photoluminescence spectroscopy and time-resolved photoluminescence of InP based quantum dots (Spektroskopia fotoluminescencyjna oraz rozdzielona w czasie fotoluminescencja kropek kwantowych na bazie InP)

Total of 10 B.Sc. Theses have been realised including two in collaboration with University of Cambridge:

a) inż. Dominik Hamara *„Optically Pumped Organic – Metallic Halide Perovskite Distributed Feedback Laser – Designing, Fabrication, Characterization, Analysis”* Supervisor Dr. Marcin Syperek, auxiliary supervisor Dr. Felix Deschler (Optoelectronics Group of the University of Cambridge);

b) inż. Ernest Rogowicz *“Pomiar wzmocnienia optycznego terahercowego kwantowego wzmacniacza kaskadowego”* Supervisorr Dr. Marcin Syperek, auxiliary supervisor Yuan Ren (Optoelectronics Group of the University of Cambridge);

Name	Semester	Title
inż. Dąbrówka Biegańska	*Winter 2017/18*	Diffusion of charge carriers in coupled quantum well – quantum dots structures (Dyfuzja nośników ładunku w strukturach sprzężonych typu studnia kwantowa - kropki kwantowe)
inż. Maciej Klimkiewicz	*Summer 2016/17*	Dynamics of excitons in AlInAsSb/GaSb type-II superlattices (Dynamika ekscytonów w supersieciach AlInAsSb/GaSb typu-II)
inż. Paulina Dałek	*Winter 2015/16*	Statistics of emission from a single photon source (Statystyka emisji ze źródła pojedynczych fotonów)
inż. Dominik Hamara	*Winter 2014/15*	Optically Pumped Organic-Metallic Halide Perovskite Distributed Feedback Laser
inż. Ernest Rogowicz	*Winter 2014/15*	Measurements of optical gain of terahertz quantum optical amplifier (Pomiary wzmocnienia optycznego terahercowego kwantowego wzmacniacza optycznego)
inż. Paweł Katolik	*Winter 2013/2014*	Photoluminescence of layered ReS2:Nb semiconductor (Fotoluminescencja półprzewodnika warstwowego ReS2:Nb)
inż. Aleksandra Mańska	*Winter 2013/2014*	(Photoluminescence and time-resolved photoluminescence of ZnO/(Zn, Mg)O multi-quantum wells on Si (111)) Fotoluminescencja i rozdzielona w czasie fotoluminescencja układu wielokrotnych studni kwantowych ZnO/(Zn, Mg)O na Si(111).

inż. Kajetan Fijałkowski	*Summer 2012/2013*	Photoluminescence dynamics of ZnO/ZnMgO quantum wells (Dynamika fotoluminescencji w studniach kwantowych ZnO/ZnMgO)
inż. Michał Studniarek	*Winter 2010/2011*	Photoluminescence and time-resolved photoluminescence of quantum wells (Fotoluminescencja i fotoluminescencja rozdzielona w czasie kropek kwantowych)

3.7.3 Lectures, exercises and laboratory classes

The candidate prepared and realised or realises, 6 lectures for first and second degree students at Wroclaw University of Science and Technology.

Type of lecture	Title	Range of topics
Monographic lecture in Polish	*New experimental methods in nanoengineering (Nowe metody eksperymentalne w nanoinżynierii)*	Introduction to physics of semiconductor structures in nanoscale and to experimental methods in nanoscale with emphasis on spectroscopy methods. Elements of quantum optics, single photon generators, light – matter interaction. Optical cavities and interaction between an emitter and a cavity mode.
Lecture for II degree students in English	*Light Matter Interaction*	Solid State Physics. Light – matter interaction.
Lecture for II degree students in English	*Optics of Solid States and Semiconductor Structures*	Solid state optics. Semiconductor structures optics.
Partially monographic lecture for II degree students in Polish	*Introduction to spintronics (Podstawy spintroniki)*	Introduction to spintronics, concept of spin in atoms and solid state. Initialization, storage and read-out of spin by electrical and optical means. Coherent and non-coherent spin relaxation, mechanisms of spin relaxation in system of different dimensionality. Introduction to spintronic devices.
Partially monographic lecture for II degree students in Polish	*Advanced methods of optical spectroscopy (Zaawansowane metody spektroskopii optycznej)*	Methods of measurement of excitation kinetics in materials interacting with light. Generators of laser impulses. Techniques of time-resolved spectroscopy: Photoluminescence classic and gated, transitional absorption, four-wave-mixing, Kerr/Faraday rotation.
Lecture for I degree students in Polish	*General Physics I (Fizyka ogólna I)*	Introduction to physics, Newtonian mechanics, mechanic waves, acoustics.
Lecture for I degree students in Polish	*General Physics II (Fizyka ogólna II)*	Electrostatics, electric current, magnetism, alternating current, induction and inductivity, electromagnetic wave and wave optic, elements of special relativity, elements of quantum mechanics and solid-state physics.

Alongside lectures, the candidate teaches exercise classes for first degree students complementary to lectures on general physics as well as basic laboratories for first degree students and advanced for second degree students of different faculties of Wroclaw University of Science and Technology. During realisation of studies of second degree students of physics at Faculty of Fundamental Problems of Technology specialistic projects are realised under supervision of the candidate. Those projects are utilising the infrastructure of Laboratory of Optical Spectroscopy of Nanostructures, including spectroscopic system constructed by the candidate and described in part 2 of this autoreferat. Those projects are complementary to lectures provided by the candidate and allow practical application of obtained knowledge.

3.8 List of internships in foreign institutions

Duration	Country/Institution	Range of activity
2005/01-2008/08	Dortmund, Germany, TU Dortmund, Experimental Physics Group II (Prof. Manfred Bayer, Prof. D. Y. Yakovlew)	Research on electron and hole dynamics in GaAs based quantum wells. Coherent dynamics of electron and hole spin in CdTe and GaAs based quantum wells.
2012/11-2012/12	Taipei, Taiwan, National University of Science and Technology, (Prof. Ying-Sheng Huang)	Research on band structure and charge carrier dynamics in type II ZnSe/ZnTe quantum dots.

3.9 Membership in expert panels

Member of panel of experts reviewing motions within City Programme of Support of Partnership between Higher Education and Science, and Sector of Economic Activity "Mozart" coordinated by Wroclaw Academic Centre.

Head of the team and member of expert panel coordinated by Wroclaw Academic Centre within Max Born Student Scholarship Programme for exceptional Ph.D. students in fields of Physics, Optoelectronics, and Information Technology.

Member of expert panel reviewing motions within "Visiting Professors" programme coordinated by Wroclaw Academic Centre.

3.10 Reviewership in international scientific journals

Range of reviewed topics in scientific articles focuses on dynamics of optical processes in low-dimensional semiconductor structures and devices based on these structure, especially phenomena regarding electron and hole dynamic, coulomb coupled electron-hole couples, and derivative complexes and spin dynamics. After Ph.D. reviews have been made for journals such as: **Scientific Reports** (2 reviews), **Journal of Applied Physics** (3 reviews), **European Physical Journal – Applied Physics** (2 reviews), and **IET Optoelectronics** (1 review).

3.11 International collaboration

International collaboration is directly connected with research projects described in paragraph 3.3. List of institutions with which the candidate undertook collaboration include:

- Wroclaw University of Science and Technology, Faculty of Fundamental Problems of Technology, Department of Theoretical Physics;
- Technische Physik, University of Würzburg & Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, Würzburg, Niemcy;
- University of Kassel, Institute of Nanostructure Technologies and Analitics, Kassel, Germany;
- University of St. Andrews, School of Physics and Astronomy, St. Andrews, Scotland;

- Experimentelle Physik 2, Technische Universität Dortmund, Germany;
- Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia;
- III V Lab, Marcoussis, France;
- Departament of Photonics Engineering, Technical University of Denmark, Lyngby, Denmark;
- National Taiwan University of Science & Technology, Department of Electronic Engineering, Taipei, Taiwan;
- Polish Academy of Science, Institute of High Pressure Physics, Warsaw, Poland;
- Stanford University, Solid State & Photonics Laboratory, Stanford, USA;
- University of Stuttgart, Stuttgart, Germany;
- National Research Council Canada, Institute of Microstructure Science, Ottawa, Canada;

3.12 Awards and distinctions

Awards and scholarships	Year
Scholarship of Foundation for Polish Science within „Mistrz" project of Prof. Arkadiusz Wójs.	**2013**
Scientific Dionizy Smolenski Award of Rector of WrUST for exceptional scientific achievements.	**2013**
Scholarship of Minister of Science and Higher Education for exceptional young scientists.	**2012**
Scholarship „Młoda Kadra 2015 Plus", Wroclaw University of Science and Technology	**2012**
Scholarship "Młoda Kadra PWr" 5th edition, Wroclaw University of Science and Technology	**2011**
Scholarship "Młoda Kadra PWr" 4th edition, Wroclaw University of Science and Technology	**2011**
Award of Rector for significant input in development of WrUST.	**2011**
Conference Scholarship of Foundation for Polish Science and Warsaw Science Society	**2010**
Award of Rector for significant input in development of WrUST.	**2010**
Scholarship of Foundation for Polish Science within START programme.	**2009**
Distinction for the best doctoral thesis, Wroclaw University of Science and Technology	**2008**
DAAD scholarship (TU Dortmund)	**2007**

Marcin
Syperek