1. Name

Tomasz Kazimierczuk

2. Diplomas, degrees conferred in specific areas of science or arts, including the name of the institution which conferred the degree, year of degree conferment, title of the PhD dissertation

2012 PhD degree in Solid State Physics
Faculty of Physics, University of Warsaw
diploma dissertation: *Excitation and relaxation mechanisms in CdTe/ZnTe quantum dots*

2009 B.S. diploma in Computer Science
Faculty of Mathematics, Informatics and Mechanics, University of Warsaw

2007 M.Sc. diploma in Solid State Physics
Faculty of Physics, University of Warsaw

3. Information on employment in research institutes or faculties/departments or school of arts

05.2012 – 09.2014	post-doc position at TU Dortmund (SPANGL4Q project)
10.2014 – 01.2017	*adiunkt* (teaching & research) at University of Warsaw
02.2017 – 01.2019	*adiunkt* (research) at University of Warsaw (ATOMOPTO project)
02.2019 – present	*adiunkt* (teaching & research) at University of Warsaw

4. Description of the achievements, set out in art. 2019 para 1 point 2 of the Act

The achievement described here is a series of publication on *optical investigation of dark (grey) excitons*.

The excitons themselves are excitations of electronic system in the solid state that are not associated with transport of charge but only the energy. The most canonical example is the Wannier-Mott exciton, i.e., the hydrogen-like bound state of a negatively charged electron and a positively charged hole. Due to zero net electric charge, excitons are predominantly studied in optical experiments. However, not all excitons can recombine optically, e.g. due to incompatible symmetry of the valence and the conduction band or due to different spin orientations between the carriers constituting the exciton. Such excitons are termed 'dark excitons', as opposed to 'bright excitons' which can recombine radiatively without any obstacle. There are also intermediate cases, where otherwise dark excitons gain some oscillator strength due to secondary effects, leading to weak optical activity, often identified as '*grey excitons*'.

In my work, I focused on grey/dark excitons in several systems of different dimensionality, namely bulk Cu_2O, self-assembled CdTe/ZnTe quantum dots and monolayer tungsten-based transition metal dichalcogenides. Below I describe each of these systems, discussing the contents of the presented series of publication.

High angular momentum excitons in bulk Cu_2O

Cuprous oxide (Cu_2O) is a direct-bandgap semiconductor with principal bandgap is 2.172 eV. It has the point group of the highest symmetry possible in the crystal, namely O_h. Since this group contains the inversion symmetry, each state at the Γ point in the Brillouin zone can be classified with respect to its parity as either even or odd. In particular the lowest conduction band transforms according to the even irreproducible representation Γ_6^+ while the highest valence band transforms according to the even representation Γ_7^+. As such, the dipole electric moment (which has odd parity) between such states should vanish, which would suggest that the excitons built from such carriers are optically forbidden (dark). Yet, the overall symmetry of the exciton wavefunction is a product of symmetries of both bands and the symmetry of the envelope function describing the relative motion. Therefore, the excitons with odd-parity envelope (such as the hydrogen-like *n*p states) may regain some of the oscillator strength and appear in the spectrum, giving raise to so-called *yellow series*. This description is known since the early studies on Cu_2O by Elliott [1] and Gross [2].

In our work **[TK1]** we investigated absorption spectrum of high-quality bulk Cu_2O crystals using balanced-detection scheme while the single-mode dye laser was scanning over the spectral range corresponding to the yellow series. Our experiments revealed that this excitonic series is remarkably long: in the recorded spectrum we were able to resolve the spectral lines up the 25p state. The reason why this series is so much longer than the one observed, e.g., in GaAs in which states from 1s to 3s were observed, is still an open question. One ingredient is the binding energy, which yields about 90 meV in Cu_2O as compared with 4.2 meV in GaAs, which makes the excitons in Cu_2O less fragile in presence of thermal excitations. However, we speculate that another ingredient may be the p-character of the studied excitons, in particular that the non-radiative recombination channels might be hindered by vanishing amplitude of the exciton wavefunction at relative electron-hole distance of 0.

Important element of this work was analysis of the parameters describing the measured excitonic lines: transition energy, the linewidth and the amplitude. While the parameters for the states with principal numbers up to about *n*=15 the measured values followed the respective power-laws ($E_0 - E \propto n^{-2}$; FWHM $\propto n^{-3}$), lines for higher-n values deviated from the predicted trends. We found that by increasing the intensity of the laser (e.g. in two-beam experiment) we can additionally quench the measured oscillator strength values for the highest observed states. This effect was interpreted in terms of Rydberg blockade, which is relevant given the fact that the excitonic states as high as 25p are extended over distances as long as 1 μm.

That work was followed up by investigation of higher-angular-momentum excitons in Cu_2O **[TK2]**. Here, we focused on additional weak, narrow lines in the absorption spectrum within the yellow series. We found groups of these lines starting from *n*=4 and we were able to resolve them up to *n*=9. Using modulation technique we could push this limit up to *n*=12, but without resolving individual lines within each group.

We attributed the observed absorption lines as related to states with angular momentum *l*=3 (i.e., f series) and *l*=5 (i.e., h series). Analysis of such envelope functions on the ground of the group symmetry confirmed that some of the eigenstates of such excitons in the crystal environment are compatible with Γ_4^- symmetry of the electric dipole moment. The predictions by the group theory was

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fully confirmed by our data. In particular, the additional spectral lines were not observed for $n<4$, for which there are no f states. Then, for $n=4$ and $n=5$ we observed groups of 3 spectral lines, which is the number of Γ_4^- states in the subspace of the f-envelope function. Finally, starting from $n=6$ we observed additional, even weaker lines, consistently with appearance of the h states. Apart from demonstration of the extraordinary agreement between the experimental data and the hydrogen-like model, our results were a base for determination of the cubic anisotropy parameter of the Cu_2O valence band.

Dark (grey) exciton in CdTe/ZnTe quantum dots

Another case of seemingly dark excitons is encountered in self-assembled quantum dots in III-V and II-VI systems, which correspond to the T_d symmetry of the host lattice. Excitons confined in such systems consists of an electron from conduction band with spin of $S_z = \pm\frac{1}{2}$ and a heavy-hole with total angular momentum of $J_z = \pm\frac{3}{2}$. Four possible combinations of these angular momenta give rise to a characteristic fine structure of the neutral excitons, described typically using three exchange parameters [3]. The primary splitting, described by exchange parameter δ_0, takes place between parallel and antiparallel orientations of the carriers. States with antiparallel orientation of the angular momenta of the electron and the hole correspond to excitons with total angular momentum of ±1. Such states can directly recombine into photons of respective circular polarization (bright states). In contrast, states with parallel orientation of the angular momenta of the electron and the hole have total angular momentum of ±2, which is too much for a photon. Such states are therefore dark. Due to in-plane anisotropy of the quantum dots, both bright as well as dark states are additionally split in the symmetric and antisymmetric superposition of pure-spin states by energy of δ_1 (bright states) and δ_2 (dark states), but this in-plane anisotropy does not affect the principal splitting into bright and dark subspace. Most of the work investigating this fine structure focused on the bright states, particularly with aim of reduction of the δ_1 splitting in order to obtain solid-state source of entangled photon pairs [4].

In our work we focused on less explored dark exciton states **[TK3]**. This study used the system of self-assembled CdTe/ZnTe quantum dots grown using molecular beam epitaxy (MBE) at Institute of Physics, Polish Academy of Sciences. Important factor in selection of this particular system was my experience from PhD studies, which proved high optical quality of such dots.

In our study [TK3] we accessed the properties of the dark excitons using in-plane magnetic field (Voigt configuration). Such magnetic field induces a mixing between the bright and the dark states, making the latter ones appear in the photoluminescence (PL) spectrum. In order to retrieve information about the pure dark states we consequently extrapolated the observed properties to zero magnetic field. Such a procedure allowed us, e.g., determine the intrinsic decay time of the dark exciton population. For that purpose we had to perform a series of time-resolved experiments for increasing magnetic field. Our data clearly evidenced that increasing magnetic field leads to systematic shortening of the dark exciton lifetime. The natural interpretation of this fact is assumption that the radiative recombination channel opened due to dark-bright mixing is competing with field-independent non-radiative channel. Fitting this model to the data collected for various quantum dots found the zero field dark exciton lifetime in order of tens to hundreds of ns, as compared with about 0.4 ns lifetime of the bright excitons.

However, the most important finding of this work was identification of the nature of this zero-field decay of dark exciton population. As we showed, it was not governed by unspecified non-radiative recombination mechanisms, but rather radiative recombination, yet with transition dipole moment oriented along the growth axis (*z*-direction). In normal geometry of the experiment such a polarization is not detected, which explains the lack of dark exciton in the zero-field PL spectra.

A vital ingredient for such a transition dipole moment is valence band mixing, e.g. due to in-plane anisotropic strain [5]. As we showed in our work, the value of z-oriented transition dipole moment is directly proportional to the light-hole admixture in otherwise heavy-hole ground state. Another metric of this admixture was the value of the in-plane g-factor of the hole state, which could be determined from the Zeeman splitting of the charge exciton transitions. Unequivocal correlation between the dark exciton zero-field lifetime (strictly speaking: the square root of the decay rate) and the in-plane g-factor of the hole was a smoking gun of the proposed mechanism.

The final proof of the hypothesized z-polarized photoluminescence was delivered by direct measurements of the PL signal from a cleaved edge of the sample. In such a configuration the dark exciton was present in the PL spectrum already in the absence of the magnetic field. Its spectral line was indeed polarized purely along the growth axis, while the bright excitons measured in the same orientation exhibited polarization close to the quantum dot plane.

For clarity, the description presented above does not emphasize the difference between the two dark exciton states. Yet, according to the theoretical model these two states are fundamentally different. While one of these states undergoes z-polarized radiative recombination as described above, the other one is truly dark and does not exhibit any transition dipole moment. The latter exciton clearly could not have been observed in the zero-field PL spectra, but it still becomes optically activated by in-plane magnetic field. In fact, the PL transients of dark excitons under such conditions were found to be bi-exponential. Interestingly, our data suggests that both components extrapolate to the same time constant at zero magnetic field, suggesting efficient thermalization of populations of both dark excitons.

The 3D confinement of a QD makes it possible to study broad variety of excitonic complexes, even the ones that might otherwise dissociate due to Coulomb repulsion. Such an example is a doubly charged exciton X^{2-}, i.e. complex of a single hole and three electrons [6]. The work [TK4] is devoted to exploration of this complex in particularly in the context of exchange interaction with a single Mn^{2+} ion. As established in earlier works [6,7], there is a subtle link between physics of X^{2-} and the neutral exciton X. Since two electrons in X^{2-} complex are bound in closed *s*-shell, its fine structure is governed solely by the third *p*-shell electron and the hole. It is therefore fully analogous to the fine structure of the neutral exciton with its bright and dark states. In a sense **the X^{2-} may be considered a model of the neutral exciton, which is described the same Hamiltonian but with different values of exchange parameters δ_i.**

The results collected in the work [TK4] evidence that such analogy works also in case of QDs doped with single Mn^{2+} ions. Following the framework of the neutral exciton, the four possible states of X^{2-} are split into "bright" and "dark". Each of these branches is additionally split due to in-plane anisotropy. Interestingly, while the *p*-character of the interacting electron enhances the splitting of the "bright" states δ_1., the splitting of the "dark" states δ_2 is still negligible. In the discussed case of a Mn^{2+}-doped QD, exchange interaction with the localized 5/2-spin of the magnetic ion results in additional 6-fold splitting of each branches.

Despite far analogy between X^{2-} and X in terms of the Hamiltonian and the resulting eigenstates, there is a clear difference in terms of selection rules. Namely, the "dark" configuration of the spins in X^{2-} complex does not prevent the radiative recombination, since always one of the electrons in the s-shell has the required spin orientation. As a consequence, each of these configurations is subjected to radiative recombination with comparable decay rate. On the other hand, there is also important factor of a structure of the final state of two electrons, which can form either singlet or triplet configuration. Closer analysis indicates that recombination of the "dark" X^{2-} configurations lead only to the triplet state. Therefore, **with respect to transitions leading to the singlet state (which are well separated in the PL spectrum) the "dark" configurations indeed are effectively dark**, elevating the analogy with the neutral exciton to the next level. The practical example of a benefit of such approach given in the work [TK4] was the utilization of the dark exciton brightening mechanism as in Ref. [8] to assess the negligible strength of exchange interaction between Mn^{2+} and the p-shell electron.

Dark (grey) exciton in tungsten-based transition metal dichalcogenides

The third studied case of the dark exciton is related to a two-dimensional system of semiconducting monolayer transition metal dichalcogenides (TMDs) such as WSe_2 or WS_2. First experimental realization of such system was done in 2010 [9]. This work was followed shortly by identification of the key features of the band structure [10–12]. In contrast to previously discussed systems, the direct band gap of monolayer TMDs occurs at K^+ and K^- points of the Brillouin zone. Excitonic states can be built from single carrier states in either valley (K^+ or K^-), but optically active can be only excitons in which both carriers are in the same valley.

Additionally, both the valence and conduction bands are split due to substantial spin-orbit coupling, resulting in spin-valley locking: situation where the ground state at given valley (K^+ or K^-) has a well defined spin projection (↑ or ↓). Depending on the relative sign of the spin-orbit splitting in the valence and conduction band, the two carriers constituting ground-state exciton have compatible or incompatible spin projections, resulting in optically active or dark exciton, respectively.

The case of dark exciton ground state is realized in monolayer WSe_2 and WS_2 [13]. A presence of population of such excitons has a number of indirect consequences for the photoluminescence signal. The first fingerprint is the increasing dependence of the bright exciton photoluminescence signal upon increasing the temperature [14], which indicates thermal activation of the dark exciton to the higher-energy bright configuration. Another signature of the dark exciton population is appearance of the additional lines in the PL spectra at energy range below bright exciton lines (neutral and charged). In raw exfoliated monolayers these additional lines were blended together into a band tentatively identified as *localized excitons* (LEs). Later progress in encapsulation by hexagonal BN [15] allowed to resolve individual components of the *localized exciton band* and identify them as recombination of compound excitonic complexes or phonon-assisted recombination of the dark excitons [16].

The presence of the LEs in the PL spectra of WSe_2 and WS_2 monolayers was consistent with dark character of the ground state in these systems. In works [TK5] and [TK6] we analyzed in more details the polarization properties of the LEs in order to elucidate their link with the dark excitons. Our approach was based on studying the efficiency of optical orientation effect. In the experiment we excited the system using circularly polarized laser, selectively creating the excitons in only one valley. The photo-created excitons partially scattered to the other valley within their lifetime, but overall the emission from the first valley was stronger than emission from the second valley, which is the essence of the optical orientation. In our work we observed that the efficiency of the optical orientation of LEs clearly increases upon application of a magnetic field of about 20 mT in Faraday configuration. This effect was baptized Field-Induced Polarization Enhancement (FIPE). The FIPE is distinctly different from the thermalization of excitons in combination with the valley Zeeman effect [17] as the recorded polarization degree does not depend on the direction of the field. Instead, our interpretation of the FIPE effect is based on the effect of the magnetic field on the character of the eigenstates, which correspond to linear polarization at $B = 0$ T and become pure valley states in the high field limit.

Moreover, in our view the relevant are eigenstates of some intermediate state – possibly the dark exciton – which is a common reservoir for different LE states, since this is the only plausible scenario explaining why the same critical field is observed across the whole LE band [TK5]. The most striking issue related to the FIPE effect is the high sensitivity to the magnetic field, i.e. critical field as low as 20 mT. Even taking into account that dark excitons in TMDs have relatively high g-factor values of about -8 [18], such low magnetic field corresponds to the lifetime of the about 100 ps [TK5]. This lifetime is significantly longer than the lifetime of the bright excitons in TMDs [19], additionally supporting our interpretation that the FIPE effect originates from the relaxation of the valley polarization occurring at the level of the dark exciton state, which subsequently feeds the LEs states. The FIPE effect was observed both for WSe_2 as well as WS_2 monolayers [TK6]. Interestingly, the critical field for both materials is nearly the same, which indicates similar valley polarization relaxation rate for the dark excitons. The difference between the two materials is manifested in changes upon increasing the temperature: while critical field stays the same for WSe_2, it gradually increases for WS_2. This difference was attributed to different regimes of dark excitons in both materials. We inferred that in WSe_2 the intervalley relaxation of dark excitons in fast compared to the dark exciton population, while the opposite relation holds for the case of dark excitons in WS_2.

In works [TK5] and [TK6] discussed above, the properties of dark excitons were studied indirectly, by observation of the resulting polarization of LEs. However, in analogy with the case of self-assembled QDs, it is possible to observe dark excitons directly in the PL spectrum. The first method is to apply in-plane magnetic field to mix dark and bright exciton states. It was demonstrated for the first time in 2017 [20], but it required strong magnetic field and subtle data processing to extract from the PL spectrum the contribution of the dark exciton. This situation was radically changed by encapsulating the monolayers in hBN [15]. The resulting improvement in the optical quality of the PL spectrum allowed to resolve dark exciton in much smaller magnetic field. Moreover, the high-quality samples enabled direct observation of the dark exciton through a z-oriented dipole transition moment [21–23]. The latter mechanism leads to emission directed in the monolayer plane, which poses additional experimental difficulty, but on the other hand opened the way for the first observation of the dark exciton fine structure in WSe_2 [23].

In our work [TK7] we studied in details the control over dark excitons in encapsulated WSe_2 monolayer using magnetic field of various orientations. Our results with respect to the Faraday magnetic field were consistent with earlier findings of Ref. [23]. At zero magnetic field there are two eigenstates of the dark excitons: grey exciton (Γ_4 in D_{3h} symmetry group) and fully dark exciton (Γ_3). The former one is present in the spectrum if the microscope objective has sufficiently large NA. Upon increasing the magnetic field in Faraday configuration, the Zeeman splitting becomes dominant and both eigenstates share the non-zero z-oriented dipole transition moment. Extrapolation of their energy position leads to determination of zero-field fine structure splitting of 0.6 meV. The same measurement yields also absolute value of g-factor of 9.6. In this work we studied also the effect of in-plane magnetic field. As expected, such field orientation leads to much smaller energy shifts due to anisotropic character of valley Zeeman effect [17]. Instead, the primary effect of such field was gradual increase in oscillator strength due to dark-bright mixing. This mechanism works for both of the dark excitons, which acquire perpendicular linear polarizations. Importantly, both these effects can be combined together, which we demonstrated by application of oblique magnetic field. Consistently with predictions of spin Hamiltonian model, the x,y-oriented dipole transition moments induced by in-plane component of the magnetic field are combined to σ^+ and σ^- polarizations, which are relevant for Zeeman effect caused by z-component of the magnetic field. Using such approach allowed us to unequivocally determine the negative sign of the dark exciton g-factor in WSe_2. Our finding is important also for future works on dark excitons, as it opens the way to selectively resonantly excite the dark excitons in a particular valley.

Due to availability of good quality charge-neutral samples, vast majority of the studies of dark excitons in TMDs was performed on WSe_2 monolayers, with implicit assumption that the properties of WS_2 should be similar. Experimental verification of such similarity is the focus of Ref. [TK8], in which we explore dark excitons in hBN-encapsulated monolayer WS_2. The measurements in strong in-plane magnetic field (up to 30 T) confirmed the presence of dark excitons about 40 meV below the emission of the bright exciton. In contrast to the case of WSe_2, two fine structure components of the dark excitons were not resolved. Determination of the fine structure splitting (yielding 0.5 meV) required performing the experiment with polarization resolution and utilization of the fact, that in-plane magnetic field imbues two dark excitons with perpendicularly oriented dipole transition moments.

Notably, the results published in Refs. [TK7,TK8] evidence that even under strong (30 T) in-plane magnetic field the radiative recombination is still not the dominant decay channel for the dark excitons. Such a conclusion can be drawn from the observation that the dark exciton decay time (measured using a streak camera) does not shorten upon increasing the in-plane magnetic field. However, the same conclusion also stems from the fact that the time-integrated PL intensity of the dark exciton increases quadratically in the whole range of accessible magnetic field, which would not be a case if the radiative recombination was already the main decay channel for the dark exciton population.

As discussed the dark excitons offer exceptional degree of control, including both energy spectrum (i.e. energy separation of the two dark eigenstates) as well as the oscillator strength making them an attractive research platform. The most deficiency recognized so far is the prevalence of the non-radiative decay. If this issue will be resolved by further technological progress, the dark excitons may become a viable option also for optoelectronic applications.

Literature

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Series of publications on the optical investigation of dark (grey) excitons

[TK1] **T. Kazimierczuk**, D. Fröhlich, S. Scheel, H. Stolz, and M. Bayer, *Giant Rydberg Excitons in the Copper Oxide* Cu_2O, Nature 514, 343 (2014).

I was the main person responsible for planning and conducting all the experiments in the work, including analysis of the data. I actively participated in data modelling, discussions and preparation of the manuscript.

[TK2] J. Thewes, J. Heckötter, **T. Kazimierczuk**, M. Aßmann, D. Fröhlich, M. Bayer, M. A. Semina, and M. M. Glazov, *Observation of High Angular Momentum Excitons in Cuprous Oxide*, Phys. Rev. Lett. 115, 027402 (2015).
I personally conducted the experiments reported in the work together with a PhD student Johannes Thewes and MSc student Julian Heckötter. I conducted a group theory calculations in collaboration with prof. D. Fröhlich.

[TK3] T. Smoleński, **T. Kazimierczuk**, M. Goryca, T. Jakubczyk, Ł. Kłopotowski, Ł. Cywiński, P. Wojnar, A. Golnik, and P. Kossacki, *In-Plane Radiative Recombination Channel of a Dark Exciton in Self-Assembled Quantum Dots*, Phys. Rev. B 86, 241305 (2012).
I supervised a M.Sc. student Tomasz Smoleński, who conducted the experiment. I actively participated in analysis of the experimental data, discussions, development of the model description of the obtained results, and preparation of the manuscript.

[TK4] T. Smoleński, M. Koperski, M. Goryca, P. Wojnar, P. Kossacki, and **T. Kazimierczuk**, *Optical Study of a Doubly Negatively Charged Exciton in a CdTe/ZnTe Quantum Dot Containing a Single Mn^{2+} Ion*, Phys. Rev. B - Condens. Matter Mater. Phys. **92**, (2015).
I supervised and actively participated in realization of the project, in particular in conceiving of the experiment, discussions of the results, data analysis and modeling, to preparation of the manuscript.

[TK5] T. Smoleński, M. Goryca, M. Koperski, C. Faugeras, **T. Kazimierczuk**, A. Bogucki, K. Nogajewski, P. Kossacki, and M. Potemski, *Tuning Valley Polarization in a WSe_2 Monolayer with a Tiny Magnetic Field*, Phys. Rev. X 6, 021024 (2016).
I supervised experimental work of PhD student Tomasz Smoleński, who played a leading role in this project. I actively participated in analysis of the experimental data, discussions and preparation of the manuscript.

[TK6] T. Smoleński, **T. Kazimierczuk**, M. Goryca, M. R. Molas, K. Nogajewski, C. Faugeras, M. Potemski, and P. Kossacki, *Magnetic Field Induced Polarization Enhancement in Monolayers of Tungsten Dichalcogenides: Effects of Temperature*, 2D Mater. 5, 015023 (2018).
I planned the reported experiments in collaboration with PhD student Tomasz Smoleński, supervised their conduction and actively participated in analysis of the experimental data. I provided the theoretical description of the observed trends and participated in preparation of the manuscript.

[TK7] M. R. Molas, A. O. Slobodeniuk, **T. Kazimierczuk**, K. Nogajewski, M. Bartos, P. Kapuściński, K. Oreszczuk, K. Watanabe, T. Taniguchi, C. Faugeras, P. Kossacki, D. M. Basko, and M. Potemski, *Probing and Manipulating Valley Coherence of Dark Excitons in Monolayer WSe_2*, Phys. Rev. Lett. 123, 096803 (2019).
I conducted the experiments performed in Warsaw using free-beam vector cryostat (the other part of experiments was performed in LNCMI, Grenoble, in fiber-based setup with a 14 T magnet). I actively participated in analysis of the experimental data, discussions and preparation of the manuscript.

[TK8] M. Zinkiewicz, A. O. Slobodeniuk, **T. Kazimierczuk**, P. Kapuściński, K. Oreszczuk, M. Grzeszczyk, M. Bartos, K. Nogajewski, K. Watanabe, T. Taniguchi, C. Faugeras, P. Kossacki, M. Potemski, A. Babiński, and M. R. Molas, *Neutral and Charged Dark Excitons in Monolayer WS_2*, Nanoscale 12, 18153 (2020).
I supervised the experiments performed in Warsaw using free-beam cryostat by a PhD student Magdalena Zinkiewicz (the other part of experiments was performed in LNCMI, Grenoble, in fiber-based setup with a resistive magnet). I actively participated in analysis of the experimental data, discussions and preparation of the manuscript.

T. Kaz

5. Presentation of significant scientific or artistic activity carried out at more than one university, scientific or cultural institution, especially at foreign institutions

After awarding the PhD degree at University of Warsaw, I worked for 30 months as a post-doctoral fellow at Technical University of Dortmund in group of Prof. Manfred Bayer. My main task was to study influence of the nuclear spins on the dynamics of electrons in pump-probe experiments, however over the course of my stay I worked also on other projects.

Part of the results, namely the experiments on bulk Cu_2O, are included in the scientific achievement described in Section 4.

Other activities (which resulted in published articles, but outside the scope of the scientific achievement in Section I) included utilization of the photon-counting mode of a streak camera. We used it to explore the influence of interactions with noncondensed particles on the coherence of a one-dimensional polariton condensate. Such experiments were made possible thanks to creative two-beam expansion of the already novel technique of ultrafast photon correlations using a streak camera.

The experiments described above were inspiration for another project: photon-statistics excitation spectroscopy as a tool to study non-linearity of the photonic system. Here we utilized more standard detection technique of Hanbury-Brown-Twiss detection scheme. Instead, we analyzed the effect of excitation of the system with light of different photon statistics (such as coherent or pseudo-thermal) to evidence that description of the laser properties in terms of mean input photon numbers is not sufficient.

6. Presentation of teaching and organizational achievements as well as achievements in popularization of science or art

Supervision over diploma theses

- Supervision of BSc work of Aleksander Rodek entitled “Correlations of single photons emitted from II-VI quantum dots in a single-mode-fiber-based experimental setup” (2017, Faculty of Physics, University of Warsaw)
- Supervision of MSc work of Piotr Starzyk entitled “Quantum dot resonant spectroscopy” (2017, Faculty of Physics, University of Warsaw)
- Co-supervision (*promotor pomocniczy*) of on-going PhD work of Aleksander Rodek
- Co-supervision (*promotor pomocniczy*) of on-going PhD work of Aleksander Bogucki

Teaching

My employment at Faculty of Physics includes teaching duties. Over last 5 years I taught following subjects:

- Physics of Condensed Matter and Semiconductor Structures (lecture)
- Digital technology (lecture)
- Programming I (lecture)
- Physics I: Mechanics (class excercises)
- Physics III: Waves (class excercises)
- Computational Tools in Data Analysis (class excercises)

- Computing workshop (class excercises)
- Programming I R (class excercises)
- Programming II R (class excercises)

Popularization of science

I am an active member of the Committee of the Polish Physics Olympiad since 2005. I am co-author the problems for the competition. I am also involved in grading participants solutions and training of the Polish representation for the International Physics Olympiad. I also actively contribute in the organizational side of the competition. I am solely responsible for the IT systems, which became particularly critical since the outbreak of COVID-19 pandemic. In 2020 I was the team leader for the European Physics Olympiad, which took place instead of postponed International Physics Olympiad.

Organizational contribution

- member of the Faculty Council at Faculty of Physics, University of Warsaw (2014-present)
- member of the Academic Council of Physical Sciences (RND) at University of Warsaw (2019-present)
- I am involved in realization of the "Excellence Initiative – Research University" (IDUB) programme at University of Warsaw. In particular, I am a member of the Coordinating Committee. I am also a coordinator of "Fund for Renovation and Development of Research Infrastructure" action, which is one of two major infrastructure-oriented tasks in the IDUB project.

7. Apart from information set out in 1-6 above, the applicant may include other information about his/her professional career, which he/she deems important.

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