Book of abstracts

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OPTO2019

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Introduction

OPTO History
The history of the OPTO conferences in Poland dates back to 2005 when the SPIE International Congress on Optics and Electronics was held in Wroclaw. The primary idea behind the meeting was to gather young scientists from all, polish SPIE Student Chapters and SPIE members from all over the world. Just the next year, the conference formula expanded to all OSA Student Chapters from Poland and other OSA members (International OSA/SPIE Student Chapters Meeting, Wroclaw, 2006). Since then, it became an annual event held each year in a different, polish city. The conference is organized each year by OSA and SPIE Student Chapters from the host city.

About OPTO 2019
OPTO 2019 is an international conference organized in Poland annually by students for students. The topics of the meeting include optics, photonics, and related fields. We strive to provide students and young researchers from (mainly) mid-eastern Europe a chance to present and discuss their latest scientific achievements. By inviting notable scientists from all over the world as Invited Speakers, we aim to establish a high scientific standard. During the meeting, young researchers get a chance not only to broaden their knowledge by attending interesting lectures but also to gain very valuable experience in presenting their research and improve soft skills. Professional development plays a crucial role in the education of a young researcher. As we wish for the conference to have a high impact on young scientist’s careers we provide special sessions devoted to these issues. It is also a unique networking opportunity, as the meetings gather a great number of students studying the same field.

This year the conference is organized for the 14th time. It will be a very special event since for the 5th time the conference is taking place in Toruń.
OPTO2019 conference is taking place at Nicolaus Copernicus University, Institute of Physics, Faculty of Physics, Astronomy and Informatics, 5 Grudziądzka Str., Toruń.

All talks will be given in room 26. Poster session will be taking place in COK Atrium.
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Invited speakers

During OPTO 2019 participants will have an opportunity to listen to plenary lectures delivered by following notable speakers:

- **Prof. Urbasi Sinha** - Raman Research Institute, Bengalore, India;
- **Prof. Vadim Makarov** - Quantum Hacking Lab, Russian Quantum Center, Moscow, Russian Federation;
- **Dr Akiko Nishiyama** - Institute of Physics, Nicolaus Copernicus University in Toruń, Poland;
- **Dr Grzegorz Soboń** - Laser & Fiber Electronics Group, Faculty of Electronics, Wrocław University of Science and Technology, Poland.
Can quantum physics break cryptography’s curse?

Prof. Vadim Makarov
Quantum Hacking Lab, Russian Quantum Center, Moscow, Russian Federation
http://www.vad1.com/lab/

The history of cryptography is a history of failures. Stronger ciphers replaced broken ones, to be in turn broken again. Quantum cryptography offers a hope to end this replacement cycle, for its security premises on the laws of physics and not on limitations of human ingenuity and computing power. I will tell about ongoing deployment of quantum cryptography networks using fiber-optic and satellite links, and efforts to certify their implementation as secure.

Ultracompact lasers emitting ultrashort pulses – from simple oscillators to mid-infrared optical frequency combs

Dr. Grzegorz Soboń
Laser & Fiber Electronics Group, Faculty of Electronics, Wrocław University of Science and Technology, Wrocław, Poland

Lasers emitting very short optical pulses (on the timescale of femtoseconds) are on demand of many applications in industry and fundamental research. Usually the term "femtosecond laser" is associated with a bulky, complex and expensive device. On the other hand, the well-established telecom fiber technology enabled the development of the probably world’s simplest fiber laser that emits pulses as short as 25 fs in the near-infrared spectral range, and comes for a price of less than 2000$. Such source can serve as pump sources for various nonlinear processes, like frequency conversion, mid-infrared generation, and optical frequency comb generation. As an example, the design of a fully-fiberized, mid-infrared frequency comb capable of covering the 6 – 9 μm wavelength region will be discussed. The heart of the comb is a graphene-based, femtosecond fiber laser. With the use of novel fiber-optic technology a broadband and tunable frequency comb with exceptional simplicity can be easily obtained. The research on compact and simple fiber lasers paves the way for outside-of-lab applications of frequency combs, e.g. in industrial process monitoring and environmental sensing.
The dual-comb spectroscopy is a new spectroscopic technique using optical frequency combs. Optical frequency combs have comb-like spectrum as shown in Fig. 1. And Fig. 2 shows a principle of dual-comb spectroscopy. In dual-comb spectroscopy, two optical frequency combs which have slightly different repetition frequencies ($f_{rep}$) are used as spectroscopic light sources. The outputs from two combs are overlapped and input to a single photo detector, and we can observe interferogram of two combs without mechanical scan of optical path length. The resulting spectrum from Fourier-transform of the interferogram shows precise comb spectrum. The dual-comb technique realizes higher resolution than conventional Fourier-transform infrared spectroscopy (FTIR) and broadband spectral measurement in short acquisition time. The dual-comb spectroscopy has proven to be a valuable tool for a variety of applications, such as precise spectroscopy [1], remote sensing [2], solid material characterization [3], and spectro-imaging [4]. Most of the dual-comb studies that are based on absorption spectroscopy detect the linear absorptions, but since the frequency combs have properties as ultrashort pulses, the dual-combs can also be applied to nonlinear spectroscopic techniques. I applied the dual-comb spectroscopy to double-resonance spectroscopy and two-photon spectroscopies, and realized precise measurements with subDoppler resolution [5, 6]. In my talk, I will show details of principle and techniques of dual-comb spectroscopy, and I will present the application of dual-comb spectroscopy to Doppler-free high-resolution spectroscopy.

References


The Quantum Information and Computing lab at the Raman Research Institute in Bangalore, India has been performing cutting edge research in quantum information processing towards quantum computation, quantum communication as well as fundamental tests of quantum mechanics itself using single and entangled photons. In this talk, I will discuss one of our recent results which is a new insight to a widely used quantum optics phenomenon [1].

The famous Hong-Ou-Mandel two-photon coincidence visibility dip (TPCVD), which accepts one photon into each port of a balanced beam splitter and yields an equal superposition of a bi-photon from one output port and vacuum from the other port, has numerous applications in photon-source characterization and to quantum metrology and quantum computing. Exceeding 50% two-photon-coincidence visibility is widely believed to signify quantumness. Here, we show theoretically that classical light can yield a 100% TPCVD for controlled randomly chosen relative phase between the two beamsplitter input beams and experimentally demonstrate a $99.635 \pm 0.002\%$ TPCVD with classical microwave fields. We show quantumness emerges via complementarity for the biphoton by adding a second beam splitter to complete an interferometer thereby testing whether the biphoton interferes with itself: Our quantum case shows the proper complementarity trade-off whereas classical microwaves fail.

I will also give a general overview of some of our other ongoing experiments and end with our broad vision for the future with our mega project on Quantum Experiments using Satellite Technology (QuEST) in collaboration with the Indian Space Research Organization.

References

Oral presentations

**Session I: Lasers**, Wednesday, 24.07, 10.30 - 11.30,
speakers: O. Drożdżowska, P. Grześ, K. Stefańska

**Session II: Sensing**, Wednesday, 24.07, 12.00 - 13.40,
speakers: M. Kołodziej, P. Kałużynski, M. Sobczak, K. Czajkowski, A. Rodek

**Session III: Single photons**, Wednesday, 24.07, 15.30 - 16.30
speakers: M. Gieysztor, A. Widomski, K. Oreszczuk

**Session IV: Measurements**, Wednesday, 24.07, 17.00 - 18.00
speakers: P. Węgrzyn, J. Dobosz, M. Surma

**Session V: Metamaterials**, Thursday, 25.07, 10.00 - 11.00
speakers: A. Korneluk, M. Bancerek, J. Szlachetka

**Session VI: Spectroscopy**, Thursday, 25.07, 11.30 - 13.10
speakers: M. Słowiński, P. Putko, M. Konefał, M. Raczyński, J. Mijas

**Session VII: Spin-waves**, Thursday, 25.07, 15.00 - 16.00
speakers: A. Golestani, A. Leszczyński, M. Lipka

**Session VIII: Quantum tomography**, Friday, 26.07, 10.00 - 11.00
speakers: J. Wilkens, A. Kamińska, M. Kopciuch

**Session IX: Nanostructures**, Friday, 26.07, 12.00 - 13.10
speakers: A. Bogucki, J. Szymczak, W. Talik, M. Müller, K. Polczyńska

**Session X: Material science**, Friday, 26.07, 16.00 - 17.00
speakers: D. Chomicki, S. Zięba, A. Łopion

**Session XI: Optical devices**, Friday, 26.07, 17.30 - 18.10
speakers: F. Łabaj, M. Bocheński
Soliton self-frequency shift in microstructured silica fibers

O. Drożdżowska1, G. Soboń1, J. Sotor1, K. Stefańska2, K. Tarnowski2, K. Poturaj3, M. Makara3, P. Mergo3, T. Martynkien2

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2. Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wroclaw, Poland
3. Laboratory of Optical Fiber Technology, Maria Curie-Sklodowska University, Plac Marii Curie-Skłodowskiej 3, 20-031 Lublin, Poland

Tunable laser sources are desirable in vast variety of applications including spectroscopy, optical metrology and microscopy. Since 90s there has been growing interest in nonlinear effects occurring in optical fibers, considering especially stimulated Raman and Brillouin scattering [1]. Soliton self-frequency shift is an effect, resulting from stimulated Raman scattering, occurring in nonlinear fibers for short pulses (< 1 ps) where one part of the soliton spectrum (high frequency components) serves as a pump for the other part of the spectrum (low frequency components). In consequence, the soliton experiences shift towards longer wavelengths [2]. Therefore, by adjusting pumping power we can easily obtain a wavelength-tunable fiber laser [3].

Figure 1: (a) Schematic of the setup providing light to the microstructured silica fiber where SSFS effect occurs (PBS - Polarizing Beam Splitter). (b) Optical spectra of the shifted solitons in the fiber of the length from 110 - 15 cm.

In this work we demonstrate generation of soliton shift in 2 µm range in silica-based, germanium-doped microstructured optical fibers. A mode-locked fiber laser operating at 1550 nm wavelength, delivering 27 fs pulses at 45 MHz repetition rate was used as a pump source. As shown in Fig. 1(a) the pulses were coupled into the core of the fiber via an aspheric lens. In the experiments, we investigated several types of fibers, provided by the Laboratory of Optical Fiber Technology, Maria Curie-Sklodowska University in Lublin. By changing the amount of optical power coupled into the core of the fiber we can adjust the wavelength of the shifted soliton. At maximum power of 115 mW, shifts up to 2.2 µm were obtained. Simultaneously, the fiber converts the pump radiation towards shorter wavelengths (so called dispersive wave, DW). The wavelength of the DW depends on the design of the fiber, and in our case it was possible to achieve DWs between 800-1100 nm.

We have investigated the influence of the fiber length on the soliton shift process. By changing the
length of the fiber from 110 to 15 cm, for the same input power we observed that the soliton could be still shifted above 2000 nm, ideally matching the gain bandwidth of Thulium-doped gain media (Fig. 1(b)).

References


**Funding:** National Centre for Research and Development (POIR.04.01.01-00-0037/17)
Relaxation oscillations suppression in nanosecond pulse generation in semiconductor lasers

P. Grześ, J. Świderski
Institute of Optoelectronics, Military University of Technology, gen. Sylwestra Kaliskiego 2, 00-908 Warszawa, Poland

Semiconductor lasers have recently attracted much attention, mainly due to high robustness, compact design and fully electronic control, which led to high accessibility of these relatively inexpensive coherent light sources. In many applications, such as medicine or LIDARs, high-fidelity nanosecond pulses from semiconductor lasers are required. Unfortunately, directly modulated laser diodes generates nano- and subnanosecond optical pulses with significant distortions due to relaxation oscillations.

One of the method to completely suppress the relaxation oscillations is light injection. In this technique a master light source rises the initial photon density in the slave laser’s cavity. In effect, initial spike amplitude is reduced and relaxation oscillations dumping factor is increased. The output pulse has a smooth temporal shape and spectral properties of the signal are improved [1, 2].

In this work a light injected laser generating nano- and subnanosecond pulses without relaxation oscillations is presented. The numerical solutions based on rate equations show high on-off ratio, demanded in many applications. The experimental setup is all-fiber optoelectronic circuit based on two pigtailed semiconductor lasers. As a result a high-speed high-fidelity optical pulse generation has been achieved.

References


Experimental investigation of group velocity dispersion in nonlinear optical fibers
K. Stefańska¹, K. Tarnowski¹, G. Soboń², J. Sotor², P. Mergo³, T. Martynkien¹

1. Department of Optics and Photonics, Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, Wybrzeże Wyspińskiego 27, 50-370 Wrocław, Poland
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3. Laboratory of Optical Fiber Technology, Maria Curie-Skłodowska University, pl. M. Curie-Skłodowskiej 3, 20-031 Lublin, Poland

The spectral dependence of group velocity dispersion (GVD) is a crucial parameter in determining the application of specific optical fibers. Nonlinear optical fibers designed for supercontinuum generation or optical signal processing require precise dispersion management in order to facilitate high pulse energies, wide bandwidths or both. The microstructured optical fibers allow tailoring of dispersion profiles while simultaneously maintaining high nonlinear coefficient. Changes in size or location of air holes affect group velocity dispersion [1, 2], hence establishing its spectral dependence in the newly designed and fabricated fibers is vital.

Figure 1: Spectral dependence of GVD of nonlinear fibers designed for different applications. Insets show cross-sections of the investigated fibers: average diameters of the air holes in the first ring are 0.96µm in fiber 1 and 0.26µm in fiber 2, fiber 3 has no air holes.

In our work we experimentally investigate spectral dependencies of GVD in three different nonlinear fibers to indicate their usefulness for distinct nonlinear applications. To achieve this goal, we employed a polychromatic light interferometric method based on Mach-Zehnder interferometer architecture. The tested fiber was placed in one arm of interferometer while the reference’s arm length was adjustable. Measurements were performed in the spectral range 1.1 – 2.1µm using broadband supercontinuum source. The length of the fibers did not exceed one meter which resulted in optimal width of interferometric fringes.

Obtained values of dispersion of investigated fibers are demonstrated in Figure 1. The spectral characteristic of GVD in fiber 1 allows to observe soliton generation and self frequency shift [1] while all-normal supercontinuum generation will be possible owing to relatively flat and negative values of dispersion of fiber 2 [2]. Finally relatively high absolute values of dispersion in fiber 3 allow to utilize it as a dispersion compensating fiber (laser cavity dispersion compensation or soliton compression) [3].
References


**Funding:** National Centre for Research and Development (POIR.04.01.01-00-0037/17)
Noise robust single-pixel video imaging with Fourier domain regularization
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Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warszawa, Poland

Single-pixel cameras [1] offer a novel paradigm for imaging that requires a single photodiode instead of a detector array to acquire an image of the target scene. These devices are especially useful for imaging in wavelength regimes for which cameras are difficult to fabricate or for specialized applications like hyper-spectral imaging or imaging through scattering media. Most of the common single-pixel cameras contain a DMD (digital micromirror device) on which sampling patterns correlated with natural images are displayed to modulate the light scattered from the scene [2]. The imaging refresh rate and quality depend on the choice and number of patterns displayed on the DMD during image acquisition and on the algorithm used for image reconstruction.

We have recently proposed a reconstruction formula based upon the regularization of the inverse problem obtained by minimizing the norms of the convolution between the reconstructed image and a set of spatial filters [3]. At high compression, this Fourier domain regularized inversion (FDRI) method provides a faster alternative to compressive sensing algorithms as it requires only a single matrix by vector multiplication to obtain the reconstructed image. Based on FDRI, we have demonstrated an experimental realization of single-pixel camera with real-time reconstruction obtained in parallel with measurement at a frame rate of 11 Hz with a resolution of 256 × 256.

To reduce the impact of noise in our experimental setup we have used balanced photodetection or sampling patterns expressed as a linear combination of vertices of a multidimensional regular simplex [4]. We have shown that by distributing sampling over simplex vertices the impact of varying experimental conditions can be mitigated at a much lower number of additional sampling patterns than when standard differential sampling is used. By combination of such sampling with FDRI we obtain a noise-robust single-pixel imaging protocol with high imaging quality and real-time image acquisition.
References


**Funding:** We acknowledge financial support from Narodowe Centrum Nauki (NCN) (UMO-2017/27/B/ST7/00885).
Properties of birefringent media measured in reflection system using the Stokes Polarimeter

M. Sobczak, M. Owczarek, P. Kurzynowski Department of Optics and Photonics, Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, Wybrzeże Wyspińskiego 27, 50-370 Wrocław, Poland

The Stokes Polarimeter consists of a linear polarizer (P) and two liquid crystal variable retarders (LCVR) [1]. It is used to generate and to analyze states of light polarization through an electro-optical modulation of LCVRs to received expected polarization states of the light. The standard set up of this polarizer/analyzer works in six states: four linear (0°, 90°, +45° and -45°) and two circular ones with ellipticity angles equal to +45° (right-handed) and -45° (left-handed).

Figure 1: Measurement setup: S – collimated light source, BS – beam splitter, SP – Stokes Polarimeter (included: P – linear polarizer, LCVR1 and LCVR2 – first and second liquid crystal variable retarders), O – tested object, M – plane mirror, CCD – CCD camera.

In the reflection system (Fig.1.), the Stokes analyzer simultaneously performs as the polarizer. Linear polarizers provide parallel-polarized polariscopes, while circular polarizer provide cross-polarized polariscopes. The light passes through elliptic polarizer then through the birefringent medium and reflect back, passes through the birefringent media and passes through the polarizer but now working as the analyzer. Thus, we effectively have the polarizer – the birefringent medium – the analyzer, i.e. the parallel-polarized polariscope for linear polarizers, and the cross-polarized polariscope for circular polarizers. The output intensity is described by equation (where - Stokes vector of input light, - Mueller matrix of birefringent media, - Stokes vector of analyzer), which after passing through the set-up gives six different intensities of the light. Obtained intensities enable to calculate first column’s, first line’s and diagonal components of Mueller matrix respectively. These components allows us to compute parameters of birefringent medium: a transmission coefficient of fast wave (T_f), a transmission coefficient of slow wave (T_s), an azimuth angle of the birefringent medium (α), an ellipticity angle of the birefringent medium (θ) and a phase shift introduced by the birefringent medium (γ). This set-up was successfully tested.

References

Effect of Scaling in Two-Plane Computer Generated Fresnel Hologram for Sub-THz Radiation

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In this work synthetic Fresnel hologram for sub-terahertz (sub-THz) radiation is presented. In comparison with visible electromagnetic waves (light) or X-rays, THz radiation is characterized by very long wavelength and non-ionizing properties. It is also known for its high absorption by water molecules, therefore it can be used for non-destructive evaluation of composite materials or for non-invasive detection of cancerous changes in skin. Terahertz radiation has been also receiving a lot of attention from telecommunication industry for increasing the bandwidth.

Computer generated hologram (CGH) or synthetic hologram opens possibilities for imaging of objects created only in the memory of a computer (not existing). One of the most amazing features of synthetic holography is the opportunity to relatively easily design object allowing for multiple image creation at different positions. This way such hologram can be used as image marker for distance detection. This feature can be also useful as another method to design MIMO (Multiple-Input-Multiple-Output) system.

Long wavelength of terahertz radiation and conveniently good optical properties of widely accessible 3D printing materials create opportunity to design cheap optical elements for this part of electromagnetic radiation.

For these reasons following paper shows 3D printed synthetic Fresnel hologram with 2 distinct image planes. Comprehensive analysis including illumination scaling and frequency change of illuminating beam is given.

![Images obtained from simulation. In case of images (a) and (b) hologram was illuminated with \( \lambda = 1.76 \text{ mm} \) (design wavelength - DWL). (c) and (d) were created after illumination with \( \lambda = 2.14 \text{ mm} \). Numbers under images show distance at which image was obtained.](image)

Table 1 shows values of lateral magnification calculated for DWL (1.76 mm) and 2.14 mm. As expected, decrease of image magnification obtained from hologram under illumination with longer wavelength can be observed.
Table 1: Comparison of magnifications calculated and obtained during experimental phase.

<table>
<thead>
<tr>
<th>Image number</th>
<th>$\lambda = 1.76\ mm$</th>
<th>$\lambda = 2.14\ mm$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory</td>
<td>1.23</td>
<td>1.61</td>
</tr>
<tr>
<td>Experiment</td>
<td>1.27</td>
<td>1.65</td>
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Presented data is the continuation of work published in the article earlier this year [1].

References

Nitrogen oxides (NOx) and nitrogen dioxide (NO₂) gases are nowadays an important point of interest for many scientists due to their nature of impact on the environment and human health. Their main source is the result of combustion of fuels in cars, especially from diesel engines. Literature reports that nitrogen oxides are also a carcinogenic factor and are associated with increased mortality. Air pollution caused by the emission of these gases is still one of the main environmental threats and is regulated by different European law and normative acts like Euro 3-6 and in future by Euro 7. Due to such normative acts, many manufacturers modify the current engine designs by reducing their cylinder volume, installing post combustion systems, DPF filters or modern catalytic solutions to reduce emissions of harmful oxides. On the other hand, modern cars use turbo-charging or compressors to increase the power of engine (in case of smaller cylinder volume), which also increases harmful gases emission. Considering all the above-mentioned aspects, monitoring of air pollution in terms of nitric oxide pollution is very important and in recent studies a lot of effort has been put into it.

Inorganic semiconductor oxides, organic conducting polymers, graphene and graphite oxides are currently being studied as a sensing materials for various sensor types, like surface acoustic wave (SAW), quartz crystal microbalance (QCM) and organic thin film transistors (OTFT). Well known polymers like: poly-3-hexylthiophene (P3HT), polystyrene, polyaniline are widely used in these devices. Unfortunately, due their poor processability, scientist are looking for novel easy processable, available and cheap materials. By grafting different functional groups to P3HT we can change it parameters.

This work presents an investigation on conductive graft comb copolymer polymethylsiloxane (PMS) with poly(3-hexylthiophene) (P3HT) and poly(ethylene) glycol as functional side groups and its mixtures with different semiconductor inorganic oxides nanomaterials like zinc oxide or titanium dioxide, which were used as a sensing layer for organic thin film transistor (Pic. 1) or chemoresistor for gas sensing.

Acknowledgments: Syntheses of graft combcopolymer materials were performed with the support from the Foundation for Polish Science grant POMOST 2011-3/8. The work was partially sponsored by the Faculty of Electrical Engineering of Silesian University of Technology within the grant BKM/563/RE4/2016.
Ultrafast studies of exciton dynamics in hBN/MoSe$_2$/hBN heterostructures by degenerate pump-probe experiments.

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Transition Metal Dichalcogenides (TMDs) are a class of materials that are subject to continuous interest due to a number of fascinating quantum phenomena that come from their specific electronic structure, symmetry breaking and strong many-body interactions.

Moreover a possibility to selectively create carriers in a given valley by excitation with circularly polarised light make TMDs a promising candidate for various opto-electronic devices and an attractive platform for studying strong light-matter interactions. Due to their structure and dimensionality they exhibit considerable potential for modification of their physical properties by constructing different van der Walls heterostructures.

Nevertheless, extremely short lifetimes of excitonic complexes in these materials require experimental techniques of subpicosecond resolution, the most versatile being pump-probe measurements allowing for tuning into different energy states.

One of the most widely explored option that leads to significant improvement of their optical properties is encapsulation in thin layers of hexagonal Boron Nitride. In particular recent studies of this process for MoSe$_2$ monolayers were followed by a discovery of a highly efficient ultrafast dielectric mirrors. In our work we study single layer of MoSe$_2$ encapsulated in hexagonal BN by means of degenerate pump-probe spectroscopy with spectral resolution. Our novel approach to beam separation allows direct probing of exciton dynamics in a given valley by measuring reflection in specific polarisation in a setup assuring µ-meter spatial resolution. This approach allows us to directly measure the rates of different decay channels in our system in low temperatures (5 K) under resonant excitation.

Figure 1: Differential reflectivity of hBN/MoSe$_2$/hBN as a function of time delay between pump and probe beams for co- and cross-circularly polarised light T=5K.
Excitation dynamics of single photon emitters in monolayer and bilayer WSe$_2$

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Monolayers of transition metal dichalcogenides (TMDs) draw a lot of attention as semiconducting materials with robust optical properties, strong Coulomb interaction and an optically accessible valley degree of freedom. Monolayer WSe$_2$ is an example of material in which, apart from free neutral and charged excitons, there is also whole band consisting of spectrally broad weakly localised excitonic states. Within this band spectral narrow lines have been observed. They are potentially interesting from photonics point of view. Such objects were shown to be spontaneously created at the edges of monolayers, defect sites or in the high-strain centers. This type of strongly localised emitter is characterized by single photon emission, very small linewidth and long luminescence lifetime [1, 2], which altogether with extraordinary properties of the free excitonic states in monolayer TMDs open up a field for many applications in photonics and optoelectronics.

In this work we show that single photon emitters in monolayer and bilayer WSe$_2$ exhibit PL rise time when the system is excited non-resonantly above the energy of the free excitons. This time of few tens to one hundred picoseconds is similar to the PL lifetime of the weakly localized states, which suggests, that non resonant excitation of single photon emitters involves weakly localized states playing a role of an intermediate state. To confirm this hypothesis and to study in detail the potential role of direct relaxation from non-localised states we compare two abovementioned characteristic times at elevated temperatures, for which lifetime of weakly localized states shortens. Furthermore we perform spatially and time resolved measurements to study the role of carrier diffusion between weakly localized states and from weakly localized states to single photon emitters.

References


Absorption of a heralded single photon by a nitrogen vacancy center in diamond

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Nitrogen-vacancy (NV) center emerges as an important system exhibiting promising properties for applications in quantum technologies, including quantum information processing, quantum metrology as well as single photon sources \cite{1}. In our work a simple, room temperature, cavity- and vacuum-free interface for photon-matter interaction is implemented. Here we report an experiment in which a heralded single photon is absorbed by a single atom-like system, which is an NV center in diamond. The NV center emits then another photon, which arrival time is measured. The heralded single photon source is based on spectrally non-degenerate spontaneous parametric down conversion (SPDC) process, where a detection of an infrared photon is used as a herald for the visible photon. The heralded single photon source used in the experiment is tunable in the range of 452-575 nm \cite{2}. The single photon at 532 nm was chosen but other pumping scenarios were tested as well. In Fig. 1 the obtained NV fluorescence decay pumped with heralded single photons is shown.

![Fluorescence decay graph](image)

Figure 1: Fluorescence decay from NV\textsuperscript{−} pumped with 532 nm quantum light. The fluorescence was filtered with 700 nm longpass filter.

References


Many experiments in ultracold physics rely on destructive detection, in particular absorption imaging. This limits the typical data acquisition rate to one measurement every 10-20 seconds, limited by the sample preparation time.

Here, we present an alternative method of detection that exploits the phase shift induced by atoms on an off-resonance probe beam with respect to a co-linear reference beam of different frequency, resulting in a phase shift of the detected beat note. The change in the density of the trapped atomic cloud and hence the atom number can be detected by such heterodyne interferometer with negligible heating of the sample. Based on the observation that in many experiments the only figure of merit is the change in the trapped atom number, cameras typically used for detection can be replaced, or at least supplemented, by photodiodes. The method can shorten the data acquisition time by removing the need for multiple repetitions of the experimental sequence. It should allow measurements with high time resolution reaching several microseconds in a single experimental realization thanks to the implementation of photodiodes as detectors.

The scheme presented here is particularly useful when the studied processes lead to atom loss or change of population to a state not interacting with the light used in the interferometer. Typical examples of application are photoassociation spectroscopy, temperature and lifetime measurements.
A SiPM-based proton detector for the BRAND project

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As the Standard Model (SM) has certain inconsistencies, e.g. it does not explain dark matter origin [1], a lot of efforts is being put on a search for the physics beyond it. The research covers both high and low energy ranges. One of the low-energy experiments is the BRAND project being conducted i.a. at Jagiellonian University in Cracow, Poland [2].

The project focuses on analyzing properties of neutrons. The aim is to simultaneously measure eleven correlation coefficients of neutron decay, some of which have never been measured before, and to look for small deviations which may indicate exotic interactions not predicted by the SM. To achieve this, an experimental setup of cylindrical geometry will be constructed. Particle detectors will be placed on the cylindrical surface around the neutron beam.

One of the tasks here is to measure exact positions of protons, originating from neutron decay, along the cylinder axis. To address this problem, we made a photomultiplier-based detector prototype in order to find the parameters of optimal position resolution. Basing on those parameters, we made another prototype using silicon photomultipliers that is currently being tested. A process of constructing a proton detector from scratch and its evolution towards the final version to be used in BRAND experiment will be presented.

References


Spatial Coherence. To destroy or not to destroy, that is the question.
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Since the original invention of the OCT, it has been greatly improved in imaging speed and axial resolution. But the other natural way to improve the OCT technique would be to make the signal acquisition parallel. Instead of using the scanning system, we could use two dimensional detector - creating full field OCT (FF-OCT)⁴. However, the challenge is that once we go to the full field image acquisition, another problem of the coherence cross-talk generated noise arises ⁵. This noise reduces the image quality and limits wide adaptation of FF-OCT for practical and clinical applications.

To face this challenge, we demonstrate and implement the spatiotemporal optical coherence (STOC) manipulation ⁶. In STOC, the phase of light in the interferometer arms is modulated in time with customized phase masks displayed sequentially on the spatial light modulator. This modulation is synchronized with light acquisition to effectively control the spatial coherence of the detected light. Reduction of the coherence area suppresses the effect of coherence cross-talk noise and enhances OCT imaging quality.

In this talk I will focus on presenting core idea behind the STOC manipulation. I will discuss different experimental configurations and present data highlighting advantages and disadvantages of each approach.

References


Development of electrically tunable multilayer metamaterial: fabrication issues

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Unique effective electromagnetic properties of metamaterials arise from their subwavelength structure. Therefore, the devices designed to operate in the visible spectral range need to have dimensions of single elements in nanometer scale. Naturally, the fabrication of such structures poses a challenge for scientists. Here we present our approach to development of multilayer metamaterial designed to act as a tunable optical filter. The system under study consists out of few stacks of alternating layers of silver, fused silica and indium-tin-oxide (ITO) sandwiched between SiO2 antireflective coatings. In order to obtain high transparency of the metamaterial we performed initial numerical modelling and chose the optimum thickness of each subwavelength layer. Electrical tuning of this metal-oxide-semiconductor structure is provided by the fact that under applied external electric field the refractive index of ITO locally alters [1], what consequently results in different optical response of the entire metamaterial structure. This mechanism arises from the fact that ITO is a highly degenerate n-type semiconductor with optical properties governed by the concentration of free electrons. Moreover, the initial amount of free electrons in ITO depends mainly on Sn doping levels and the oxygen vacancy concentration [2], and may be modified by adjusting fabrication process parameters [3].

We report on the metamaterial fabrication process and describe the encountered issues. In our analysis we mostly concentrate on properties of ITO layers, which quality is the most essential for the successful operation of our tunable filter. The ITO layers were evaporated in different environmental conditions using e-beam vapour deposition system and later characterised using SEM, EDS and optical spectroscopy.

We focused on four aspects: i) thermal annealing, ii) presence of pure oxygen, iii) presence of oxygen ions and iv) substrate roughness and their impact on the electric, optical and morphological properties of individual layers as well as the entire structure.

We discovered that the usage of oxygen ion assisted deposition has the most straightforward effect as it greatly improves smoothness and transparency of the sample (see Fig. 1). We also demonstrate that the thermal processing has to be applied carefully as it might improve the optical properties but at the cost of ITO surface quality. Finally we show that too high temperature leads to discontinuities in silver electrodes and consequently blocks the electrical operation of the metastructure device.

Figure 1: SEM images of: ITO thin film deposited in ambient temperature (left), ITO thin film deposited with ion assistance (middle), silver electrode in a thermally annealed multilayer system (right).
We believe that overcoming of described technological problems would allow us to create a fully functional electrically tunable multilayer metamaterial which unique properties like e.g. spatial and temporal frequency filtering could be activated simply by the applied voltage.

References


Characteristics of a nanostructural beam splitter
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Photons produced in the Spontaneous Parametric Down-Conversion (SPDC) process typically propagate through optical elements such as waveguides, lenses and beam splitters. We aim to exploit unconventional optical elements, whose fabrication has recently become possible due to the rapid development of nanotechnologies [2]. Such miniaturized devices are typically integrated on microchips that may later become parts of larger quantum circuits. An example is provided by metamaterials, which are periodic arrays of metallic nanoparticles. These nanoparticles support surface plasmon polaritons - hybrid excitations that combine electromagnetic fields with coherent oscillations of valence - electron plasma [4, 5].

Here we experimentally characterize a nanostructural beam splitter, which was designed to feature 25% of reflection and transmission, and 50% of absorption [7]. Furthermore we used photons in weak coherent state to observe Hong-Ou-Mandel effect on metamaterial beamsplitter [8].

References


Nanoparticle based light coupling into hyperbolic metamaterials

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The unique dispersion relation of hyperbolic metamaterials makes them suitable for encoding in the frequency spectrum spatial information with resolution beyond the diffraction limit [1]. This so-called spatial-spectral transformation [2] gives rise to potential applications in compressive super-resolution microscopy in which compressive sensing algorithms are used to reconstruct super-resolved images from a broadband measurement of an object’s spectrum illuminated by structured light through the hyperbolic metamaterial.

The spatial-spectral transformations considered by us rely on wavelength-dependent directional light propagation in the hyperbolic metamaterial that occurs when subwavelength information is coupled to high-k modes of the metamaterial. One approach to couple light into a hyperbolic metamaterial is to exploit diffraction on nanoholes in a Cr mask to provide additional momentum. However, this method suffers from low transmittance, which is especially detrimental for compressive imaging applications. We analyze various kinds of spherical metallic or dielectric nanoparticles as an alternative broadband coupling method with increased coupling efficiency (Fig. 1a). Use of a nanoparticle creates subwavelength hot-spots which enhance the coupling of light to the modes supported by the metamaterial.

We perform a finite-difference time-domain study of a structure consisting of a nanoparticle on top of a hyperbolic medium to find wavelength-dependent coupling efficiency, beam width and intensity peak position (Fig. 1b) as a function of nanoparticle size, composition and the properties of hyperbolic medium. The analysis includes modeling hyperbolic metamaterial as an effective medium, as well as a multilayer structure.

Figure 1: a) Electric field magnitude distribution in metamaterial modelled as effective medium. The light is coupled into the metamaterial using a silver nanoparticle with 50 nm radius. The incident light is linearly polarized in x direction and its wavelength is 490 nm. The values are normalized to the intensity of incident field. b) Intensity profile at metamaterial/substrate interface for varying wavelength of incident light. The position of intensity maximum depends on the wavelength due to dispersion relation [3].


References


Highly sensitive and accurate spectroscopy of O$_2$

near 1.27 µm

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The atmospheric band of O$_2$ near 1.27 µm plays an important role in determining the air mass from ground or spaceborne atmospheric spectra. In particular, the 1.27 µm band is used by Total Carbon Column Observing Network (TCCON) for ground-based air mass determination [1, 2].

Low pressure (5 and 10 Torr) spectra were recorded with unprecedented sensitivity in the 7920-8085 cm$^{-1}$ interval (noise equivalent absorption $\alpha_{\text{min}} \sim 10^{-12}$ cm$^{-1}$) with Cavity Ring Down Spectroscopy (CRDS). About two hundred lines including electric quadrupole transitions were accurately measured. The weakest lines have intensity on the order of $10^{-30}$ cm/molecule. The CRDS spectrometer being combined with a self-referenced frequency comb, line centers could be determined with accuracy on the order of 100 kHz. Detailed line profile analysis was performed for a series of twelve lines recorded at pressures up to 150 Torr using the Speed Dependent Nelkin Ghatak profile [3]. Significant deviations compared to the HITRAN database [4] will be discussed.

References


Estimation of overlap function
for Warsaw Aerosol-Depolarisation-Raman lidar
- numerical and experimental approach

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Lidar profiling of altitude resolved atmospheric aerosol properties is an important topic in climate research. One of the state-of-art lidars used for this purpose is PollyXT-UW - the next generation type lidar [1].

The lidar is providing wavelength-dependent elastic and Raman scattering measurements, including determination of polarization, with the set of two telescopes at 12 channels. Performance of the system depends on the quality and altitude range of the signal collected by each telescope, whereby the larger one provides information at a farther range from the lidar, and the smaller one at closer range. The performance can be improved by minimizing the so-called overlap function of the signal. This function describes the overlap of light path of each beam emitted by laser system with the full field of view of the telescope. Determination and application of overlap function enables usage of signals from lower altitudes.

In current paper, an analytical formula was used for overlap function formulation [2], which was calculated for both of the telescopes at 12 detection channels. The changes in the obtained overlap function curves were modelled as dependent on several parameters of the laser-telescope system (transceiver). Based on the influence of each of the parameters’ changes on the overlap function, the optimal sets of parameters in terms of improving overlap function were estimated. Using those, overlap function gradient at low ranges can be greatly improved, effectively enabling moving the lower limit of signal detection and broadening the actual altitude range of the measurements.

To verify the numerical calculations of the overlap function, specific measurements of the lidar signals were conducted using the so-called telecover test setup, which enabled the lidar overlap adjustment and assessment of its overall performance. Finally, by using ratios of signals received by each telescope, the overlap functions for the larger one was assessed and compared with the numerical results.

References


Spectral dynamic of atomically thin semiconductor with indirect energy bandgap

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Two-dimensional semiconducting transition metal dichalcogenides (s-TMDs) attract much attention due to their robust optical properties and energy gap in a visible or near infrared range. Particularly strong photoluminescence (PL) is observed for the monolayers of such materials due to their direct bandgap. In the case of thicker layers the bandgap becomes indirect, which hinders the photoluminescence.

Here we present a study of the photoluminescence decay times measured for WS₂ flakes of different thickness varying from 2 to 8 layers. The experiments were conducted with the use of a femtosecond laser and a streak camera providing temporal resolution of a few picoseconds. The investigated samples were kept in a helium cryostat at temperature down to 10 K.

The samples were prepared by mechanical exfoliation and deposited on a Si/SiO₂ substrate. Thickness of the flakes was determined based on their optical contrast and crosschecked with PL measurements performed under continuous-wave (CW) excitation. Our results stay in agreement with recent measurements by Molas et al. [1], who established a monotonic relationship between the number of monolayers and the energy of the PL signal in few-layer WS₂ (from 1 to 8 layers).

We have found a significant increase of the PL lifetime, when increasing the layer thickness. This trend is followed by a strong decrease of the PL signal. Our results clearly illustrate a gradual nature of transformation of the excitonic state from a fully bright (in the monolayer) to a fully dark (in the bulk).

The observed dependence is interpreted as an intrinsic phenomenon rather than an effect of competing non-radiative decay channels. This conjecture is supported by additional measurements of the decay time as a function of temperature. The experiment evidenced that the decay time is constant in the whole studied range of 10 K–295 K, as expected for a truly intrinsic mechanism.

References

Cavity-enhanced spectroscopy and \textit{ab initio} calculations for spectroscopic databases

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Hydrogen molecule in its ground electronic state perturbed by the helium atom constitutes the simplest system of perturbed molecule. This gives possibility to make a link between the experiment and the theory from first principles.

We utilize highly accurate cavity ring-down spectroscopy to study the H\textsubscript{2}-He collisions and interactions \cite{1}. In contrast to most of the previous studies, we directly \cite{2} superimpose theoretical profiles, originating from our \textit{ab initio} calculations, on the experimental spectra without fitting any of the line-shape parameters. Within this approach not only the shapes of experimental lines are reliably reproduced, but also the underlying physics of molecular collisions can be traced. Besides the analysis of the basic line-shape effects (such as relaxation or phase changes of the internal states of the molecule), we also analyze the more sophisticated ones such as speed-dependent effects or velocity-changing collisions (complex Dicke narrowing parameter) \cite{3, 4}, which are particularly pronounced for the H\textsubscript{2}-He system\cite{1, 5, 6, 7}. We achieved good agreement at the 1\% level between experimental data and \textit{ab initio} calculations. In addition, we show that measured spectral line shapes can be interpolated within similar accuracy \cite{5, 8} by \(\beta\)-corrected Hartman-Tran line shape profile \cite{9}, which has been implemented as a standard for HITRAN database \cite{10}.

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Bioavailable forms of silicon in dietary supplements

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Silicon is the third most important element in the human body and its content is from 6 to 7 g. It is twice the amount of iron, from where its biological significance comes from. Silicon is one of the most significant elements of connective tissue, blood vessels and bones. The amount of this element in particular organs depends mainly on the content of the connective tissue. However, the silicon content in the body decreases with age [1, 2].

Dietary supplements containing silicon both in the form of choline stabilized orthosilicic acid (OSA) and monomethylsilanetriol (MMST) were tested by UV-VIS, ATR-FTIR and Raman spectroscopy. The spectro- fotometric method was used to determine silicon in a dissociated form. This method is based on the reaction in the acidic environment of dissociated silicon with ammonium molybdate. Whereas for FTIR and Raman methods, dietary supplements were not modified.

The results of the research show that the highest concentrations of bioavailable form of micronutrient are contained in preparations containing orthosilicic acid in the form of monomers (up to 1900 ppm). It was observed that on the basis of ATR and Raman spectra it is possible to recognize in which form silicon (orthosilicic acid or monomethylsilanetriol) is contained in dietary supplements. Characteristic peaks were observed, allowing for the existence of silicon to be unambiguously verified.

References

Spin-wave quantum operations via ac Stark modulation

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We want to present a spatial spin-wave modulator, allowing engineering of a spatial phase of spin-waves stored in a cold atomic memory. We demonstrated that the spatial structure of spin-waves can be manipulated via the off-resonant ac Stark shift [1, 2]. Through spin-wave diffraction-based beam splitter transformation, we realize the Hanbury Brown–Twiss (HBT) type measurement in the SW domain, demonstrating precise control and nonclassical statistics of atomic excitations. Finally, we observed Hong-Ou-Mandel interference of two spin-waves stored in different spatial modes of our quantum memory [3]. The ability to perform beam splitter transformations with wave vector eigenmodes constitutes a full spin-wave analog of complex linear-optical networks. The inherently nonclassical HOM interference with 80% visibility is a concise demonstration of such transformation, which we realize with a three-way (in the sense of the first three diffraction orders) splitter to demonstrate that spin-waves always occupy either of the output modes.

Figure 1: The protocol for quantum interference of spin-waves. Detection of two $w$ photons in modes $w_a$ and $w_b$ (selected through single-mode fibers) heralds generation of a SW pair in modes $r_a$ and $r_b$. The three-way splitter is then used to interfere the two spin-waves. By detecting the spin-waves through photons converted to $r_c$ and $r_d$ modes, we observe bunching due to their bosonic nature. Inset (i) presents the input SW modes in the $(K_x, K_y)$ plane. Photonic detection modes are always set to collect photons emitted from heralded SW modes.

References


Timing jitter measurement of temporal phase modulation patterns by temporal interferometry
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Temporal-spectral modes of quantum states of light offers remarkable capability in information encoding specially for establishment of high dimensional quantum networks. In this context, an important task is to set up efficient tools for coherent manipulation of the temporal-spectral properties of fragile single photons. Such manipulations can be realized by applying time-dependent phase modulation to single photon pulses. Here we present a technique for direct characterization of temporal phase modulation patterns applied to optical pulses, which is applicable in the quantum regime, including timing jitter measurements.

We used an interferometric technique to characterize temporal phase applied by an electro-optics phase modulator (EOPM) to optical pulses. 200 fs pulses are sent into a balanced Mach-Zehnder interferometer with EOPM in one of its arms. The EOPM is driven by a RF signal synchronized with the optical pulse. To obtain the temporal phase modulation profile we scan the delay of the optical pulse with respect to the RF signal. At output of the interferometer, intensity measurements with a single photodiode enable monitoring of the time-dependent phase modulation introduced by the EOPM. Timing jitter can be extracted from measurements on sequences of optical pulses. Using this technique we characterize the stability of temporal phase modulation patterns for different methods of generating an RF signal synchronized to single-photon pulses.

In summary, we developed an interferometric setup for characterization of temporal phase modulation and measuring timing jitter for time-dependent phase modulation of optical pulses. This technique offers a robust platform for characterization of electro-optic phase modulation devices for pulse shaping in both classical and quantum regime.
Spatial modulation of Spin-waves in a Quantum Memory

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An ability to shape and detect spatial and temporal structure of light lays at the foundations of modern quantum optical technologies. In particular utilization of the spatial degree of freedom offers a tremendous increase in the dimensionality of the accessible Hilbert space and information capacity. This asset has been vastly exploited in quantum optical communication, quantum memories, and information processing. Multi-mode quantum memories constitute a viable candidate for quantum and classical information processing; however, full utilization of the assets of high-dimensionality requires a flexible processing technique.

While several methods of information processing have been realized in quantum memories, thorough utilization of the spatial degree of freedom in highly-multi mode memories demands a flexible method analogous to spatial light modulators (SLM) widely exploited in the broad field of optics to modulate the amplitude or phase of light. In [2, 3] by employing spatially varying ac-Stark effect simple few-mode operations have been demonstrated in the discrete domain on a coherent states of collective atomic excitations - spin-waves as well as on single spin-wave Fock states, stored as a coherence between two metastable ground states in a cold $^{87}$Rb ensemble.

Here we characterize a spatial spin-wave modulator (SSM) [1], allowing engineering of one dimensional (1D) spatial phase of spin-waves stored in a cold atomic memory. Phase modulation of a spin-wave state inherently transfers to the phase profile of light readout from the memory. SSM modulation offers flexibility of SLM modulators for light yet operates in the matter domain enabling long interaction times and opening broad possibilities for continuous domain quantum information processing in quantum memories. A full quantum information framework is thus built for spin waves in an analogy to electrooptic and dispersive manipulation of spectro-temporal degrees of freedom of photons.

In the far-field the SSM modulation enables shaping of the spatial intensity profile of the readout pulse and may be utilized for memory readout routing or mode matching e.g. for an enhanced coupling to an external photonic interface. With the ability to introduce parabolic phase profiles on a μs time scale, the SSM also provides a convenient method to dynamically switch between position - momentum measurement bases expanding quantum information processing capabilities or aiding fundamental study of

Figure 1: (I) Memory and SSM sequence. Spatial intensity profile of the SSM beam induces spatially varying ac-Stark shift producing phase modulation of a stored spin-wave state, retained in the readout light pulse. (II) Far-field image of the memory readout (a) unaltered, (b) with a cylindrical lens introduced in the readout path. (c) SSM imposes 1D parabolic phase profile onto a stored spin-wave (d) compensating the cylindrical lens upon memory readout with efficiency of $\eta \approx 80\%$ in terms of preserved total energy of the unaltered readout. The spatial fidelity between unaltered $I_0(x',y')$ and compensated $I(x',y')$ readout intensities amounts to $F \approx 96\%$. 
multi-dimensional entanglement. Additionally, with the possibility of temporally sequencing or splitting
the readout of a single coherent spin-wave state into several light pulses, an arbitrary phase modula-
tion could serve in a feedback loop for adaptive measurements e.g., enhancing the discrimination of
non-orthogonal states of light.

References


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The main goal of this research was to assess possibility of the thickness evaluation of thin layers using optical coherence tomography (OCT). In the proposed solution, multiple beam interferometer has been presented. OCT system was modeled accordingly Michelson interferometer, where one beam propagates from the reference arm and others come from Fabry-Pérot interferometer [1]. Consequently, the mathematical model consists of the main Michelson interferometer, in which the measuring arm represents the Fabry-Pérot interferometer. The developed model predicts the use of different materials (with different refractive indexes) located at different depths. The idea of this model is presented in the figure 1.

Figure 1: The idea of the proposed OCT model based on a) Michelson interferometer and b) Fabry-Pérot interferometer.

To verify the proposed model, experiment with a wedge cell has been carried out. The wedge cell was shifted using linear translation stage with micrometer screw under scanning head. Correlation between position on wedge cell and simultaneously thickness of the wedge cell at the scanning point and output signal from the proposed model was demonstrated. These experiments and simulations present preliminary research for evaluating the potential of the proposed measurement method.

References

For the last 20 years, the research on quantum information processing is experiencing a rapid growth and holds great promise for revolutionary new technology. In the development of these quantum technologies efficient and flexible methods for extracting information about a quantum state from measurements are required. One important task is to fully determine a quantum state from the measured data with only mild structure assumptions on the state. This is the problem of quantum state tomography.

Using a signal processing paradigm called compressed sensing, quantum tomography schemes for low-rank states were developed that are resource-optimal. But to date compressed sensing schemes for quantum state tomography lack robustness against imperfection of the measurement devices. For this reason, experimental setups performing these schemes need to have measurements devices that are calibrated to a high precision. In this work we develop the framework of blind calibration tomography which allows for incomplete knowledge of the measurement device during the tomography of a quantum state. It simultaneously determines both the device calibration and the quantum state with minimal resources and efficient classical post-processing.

Building on recent techniques from the field of compressed sensing, we derive algorithmic strategies for blind calibration tomography and provide analytical performance guarantees. We further demonstrate their performance in numerical simulations.
Quantum-state tomography is a crucial ingredient in quantum-state engineering and computing. From the point of view of these fields, it is important to determine a state of a photon as well as atoms. While the first is commonly used for quantum-information transmission, the latter offers the possibility to manipulate the state by external magnetic and electromagnetic fields. Atomic gasses are also among the most promises candidates for quantum-information storage. Typically, this task is performed in cold atomic clouds, where various relaxation processes are mitigated, yet hot atomic vapours also offer various advantages, like the simplicity of ensemble preparing (lack of cooling apparatus).

During our presentation, we will describe a method enabling measurements of collective quantum-state in hot atomic vapours via weak nondemolition measurement performed by off-resonant laser light. Quantum state estimation is performed by measurement of Faraday rotation of transmitted light, while the external optical and magnetic field are used to control over the evolution of the atomic state.
Ultra-long working distance spectroscopy of single nanostructures with aspherical solid immersion micro-lenses
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Standard experimental setup for spectroscopic studies of single semiconductor nanostructures requires an microscope objective in front the studied sample. In order to avoid photon losses the numerical aperture (NA) of used microscope objective should be as high as possible. On the other hand longer distance from the sample to the light collecting optics (working distance, WD) is often desirable. It is particularly important in systems with restricted access to the sample, e.g., in case of split-coil superconducting magnets. Commercially available microscope objectives with magnification 100x has NA=0.6 for WD=8 mm, which is not sufficient for all applications.

In this work we present aspherical micro-lenses which redirects emitted photons from semiconductor nanostructure into light cone of NA=0.025 - the outcoming light can be collected by 1 inch-diameter lens at the distance of 590 mm from the sample. Resulting working distance is more than 70 times longer than the one offered by conventional microscope objectives.

Micro-lenses were fabricated by two-photon polymerization direct laser writing (TPP-DLW). This technique allows for three dimensional printing of micro objects made of transparent non-conductive resin that withstands cryogenic temperatures [1]. The resin after polymerization has refractive index n=1.52 which is intermediate value between higher refractive index of semiconductor and much lower refractive index of air. As a result, one also obtain an increase in photon extraction efficiency due to reduction of internal reflection of light in semiconductor.

We demonstrate usability of the proposed solid immersion lenses with monolayers of transition metal dicalcogenites (TMDs), in particular MoSe₂ and WSe₂ (λ ≈ 790 nm and λ ≈ 760 nm respectively). We have observed more than a hundred-fold increase in collection efficiency in spectroscopic setup with NA < 0.025. The lenses were also tested with single self-assembled CdTe/ZnTe quantum dots (λ ≈ 600 nm) containing single manganese and cobalt ions. Finally, we show that our solution works at shorter wavelength with single CdSe/ZnSe quantum dots (λ ≈ 500 nm), thus confirming the feasibility of broadband operation of fabricated lenses.

Presented micro-lenses could be especially useful for single nanostructure spectroscopy in very high magnetic fields - due to the absence of metal elements as well as in microwave cavities or optical dilution refrigerator systems.
References

Electrically tunable multilayered hyperbolic nanostructure for optical filtration
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The optical properties of transparent oxide layers and, in particular, indium tin oxide (ITO) have attracted attention of many nanophotonics and plasmonics oriented scientific groups in recent years. This highly doped n-type semiconductor owes its popularity due to the combination of high electrical conductivity and optical transparency in the visible spectral range. In addition, as shown in the article published in 2010 [1], applying external electric field to the ITO-dielectric interface leads to the local increase in carrier concentration on the semiconductor side of the boundary and consequently to the local change of refractive index. In our approach we exploit this mechanism in order to tune electrically the optical response of the hyperbolic metamaterial device.

Here, we report on numerical modelling of light propagation in heterostructure consisting of several metal-oxide-semiconductor thin layers (see Fig. 1(a)) with indium-tin oxide serving as active material and show that such structure can act as a fast light modulator. In order to optimize optical performance of the propose device and to achieve strongest modulation we have use two different numerical modelling techniques. The first one is a finite-difference time-domain method (FDTD), a fully vectorial algorithm which allows to solve Maxwell’s equations in electrodynamic problems. The second technique is a Transfer Matrix Method (TMM), a very computationally effective algorithm, which we use to calculate transmission refection, and the absorption of 1D multilayer stack. Numerical simulations provided information about the most favorable thicknesses of individual dielectric and semiconductor layers. To estimate the isofrequency contours associated with the metamaterial, and thus to verify dispersion operation regimes we use the effective medium theory.

![Figure 1: (Left) Schematic of studied multilayered metamaterial structure. (Right) Transmission of the structure with and without applied voltage.](image)

In Fig.1(b) we demonstrate the impact of the applied voltage on the optical properties of optimized multilayer metamaterial. Under 2.5V of external field the structure exhibits a broad transmission window ranging from 625 nm up to 800 nm with transmissivity reaching 30% for 650 nm. Without the voltage the transmission window shift towards longer wavelengths and the transmissivity drops to 3% for 650nm illumination. We believe that presented effect can be utilized in ultrafast modulation or spectral filtration of metamaterial-based devices of the future.
References

Finite-difference time-domain calculations of epitaxial photonic crystals

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Photonic crystals (PC) are periodic nanostructures that modify the electromagnetic (EM) field distribution. Such structures with graded refractive index can be obtained by various methods top-down as well as bottom-up. We prepared our samples using molecular beam epitaxy (MBE) which provides high quality plane layers on whole surface. The most popular example of PC made by MBE is distributed Bragg reflector. It contains layers of two materials that exhibit diverse refractive indices. Thickness of each layer is equal $\lambda/4n$ where $\lambda$ is wavelength of stopband and $n$ is refractive index of material [1]. That provides constructive interferences between layers and almost 100% reflectance of wishing $\lambda$.

However, knowing the exact recipe on structure is not always the case. In order to perform innovative photonic ideas numerical simulations are needed. Such simulations are mostly incomparably cheaper than preparing a sample. Moreover, calculations allow testing various systems and effective searching certain effects. For instance finite-difference time-domain (FDTD) method can be applied to obtain EM field distribution inside the structure as well as in its surroundings.

We performed FDTD calculations using MEEP [2] which simulated propagation of electromagnetic waves propagation in designed structures. Than we prepared samples corresponding to considered photonic objects. Two systems were investigated. Firstly, multiple quantum well CdTe/(Cd,Mn)Te as a graded index photonic crystal [3] was considered. The second case was DBR made of CdSe and ZnTe. Measured and calculated reflectance spectra were consistent as shown at the Fig. 1.

References


Analytical and numerical analysis of linear and nonlinear properties of an rf-SQUID based metasurface

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We derive an analytical model to describe the interaction of an rf-SQUID (radio frequency superconducting quantum interference device)-based metasurface with free space electromagnetic waves. We assure that the system is well-posed and show, that it has a unique solution. In the small amplitude limit, we provide analytical expressions for reflection, transmission, and absorption, depending on the frequency (Fig. 1(left)). To investigate the nonlinear regime, we numerically solve the system of coupled differential equations using a finite element scheme with transparent boundary conditions. The simulation results for the adiabatic increase of either the field’s amplitude or its frequency show that the metasurface’s response in the nonlinear interaction regime exhibits bistable behavior both in transmission and reflection (Fig. 1 (right)).

Figure 1: (Left) reflection, transmission and absorption coefficient of an rf-SQUID based metasurface. (Middle) equivalent circuit diagram of the rf-SQUID meta-atom, consisting of a resistance (R), a capacitor (C), an inductance (L) and a Josephson junction (JJ), carrying superconducting current. (Right) reflected magnetic field amplitude as a function of the incoming field amplitude in the nonlinear interaction regime (normalized units).

A referential example for a meta-atom with a strong magnetic response is the split ring resonator (SRR) [1, 2]. An SRR is a metal ring acting as an inductance with a small gap forming a capacitance, i.e., an LC circuit. In a natural way, determined by its geometry and material, the SRR has a resonance frequency. In 2007, it was proposed to insert a Josephson Junction (JJ) into the gap to introduce both nonlinearity and to make use of the low-loss properties of superconducting charge transport through the JJ [3]. These metaatoms are then called rf-SQUIDs. They provide a tunable intrinsic inductivity via externally applied magnetic fields and temperature gradients [4]. Thus, external parameters have an impact on the intrinsic resonance properties of the individual meta-atoms. Hence, an rf-SQUID is a promising candidate as building block to create novel, efficient, and tunable metasurfaces. For the description of the rf-SQUIDs, we rely on an equivalent circuit model (Fig. 1 (middle)). While rf-SQUIDs are already well investigated in the context of transmission line theory [4], the interaction with free space electromagnetic radiation has only been dimly lit so far. The present contribution develops a comprehensive theoretical framework for that purpose and explores linear and nonlinear properties.
References


Metal nano-particles composite glasses synthesized by ion-exchange process and subsequent annealing or laser irradiation, have been shown as promising nonlinear photonic material. Such extraordinary features are directly related to the localized surface plasmon resonance (LSPR) of noble metal nanoparticles NPs and so gigantic amplification of the incident laser field in the proximity of NPs.

The LSPR characteristics like amplitude or spectral location and bandwidth strongly depend on the nanoparticle size, shape as well as on its local environment which can be controlled during their precipitation. In performed experiment, the composite glasses with Ag NPs are prepared first introducing silver ions during ion-exchange process by immersing sodalime glass slides into a molten bath of 10mol% \( \text{AgNO}_3 : \text{NaNO}_3 \) at a temperature of 400°C.

Then, the ionexchanged samples are either annealed or locally irradiated with nanosecond laser pulses which makes Ag ions to be reduced into atoms, which migrate and aggregate into nanoparticles. The samples are first characterized by UV-VIS absorption spectroscopy and then using the Z-scan technique. Both nonlinear absorption and refraction are determined from the open and closed Z-scan measurements, respectively. In performed measurements femtosecond laser pulses at 800 nm was used in order to attenuate linear absorption but also to avoid thermal effects commonly occurring when nanosecond pulses are applied. However, at the high repetition rate (76 MHz) of the femtosecond laser the accumulative thermal effects are still present which indicate the results of performed Z-scan experiments.
Optically Detected Magnetic Resonance Study of Manganese Ion Relaxation in Strained Quantum Well

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The relaxation of single manganese ion in CdTe quantum dot which is strongly confined and strained system is much faster than relaxation in highly diluted limit of unstrained (Cd,Mn)Te bulk crystal [1, 2]. This observation opens the question of the role of strain in spin relaxation of magnetic ions. The systematic studies for quantum well system of well-defined strain should cast more light on that problem.

Here we report time resolved Optically Detected Magnetic Resonance (ODMR) studies of single (Cd,Mn)Te/(Cd,Mg)Te quantum wells. The Mn content equal about 0.3% was chosen to assure sufficient Zeeman effect and negligible direct ion-ion interactions. The strain in QW was defined by content of Mg in buffer layer, in the range from 0 to 30%. Samples were mounted on holder with antenna to provide microwave radiation in a wide range of frequencies from 10 to 25 GHz. We performed measurements at pumped liquid helium temperature in a cryostat placed inside a superconductive magnet with magnetic field up to 3T. For magnetic fields and microwave frequencies corresponding to paramagnetic resonance the heating of the magnetic ions system was observed by decrease of the giant Zeeman shift of photoluminescence lines related both to neutral and charged exciton recombination. Dynamics of magnetic ions disorientation induced by pulse of microwave excitation was measured by probing photoluminescence excited by short laser pulses with variable delay. The measurements were performed for series of samples of different Mg content in buffer layer which result in different strain in QW. Strain was checked by analysis of the heavy-light hole splitting of the excitonic transitions observed either in reflectivity or PLE spectra.

We discuss strain dependence of magnetization dynamics in QW system, which is intermediate between less strained bulk and more strained quantum dots. We find that the relaxation is significantly shortened in the presence of the strain in the structure.

References


Azobenzenes are an important class of organic dyes. They are constituted of two phenyl rings linked by an azo (–N=N–) bridge. One of their features is that they can appear in two isomeric forms: stable trans and metastable cis. The change in conformation is caused by reversible trans-cis photoisomerisation. The molecule can undergo trans-cis isomerisation upon $\pi - \pi^*$ excitation with light. The cis-trans isomerisation can be induced by n-$\pi^*$ excitation with light or can take place spontaneously by thermal back reaction. It should be mentioned that these two isomeric forms of azobenzenes have different spectroscopic properties. Azo dyes found many optical applications including optical data storage, surface relief holography and nonlinear optical devices to name a few [1, 2].

Optical properties of azobenzenes can be tailored by introducing various electron donating/withdrawing substituents into the molecule. The change in molecular structure affects spectroscopic properties as well as isomerisation quantum yields and thermal relaxation rate. Understanding of a relationship between the structure and properties is crucial for designing materials suited for specific applications.

We present the optical properties of a novel class of methacrylic polymers containing quinoline azo-dyes in side chain (Fig. 1). The goal of our study was to examine the influence of various substituents in the chromophores on their spectroscopic properties. The thin films of studied polymers were prepared by spin-coating technique. The absorption coefficient and changes of absorbance during sample irradiation under irradiation by $\lambda = 365$ nm light were investigated using Cary 50 Scan UV-Visible Spectrometer (Varian). Refractive index was measured using spectroscopic ellipsometry (V-VASE ellipsometer, J.A. Woollam Co., Inc.) in the non-absorbing spectral range [3].

Figure 1: Chemical structure of methacrylic polymers with quinoline azo-dyes in side chain, where R = {H, OCH₃, Br}.

References

Investigations of proton conducting materials composed of imidazole and aromatic acids

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There has been a growing interest in materials which can be used in fuel cells in recent years. One of the groups of materials, which can be used as an electrolyte in fuel cells, are proton conductors. The proton conductors, which are analyzed here are built by aromatic acids and diazole base molecule. Aromatic acids, which are chosen to synthesize were: benzoic acid (pKa=4.20), salicylic acid (pKa=2.97), orthophthalic acid (pKa=2.89), and terephthalic acid (pKa=3.51). We will present and discuss the properties of four salts, which were synthesized by our group. For these materials, thermal stability, electric conductivity, and vibrational properties were analyzed. What is more, the paths of hydrogen bonds were analyzed with the use of the quantum theory of atoms in molecules (QTAiM) [1] and Hirshfeld surface analysis method [2]. The infrared and Raman spectra were also collected.

Heterocycles are an interesting class of compounds for crystal engineering due to their ability to form moderate and weak hydrogen bonds. This system of intermolecular hydrogen bonding lattice allows the diffusion of protons that can be described by the Grotthuss mechanism. The physical properties of the newly synthesized proton conducting materials: imidazolium benzoate (salt 1) [3], imidazolium salicylate (salt 2) [3], imidazolium phthalate (salt 3), and imidazolium terephthalate (salt 4) were investigated. The study of critical points and structure of these crystals shows that there are two types of intermolecular hydrogen bonds: weak hydrogen bonds (C-H...O) and medium strength hydrogen bonds (N-H...O). The melting temperature is equal to 374, 403, 422, and 464 K for salt 1-4, respectively. The electrical conductivity equals 2·10⁻⁶ for salt 1 and 2, 2·10⁻⁰ for salt 3, and 10⁻⁵ for salt 4. For studied salts 1-4 were used theoretical methods to study the proton transport mechanism. The energetic barrier related to the motion of proton within the double-well hydrogen bonds are similar and equals about 0.17 eV for studied salts 1-4. In the studied salts 1-4, the activation energy associated with the 180 degree flip of imidazole and acid molecules around the pseudo-2-fold axis is less than 2 eV.

Studied salts 1-4 show that the conductivity increases with increasing acidity (lower pKa). The study shows that the number of carboxyl groups and their substitution in the benzene ring have a crucial role in electrical conductivity and thermal stability properties.

References


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Compact laser system for experiments with ultracold potassium isotopic mixtures

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We present our work on building a compact laser setup capable of laser cooling of all stable potassium isotopes \((^{39}\text{K}, \; ^{40}\text{K}, \; ^{41}\text{K})\). The setup consists of a master laser, frequency distribution module and an amplifying stage.

The core of our setup is a master laser stabilized to the crossover of the most abundant potassium isotope, \(^{39}\text{K}\). The beam is then sent via a single mode, polarization maintaining fiber to the frequency distribution module, where it is split into a cooling and a repumping path. In each path, one acousto-optic modulator (AOM) in a double pass configuration is used per isotope to tune the frequency to create beams detuned by +80 MHz and -80 MHz from the cooling and repumping transitions, respectively. The beams are fiber coupled to seed dedicated tapered amplifiers and the amplified light is then frequency shifted into resonance with cooling and repumping transitions. We obtain near 1 W of cooling and repumping light, more than enough for typical ultracold applications.

The setup incorporates additional master laser stabilized to a transition of the D1 line of potassium \(^{39}\text{K}\), which utilizes the same frequency distribution module and the amplifying stage to prepare coherent cooling and repumping beams for sub-doppler cooling of all stable potassium isotopes with gray molasses. For this purpose, only the frequency of the AOMs used for D2-line cooling needs to be changed.

The switching between isotopes is done without any moving parts, is computer controlled and can be reliably performed in less than 1 ms, limited only by the settling time of the tapered amplifiers used in the setup. The system can also provide light for a 2D-MOT. Sequential loading of magneto-optical traps for each isotope is possible with the presented design, enabling studies of ultracold isotopic mixtures. Our design circumvents the common problem of setting up multiple laser systems simplifying the experimental setup while maintaining the flexibility of working with all isotopes, in particular with the \(^{41}\text{K}\) and \(^{40}\text{K}\) mixture, where the bosonic isotope \((^{41}\text{K})\) can be used to sympathetically cool fermionic \(^{40}\text{K}\) to obtain a quantum degenerate Bose-Fermi mixture.
Digital holography is a technology providing novel solutions to the problems affecting other methods of imaging, by allowing direct numerical access to the registered complex optical field [1]. The project was focused on designing and building a low-cost Digital Holographic Microscope (DHM) system that would allow for visualization and measurement of phase objects, both biological and inorganic.

The system is based on the Mach-Zehnder interferometer architecture, with off-axis hologram recording in the image plane. Our DHM’s mechanical components have been built out of LEGO parts. This provides a fast and easy way to prototype and change various modules of the microscope. Phase reconstruction from the recorded data is performed using Fourier transform method [2].

Measurements have been carried out on various biological and technical samples. Measuring standardized PMMA microspheres has shown the ability to determine their integrated phase with $\frac{\pi}{40}$ [rad] accuracy and the refractive index with accuracy to the third decimal place. We are planning on expanding our DHM’s mechanical setup and software, especially to allow vertical measurements of objects, real-time monitoring of phase changes, as well as implementing automatic numerical focusing.
References


High-speed camera for telecom quantum light pulses with spatial resolution mapped to the time domain

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Spatially resolved single photon detection is of great importance for multiple metrology tasks. Unfortunately, due to a lack of multipixel single-photon detectors, it is difficult to achieve, especially outside the visible wavelength range.

An entirely different approach for spatially resolved detection may be based on space-to-time mapping. Here the information about spatial structure of the image is first encoded in the spectrum of a broadband optical pulse and then translated from the frequency domain into the time domain using a Fourier dispersive transformer [1]. This allows detecting the position of single photons based on their arrival time with a single-pixel time resolving detector.

The method of space-to-time mapping enables reaching extremely fine temporal resolution of measurements, which finds use in imaging of rare, dynamical events like laser ablation or microfluidic flow. We present a high-speed one-dimensional camera employing this technique that can be applied for imaging of 3D-printed static samples as well as a chosen fast-changing event.

References

Cavity-Enhanced Frequency Comb Fourier Transform Spectrometry for Mirror Characterization

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Fourier-transform spectrometry (FTS) is a spectroscopic method capable of measuring broadband spectra in range limited only by the detector sensitivity and emission spectrum of the light source, which has made it the golden standard in many fields of science. This method however has always had a significant tradeoff: it necessitates a mechanical travel scheme to produce an optical path difference (OPD). The spectral resolution is set by this distance, which causes high-resolution measurements to be slow.

Direct use of optical frequency combs (OFC) as light sources for FTS setups has been a breakthrough: careful choice of the OPD enabled cancellation of the effect of the instrumental line shape by sampling the frequencies in the interferogram exactly on the frequencies of the subsequent OFC modes [1, 2]. This effectively sets the spectral resolution limit to the width of the comb mode, orders of magnitude lower than before. Another advantage is the possibility to exploit the similar spectral structures of the frequency comb emission spectrum and transmission spectrum of an optical cavity. Frequency combs are among a few broadband sources which can be efficiently coupled into optical cavities, offering a unique opportunity to perform broadband and fast cavity-enhanced measurements. We present an instrument capable of performing cavity-enhanced direct frequency comb spectroscopy (CE-DFCS), cavity mode-width spectroscopy (CMWS) and cavity mode dispersion spectroscopy (CMDS) [3, 4, 5].

The latter two methods require measuring the Lorentzian shapes of the cavity modes, which depend on the dispersion and losses of the cavity. This allows retrieval of the parameters of the mirrors such as their group delay dispersion and reflectivity and assessing absorption and dispersion of the intracavity medium. Those features are attractive both for science and industry, especially considering that optical frequency combs can be readily transferred into mid-infrared, a region where it has historically been difficult to characterize mirrors. We present broadband measurements of mirror and gas dispersion performed with above-mentioned methods. The measurements were performed on an evacuated cavity and cavity filled with argon and nitrogen, then the results were compared to the group velocity dispersion calculated from previous measurements of those gases performed in the 1960’s [6, 7].

References


Influence of 2-methylbenzothiazole group on optical properties of heterocyclic azo dye

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In recent years azo dyes received much scientific attention due to their opto-electronic properties and reversible trans-cis photoisomerisation. These features make them attractive for applications such as optical data storage, optical limiting, optical switching, signal processing and nonlinear optical devices.

Azo dyes with electron donating/withdrawing substituents show strong nonlinear optical properties. One of the reasons is charge transfer character of their excited states which cause change in a dipole moment of a molecule upon excitation. Other is change of a dipole moment due to trans-cis isomerisation. Incorporating heterocyclic groups into azo dyes further enhances their nonlinear optical response due to the increase in the polarizability of the noncentrosymmetric molecule.

In this study we investigate the influence of 2-methylbenzothiazole group on optical properties of heterocyclic azo dye (Fig. 1) embedded into poly(methyl methacrylate) matrix (guest host system). In order to study this system, thin films on glass slides were prepared using spin-coating technique. Refractive index and extinction coefficient were measured using spectroscopic ellipsometry (V-VASE ellipsometer, J.A. Woollam Co., Inc.) for 65°, 70° and 75° angles of incidence. Transmittance measurements were done in UV-VIS spectral range (275-2000 nm) using Cary 5000 spectrometer. To characterize the topology of the layers AFM measurements were examined using Innova device (Bruker) with standard Si tips. Imaging scan size was 1 µm × 1 µm [1, 2]. The light-induced birefringence in heterocyclic azo dyes was also studied.

![Chemical structure of heterocyclic azo dye compounds](image)

Figure 1: Chemical structure of heterocyclic azo dye compounds.

We found that azo compound with additional 2-methylthiazole group has higher birefringence saturation level and in the same time it exhibits lower relaxation of birefringence and lower absorption coefficient.

References


We present the preliminary results of glass micromachining using an UV excimer laser. We used a KrF laser working in a pulse mode at a wavelength of 248 nm introduced into a custom built optical system to perform ablation in glass plates and silica optical fibers. The system consists of precise motorized X-Y-Z stages and rotational fiber holder for sample positioning, UV focusing objective, and observation module for real-time preview of micromachining process. We investigated the relation between laser pulse energy density and its spot size on final geometry of micro-holes in glass plates and optical fibers’ end face. Proper control of those parameters is crucial for precise ablation of glass material and therefore obtaining desired microstructures in repeatable way.

Figure 1: Sample micro-holes obtained by ablation of glass plates.

Previous studies showed the usability of this method and possible applications in fiber optics. [1] Despite the lack of precise control of laser beam’s focal spot, we were able to demonstrate first results of micromachined silica optical fibers obtained with presented setup.

This method may be used e.g. in fabrication of optical fibers sensors. By removing parts of the cladding in optical fibers, we will be able to expose the core and, therefore, change the light propagation conditions. The main parameters that can be modified with proposed method are far-field light propagation, reflectance and polarization of output beam, thus allowing to design a wide range of optical fiber sensors.

References

Evolution of a low-frequency impulse in a medium of asymmetric atomic systems

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A two-level atomic system is one of the simplest examples one can investigate in the context of interactions with light. Nevertheless, there is still room for new or poorly examined phenomena. If a two-level atomic system characterized by inversion symmetry in space, such as an atom, is coupled to a classical electromagnetic field, it undergoes Rabi oscillations where the population flips between the ground and excited levels. In this contribution we investigate a scenario, where a system of broken inversion symmetry is used instead. In such case the dynamics is modified for the following reason: Eigenstates of an asymmetric system can be characterized with a permanent electric dipole moment originating from the polarization of charges, which plays a significant role of an additional source of dipole radiation. Its frequency corresponds to the Rabi frequency of population transfer between the eigenstates \([1, 2]\), and therefore is optically tunable with the intensity of the driving field. If the driving field is strong, the frequency of the generated impulse might reach the terahertz regime.

For a realistic description of the process and access to the full propagation dynamics, it is essential to examine not only one individual two-level system, as in previous works \([1, 2]\), but a coherent ensemble thereof. For this purpose we apply a semiclassical approach, to describe a medium of two-level asymmetric systems driven by a strong coherent beam of light \(E_{\text{drive}}(t)\), and being a source of dipole radiation at Rabi frequency \(E_{\text{Rabi}}(r, t)\). The interaction Hamiltonian describing the process reads

\[
\hat{V} = -[E_{\text{drive}}(t) + E_{\text{Rabi}}(r, t)] \cdot \hat{d},
\]

where \(\hat{d} = \sum_{i,j \in \{e,g\}} d_{ij} |i\rangle\langle j|\) is the dipole moment operator of the asymmetric system, while \(e\) and \(g\) correspond to the excited and the ground state of the system. Its diagonal elements stand for the permanent dipole moments in the system’s eigenstates. They are unique to asymmetric two-level systems and have typically been neglected.

In our semiclassical approach, optical Bloch equations are used to describe dynamics of the medium, in particular to evaluate its polarization \(P = N \cdot Tr(\rho \cdot \hat{d})\). Here, \(N\) is the number of two-level systems per unit volume and \(\rho\) is their density matrix. The polarization is a source in the Maxwell’s wave equation describing the propagation of the generated low-frequency pulse \(E_{\text{Rabi}}(r, t)\), initially being zero and gradually building up and propagating in the medium.

Two approximations commonly applied in similar problems are the rotating wave approximation (RWA) removing fast oscillations from evolution equations, and the slowly varying envelope approximation (SVEA) valid if frequency of the pulse largely exceeds the inverse time-scale of the dynamics set by Rabi frequency. Here, the RWA must be adjusted to account for oscillating permanent dipole moments, essential for the impulse buildup. The SVEA is not applicable, since the frequency of the generated pulse precisely corresponds to the time-scale of dynamics of the investigated system.

In general, the impulse propagation equation coupled to Bloch equations for the medium cannot be solved analytically. Therefore, a numerical approach is applied \([3]\). We construct a solver to calculate dynamics of an impulse propagating along the medium driven by an electromagnetic field in the visible domain. The goal is to identify realistic parameter regimes for future experiments where a stable buildup of the low-frequency impulse occurs.
References


The degree of polarization study of a non-pretilt vertically aligned nematic liquid crystal

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An ideal depolarizer is an optical device which produces a beam with the degree of polarization (DOP) equal to 0 for any input state of polarization (SOP). However, depolarization of the light is more difficult to obtain than polarization. For some applications the depolarization of the light is required to minimize the errors in optical systems. The dispersion on rough surfaces is one of the most known method to depolarize the light [1]. In this case, the light is scattered what produces optical losses. Therefore, other methods of depolarization of light were investigated.

Most likely liquid crystal (LC) based devices are proposed as depolarizers [2, 3, 4, 5]. LCs have a unique property that the DOP can be electrically controlled and changed by varying the voltage applied to the device. At the same time, they are low weight and inexpensive. However, there is still a lot of problems to solve in this technology, such as instability in time of a LC depolarizer or low DOP for sources with high coherence length.

In presented work we analyze the depolarization properties of a vertically aligned nematic (VAN) liquid crystal. The organic alignment layers like dimethyldioctadecylammonium chloride (DODMAC) crosslinked with surfactant complex such as hexadecyltrimethylammonium chloride (CTMA) allows to obtain vertical alignment of LC molecules with a non-pretilt. In this case, the LC orientation upon electric switching is undefined. Therefore, the cell generates chaotic structures. This produce the depolarization of the incident polarized light because the switching direction of the molecules is undefined, resulting on spatial distribution of birefringence which produce the depolarization of polarized beam. We present the results of DOP, for six different input SOPs, as a function of voltage of driving signal applied to the LC cell. We investigate the impact of the thickness of the cell on the performance of the depolarizer. Proposed depolarizer is insensitive to the SOP of incident light.

References


Photonic behaviour of CdTe/PbTe periodic structures

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Low-dimensional CdTe/PbTe heterostructures are widely known for their potentially applicable optical [1] and thermoelectrical [2] properties. Use of molecular beam epitaxy method in combination with appropriate temperature and time of annealing of CdTe/PbTe multilayer structures allows to easily obtain samples containing PbTe (CdTe) quantum dots or nano-pilars. Their well controllable spatial dimensions and periodic distribution together with over two times higher refractive index of PbTe ($n_{\text{PbTe}} = 5.75$) in comparison to CdTe ($n_{\text{CdTe}} = 2.75$) makes light see CdTe/PbTe heterostructures as a new meta-material, which creates potential for obtaining composite crystal with photonic gap.

First step of our work was simulating an optical behaviour of CdTe/PbTe multilayers and PbTe quantum dots in CdTe matrix. Open-source Meep (MIT Electromagnetic Equation Propagation) software was used to perform the calculations. Finite-difference time-domain (FDTD) method used by Meep allows to predict propagation of light in any electromagnetic system [3]. Calculations showed the existence of photonic band gap already for matrix of 100 quantum dots. We have found, that in the case of 50 nm PbTe dots periodically dispersed in CdTe, investigated heterosystem exhibit photonic gap in region of wavelength between 600 and 900 nm. Further, doubling the period of the crystal up in direction of light propagation causes arising the additional gap between 1200 and 1400 nm. Moreover, removal of few dots from randomly chosen positions in the crystal results in appear of impurity-like levels in photonic gap.

To confirm the compatibility of the simulation with reality, the multilayered structures were made using the MBE method. The structures were subjected to a thermal treatment, thanks to which matrices of almost symmetrical dots were obtained. A discussion was conducted on the conformity of the results of simulations and measurements of real structures.

References


Correction to the frequency of velocity-changing collision parameter in the Hartmann-Tran profile

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We model an analytical extension of the frequency of the velocity-changing collision parameter in recently recommended line-shape profile - the Hartmann-Tran Profile (HTP) [?]. HTP includes all significant effect used in line-shape modeling nowadays. Nevertheless, HTP gives unsatisfactory results in the analysis of high-resolution spectra with a prominent effect of the Dicke narrowing, particularly in H₂ spectra [?]. The proposed method allows reducing the discrepancy between HTP and more physically justified, but numerically complicated line-shape profile originated in the transport-relaxation equation, the Speed Dependent Billiard Ball Profile (SDBBP) [?]. The correction reduces HTP fit residuals fivefold, while keeping the computational time of the line-shape profile comparable to a standard Voigt profile. We introduce the correction in regards to commonly analyzed atmospheric and planetary molecular systems.

References

Emission rates of quantum systems in a nanostructured environment beyond electric dipole approximation

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Interaction of a quantum emitter with the surrounding photonic bath in its ground state yields a correction to the emitter’s transition energy, referred to as Lamb shift, and gives rise to the process of spontaneous emission. If multiple emitters are present, shared photonic bath acts as a carrier of interactions between them and is responsible for collective emission. An example is the phenomenon of Dicke superradiance.

We provide analytical expressions for the spontaneous emission rate, Lamb shift and collective effects from an emitter located in a photonic bath which can be spatially and spectrally tailored, e.g. with plasmonic or dielectric nanoparticles. Their influence on the properties of the bath, quantified in terms of local density of states, is unprecedented and in some conditions might require a step beyond the paradigmatic electric dipole approximation [1, 2].

To evaluate this impact we use the dyadic Green’s tensor formalism following Refs. [3, 4] and generalize it beyond the electric dipole approximation. For this purpose we consider quantum emitters’ transitions characterized simultaneously by multiple moments: the electric dipole, magnetic dipole, and electric quadrupole. Remarkably, the optical properties of the photonic bath are described by a classical quantity: the electromagnetic Green’s tensor. In particular, it accounts for the geometry and material properties of the nanoparticle which the quantum emitter is adjacent to. In this framework we solve Heisenberg equations for field and emitters’ operators dynamics combined with the Markovian approximation, to arrive at the desired expressions for transition rates and interaction strengths.

To provide examples, we apply the formalism to simple geometries like a planar interface between two different media or a nanoparticle, and identify scenarios where a step beyond the electric dipole approximation is necessary for accurate description of emitters’ dynamics.

References


Human heart is a powerful muscle contracting in a short periods of time. An electrical signal is linked to every muscle contraction. One way to measure those signals is so called heart echo (ECG). Another approach is measuring the magnetic field (up to 100 pT) induced by the electrical signals. Magneto-cardiography (MCG) is non-invasive and contact-free diagnostic method providing precise arrhythmia localisation and early detection of myocardial ischemic diseases.

Optical magnetometers commonly reaching precision of $1 \text{ fT/}\sqrt{\text{Hz}}$ are strong candidates for diagnostic application. At the Institute of Physics of the Jagiellonian University optical magnetometers based on rubidium vapor cells are used to measure magnetic field induced by a human heart. Magnetic field map delivers information needed for the diagnostics.

An artificial source of magnetic field is needed to examine the diagnostic device. A simple phantom was built. It consists of short wires connected to multichannel current source. The model enables induction of different magnetic fields (static or propagating over time). A Mathematica-based (CDF format) application was provided to simulate 2D map of the magnetic field induced by the wires. Simulations were compared to the experimental results.
Single photon detection system sensitive for visible and infra-red wavelength range

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Recent advances in field of the superconducting single-photon detectors (SSPD) has brought many conceptual ideas which allowed to push forward their capabilities. Specifically, quantum efficiency (QE) of SSPD and the system detection efficiency (SDE) of the SSPD-based systems was increased up to near-unity values at telecom wavelength range [1, 2, 3]. The timing resolution reached the value below 20 ps [4], which is inaccessible for other single-photon detection technologies, such as silicon and InGaAs/InP photodiodes. In addition to that, SSPDs are considered to be the only available type of the single-photon detectors capable of operation in the wide spectral range, starting from near-UV up to mid-IR [5, 6, 7] wavelength.

Here, we demonstrate niobium nitride based superconducting single-photon detectors sensitive in the spectral range 450 - 2300 nm. The system performance was tested in real-life experiment with correlated photons generated by means of spontaneous parametric downconversion, where one of the photons was in the visible and one in the infrared range. We present a measured signal to noise ratio as high as 20000 for a photon pair detection scheme. The photon detection efficiency as high as 64% at 1550 nm and 15% at 2300 nm was observed.

References


Structure and optical investigations of the new polypyrrole derivatives

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The polymers are organic materials which can be exploited for many applications, e.g., in thin-film organic field-effect transistors, in energy storage and conversion devices [1, 2, 3]. Among them, polypyrroles are potentially useful due to their favorable mechanical and electrical properties. In such type of materials, the motion of the delocalized electrons occurs through the π conjugated system. The heteroaromatic and elongated π conjugated backbone structure ensures chemical stability and electrical conductivity. The feature usually associated with π conjugation is the planarity of the compound, which favors the maximum overlap of atomic orbitals.

Recently, we synthesized by chemical and electrochemical polymerization methods new polypyrrole derivatives: polypyrrole-3,4-dicarboxylic acid (PPyDCA) and polypyrrole-3-carboxylic acid (PPyMCA). For these polymers, we have performed a detailed theoretical investigation of the HOMO and LUMO energy levels, which is important in the description of the electrical properties of polymers. Moreover, polymers were characterized by IR and Raman spectroscopy studies. The IR spectra are obtained using different techniques: the KBr pellet method and specular reflectance techniques. The optical conductivity spectra were obtained by Kramers–Krönig analysis of the reflectance spectra recorded from the surface of a compressed pellet of a polycrystalline sample. Furthermore, we realized measurements of electrical conductivity for these polymers using the four-probe method and impedance spectroscopy. Characteristics of electrical conductivity for studied polymers were recorded in the temperature range from 100 to 300 K with 3 K step during both cooling and heating.

References


Mixture of liquid crystals with gold nanoparticles as a modified cladding for tapered optical fiber

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In the standard optical fiber the light is propagated in the core. Only small part of light is propagated by the cladding. If we prepared optical fiber taper, the diameters of core and cladding decrease [1, 2]. In this area, light is exposed to surroundings. Changes of reflective index this medium is detected by tapered optical fiber. This phenomena give possibility of connected optical fiber taper with extra material. In this research it is a mixture of liquid crystal and nanoparticles of gold. This material perform function of “new modified cladding” of tapered optical fiber. Liquid crystal (LC) was chosen due to their anisotropic properties which can be controlled by electric field and temperature [3]. Nanoparticles of gold (Au NPs) were added because increase conductivity, affect to the switching time, form additional centers of crystallization. Modified cladding consist of liquid crystal 1550* and the Au NPs with diameters in the range of 1-3 nm [4]. Tapered optical fiber was characterized by the parameters: loss < 0.5 dB, diameter of taper waist 15.±0.5 µm. Chosen materials were connected by the cell. The cell determined orientation of LC molecules by the orientation layer and provided changes of their orientation by conductivity layer ITO. The thickness is equal 40 µm, the threshold voltage is 80V. The measurements showed changes on transmission characteristic depended on voltage in range 0-200V, with modulation frequency of signal in the range 1-10 Hz. The relaxation time was calculated based on time course measurement from oscilloscope.

References


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Aberration correction using optical vortex image and matched Zernike polynomials

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Spatial light modulator (SLM) and Digital Micro-mirror Device (DMD) are both basic tools for a laser beam shaping in modern science. More and more scientific groups use these modulators to shape the light into almost any desired output. Simultaneously, with growing interest in laser beam shaping, the need for high quality devices is increasing, especially for the demanding applications. Over the years, many of methods for modulators' correction were proposed. Most of them take into account imperfections of the whole optical system, which quite often is responsible for any distortion of optical beam. However, the beam with reach internal structure are still hard to generate. This paves the way for farther development of the correction methods.

Almost any optical wavefront can be represented as a finite set of Zernike polynomials. These polynomials are orthogonal in a continuous fashion over the interior of a unit disk [1]. They can be used for a representation of correction term for the modulators. Finding this correction term is a purpose of this project, based on the work of Lian and et al. [2].

In principal our approach requires registration of distorted optical vortex image and subsequent addition of Zernike polynomials, having a constant feedback from optical system. The software compares correlation between perfect (simulated) and experimental optical vortex image (Fig. 1.). The whole procedure can be divided into two steps. Firstly, the main aberration and its coefficient is determined. Secondly, starting from the determined main aberration, each of remaining primary aberrations is sequentially corrected by determining proper aberration coefficients. At each point, the aberration correction includes results from previous points, merging to final aberration correction.

Figure 1: (Left) Simulated ideal optical vortex. (Right) Distorted optical vortex image obtained in the experiment.

In this paper, the results for the correction using higher order optical vortices will be presented. Although method of searching for suitable Zernike polynomials seems to be robust, comparing to more sophisticated methods, such as those based on Gerchberg - Saxton iterative algorithm, the Zernike method is sufficient, prospective and suitable for further development. The flexibility of this method makes it possible to apply it to more advanced optical setups, optical trapping [3] or optical vortex scanning microscope [4].
References


Ultrafast holmium-doped fiber laser with metallic carbon nanotube-based saturable absorbers

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Despite the huge popularity of carbon nanotube-based saturable absorbers their applicability to Ho-doped fiber lasers was not extensively investigated in terms of stability, scalability, and operation in different dispersion regimes. Moreover, carbon nanotube-based saturable absorbers demonstrated so far consisted of either a mixture of metallic and semiconducting, or exclusively semiconducting carbon nanotubes. In this work we show fabrication of purely metallic single-walled carbon nanotube (m-SWCNT) films and present their application as saturable absorbers for a Ho-doped fiber laser operating in solitonic and stretched-pulse dispersion regimes.

The polymer-free m-SWCNT films were fabricated by a vacuum filtration method [1, 2]. The scanning electron microscope image of the film is shown in Fig. 1a. The characteristic M₁₁ band present in the absorbance spectrum (Fig. 1b) confirms that nanotubes used for film preparation are only metallic. After transferring the film to a fiber connector end facet a fully fiberized saturable absorber is formed.

The all-fiber Ho-doped oscillator is arranged in a ring configuration. As a pumping source a custom-made 1940 nm Tm-doped fiber laser is used. Commercially available Nufern SM-HDF-10/130 active fiber serves as a gain medium. Stable solitonic operation was achieved with saturable absorbers incorporating 100 – 400 nm thick m-SWCNT films. As the film thickness increases, the central wavelength of the emitted pulses exhibits shift towards the shorter waves, while the pulse duration shortens. The best performance was observed for the 400 nm film, when the generated optical solitons were centered at 2079 nm with the bandwidth and pulse duration of 6.6 nm and 683 fs, respectively (Fig. 1c). The repetition frequency of the laser was 54.4 MHz, and its radio frequency spectrum measured in a 0-3 GHz span is shown in Fig. 1d. Laser stability was confirmed by performing a 70 h stability test [4] – the laser operated without failure over the measurement period, and very little fluctuations in central wavelength and optical bandwidth of the spectrum were observed.

In order to reach the stretched-pulse regime of operation, Nufern UHNA4 fiber was included in the laser cavity to serve as a dispersion compensating fiber [3]. As a result of the elongation of the laser cavity, the repetition frequency of the laser decreased to 22.1 MHz. At net cavity dispersion of -0.006 ps², the...
bandwidth of the optical spectrum was 31.4 nm (Fig. 1e), and pulses as short as 212 fs were generated (Fig. 1f). The output coupling ratio was 70%, and therefore very high average output power of 84 mW (corresponding to pulse energy of 3.79 nJ) could be reached. Our results show that m-SWCNTs are suitable for producing versatile and stable saturable absorbers for mode-locked fiber lasers operating in the 2 µm spectral range.

References


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It is well known that X-ray Photoelectron Spectroscopy is surface sensitive technique. In this method, for most materials, majority of registered signal is collected from ca. topmost 5 nm of the sample, therefore it is a superposition of the surface and subsurface properties. This is a huge disadvantage, when properties of surface only are to be determined. An alternative approach, such as angle-resolved measurement, has been developed. Unfortunately, it is not applicable for non-flat systems, such as core – shell systems or nanoparticles and pseudomorphic layers.

Surface properties are crucial for heterogeneous catalytic processes, which makes distinguishing between bulk and surface properties even more important. To address this issue we used a few X-ray lines of different energies to excite photoelectrons from varying depth of the sample. Using different energies of X-ray (151.4 eV - Zr M\(\gamma\) line, 929.7 eV - Cu K\(\alpha\) line, 1486.6 eV - Al K\(\alpha\) line, 2024.4 eV and 2124.4 eV - Zr L\(\alpha\) and L\(\beta\) lines), excited photoelectrons have different kinetic energy and, consequently, different Inelastic Mean Free Path (IMFP). As a result we were able to distinguish between the bulk electronic properties and mostly surface electronic properties, as well as composition of the studied material.

In this report we present the results of studying layered structure: vacuum deposited Pt on Au and Au on Pt, which to some degree resembles pseudomorphic layers. The advantage of this system is the possibility of varying the coverage and thickness of the deposited layers. This allowed us to study a wide range of Au or Pt layer thicknesses from submonolayers to almost bulk material, and better understand the difference between electronic properties of surface, subsurface and bulk.

Figure 1: Electrons’ (IMFP) as a function of electrons’ energy in Au and Pt [1]. The vertical arrows denote the excitation energy used during the experiment and the respective IMFP obtained.

References

Fingerprint of the higher order fields in the quadrupole trap

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The geometric imperfections which occur in Paul traps lead to multipoles of higher orders in the quadrupole potential. The harmonics within the ion motion are the fingerprint of the higher order multipole fields. They are exclusively introduced by these fields and are responsible for some effects such as nonlinear resonances. Understanding these effects is crucial for the operation of mass spectrometers and the interpretation of the data they provide. Identification and characterization of observed nonlinear resonances are discussed.

Paul traps use alternating electric field with radio frequency $\Omega$, which in combination with quadrupole trap geometry, provide the trapping potential with eigenfrequency $\omega$. In the system with perfect layout, quadrupole potential would be created. However, the field in real trap is not "clean" and contains components with higher multipole moments, which result from various geometric imperfections of the device. These limitations cause formation of nonlinear resonances in the motion of ions in the potential of the trap. Such phenomena could be observed as the ions’ escape from the trapping region, which is caused by rapid increase of their kinetic energy gained from the electric field of the trap. In the stability diagram they form characteristic lines which were observed experimentally and discussed in our previous work [1].

The numerical simulation for different trapping conditions were carried out to observe ion motion in the trap potential. The results obtained for pure quadrupole potential and quadrupole mixed with higher order multipoles were analysed. Moreover, the Fourier transform was used to determine and compare the characteristic frequencies of the ion motion [2]. The observed differences between spectra in frequency domain allowed for identification conditions for which nonlinear resonances can be expected (Figure 1).

The resonances observed in the experiment will be discussed and compared with results of numerical simulations.

![Image](https://example.com/image1.png)

Figure 1: Example of: motion of ion in quadrupole trap (a), frequency domain analysis of ions in quadrupole field (b) and quadrupole field disturbed with an octupole (c). The letter $\omega$ denotes secular frequency (red line on subplot a) and $\Omega$ the trap driving AC field frequency (blue line). Plots on subfigure (a) and (b) are obtained for different trapping conditions.

References


The influence of deposition rate on formation and optical properties of the thin Sn layers deposited on the silicon substrate

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The idea of the research was to study the mechanism of growth and optical properties of thin tin layers on silicon substrate. For this purpose, Sn layers with thicknesses of 2.5 nm, 5 nm, 7.5 nm, 10 nm and 20 nm were deposited on the silicon substrates, at a pressure about $1.5 \cdot 10^{-5}$ mbar, using the thermal vapor deposition method. It was noticed that the microstructure and growth mechanism of thin films strongly depend on the deposition conditions (e.g. deposition rate) [1]. For this reason, the studied layers were prepared at two different deposition rates: 0.05 Å/s and 2.50 Å/s.

The change of the microstructure of layer has a significant impact on the change of its optical properties [1, 2]. Therefore, the produced tin layers have been tested in terms of microstructure and optical properties using Atomic Force Microscopy and Spectroscopic Ellipsometry, respectively.

The influence of deposition rate of the tin layers on its microstructure and, hence, on its optical properties is clearly visible in determined dielectric functions, which show the largest differences for lower energies of photons. This fact is associated with different response of free electrons on the incident light and thus with different contribution of the Drude term to the complex dielectric function of the thin tin films.

References


Qudit encoding by utilizing temporal modes of single photons

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Quantum communication protocols can be significantly enhanced by careful preparation of photon wavepackets. Unfortunately, most realistic sources produce photons, which are spectrally broadband. As consequence of this the signal is affected by temporal broadening during its propagation through dispersive media. This effect can considerably limit the efficiency of temporal filtering in long-distance applications.

In [1, 2] we proposed a method to reduce temporal broadening. Here, we present how preparation of spectral entanglement and time-resolved heralding can substantially narrow the wavepacket of the propagated photons, as compared to the classical case [3]. We observed the reduction of the width of the heralded wavepacket to approximately 29% in comparison with the case of non-heralding scenario. Next, we show how the results of theoretical analysis allow for encoding information in the temporal mode of single photon wavepacket. The experimental technique and the proper control of the pump spectral mode can be used to generate and measure entangled qudit pairs encoded in temporal modes of photon pair [4]. Our method and a technique of entangled photon pairs production can be extended in order to generate correlated states of multilevel systems.

References


A new method for automatic identification of anterior and posterior corneal limbal points based on numerical OCT image analysis

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Aim: The corneoscleral limbus is an intermediate area between cornea and sclera. Within this area there are located specific cells responsible for regeneration of the cornea, as well as the outflow pathways of aqueous humor, which is crucial for the process of maintaining the proper magnitude of intraocular pressure. Existing methods for limbus determination are mostly based on manual identification of limbal points, which makes them time-consuming and operator-dependent. The aim of this paper is to present new, fully automatic methods of identification of the anterior and posterior corneal limbal points by means of OCT imaging.

Methods: The images of the anterior segment of the eye were captured with use of Casia 2 SOCT instrument and were processed and analyzed in Matlab environment. The first step was segmentation, surface smoothing and correction of the distortion, in order to obtain realistic geometrical parameters of the anterior segment of the eye [1]. The limbus of the anterior corneal surface was determined by the point, in which the curvature of the anterior corneal surface reaches the zero value (Fig. on the right-hand side). The posterior corneal limbal point was defined as the point on the posterior corneal surface, in which the corneal thickness (measured along the straight line perpendicular to the anterior corneal surface) reaches the maximum value (Fig. on the left-hand side). The next step was to determine the anterior and posterior corneal diameter as the line segment that connects the appropriate limbi. For each examined subject, the procedure was repeated 10 times for various OCT images. The obtained results were compared with the manual determination of the limbi on the OCT images.

Results: The anterior corneal diameter, as an average of 80 measurements, was equal 12,05 mm with SD=0,013 (for automatic method) and 11,84 mm with SD=0,027 (for manual method). In the case of posterior corneal diameter obtained result was equal 11,12 mm with SD=0,013 (for automatic method) and 11,67 mm with SD=0,023 (for manual method).

Conclusions: The presented automatic methods of determination of anterior and posterior corneal limbal points allowed us to obtain better accuracy and more reproducible results than manual identification of limbus. Obtained values of standard deviation were more than 2 times smaller for the automatic methods than for the manual methods. This will allow in the future for more precise estimation of...
the iridocorneal angle, the determination of which depend strongly on the proper identification of the posterior limbus.
Ab initio calculations of collisional effects and CRDS measurements of deuterium towards sub-MHz line position determination

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As a simplest molecule, hydrogen is a perfect candidate for testing quantum electrodynamics (QED) for molecules as well as for studies on new physics beyond the Standard Model [1] such as new forces. Theoretical predictions for energies of rovibrational transitions of hydrogen isotopologues are reaching \(4 \cdot 10^{-5} \text{cm}^{-1}\) accuracy [2, 3, 4]. In the Doppler limit line position of \(\text{H}_2\), HD or \(\text{D}_2\) becomes affected by the line-shape effects including its asymmetry [5]. Our experimental approach takes advantage of cavity-enhanced spectroscopy, and thereby we achieved sub-MHz level of accuracy on the weak quadrupole line position [4], typical for Doppler-free techniques.

To reach kilohertz level of accuracy we applied ab initio quantum scattering calculations to describe the collisional line-shape effects. We performed measurements in several pressures to obtain determination of the line position free from systematic errors caused by incorrect line-shape characterization. Similar ab initio line-shape model was tested in separate measurements with He perturber. Moreover, we extended our experiments to a wide range of temperatures and validated temperature dependences of line-shape effects [6]. Line S(2) 2-0 of \(\text{D}_2\) has been measured by the frequency-stabilized cavity ring-down spectroscopy (FS-CRDS) method assisted by an optical frequency comb (OFC) [7, 8], using experimental setup described in Refs. [9, 10].

References


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Microscopic analysis of cells morphological response to substrates casted from polyhydroxyalkanoates

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Conducting scientific research at the cellular level is an essential procedure, striving to explore the mechanisms governing the entire organism including physiological processes that occur continuously in the body, like migration or proliferation, and pathological such as carcinogenesis [1]. One of the factors strongly modulating these mechanisms is the interaction between cells and the environment (extracellular matrix or other cells) [2, 3, 4, 5]. A new trend in material science is to search for biodegradable and biocompatible biopolymers in order to create biomedical products such as dressings, scaffolds or endoprostheses coatings [6, 7, 8, 9]. Polyhydroxyalkanoates (PHAs) are polyesters of (R)-3-hydroxy-alkanoates (HAs) synthesized and stored in the cell cytoplasm as water insoluble inclusions by various microorganisms.

Biopolymers, such as polylactide (PLA) and poly (3-hydroxyoctanoate) (PHO), can find application in biomedical devices and medicine because are non-toxic materials and biodegrade to harmless products in the environment. In vivo tests have shown that these polyesters are biocompatible to osteoblastic, epithelial and neuronal cells [10]. Additionally, they are highly versatile and have a broad range of physical/chemical properties, depending on monomer composition. The combination of advanced research methods such as high-resolution confocal microscopy, fluorescent staining protocols and quantitative data analysis with new materials of natural origin gives the opportunity to achieve revolutionary results and can contribute to significant advances in research on biopolymers.

References


Sensor of hemoglobin properties based on integrated optics circuit

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In modern medical care fast and accuracy diagnosis methods are required. In medical diagnosis one of the basic test of patient health is research of blood properties, in particular determination of hemoglobin properties. In the case of hemoglobin, two parameters are most interesting for the determination of patient health: hemoglobin concentration and hemoglobin oxidation level [1, 2].

This manuscript presents design and theoretical analysis of the sensor structure based on integrated optics circuit for detection of hemoglobin properties (oxidation level as well as concentration level). The theoretical analysis was focused on optimization of geometrical, optical and sensitivity properties of the presented sensor structure for research of hemoglobin properties. The analysis was focused on determination of the sensing properties of the presented structure including: effective refractive index $N_{eff}$ as a function of refractive index $n_w$ and thickness $d_w$ of waveguide layer, refractive index of the hemoglobin cover layer $n_{CH}$ and substrate layer $n_s$, homogeneous sensitivity $\frac{dN_{eff}}{dn_{CH}}$, and modal field distribution of guided waveguide modes.

The presented hemoglobin sensor based on integrated optics circuit is composed of three sections: prism coupler, planar waveguide (with length $L$) and grating coupler (with spatial period $\Lambda$) Fig. 1.

- The first section - prism coupler is responsible for coupling of light into waveguide structure.
- The second section - planar waveguide with length $L$ is responsible for the determination of imaginary part of refractive index $k$ of the cover layer by evanescent field of guided mode. The imaginary part of refractive index $k$ of the cover layer – corresponding to hemoglobin oxidation level. Changes of imaginary part of refractive index of cover layer $k$ (hemoglobin) causes changes of attenuation coefficient of light into waveguide and hence attenuation of waveguide mode, which can be registered by detector as a changes of signal intensity.
- The third section - grating coupler have two functions: is responsible for uncoupling the light from waveguide to cladding. Second function the grating coupler in presented sensor structure is determination of the real part of refractive index of the cover layer $n_{CH}$, and hence the refractive index of hemoglobin, which correspond to hemoglobin concentration. Changes of refractive index in the cover layer $n_{CH}$ and hence, changes in effective refractive index $N_{eff}$ have influence of the uncoupling angle $\alpha$ of the waveguide mode to cladding by grating coupler (measured by detector).

Figure 1: Scheme of the hemoglobin sensor structure.
References


Fabrication of large-area plasmonic nanostructures for biosensing applications

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In recent years plasmonic nanostructures have attracted a lot of attention allowing studies on enhanced light-matter interactions. Those are manifested in sub-wavelength light confinement and electromagnetic field enhancement, both associated with excitation of surface plasmons (SP). This opened up new applications including subdiffraction imaging, plasmon-enhanced photovoltaics and plasmonic sensing [1, 2]. In case of the nanosensors, electromagnetic field localization in the vicinity of nanoobjects leads to high sensitivity to surface binding events and high resolution reaching up to the single-molecule detection capabilities [3]. Various designs have been used, such as nanohemispheres, nanorods and nanohelices. Silver nanoparticle (nAg) nanohelices are especially suitable because of their chiroptical properties and relatively high resonance quality factors with low losses at optical frequencies.

Performance of a SP-based biosensor depends on the quality factor of surface plasmon resonance (SPR) which in turn requires well-defined nanostructures achievable mostly by expensive and inefficient techniques like electron-beam or focused ion-beam lithography. Those commonly used nanotechnological tools allow for an up to nanometer resolution, but they tend to be time-consuming and limited to a micrometer-scale operation area.

In this study our focus is to master the manufacturing process of large-area metallic nanostructures in form of nanoparticles, nanopillars and nanohelices by means of Physical Vapor Deposition (PVD) technique combined with thermal annealing. In order to achieve anisotropic nanoparticles, Glancing Angle Deposition approach is used. To optimize the nanostructures and quality factor of SPR we systematically characterized several fabrication conditions including the type of substrate, the temperature and time of annealing and the rate and angle of deposition. Prepared samples are measured using UV-VIS reflectometry, spectrophotometry and scanning electron microscopy. Sensitivity of the final products is investigated using various substances of well-known refractive indices. This whole procedure makes it possible to prepare uniform, a few centimeter square substrates of different plasmonic responses (Fig. 1) which can be controlled by adjusting only a handful of settings.

Figure 1: Left: Reflectance of a 5 nm thick Ag layer deposited on various substrates: microscope glass (continuous line), fused silica (dashed) and sapphire (dashdotted), all annealed at 300°C for 20 minutes. Right: a) 5nm Ag on a microscope glass substrate; b) SEM image after annealing; c) nAg size distribution histogram.
References


Infrared characterization of methacrylic polymers based on 1-(4-Nitrophenyl)piperazine

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The aim of this study was to characterize the methacrylic polymers based on 1-(4-Nitrophenyl)piperazine (Fig. 1) by infrared and Raman spectroscopy. The FTIR spectra were recorded in the spectral range from 400 cm⁻¹ to 1500 cm⁻¹ using the spektrometr FT-IR Vertex 70V. The differences between spectra registered for thin layers and powders of these materials are also analyzed.

In addition, Raman results are presented. In this case, Micro-Raman spectrometer (Senterra, Bruker Optik) with a λ = 785 nm laser, optical zoom of about 20x and laser power 50mW was utilized for these measurements.

![Infrared characterization of methacrylic polymers based on 1-(4-Nitrophenyl)piperazine](image)

**Figure 1:** Methacrylate copolymers with arylpiperazine moiety.
Band-shape luminescence nano-thermometers with optical tweezers

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Optical tweezers [1] allow for optical trapping and manipulation of nano- and micro-sized particles being held by optical forces. These forces are in the range of pN and arise out of powerfully focused laser radiation. The usefulness of optical manipulators is widely recognized in biology and biophysics where it is applied for force detection, temperature sensing and viscosity measurements in tiny volumes (\(\approx \mu l\)). Remote and precise temperature detection is crucial in many different fields such as electronics, mechanics and biology. Our research is directed to biological systems. Temperature mapping facilitates heat localization; can be used for observation of a system reaction for a temperature change, which can be affected by inner and/or outer conditions and can make a distinction between healthy and inflammatory cells. Accurate laser (over)heating can be related to cell studies and their response to localized temperature increase.

A tool used for contact free manipulation and distant temperature sensing is an optical tweezers set-up supplied with spectrophotometric detectors. The optical set-up consists of a laser diode 980 nm to trap and excite particles, oil immersion high numerical aperture objective to generate strong optical gradient, spectrophotometer to measure the luminescence of nanoparticles and quadrant photodiode to study its motion. In our research colloidal NaYF\textsubscript{4}:Er,Yb nanoparticles (200 nm in diameter) are used for trapping and sensing temperature. Because of rare earth ions dopant they exhibit up-conversion phenomenon and based on their luminescence intensity ratio (LIR) it is feasible to determine the temperature of such a trapped particle which is in a constant contact with a measured object. LIR described as the ratio of two bands intensities is given by [2]:

\[
LIR = C \exp \left( - \frac{\Delta E}{k_B T} \right),
\]

where \(I\) stands for integrated intensity of bands with a mean wavelength of 525 nm and 545 nm, \(\Delta E\) is the energy gap, \(k_B\) is a Boltzmann constant, \(T\) is the absolute temperature and \(C\) is a calibration constant. The working principle of luminescent nano-thermometry is the change of optical spectrum, emitted by rare earth ions doped nanoparticles, with temperature.

Within our scientific research, we have investigated the dynamics of optical trapped Er\textsuperscript{3+} and Yb\textsuperscript{3+} ions doped NaYF\textsubscript{4} colloidal nanoparticles at various concentrations. This allowed us to ascertain the concentration of nanoparticles enabling to trap a single piece for a long period of time in order to measure the luminescence spectrum as well as to study plant cells changes such as their response to laser heating and viscosity of inner structure as a function of temperature. The reference measurements have been performed for glycerol-water solutions.

References


In metrology, frequency is one of the most important quantities determining accuracy of measurements. One of areas where this is crucial is laser spectroscopy, utilizing stable, narrowband light source to probe e.g. molecular transitions or to serve as an optical reference. This often requires transmitting this light over non-negligible distances using optical fibers, which in turn introduces phase noise modulation, harmful for the measurement. For typical laboratory settings, this translates into frequency shifts on the order of hundreds or thousands of hertz. We propose a system to actively compensate those shifts.

In this work we focus on theoretical foundations of electromagnetic wave propagation and polarization of light and on the description of the optoelectronic, electronic and optical elements used in the setup. As for experimental results, we present characterization of the acousto-optic modulator for single and double pass configurations of the optical setup.

References


Bound states of simple molecular systems: close-coupling and DVR calculations

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Ultracold matter is one of the most important research areas in modern physics. Applications of ultracold atoms and molecules include quantum simulations and search of new physics. In the latter case the ultracold molecular systems are particularly useful as their structure might be sensitive to variation of fine structure constant and proton-to-electron mass ratio.

This contribution describes calculations of the spectroscopy of diatomic molecules. We prepared a code for calculating bound states utilizing close-coupling method. Propagation of the wave function using renormalized Numerov method was performed for Yb+Yb* molecules. The results were compared with experimental data and pseudo-spectral methods (DVR).

As the next step we plan to study sensitivity of vibrational energy levels to subtle changes of the reduced mass.
Advanced microscopic studies of MEF 3T3 cells grown on polyhydroxyalkanoate substrate

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Biopolymers represent one of the leading sectors for bio-based products and their expected growth is foreseen to be significant within the next years [1]. Polyhydroxyalkanoates (PHAs) represent a class of optically active biodegradable polyesters accumulated by numerous bacteria as discrete intracellular granules or as a net like extracellular structures [2]. PHAs are non-toxic materials and biodegrade to harmless products in the environment.

The work focused on the analysis of impact of PHA based substrates on mammalian cells physiology and morphology. Techniques such as double staining with fluorescent diacetate (FDA) and propidium iodide (PI) cytotoxicity assessment and long-term microscopic studies revealed high biocompatibility level of polymer and no toxic impact on Mouse Embryonic Fibroblast cells. Further research concerned advanced cytoskeletal analysis employing confocal and fluorescent microscopy. The received data indicates the influence of biopolymer on the structure and morphology of the cytoskeleton relative to the reference material like glass. Additionally, both the shape of the cells and the structure of actin filaments suggest a high level of cell adhesion to the biopolymeric substrate while compared with glass control. A quantitative analysis was also applied to determine the impact that PHA exerts on both cells’ morphology, cytoskeleton architecture and migration velocity.

PHAs can be subjected to simple modifications that can change both their biological and chemical properties, as well as their physical properties such as hydrophobicity or hardness [3]. These features make polyhydroxyalkanoates versatile polymers, which applications and commercial use can be dictated by the needs of the market and not by limitations posed by the material itself. Thanks to employment of advanced experimental methods like high resolution confocal and fluorescent microscopy combined with complex data analysis it was possible to precisely elucidate the impact of biopolymeric substrates on living mammalian cells and confirm their suitability in biomedical devices and medical applications.

References

The rapid growth of optical waveguide technology in this day are led by the needs to achieve a very high traffic capacity and superfast quantum computing. Optical waveguide has been used extensively in a telecommunication system to carry the information in a form of photon efficiently compared to copper-based interconnecting system. With an ability to produce more broadband, low loss and minimal power consumption these promising optical devices offer a bright future for quantum communication. The selection of material with a high refractive index and transparent within the telecommunication wavelength range are crucially needed to achieve these.

In this paper, the performance of two promising quantum materials, Silicon on Insulator (SOI) and Lithium Niobate on Insulator (LNOI) rib waveguide were studied. The mode analysis was conducted by using a finite element method to observe the confinement electromagnetic wave across rib waveguide. Apart from the variation of a material index, the width and height of core were optimized to achieve single mode propagation at the wavelength of 1550 nm. Based on the simulation work, it is shown that both material structures were able to produce single mode propagation with SOI showing higher confinement compared to the LNOI rib waveguide structure.
Global Network of optical atomic clocks to search for the footprint of SM-DM coupling

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Astrophysical observations indicate that the Universe contains five times more dark matter (DM) than standard matter, however its nature still remains an unsolved mystery. Dark matter candidates like topological defects and oscillating massive scalar fields can be searched for by a single optical atomic clock [1, 2].

We describe the optical atomic clocks readouts analysis and provide a recipe for analyzing the data obtained from transcontinental network made of already existing optical atomic clocks placed in Poland, France, Japan and United States [3]. We describe, basing on Very-Long-Baseline Interferometry (VLBI) procedures, how to correlate the data obtained from already operating optical atomic clocks to search for topological-defect dark matter. Furthermore, we discuss the methods of improving already existing limits on dark matter fields couplings to standard model fields (SM-DM coupling). We also consider DM candidate in the form of oscillating massive scalar fields and constrain their couplings to standard matter.

References


