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BOOK OF ABSTRACTS

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Poster session

Amaliah Arifah Nurul *"Spectral shift using an electro-optic phase modulator"*

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Spectral shift using an electro-optic phase modulator

Key words: *spectral shift, electro-optic phase modulator*

Abstract

Applying a spectral and temporal phase to the beam can modify the optical properties of the beam by passing it through a phase modulator. An electro-optic phase modulation (EOPM) can introduce spectral shift by applying a linear time-dependent phase to the optical pulse. The phase imprinted on the pulse depends on the amount of the driving voltage applied to the modulator [1]. To see the modulation amplitude at a given RF power, a former experiment has been done by passing a CW-light through the modulator which results in sidebands of the signal after passing through the modulator. The output beam after passing the modulator is given by a first-type Bessel function of the order n, and also modulation amplitude [2]. Introducing external spectral shift to optical pulse can be obtained by aligning the pulse to the sinusoidal phase modulation [3]. The spectral shift experienced is in the function of the driving voltage applied to the modulator, as well as the modulation amplitude.
Electro-optic phase modulation requires an rf driving signal that should be in time correlation with the optical signal [1]. Traveling wave EOPM allows accumulating the phase shift along the length of the modulator and can be achieved by matching the phase velocity of the rf signal to the group velocity of the optical pulse. The synchronization both of the RF signal and optical pulse can be obtained by applying a phase-locked loop (PLL) that able to track the frequency and phase of the input when it is locked through VCO (voltage-controlled oscillator).
Finally, the experiment was done by synchronizing an 80 MHz pulse signal out of the photodiode with an 80 MHz signal from the AWG generator. A mixer is used as a phase detector and active feedback is controlled by a PID controller resulting in a lock condition of the PLL system. A spectral shift is obtained by passing the optical pulse to the EOPM driving by the synchronized rf signal. The amount of spectral shift when EOPM is driven by 5.6 GHz 16 dBm rf signal (amplified using a ZVE-3W-183+ Mini-circuits amplifier) is about 438 pm or equal to ±54.1 GHz.

References:

[1] *Wright, L.J., Karpiński, M., Söller, C. & Smith, B.J. 2017: Phys. Rev. Lett. 118, 023601. Spectral*

shearing of quantum light pulses by electro-optic phase modulation. (2017).
[2] *Changchen Chen., Hayes, J. E., Shapiro, J.H. & Wong, F. N. C. 2021: Nature, Scientific reports. 11, 300.*
[3] *Karpiński, M., Jachura, M., Wright, L.J. & Smith, B. J. 2017: Nat. Photonics. 11, 53-57.*

Amoros-Binefa Júlia *"Noisy Atomic Magnetometry in Real Time"*

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Noisy Atomic Magnetometry in Real Time [1]

Key words: *noisy magnetometry, atomic sensor, continuous measurement, Kalman Filter*

Abstract

Continuously monitored atomic spin-ensembles allow, in principle, for real-time sensing of external magnetic fields beyond classical limits. Within the linear-Gaussian regime, thanks to the phenomenon of measurement-induced spin-squeezing, they attain a quantum-enhanced scaling of sensitivity both as a function of time, t, and the number of atoms involved, N [2]. In our work, we rigorously study how such conclusions change when inevitable imperfections are taken into account: in the form of collective noise, as well as stochastic fluctuations of the field in time. We prove that even an infinitesimal amount of noise disallows the error to be arbitrarily diminished by simply increasing N, and forces it to eventually follow a classical-like behaviour in t. However, we also demonstrate that, "thanks" to the presence of noise, in some regimes the model based on a homodyne-like continuous measurement actually achieves the ultimate sensitivity allowed by the decoherence, yielding then the optimal quantum-enhancement. We are able to do so by constructing a noise-induced lower bound on the error that stems from a general method of classically simulating a noisy quantum evolution, during which the stochastic parameter to be estimated—here, the magnetic field—is encoded. The method naturally extends to schemes beyond the linear-Gaussian regime, in particular, also to ones involving feedback and active control.

References:

[1] *J. A. Binefa, and J. Kołodyński, arXiv:2103.12025 (2021).*

[2] *J. Geremia, J. K. Stockton, A. C. Doherty and H. Mabuchi, PRL, 91(25), 250801 (2003).*

Arciszewski Paweł *“Web–based data analysis and acquisition software”*

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WEB–BASED DATA ANALYSIS AND ACQUISITION SOFTWARE

Key words: *Data acquisition, Data analysis, Experimental Architecture*

Abstract

Ultra cold atom experiments are based on a custom built, dedicated apparatus, that usually is designed solely for the purpose of a given project. It means that each laboratory needs to develop their own approaches for system control and data acquisition. This fact often results in solutions that have little flexibility or scalability, which renders those frameworks unusable or highly impractical in implementation in the cases of new or already existing experiments. Moreover, those limitations can further impact a project development as an architecture may not be prepared for a growing number of measurement equipment or even replacement of the existing one.

To overcome those problems we developed an architecture for data acquisition and analysis that is decoupled from the hardware–side of the experiment. The designed and implemented software can support user defined analysis operations as well as any type of measurement equipment. Whole solution is based on modern and widely used frameworks, namely Django and React Redux. Because of that it merges both excellent community support for its further development with advantages of a web–based application. This approach presents a universal solution that can be incorporated not only in AMO experiments, but also in all other projects where experimental sequences are consisting of distinguishable iterations.

Bancerek Maria *“Strong light–matter coupling using Mg nanoparticles”*

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Strong light–matter coupling using Mg nanoparticles

Key words: *light–matter coupling, plasmon polaritons, Mg nanoparticles, vacuum Rabi splitting*

Abstract

In the strong light–matter coupling regime, the interaction between photons and excitons is greater than any competing losses in the coupled system, leading to new emergent properties of the considered system via hybridization of the two interacting resonances. These mixed light–matter states, called polaritons, depend strongly on both constituents of the system, however, they can exhibit different properties, such as induced chemical reactivity or conductivity.

Strong coupling can be realized in relatively simple systems consisting of plasmonic nanoantennas, acting as an optical cavity, and molecules with electronic transitions [1]. The nanoantenna confines modes to ultrasmall volumes of the order of a few cubic nanometers, leading to large electric field enhancement. The cavity mode, also termed a localized surface plasmon polariton, whose parameters can be tuned by varying the geometry of the plasmonic particle, facilitates strong coupling. By changing the shape of the particle, plasmonic resonance — its strength and position — can be designed to overlap that of a molecule, allowing us to study a wide regime of interaction parameters, such as different vacuum Rabi splitting.

In my work I study the effect of collective plasmonic oscillations in Mg nanoparticles on the strong coupling to organic molecules, such as tetracene. Density functional theory (DFT) calculations are performed to investigate the alteration of molecular energy levels in order to pin down key parameters determining the efficiency of coupling in nanoplasmonic-molecular systems.

References:

[1] *Tuomas P. Rossi, Timur Shegai, Paul Erhart and Tomasz J. Antosiewicz: Strong plasmon-molecule coupling at the nanoscale revealed by first-principles modeling, Nature Communications 10, 3336 (2019).*

Dobosz Jakub *"Semiconductor laser locking methods"*

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Semiconductor laser locking methods

Key words: *laser, locking, current modulation, frequency modulation*

Abstract

In applications such as laser spectroscopy, laser cooling, photoassociation, laser combs and many others knowing the frequency of one's laser is crucial. The need of stabilizing the frequency down to the kHz regime resulted in a plethora of methods [1–4]. In this work we describe a few of them used in our laboratory. Commonly used semiconductor lasers can be stabilized by controlling both injection current and the length of external cavity. Error signal for stabilization is obtained with saturation spectroscopy, where frequency scan is performed with modulating the diode current. Such procedure results in obtaining an error signal, but also broadens the linewidth of the locked laser. We show a method of obtaining error signal with external modulation of laser light with Acousto Optic Modulator which suppresses laser linewidth. Saturation spectroscopy requires additional optical setup and a cell with atomic vapour to lock to. We also show an approach of beatnote offset frequency locking which locks slave laser to already locked master by detecting the beatnote between two laser beams. Offset locking offers a wide range of tunable frequencies of slave laser. Our solution is based on a cheap FPGA board RedPitaya [5].

References:

[1] *A. Arie, et al., "Absolute frequency stabilization of diode–laser–pumped Nd:YAG lasers to hyperfine transitions in molecular iodine", Opt. Lett. 17, 1204-1206 (1992).*

[2] *K. L. Corwin, et al., Frequency–stabilized diode laser with the Zeeman shift in an atomic vapor, Appl. Opt. 37, 3295-3298 (1998).*

[3] *G. Ritt, et al., Laser frequency offset locking using a side of filter technique, Appl. Phys. B 79, 363–365 (2004).*

[4] *N. M. R. Hoque and L. Duan, Direct Frequency Locking of a Diode Laser to a Meter–Long High–Finesse Fiber Fabry-Perot Cavity, in Conference on Lasers and Electro-Optics, OSA Technical Digest (Optical Society of America, 2019)*

[5] *T. Preuschoff, et al., Digital laser frequency and intensity stabilization based on the STEMlab platform (originally Red Pitaya), Rev. of Sci. In. 91, 083001 (2020)*

Dominik Dobrakowski *"Tm-doped structured silica fiber with birefringence and normal dispersion at 2 μm"*

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Tm-doped structured silica fiber with birefringence and normal dispersion at 2 μm

Key words: *optical fibers, fiber designing, fiber lasers, active fibers, anisotropic media*

Abstract

Standard optical fibers made from silica glass possess chromatic dispersion in the normal range up to a wavelength of around 1.3 μm. Providing a microstructured cladding of the fiber enables shaping of the fiber's dispersion characteristics.

In ultrafast fiber laser technology pulse energy scaling in an oscillator is limited by the soliton area theorem[1], related to pulse duration and chromatic dispersion. Such a limitation is greatly released for the case of ytterbium-doped fiber lasers due to normal dispersion of the fiber and operation in the dissipative soliton regime[2]. This allows for significantly higher pulse energies directly from the oscillators, compared to the soliton systems. However, at 2 μm (thulium- and holmium-doped systems) normal dispersion fibers are technologically challenging because of strong anomalous dispersion of silica at that wavelength range. There is strong interest in transferring from the ytterbium to thulium-doped fibers in ultrafast laser technology. It is motivated by the latter's advantage of factor of four higher threshold for transverse mode instability, which is a detrimental phenomenon in peak power scaling in ultra-fast photonics systems[3].

Here we propose a silica fiber design with a doped silica core and a microstructured cladding consisting of air holes. The core of the fiber is made from fused silica glass and silica doped with thulium and co-doped with aluminum. The presence of aluminum dopant is beneficial for thulium ions in silica matrix[4]. Maximal dimension of the fiber's core is 2.3 μm. The cladding of the fiber contains 6 rings of air holes surrounding the core with lattice pitch equal to 2.3 μm and diameter of 600 nm.

The design allows to anticipate normal dispersion values covering a wide spectral range, including the 2 μm wavelength and above. Due to the small core, the fiber supports only the fundamental mode at the full examined wavelength range, starting from 800 nm. Additionally, the fiber possesses relatively high birefringence of the order of 10^{-5}. Phase birefringence values are monotically decreasing with wavelength, taking a value of 3.6×10^{-5} at 2 μm.

According to our previous experiences, the designed fiber structure is technologically feasible. A significant advantage of the proposed design is the normal dispersion profile at the wavelength range of thulium-doped fiber laser systems. This enables dissipative soliton operation without the necessity of using additional dispersion compensation fiber sections, which would be desirable, e.g., for increasing the oscillator repetition rate. Moreover, single mode operation and expected polarization maintenance feature of the fiber together with high active ion doping, makes the designed fiber an appropriate medium for efficient laser emission around 2 μm.

References:

[1] *W. H. Renninger, A. Chong, and F. W. Wise, "Area theorem and energy quantization for dissipative optical solitons," J. Opt. Soc. Am. B 27(10), 1978 (2010).*

[2] *L. M. Zhao, D. Y. Tang, H. Zhang, X. Wu, Q. Bao, and K. P. Loh, "Dissipative soliton operation*

of an ytterbium-doped fiber laser mode locked with atomic multilayer graphene," Opt. Lett. 35(21), 3622 (2010).
[3] *C. Gaida, M. Gebhardt, T. Heuermann, F. Stutzki, C. Jauregui, and J. Limpert, "Ultrafast thulium fiber laser system emitting more than 1 kW of average power," Opt. Lett. 43(23), 5853 (2018).*
[4] *D. C. Kirsch, S. Chen, R. Sidharthan, Y. Chen, S. Yoo, and M. Chernysheva, "Short-wave IR ultrafast fiber laser systems: Current challenges and prospective applications," J. Appl. Phys. 128, 180906 (2020).*

Karpate Tanvi *"Implementation of nonlinear refractive index measurement techniques for fiber–drawable glasses and photonic crystal fibers"*

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Implementation of nonlinear refractive index measurement techniques for fiber–drawable glasses and photonic crystal fibers

Key words: *nonlinear index, Z–scan, self–phase modulation*

Abstract

Propagation of high intensity light beams in a medium enables observation of practical application of various nonlinear optics phenomena originating from different orders of susceptibility () of the materials. One such nonlinear effect is the change in refractive index (n) of the medium as a function of incident intensity (E) as $\tilde{n}(\omega, |\mathrm{E}|) = n(\omega) + n_2|\mathrm{E}|^2$.This is called optical Kerr effect and is associated with third order susceptibility (3) of the material. This work outlines two popular techniques based on Kerr effect for measuring nonlinear refractive index (n_2): the Z–scan and the self–phase modulation induced pulse reconstruction. In Z–scan, we study the spatial changes in an intense laser pulse caused by self–focusing. By moving a sample through the focus of a Gaussian beam, the sample experiences different intensities, consequently different self–focusing contributions, at different positions across the Rayleigh range. Thus, information about the phase change of the pulse can be obtained by the detecting the transmitted intensity variation on a detector with a pinhole. In our set–up for Z–scan, we incident a 100 fs Gaussian pulse with average power of 450 mW centered at 1560 nm wavelength. This beam is focused on a bulk sample with a 5 cm focusing lens and the transmitted intensity is detected by aphoto–diode. We present the results of n_2 measured through this system for highly nonlinear glasses such as tellurite and heavy metal oxide glasses which can be characterized in terms of their n_2 despite the limited laser pulse energy and peak power. Another less popular method for measuring n_2 is by observing the spectral changes caused by the Kerr effect, in particularly, self–phase modulation (SPM). In our set–up, we induce self–phase modulation in the sample by the means of a 400 fs pulse centered at 1030 nm and measure the phase using a second–harmonic frequency–resolved optical gating (SHG FROG) set–up. From the phase and intensity information of the pulse after the sample, we calculate the n_2 of the sample. This method holds an advantage as unlike Z–scan technique, it can be used to measure n_2 of fibers and waveguides. These measurement techniques play a pivotal role for characterization of in–house developed non–standard specialized glasses and fibers.

References:

[1] *M. Sheik–Bahae et al. High–sensitivity, single–beam n_2 measurements. Opt. Lett. 14 (17), 955 (1989).*

[2] *M. Sheik–Bahae et al. Sensitive measurement of optical nonlinearities using a single beam. IEEE J. Quantum Electron. 26 (4), 760 (1990)).*

[3] *J. Cimek et al. Experimental investigation of the nonlinear refractive index of various soft glasses dedicated for development of nonlinear photonic crystal fibers. Opt. Mater. Express 7, 3471-3483 (2017).*

[4] *P. Kabacińnski et al. Nonlinear refractive index measurement by SPM-induced phase regression. Opt. Express 27, 11018-11028 (2019).*

Korneluk Alexander *"Electrical control of optical properties in multilayer heterostructure"*

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Electrical control of optical properties in multilayer heterostructure

Key words: *electro–optical light modulation, active photonics, indium tin oxide, metamaterial*

Abstract

Efficient control of optical properties is a key–enabling technology for a wide variety of active photonic devices like waveguides, nanoantennas, or switches. One way to obtain mentioned functionality is by exploiting the effect of an electrically–induced local change of carrier density in a MOS (Metal–Oxide–Semiconductor) multilayer stack. As demonstrated recently, this mechanism can lead to unity–order alteration of the refractive index values in the active layer. Such strong optical modulation is unattainable via the typically used Pockels or Kerr effect.

In this work, we present a functional nanodevice in which optical properties alter under applied external voltage. The proposed device has a form of a multilayer heterostructure, composing of silver, silicon dioxide, and ITO layers. The structure is subwavelength, with overall nanoscale thickness. ITO layer acts as an active layer where electrons locally form an accumulation layer at the silicon dioxide interface. Using spectroscopic ellipsometry, we demonstrate that applied voltage affects the polarization state of the reflected beam from the device surface. We also show that the change in the ellipsometric parameters Ψ and Δ values is observable for voltage values as low as 0.5 V and gradually increases with the strength of the electric field. Finally, we reveal that reverse bias leads to the formation of the depletion layer with the opposite influence on the optical properties of the device.

References:

[1] *Feigenbaum, E., K. Diest, and H.A. Atwater, Unity–order index change in transparent conducting oxides at visible frequencies. Nano Lett, 2010. 10(6).*

Kuk Natalia ***"Module for injection locking of high power laser diode"***

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Module for injection locking of high power laser diode

Key words: *injection locking, laser system, laser module, optical circulator*

Abstract

We report on generation of stabilized laser light at 1064 nm through injection locking of a high power slave laser diode with light from a master narrow-bandwidth fibre laser. The slave's laser diode is capable of producing 300 mW of laser light and its injection locking is performed with 3 mW of the seeding light. The seeding light is coupled into the slave laser diode's cavity through an optical circulator, hence eliminating requirment of using an optical isolator between slave and the coupling fiber, though a fiber optical isolator is required between the master's output and optical circulator input port to prevent leaking light from entring fiber laser's cavity as it worsens its performance. The slave laser is integrated in a fully fiber–running module with output ports for reference and experimental purposes. The module is an aluminum body cut out of one piece of metal with a lid that is matched to the fiber laser package. This enables combining these lasers into one mobile laser system. The injection locked slave's output power will be split to seed two optical amplifiers which will be used for optical lattices generation in cold atoms experiment.

Lipka Michał *“How to observe single photons at 200 000 camera frames per second?”*

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How to observe single photons at 200 000 camera frames per second?

Key words: –

Abstract

A significant part of quantum-optical research and technology relies on the ability to detect single photons. In particular, multimode non-classical states of light, representing high-dimensional qudits, open new avenues in near-term applications [1] as well as fundamental research [2]. Single-photon sensitive cameras are a very flexible way to detect weak spatially-multimode light, especially when the number of modes is very high [3]. On the other hand, their efficiency and acquisition speed is often relatively low. In this contribution we present a camera able to detect single photons at up to 2×10^5 frames per second i.e. an order of magnitude faster than off-the-shelf equivalents. Furthermore, integrated processing allows for real-time (several s delay) localization of the photons within the frame. We envisage the real-time processing will enable adaptive strategies greatly enhancing numerous quantum optical protocols, as well as enabling novel applications of existing schemes e.g. heralded single-photon generation with spatially multimode quantum memories. The camera prototype combines an image intensifier (II) with a fast CMOS sensor, as schematically depicted in Fig. 1 (a). The II produces relatively bright (107 photons) flashes on the phosphor screen for ca. 20% of the single photons at the input. The phosphor screen is imaged onto the camera sensor. The novelty here is in the application of a very fast sensor which is inherently noisy and of low sensitivity, yet with adjusted real-time image processing can still localize phosphor flashes and hence the input photons.

As a demonstration and verification of the camera capabilities, we measure correlations between the spectra and angle of emission for twin-photons [4] produced in non-collinear spontaneous parametric down-conversion (SPDC). The 4-dimensional correlation function for pairs of photons is measured by selecting photons with non-zero wavevector along one axis and applying a diffraction grating to provide wavelength-dependent shift in the wavevector along the second axis. The experimental setup is depicted in Fig. 1 (b). A high-resolution measurement of the full 4-dimensional correlation function for pairs of photons requires a tremendous statistics, previously very difficult to acquire. For the measurement we collected $\approx 10^9$ camera frames in roughly one day. Exemplary wavevector and spectral slices of the measured correlations are depicted in Fig. 1 (c),(d), respectively.

We present a prototype of a single photon camera consisting of a fast CMOS sensor and an image intensifier. The camera achieves an order of magnitude higher acquisition rate (ca. to 2×10^5 frames per second) than off-the-shelf intensified CMOS cameras, without loss of quantum efficiency. Due to real-time image processing, we are able to localize the photons within a frame with just a few μs delay, enabling adaptive applications requiring fast feedback loops. To demonstrate some of the camera capabilities we measure the 4-dimensional joint spectral-wavevector correlations of twin-photons, requiring a huge experimental statistics.

References:

[1] *M. Lipka, M. Mazelanik, and M. Parniak, "Entanglement distribution with wavevector-multiplexed quantum memory," arXiv:2007.00538*

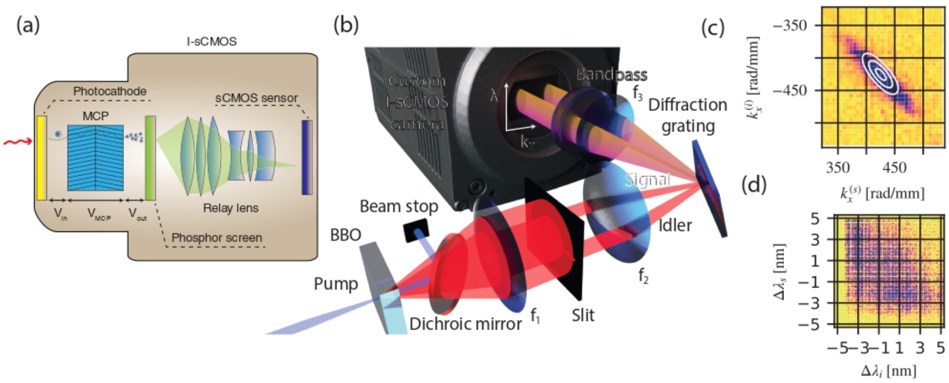

Figure .1: (a) Schematic of an intensified scientific CMOS (I-sCMOS) camera, able to observe single photons. (b) Experimental setup for measuring correlations between the angle of emission (wavevector) and the spectrum of twin-photons produced in non-collinear SPDC. The measurement serves as a test for a fast custom I-sCMOS. (c),(d) Exemplary slices of the 4-dimensional wavevector-spectral correlations (photon number covariance) between pairs of photons captured in the same camera frame, over 109 frames. Correlation is integrated over narrow ranges of signal and idler (c) spectra (d) transverse wavevectors.

[2] *Wang Yuchen, Hu Zixuan, B. C. Sanders, and K. Sabre,"Qudits and High-Dimensional Quantum Computing," Front. Phys. 8, 479 (2020)*

[3] *M. Parniak, M. Dąbrowski, M. Mazelanik, A. Leszczyński, M. Lipka and W. Wasilewski, "Wavevector multiplexed atomic quantum memory via spatially-resolved single-photon detection," Nat. Commun. 8, 2140 (2017).*

[4] *M. Lipka, and M. Parniak, "Fast imaging of multimode transverse-spectral correlations for twin photons," arXiv:2101.03120*

Longobucco Mattia *"Ultrafast All–Optical Dual-Colour Switching in Asymmetric Dual–Core fiber"*

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Ultrafast All–Optical Dual-Colour Switching in Asymmetric Dual–Core fiber

Key words: *Dual–core optical fibers; Soft glass optical fibers; Nonlinear fiber optics; All–optical switching; Asymmetric coupler*

Abstract

We present an improved approach of all–optical switching of femtosecond solitons in the C–band at sub–nanojoule switching pulse energies, using a highly nonlinear, all–solid dual–core fiber with high contrast of refractive index and slight asymmetry between cores. It is based on two–colour control–signal switching, which permits to achieve even higher switching contrasts and better pulse shape preservation than the standard self–switching approach [1-3].
Two 10 kHz repetition rate sequences of timely synchronized fs pulses with different central wavelengths were launched into one fiber core: 1030 nm, 270 fs control pulses with energy in the range of 1 — 15 nJ from a commercial Yb:KGW amplifier (Pharos, Light Conversion); 1560 nm, 75 fs signal pulses with energy of 100 pJ from a double pass OPA, pumped by frequency doubled output of the Yb:KGW amplifier. A series of camera images of the signal field spatial distribution at the output fiber facet was recorded increasing the control pulse energy for different fiber lengths in the range of 16 – 10.5 mm. The values of extinction ratio (ER) were obtained by spatial integration of the intensity distribution in the excited and non-excited ($E_{\text{non}-\text{ex}}$) cores, resulting in values E_{ex} and $E_{\text{non}-\text{ex}}$, respectively. Using them, it was calculated with the equation 10 $\log(E_{\text{ex}}/E_{\text{non}-\text{ex}})$. The fiber length dependence of the minimum of ER, which indicates the maximal energy transfer to the non–excited core, revealed the extreme value of -23.2 dB at the optimal fiber length of 14 mm, applying control pulses with 12.6 nJ energy.
The explanation of the control-signal switching performance is the nonlinear balancing of the dual–core asymmetry: the Kerr nonlinearity in the guiding glass causes the decrease of the group velocity v_g of the excited core in the time window of the control pulse duration to the level of the non–excited core v_g [4]. This interpretation is supported by the calculations of the optimal coupling length L_c of a hypothetically symmetrical structure (13 mm vs. experimentally retrieved 14 mm). Moreover, the improvement with respect to the self–switching approach relies on the longer time duration of the control pulse than the signal one. The difference in their group velocities cause a walk–off between 1030 and 1560 nm of about 152 fs for 14–mm long fiber, which indicates that the signal pulse propagates faster than the control one. This allows us to assume that the optimal high-contrast switching performance is reached when the pulses overlap in correspondence of half of the fiber length. The demonstrated approach represents high application potential due to its simplicity, compactness and fiber compatible character.
References:
[1] *A. Betlej et al., Opt. Lett. 31, 1480 (2006).*
[2] *P. Stajanca et al., Opt. Express 22, 31092 (2014).*
[3] *V. H. Nguyen et al., Opt. Lett. 45, 5221 (2020).*
[4] *M. Longobucco et al., J. Light. Technol., accepted (2021), arXiv:2101.12183 [physics.optics].*

Ludwiczak Katarzyna *"Tm-doped structured silica fiber with birefringence and normal dispersion at 2 μm"*

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High optical quality of wafer-scale monolayer of molybdenum diselenide

Key words: *transition metal dichalcogenides, molecular beam epitaxy, metalorganic vapour phase epitaxy, hexagonal boron nitride*

Abstract

For the past several years, ultrathin materials are being intensively studied. Out of a large variety of layered crystals, transition metal dichalcogenides (TMD) gained a lot of attention due to their optical properties, that make them perfect candidates for optoelectronics and quantum computing devices. The vast majority of experiments concerning TMD is however conducted only on few-microns small, mechanically exfoliated flakes. Producing large-scale, high quality ultrathin materials is therefore a great challenge and a big step forward towards future applications. Here, we present optical studies of a wafer-scale (2") sample of molybdenum diselenide (MoSe2) grown by molecular beam epitaxy (MBE) on hexagonal boron nitride (h-BN) grown by metalorganic vapour phase epitaxy (MOVPE) (Fig. 1a). In our heteroepitaxial growth method, high-quality hexagonal boron nitride is of a great importance as a substrate for further TMD growth. The material possesses a wide band gap (6 eV) that makes it a perfect electric insulator and is also known to improve optical properties of other layered materials due to the lack of dangling bonds on its surface. Our previous efforts allow us to grow few nanometers thick, high quality hexagonal boron nitride on 2 inch sapphire substrates by MOVPE [1,2]. Subsequently MBE MoSe2 growth [3] was performed using such a substrate. In our work, we discuss the effect of different growth conditions on the properties of the produced material. We analyze its quality mainly by optical studies: Raman and photoluminescence spectroscopy. Raman mapping confirms homogeneous MoSe2 monolayer coverage on the whole wafer(Fig 1b). We also present low-temperature (5 K) photoluminescence spectra, that unveil an excellent optical quality of the sample. The visible excitonic lines are narrow and can be resolved into two peaks corresponding to the neutral A exciton and trion (Fig 1c-d). The obtained results allow us to discuss the impact of MOVPE grown h-BN layers on the properties of the
MoSe2 structures grown by MBE on top of it. In summary, we are able to produce excellent optical quality MoSe2 samples on a scale 3 orders of magnitude larger than typical, mechanically exfoliated flakes. Our achievement constitutes a large step towards wafer-scale production of heteroepitaxial structures of layered crystals, which is of crucial importance for their future applications.

Refrences:

[1] *K. Pakuła, A. Dabrowska, M. Tokarczyk, R. Bożek, J. Binder, G. Kowalski, A. Wysmo lek, R. Stepniewski "Fundamental mechanisms of hBN growth by MOVPE" arXiv: 1906.05319 (2019)*

[2] *K. Dabrowska, M. Tokarczyk, G. Kowalski, J. Binder, R. Bo zek, J. Borysiuk, R. Stepniewski, A.Wysmołek "Two stage epitaxial growth of wafer-size multilayer h-BN by metal-organic vapor phase epitaxy – a homoepitaxial approach", 2D Mater.,8, 015017 (2021)*

[3] *W. Pacuski, M. Grzeszczyk, K. Nogajewski, A. Bogucki, K. Oreszczuk, J. Kucharek, K. E. Połczyńska, B. Seredyński, A. Rodek, R. Bożek,T. Taniguchi, K. Watanabe, S. Kret, J. Sadowski, T. Kazimierczuk, M. Potemski, and P. Kossacki, "Narrow Excitonic Lines and Large-Scale Homogeneity of Transition-Metal Dichalcogenide Monolayers Grown by Molecular Beam Epitaxy on Hexagonal Boron Nitride", Nano Lett.20, 3058–3066 (2020)*

Markowicz Bartosz *"Bayesian inference of cavity optomechanics parameters by photon counting measurements"*

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Bayesian inference of cavity optomechanics parameters by photon counting measurements

Key words: *Cavity optomechanics, Bayesian inference, Parametes estimation*

Abstract

The field of optomechanics has gone through many impressive developments in recent years. The coupling between an electromagnetic field and a mechanical degree of freedom, was an early proposal of an ideal setting to explore the classical and quantum limits of ultrasensitive measurements [1].
In our work we present a measurement protocol based simply on photon counting and applying Bayesian inference methods to estimate any parameter of interest. We demonstrate its performance by generating sample quantum trajectories through a stochastic master equation and subsequently analyse the accuracy of the measurements. Due to the fact that analytical analysis of a cavity's optomechanics behavior is possible only in very limted number of cases to examine our protocol we designed a numerical toolbox that simulates the evolution of cavity optomechanics in full generality and estimates the cavity's parameters according to our protocol.
This program can help to understand the behavior of cavity optomechanics for an intermediate regime of coupling constant, which until now has largely been unexplored. Furthermore, our protocol provides high precision measurement that may also be better than standard strong measurements due to the correlations in the photon statistics of the cavity.

References:
[1] *Francesco Fogliano et al., Phys. Rev. X 11, 021009 (2021).*

Pylypenko Uliana *"Application of quantum technologies in astronomical instrumentatio"*

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Application of quantum technologies in astronomical instrumentation

Key words: *quantum technologies, astronomical instrumentation, quantum astronomy*

Abstract

A new era of astronomical discoveries requires a new generation of astronomical instrumentation. Simple scaling of the existing technologies at the current stage will lead to creating bulky and costly instruments, so we need to implement the new ones. One of the possible solutions may be application of quantum technologies. A couple of imaging systems based on e.g. ghost imaging or photon clonning have been proposed and several prototypes have been created. They can enable us to beat the diffraction limit, detect very faint objects, from which only single photons arrive, observe high time-resolution events, etc. The application of astronomical instruments based on quantum technologies can be extremely broad: from distant Solar System objects and stars at late evolution stages exploration to studying the evolution of the Universe as a whole.

The current state as well as possible development paths of quantum technologies implementation in astronomical instruments have been reviewed and will be presented during the poster session.

References:

[1] *A. Kellerer, "Beating the diffraction limit in astronomy via quantum cloning", Astronomy and Astrophysics (2014)*

[2] *T. Occhipinti et al., "Quantum astronomy: scientific background, technologies, achieved results, and future developments", spiedigitallibrary.org (2018)*

[3] *D. Dravins, "Photonic Astronomy and Quantum Optics", High Time Resolution Astrophysics, Astrophysics and Space Science Library (2007)*

[4] *D. Gottesman, "Quantum telescopes", spiedigitallibrary.org (2020)*

[5] *E. T. Khabiboulline et al., "Quantum-Assisted Telescope Arrays", Physical Review A (2019)*

[6] *G. Gumpel E. N. Ribak, "Optical amplification for astronomical imaging at higher resolution", Journal of the Optical Society of America (2021)*

[7] *J. Bland-Hawthorn et al., "Quantum memories and the double-slit experiment: implications for astronomical interferometry", Optics Letters (2021)*

Rajchel-Mieldzioć Paulina *"Photoactive properties of peptide-based structures"*

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Photoactive properties of peptide-based structures

Key words: *FF, diphenylalanine, peptide-based photoactive systems*

Abstract

Photoactive structures composed of short peptides are a popular object of interest due to possible biocompatibility and often unusual material properties[1]. A key element in the design of peptide-based photoactive systems is the control of the crystal growth process in order to obtain structures with pure morphology. A particularly interesting building block is phenylalanine-phenylalanine dipeptide (FF, also called diphenylalanine), which is the core recognition motif of Alzheimer's β-amyloid—thus, the analysis of the process of its self-organization is also of added value in understanding the mechanisms of the formation of amyloid structures associated with neurodegenerative diseases.

The self-organization of the phenylalanine-phenylalanine dipeptide can be controlled by selecting the concentrations of the stock solutions[2,3], solvents—including solvents used to prepare the dipeptide-containing stock solution[3] and also by incorporating sonication into the crystal growth process[2]. In this context, it is possible to self-assemble the discussed dipeptide into nanofibers, microtubes and especially desirable microrods[2]. The analysis of a single FF microrod indicates that it can act as an active optical fiber material, allowing locally excited photoluminescence to propagate along the length of the microrod[2].

So far, as part of the work, the characteristics of an experimental sonoreactor or sonication of small amounts of solutions with high-frequency ultrasound have been carried out. Based on the analysis of the sonocrystallization process of phenylalanine-phenylalanine dipeptide aggregates, a method of ultrasonic control of the crystal growth process was developed. The photophysical properties of the obtained dipeptide crystals were investigated—also with the addition of a dye showing affinity to amyloid structures, thioflavin T.

References:

[1] *Kholkin, A., et al. Strong Piezoelectricity in Bioinspired Peptide Nanotubes, ACS Nano. 4 (2010) 610–614.*

[2] *Li, Q., et al. Controlled Rod Nanostructured Assembly of Diphenylalanine and Their Optical Waveguide Properties, ACS Nano. 9 (2015) 2689–2695.*

[3] *Mason, T.O., et al. Expanding the Solvent Chemical Space for Self-Assembly of Dipeptide Nanostructures, ACS Nano. 8 (2014) 1243–1253.*

Samaei Saeed *"Depth-resolved blood flow assessment based on time-domain diffuse correlation spectroscopy"*

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Depth-resolved blood flow assessment based on time-domain diffuse correlation spectroscopy

Key words: *time-domain diffuse correlation spectroscopy, blood flow quantification, speckle pattern*

Abstract

Diffuse correlation spectroscopy (DCS) is an optical technique that quantifies cerebral blood flow non-invasively [1]. In this technique, near-infrared photons generated by a long coherent length continuous-wave laser are illuminated to the biological tissue. Due to the scattering properties of the tissue, the propagated light experiences a phase shift in each scattering event, which causes constructive and destructive interference between photons. Eventually, the temporal back-scattering speckle patterns are collected a few centimeters away from the illumination point by a single-mode fiber located on the sample surface and delivered to a single-photon detector. The intensity autocorrelation curve decay of the recorded signal contains information of the dynamics of the moving scattering particles (blood cells flow), which is extracted by fitting the theoretical model to the experimentally obtained curve. Since the CW-DCS is incapable of distinguishing the photons propagated in different depths, sensitivity to deeper layers is improved by increasing the interoptode separation, which dramatically increases the noise effects on the signal. To tackle this issue, Sutin et al. [2] introduced the time-domain approach of this technique (TD-DCS), in which employing a picosecond pulsed laser allows to distinguish the detected photons based on their traveling time (or time-of-flight, TOF) in the tissue. This feature improves the sensitivity to the deeper layers by separating late TOF photons from the early arrived ones at short source-detector separations (SDS).

In this work, we developed a compact and portable time-domain diffuse correlation spectroscopy (TD-DCS) instrument based on commercial components to be used in laboratory or clinical applications. The performance of the system was evaluated across a series of homogeneous and layered phantom measurements. Moreover, we validate the feasibility of the TD-DCS method to quantify depth-length-resolved blood flow information during cuff occlusion measurement on the forearm of healthy volunteers in vivo at 1 cm SDS [3]. The results of the in vivo measurement show higher hyperemia peak amplitude for the late photons propagated across muscular tissue compared with the photons mainly passed through the superficial layers, which correspond with the results reported in literature [4].

References:

[1] *Boas, D. A., Campbell, L. E. Yodh, A. G. Scattering and imaging with diffusing temporal field correlations. Phys. Rev. Lett. 75, 1855 (1995).*

[2] *Sutin, J. et al. Time-domain diffuse correlation spectroscopy. Optica 3, 1006–1013 (2016).*

[3] *Samaei, S., Sawosz, P., Kacprzak Michał and Pastuszak, Z., Borycki, D. Liebert, A. Time-domain diffuse correlation spectroscopy (TD-DCS) for noninvasive, depth-dependent blood flow quantification in human tissue in vivo. Sci. Rep. 11, 1–10 (2021).*

[4] *Yu, G. et al. Time-dependent blood flow and oxygenation in human skeletal muscles measured with noninvasive near-infrared diffuse optical spectroscopies. J. Biomed. Opt. 10, 24027 (2005).*

Słota Przemysław *"Modulation transfer microscopy"*

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Modulation transfer microscopy

Key words: *microscopy, fluorescence, ultrafast pulses, imaging*

Abstract

Modulation transfer microscopy is a microscopy technique directly connected with pump-probe experiment. It allows imaging of fluorochromes which undergo fast, nonradiative decay. Those fluorochromes cannot be imaged in classical fluorescence microscopy. In modulation transfer microscopy the molecule is first stimulated by a pump beam, ideally from an ultrashort (fs) pulse laser. The molecule is then probed with another pulse, with adjustable delay between the two pulses (pump and probe). If the pump beam is modulated, the interaction with exited molecules modulates the probe beam [1]. This modulation depends on the delay between the pulses [2], which is utilised in pump-probe experiment to study dynamics of the exited state. In microscopy the modulation signal can be used to reconstruct an image of the sample.

The author constructed a microscope utilizing the discussed technique to image tissue sample stained with various dyes. The microscope uses a single laser for, firstly, stimulation via two photon absorption (the stimulation beam is modulated). Secondly, it is used in generation of the second harmonic beam, which then probes the dye. After passing through the sample, pump is filtered out, and the probe is measured by a photodiode. Photodiode output signal is demodulated and the obtained information forms the image.

References:

[1] *Modulation Transfer Microscopy – Versatile Tool for Ultrafast Nanoscopy H. Orlikowska, L. Piatkowski, Acta Physica Polonica, A. Vol.139, page 288*

[2] *Ultrafast stimulated emission microscopy of single nanocrystals L. Piatkowski, N. Accanto, G. Calbris, S. Christodoulou, I. Moreels, N. F. van Hulst, Science, Vol.366, page 1240*

Sokołowski Marek *“Investigation of the selection of new two-dimensional MxB1-x alloys using ab initio and machine learning methods”*

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Investigation of the selection of new two-dimensional MxB1-x alloys using ab initio and machine learning methods

Key words: *new two-dimensional materials, machine learning, GCNN*

Abstract

The subject of research is the search for new two-dimensional materials and ways of finding them using artificial intelligence.
Since the first exfoliation of graphene, the world of 2D materials has flourished and several thousand stable 2D materials have been found out of more than ten thousand tested. The dilemma is that the computation to find the energy of a given 2D material for more than six atoms takes more than an hour on a supercomputer for only one material, so when checking for new materials you need to be sure that you only check those that have a high probability that you will be searching what you are looking for and this is our part. Beware that latices with less than seven atoms have been established as unstable 2D materials so computations have been done for more than six atoms.
Firstly, we establish nonrepetitive crystal cells from which we set up the database using the Density Functional Theorem to establish material properties as a test-validation set which is used as learning data for artificial intelligence, then we looked for those two-dimensional materials that were skipped using artificial intelligence for which we establish that graph-based convolutional neural network is the best for our topic.

Sośnicki Filip *"Electro–optic shaping of quantum light"*

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Electro–optic shaping of quantum light

Key words: *quantum optics, ultrafast optics, electro–optics, electro–optic phase modulation*

Abstract

One of the most important tasks in the field of quantum optics is the ability to fully control single photons, meaning controlling them in all degrees of freedom (DoF). While many experiments demonstrated control of single photons in polarization or transverse–spatial mode, one still requires methods for unitary, phase–only manipulation in the time–frequency DoF. In my presentation, I will show a method for shaping single photons in time and spectrum by employing electro–optic phase modulation combined with dispersive propagation. I will show our recent results on tuning single–photon's center wavelength and bandwidth. Especially I will focus on using photonically generated RF signals achieving very high stability of the modulation in the course of 24h. I will show also employing complex phase modulation patterns for spectrally compressing single photons by more than 2 orders of magnitude down to hundreds of MHz of spectral width.

Walter Piotr *"Biosensing methods for rapid, on-site detection of organophosphorus pesticides"*

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Electro–optic shaping of quantum light

Key words: –

Abstract

Due to the bioaccumulation effect, organophosphorus pesticides cause long-term damage to mammals, even at small concentrations. The ability to perturb the phospholipid bilayer structure as well as the overstimulation of cholinergic receptors makes them very hazardous to humans. Therefore, there is a need for a quick and inexpensive detection of organophosphorus pesticides for agricultural and household use. Since organophosphorus pesticides are acetylcholinesterase (AChE) inhibitors, amperometric biosensors utilizing this mechanism hold a great promise to meet these requirements utilizing a fraction of reagents and time for measurement, compared to laboratory methods.

References:

[1] *Walter, P., et al. "Common configurations and challenges in screen-printed enzymatic electrochemical biosensors." Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018. Vol. 10808. International Society for Optics and Photonics, 2018.*

[2] *Walter, Piotr, et al. "Disposable, acetylcholinesterase-coated, screen-printed carbon electrodes for the determination of organophosphorus pesticides." Microelectronics International (2019).*

[3] *Walter, Piotr, et al. "Acetylcholinesterase-based biosensing solutions for the detection of organophosphorus pesticides." Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2019. Vol. 11176. International Society for Optics and Photonics, 2019*

[4] *D. R. Thévenot, K. Toth, R. A. Durst, and G. S. Wilson, "ELECTROCHEMICAL BIOSENSORS: RECOMMENDED DEFINITIONS AND CLASSIFICATION," Anal. Lett., vol. 34, no. 5, pp. 635–659, Mar. 2001.*

Węgrzyn Piotr *"Functional Imaging of Human Retina Response to Light Stimulus With Full Field Fourier Domain Optical Coherence Tomography (STOC–T)"*

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Functional Imaging of Human Retina Response to Light Stimulus With Full Field Fourier Domain Optical Coherence Tomography (STOC–T)

Key words: *oct, functional imaging, eye, retina*

Abstract

Optical coherence imaging (OCI), including optical coherence tomography (OCT) and optical coherence microscopy (OCM) uses interferometric detection to generate high–resolution volumetric images of the sample at high speeds. Such capabilities are significant for in vivo imaging, including ophthalmology, brain, intravascular imaging, as well as endoscopic examination. Nevertheless, most of OCI setups use the single detection channel and scan the incident light laterally. Hence, we can further enhance OCI by parallelization implemented with wide–field illumination and detection. This approach, however, is very susceptible to the so–called crosstalk–generated noise, which distorts the final sample image. Recently our group presented a way to overcome cross–talk problem by modulating the light that illuminates OCT system [1]. Here we apply modified version of this setup called Spatio–Temporal Optical Coherence Tomography STOC–T to functional studies of IS/OS–RPE (inner and outer segments- retinal pigment epithelium) region in the human retina.
In the last few years, there has been a growing interest in research aimed at in–vivo measurements of human eye retina response to light stimulus. Hillmann et al. have presented measurements of photoreceptors' response with the application of a swept–source OCT system with a parallel data acquisition [2]. To prove the possibility of measuring the photoreceptor response in the STOC–T setup (see Figure 1), we performed example measurements of a healthy volunteer. First, we acquired a set of 60 volumes without illumination to check the phase stability. The calculated phase difference oscillated slowly in the range of +/−3 nm. Next, we conducted measurements with the stimulus, in these measurements, we acquired 120 volumes. During the acquisition of the first 20 volumes, we kept the illumination off, and next we turned it on for 25 ms while continuing the data acquisition. We present the example results in Fig. 2: (a) as a B-Scan (XZ or YZ cross-section) through the average of first 20 volumes with good visible separation of layers in IS/OS–RPE region; (b) as a mean change of ΔOPL (optical path length). In the B–Scan image, we marked layers used for phase-change calculation as L_1 and L_2. The calculated plot shape is in agreement with the results obtained by other groups. After switching on the illumination, we saw about 5 nm short dip in the ΔOPL, next the ΔOPL increased fast and reached a maximum of 33 nm, after which it slowly began returning to normal (not illuminated) value.

Recently there has been an increasing interest in the functional study of the human retina as it might lead to quick detection of retinal diseases, and it might also help in tracking disease progress and

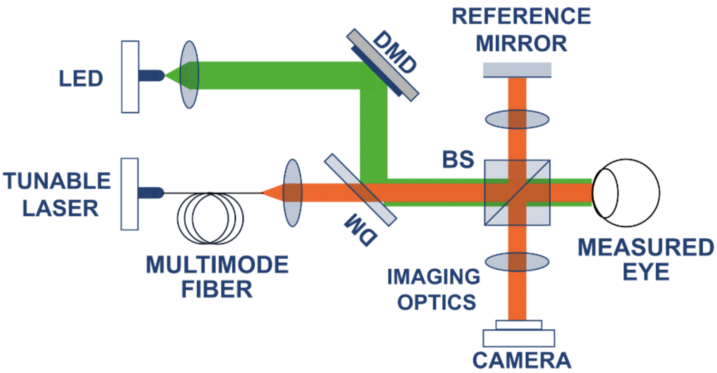

Figure .2: Conceptual scheme of Spatio–Temporal Optical Coherence Tomography setup with a stimulation path: DMD — dichroic mirror, BS — beam splitter, LED — light emitting diode. The system provided stimulation path for delivering white light stimuli to the retina and detection path with Full Field Fourier Domain Optical Coherence Tomography functionality.

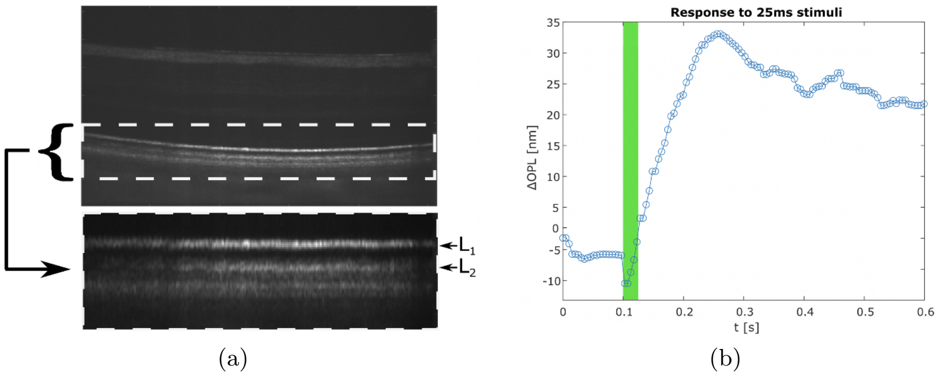

Figure .3: Example measurement results: (a) B–Scan taken from the average of the first 20 acquired volumes, with the area of interest marked. L_1 and L_2 represent positions of layers used for response calculation; b) Calculated phase change (averaged from 128x128 pixels) in response to light stimulus, highlighted part of the plot marks retina illumination.

treatment. We show that our STOC–T setup can be used in the functional study of the human retina by detecting the response of photoreceptors to light stimulus. Our studies showed that the system could detect both fast and slow responses of the photosensitive layer.

References:

[1] *E. Auksorius, D. Borycki, and M. Wojtkowski, Crosstalk-free volumetric in vivo imaging of a human retina with Fourier-domain full-field optical coherence tomography, Biomed. Opt. Express 10, 6390-6407 (2019).*

[2] *D. Hillmann, H. Spahr, C. Pfäffle, H. Sudkamp, G. Franke, G. Hüttmann, In vivo optical imaging of physiological responses to photostimulation in human photoreceptors, PNAS, 113 (46) 13138-13143 (2016).*

Widomski Adam *"Generation and detection of QKD symbols encoded in time and frequency"*

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Generation and detection of QKD symbols encoded in time and frequency

Key words: *QKD, time, frequency, symbols*

Abstract

In this work generation and detection of QKD symbols encoded in time and frequency was addressed. The QKD symbols were generated as faint laser Gaussian-shaped pulses[1] satisfying specific relations between their spectral and temporal profiles to provide security of encoding[2]. Temporal and spectral properties of the symbols were examined. Measuring spectral profiles involved using dispersive Fourier transformation[3] (DFT) technique implemented with a chirped fiber Bragg grating serving for a highly dispersive medium. Four-dimensional symbols were properly generated, detected, and characterised at the single-photon level.

References:

[1] *M. Leifgen, R. Elschner et. al., "Practical implementation and evaluation of a quantum-key-distribution scheme based on the time-frequency uncertainty", Physical Review (2015)*

[2] *J. Röodiger, N. Perlot, et. al., "Numerical assessment and optimization of discrete-variable time-frequency quantum key distribution", Physical Review (2017)*

[3] *K. Goda, B. Jalali, "Dispersive Fourier transformation for fast continuous single-shot measurements" Nature Photonics (2013)*