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SUMMIT
SOFIA UNIVERSITY MARKING MOMENTUM FOR INNOVATION AND TECHNOLOGICAL TRANSFER

National Recovery and Resilience Plan
OF THE REPUBLIC OF BULGARIA

National Recovery and Resilience Plan of the Republic of Bulgaria
Project No BG-RRP-2.004-0008-C01

SUMMIT Annual Conference

23 – 24 April 2024

Sofia University St. Kliment Ohridski, Sofia, Bulgaria

Work Group 3.2.3

New Materials and Photonics

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Scope and Contents of the Research Project

Materials Characterization
- Computer simulations (DFT)
- Raman spectroscopy

Carbon Nanostructures
- Deposition of graphene layers and graphene nanostructures for applications in energy-storage devices
- Graphene-based materials for photonics and photovoltaics applications

Photonics
- Ultrafast spectroscopy
- Singular laser beams
- Methods for diagnostics of femtosecond laser pulses and singular light beams
- Photoinduced quantum systems
- Development of new laser sources
- Optical metasurfaces for controlling and manipulation of light

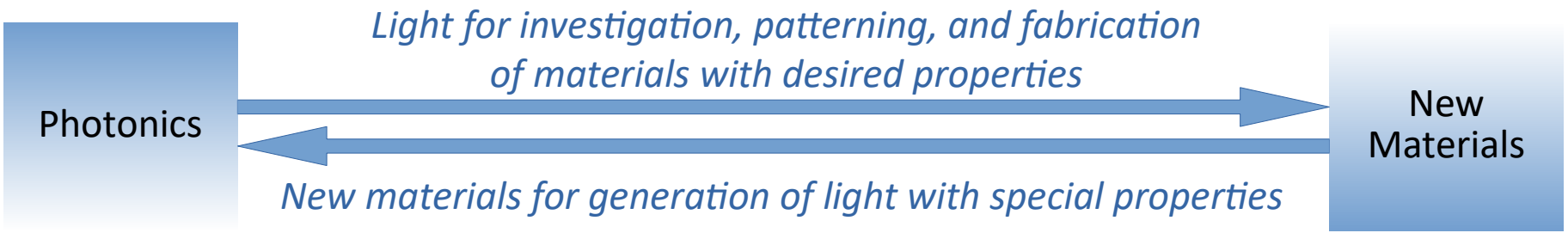
Photonics for the Investigation and Fine Tuning of the Properties Determining the Functionality and Biocompatibility of Biomaterials
- Optimization of the surface wetting of contact lenses by direct laser patterning of nanophotonic structures

Perovskite ($CaTiO_3$) Materials and Structures for Photovoltaics
- Breaking the current efficiency limit of 33%

Plasmonic Materials
- Light control beyond the diffraction limit

Goals and Objectives of the Research Project

1. Enhancing the synergy of interdisciplinary research
2. Addressing challenging topics in science and modern technologies



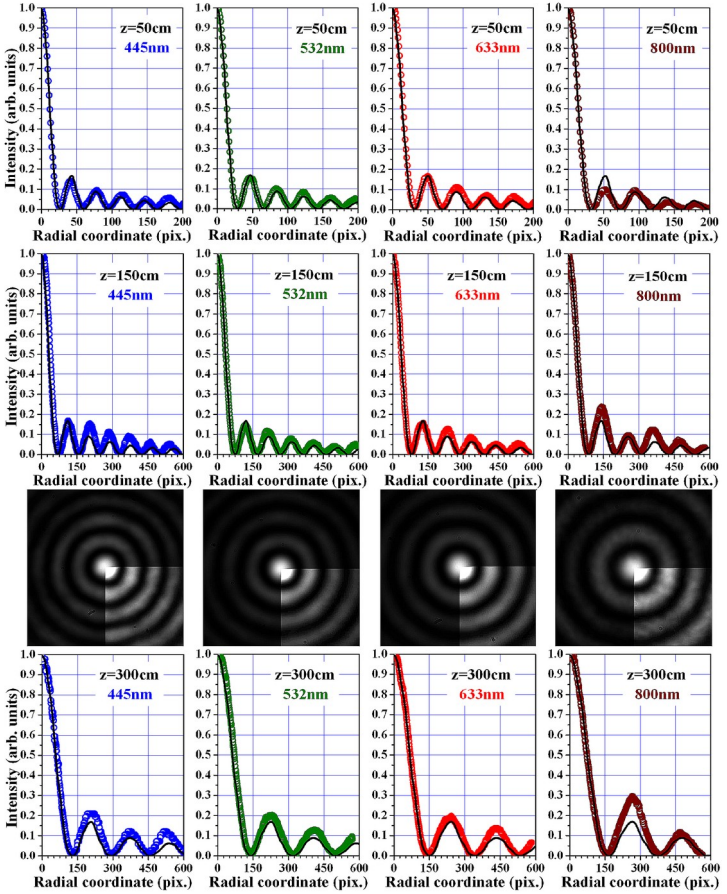
3. Creating a modern and competitive research ecosystem through involvement and fostering of young scientists

Structure of the Research Project

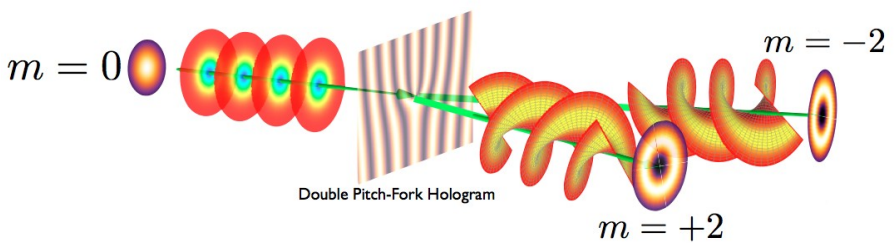
1. ***Work Package WP1*** Linear and Non-linear Photonics (Prof. A. Dreischuh)
2. ***Work Package WP2*** Development of Yb-based Amplifiers Employing a Single Unordered Ytterbium (Yb) Crystal (Assoc. Prof. I. Buchvarov)
3. ***Work Package WP3*** Structuring of Ultrashort Light Pulses Employing Optical Metasurfaces (Assoc. Prof. I. Buchvarov)
4. ***Work Package WP4*** Design and Synthesis of Annealed Metalized Macrocycles
   - 4.1. Raman Spectroscopy (Prof. M. Abrashev)
   - 4.2. Raman Scattering (Assoc. Prof. G. Tsutsumanova)
   - 4.3. Carbon Nanostructures in Composites with a Ceramic Matrix (Assoc. Prof. J. Kisiovski)
   - 4.4. Organic Optoelectronics (Prof. S. Balouchev)
5. ***Work Package 5*** Loss Compensation in Plasmonic Structures
   - 5.1. Perovskite Materials (Prof. V. Donchev)
   - 5.2. Investigation of One-dimensional Nanowires and Magnetic Spinels (Prof. V. Ivanov)
6. ***Work Package 6*** Wetting and Functionality of Contact Lenses (Assoc. Prof. G. Georgiev)

Results

Work Package WP1 Linear and Non-linear Photonics



1. With their nearly non-diffracting and self-healing nature, Bessel-Gaussian beams (BGBs) are attractive for many applications ranging from free-space communications to non-linear optics.
2. As a result of the recent theoretical and experimental analyses conducted in the Laboratory of Femtosecond Photonics, a novel method based on singular optics employing multiple-charged optical vortices (OVs) was developed for the generation of long-range BGBs.
3. Figure on the left shows a very good agreement between theory and experiment.



Results

Work Package WP2 Development of Ytterbium-based Amplifiers Employing a Single Unordered Yb Crystal

1. Detailed theoretical analysis of the main physical processes underlying the (CPA)-laser amplification systems for explanation of the fundamental causes for the current limitations.
2. Development of new technical solutions based on the model and theoretical analysis to overcome the current limitations.
3. Building of an experimental laser system to complete the research and substantiate the theoretical modeling with experimental results.
4. Performing of a comprehensive modeling of the high-order dispersion, which has turned out to have a much more significant effect.
5. Another matrix (CALGO) with a strong non-uniform field has also been employed to investigate the Yb^{+3} capabilities for regenerative amplification, and the results have been compared with previous studies for Yb:CALYO.
6. Feasibility analysis for the development of new scientific and industrial applications of Yb-ultrafast lasers based on the already obtained results.

Results

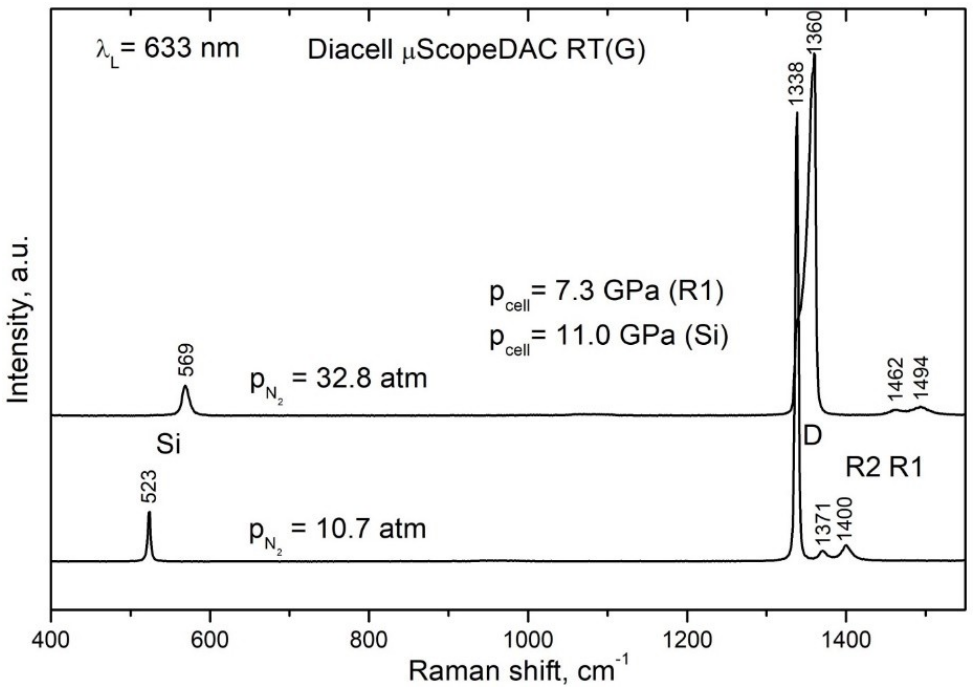
Work Package WP3 Structuring of Ultrashort Light Pulses Employing Optical Metasurfaces

1. The team responsible for these studies during the past period focused its efforts on the development of fs-laser systems (WP2) that will later be used to develop a technique for characterization of fast and utrafast processes in metamaterials.
2. Our research was focused on ultra-fast modulation capabilities of dielectric metasurfaces. We demonstrate a high-contrast transmission modulation metasurface with ultra-fast response.

Results

Work Package WP4 Design and Synthesis of Annealed Metalized Macrocycles

Raman Spectroscopy



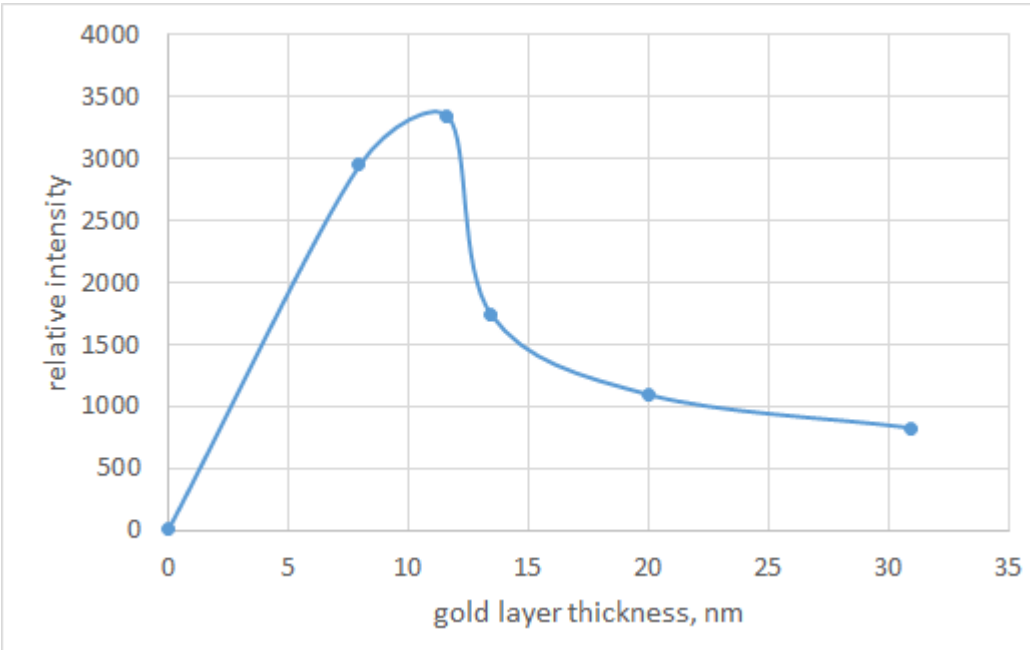
Raman spectra for two different cell pressures and media.

1. Raman spectra of different rhodamine 6G-treated objects were compared to verify the surface-enhanced Raman spectroscopy (SERS) capabilities (cooperation with Assoc. Prof. G. Tsutsumanova (Faculty of Physics, “St. Kliment Ohrisdski” Sofia University)).
2. Investigation of carbon materials as powder specimens: graphene, nitrogen-doped graphene, graphene oxide (cooperation with Prof. Elena Tatarova (Universidade de Lisboa, Portugal).
3. Thin layers of carbon nanostructures deposited on different surfaces - crystalline silicon, silicon carbide and nickel foam (collaboration with Prof. Zhivko Kissiovski (Faculty of Physics, “St. Kliment Ohrisdski” Sofia University)).

Results

Work Package WP4 Design and Synthesis of Annealed Metalized Macrocycles

Raman Scattering



Dependence of the the relative intensity of the Raman signal on the thickness of the gold layer.

1. There is an optimal thickness of the gold layer at which the intensity has a maximal value.
2. It is assumed that in the initial stage of the deposition of the gold, some isolated nano-islands start to grow.
3. Just before the percolation threshold, the number of “hot-spots“ onto the surface reaches a maximum, which eads to the strongest signal enhancement.
4. These results show that glass coverslips covered with thin gold layer can be successively used as SERS substrates.

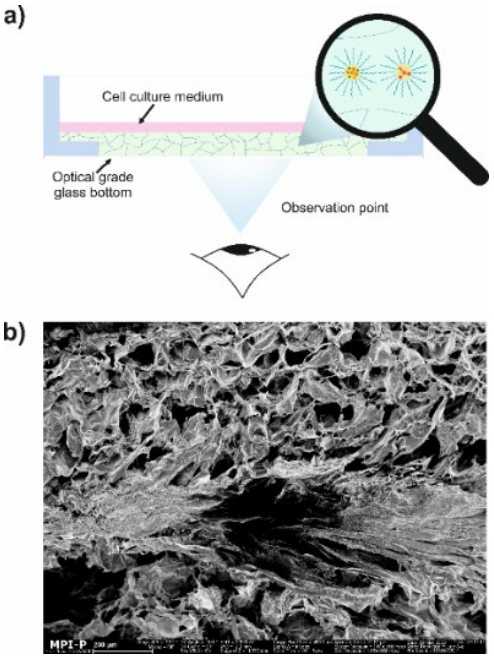
Results

Work Package WP4 Design and Synthesis of Annealed Metalized Macrocycles Carbon Nanostructures in Composites with a Ceramic Matrix

1. Investigation and optimization of graphene deposition processes by PECVD on porous ceramic matrix and formation of internal conductive layers.
2. Information on the number and alignment of graphene layers has been obtained from Raman spectroscopy and the morphology of the structures from analysis of scanning electron microscope (SEM) images.
3. Investigation of the dielectric permittivity and magnetic permeability of composite materials. An experimental set-up was prepared to measure the dielectric permittivity of the obtained composite materials in the microwave range from 18 to 26.5 GHz.
4. Theoretical model of gas outflow from a microwave electrothermal thruster with surface wave discharge. The process of outflow of heated gas and plasma from the ceramic tube of a microwave plasma source at low pressure was investigated. The high value of outflow velocity and resulting plasma parameters are important for the technological applications of surface wave microwave plasma sources.

Results

Work Package WP4 Design and Synthesis of Annealed Metalized Macrocycles Organic Optoelectronics

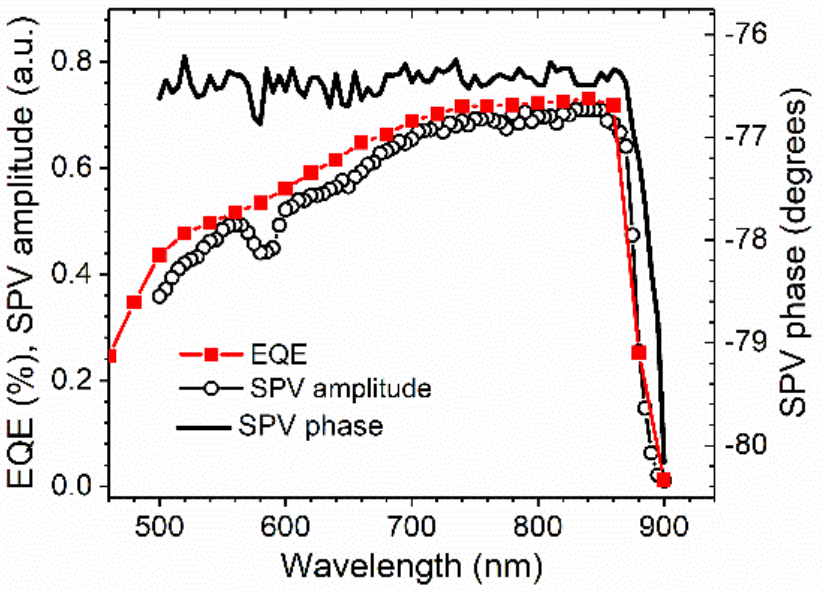


(a) Observation setup. (b) SEM image of freeze-dried agarose / silk fibroin hydrogel showing its structure. Scale bar: 200 µm.

1. **All-optical Minimally Invasive Sensing in Agarose / Silk Fibroin.** *Challenge:* determining the temporal variation of local temperature and/or local oxygen concentration in biological objects.
   Solution: triplet-triplet annihilation upconversion, performed in a nano-confined environment. Temperature sensitivity of better than 100 mK for the physiologically important range around 36°C.
2. **Tunable, reagent-loaded polyurethane nanocapsules cleavable by NIR light. Selective release of encapsulated material triggered by temperature or NIR light.**
3. **Molecular design and synthesis of asymmetric cyanine fluorogenic probes for ultrasensitive and selective detection of heparin (coagulant) and protamine.**
   Method: the interaction of fluorescent probes with heparin is studied using steady-state absorption, fluorescence, and circular dichroism spectroscopy.

Results

Work Package 5 Loss Compensation in Plasmonic Structures
Perovskite Materials



External quantum efficiency (squares) and SPV amplitude (circles) spectra of a GaAs solar cell p-n structure. The SPV phase spectrum of the same structure is shown by a line.

1. Investigation of perovskite (PSK) materials and partial solar cell structures based on PSK absorbers deposited on electron transport layers (TiO_2), such as PSK/TiO_2/FTO/glass, PSK/FTO/glass, and PSK/glass (FTO = fluorine-doped tin oxide) (cooperation with Laboratoire de Génie électrique et électronique de Paris (GeePs), France).
2. Measurement of solar photovoltaic (SPV) spectra of solar cell structures based on GaAs and GaAsSb(N) and and comparison to the spectra of external quantum efficiency (EQE). SPV can be used as a quick and easy-to-perform characterization technique in the development of new solar cells as well as for in-line production process control to reduce production costs.

Results

Work Package 5 Loss Compensation in Plasmonic Structures
Investigation of One-dimensional Nanowires and Magnetic Spinels

1. Investigation of one-dimensional MoBrx nanowires encapsulated in carbon nanotubes (MoBrx@CNT composites) (collaboration with University of Warwick, UK) by acquisition of Raman spectra of the MoBrx@CNT composites and their theoretical modelling by means of density functional theory (DFT) calculations.
2. Investigation magnetic spinels ZnxCd1-xCr2S4. The work was motivated by the earlier experimental finding that depending on zinc content, the compound undergoes three magnetic phases – ferromagnetic, spin glass and antiferromagnetic: Raman spectroscopy and the calculations of the lattice dynamics

Results

Work Package 6 Wetting and Functionality of Contact Lenses

1. An approach has been developed to determine the adhesion strength between particles (bacteria, cells, nanoparticles) and contact lenses based on the analysis of contact angles measured by sessile water drops.
2. The effect of surface roughening of contact lenses with a femtosecond laser on water contact angles was investigated (cooperation with Laboratory of Femtosecond Photonics).
3. A methodology has been developed to determine the wetting of contact lenses on the eye *in vivo* and in laboratory conditions *in vitro*.
4. An algorithm has been developed to characterize the wetting of silicone hydrogel materials on the eye *in vivo* and in laboratory conditions *in vitro*.

Administrative Activities

1. Appointment of new research fellows

	WP 1	WP 2	WP 3	WP 4	WP 5	WP 6
Technical Assistant						1
First-stage Researcher (Doctoral Student)(R1)		2	1	4		
Recognized Researchers (Postdocs) (R2)	1					
Established Researcher (R2)	3			2	3	

2. Scientific Publications

Publication Type and Status	Published Paper		Submitted Manuscript	Manuscripts in Preparation
	Journal Article	Conference Paper		
Number of Publications	11	5	4	2

You are cordially invited to the topical session (presentations and posters) on

New Materials and Photonics

Time: *24 April 2024 (Wednesday), 13:30 – 17:00*
Venue: *Lecture hall A205, Faculty of Physics, James Bourchier Blvd. 5, Sofia*

Thank you for your attention!