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Keynote Presentations

Femtosecond-laser-fabricated Three-dimensional Cyclized Transparent Optical Polymer Microfluidic Chips Enabling Super-resolution Live Imaging of Cell Behavior in Confined Microspaces

Koji Sugioka[1*], Mirai Hanzawa[1,2], Kotaro Obata[1], Sota Matsumoto[1,2], Masatoshi Takagi[3], Asako Sakaue-Sawano[3], Asako Tosaki[3], Satoshi Shimozono[3], Felix Sima[1,4], Hiroyuki Kawano[1,3], Takuro Tojima[1], Daisuke Miyashiro[1], Kazunari Ozsaa[1], Godai Miyaji[2], Akihiko Nakano[1] and Atsushi Miyawaki[1,4]

[1]RIKEN Center for Advanced Photonics, Wako, Japan
[2]Tokyo University of Agriculture and Technology, Tokyo, Japan
[3]RIKEN Center for Brain Science, Wako, Japan
[4]National Institute for Laser, Plasma and Radiation Physics, Magurele, Romania

Abstract

Live imaging of cellular dynamics in confined microspaces is crucial for understanding biological processes such as cancer cell invasion, immune response, and neuronal development. However, glass or polydimethylsiloxane-based microfluidic chips that provide such microspaces suffer from image distortion due to refractive index mismatch with water-based culture media, making high-resolution imaging challenging. To address this problem, we have developed a technique to fabricate three-dimensional (3D) microfluidic chips using the fluoropolymer cyclized transparent optical polymer (CYTOP) with a refractive index (~1.34) similar to that of water (~1.33). Our fabrication approach combines two-photon polymerization of SU-8 with mold processing, enabling the creation of defect-free, flexible 3D structures with sub-micrometer precision. The fabricated CYTOP microfluidic chips enabled super-resolution imaging of cancer cells in the microchannels, clearly visualizing the rupture and repair of the nuclear envelope and the progression of proliferation during migration. Such super-resolution imaging ability in microspaces expands opportunities for investigating biological processes beyond cancer cell migration.

Interface Thermal Resistance Between Sub-10 Nanometer Single-walled Carbon Nanotube Bundle and Silica

Xinwei Wang[*]

Department of Mechanical Engineering, Iowa State University, Ames, USA

Abstract

The interfacial thermal resistance (ITR) between single-walled carbon nanotubes (SWCNTs) and the surroundings are of great science and engineering importance but is rarely experimentally investigated. Even the few reported experimental work suffers very large uncertainties, which hinders in-depth physics understanding of the SWCNT interface energy transport. This is attributed to the very large difficulty faced in characterizing thermal transport across a nanometer (nm)-wide one-dimensional interface. This talk will cover our latest work on new technique development and characterization of the ITR at the interface between an SWCNT bundle (<10 nm thickness) and silica substrate. Our energy-transfer Raman technique makes it possible to simultaneously measure the thermal conductivity and ITR of the bundle with high confidence. Our study of the ITR dependence on temperature uncovers very strong phonon diffuse mismatch at the interface, which is further interpreted by our equivalent interfacial medium theory. By studying the thermal response of the SWCNT under different modulated laser heating upto 25 million hertz, we are able to distinguish the optical and acoustic phonon temperatures of SWCNTs, which is the first time to date. It uncovers very strong phonon mode-wide thermal non-equilibrium.

Laser-based Fabrication and Modification of Nanotopography for Studying and Controlling the Behavior of Cells

John T. Fourkas* and Wolfgang Losert

University of Maryland, College Park, USA

Abstract

In natural environments, physical interactions between cells and nanoscale objects modulate many types of cellular behaviors, and particularly those that involve dynamics. The mechanisms of interactions with objects in the 1 - 10 nanometer (nm) size range are fairly well understood, and lead to processes such as endocytosis. Objects with one or more characteristic dimensions on the order of 100 nm, such as the collagen fibers in the extracellular matrix (ECM), also have a strong influence on cellular behavior, but the mechanisms and implications of such interactions are not yet as well understood. We and our collaborators have, for more than a decade, used multiphoton absorption polymerization to create controlled nanotopography to help us understand, and control, the response of cells to ECM-scale nanotopography. More recently we have also developed laser-based techniques to modify nanotopography in a controllable manner. We have discovered a process in which physical interactions between nanotopography and cells that have dynamic shapes preferentially nucleate and guide the polymerization of actin. This process, which we have named esotaxis (Greek for "inner guidance"), is broadly conserved in dynamic eukaryotic cells. Esotaxis underlies processes such as the guidance of cell migration by nanotopography and the activation of immune cells and may play a role in disease states such as the development of mesothelioma and metastatic cancer. I will discuss how esotaxis influences cellular behavior in a number of different contexts, how we have harnessed this phenomenon to control cell behavior, and insights that our studies have provided in human health.

Ultrafast Laser Filamentation for Long-range Remote Plasma Generation and Detection

Sung-Uk Choi[1], Changmin Kim[1], Jose Chirinos[1], Xianglei Mao[1] and Vassilia Zorba[1,2*]

[1]Lawrence Berkeley National Laboratory, Berkeley, USA
[2]University of California, Berkeley, USA

Abstract

The ability to remotely sense isotopes and elements with ultrafast laser-matter interactions is important for many applications in energy and security. One of the few technologies capable of delivering laser energy over long distances is long-range femtosecond filament propagation. By interacting with solids, filaments can generate plasmas remotely, enabling the detection of isotopes through optical emission. Femtosecond filaments allow propagation with minimal diffraction due to a balance between non-linear self-focusing and air ionization. However, a significant limitation of filament propagation and isotope detection is intensity clamping, a phenomenon that restricts the maximum energy that can be delivered to the target, making it harder to generate intense plasmas. One approach to overcoming the limitations imposed by intensity clamping is the use of plasma gratings, which are created by the constructive interference of two or more overlapping filament beams that are appropriately timed. This work explores the application of plasma gratings in remote isotope detection. We demonstrate that plasma gratings can significantly enhance spectral emission and isotope signal intensity compared to traditional single-filament irradiation, using the same amount of energy. The study also examines how the angle and delay between pulses affect the interaction between the plasma grating and solid matter. Furthermore, advanced diagnostics are employed to investigate the coupling effects between the filament and the target, as well as plasma expansion, providing insight into the underlying mechanisms. The goal of this research is to improve sensitivity and reduce the uncertainty of remote laser plasma-based sensing techniques for isotope quantification.

Laser-induced Breakdown Spectroscopy in Combination with Artificial Intelligence for Understanding and Predicting Corrosion in Metals

Yongfeng Lu[1*], Lei Liu[1], Xi Huang[1], Haoyu Dong[1], Aofei Mao[1], Peizi Li[1], Bai Cui[2] and Jean-Francois Silvain[3]

[1]Department of Electrical and Computer Engineering, University of Nebraska, Lincoln, USA
[2]Department of Mechanical and Materials Engineering, University of Nebraska, Lincoln, USA
[3]National Centre for Scientific Research, University of Bordeaux, Pessac, France

Abstract

The 5xxx series aluminum (Al) - magnesium (Mg) alloys are extensively used in marine transportation and ships due to their

high strength-to-weight ratios and great corrosion resistance properties. However, material degradation of the 5xxx alloys occurs over time after exposure to environments at elevated temperatures, referred as sensitization. Sensitization is characterized by β-phase precipitates along the grain boundaries, which increases the susceptibility to intergranular corrosion and stress corrosion cracking. Therefore, it is important to assess the degree of sensitization (DoS) in modern ships, whose structures are primarily made of Al-Mg alloys, to determine whether they have reached a DoS threshold that may require maintenance or repair activities. In this study, laser-induced breakdown spectroscopy within combination with artificial intelligence was successfully developed to assess the DoS levels of the 5xxx alloys.

Monolithically Integrated Fourier Injected Resonator on a Chip for Coherent Laser Combination

Christopher Corcoran[1*], Lance Sweat[2] and Lin Zhu[2]

[1]*Corcoran Engineering, Inc., USA*
[2]*Clemson University, South Carolina, USA*

Abstract

In this presentation, we will discuss the theory, fabrication, and experimental results of a 5-element laser array fabricated on a single, monolithic chip and coherently combined by integrating the individual laser channels with a passive fourier injected resonator (FIRE) slab waveguide. The theory of the FIRE resonator is first described. In order to couple the parallel waveguides of the gain chip with the angled inputs to the FIRE cavity, we incorporate a set of Euler bends in each channel to minimize the loss associated with this curvature. The eigenvector analysis of the FIRE coupling matrix was performed using both matrix laboratory and mathematical computer aided design. The model of operation is presented showing how the passive FIRE cavity provides high inter-element coupling along with reduced edge losses to result in high supermode discrimination allowing only a single supermode to operate. These results are compared and contrasted with the well-known Talbot cavity. A working device was fabricated at Clemson University, and we experimentally measured high-visibility fringes in the far field (V = 97.7%) that demonstrate excellent coherence of the laser array. Results are presented showing good agreement between the predicted results and the experimental results.

Further Advances in Intensity Correlation Imaging: Algorithms and Practice

David Charles Hyland[*]

Department of AeroSpace Engineering, Texas A&M University, Texas, USA

Abstract

Recent work by the present author has succeeded in achieving a vast reduction in integration times that have plagued the Hanbury Brown–Twiss effect for so long. These results are shown in three manuscripts, culminating with a sequence of asymptotic theorems required for the stochastic search algorithm. The way is now open to reaping the advantages of simple, inexpensive flux-collecting hardware, near zero phase and intensity fluctuations, and unlimited baselines and image resolution. Furthermore, since the Brown-Twiss effect has been extended to two-dimensional imaging, it is appropriate that we term the algorithm as intensity correlation imaging (ICI) algorithm. Next, we review the author's presentation for optics, photonics, and lasers-2024 with its design for an ICI observatory for the high-resolution imaging of commercial geostationary satellites in the range of apparent magnitudes from 10 to 14. Moreover, this design is far less expensive yet far more powerful than conventional concepts since it is ground-based and immune to seeing conditions. Finally, we display several significant improvements in the algorithm, namely: (1) streamlining ICI transformed as a non-negative discrete-time system in order to couple with spiking, fast acting, neural networks for artificial intelligence, (2) the stochastic search algorithm based upon random coherence phases, (3) then we discuss the possible role of the stellar intensity interferometry community in harnessing the ICI algorithm, (4) we harness both ICI and insect eye framework to increase image resolution (for space-based systems), and last but not least, and (5) a proof that however noisy an image is, the algorithm will converge to the zero-noise image.

Recent Progress on Photomechanical Polymers Research

Zouheir Sekkat[1,2,3*]

[1]*Optics and Photonics Center, Moroccan Foundation for Advanced Science, Innovation and Research, Mohammed VI Polytechnic University, Ben Guerir, Morocco*
[2]*Department Institute for Advanced Studies, Mohammed VI Polytechnic University, Ben Guerir, Morocco*
[3]*Faculty of Sciences, Mohammed V University, Rabat, Morocco*

Abstract

Mechanics enabled by photon absorption generates work from materials and is perhaps one of the most important applications of light active matter, which mediates an intensity-to-stress transduction and moves in intensity gradients. Photomechanics can be put at work in several areas of science and engineering including photonics and biology and medicine. Smart photo-functional materials have attracted increasing attention in the past decades owing to applications in several areas of photonics including non-linear and integrated optics, switching, data storage, holography, actuation and so on, and one of the most important applications is photomechanics. Such polymers contain chromophores that transform light energy into mechanical energy, i.e., photoisomerize, and confer to polymers the possibility of undergoing molecular and mass motion at temperatures far below the glass transition temperature (T_g). One of such chromophores is the azobenzene molecule, and it is at the center of azo-polymers research, and azo dyes are central to industrial applications in printing, food, drugs and cosmetics, and recent advances in azobenzene research span a wide range of fields, including chemistry, physics, materials science, engineering, energy, and medicine. In this talk we give an overview of research, and we discuss our latest results in this field interfacing photochemistry and non-linear optics and polymer science and photomechanics.

Multidimensional Solitons in Photonics and Related Fields

Boris Malomed*

Department of Electrical Engineering, Faculty of Engineering, School of Electrical Engineering, Tel Aviv University, Tel Aviv, Israel

Abstract

It is commonly known that the interplay of linear and non-linear effects gives rise to solitons, i.e., self-trapped localized structures, in a wide range of physical settings, including optics, Bose-Einstein condensates (BECs), hydrodynamics, plasmas, condensed-mater physics, etc. Nowadays, solitons are considered as an interdisciplinary class of modes, which feature diverse internal structures. While most experimental realizations and theoretical models of solitons have been elaborated in one dimensional (D) settings, a challenging issue is prediction of stable solitons in 2D and 3D media. In particular, multidimensional solitons may carry an intrinsic topological structure in the form of vorticity. In addition to the "simple" vortex solitons, fascinating objects featuring complex structures, such as hopfions, i.e., vortex rings with internal twist, have been predicted too. A fundamental problem is the propensity of multidimensional solitons to be unstable (naturally, solitons with a more sophisticated structure, such as vortex solitons, are more vulnerable to instabilities). Recently, novel perspectives for the creation of stable 2D and 3D solitons were brought to the attention of researchers in optics and BEC. The present talk aims to provide an overview of the main results and ongoing developments in this vast field. An essential conclusion is the benefit offered by the exchange of concepts between different areas, such as optics, BEC, and hydrodynamics.

Photoaligned Azo Dye Nanolayers for Liquid Crystal Devices: Physics and Applications

Vladimir G. Chigrinov[1-4*]

[1]*Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong*
[2]*Nanjing Jingcui Optical Technology Co., Ltd, Nanjing, China*
[3]*Department of Fundamental Physics and Nanotechnology, State University of Education, Moscow, Russia*
[4]*Peoples' Friendship University of Russia, Moscow, Russia*

Abstract

Photoalignment and photopatterning have been proposed and studied for a long time. Light is responsible for the delivery of energy as well as phase and polarization information to materials systems. It was shown that photoalignment liquid crystal (LC) by azo dye nanolayers could provide high quality alignment of molecules in a LC cell. Over the past years, a lot of improvements and variations of the photoalignment and photopatterning technology have been made for photonics applications. In particular, the application of this technology to active optical elements in optical signal processing and communications is currently a hot topic in photonics research. Sensors of external electric field, pressure and water and air velocity based on LC photonics

devices can be very helpful for the indicators of climate change. We will demonstrate a physical model of photoalignment and photopatterning based on rotational diffusion in solid azo dye nanolayers. We will also highlight the new applications of photoalignment and photopatterning in display and photonics such as: (i) fast high resolution LC display devices, such as field sequential color ferroelectric LCD; (ii) LC sensors; (iii) LC lenses; (iv) LC E-paper devices, including electrically and optically rewritable LC E-paper; (v) photo induced semiconductor quantum rods alignment for new LC display applications; (vi)100% polarizers based on photoalignment; (vii) LC smart windows based on photopatterned diffraction structures; and (viii) LC antenna elements with a voltage controllable frequency. We started to use photoalignment and photopatterning nano technology for biomedical sensor applications.

Invited Presentations

Blue and Infrared Hybrid Laser Welding of Copper Wires for E-mobility Components

Daisuke Nakamura[1*], Rikuto Kokubo[1], Toshifumi Kikuchi[1] and Hiroshi Ikenoue[2]

[1]Graduate School of Information Science and Electrical Engineering, Kyushu University, Fukuoka, Japan
[2]Research Institute, Kochi University of Technology University, Kochi, Japan

Abstract

As the global shift toward carbon neutrality accelerates, the production of electric vehicles is rapidly increasing, driving an urgent demand for advanced welding technologies for the fabrication of key components such as motors and batteries. In this context, spatter-free and defect-free welding processes are essential to ensure reliability and productivity in large-scale manufacturing. Laser welding, with its inherent advantages of high speed, high precision, and non-contact processing, has emerged as a core technology for next-generation e-mobility production. In this study, we have developed a copper wire welding system that integrates high-power blue and infrared hybrid lasers with a galvanometer-based coaxial scanning module, a gas-flow system for efficient fume removal, and an artificial intelligence driven real-time monitoring system for quality assurance. This presentation highlights the recent progress in applying hybrid laser welding to copper wire interconnections, demonstrating its potential for industrial deployment in e-mobility manufacturing.

Investigations of Molecular Gyroscopes Made with an Optical Centrifuge

Amy S. Mullin[*]

University of Maryland, College Park, USA

Abstract

An optical centrifuge is an ultrafast laser-based technique for driving molecules into extreme rotational states. The centrifuge pulses are prepared by combining oppositely chirped pulses to create a linearly polarized optical field that undergoes angular acceleration over the time of the pulse. Molecules with non-uniform polarizability are trapped in the optical field and driven into high J states. Individual rotational states of the centrifuged molecules are detected with high-resolution transient infrared absorption spectroscopy. Relaxation dynamics of the centrifuge molecules are characterized by relatively slow population decay, relative to collision rates, and even slower alignment decay. Evidence is seen for near-resonant energy transfer in high-J states, along with non-resonant energy transfer that imparts large amounts of translational energy to the centrifuged molecules.

High Intensity Laser Beams as Tools for Cancer Research

Felix Sima[1,2*], Alexandra Bran[1], Stefana Orobeti[1,3], Livia Elena Sima[3], Ioana Porosnicu[1], Constantin Diplasu[1], Georgiana Giubega[1], Gabriel Cojocaru[1], Razvan Ungureanu[1], Cosmin Dobrea[1], Mihai Serbanescu[1], Alexandru Mihalcea[1], Elena Stancu[1], Cristina Elena Staicu[1], Florin Jipa[1], Emanuel Axente[1], Simion Sandel[1], Marian Zamfirescu[1], Ion Tiseanu[1] and Koji Sugioka[2]

[1]National Institute for Laser, Plasma and Radiation Physics, Magurele, Romania
[2]RIKEN Center for Advanced Photonics, Wako, Japan
[3]Institute of Biochemistry of Romanian Academy, Bucharest, Romania

Abstract

Radiotherapy delivered with ultra-high dose rate irradiation, known as FLASH, demonstrated the efficacy to affect the tumors

as conventional dose rate radiotherapy and, at the same time, reducing the toxicity of healthy tissue. We evaluate herein this effect for high-energy electron irradiation with a view to increasing the understanding of the FLASH effect at cellular and molecular level. High-intensity petawatt laser-driven accelerators were employed to deliver FLASH electrons at dose rates as high as 10^{13} gray/s in very short pulses (10^{-13} s). Cancer cells and normal healthy cells cocultures grown on chamber slides were concurrently exposed to FLASH irradiation. In parallel experiments, cells were exposed to pulsed X-ray irradiation, which served as positive controls for radiation-induced nuclear DNA double-strand breaks. The largest proportion of the electron damaged DNA-containing nuclei was attained on restricted irradiated areas of the cell monolayers at a cumulative dose one order of magnitude lower than the dose obtained by pulsed X-ray irradiation. We also observed that normal cells were less affected than cancer cells after electron exposure. This result is the first demonstration *in vitro* of a differential response of tumor and normal cells exposed the FLASH irradiation and may contribute to the development of new cell culture strategies to explore fundamental understanding of FLASH-induced cell effects. We further propose tumor-on-chip models to explore mechanisms behind cellular response to unconventional irradiation radiotherapy schemes.

Cancer Cell Behavior in Tissue-like Environments Fabricated by Two Photon Polymerization

Alexandra Bran[1,2*], Florin Jipa[1], Anca Bonciu[1], Stefana Orobeti[1,3], Emanuel Axente[1], Livia E. Sima[3], Felix Sima[1,4] and Koji Sugioka[4]

[1]National Institute for Laser, Plasma and Radiation Physics, Magurele, Romania
[2]National University of Science and Technology Politehnica Bucharest, Bucharest, Romania
[3]Institute of Biochemistry of Romanian Academy, Bucharest, Romania
[4]RIKEN Center for Advanced Photonics, Wako, Japan

Abstract

Cancer cells suffer drastic morphological deformations during metastatic processes when passing through constrictive spaces. We herein evaluated cancer cell behavior inside narrow micrometer pores of tissue-like scaffolds fabricated by two photon polymerizations. A nanoscribe platform equipped with a 780 nanometer wavelength femtosecond laser at 80 million hertz repetition rate was used to induce polymerization in SU-8 commercially available negative photoresist. Two geometries of woodpile-like three-dimensional (3D) scaffolds consisting of parallel straight lines and circles of different curvatures were used to evaluate the invasive potential of melanoma cancer cells as function of narrow space dimensions and circle curvatures. Quantitative evaluation of the cellular adhesion and invasive potential within pores between lines of null curvature was performed by analyzing cellular nuclei, cytoskeleton and focal adhesion points from fluorescent microscopy images. The cellular affinity was found to double in the presence of collagen coating when counting the number of cell nuclei around the scaffold and the anchoring adhesion points. The cell behavior in confined spaces was further correlated with cellular motility in unrestricted 2D environment by performing time lapse microscopy to evaluate cellular trajectories. Based on this assay, an increased cell velocity and spreading area were observed on collagen-coated substrates, which were correlated to the increased cell invasive behavior within collagen-coated scaffolds.

Experimental Journey at the Edge of Quantum Materials

Alberta Bonanni[*]

Johannes Kepler University, Austria

Abstract

Over the last decades, condensed matter physics has been the playground for the realization of physical systems in which quantum effects persist over a wide range of energy and length scales. The resulting quantum materials include topological insulators, topological crystalline insulators, magnetically doped topological quantum materials, 2-dimensional (2D) van der Waals materials, Kitaev, and spin-orbit-materials, etc. An overview is here given of the most relevant research results we have achieved on emergent phenomena in quantum materials, with particular attention to topology, symmetry, and spin-orbit coupling. The summary overarches the demonstration of Rashba spin-orbit coupling in wurtzite n-type gallium nitride doped with silicon, the discovery of infra-red optically active centers in co-doped gallium nitride material with both manganese and magnesium, the electronic characteristics that emerge in the manganese doped topological crystalline insulator tin telluride and in the intrinsic ferromagnetic topological insulator manganese, antimony, and bismuth form a layered crystal structure with tellurium. Moreover, it is shown that the study of 2D topological semimetals has revealed (i) quantum chiral anomaly in flakes of the Weyl semimetal orthorhombic tungsten ditelluride up to a record temperature of 100 Kelvin, and (ii) platinum vacancy-induced Kondo effect in non-magnetic platinum diselenide.

Solutions for Distributed Acoustic Sensing and Coexistence with Data Traffic in Repeatered Submarine Optical Lines

Alessandro Petocchi*, Giorgio Grasso and Aldo Righetti

Subphoton Srl, Italy

Abstract

In this study, new solutions were proposed for addressing the main challenges of distributed acoustic sensing (DAS) in long haul submarine optical lines: extending sensing coverage and enabling the coexistence of high-speed data transmission with DAS monitoring on a single fiber. Firstly, lab tests were conducted using a DAS interrogator operating on a dedicated 300 km long fiber equipped with a specifically designed bidirectional amplifier. It was demonstrated that the spontaneous emission noise introduced by these amplifiers had a negligible effect on DAS sensitivity and that the amplification did not introduce any distortion on sensing pulses. Furthermore, the possibility of exploiting single fiber for both coherent dual-polarization quadrature phase shift keying (QPSK) data transmission and DAS pulses was explored. The interactions between the two signals were examined by implementing tests in both co-propagation and counter-propagation configurations. The results demonstrated that while co-propagation introduced impairments on data signals, the counter-propagation scheme did not show any trace of inter-channel crosstalk. The dual use of single fiber for data transmission and sensing necessitated the development of novel solutions for amplification. A specialized telecommunications amplifier was designed to support bidirectional DAS signals alongside standard telecom traffic. Employing filtering and other techniques, the same amplifier was capable of amplifying mono-directional coherent QPSK signals while ensuring amplification of bidirectional DAS pulses. Tested in a counter-propagating configuration, both data and sensing signals exhibited no penalties. The experimental results demonstrated the feasibility of an amplified submarine optical link with sensing features and with optimal fiber utilization of the cable.

Integrated Photonic Memory for Future Computing Systems

Zefeng Xu*

Hong Kong University of Science and Technology, China

Abstract

With the rapid expansion of artificial intelligence, computing demands have become increasingly energy intensive. To address these challenges, advanced photonic circuits and systems have been proposed, offering key advantages such as large bandwidth, low energy loss, and multi-wavelength multiplexing, which aim to complement or even replace conventional electronic systems. However, realizing these capabilities requires low-latency, energy-efficient data translation and transfer, particularly for electro-optic hybrid chips. The emerging concept of photonic memory shows great promise in overcoming these challenges and advancing future computing systems.

Advances in Lithium Niobate Photonics and Electronic-photonic Integration for High-performance Devices and Systems

Yang Jie*

National University of Singapore, Singapore

Abstract

This talk presents recent advances in hybrid electro-optic integration, targeting ultra-low-loss photonic devices and scalable neural network acceleration. We first introduce a complementary metal-oxide-semiconductor compatible fabrication approach that combines dry etching with wet polishing, enabling ultra-low-loss lithium niobate (LN) waveguides and high-Q microring resonators. These developments lay a robust foundation for high-performance electro-optic modulators in large-scale photonic systems. To harness the low-loss and high-speed advantages of photonic modulation, we propose a novel 2-transistor-1-modulator electro-photonic hybrid memory architecture for compute-in-memory (CIM) applications. By incorporating optical bitlines with ultra-low propagation loss, this architecture overcomes the scalability limitations of conventional electronic CIM arrays, supporting large-scale inference tasks such as transformer models (e.g., A Lite Bidirectional Encoder Representations from Transformers (ALBERT)) with up to 45% accuracy improvement. Furthermore, to extend hybrid integration to silicon-based systems, we demonstrate the first compact LN-on-silicon microring modulator using micro-transfer printing, featuring a high-efficiency vertical adiabatic coupler. This device achieves high modulation efficiency and high-speed performance

within a compact footprint, offering a promising route toward dense, heterogeneous photonic integration. Together, these works represent a unified effort to advance low-loss photonic integration, energy-efficient modulation, and scalable photonic computing for next-generation artificial intelligence and communication technologies.

Fast Detection of Water and Environmental Pollution Using Cutting-edge Laser Technology

Walid Tawfik[1*] and Mohamed Fikry[2]

[1]Department of Laser Applications in Metrology, Photochemistry and Agriculture, National Institute of Laser Enhanced Sciences, Cairo University, Giza, Egypt
[2]Department of Physics, Faculty of Science, Cairo University, Giza, Egypt

Abstract

Detecting and quantifying heavy toxic elements in environmental samples can now be performed in a few seconds using an advanced method based on cutting-edge ultrafast picosecond laser induced breakdown spectroscopy (PsLIBS). This technique assessed heavy-metal contamination in Egyptian agricultural environments, including soils and various plant species irrigated from potentially polluted sources. An optimized 1064 nanometer neodymium-doped yttrium aluminum garnet PsL (170 Ps pulse duration, ~100 J/cm^2) enabled high-resolution, multi-element spectral acquisition. A calibration-free LIBS approach allowed direct quantification without matrix-matched standards. Results revealed significant soil contamination, with concentrations such as iron (Fe): 138.66 ppm, zinc (Zn): 135 mg/kg, cadmium (Cd): 0.05 - 0.064 mg/kg, chromium (Cr): 0.14 mg/kg, copper (Cu): 3.6 ppm, and manganese (Mn): 1.2 ppm. These values exceed several permissible limits, indicating environmental risk. Plant tissues collected from the same areas also showed elevated metal contents, with Fe, Zn, and Cd bioaccumulation factors >1, confirming active uptake from the soil. Plasma diagnostics using Boltzmann plot and Stark broadening techniques yielded electron temperatures of 6.7 - 9.0 Kelvin and electron densities of 0.9 - 2.6 × 10^{17} cm^{-3}, strongly correlating with heavy-metal concentrations. The LIBS systems *in situ* capability and minimal sample preparation make it highly suitable for rapidly mapping contamination hotspots. The study highlights widespread pollution from irrigation water, likely influenced by untreated industrial discharges. Elevated Fe, Zn, Cd, Cr, Cu, and Mn levels pose potential threats to food safety, soil health, and human well-being. This ultrafast LIBS-based methodology offers a non-destructive, multi-element, and real-time analytical solution, providing critical data for environmental remediation, pollution management, and sustainable agricultural practices in Egypt.

Highly Efficient Neodymium-doped Lanthanum Gallium Strontium Borate Infrared Laser Pumped Directly into the Emitting Level

Catalina-Alice Susala[*]

National Institute for Laser, Plasma and Radiation Physics, Magurele, Romania

Abstract

Efficient laser emission at 1061 nanometer (nm) of a neodymium-doped lanthanum gallium strontium borate (Nd: LGSB) laser medium is reported in this work. A c-cut 4.6 at %Nd: LGSB laser crystal, grown by the Czochralski pulling method in our laboratory, was pumped with laser diodes at 808 nm, i.e., classically in the $^4F_{5/2}$ level, as well as directly in the $^4F_{3/2}$ emitting laser level at 880.6 nm. A thorough analysis of the output characteristics in the free generation regime, using quasi-continuous wave as well as continuous wave pumping is performed, using similar laser resonators and pump beam dimensions. Direct pumping increases the stokes efficiency while reducing the thermal effects associated with nonradiative transitions from $^4F_{5/2}$ down to $^4F_{3/2}$ lasing level of Nd^{3+}. Consequently, under optical pumping at 880.6 nm the Nd: LGSB crystal yielded 3-watt output power with an optical-to-optical efficiency of 0.72 (with respect to the absorbed pump power); the slope efficiency reached 0.80 (very close to the quantum defect limit). On the other hand, the best laser emission slope efficiency achieved using the pump at 808 nm was 0.71. An analysis of the thermal effects induced in the Nd: LGSB laser medium for the two pump wavelengths is used to explain the obtained results. Optical pumping into the $^4F_{3/2}$ upper level, investigated here for the first time in the case of Nd: LGSB, may prove extremely advantageous for further self-frequency doubling experiments, aiming boosting of visible output from the Nd: LGSB bifunctional crystal.

Exploring Densification Mechanisms of Silica Glass in Femtosecond Laser Modifications Us-

ing Nano-fourier Transform Infrared

Shchedrina N.[1,2*], Ollier N.[2], Sosa M.[1,3], Nemeth G.[4], Borondics F.[4] and Lancry M.[1]

[1]*Institute of Molecular Chemistry and Materials of Orsay, Paris-Saclay University, France*
[2]*Laboratory of Irradiated Solids, Polytechnic School, France*
[3]*Paris-Saclay University, France*
[4]*SMIS Beamline, Synchrotron Soleil, France*

Abstract

Femtosecond laser pulses can induce localized structural changes inside silica glass, commonly classified as types I, II, and III. Type I shows isotropic index change; type II forms anisotropic nanogratings; and type III creates micro/nano-voids surrounded by a densified shell. These modifications alter optical, mechanical, and thermal properties, yet the degree and mechanisms of densification remain uncertain, especially at the nanoscale. We investigate nanoscale densification in laser-modified silica using scattering scanning near-field optical microscopy and nano-fourier transform infrared (Nano-FTIR) spectroscopy at Synchrotron Soleil. The silicon-oxygen-silicon (Si–O–Si) asymmetric stretching vibration, sensitive to density, was probed inside and outside modified zones. Nano-FTIR amplitude and phase spectra were converted to density values using the established linear relation between band position and silica density. All examined modification types show a redshift of the Si–O–Si band, confirming densification. Type I regions exhibit a ~7 cm^{-1} shift, equivalent to ~3 - 4% densification, likely driven by defect-mediated structural rearrangement and rapid thermal quenching. Type II nanograting's display periodic band shifts, reflecting alternating densified and porous layers, with overall densification reaching 8 - 13%, happening due to high-pressure, high-temperature conditions during nanograting's formation. Type III modifications, void formation, show ~6% densification in the surrounding shell. These findings clarify the nanoscale structural response of silica to ultrafast laser exposure and provide quantitative insight into how different modification regimes achieve distinct density changes.

Oral Presentations

Design of a High-speed Partial Differential Equation Solver at 20 Gigahertz with Hybrid Electronic Photonic Technology

Kaustab Ghosh*, Sujan Chowdhury, Kavish Ranawella, Mircea R. Stan and Avik W. Ghosh

Charles L Brown Department of Electrical and Computer Engineering, University of Virginia, Virginia, USA

Abstract

Partial differential equations (PDEs) are the basic foundation toward modeling complex physical, biological and engineering systems, including fluid dynamics, heat transfer and electromagnetics. However, the increasing complexity and scale of modern scientific problems demand computational performance that far exceeds the limits of traditional electronic solvers. In this context, hybrid electronic-photonic technology offers a transformative paradigm for accelerating PDE solvers, combining the high-speed, parallel-processing capabilities of photonics with the programmability and control of electronics. Photonic components such as modulators and photodetectors enable ultra-fast matrix-vector and matrix-matrix multiplications, which are core operations in finite difference modeling used to solve PDEs. With this in view, we have designed a non-linear PDE solver based on the aforementioned technology. Different algorithms to solve the PDE were analyzed such time explicit forward Euler and Runge Kutta as well as time implicit Crank Nicolson method. Although Runge Kutta outweighs others in terms of accuracy and Crank Nicolson on stability, it comprises more multiply-accumulate operations per time step compared to forward Euler. This enhances energy costs with a greater number of modulators and photo detectors. Thus, the layout of the PDE architecture is created based on forward Euler method. Effective number of bits (ENOB) varied from 3 to 12 to capture the quantization error for emulating the hardware on the basis of a recent experiment. For ENOB = 6, we obtained an accuracy of 97.1%. We further analyzed bit splicing to assess the reduction in power consumption and batch processing to amortize the cost over time.

Complex Dynamics of a Photonic Neuron with Dual Feedback

Andrés Aragoneses*, John P. Bannon, Eli Main and Thomas Hill

Whitman College, Washington, USA

Abstract

We investigate the dynamics of a photonic neuron a diode laser with dual optical feedback. By varying the feedback intensities from two external mirrors, we examine how their interplay shapes the system's spiking behavior. Our results show that

the addition of a second feedback source not only modifies the statistical properties of inter-spike intervals but also enhances determinism and alters temporal correlations. Key findings include, inhibition of spiking maximizing both feedbacks reduces spiking frequency, demonstrating that dual feedback can suppress activity typical of single feedback; modified temporal correlations differences in word probabilities with one or two feedback sources reveal the capacity to tune dynamics; enhanced determinism dual feedback increases regularity, supported by pronounced temporal symmetries and word distributions; robust symmetries (Temporal and reversible dynamical symmetries) quantifiers highlight persistent symmetries across parameter ranges; and Φ-vector space significance the system's dynamics follow a well-defined curve in Φ-space, providing a compact representation of deterministic behavior. These results indicate that dual feedback enables modulation of temporal correlations while respecting intrinsic symmetries. Machine learning analysis further reveals that dual feedback induces correlations resembling pink noise, while single feedback aligns with white noise. Such control mechanisms may improve performance and robustness in reservoir computing devices and optical neural networks. Future work should explore the role of additional parameters, such as time delay, phase, and feedback strength, and extend the analysis to other non-linear oscillators to uncover general principles of feedback-induced dynamics.

High-order Domain-wall Dark Harmonic Pulses in a Dumbbell-shaped Fiber Laser at 1563 nanometer

Alejandro Reyes-Mora[1*], Manuel Durán-Sánchez[1], Baldemar Ibarra-Escamilla[1], Miguel Ángel[1] and Bello-Jiménez[2]

[1]National Institute of Astrophysics, Optics and Electronics, Puebla, Mexico
[2]Autonomous University of San Luis Potosí, Mexico

Abstract

This work presents the formation of mode-locked high-order dark harmonic pulses in a dumbbell-shaped erbium/ytterbium co-doped fiber laser. The laser cavity has a length of 644 meters and consists of two non-linear mirrors known as non-linear optical loop mirror and non-linear amplifying loop mirror. By increasing the pump power and tuning the quarter-wave retarder plates, we experimentally achieved dark pulses of order 310 harmonics. To achieve higher-order dark harmonic pulses, the pump power was tuned to 6.26-watt near the fundamental dark pulse generation threshold in addition to fine-tuning the polarization controller plates that make up the cavity. By adjusting the retarder plates and pump power, the repetition frequency was changed from 321.34 kilo hertz to 99.61 million hertz, and the pulse duration varied from 500 to 12 nanoseconds. At the 310th harmonic, the pulse shape can no longer descend or ascend sharply, occasionally emitting dark triangular pulses. To confirm that the emissions correspond to the dark harmonics found, the repetition frequency of each harmonic is measured with the radio frequency spectrum analyzer. This study provides new insights into complex pulse dynamics in fiber lasers and demonstrates the versatile emission regimes achievable through precise pump and polarization control.

Laser Absorption Spectroscopy of Hyperfine and Zeeman Transitions: Saturation Effects and Methodological Approaches

L.M. Sobolewski[1*], J. Kwela[1] and L. Windholz[2]

[1]Faculty of Mathematics, Physics and Informatics, Institute of Experimental Physics, University of Gdansk, Gdansk, Poland
[2]Institute of Experimental Physics, Graz University of Technology, Graz, Austria

Abstract

Using laser absorption spectroscopy techniques, such as optogalvanic spectroscopy or laser-induced fluorescence, it is often possible to resolve and record individual components of hyperfine or Zeeman structures. However, for complex atomic structures where spectral lines overlap, accurately determining the intensity peaks becomes challenging. One major difficulty is the saturation effect. Standard fitting methods rely on theoretically predicted relative intensities, but saturation causes deviations where stronger components appear weaker than expected, resulting in discrepancies between theory and experiment. Reducing laser power can sometimes mitigate this, but often saturation is unavoidable. In our recent work analyzing Zeeman structures, we enhanced our fitting software by introducing a free parameter, the saturation intensity A_v. The transition rate of each Zeeman component A_s was modified according to:

$$A_\nu^{\mathrm{sat}} = \frac{A_\nu}{1 + A_\nu / A_s}$$

where A_v is the unsaturated decay rate proportional to laser intensity. We also emphasize that under saturation, the polarization

of the excitation laser strongly influences the recorded hyperfine spectrum, contradicting the common assumption that polarization has no effect. The program calculates the intensity of each hyperfine component at zero magnetic field (B = 0) as a sum over all magnetic sublevels (M, M'). Due to saturation, spectra obtained with π and σ polarizations differ and must be treated accordingly in simulations. Accurate hyperfine structure measurements require controlled laser polarization, which must be included in simulations to reliably compare experimental and theoretical spectra.

Temporal Gating and Vortex-beam Control of High-order Harmonic Generation

Nicolas Douguet*

University of Central Florida, Florida, USA

Abstract

I will present two distinct high-order harmonic generation (HHG) schemes that extend control of attosecond emission in time and in wavefront. In the first, a few-cycle ultraviolet (UV) pulse is phase-locked to and delayed relative to a strong mid-infrared (MIR) driver (2 -3 μm). The UV pulse seeds multiphoton ionization near MIR field maxima, selects recollisional trajectories, and enables the generation of bright, isolated X-ray attosecond pulses with multi-cycle MIR drivers. By tuning the UV–MIR delay and carrier-envelope phase, we steer the spectral content and obtain robust, orders-of-magnitude enhancements over MIR-only driving. Time-dependent Schrödinger simulations are interpreted with simple semiclassical, barrier suppression, and strong-field approximation models. In the second scheme, HHG is driven by optical bessel vortex beams, transferring orbital angular momentum (OAM) to the harmonics. Time-dependent single-atom calculations, combined with Fraunhofer propagation of the collective emission from a thin gas target, show that in the intense few-cycle regime the harmonics exhibit mixed OAM content rather than the linear scaling characteristic of long, weak pulses, producing ringed far-field profiles and a structured helical phase. Together, these studies support temporal gating and wavefront shaping as effective means of tailoring HHG for ultrafast spectroscopy applications.

Non-dispersing Trojan-like Wave Packets on Langmuir Type (2) Click Clack Balls Trajectories with Dichotomy in Helium Atom and Quantum Dots

Matt Kalinski*

Department of Chemistry and Biochemistry, Utah State University, Utah, USA

Abstract

Some time ago we have discovered that placing the Langmuir trajectories of the type one i.e., those in what we called the "Hoop earrings" configuration in a combination of the symmetry augmented circularly polarized (C.P.) electromagnetic field and the magnetic field perpendicular to the planes of the both electron parallel circular motions results in classical stabilization of the resulting Langmuir trajectories which therefore can support the stable non-dispersing quantum trojan wave packets. We have also recently shown that the Langmuir trajectories of the type two i.e., those corresponding to the popular toy, the click clack balls, when two electrons are moving in one plane on the semi-circular trajectory with the opposite angular velocity, they bounce from each other, reverse the velocities and continue bouncing again and again also support such packets. To stabilize and confine the system further the perpendicular static magnetic field can be added in addition to the resonant low polarized (L.P.) field. We have also found the non-dispersing wave packets in the joined combination of the external L.P. field and the parallel static magnetic for the several electrons which planes of the semi-circular bouncing motion are symmetrically oriented with respect to each other under the multiples of the integer fraction of the full 360 degrees angle. We also have found such trajectories and the corresponding wave packets to be possible in the more complicated multi-layer polaronic configuration when not one but the several electrons each in a parallel layer are moving on each semi-circle. We use the generalized Gaussian ansatz for the packet wave function and solve the equations for the localization matrix M(t) together with the classical equations of the motion.

$$\psi = N \exp\left[-\sum \mathcal{M}_{ij}\tilde{x}_i\tilde{x}_j\right]$$

Here we find such trajectories and the moving-along corresponding non-dispersing wave packets to be possible also with the dichotomy i.e., when each of the electron line-like trajectory splits into close loop deformed elliptical trajectory i.e., when the rebouncing of the electros is not perfectly momentum-reversible, but the trajectory is perfectly closed.

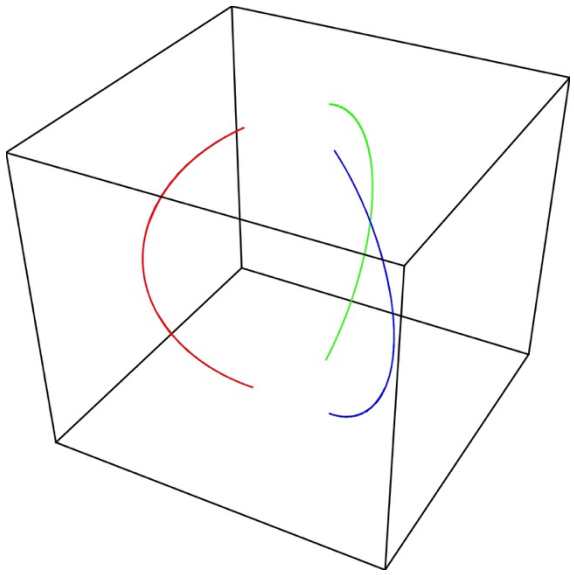


Figure 1: Langmuir three-electron (three-colors) trajectories executing the periodic motion of the multiple click clack balls.

Laser-induced Photovoltaic Response and Robust Superconductivity in Yttrium Barium Copper Oxide/Strontium Titanate Thin Films

Luz Esther González Reyes[1*], Lina M. Segura-Gutiérrez[2], John Edward Ordoñez[2], Gustavo Zambrano[2], Omar Calderón-Losada[3] and John Henry Reina[3]

[1]Semiconductors and Superionics Materials Research Group, Department of Physics, Faculty of Sciences, University of Tolima, Colombia
[2]Thin Film Group, Department of Physics, University of Valle, Colombia
[3]Quantum Technologies, Information and Complexity Group, Centre for Bioinformatics and Photonics, Department of Physics, University of Valle, Colombia

Abstract

The interaction between superconductivity and light in yttrium barium copper oxide (YBCO) thin films offers an emerging pathway for multifunctional device applications. In this work, we report that YBCO/strontium titanate ($SrTiO_3$) heterostructures maintain a high critical temperature of 88 Kelvin and remarkable superconducting stability, even under pulsed laser irradiation at energies beyond the superconducting gap. Unexpectedly, a residual resistance and a pronounced photovoltaic effect were detected, suggesting unconventional carrier dynamics and light-induced electronic states. Reflectance spectroscopy further revealed that superelectrons play a dominant role in shaping the optical response of the films, strengthening the link between their photonic and superconducting properties. These results point to the feasibility of light-modulated superconducting functionalities and indicate that YBCO thin films can serve as promising platforms for optoelectronic devices and high-efficiency solar cells.

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