Q 17: Photonics and Biophotonics I

Time: Tuesday 11:00–13:00 Location: P 3

Q 17.1 Tue 11:00 P 3

Stable Optical Vortex Rings in Linear and Nonlinear Media — •Zhamila Kulchukova[1] and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany — [2]Institut für Mathematische Physik, Technische Universität Braunschweig, Mendelssohnstrasse 3, D-38106 Braunschweig, Germany

Vortex rings are fundamental to both classical and quantum physical systems, from turbulent fluids to BECs. In optics, vortex rings are quantized ring-shaped vortices with vanishing intensity at the core, appearing as threads of darkness tied into a loop. Studying the nature of optical vortex rings and ways of manipulating them opens novel avenues for applications of structured light, i.e. optical tweezers, and helps to uncover the underlying mechanisms of physical phenomena not yet fully understood, such as quantum turbulence and spontaneous knotting. In this talk, we theoretically investigate an experimentally accessible system that exhibits stable vortex rings in vacuum and in nonlinear (focusing and defocusing) Kerr media. We demonstrate that the rings are not destroyed by symmetry-breaking and nonlinear effects, but instead undergo topological transformations of varying complexity. Despite its simplicity, our system provides a useful framework to study optical vortex rings and their dynamics. Moreover, it can open new ways to investigate the fine structure of the light and its applications in light-matter interactions.

Q 17.2 Tue 11:15 P 3

Active Electrically Switchable Polymer Metasurfaces for Microscope Imaging Functionalities — •Dominik Ludescher[1], Leander Siegle[1], Robert Horvat[1], Jonas Herbig[1], Pavel Ruchka[1], Junqi Lu[2], Marcos A. Dahlem[2], Sabine Ludwigs[2], Mario Hentschel[1], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]IPOC - Functional Polymers, Institute of Polymer Chemistry, University of Stuttgart, Germany

Integrating dynamic functionalities into 3D-printed optical components has remained a major challenge, leaving printed optics limited to static behavior. Electrically tunable materials such as the conducting polymer PEDOT:PSS offer a promising route toward adaptive, and compact optoelectronic systems. A key bottleneck has been the high-resolution patterning of PEDOT:PSS. However, we recently introduced two direct nanofabrication strategies that overcome these limitations: electron-beam-induced solubility modulation, and laser-based patterning using the same systems employed for two-photon polymerization of optical resins. The latter method enables true nanoscale patterning and is fully compatible with 3D-printed micro-optics. Using these techniques, we present a versatile integration scheme in which tunable PEDOT:PSS structures are positioned either beneath or atop static 3D-printed elements. This hybrid platform enables voltage-controlled transitions between dark-field and bright-field operation at CMOS-compatible voltages from -2 V to +2 V. The approach establishes a robust foundation for future reconfigurable photonic components.

Q 17.3 Tue 11:30 P 3

Controlling quantum noise through programmable nonlinear optics — •Michael Horodynski[1,2], Jamison Sloan[3,4], Shiekh Udding[1], Yannick Salamin[1], Michael Birk[5], Pavel Sidorenko[5], Ido Kaminer[5], Marin Soljačić[1,3], and Nicholas Rivera[6,7] — [1]Department of Physics, Massachusetts Institute of Technology — [2]Photonics Institute, TU Wien — [3]Research Laboratory of Electronics, Massachusetts Institute of Technology — [4]E. L. Ginzton Laboratory, Stanford University — [5]Department of Electrical and Computer Engineering, Israel Institute of Technology — [6]Department of Physics, Harvard University — [7]School of Applied and Engineering Physics, Cornell University

Light fields are now routinely structured across many degrees of freedom (i.e., spatial, temporal, and spectral), enabling unprecedented control over their classical properties. Although light's quantum properties limit important applications such as communications, imaging, and spectroscopy, an approach to shape the quantum statistical properties of light, such as correlations and noise, is missing. Here, we show that combining wavefront shaping with optical nonlinearity offers an unprecedented degree of control over the classical and quantum properties of light simultaneously. In our experimental demonstration, we combine spatial light modulation with the nonlinear dynamics offered by a multimode fiber to focus a region of high intensity, yet low noise, at the output of the fiber. The fiber output has intensity noise 20 times lower than what is achievable by linear means, and is at the quantum shot-noise level despite a highly noisy input.

Q 17.4 Tue 11:45 P 3

Experimental implementation of thermalisation in a nonlinear non-Hermitian optical lattice — •Julia Görsch[1], Joshua Feis[1], Andrea Steinfurth[1], Sebastian Weidemann[1], Georgios G. Pyrialakos[2], Matthias Heinrich[1], Mercedeh Khajavikhan[2], Alexander Szameit[1], and Demetrios N. Christodoulides[2] — [1]Institute of Physics, University of Rostock, Rostock, Germany — [2]Ming Hsieh Department of Electrical and Computer Engineering, University of Southern California, Los Angeles, California, USA

Optical thermodynamics has emerged as an efficient framework for describing and predicting the dynamics of strongly multimode, nonlinear systems. Yet, in non-Hermitian settings, many of the theoretically predicted effects have remained experimentally unexplored. Here, we report the first experimental observation of thermalisation in a nonlinear, non-Hermitian optical lattice using a platform based on coupled optical fiber loops. This arrangement emulates light propagation in a one-dimensional lattice by coupling two fiber loops of unequal length via a beam splitter, thereby mapping pulse evolution onto a doubly discrete (1+1)D lattice. Within this system, we engineer a pseudo-Hermitian lattice whose non-Hermiticity arises from anisotropic nearest-neighbor coupling, implemented via a tunable beam-splitting ratio combined with amplitude modulation. Following excitation with a superposition of eigenmodes, the system undergoes a clear thermalisation process - despite its intrinsic non-Hermiticity - revealing a previously inaccessible regime of non-Hermitian optical thermodynamics and opening the door to further experimental investigations.

Q 17.5 Tue 12:00 P 3

Loss-Minimized Incoherent Photonic Computing on a Mach-Zehnder interferometer network — •Konrad Tschernig[1,2], Mingwei Yang[1,2], Felix Kübler[1], Okan Akyüz[1], Lennart Mannteuffel[1], Enrico Stoll[1], and Janik Wolters[1,2] — [1]Technical University of Berlin, Berlin, Germany. — [2]German Aerospace Center (DLR), Berlin, Germany.

We present an algorithm for loss-minimized incoherent photonic multiplication of N-dimensional vectors with $N \times N$ matrices on standard Clements Mach-Zehnder interferometer (MZI) meshes [1]. By applying arbitrary unitary transformations to incoherent light states, our method avoids phase control and additional MZI blocks required by the singular value decomposition in coherent schemes [2]. In comparison, the crossbar architecture [3] requires N times more optical energy than our scheme to perform the same $N \times N$ matrix-vector multiplication (MVM). Experimentally, we implement a 4×4 photonic MVM and demonstrate an optical convolutional neural network for MNIST classification. Utilizing our loss-minimized architecture, we aim to reduce the input intensity to the single photon regime to explore the limitations from shot noise.

[1] Clements, William R., et al., Optica 3.12 (2016): 1460-1465.
[2] Shen, Yichen, et al., Nature photonics 11.7 (2017): 441-446.
[3] Feldmann, Johannes, et al., Nature 589.7840 (2021): 52-58.

Q 17.6 Tue 12:15 P 3

Colloidal Self-Assembly for 3D Second-Harmonic Photonic Crystals — •Thomas Kainz[1], Ülle-Linda Talts[2], Helena Weigand[2], Rachel Grange[2], Ullrich Steiner[1], and Viola Vogler-Neuling[1] — [1]Adolphe Merkle Institute and NCCR Bio-inspired Materials, University of Fribourg, CH-1700 Fribourg, Switzerland — [2]Institute for Quantum Electronics, Department of Physics, ETH Zürich, CH-8093 Zürich, Switzerland

Three-dimensional nonlinear (second-harmonic) photonic crystals can simultaneously generate different nonlinear processes. However, creating large crystals in all three dimensions presents a considerable challenge, primarily due to the chemical inertness of metal oxides. This study presents the first demonstration of colloidal-crystal templating into a second-order optical material. Self-assembled polystyrene opal templates are infiltrated with barium titanate sol-gel, resulting in an inverse fcc network of tetragonal barium titanate after calcination. Our samples have unprecedented sizes (>3000 unit cells in x, y directions and >100 in z) and reflectivity values above 80%. We engineered the final linear photonic bandgap and measured the second-harmonic generation (SHG) over it, including its intensity under polarization and its power dependence. We successfully replicated the photonic network into a second-order material and demonstrated, for the first time, a linear photonic band gap from a fully scalable three-dimensional photonic crystal made of a nonlinear optical material. We present the influence of a stopband on the SHG generation, with edge enhancement and inhibited spontaneous emission.

Q 17.7 Tue 12:30 P 3

Electric field-Induced second-harmonic generation in silicon-rich nitride — •Laurids Wardenberg, Krishna Koundinya Upadhyayula, and Jörg Schilling — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Germany

Applying a DC electric field to PECVD-grown films of silicon-rich nitride enables a voltage-controllable second-order susceptibility, giving rise to electric field-induced second-harmonic generation (EFISH). From the quadratic scaling of the second-harmonic output with the applied field, both the field-dependent and field-free second-order susceptibilities are experimentally extracted, reaching values comparable to those of traditional nonlinear crystals. The associated third-order susceptibility is likewise obtained and shown to increase significantly with higher silicon content in the SiNx films.

To further boost the nonlinear response, a quasi-bound state in the continuum is excited by implementing an extended square 2D nanopillar array on a SiNx base layer. The resulting strong field confinement in this waveguide-like structure, combined with the field-free second-order nonlinearity, produces a pronounced enhancement of TM-polarized second-harmonic generation.

Finally, by applying a DC electric field parallel to the polarization of the pump in a similar resonant structure, the interaction between photonic resonances and the EFISH mechanism is demonstrated. Together, these results open the door to low-power, on-chip frequency-conversion applications using both second- and third-order nonlinearities of the CMOS-compatible silicon-rich nitride platform.

Q 17.8 Tue 12:45 P 3

Training nonlinear optical neural networks with Scattering Backpropagation — •Nicola Dal Cin[1,2], Florian Marquardt[1,2], and Clara Wanjura[1] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany

As deep learning applications continue to deploy increasingly large artificial neural networks, the associated high energy demands are creating a need for alternative neuromorphic approaches. Optics and photonics are particularly compelling platforms as they offer high speeds and energy efficiency. Neuromorphic systems based on nonlinear optics promise high expressivity with a minimal number of parameters. However, so far, there is no efficient and generic physics-based training method allowing us to extract gradients for the most general class of nonlinear optical systems. In this work, we present Scattering Backpropagation, an efficient method for experimentally measuring approximated gradients for nonlinear optical neural networks. Remarkably, our approach does not require a mathematical model of the physical nonlinearity, and only involves two scattering experiments to extract all gradient approximations. The estimation precision depends on the deviation from reciprocity. We successfully apply our method to well-known benchmarks such as XOR and MNIST. Scattering Backpropagation is widely applicable to existing state-of-the-art, scalable platforms, such as optics, microwave, and also extends to other physical platforms such as electrical circuits.