Electronics–Photonics co-design for the Control of Programmable Silicon Photonic Circuits

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Silicon photonics (SiP) shares the same fabrication technologies of microelectronics for the realisation of a number of miniaturized optical devices, like Mack Zehnder Interferometers (MZI) and Ring Resonators, on small chips. However, the widespread use of complex SiP architectures is still limited by their high sensitivity to temperature and thermal crosstalks. Electronic feedback control, supported by CMOS-compatible light sensors for transparent monitoring of the optical power, is therefore essential to sense, steer and lock the working point of Si-photonic devices.

The talk will recall the recent advances in the realization of light sensors to locally probe the optical power in a non-invasive way and in the co-design of the control electronic and the photonic chip. The interplay among sensing, controlling and actuating indeed allows to perform advanced operations as reconfigurable routing schemes, wavelength-division multiplexing [1] or mode unscrambling [2], potentially bringing cost and size reduction to scale up the capacity of optical networks.

The talk will concentrate on the successful co-integration of electronic functionalities onto a photonic technology platform not originally conceived for accepting standard CMOS circuits [3]. A 16-to-1 MUX has been integrated into an optical router, enabling on-chip time-multiplexing of the photodiodes readout, without any penalty in the optical quality. This attempt has demonstrated the advantages in decreasing the numbers of required SiP connections to manageable values and has solicited for a truly electronic-photonic co-design on the same platform to face optical computing bottlenecks.

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Solving computational problems with coupled lasers

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Computational problems may be solved by realizing physics systems that can simulate them. Here we present a new system of coupled lasers in a modified degenerate cavity that is used to solve difficult computational tasks. The degenerate cavity possesses a huge number of degrees of freedom (300,000 modes in our system), that can be coupled and controlled with direct access to both the x-space and k-space components of the lasing mode. Placing constraints on these components are mapped on different computational minimization problems. Due to mode competition, the lasers select the mode with minimal loss to find the solution. We demonstrate this ability for simulating XY spin systems and finding their ground state, for phase retrieval, for imaging through scattering medium, and more.

The Berkeley surface emitting laser (BerkSEL): A scale-invariant laser?

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The scaling of lasers and in-particular of surface emitting lasers is a multi-decade long question that has been investigated since the invention of lasers in 1958. It is an important question with numerous contemporary applications. In the first part of this talk, I will discuss our invention of topological lasers: integrable non-reciprocal coherent light sources as well as compact bound state in continuum sources. In the second part of the talk, I will discuss a scalable aperture that solves the optics challenge of single apertures scaling. I will discuss the physics of the discovery that we named Berkeley Surface Emitting Laser (BerkSEL).

Electron–photon coupling: From fundamentals to quantum correlated nanoscopy

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Free electrons play functional roles with similarity to photons, where a prime example is electron microscopy and spectroscopy in regimes below an optical wavelength. But to what extent can one extend analogies from photonics science to a clearly distinct fundamental particle? Can one apply quantum optics on free electrons, both conceptually and practically? This talk discusses the quantum coupling between free electrons and photons within electron microscopes, and show recent results on utilization for enhanced nanoscopy.

Observation of the Orbit–Orbit Interaction of Light in Plasmonics

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Light can carry three types of angular momenta: a spin angular momentum, an intrinsic orbital angular momentum (OAM), and an extrinsic OAM [1]. These momenta are associated with the handedness of the circular polarization, optical vortex beams with helical phase fronts, and varying beam trajectories, respectively [1]. The interplay between these momenta yields the spin–orbit interaction (SOI) of light [2], in which the spin (circular polarization) controls the spatial (orbital) degrees of freedom of light: either the extrinsic OAM (trajectory) or the intrinsic OAM (vortex). SOI provides a toolbox for spin-controlled light manipulations, thus playing a crucial role in the new reality of nano-optics. However, while the SOI of light has been studied extensively [2], the interaction between the intrinsic OAM and the extrinsic OAM—the orbit–orbit interaction (OOI) of light—has remained elusive. In this nontrivial interplay, the helical phase fronts of optical vortices control the spatial trajectory of light, which gives rise to vortex-dependent shifts of optical beams. Strikingly, the OOI of light significantly enhances the toolbox available for controlling light by leveraging the *manifold* OAM states for vortex-controlled light manipulation, in contrast to SOI-based light manipulation [2], which exploits the *binary* polarization helicity.

Here, we report the OOI of light in a plasmonic ellipse cavity, whose unique geometry facilitates the OOI when a vortex is considered in one of the foci of the ellipse (Fig. 1A). In this configuration, the OOI between the intrinsic OAM and the extrinsic OAM is achieved by the interplay between the vortex of the source and the ellipse-induced transverse shift of the source beam, positioned at one of the focal points. The OOI of light in the plasmonic ellipse cavity induces transverse vortex-dependent shifts, i.e., shifts that depend on both the vortex helicity and strength, at the second focal point (Figs. 1A and 1B). Moreover, we demonstrate information processing via on-chip OAM demultiplexing based on the OOI by encoding information via different vortex states and decoding it via the spatially separated vortex-dependent shifts. By utilizing the multiple OAM states as a new degree of freedom in light manipulation, the OOI of light offers great potential for OAM-supported applications, including high-bandwidth optical communication and quantum information processing, enhanced resolution in imaging and microscopy, control of matter by optical trapping and tweezing, and many more.

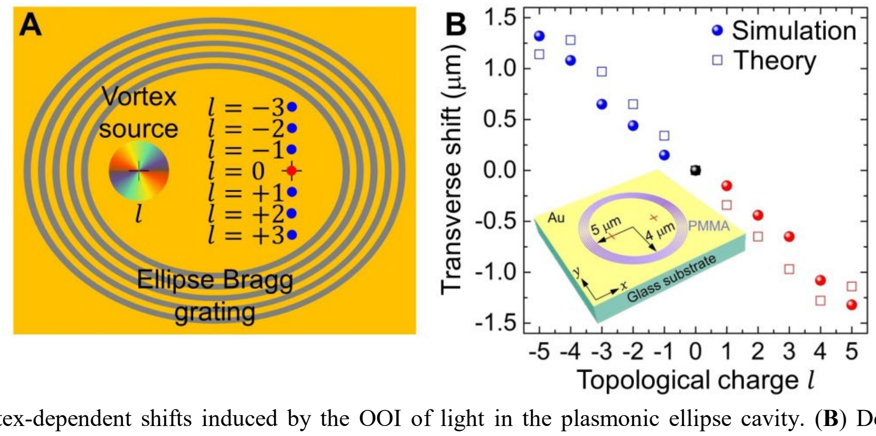

Fig. 1. (**A**) Vortex-dependent shifts induced by the OOI of light in the plasmonic ellipse cavity. (**B**) Dependence of the transverse shift on the topological charge l of the source beam. The inset shows the simulated structure.

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Smart surfaces enable Near-field Detection by Simple Far-Field Optic

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Characterization of ultra-thin transparent films is paramount for various opto-electronic materials, coatings and photonics. Yet, the characterization of thin layers has been difficult, and it requires specialized clean-room equipment and trained personnel. In the present paper, we introduce and validate a contact-less, all-optical characterization method for nanometric transparent films using far-field optics. To this end, we first fabricate a series of nanometric, smooth and homogeneous layered samples, alternating transparent spacer and fluorescent layers in a controlled manner. We then record and analyze fluorescence radiation pattern originating from the thin fluorophore layer and use quantitative image analysis to perform *in-operando* measurements of the refractive index, film homogeneity and to estimate axial fluorophore distances at a sub-wavelength scale with a precision of a few of nanometers. Our results compare favorably to those obtained through more complicated and involved techniques. Applications in nanometrology and axial super-resolution imaging are presented. Our approach is cheap, versatile and it has applications in various field of photonics.

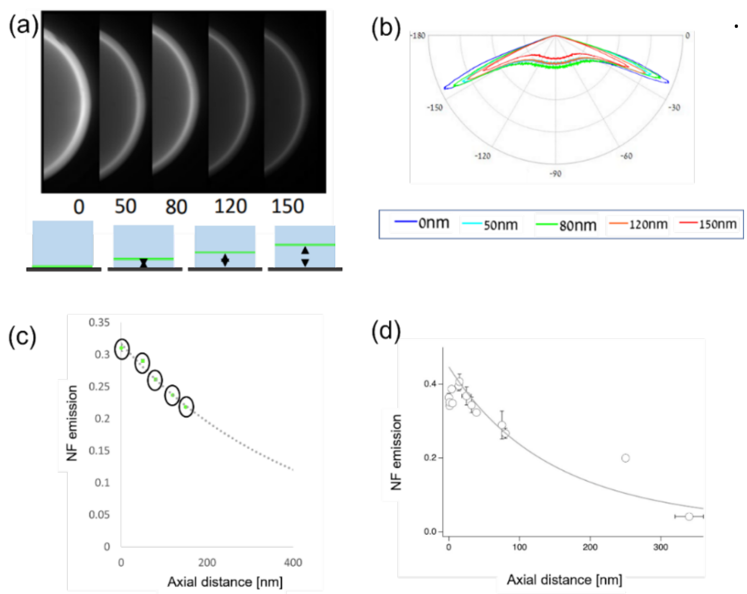

Fig1: *Back focal plane (BFP) imaging and analysis of homogenous fluorescence layers (ATTO 488) deposited onto fused silica in different axial distance from the surface. (a) BFP images (only part are shown) at different axial distances, as is indicated below. (c) quantified emission intensity as function of axial distances (analysis done from the BFP images) (d) as (c) but for J-aggregates thin layer as an example.*

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Antireflective structures directly imprinted on chalcogenide glasses

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Chalcogenide glasses are thermoformable materials with a relatively low glass transition temperature (between 150 to 300ºC) and a high refractive index that makes them attractive for optical applications. Direct nanoimprint of chalcogenide glasses could pave the way to fabricating functional nanostructures, such as Moth-Eye antireflective coating or sub-wavelength diffraction gratings. However, applying pressure and high pressure needed for the surface nanoimprint produces global deformation of the imprinted substrate. On the other hand, low pressure and temperature result in insufficient pattern transfer. To circumvent this fundamental limitation, we recently demonstrated three different new nanoimprint approaches:

The *first approach* is based on the imprint with IR radiative heating using a soft mold. Here, the mold is produced from PDMS reinforced with carbon nanotube, making it a good radiation absorber. Since chalcogenide glasses are transparent in IR, only a thin layer at the mold-glass interface is sufficiently heated above the glass transition point during the radiative imprint . At the same time, the rest of the bulk remains below its glass transition point and therefore is not deformed. Using this approach, we demonstrated a full pattern transfer of micron and sub-micron-sized features on a flat surface of chalcogenide glass and on a lens [1].

The second approach is based on the soft imprinting of a solvent-plasticized glass layer formed on the glass surface [2]. Here, we established a methodology for surface plasticizing by controlling its glass transition temperature through process conditions . This control allowed us to imprint the surface of chalcogenide glass with features sized down to 20 nm and achieved an unprecedented combination of full pattern transfer and complete maintenance of the shape of the imprinted surface of the Chalcogenide glass substrate.

The third approach is based on an elastomeric stamp soaked in an organic solvent. During the imprint, the solvent diffuses into the imprinted substrate, plasticizes its surface, and thereby allows its imprint at the temperature below its glass transition point [3]. As two previous approaches, this one combines the full pattern transfer with the maintenance of the shape of the imprinted substrate, which is necessary for optical devices. By using this approach, we demonstrated functional antireflective microstructures directly imprinted on As_2Se_3 surface . Furthermore, we showed that our approach could produce imprinted features sized down to 20 nm scale.

Overall, these three novel approaches enables facile, high-throughput, and high-quality patterning of chalcogenide glasses, pave the way for myriad future applications of these emerging optical materials.

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