UC San Diego –National Sun Yat-sen University

2019 Bilateral Research Symposium

Photonics and Materials Breakout Session II

SATURDAY MORNING, MARCH 9, 2019

HENRY BOOKER'S CONFERENCE SUITE
ROOM 2512, JACOBS HALL

9:30 - 11:30 Photonics and Materials II (Co-Chairs: Yuhwa Lo and Yi-jen Chiu)

- Tsung-Hsien Lin, Professor and Chair, Department of Photonics, NSYSU
  "Lattice control of 3D Photonic Liquid Crystal"
- Yuhwa Lo, Professor, ECE Department, UCSD
  "Cameraless High-throughput 3D Imaging Flow Cytometry"
- Chin-Ping Yu, Professor, Department of Photonics, NSYSU
  "SOI-based Polarization Beam Splitters"
- Shaochen Chen, Professor, Department of NanoEngineering, UCSD
  "Rapid 3D Printing of Multiscale and Multi-Functional Materials"
- Yung-Jr Hung, Professor, Department of Photonics, NSYSU
  "Optical Spectrometer based on Continuously-chirped Guided Mode Resonance Filters"
- Zhaowei Liu, ECE Department, UC San Diego
  "Enhanced Second Harmonic Generation by Metallic Quantum Wells and Metasurfaces"
- Yuan-Yao Lin, Professor, Department of Photonics, NSYSU
  "Chaos in Optical Vortex Laser formed by the Coherent Superposition of the Off-axis Resonant Modes"
- Kenji Nomura, Professor, ECE Department, UCSD
  "*P*-channel Oxide-TFT Technology for Next Generation Flexible Electronics"

ABSTRACTS

Lattice control of 3D Photonic Liquid Crystal

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Blue phase (BP) liquid crystals (LC) are soft 3D photonic crystals with extraordinary tunability, electro-optic properties, as well as optical nonlinearities. While most techniques can only fabricate 3D photonic crystals that work in the infrared–microwave regime, the bandgaps of BPLCs are inherently located in the ultraviolet–visible–near infrared regime. Recently, we have succeeded in developing a gradient temperature scanning technique to grow such 3D photonic crystals into mm^2–cm^2 in areal size and submillimeter in thickness. These large BP single crystals are however limited to cubic lattice structures, namely body-centered cubic (in BPI) and simple cubic lattices (in BPII). It is known that non-cubic BPs can be induced by stretching a cubic lattice of either BPI or BPII with an electric field but will relax back to the cubic form if removing the applied field. In this research, we propose a method to fabricate non-cubic BPLCs with high stability in this absence of an applied field. The structures are further confirmed by reflective spectroscopy and *Kössel* diffraction patterns. We also propose a macroscopic model adapted from a soft matter mechanical model to correlate the crystal structure with fabrication parameters.

Keywords: Liquid crystal; Photonic crystal

Cameraless High-throughput 3D Imaging Flow Cytometry

Yuhwa Lo

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A central challenge of biology is to correlate the phenotype of heterogeneous individuals in a population to their genotype in order to understand the extent to which they conform to the observed population behavior or stand out as exceptions that drive disease or the ability to become threats to health. While optical microscopy is a cornerstone method to study the morphology and molecular composition of biological specimens, flow cytometry is a gold standard for quantitative high-throughput single-cell characterization in numerous biomedical applications. Recognizing the need to merge these two powerful platforms, several groups have proposed techniques for imaging flow cytometry (IFC) to produce high-content spatial metrics from individual cells in a large population of cells. However, an important limitation of existing IFC systems is that only 2D cell images can be obtained. The absence of 3D cell tomography results in occlusion of objects, blurring by focal depth, loss of z-axis spatial resolution, and artifacts due to projection of a 3D cell into a 2D image. Here we present a solution by demonstrating the world's first three-dimensional imaging flow cytometry (3D-IFC). We combine orthogonal light-sheet scanning illumination with spatiotemporal transformation detection to produce 3D cell image reconstruction from a cameraless single-pixel photodetector readout. We demonstrate this capability by co-capturing 3D fluorescence and label-free side-scattering images of single cells in flow with a throughput of approximately 500 cells per second. The unique tool can be a key enabler for phenotype drug discovery (PDD), studies of drug responses and diseases caused by abnormal protein trafficking, as well as intracellular phenotypes such as organelle changes that reflect the physiology and pathology of cells in a heterogeneous cell population.

SOI-based Polarization Beam Splitters

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Silicon on insulator (SOI) structures is proven to be a very promising technology for developing high-density photonic integrated circuits (PICs). Due to the high index contrast and low loss, SOI structures can efficiently reduce the device sizes. However, the asymmetric geometry of SOI devices induces strong polarization dependence which may degrade the performance of optical communication systems or highly polarization-dependent systems. To overcome this issue, one can implement polarization diversity scheme to achieve a single polarization on-chip network. One of the essential components in a polarization diversity scheme is the polarization beam splitter (PBS). We have proposed several SOI-based PBSs based on directional couplers or multi-mode interference structures. To reduce the device size and broaden the operation bandwidth, subwavelength gratings (SWGs) or hybrid plasmonic waveguides are employed in the PBS designs. In addition, we have also cascaded two PBSs to enhance the polarization extinction ratio for applications in highly polarization-dependent systems.

Keywords: Silicon on insulator; Polarization beam splitter; Subwavelength grating

Rapid 3D Printing of Multiscale and Multi-Functional Materials

Shangting You, Claire Yu, and Shaochen Chen

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The goal of my laboratory is to develop micro- and nano-scale 3D printing and bioprinting techniques to create 3D designer scaffolds for bioengineering applications. In this talk, we will present my laboratory's recent research efforts in rapid continuous projection 3D printing to fabricate 3D functional scaffolds. These 3D devices are functionalized with precise control of micro-architecture, mechanical (e.g. stiffness and Poisson's ratio), chemical, and biological properties. Design, fabrication, and experimental results will be discussed. Such functional scaffolds allow us to investigate cell-microenvironment interactions at nano- and micro-scales in response to integrated physical and chemical stimuli. From these fundamental studies we can create both in vitro and in vivo tissue models for precision tissue engineering and regenerative medicine.

Optical Spectrometer based on Continuously-chirped Guided Mode Resonance Filters

Yung-Jr Hung, Chuan-Ci Yin, Chia-Wei Kao, Tzu-Chieh Kao, Chia-Wei Huang, and Jia-Jin Lin

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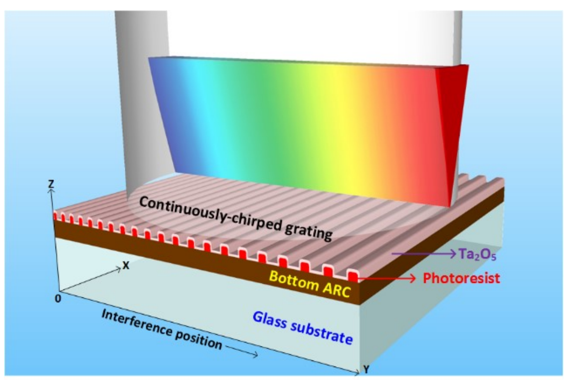
We introduce a tunable Guided Mode Resonance (GMR) filter based on continuously period-chirped (ΔP = 130 nm) gratings using a Ta_2O_5 waveguide layer with graded thickness (ΔT = 36 nm). The structure of the gradient-period grating is defined using a modified Lloyd's mirror interferometer with a convex mirror, and Ta_2O_5 film used for the gradient is deposited using masked e-beam evaporation. The as-realized chirped GMR filter provides sharp transmission dips at resonant wavelengths with a filter bandwidth of approximately 4.2 nm and 0.78 nm when respectively applied to TE and TM polarized light under normal incidence. Gradually sweeping the chirped GMR filter makes it possible to monotonically sweep through resonant wavelengths from 500 to 700 nm, while maintaining stable filter bandwidth and transmission intensity. The optical spectrum of the incoming light can then be reconstructed accordingly. The same device concept can be further applied for near-infrared spectral region. We recently demonstrated a chirped GMR filter to discriminate telecom o-band wavelengths with a filter bandwidth of 0.743 nm. It can be applied as a dispersive device to enable optical spectroscopy in a cost-effective manner.



Keywords: Guided mode resonance filter; Laser interference lithography; Optical spectrometer

Enhanced Second Harmonic Generation by Metallic Quantum Wells and Metasurfaces

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A key challenge for optical circuits is the ability to integrate nonlinear optical signal processing components such as optical modulators and frequency mixers at the chip scale. Here, we introduce two methods to significantly improve the second harmonic generation (SHG) efficiency. The first method is to design a self-assembled metasurface, possessing two independently tunable resonances for both fundamental and SHG frequencies. The second method is to create an extremely high 2nd order susceptibility material system with approximately 1500 pm/V at NIR frequencies. This material system is enabled by coupled metallic quantum wells with film quality close to epitaxy. By combining the aforementioned metasurface, the power efficiency of SHG has achieved 10^{-4} at an incident pulse intensity of $10 GW/cm^2$, which is an improvement of several orders of magnitude compared to that of previous demonstrations from nonlinear surfaces at similar frequencies.

Chaos in Optical Vortex Laser formed by the Coherent Superposition of the Off-axis Resonant Modes

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Optical vortex laser is generated by the superposition of coherently phase-locked off-axis laser beamlets in a nearly hemi-spherical optical resonator with an intra-cavity spiral phase plate. Due to the broken azimuthal symmetry, this laser resonator rejects radiation to resonate on-axis but supports off-axis beamlets belonging to the multiple-pass transverse modes. Continuous wave vortex laser of ultra-high vortex purity (>99.99%) at a topological charge mirroring the intracavity spiral phase element is generated when the laser with Nd:YAG gain media is pumped by conventional diode laser without critical beam shaping1. Due to the multiple mode nature, the nonlinear interactions the electromagnetic fields are expected to cause instability when additional degrees of freedom are considered. By inserting a Cr:YAG saturable absorber into the laser cavity right after the gain crystal, we observe in vortex laser, the periodic-II oscillation, chimera state and periodic-VI oscillation when gradually increase pump power suggesting an intermittency route to chaos. Notably this is the first chaotic laser exhibiting stable vortex property. This novel resonator configuration not only provide an easy approach to generate intrinsic vortex laser with power scalability but also serves an useful platform to shape laser beams structurally, to study the laser dynamics and to combine radiations coherently.

Keywords: Optical vortex; Orbital angular momentum; Laser dynamics; Chaotic lasers, Nonlinear dynamics

P-channel Oxide-TFT Technology for Next Generation Flexible Electronics

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Amorphous oxide semiconductors represented by a-In-Ga-Zn-O (a-IGZO) based thin film transistor (TFT) are widely recognized as a technology to develop next generation high-performance flexible, and low-cost electronic devices because of its superior electrical properties such as high mobility (> 10 cm^2 $(Vs)^{-1}$), low-off current, low-voltage operation, in addition to the wide compatibility of processing such as dc sputtering and low-cost solution.

Next challenge is to develop high performance p-type oxide to realize *p*-channel TFT and the complimentary circuit. However, most oxides with excellent electrical property are all *n*-type due to the nature of electronic structure composed of n*s* orbital (*n* is quantum number) of cation for conduction band minimum (CBM) and 2*p* orbital of oxygen with strong directivity for valence band maximum (VBM). Therefore, hole transport is very sensitive to structural defect and disordering due to the VBM nature and is easily degraded. The absence of high-performance *p*-type oxide is largest drawback in oxide TFT technology and it is imperative to develop high performance *p*-type oxide material and *p*-channel TFTs.

Here I will present the material design for p-type oxide semiconductor and development of *p*-channel oxide-TFTs. Firstly, I will introduce amorphous oxide semiconductor and oxide TFT technology. Then I will present high-performance *p*-channel oxide-TFT and the oxide-based complimentary inverter applications.