## Mid-IR Optoelectronics: Materials and Devices
## Room Lecture Hall, Nielsen Hall - Session MIOMD-ThA2

## Metamaterials and Polaritons

**Moderator: Lukasz Sterczewski**, Wroclaw University of Science and Technology, Poland

3:50pm **MIOMD-ThA2-15 A 231 GHz Generation in High-Power Long-Wavelength Quantum Cascade Laser Operating at Room Temperature***, **Shohei Hayashi**, A. Ito, T. Dougakiuchi, M. Hitaka, A. Nakanishi, K. Fujita,* Hamamatsu Photonics K.K., Japan

The extension of the operating range on the low-frequency side down to <300 GHz in a terahertz nonlinear quantum cascade laser source based on intracavity frequency mixing in a long-wavelength (~13.7 µm), high-performance mid-infrared active region was achieved. The device was fabricated two section distributed feedback gratings with slightly different periods in order to obtain quite close dual mid-infrared laser pumps ($\lambda_1$ ~13.53 µm and $\lambda_2$ ~13.39 µm), achieving an emission at a frequency of 231 GHz as the difference frequency at room temperature. This is the lowest operating frequency in electrically pumped monolithic semiconductor laser sources operatable at room temperature.

4:10pm **MIOMD-ThA2-17 Mapping Surface Phonon Polaritons with Near-IR Light***, **Kiernan Arledge**,* The University of Oklahoma*; M. Meeker,* U.S. Naval Research Laboratory*; C. Ellis,* U.S. Naval Research Lab*; N. Sarabi, V. Whiteside,* The University of Oklahoma*; C. Kim, M. Kim, D. Ratchford, B. Weng,* U.S. Naval Research Laboratory*; J. Tischler,* The University of Oklahoma

Surface phonon polaritons (SPhPs) show great promise for tailoring light-matter interactions in systems below the diffraction limit. Investigating SPhP modes has mostly been pursued by measuring the energy resonances of these modes (i.e., eigenvalues). In other instances the study of SPhPs has been accomplished, by mapping electromagnetic fields (i.e., eigenstates) only at the material interface by atomic force assisted techniques, and in some limited cases measuring the three-dimensional fields using electron scattering. An accurate knowledge of SPhPs has been hindered by the lack of experimental techniques to map eigenstates in three dimensions, that are easy, cheap, and non-destructive. In this work we demonstrate the direct experimental measurement of infrared SPhPs eigenstates through three-dimensional Raman mapping. We apply this technique to map SPhPs in nanopillars of Indium Phosphide (InP). Furthermore, we demonstrate that SPhPs couple to bulk Raman modes through the material's polarizability and to a lesser extent via electron-phonon coupling. These observations provide a new method for measuring SPhP modes in nanostructured materials, as well as a novel way to investigate the physical phenomena involved in the coupling of bulk phonons to SPhPs.

4:30pm **MIOMD-ThA2-19 Surface Phonon Polariton Coupling to 4H SiC Triangular Gratings Produced by Two-Photon Polymerization***, **Nazli Rasouli Sarabi**, V. Whiteside,* University of Oklahoma*; E. Cleveland, E. Seabron, C. Ellis,* Naval Research Laboratory*; J. Tischler,* University of Oklahoma

Surface phonon polaritons (SPhPs) are a promising alternative to plasmon polaritons for localizing mid-IR to terahertz light in the nanoscale with low optical loss and higher quality factor. However, to excite SPhPs modes on the crystal surface, additional in-plane momentum needs to be added with methods such as grating coupling or evanescent fields from prism internal reflections. Previous work on square gratings has been limited by unwanted spatial frequencies and difficulty adding desired spatial frequencies, limiting their functionality [1]. Here, we propose using sinusoidal gratings as a Fourier surface to couple input light to surface modes and design the diffractive properties of the surface accordingly. Two-photon polymerization enables the creation of 2.5D metasurfaces of arbitrary shape on various materials.

In this work, we demonstrate the ability to produce metallic-like triangular one-dimensional gratings using a Photonic Professional GT2 Nanoscribe. We produced 4H SiC triangular gratings that support surface phonon polariton resonances within the Reststrahlen band of SiC between 797 cm-1 and 972 cm-1. Gratings were produced by etching a grayscale mask into the SiC substrate, resulting in triangular gratings with periods varying from 1 to 6.2 µm and heights varying from 0.3 to 2 µm. The Q factors of the resonances within the Reststrahlen band were in the range of 50-110, as expected from a low-loss phonon polar dielectric. To understand the origin of these surface phonon polariton resonances, we performed finite element calculations using COMSOL showing good agreement between theory and experiment.

[1] Caglayan, Humeyra, et al. "Near-infrared metatronic nanocircuits by design." Physical review letters 111.7 (2013): 073904.

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4:50pm **MIOMD-ThA2-21 Dielectric Resonances in Hexagonal Boron Nitride Nanodisks***, **Milad Nourbakhsh**,* University of Oklahoma*; H. Ling,* University of California at Los Angeles*; V. Whiteside,* University of Oklahoma*; A. Davoyan,* University of California at Los Angeles*; J. Tischler,* University of Oklahoma

High-index nanomaterials play a substantial role in the enhancement of optical effects based on electric and magnetic Mie resonances. While hexagonal boron nitride (hBN) has been heavily explored within the Reststrahlen bands (RB) as a natural hyperbolic phonon polariton material [1], close to the transversal optical modes outside the RB the dielectric constant has extremely high positive values. The latter provides the opportunity of producing dielectric resonators with very large dielectric constants. We report infrared Mie resonances of hBN nanodisks (NDs). Reflection and transmission spectra of hBN NDs of different sizes have been investigated to understand Mie resonances within the infrared range. We show the presence of a strong magnetic dipole resonance which energy and strength depends on the size and geometry of the hBN NDs as well as the substrate properties. Finite element modeling of the electromagnetic fields has been performed and is in excellent agreement with our experimental results. Numerical and experimental data have indicated that by selecting the proper substrate thickness and hBN NDs radius, much more prominent Mie resonances are achieved. Mie resonances provide an opportunity to easily manipulate light confinement for the design of optical devices such as nanoresonators, nanolasers, highly efficient metasurfaces and ultrafast metadevices.

[1] Caldwell, Joshua D., et al. "Sub-diffractional volume-confined polaritons in the natural hyperbolic material hexagonal boron nitride." *Nature communications* 5.1 (2014): 5221.

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5:10pm **MIOMD-ThA2-23 Closing Remarks***,*

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