Tuesday Afternoon, August 8, 2023

Mid-IR Optoelectronics: Materials and Devices
Room Lecture Hall, Nielsen Hall - Session MIOMD-TuA2

Mid-IR Plasmonics

Moderator: Qijie Wang, Nanyang Technology University, Singapore

3:30pm **MIOMD-TuA2-13 All-Epitaxial Nanophotonic Architectures for Mid-Infrared Optoelectronics***, L. Nordin,* University of Texas at Austin*; A. Kamboj,* University of Delaware*; P. Petluru, M. Bergthold, Y. Wang, A. Muhowski, **Daniel Wasserman**,* University of Texas at Austin **INVITED**

The mid-infrared (mid-IR) provides a design space where a wide range of engineered and intrinsic light matter interactions can be harnessed to develop a new generation of optical materials and devices. In particular, the highly-doped semiconductor class of materials offers an intriguing opportunity to control the permittivity of epitaxially-grown semiconductors, and can serve as low-index dielectrics, epsilon-near-zero materials, or even as plasmonic materials. Because these materials can be directly integrated with epitaxially-grown optoelectronic device active regions, there exists an opportunity to develop new mid-IR device architectures leveraging co-design of optical and electronic properties, all in a monolithic material system.

In this presentation I will discuss recent results showing strongly enhanced performance of mid-IR structures and devices leveraging all-epitaxial photonic enhancement of response, including distributed Bragg reflectors, leaky cavity LEDs and detectors, guided mode LEDs and detectors, and plasmonic infrared detectors, operating across the mid-infrared. I will present the opportunities and challenges for these new device architectures, and discuss potential future approaches for further enhancement and systems integration.

4:00pm **MIOMD-TuA2-16 Strategies for Electrical Tuning of Thermal Emissivity in Metamaterials***, B. Shrewsbury, A. Ghanekar, R. Audhkhasi, M. Sakib, **Michelle Lynn Povinelli**,* University of Southern California **INVITED**

Achieving tunable control over the thermal emission spectrum of materials is expected to enable new possibilities in applications including thermophotovoltaics, waste heat recycling, and infrared communication and sensing. In recent work, we have introduced several strategies for achieving electrical control over thermal emission based on resonant coupling and symmetry breaking in infrared metamaterials.

In one thrust of our work, we consider control over emissivity amplitude. We employ metamaterials comprised of several, coupled resonators in each unit cell. By tuning the dimensions of each resonator, we can arrange for either a bright mode (one that couples to normally incident light) or a dark mode (one that does not) to fall within a specified region of the spectrum. This leads to several possibilities for spectral control. In an exemplar strategy, we consider two, initially bright modes that couple to form a dark mode. At zero applied voltage, the system is mirror symmetric, and the dark mode does not produce any observable feature in the emission spectrum. When a voltage is applied to tune the refractive index in a portion of the unit cell, mirror symmetry is broken. The formerly dark mode becomes bright, switching on an emissive peak. We present design strategies for implementing this concept within both graphene and III-V semiconductor platforms.

In a second thrust, we consider control over directionality of thermal emission. In this case, we consider a metamaterial based on weakly coupled resonators, which give rise to a nearly flat photonic band. We then consider the effect of a small index perturbation of the refractive index of the structure. We show that for fixed wavelength, the flatness of the photonic band magnifies the change in angle for emitted radiation. We present several practical designs for realizing this effect in a III-V semiconductor platform.

4:30pm **MIOMD-TuA2-19 Nonlocal Effects in Heavily Doped Semiconductor***, P. Loren,* University of Montpellier, France*; E. Sakat,* Université Paris-Saclay, CNRS, C2N, 91120 Palaiseau, France*; J. Hugonin,* Université Paris-Saclay, CNRS, Laboratoire Charles Fabry, 91127 Palaiseau, France*; L. Cerutti, F. Gonzalez-Posada,* IES, Univ Montpellier, UMR CNRS 5214, Montpellier, France*; A. Moreau,* Université Clermont Auvergne, CNRS, SIGMA Clermont, Institut Pascal, F-63000 Clermont-Ferrand, France*; **Thierry Taliercio**,* IES, Univ Montpellier, UMR CNRS 5214, Montpellier, France

The Drude model is the most adapted model to describe the optical properties of metal and nano-antennas. Unfortunately, it starts to fail when the size of the nanostructures becomes small enough, that is a few nanometers for noble metals or a few tens of nanometers in the case of heavily doped semiconductors. It is then necessary to consider a nonlocal susceptibility tensor to describe accurately the optical properties of these metallic nanostructures. The best-suited approaches are the semi-classical quantum model [1] or the hydrodynamic Drude model (HDM). HDM can describe accurately the ultra-confined light of the plasmonic mode by the introduction of an electron quantum pressure in the equation of motion of the free electron gas.[2] It is particularly well adapted to be implemented in electromagnetic modeling. In this work, we compared experimental measurements of the volume plasmon modes with HDM.

[1] L. Wendler and E. Kändler, Phys. Status Solidi B 177, 9 (1993).

[2] E. Sakat, A. Moreau and J.-P. Hugonin, Phys. Rev. B 103, 235422 (2021).

4:50pm **MIOMD-TuA2-21 Low Doping Level and Carrier Lifetime Measurements in InAs with a Novel THz Characterization Technique***, **Julien Guise**, S. Blin, T. Taliercio,* Univ. of Montpellier, Montpellier, France

In this abstract, we present a novel, contactless opto-THz technique for measuring low doping levels and carrier lifetime in InAs. Preliminary studies proved that THz waves can be modulated using an optically-pumped InAs slab [1]. This optically-driven modulation is efficient in the 0.75–1.1-THz frequency band because of its vicinity with the plasma frequency of electrons, that leads to a strong dependence of the real and imaginary parts of the dielectric permittivity of InAs on free carrier density, the latter being strongly increased using optical pumping. Additionally, without any optical pumping, we show that n-type doping levels around 1016 cm-3 could be measured thanks to THz transmission measurements analyzed using a single-variable Drude-Lorentz model, as shown in Fig. 1(a), thus offering an original and accurate technique to measure very low doping levels. Using an amplitude- modulated optical pump, we could also easily retrieve the effective carrier lifetime by measuring the transmission of a THz probe signal, as shown in Fig. 1(b).

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