Thin Films Division
Room B131 - Session TF2-WeM

Thin Film Late News Session

Moderator: Virginia Wheeler, U.S. Naval Research Laboratory

11:00am **TF2-WeM10 Peter Mark Memorial Award Lecture: Molecular Beam Epitaxial Growth of Novel Plasmonic Materials: Heavily-doped Semiconductors and Topological Insulators***, Stephanie Law*[1]*,* University of Delaware **INVITED**

Plasmonic devices have great potential to advance the science and technology of photonics by confining light to subwavelength volumes. Traditional plasmonic devices in the visible spectral range have been made using metals like gold, silver, and aluminum. However, in order to create plasmonic devices at infrared and terahertz frequencies, we must look to alternative materials and heterostructures. In this talk, I will discuss our recent results on the molecular beam epiatxy growth of heavily-doped semiconductors for infrared plasmonics and topological insulators for terahertz plasmonics. We find that the morphology of heavily-doped semiconductors is significantly improved with the use of a bismuth surfactant. These improved materials are then incorporated into layered heterostructures that function as infrared hyperbolic metamaterials. These hyperbolic metamaterials show large mode indices and relatively high quality factor simultaneously, laying the groundwork for new infrared plasmonic devices. In addition to our work on semiconductors, I will also discuss our efforts on the growth of topological insulators (TIs) for terhertz plasmonics. We have found that the unintentional doping density can be reduced by a factor of two in TI thin films by growing a trivially-insulating lattice-matched buffer layer between the film and the substrate. These films can then be used as terahertz plasmonic films, which are then able to confine light into spaces 200 times smaller than the free space wavelength. Finally, I will discuss our recent efforts to grow self-assembled TI nanoparticles for use as quantum dots.

11:40am **TF2-WeM12 Impact of Interface Quality on the Strength of Volume Plasmon Polaritons in Hyperbolic Metamaterials***, Patrick Sohr, D. Wei,* University of Delaware*; S. Tomasulo, M.K. Yakes,* U.S. Naval Research Laboratory*; S. Law,* University of Delaware

In this work, we investigate doped and undoped semiconductors as alternative materials for hyperbolic metamaterials (HMMs) for applications in the mid to long wave infrared regimes. HMMs are artificial materials composed of subwavelength metallic and dielectric structures. In this work, we focus on layered HMMs, where the metal and dielectric layers are deposited on top of one another. These materials are highly anisotropic with a positive permittivity along one axis and a negative permittivity along the perpendicular axis. This behavior results in an open hyperbolic isofrequency surface, which is theoretically capable of supporting infinitely large wavevectors and a large photonic density of states. These materials have the potential to increase the emission rate of radiative emitters and permit for subwavelength imaging. These capabilities and others have made HMMs an interesting area of study for the fields of optics and optoelectronics.

Initially, HMMs were made using traditional metals (i.e. gold and silver) and paired with traditional dielectrics (i.e. silica and alumina). These materials have been shown to work exceptionally well in the visible to near infrared range. However, in the mid- to long wave infrared, these materials are no longer viable, and an alternative material system is required. One alternative is using doped and undoped semiconductors as the metallic and dielectric layers, respectively. Not only are semiconductors a promising material for the infrared, but also allow for easy integration with current optoelectronic devices.

In this work, we investigate three material systems for use as a semiconductor HMM: Si:InAs/AlSb, Si:InAs/GaSb, and Si:InGaAs/InAlAs. These materials are all grown by molecular beam epitaxy and characterized using Fourier Transform Infrared Spectroscopy. We show that the quality of the high wavevector modes is strongly dependent on the conduction band offset at the interface of the metal and dielectric layers. The Si:InAs/AlSb, which has the largest conduction band offset, exhibits the strongest and highest quality modes. While the Si:InGaAs/InAlAs and Si:InAs/GaSb, which have smaller conduction band offsets, exhibit weaker modes. This is due to the large wavevector modes within the HMM being comprised of coupled surface plasmon polaritons (SPPs) that exist at the interface of the metal and dielectric layers. When the electronic confinement at the interface is weak, the SPPs are less confined and do not couple as efficiently. Now that we have shown that we can grow high quality semiconductor HMMs, we can investigate some of their phenomenon in the infrared regime.

12:00pm **TF2-WeM13 Transparent Microelectrode Arrays made by Ion Beam Assisted Deposition for Neuronal Cell *in vitro* Recordings***, Tomi Ryynänen,* Tampere University, Finland*; R. Mzezewa, E. Meriläinen, T. Hyvärinen, J. Lekkala, S. Narkilahti, P. Kallio,* Tampere University

Microelectrode arrays (MEAs) are a common measurement platform in various biological *in vitro* studies where neuronal cells or cardiomyocytes are applied e.g. for drug screening, toxicity testing, cell model development or simply for increasing understanding of cell behavior. The field potential or impedimetric measurements, or stimulation performed with MEA are usually complemented with fluorescence imaging or microscopic inspection while or after the MEA recordings. The use of an inverted microscope is preferred, as imaging from the top side is often impossible because of the cell culturing medium and its reservoir placed on top of the MEA. With the inverted microscope there exists, however, another challenge. Typically, the tracks and the electrodes of the MEA are opaque and thus they prevent the full visibility of the cells from the bottom side. Partial solution is to make the tracks from transparent indium tin oxide (ITO) material. However, ITO electrodes are rare, simply because of their relatively high impedance and noise level. Instead, opaque low impedance Pt black or titanium nitride (TiN) electrodes are usually used with ITO tracks. Transparent low impedance graphene or conducting polymer electrodes have been demonstrated, but usually with challenges related to the ease of fabrication and stability. A recent approach is to use a very thin TiN layer made by atomic layer deposition (ALD) [1] or reactive sputtering [2] in the electrodes. The idea is to take benefit from TiN's columnar structure and thus capability of decreasing impedance, but still maintain the transparency, at least to some extent.

In this study, we show that ion beam assisted electron beam deposition (IBAD) is a valid alternative for sputtering and ALD in depositing both transparent ITO tracks and very thin transparent TiN layers for the MEA electrodes. We evaluate the performance of different combinations of ITO tracks and ITO or TiN electrodes, both from imaging and impedance point of view. In the first version, both tracks and electrodes were made of ITO to guarantee full transparency and thus optimal imaging capability. In the 2nd version, ITO electrodes were coated with thin TiN layer to decrease impedance but still maintain (partial) transparency. In the third version the measurement capability was optimized by thick opaque TiN electrodes. The optical transmission and electrical impedance of these three versions were characterized and the biocompatibility of the MEAs was verified by cell experiments with human embryonic stem cell-derived (hESC) neuronal cells.

[1] Ryynänen et al. doi: 10.3389/fnins.2019.00226

[2] Mierzejewski et al. doi: 10.3389/conf.fncel.2018.38.00027

[1] **Peter Mark Memorial Award Winner**

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