Mid-IR Optoelectronics: Materials and Devices
Room Lecture Hall, Nielsen Hall - Session MIOMD-ThM2

Detectors II
Moderator: David Ting, NASA Jet Propulsion Laboratory

10:30am **MIOMD-ThM2-14 Top-Illuminated Mid-IR HgTe Colloidal Quantum Dot Photodiodes*, John Peterson,*** *P. Guyot-Sionnest,* The University of Chicago

Colloidal quantum dots offer an inexpensive, solution-processed alternative to conventional, crystalline material devices for mid-infrared photodetection. pn-junction devices using HgTe quantum dots previously reached the background limit at cryogenic temperatures. These devices have since shown increased effective operating temperatures. [1] [2] For use in thermal imaging arrays, devices must be developed which are illuminated from the top.

The focus of this work is to understand and improve the performance of top-illuminated HgTe quantum dot photodiodes. Signal collection is a function of series resistance, diffusion length, and thin film absorption, and all can be improved separately for higher operating temperatures. We show results with a bottom n-type reflector contact, varying thicknesses of HgTe films of different mobility and doping profile and a semi-transparent metallic top electrode, made in a process compatible with integration into silicon readout chips. We also show an analysis of the temperature and photon flux dependence of the diode current, to gain insight into the dominant recombination mechanisms present in the device and the nature of the shunt resistance.

10:50am **MIOMD-ThM2-16 Synthesis of HgTe Colloidal Quantum Dots and Processing of Films to Maximize Photodetector Performance*, Philippe Guyot-Sionnest,*** University of Chicago

Since 2011, HgTe colloidal quantum dots have been researched for infrared photodetection in the MWIR,[1] but also in the SWIR and LWIR. They are readily tunable in the MWIR by controlling the size around 12 nm as shown in Fig. (a). The detector performances are still below those of single crystal and epitaxial materials, but the solution processing promises high throughput and low-cost fabrication of simple detectors and imagers. Our goal is to raise the performance of 4.5 microns HgTe quantum dot at 300K to match polycrystalline PbSe ($D^*=10^{10}$Jones), for fair and fast thermal imaging at room temperature, and another related goal is to raise the BLIP temperature to thermolelectric temperatures.

This presentation focuses on the measurements of optical absorption, carrier mobility, and carrier lifetime of MWIR HgTe colloidal quantum dots, and how these properties inform the best possible performance achievable. Simple experimental methods based on photoconductors, as shown in Fig. (b), allow to obtain these properties.[2] Then we distinguish film preparations that use non-polar inks or polar inks of quantum dots.While both can give similar carrier mobility after mild annealing, the carrier lifetime is retained in one instance, while the carrier lifetime is shortened by trapping in the other. Such a study indicates clearly which is the better process, and leads to improved device performances as shown in Fig (c).

11:10am **MIOMD-ThM2-18 Exploring Quantum Dots/Graphene van der Waals Heterostructures for Uncooled SWIR-MWIR Detection*, Judy Wu,*** University of Kansas

Semiconductor quantum dots/graphene (QD/Gr) heterostructures provide a quantum sensor scheme for photodetection and have witnessed remarkable progress in broadband photodetection. The QD/Gr photodetectors take advantages of the quantum confinement in QDs for spectral tunability and that in graphene for superior charge mobility to enable a high photoconductive gains or high photoresponsivity. A key question on whether high detectivity (D*) may be achieved in uncooled QD/Gr photodetectors in infrared (IR) spectrum is whether thermal noise in narrow bandgap semiconductor QDs in the QD/Gr photodetectors would degrade the detector performance in a similar way to conventional IR detectors based on semiconductor films and therefore demand cryogenic cooling to reduce the thermal noise. In order to answer this question, this talk presents our recent investigation on the noise origin of the QD/Gr heterostructures in the short-wave to middle-wave (SWIR-MWIR) spectra.Interestingly, it is found to be dominated by the noise in graphene either in dark or illuminated by SWIR-MWIR illumination. Furthermore, it has been found that the narrow-bandgap semiconductor QDs may be designed to reduce the noise towards the intrinsic limit in graphene by shifting its Fermi energy towards the Dirac point. Through development of atomic-scale surface and interface engineering approaches for optimize QD/Gr interface, uncooled $D^* > 10^{11}$ Jones at wavelengths of 2.25-3.25 mm has been achieved. This result reveals a different noise origin in the QD/Gr heterostructures, which is not directly affected by the thermal noise in narrow-bandgap semiconductor QDs. Therefore, QD/Grheterostructures may provide a promising low-cost, scalable scheme for uncooled SWIR-MWIR detection.

11:30am **MIOMD-ThM2-20 Core-Shell Pbse/CdSe Quantum Dot Mid-Infrared Photoconductor*, Milad Rastkar Mirzaei,*** *Z. Shi,* University of Oklahoma

Reducing Size, Weight, Power consumption, and Cost (SWaP+C) while maintaining good range and resolution has been the key goal for focal plane array (FPA) imagers. In mid-wave infrared (MWIR), a low SWaP+C imager with fast response time is highly desirable for many applications such as small unmanned aerial vehicles, smart munitions, and missile defense. Elimination of bulky and expensive cryogenic cooling systems and monolithic integration on Si readout integrated circuitry (ROIC) to reduce fabrication cost and to increase yield become two essential requirements for low SWaP+C MWIR imagers. Polycrystalline IV-VI semiconductor PbSe photoconductor (PC) meets both requirements and thus has been used by for years. However, one key challenge for the current PbSe PC FPA is the inhomogeneity of polycrystalline film which requires ROIC to perform non-uniformity correction on pixels and thus increases the power consumption and cost.

In this study, we report a novel threading core-shell PbSe/CdSe quantum dots (QDs) (QD Shish Kebab) room-temperature MWIR detector with much-improved homogeneity. The detector is grown on a SiO_2/Si substrate which enables monolithic integration of FPA on Si ROIC. We have optimized the QDPC's layer thickness, Core to shell ratio, and the total number of layers to improve its performance. The cutoff wavelengths can be tuned with different QD sizes.

To evaluate the performance of the QDPC, we have performed various characterization measurements, including current-voltage (IV) measurements, and blackbody radiometric measurements. The charge separation model is used to explain the QD 3-dimensional (3D) Shish Kebab detector structure.

The successful demonstration of our 3D network Core-Shell PbSe/CdSe nano-structured Photoconductor with improved homogeneity will have significant implications for many applications including large-format FPA monolithically integrated on Si ROIC with small pixel size.

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Author Index

Bold page numbers indicate presenter