# Tuesday Evening Poster Session, August 8, 2023

## Mid-IR Optoelectronics: Materials and Devices
## Room Great Hall, Sam Noble Museum - Session MIOMD-TuP

## Mid-IR Optoelectronics: Materials and Devices Poster Session

**MIOMD-TuP-1 Temperature Dependence of the Infrared Dielectric Function and the Direct Band Gap of InSb from 25 to 800 K**, ***Sonam Yadav***, New Mexico State University

In experiment, the infrared dielectric function of InSb in the region of the direct band gap at temperatures from 77 to 725 K using Fourier-transform infrared spectroscopic ellipsometry is determined. At the highest temperatures, the free carrier concentration due to thermally excited electron-hole pairs becomes very large and the Fermi level is above the conduction band minimum. The observed band gap increases again at 600 K (Burstein-Moss shift).

Theoretically, the temperature dependence of the chemical potential $\mu$ for an ideal intrinsic semiconductor (InSb) at fixed temperatures is calculated by using Polylogarithm forms of FD integrals from 25 K to 800 K. It is known that at absolute zero, the chemical potential ($\mu$) is equal to the Fermi energy ($\varepsilon_f$). $\mu$ versus T is plotted for Degenerate and Non-Degenerate case (this calculation assumes parabolic bands, a constant band gap, and constant effective masses). On comparing both graphs we can see at higher temperature degenerate graph goes up (deviate up) but for non-degenerate case, it remains linear. Due to the small electron to hole mass ratio, the optical activation energy (OAE, i.e., the experimental band gap measured with transmission or ellipsometry measurements) is almost the same as the chemical potential, once μ is larger than the band gap (above about 400 K). It is apparent that there is a thermal Burstein-Moss shift for temperatures above 400 K, because the chemical potential and the OAE are larger than the intrinsic band gap.

**MIOMD-TuP-3 Sb-based Mid-Wave Infrared Laser Arrays**, ***Rowel Go***, *A. Lu, M. Suttinger,* Air Force Research Laboratory

Mid-wave infrared lasers have advanced in both spectral coverage and power level in the past decade. Particularly, Sb-based semiconductor laser structures are of interests for many applications such as remote sensing, direct diode pump sources, and defense countermeasures. Here we report high power diode laser arrays using these laser structures. The laser structures as shown in Fig 1. were grown using molecular beam epitaxy on GaSb substrates with designed emission wavelengths of 2.0µm, 2.4µm, and 2.7µm. All structures share the same lattice-matched AlGaAsSb quaternary cladding doped with Te for n-type and Be for p-type clad layers. The waveguide consists of lattice-matched quaternary or quinary alloy and compressively strained InGaAsSb quantum wells laced at the center with inter-well spacings. Changing in wavelength is controlled by adjusting In content in the waveguide. Single and four-bar stack arrays were processed, fabricated, and packaged with water-cooled microchannel coolers. Some of the laser performance results tested in various conditions are shown in Fig 2.

**MIOMD-TuP-5 Carrier Concentration-Dependent Optical Properties of Narrow Gap Semiconductors**, ***Yixuan Shen***, *R. Yang, M. Santos,* University of Oklahoma

This work provides a comprehensive assessment of the optical properties of narrow bandgap semiconductors based on the k.p method [1] across a wide range of carrier concentrations and wavelengths. Based on a commonly used two-band model [2] and a less explored three-band model that include the spin-orbit split-off band, the refractive index and absorption coefficient due to free-carrier absorption are evaluated and compared with experimental data to assess their suitability for different scenarios. It is found that the values of electron energy based on the two models can substantially differ as the carrier concentration is increased. Fig. 1 shows the energy calculations for InAs, with the resulting effective masses shown in Fig. 2. The refractive index and absorption coefficient calculated from the two models will have some differences that depend on the carrier concentration. The results provide a guideline for selecting the appropriate model in different wavelength and carrier concentration ranges for various applications. The attained results may help with the optimization of interband cascade laser performance and other applications, and lead to improved device performance and more accurate measurements.

This work was partially supported by NSF (No. ECCS-1931193) and OCAST (AR21-024).

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**MIOMD-TuP-7 Tuning the Plasmonic Response of Heavily-Doped Semiconductors in Epsilon-Near-Zero Regime**, *P. Fehlen,* French-german research institute of Saint-Louis, France; *J. Guise,* University of Montpellier, France; *G. Thomas,* French-german research institute of Saint-Louis, France; *F. Gonzalez-Posada, J. Rodriguez, L. Cerutti,* University of Montpellier, France; *D. Spitzer,* French-german research institute of Saint-Louis, France; ***Thierry Taliercio***, University of Montpellier, France

Epsilon-near-zero (ENZ) materials display vanishing permittivity at precise frequencies, e.g., plasma frequency ωp. They exhibit several peculiar properties such as a unique field enhancement or ultrafast nonlinear efficiencies, and will be useful in the field of integrated Photonics. Heavily doped semiconductors have a tunable ENZ regime over the infrared spectral range by adjusting their doping level and thus their plasma frequency ωp. In this work, we investigate the correlation between the localized surface plasmon-polariton resonance and the nano-antenna size within a metal-insulator-metal structure composed of heavily-doped semiconductor InAsSb:Si. In this study, while the metals have a high plasma frequency ωp1, the insulator is also doped InAsSb:Si at lower plasma frequency ωp2. In doing so, we uncover the origin of the resonance pinning, which has been previously mentioned in the literature, as the spacer permittivity approaches zero [1]. Plus, we demonstrate that doping is an excellent additional degree of freedom to engineer the optical response of plasmonic structures, especially in the ENZ regime where the response becomes nearly geometry-independent, and is rather dispersive dependent.

**MIOMD-TuP-9 Interfacial Misfit Dislocation Array Assisted MBE Growth of InSb Quantum well on InAs using AlInSb Buffer Layer**, ***Fatih Furkan Ince***, *A. Newell, T. Rotter, G. Balakrishnan,* University of New Mexico; *M. McCartney, D. Smith,* Arizona State University

Mid-wave infrared (MWIR) detectors are commonly used in medical devices, remote sensing, and spectroscopy. InSb-based infrared focal plane arrays (FPAs) offer spatial uniformity, temporal stability, scalability, and affordability. Type-II superlattices and metamorphic buffers are used to cover the MWIR spectrum and reach the long-wave infrared (LWIR) region. We propose using interfacial misfit dislocations to grow fully relaxed InSb on InAs substrate, and direct growth of AlxIn1-xSb buffer layers on InAs, for developing tunable InAsSb absorbers for MWIR and LWIR applications [1], [2].

In this presentation will discuss the interfacial misfit dislocation growth mode to form instantly relaxed buffer layer on top of InAs substrates. We analyze both directly grown AlInSb and InSb epilayers on InAs substrates using HR-XRD ω-2θ scans as well as reciprocal space mapping. HR-XRD results indicate a relaxation of 99.4% for InSb directly grown on InAs, and a slightly reduced value for the Al0.1In0.9Sb and Al0.2In0.8Sb epilayers. Reciprocal space mapping allows us to estimate the screw and mixed dislocation density for the layers. Additionally, TEM analysis shows the formation of misfit dislocation arrays at the AlInSb/InAs interface. We investigate InSb quantum wells grown with different AlxIn1-xSb barrier layers using photoluminescence (PL). We will present a comprehensive analysis of the buffer layers with respect to threading dislocation density using XRD scans and TEM images. Furthermore, we will provide a detailed analysis of the InSb QWs based on PL and TRPL results.

**MIOMD-TuP-11 High Efficiency Room Temperature 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. Photodiodes of size 1 mm by 1 mm made using HgTe quantum dots previously reached the background limit at cryogenic temperatures but suffered from a 30-fold decrease in signal near room temperature. This was attributed to a decreased carrier diffusion length at higher temperatures, where the thermal carrier concentration is high. An alternative explanation based on a simple circuit model suggests that it is instead due to the effects of a finite series resistance, coming mainly from the semitransparent indium tin oxide electrode.

Using microfabrication, devices were prepared which use an insulating polymer to restrict the active device area to 50 by 50 microns. This decrease in size increases the shunt resistance to be greater than the series resistance even at room temperature. It was also found to be important to employ a guard ring in the final design to only collect carriers within this restricted area, which limits crosstalk between nearby devices and allows one to measure the true resistance of the devices. As a result of these alterations, greater signal is collected, leading to 15% EQE and a four-fold improvement in the detectivity in excess of $10^9$ Jones near room temperature for photodiodes with a cutoff at 4 microns.

**MIOMD-TuP-13 Experimental Study of Band Offsets at the GeSn/SiGeSn Interface by Internal Photon Emission***, **Justin Rudie**, H. Tran, S. Amoah, S. Ojo,* University of Arkansas*; M. Shah,* University of Arkansas at Pine Bluff*; S. Yu,* University of Arkansas

In heterojunction semiconductor devices the band structure of the interfacing materials plays a pivotal role in the resulting device's performance and characteristics. Therefore, measuring and understanding the band offsets of emerging materials is crucial since the type of band alignment (Type I, Type II, Type III) and the magnitude of energy offsets determine the magnitude of the potential barriers, and thus, the possible carrier confinement in any resulting device. [1]

The band offsets between GeSn and SiGeSn in a quantum well photoconductor device were measured using internal photon emission (IPE). This technique was used as it is precise with values reported with sub millielectronvolt resolution and is not limited by surface depth penetration like many electron spectroscopy techniques.[1],[2] IPE is characterized by the product of a device's responsivity and energy of incident exciting photons. This product is known as quantum yield (Y) and is proportional to photon energy exceeding the energy threshold required for photocurrent generation from an emitter material to a collector material.[2] In the measurement of the GeSn/SiGeSn device it was determined that the band alignment was Type-1 with a VBO of 0.06 eV and a conduction band offset (CBO) of 0.02 eV.

**MIOMD-TuP-15 A Comparative Study of Ion-Implantation of As and B in GeSn Epilayers Grown on Si (001) by Chemical Vapor Deposition***, **Amoah Sylvester**, H. Stanchu, F. Yu,* University of Arkansas

Recently, direct band gap GeSn alloy semiconductors with Sn concentration above 6-8% have attracted considerable attention as a tunable mid- and near-infrared materials of group IV for light emitting and detection applications with the advantage of monolithic integration on Si substrate and CMOS compatibility [1]. Due to the low miscibility of Sn and Ge, Sn-rich metastable GeSn alloys are typically grown under non-equilibrium conditions, such as by chemical vapor deposition (CVD) and molecular beam epitaxy (MBE). With these techniques, *in-situ* doping is somehow limited, in particular for the fabrication of devices with laterally selected doping regions. Alternatively, *ex-situ* ion implantation is a commonly used process for engineering the structure and precise control of different dopant species in materials.

The poor thermal stability of Sn-rich GeSn materials imposes a low thermal budget for dopant activation. At elevated annealing temperatures, phase separation into thermodynamically favored elemental Ge and β-Sn is ubiquitous. Recently, an annealing study of ion-implantation of As in Ge have shown a 60% substitutional occupation of As atoms in the Ge lattice for annealing temperatures below 200 °C and almost 100% substitutional occupation at higher temperatures [2]. In this work, the implantation of As and B in GeSn epilayers is investigated under different conditions.

**MIOMD-TuP-17 Snowflakes Patterns Formation Enhances Performance of Nanostructure-based MWIR PbSe Photoconductive Detector***, **Richard Kim**, R. Dahl, J. Park,* OPTODIDOE/ITW Research and Development

We present a novel approach to fabricate a PbSe thin film photoconductive detector using the chemical bath deposition technique, resulting in the formation of various snowflakes-like patterns on the active area of the detector. Our findings reveal the presence of clusters of nanostructures, primarily nanoprisms, beneath the snowflakes patterns, which enhance the performance of the PbSe photoconductive detector. This is a new observation that has not been previously reported. Our investigations have shown that when snowflakes-like patterns appear on the surface of the detector's active region, a large number of PbSe nanostructures are formed within the PbSe thin film. We have also found a strong correlation between the size and compactness of the snowflakes patterns, and thus the nanostructures, and the performance of the PbSe photoconductive detector. As the snowflakes patterns get larger, the detection signal becomes stronger. We have examined changes in the microstructure and carrier concentrations resulting from sensitizing treatments such as oxygen and iodine. Our findings suggest that the snowflakes patterns are a direct evidence of the crystallization process. Finally, we have thoroughly examined the FTIR spectral response of the nanostructure-embedded PbSe photoconductive detector at various temperatures ranging from 77K to 340K.

**MIOMD-TuP-19 GaSb-based Interband Cascade Lasers with Hybrid Cladding Layers Operating in the 3-4 µm Wavelength Region***, Y. Shen, **Jeremy Massengale**, R. Yang, T. Mishima, M. Santos,* University of Oklahoma

We report the demonstration of interband cascade lasers (ICLs) [1] with hybrid cladding layers [2-4] in the 3-4 µm wavelength region. These ICLs were grown on GaSb substrates and employed $n^+$-doped $InAs_{0.91}Sb_{0.09}$ cladding layers and n-doped InAs/AlSb superlattice (SL) intermediate cladding layers. In contrast to a regular ICL with only SL cladding layers, an ICL with the hybrid cladding layers can have an enhanced optical confinement and improved thermal dissipation. A room temperature (RT) threshold current density ($J_{th}$) as low as 177 A/cm$^2$ was measured for a broad area device emitting at 3.28 µm (Fig. 1) with pulsed operation extending up to 390 K. The characteristic temperature ($T_0$) was nearly 60 K, which is the highest value among RT ICLs with similar lasing wavelengths. ICLs from two wafers grown later exhibited a RT pulsed $J_{th}$ as low as 151 A/cm$^2$ for emission near 3.82 µm (Fig. 2), which is comparable to the best ICLs with only SL cladding layers [5]. Considering the substantial deviations (>10%) in the grown layer thicknesses from the design values, it is expected that ICLs with hybrid cladding layers will have significantly better performance once the growth process is improved. Updated results will be reported at the conference.

**MIOMD-TuP-21 Halide Perovskite Material Development, Growth, and Characterization for Infrared Optoelectronics***, **Yash Mirchandani**,* Syrnatec

Syrnatec has developed innovative technology for the growth, characterization, and development of halide perovskites. The technology is based on a two-step solution process, which involves the deposition of a precursor film followed by annealing to form the perovskite.The precursor film was deposited using a novel spin-coating method that utilizes a mixture of $PbBr_2$ and CsBr in dimethyl sulfoxide (DMSO). The deposition was followed by annealing at a temperature of 150°C for 15 minutes to convert the precursor film to the perovskite.The synthesized $CsPbBr_3$ perovskite was characterized using various techniques such as X-ray diffraction, scanning electron microscopy, and photoluminescence spectroscopy. The X-ray diffraction patterns of the perovskite showed sharp diffraction peaks, indicating excellent crystallinity. The scanning electron microscopy images revealed that the perovskite had a well-defined morphology with a cubic shape. The photoluminescence spectra of the perovskite showed a narrow emission peak at around 510 nm, indicating a narrow bandgap of 2.25 eV and indicative of high quantum efficiency.The unique technology also enables the control of the crystal structure and morphology of the synthesized $CsPbBr_3$ perovskite. By adjusting the annealing temperature and time, we were able to obtain different crystal structures of the perovskite, including tetragonal and orthorhombic structures. We were also able to control the morphology of the perovskite by varying the concentration of the precursor solution.Our experiments demonstrated that the synthesized $CsPbBr_3$ perovskite has potential applications in United States optoelectronics. The photodetector showed excellent photoresponse with 23.4% external quantum efficiency and a fast response time of 40ms.Finally, this proposed technology will be having a potential for the large-scale production of $CsPbBr_3$perovskite for US infrared optoelectronic applications like solar cells, photodetectors, and light-emitting diodes. The technology will provide a simple and low-cost solution-based approach for the synthesis and growth of high-quality $CsPbBr_3$ perovskite with controlled crystal structure and morphology and will makes it a promising candidate for the commercialization of infrared optoelectronics applications in US.

**MIOMD-TuP-23 Infrared Endovascular Navigation for Enhanced Sensing and Treatment**, *D. DeVries, M. Salter, S. Balzora,* ***Linda Olafsen****, J. Olafsen, K. Schubert,* Baylor University*; S. Dayawansa, J. Huang,* Baylor Scott & White Health System

We present recent results toward development of an endovascular navigation system comprised of a programmable surgical wire with infrared (IR) emitters and detectors on the tip. This system is intended for enhanced sensing and medical treatment, particularly for remote treatment sites, including telemedicine. Successful demonstration of this system has the potential to enhance urgent care provided by field surgeons and medics, as well as to open opportunities for remote practitioners minimally to observe and provide expertise and maximally to operate or assist in the field by expertly guiding the wire. The proposed device has great potential (1) to enable imaging and sensing deeper in the head and body, (2) to increase the sensitivity of infrared measurements of biomarkers, (3) to result in more efficient and safer navigation of catheters and surgical instruments for treatment of aneurysms and other endovascular procedures, especially in remote settings, and (4) to reduce exposure of patient and surgeon to harmful radiation by employing ultrasound or infrared imaging techniques. This endovascular device uses wire made of a shape-memory alloy, such as Nitinol, to navigate arteries for treatment.Nitinol has prior FDA approval and a long record of biocompatibility, especially when an oxide and/or another passivating layer is applied. The wire is programmed to bend at temperatures above core body temperature and navigate arterial branches using current control.Blind navigation of wires by physical pushing can result in rupture of vessel walls with lethal consequences.Stents have been used to deploy deep brain stimulation devices, but no deep system for *in vivo* near-infrared spectroscopy exists.The ability to effectively insert and guide an infrared emitter to the brain for neurological monitoring and treatment would be of significant benefit in the operating room, particularly during cardiothoracic surgery or neurosurgery.

**MIOMD-TuP-25 Residual Gas Analysis of Reactions between Germane and Tin Tetrachloride for the Optimization (Si)GeSn CVD Growth**, ***Joshua M. Grant****, E. Yang, A. Golden, W. Du,* University of Arkansas*; B. Li,* Arktonics LLC*; S. Yu,* University of Arkansas

Since the introduction of (Si)GeSn alloys to the world of semiconductors for silicon based photonic applications, the material has become highly desired for both detectors and sources [1]. By capitalizing on the ability to tailor the band gap of the material by varying the Sn content, transforming an indirect bandgap material to a direct, holds great potential for Near to Mid-IR wavelength photonics. The growth of GeSn for devices and material study has been performed by Molecular Beam Epitaxy (MBE) and Chemical Vapor Deposition (CVD), with Plasma-enhanced Chemical Vapor Deposition (PECVD) and its low thermal requirements [2, 3] gaining popularity. The CVD growth of GeSn has been performed using the commercially available precursors Tin tetrachloride (SnCl4) and Germane (GeH4) [4]. To better understand the growth mechanisms of GeSn on a Si (100) substrates using $SnCl_4$ and $GeH_4$ during the CVD process, reactions between the two precursors was studied utilizing a differential pumping system for a 300 amu Residual Gas Analyzer (RGA) that was isolated from the CVD reactor. The focus of this talk will be to present the most recent findings from the mass spectra of the interactions between the two precursors.

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**MIOMD-TuP-27 Low Temperature Plasma Enhanced Growth of $Si_{1-x}Sn_x$ by Chemical Vapor Deposition**, ***Alexander Golden****, J. Grant, E. Yang, S. Acharya, S. Yu,* University of Arkansas

Thin films of Silicon-tin alloys ($Si_{1-x}Sn_x$) were grown on Si (001) substrate using low temperature plasma-enhanced chemical vapor deposition. These alloys have potential in the application of optoelectronic devices however their growth conditions have not been studied as thoroughly as similar GeSn materials [1]. Precursors like silane have a high breakdown temperature compared to the CMOS process and the solid solubility of Sn in Si is very low and is further complicated by segregation at higher temperatures. Therefore, the growth mechanism of $Si_{1-x}Sn_x$ needs to be better understood [2]. The thin film growth of $Si_{1-x}Sn_x$ in this work was accomplished by adjusting plasma intensity and controlling the precursor flow fractions. The film thickness was measured by Spectroscopic Ellipsometry, and the Sn incorporation and crystallinity were estimated using X-ray Diffraction measurements. In particular, an increase of Sn composition in the Si1-xSnx epilayers was concluded by observing the migration of the (004) peak towards the lower angles on the X-ray diffraction 2θ/ω scans, Figure 1, which corresponded to an overall improvement of Sn incorporation of more than 10% relative to the previous work. Moreover, a significant enhancement in material quality was concluded by comparing the line widths (FWHM) of the SiSn peak to those reported previously [3].

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**MIOMD-TuP-29 Long Wavelength Distributed Feedback Tapered Quantum Cascade Lasers**, *D. Pinto, B. Lendl,* TU Wien, Austria*; A. Baranov,* ***Kinjalk Kumar****,* Université de Montpellier, France

We present an investigation of tapered QCLs with taper angles between 0° and 3°. Tapered cavities benefit from bigger active zone volume, preserving the beam quality of the fundamental transverse mode [1]. The QCL was based on the InAs/AlSb material system emitting around 14-15 µm [2], where BTEX compounds exhibit strong absorption, making such laser source interesting for sensing applications. The active zone is composed of an InAs/AlSb superlattice sandwiched between undoped InAs spacers and highly-doped InAs cladding layers. The wafer grown by MBE on an InAs substrate was processed into deep mesa ridge lasers using optical photolithography and wet chemical etching. E-beam lithography and dry etching were employed to pattern Bragg gratings on top of the ridge waveguide, for single longitudinal mode operation. A gold layer was deposited to provide electrical contact.

In Fig. 1(a) a scanning-electron microscope image of the tapered devices is shown. The devices were tested and compared in terms of electrical and optical properties, and in terms of spectral purity. Single-longitudinal mode operation was obtained, with a side-mode suppression ratio (SMSR) greater than 15 dB. In Fig. 1(b), emission spectra of a straight QCL, measured at different temperatures in CW operation, are portrayed. In Fig. 1(c) voltage-light-current characteristics of the tapered devices are shown. Tapers with wider angles provide a greater power output. The different improvement of the slope efficiency is observed, which can be justified by the higher collection efficiency of the system towards higher taper angle devices. The larger front facet of tapered lasers reduces the divergence angle along the slow axis, allowing to collect more light. The far-field intensity profiles were measured in order to determine the beam divergence and estimate the devices brightness.

**MIOMD-TuP-31 Low-Loss Plasmonic Resonances in Heavily Doped InAs for Infrared Optoelectronic Integration**, ***Ethan Caudill****, C. Cailide,* University of Oklahoma*; M. Lloyd, J. Murphy,* Naval Research Laboratory*; K. Arledge, T. Mishima,* University of Oklahoma*; J. Nolde, J. Frantz, C. Ellis,* Naval Research Laboratory*; P. Weerasinghe, T. Golding,* Amethyst Research Inc.*; M. Santos, J. Tischler,* University of Oklahoma

Plasmonic resonances supported by traditional metals (e.g., gold, silver, and aluminum) have been used to enhance optoelectronic devices such as emitters and detectors. However, these materials are very lossy in the infrared region, hindering their use in actual devices that operate in the infrared. To overcome this issue, we use doped III-V semiconductors as a low-loss plasmonic material that can be easily integrated with traditional III-V infrared optoelectronic devices. Here we show that an InAs epilayer, when highly-doped with Tellurium (up to $10^{20}$ $cm^{-3}$), exhibits a plasma frequency corresponding to light at a free-space wavelength of 4.5 µm.

When a 1D grating with a period shorter than 5 µm is formed in the epilayer via dry etching, resonances at longer wavelengths (5.5 to 14 µm ) are observed with quality factors around 7 and absorption as high as 95%. Finite element electromagnetic models of the resonances show good agreement with our experimental results. This material is based upon work supported by the Office of the Undersecretary of Defense for Research and Engineering Basic Research Office STTR under Contract No. W911NF-21-P-0024. Disclaimer: The content of the information does not necessarily reflect the position or the policy of the Government, and no official endorsement should be inferred.

**MIOMD-TuP-33 Advancing Precise Control of Electromagnetic Radiation: An Innovative Nanophotonic Multilayer Structure for Mid-Infrared Applications***, **Masoumeh Nazari**, M. Banad, S. Sharif,* University of Oklahoma

The precise control of electromagnetic radiation within atmospheric windows holds significant importance in diverse applications, including solar energy harvesting [1] thermal regulation, and optical communication systems. In this study, we propose an innovative nanophotonic multilayer structure designed with a combination of graphene, polymer, and PbSe (lead selenide) materials to achieve accurate control over electromagnetic wave absorption in the mid-infrared (mid-IR) range.

Our research demonstrates that the carefully chosen materials, layer composition, number of layers, and optimized thickness yield a highly efficient structure with narrow band absorption capabilities across the entire mid-IR wavelength range. Moreover, we showcase the ability to manipulate the absorption range at each wavelength by applying a DC bias electric field to the graphene surfaces.

The proposed nanophotonic multilayer structure is composed of alternating layers of graphene, polymer, and PbSe, strategically leveraging the unique properties of each material as shown in figure 1. Graphene and polymer layers contribute exceptional electrical and optical characteristics, including high conductivity and broad spectral absorption. Meanwhile, PbSe exhibits remarkable properties in the mid-IR region, such as strong absorption and efficient thermal management. To enhance the absorption rate in the graphene layers, we incorporate a semi-infinite layer of gold as the substrate, effectively reflecting light in the mid-IR range.

This well-designed nanophotonic multilayer structure promises enhanced control over absorption rates and presents a promising avenue for advancing various applications reliant on precise electromagnetic radiation control in the mid-IR spectrum.

To design and evaluate the performance of the proposed structure, we employ rigorous electromagnetic simulations based on the finite-difference time-domain (FDTD) method in COMSOL and we combine it with the Micro-genetic algorithm to define the minimum thickness of each layer to find the optimized unique thickness for each wavelength. Next we modeled the conductivity of graphene using Kubo formula leading to electrical control of graphene's refractive index.

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