Development of High-Performance Graphene-HgCdTe Detector Technology for Mid-wave Infrared Applications

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Overview of Technology and Applications

• High performance detector technology being developed for sensing over mid-wave infrared (MWIR) band for NASA Earth Science applications.

• The graphene-based HgCdTe detector technology combines the best of both materials, enabling higher MWIR (2-5 μm) detection performance compared to photodetectors using only HgCdTe.

• Room temperature operation of HgCdTe-based detectors and arrays can provide significantly reduced size, weight, power and cost (SWaP-C) for MWIR sensing applications such as remote sensing and earth observation, e.g., in smaller satellite platforms.
Progression of Development Effort

- Program effort initially focused on device structure using MWIR-sensitive PbSe layer in contact with graphene.
- Interfacial barrier between absorbing material and graphene functions as a tunable rectifier.
- The graphene acts as a high mobility channel that whisks away carriers before they can recombine, further enhancing detector performance.

Initial graphene-enhanced MWIR detector design featuring PbSe absorber
HgCdTe has shown promise for development of MWIR detectors with improvements in carrier mobility and lifetime. In addition, HgCdTe layers can be grown using molecular-beam epitaxy (MBE), which yields greater precision in deposition of detector material structures leading to improved electro-optical / infrared performance.
Program Objective and Focus

**Objective:** Demonstrate graphene-based HgCdTe room temperature MWIR detectors and arrays through modeling, material development, and device optimization.

- Primary driver is the enablement of a scalable, low cost, low power, and small footprint infrared (IR) technology component that offers high performance for new earth observation measurement capabilities.
Graphene-HgCdTe detector structure composed of three principle layers:

1. **Gate (Si/CdTe):**
   - Si layer functioning as gate terminal provides electrical field aiding carrier transport

2. **Absorber (HgCdTe):**
   - Active optical layer where carrier photogeneration occurs

3. **Channel (graphene):**
   - High mobility, low noise graphene channel transfers photogenerated carriers to electrical readout
1. Carrier generation and separation:
   - Incident IR photons transmitted into HgCdTe absorber produce electron-hole pairs, or excitons

2. Carrier transport and injection:
   - Carriers then transported through absorber and injected into graphene

3. Carrier transport in graphene channel:
   - Injected carriers transported to and collected by readout integrated circuit (ROIC)
Modeling of HgCdTe-Graphene Detector

- Modeling approach built upon individual pieces forming comprehensive detector model.
  - Allows for design optimization
  - Collaboration with Prof. Avik Ghosh of UVA
- **Goal**: Derive electrical behavior from basic material parameters through simulation.
Materials Modeling Approach

• Materials modeling used to relate all properties of interest:
  – Current, photoexcitation, recombination velocity, carrier lifetime, noise, etc.
• We have initially considered PbSe material and are now focused on HgCdTe material modeling.
• HgCdTe-graphene modeled using charge carrier transfer method.
Bandgap Engineering of HgCdTe MWIR Detector

- Bandgap engineering of HgCdTe detector achievable through varying material device parameters.
- Hg$_{1-x}$Cd$_x$Te band structure most impacted by stoichiometry.
  - Stable bandgap at ~0.29 eV for Hg$_{0.7}$Cd$_{0.3}$Te for MWIR detection.

Band diagram for HgCdTe detector (top). Plots of $E_g$ as function of $T$ and $x$ for Hg$_{1-x}$Cd$_x$Te (below).
HgCdTe Mobility and Lifetime

- HgCdTe mobility highest for low Cd \((x)\) concentrations.
- Carrier lifetime likewise important for IR performance.
  - At higher temperatures Auger effect is dominating mechanism.

HgCdTe mobility as function of stoichiometry and temperature (*left*). Mobility vs. *T* for different stoichiometries (*center*). Various Auger lifetimes in HgCdTe plotted vs. temperature (*right*).
We are collaborating U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) for MBE growth and characterization of HgCdTe films on Si for graphene-enhanced MWIR detectors and focal plane arrays (FPAs).
Device Development / Testing at Albany Nanotech

- Also use facilities and tools available to us at Albany Nanotech, SUNY Polytechnic Institute for device development and testing of HgCdTe-graphene MWIR detector arrays.

Albany Nanotech campus in Albany, NY, where Magnolia Office is located
Summary: Graphene-HgCdTe MWIR Detector Technology

- HgCdTe-graphene MWIR detector technology is being developed for NASA Earth Science applications, combining best of both materials.
- Improvements in carrier mobility and lifetime in HgCdTe enable enhanced IR sensing performance.
- Goal is to demonstrate high performance HgCdTe-graphene-based room temperature MWIR (2-5 μm) detectors and FPAs with reduced SWaP-C to benefit variety of NASA ESTO applications.