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

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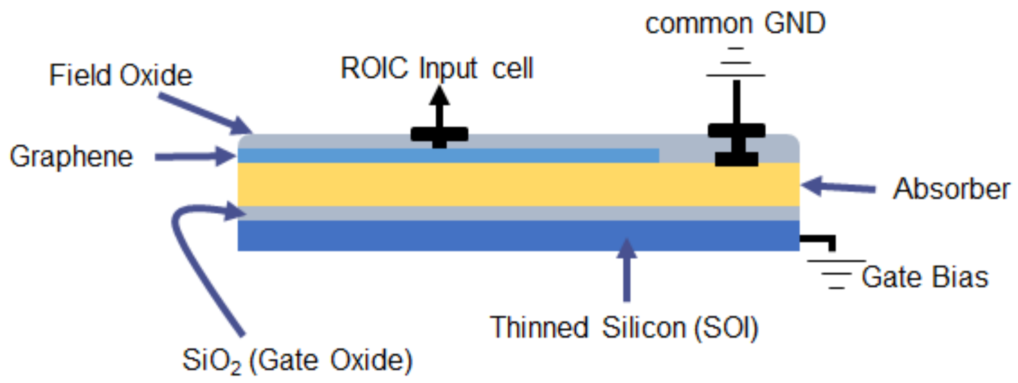
Overview of Technology and Applications

- 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.

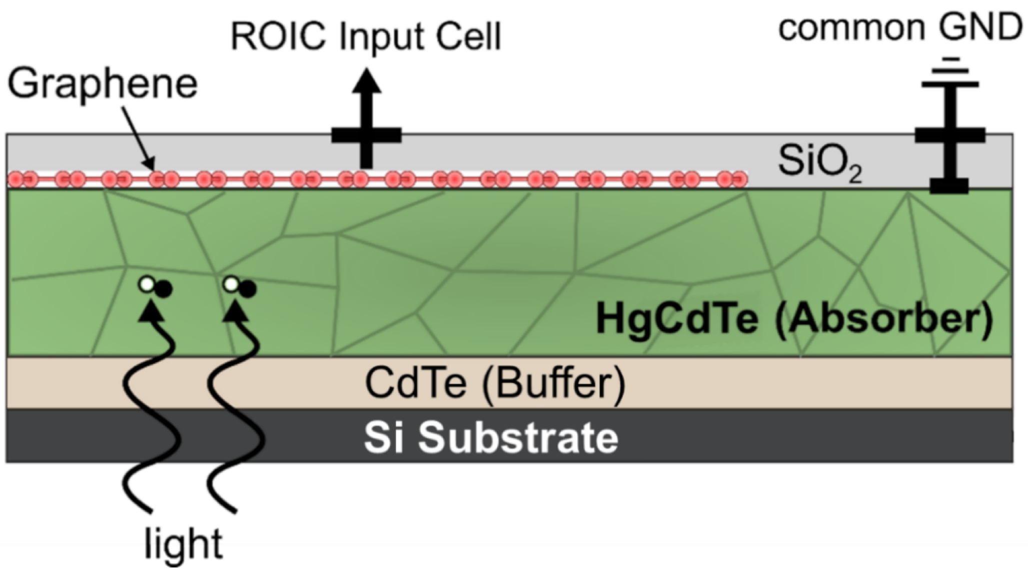
Progression of Development Effort



Initial graphene-enhanced MWIR detector design featuring PbSe absorber

- 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 tunable rectifier.
- The graphene acts as a high mobility channel that whisks away carriers before they can recombine, further enhancing detector performance.

HgCdTe-based Graphene-enhance MWIR Detector



HgCdTe graphene heterostructure based IR photodetector design

- 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.

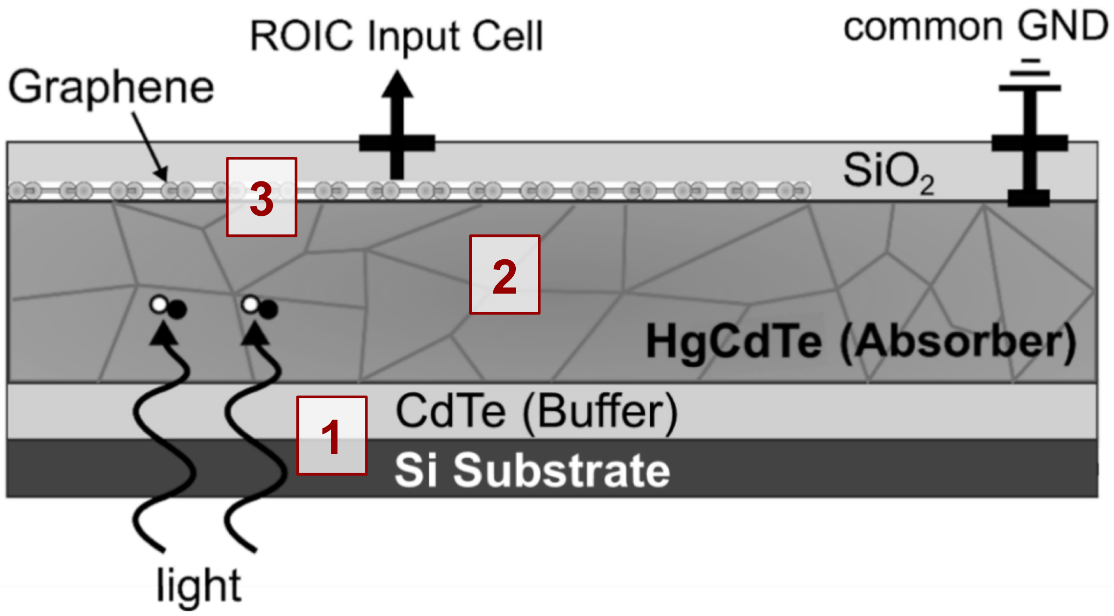
Program Objective and Focus

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.

MWIR Detector Material Structure

Graphene-HgCdTe detector structure composed of three principle layers:

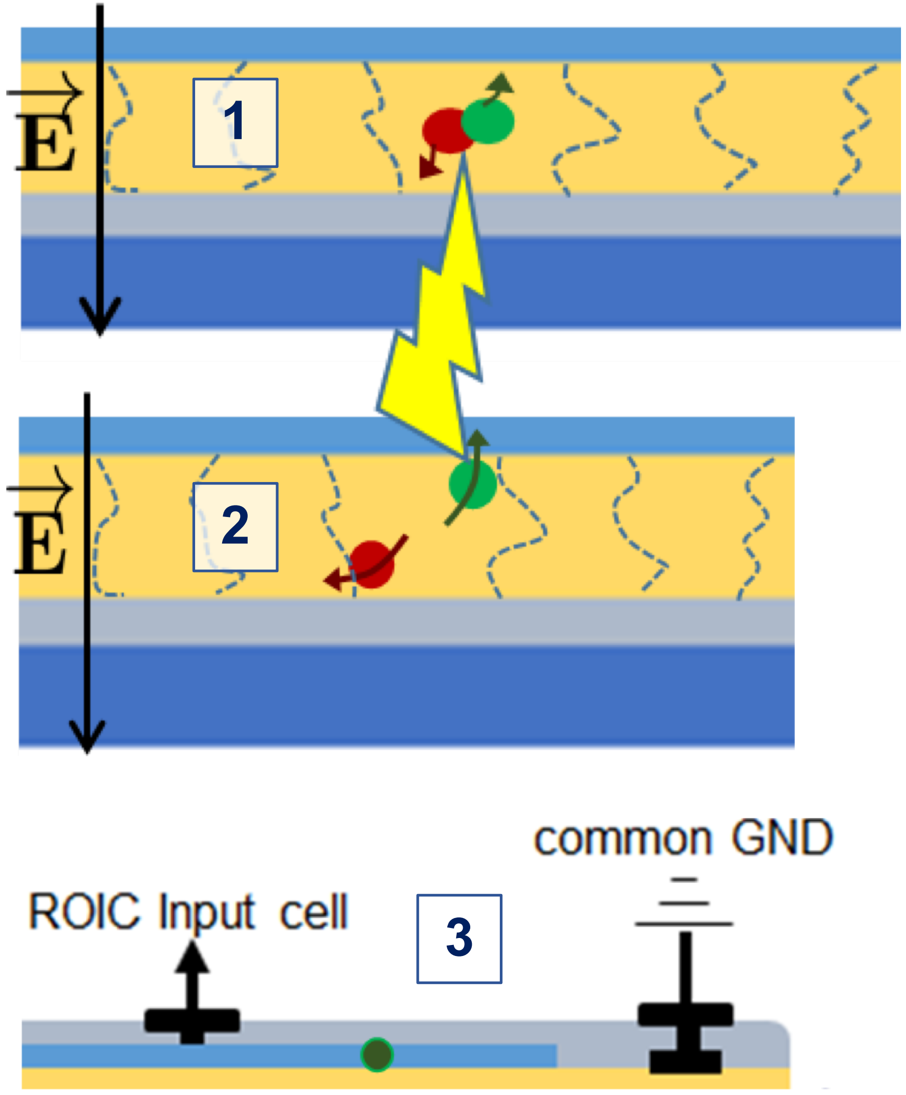


1. Gate (Si/CdTe):
- Si layer functioning as gate terminal provides electrical field aiding carrier transport

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

MWIR Detector Operating Principle



1. Carrier generation and separation:

- Incident IR photons transmitted into HgCdTe absorber produce electron-hole pairs, or excitons

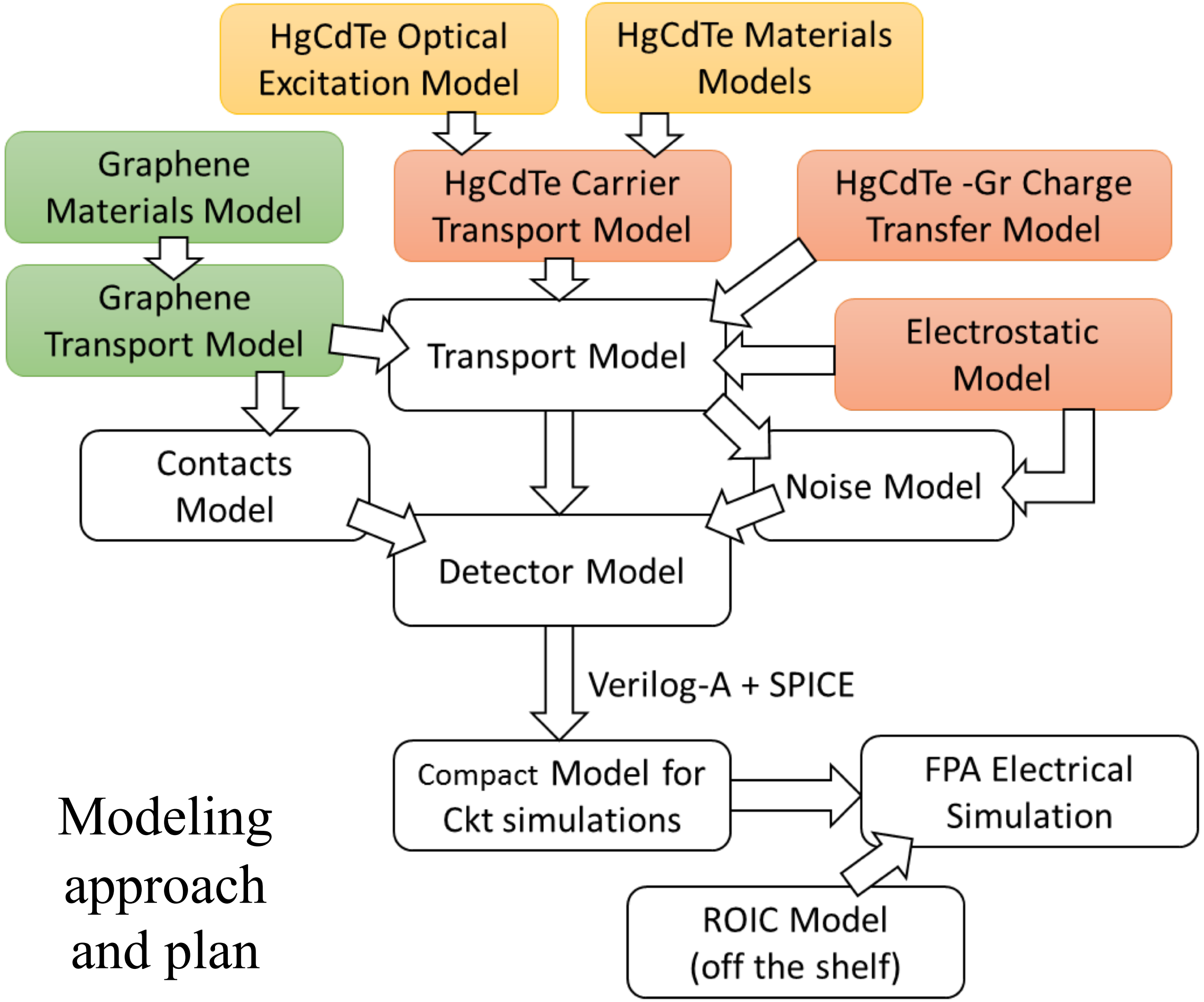
2. Carrier transport and injection:

- 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)

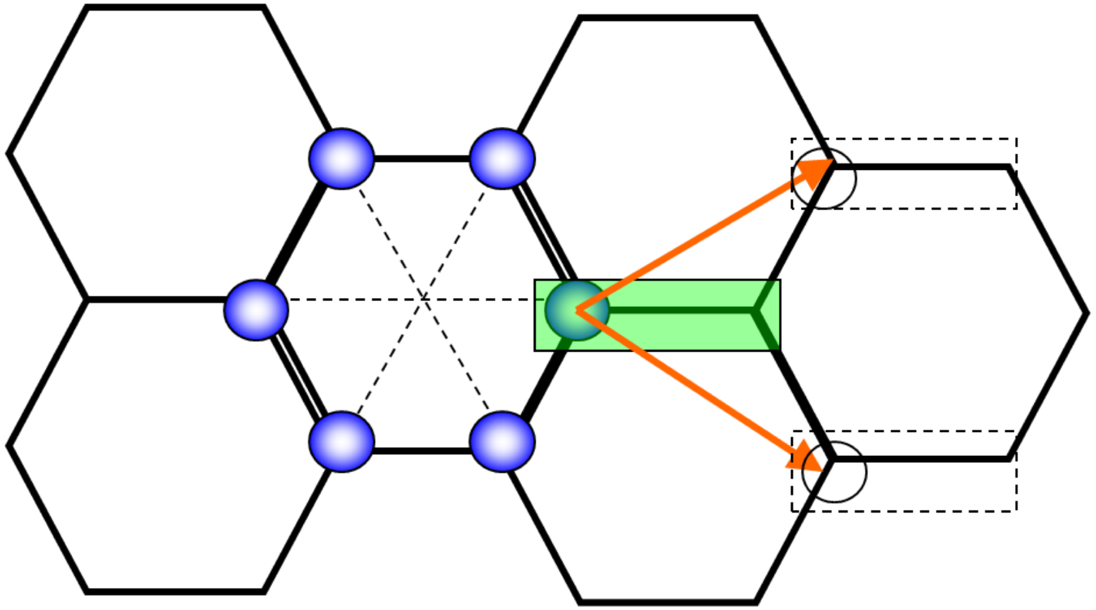
Modeling of HgCdTe-Graphene Detector



Modeling approach and plan

- 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.

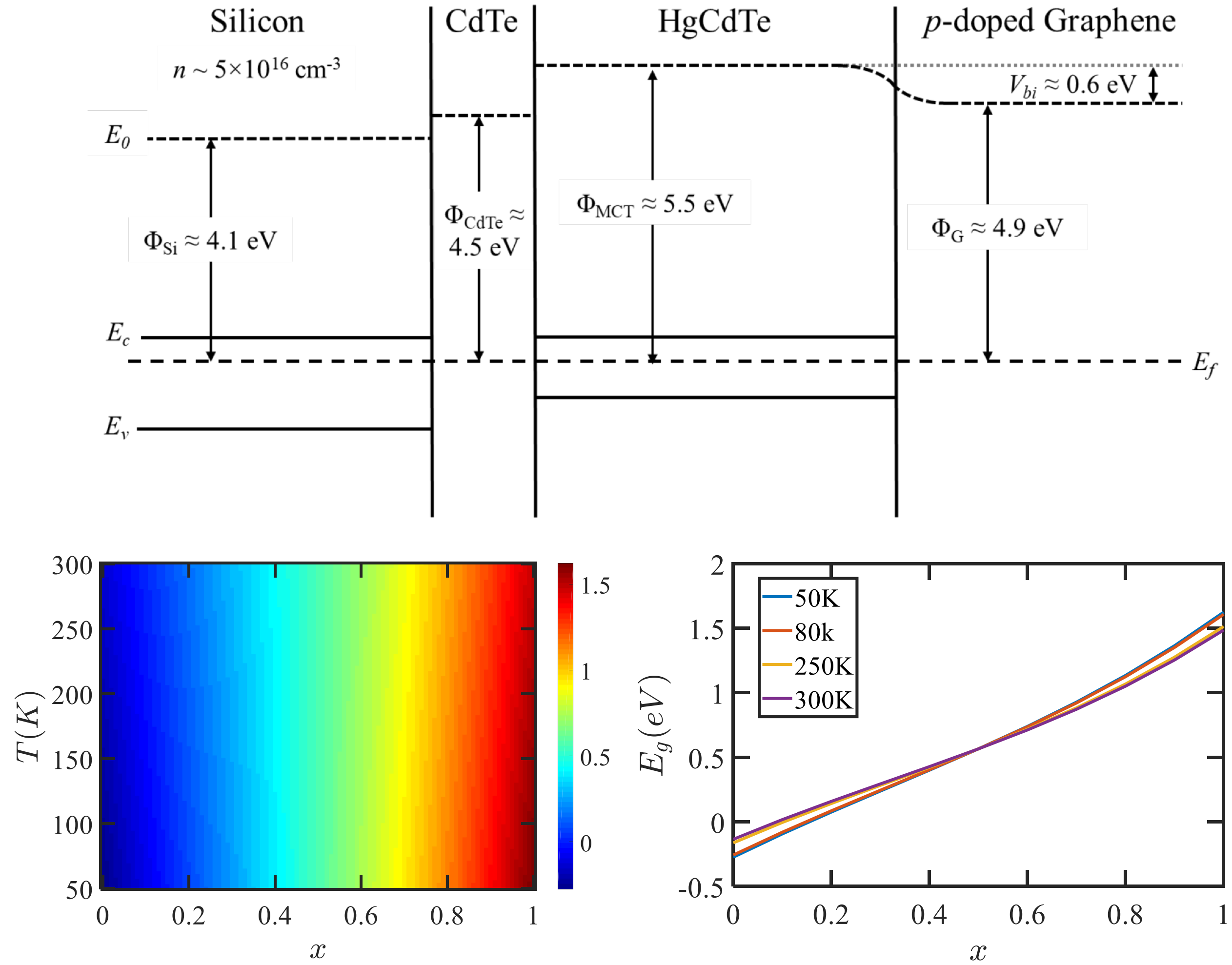
Materials Modeling Approach



Schematic depiction of exact tight-binding model for graphene

- 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

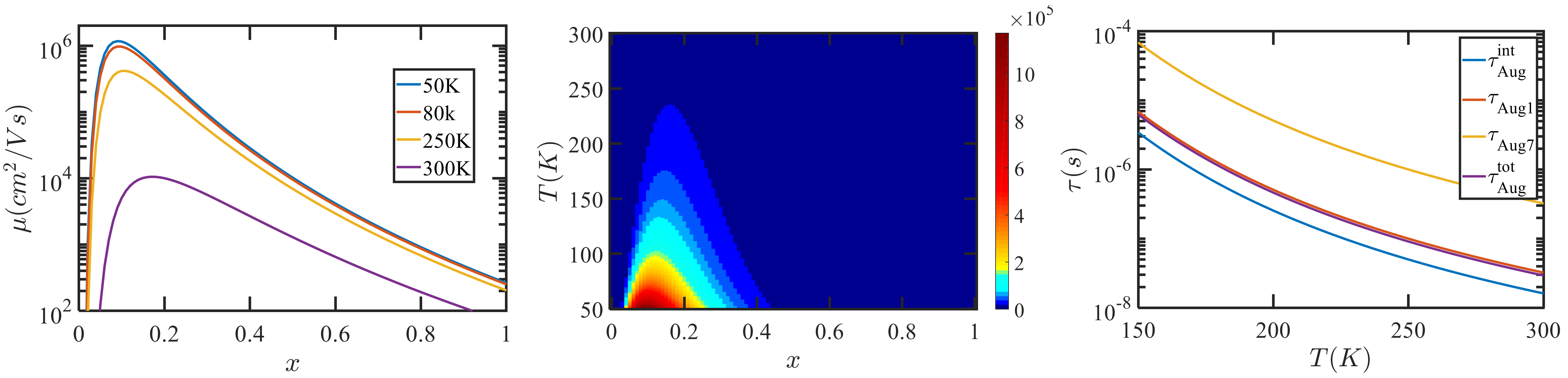


Band diagram for HgCdTe detector (*top*). Plots of E_g as function of T and x for $Hg_{1-x}Cd_xTe$ (*below*).

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

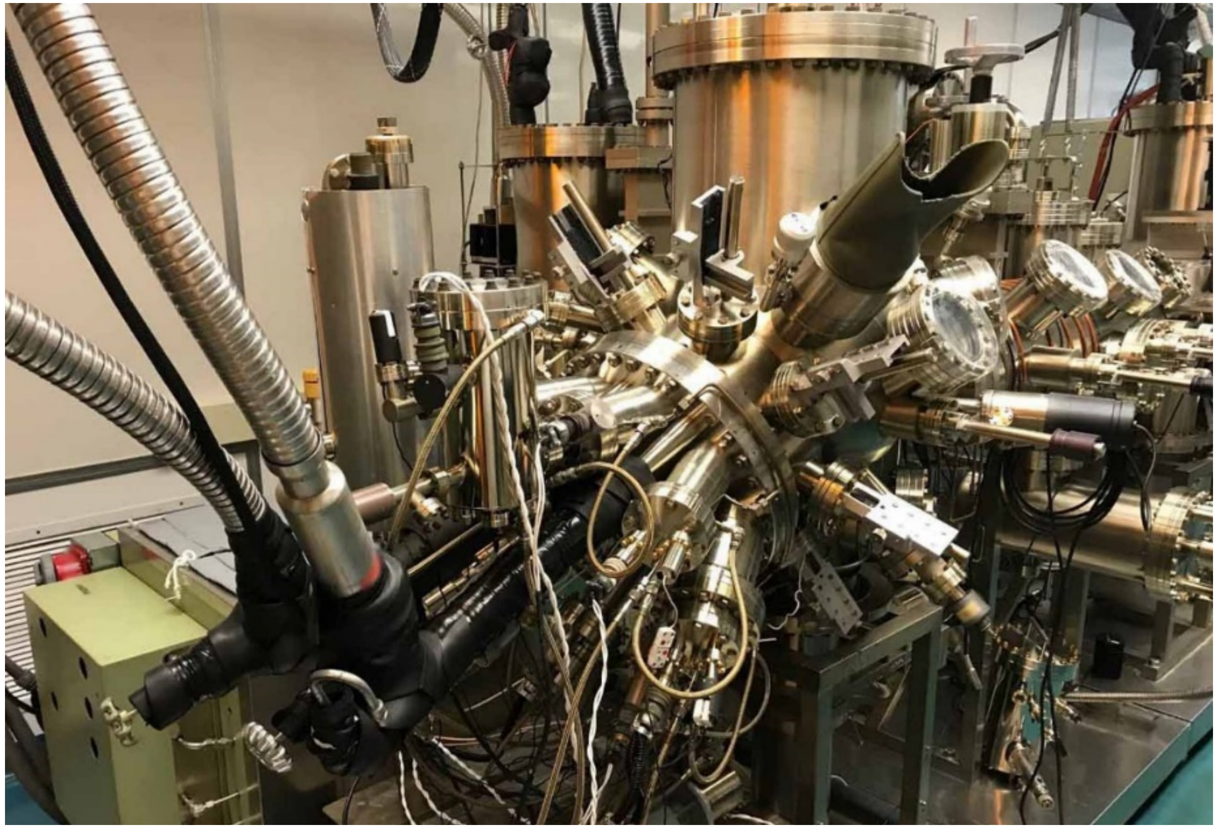
HgCdTe Mobility and Lifetime

- 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*).

HgCdTe-Graphene Detector Material Development at NVESD



Type of MBE system for growth of HgCdTe/CdTe layers on silicon for MWIR detectors and arrays

- 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

Albany Nanotech campus in Albany, NY, where Magnolia Office is located

- 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.

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.