SAND2014-0850C

Application of plasmonic subwavelength structuring to enhance infrared detection

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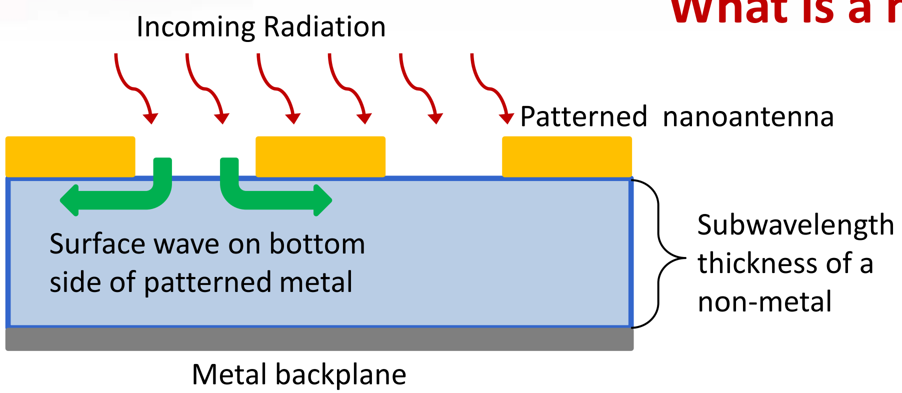
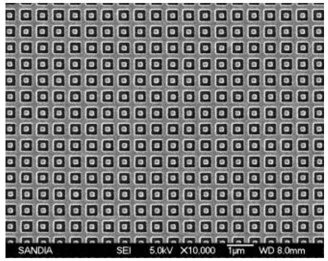
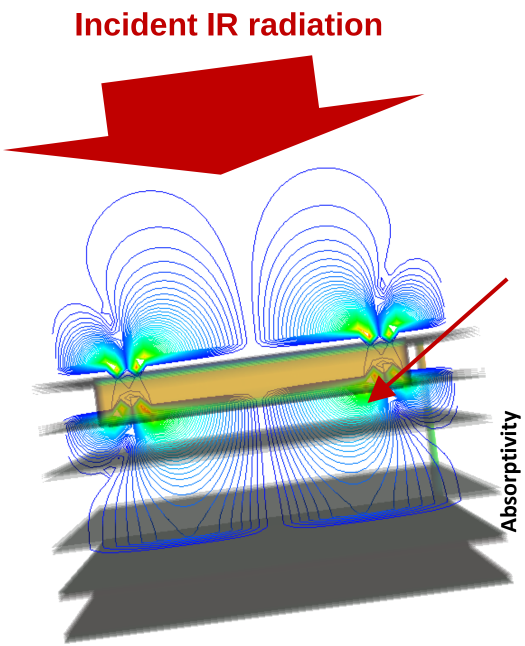
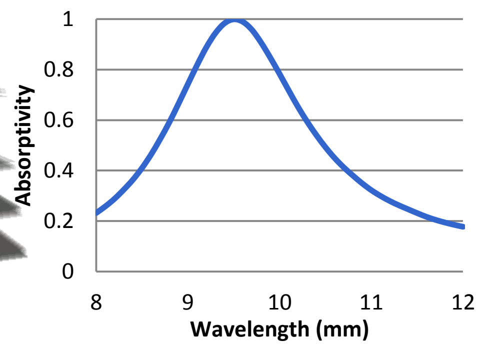
Nanoantenna-Enabled Thin Detectors

What is a nanoantenna?









- Nanoantennas are a fundamental technology that spans numerous sensor types
- Nanoantennas are an enabling technology for new applications such as 2D materials
- A nanoantenna is a distributed energy conversion device: the entire surface is the device
- A nanoantenna converts incoming radiation to a surface wave with energy confined to a small volume under the nanoantenna
- This confinement is what enables us to look at interesting applications
- The pattern is subwavelength, with many nanoantenna periods per device pixel. This pattern may be changed on a pixel-to-pixel basis allowing adjacent pixels to have different spectral or polarization response
- Our IR devices are enhanced by, or completely reliant on, the radiation conversion achieved by the nanoantenna

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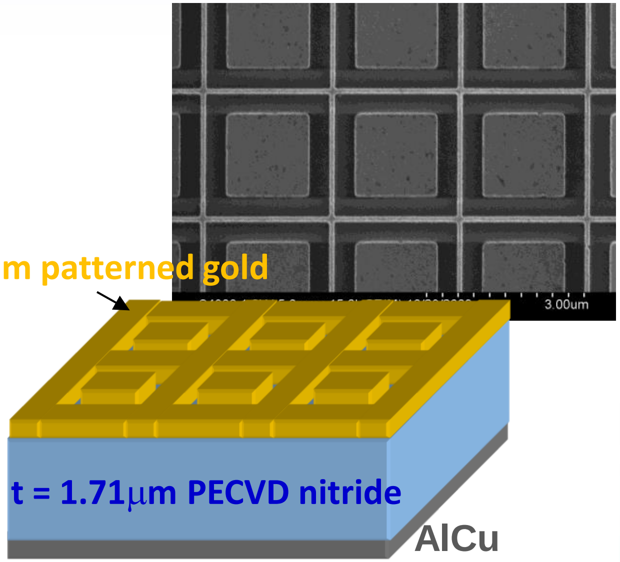
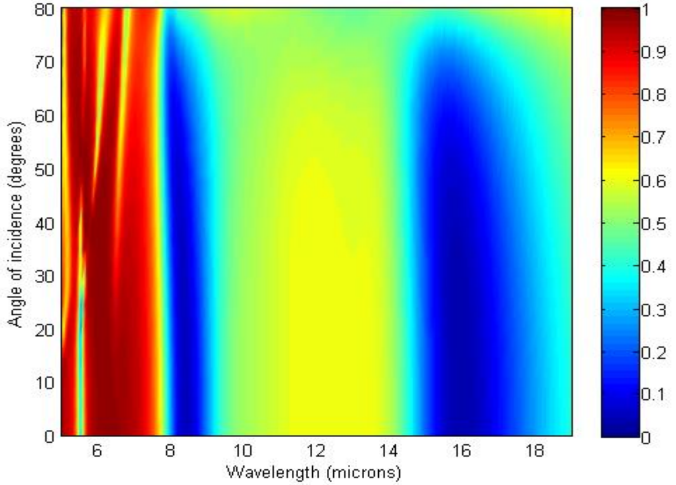
Background: Perfect Absorbers

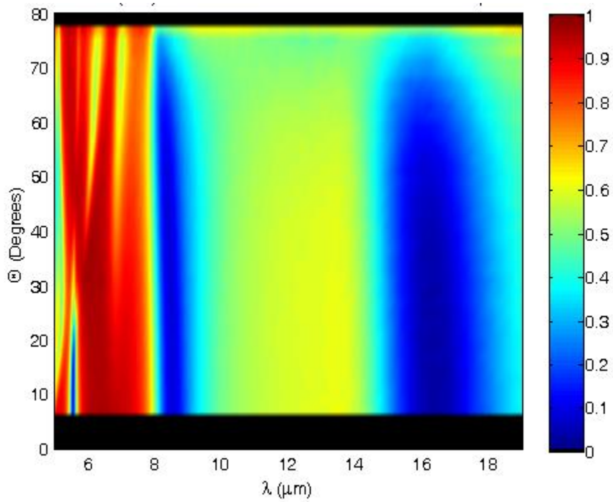
- We designed and made a dual-band perfect absorber.
- Excellent agreement between simulation and measurement → Great confidence in our models.
- Measured absorption of 99% in two bands.
- If we can absorb it, why not use that energy?



Simulated Reflectivity



Measured Reflectivity



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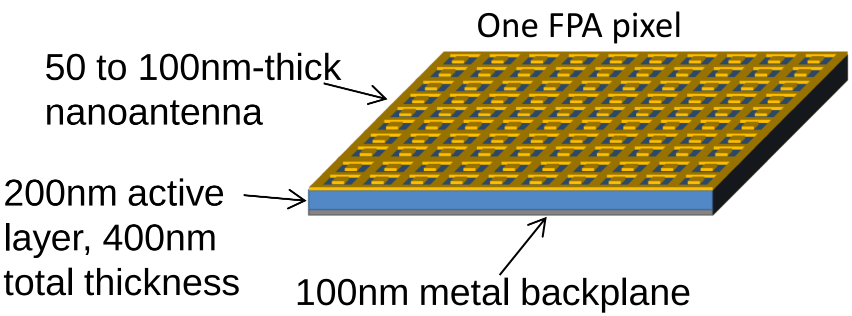
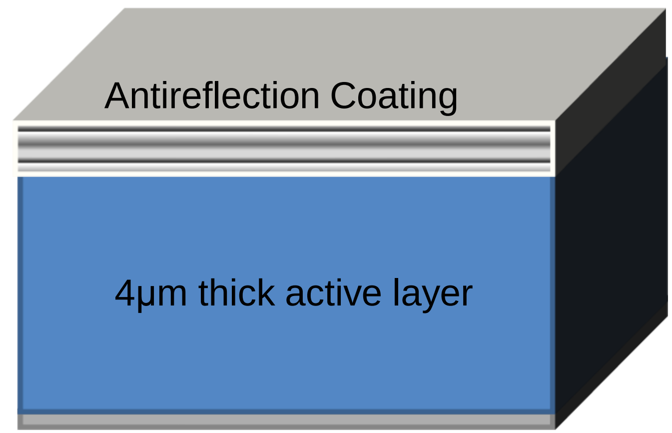
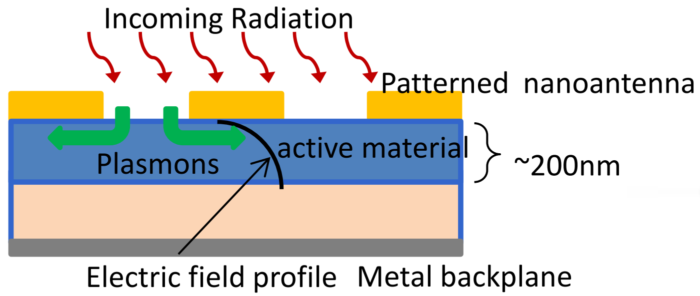
Incorporation with Existing Detector Materials in the Midwave

Integrate subwavelength nanoantenna with active material (MCT or InGaSb) for high-performance focal plane array (FPA).

Using dense fields to thin the active region.







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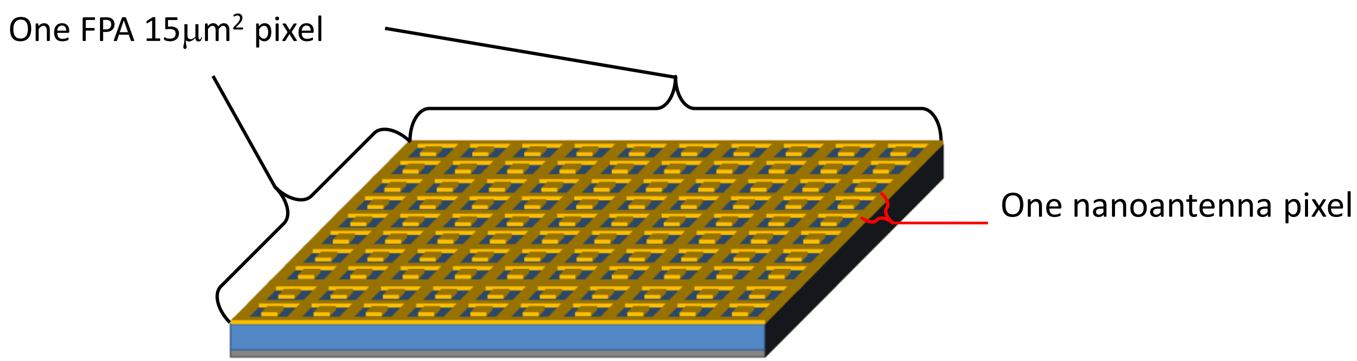
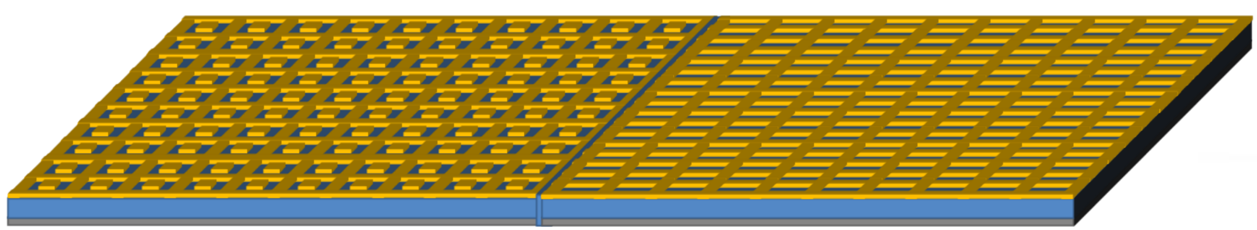
Advantages of the Nanoantenna Structure

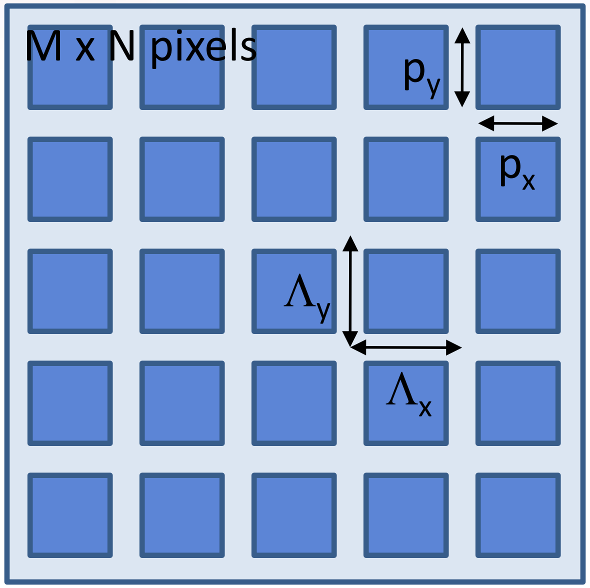
- **Top and bottom contacts allow direct connection.**
- **Filtering can be changed from FPA pixel-to-pixel simply by changing the antenna pattern (Spectral or polarization). This is difficult to do with thin films.**
- **Small antenna unit cell allows multiple unit cells per FPA pixel (for broadband).**



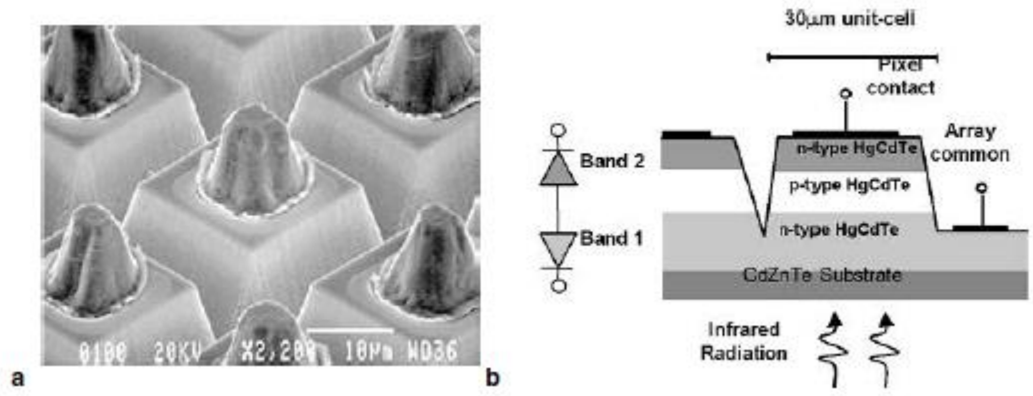
Two adjacent FPA pixels with different functionality.



Maximizing Active Area Improves MTF and Signal

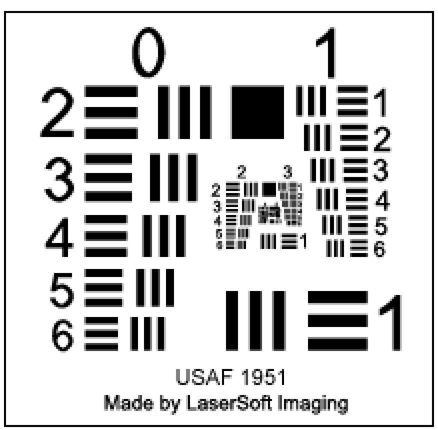


MCT FPA architecture



from E.P.G. Smith, et al, *J. of Electr. Matl.*, 2004.

$$MTF(f_x, f_y) = [\mathrm{sinc}((M \cdot \Lambda_x) \cdot f_x, (N \cdot \Lambda_y) \cdot \eta) * \mathrm{comb}(\Lambda_x \cdot f_x, \Lambda_y \cdot f_y)] \cdot \mathrm{sinc}(p_x \cdot f_x, p_y \cdot f_y)$$



Ideally for the mathematical MTF function, we want Λ_x, Λ_y and p_x, p_y as small as possible to maximize the MTF.

This is clearly impossible, but we can make Λ_x and Λ_y as small as possible for a given p_x and p_y.

Our architecture gives us near 100% fill factor.

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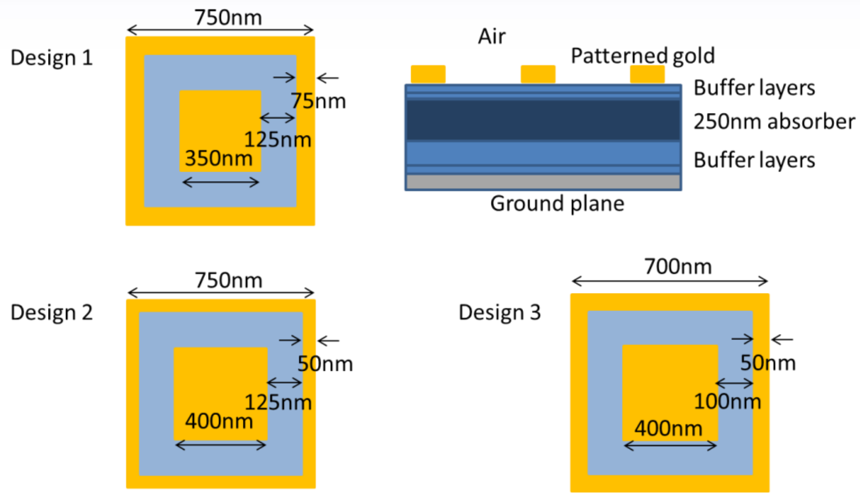
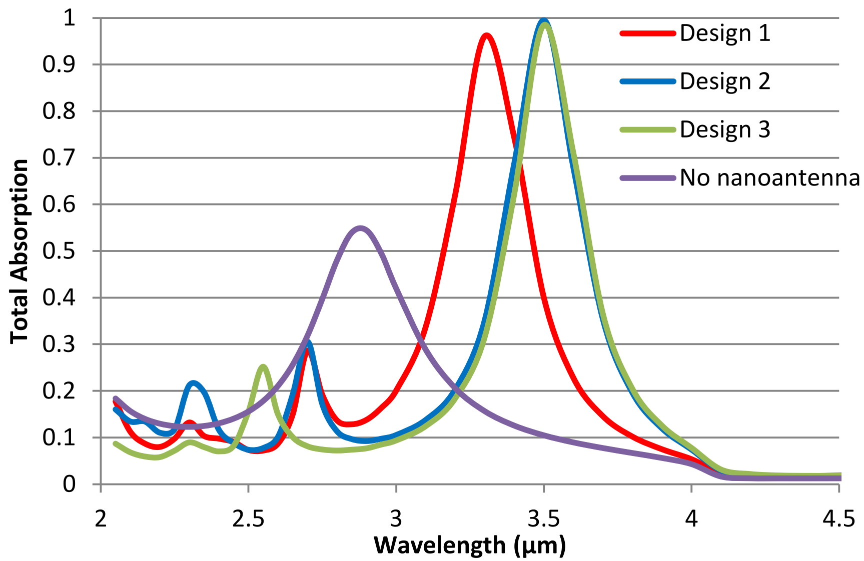
Simulation of InAsSb Design

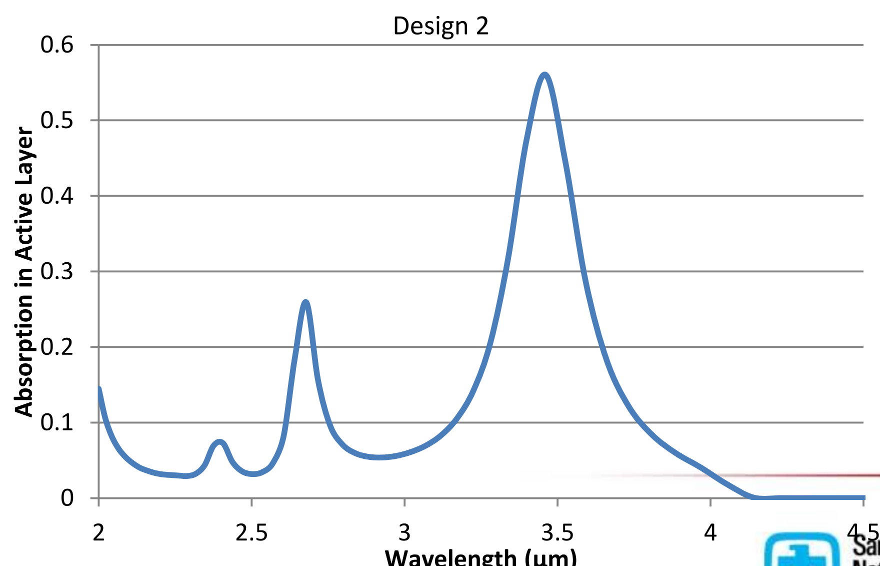
Designs for peak responsivity in the 3.25µm to 3.5µm range.

Three designs were fabricated with different patterns but similar peak resonances.

Designs were not optimized to maximize absorption in the active layer.







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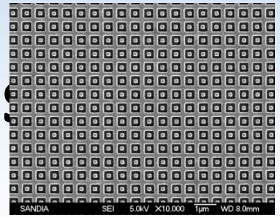
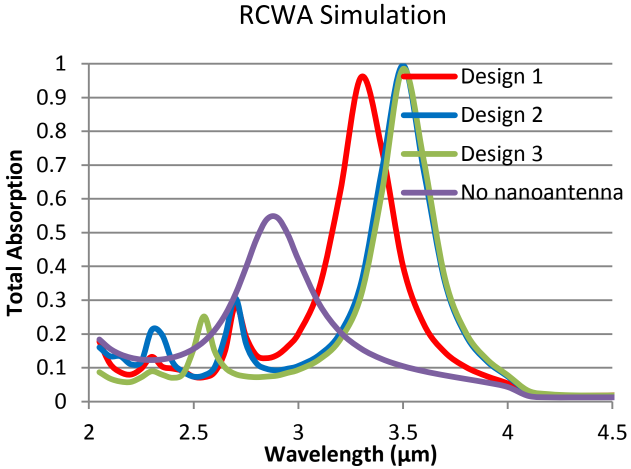
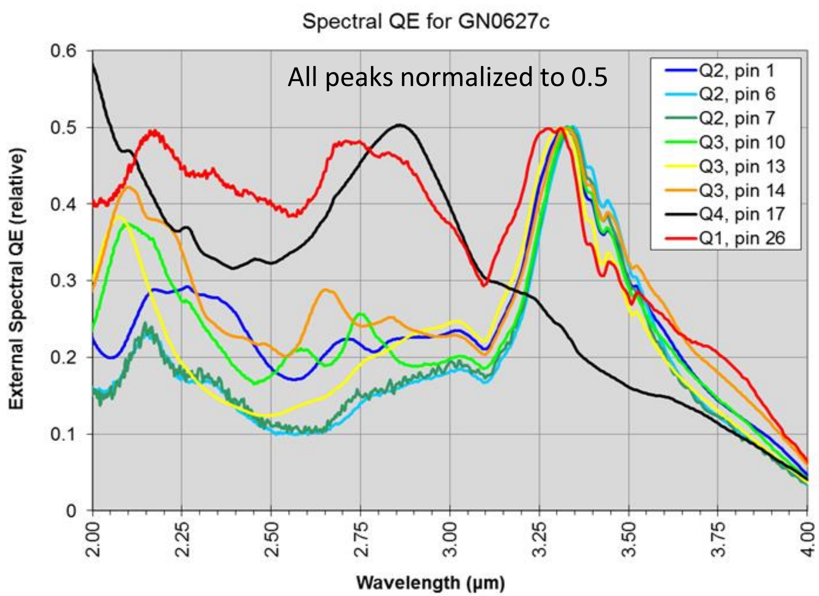
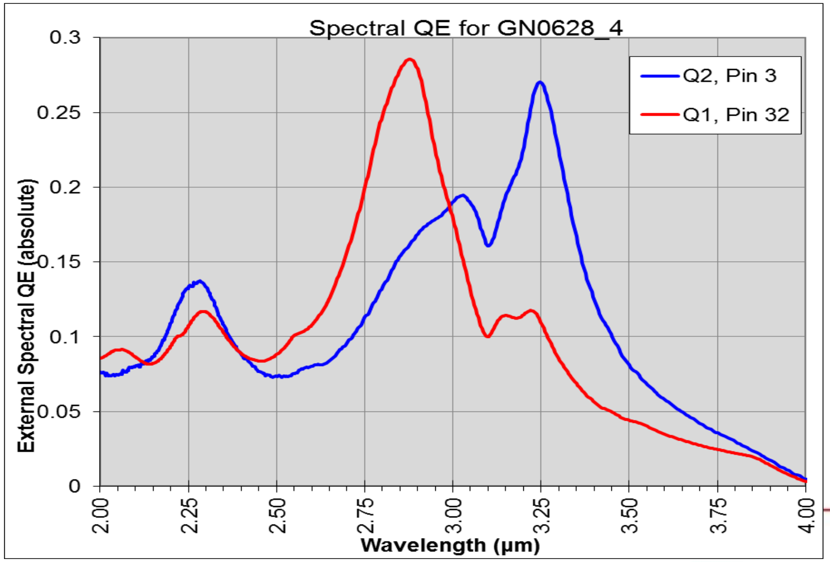
Nanoantenna-Enhanced InAsSb Detector Res



- Epitaxial growth of two designs for integration with NA for test/ evaluation.
- Successful fabrication of detectors with integration of NAs using a flip-chip bonding process and selective substrate removal.
- Room for optimization in modeling and in characterization procedures.







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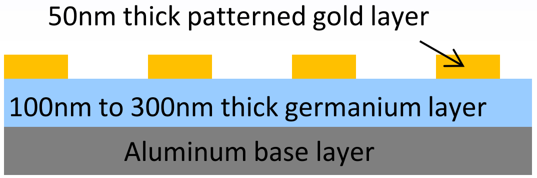
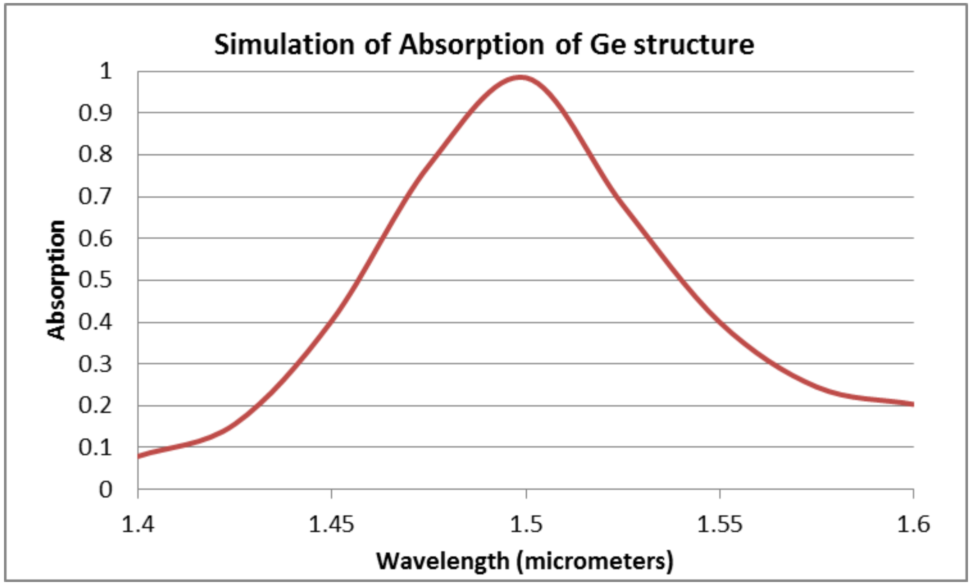
Germanium Detector

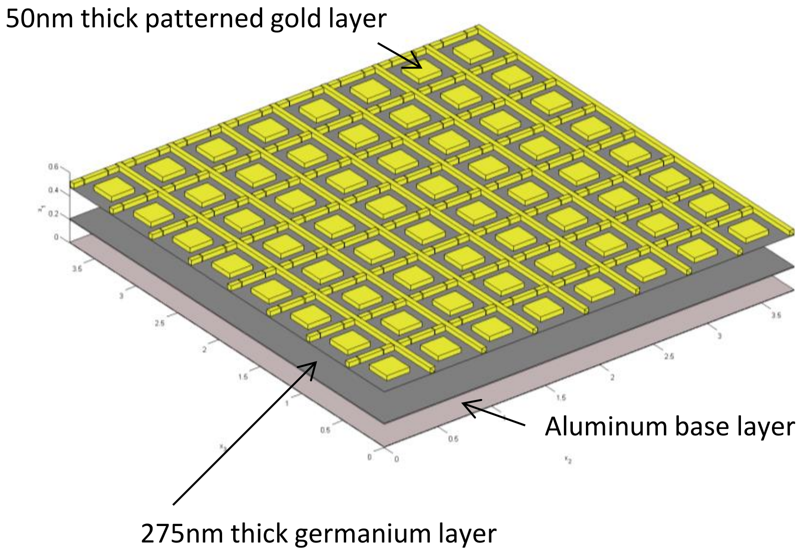
As with the MWIR designs, this one involves a detection material between two metal layers. Since it is for the near-IR, the detector layer is quite thin. The metal top and bottom layers act as contacts.



As it is thin, it is very fast as carriers move to a metal electrode quickly. Since the metal wire grid is not a large solid piece of metal, the capacitance should also be low.

We designed and simulated a structure with dimensions below to work at 1.5µm. This is in the telecommunications wavelength band.



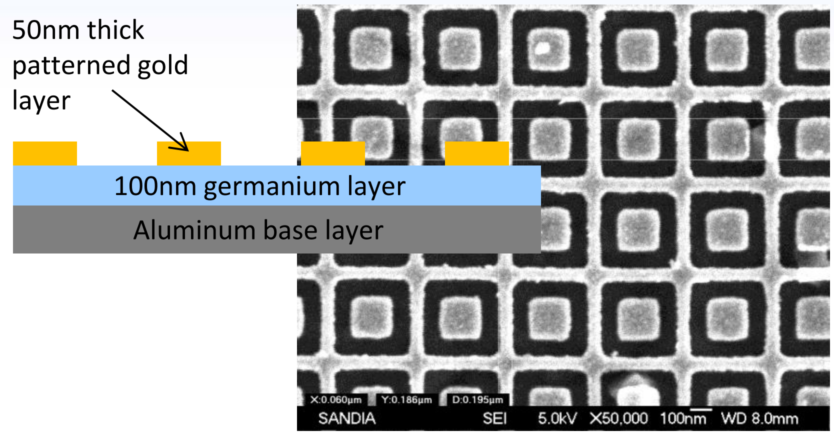


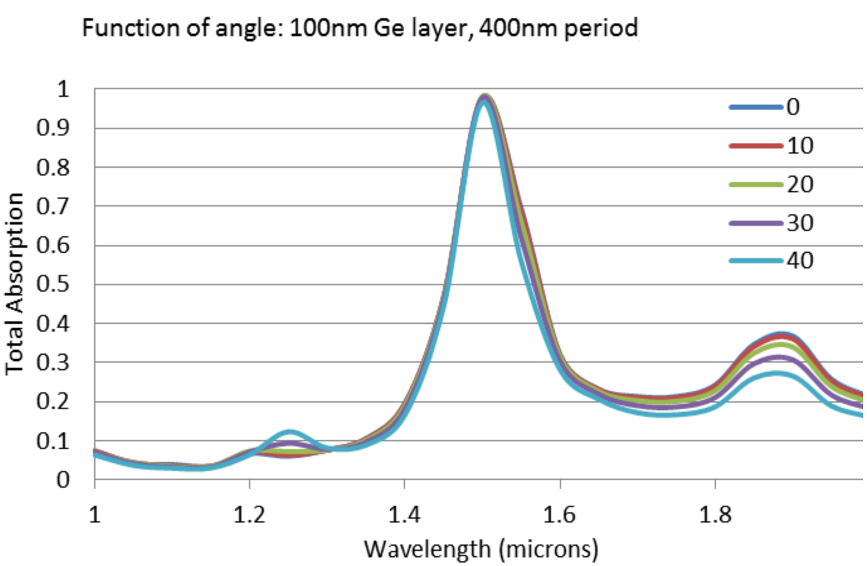
Period of nanoantenna = 475nm
Width of continuous gold bars = 50nm

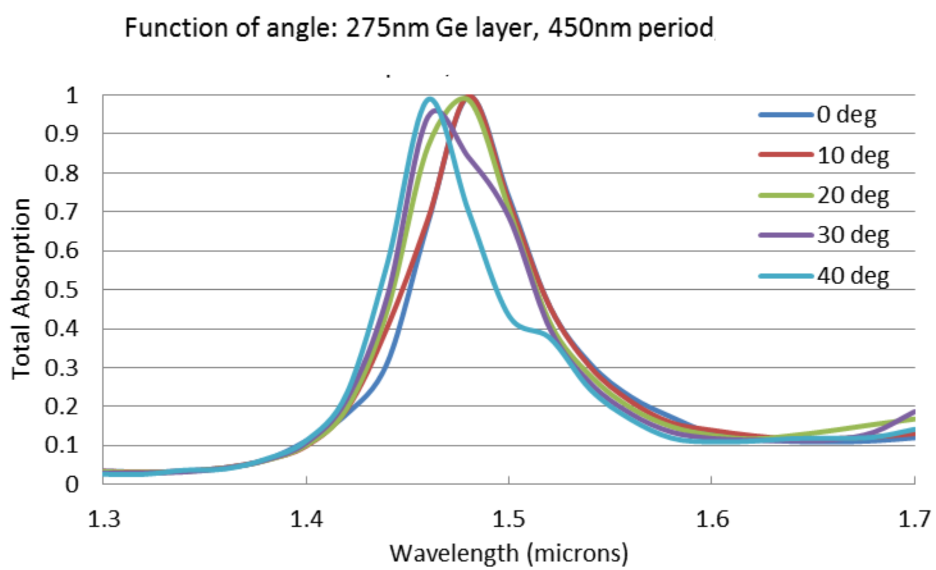
Germanium Detector Design

There is virtually no change from normal out to 40° in the 100nm thick design. In any practical imaging system, this is more than enough.

In the 275nm-thick design we see a change in peak wavelength between 20° and 30°.







Graphene Detectors: *Bilayer* Graphene Tunability

nature Vol 459 | 11 June 2009 | doi:10.1038/nature08105

LETTERS

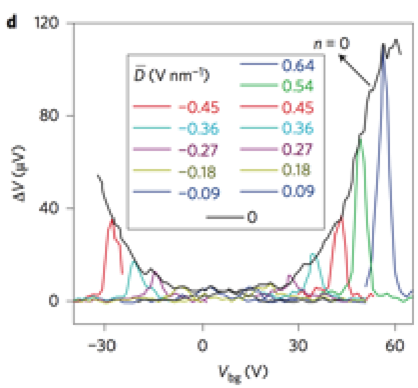
Direct observation of a widely tunable bandgap in bilayer graphene

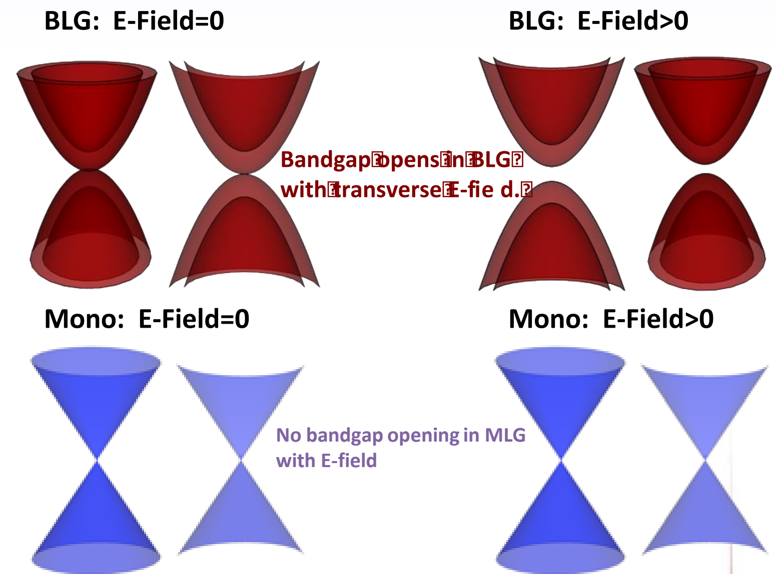
Yuanbo Zhang[1]*, Tsung-Ta Tang[1]*†, Caglar Girit[1], Zhao Hao[2,4], Michael C. Martin[2], Alex Zettl[1,3], Michael F. Crommie[1,3], Y. Ron Shen[1,3] & Feng Wang[1,3]

ARTICLES
PUBLISHED ONLINE: 3 JUNE 2012 | DOI: 10.1038/NNANO.2012.88
nature nanotechnology

Dual-gated bilayer graphene hot-electron bolometer

Jun Yan[1,2], M-H. Kim[1,2], J. A. Elle[2,3], A. B. Sushkov[1,2], G. S. Jenkins[1,2], H. M. Milchberg[2,3], M. S. Fuhrer[1,2]* and H. D. Drew[1,2]





Problems:

1. Scalability
2. Low absorption
3. Multiphysics problem

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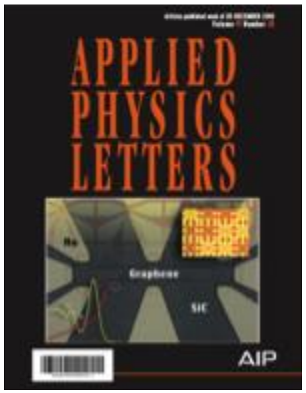
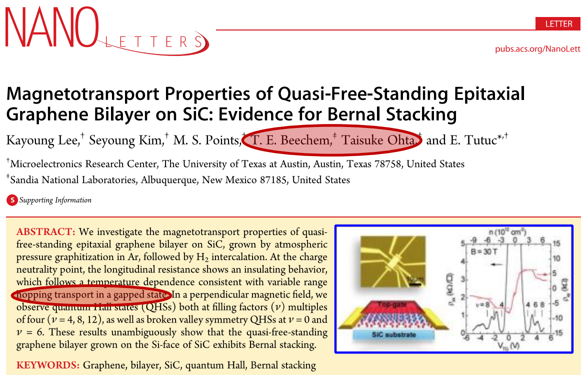
Approach: Combination of Technologies

Scalability: Wafer-Scale BLG




NANO LETTERS
LETTER
pubs.acs.org/NanoLett

Magnetotransport Properties of Quasi-Free-Standing Epitaxial Graphene Bilayer on SiC: Evidence for Bernal Stacking

Kayoung Lee,[†] Seyoung Kim,[†] M. S. Points,[‡] T. E. Beechem,[‡] Taisuke Ohta,[‡] and E. Tutuc*[,†]
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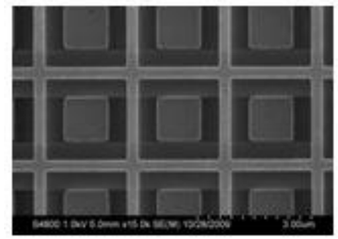
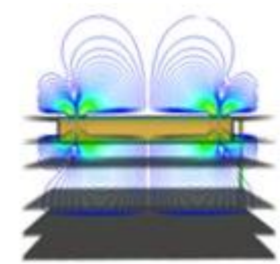
Supporting Information

ABSTRACT: We investigate the magnetotransport properties of quasi-free-standing epitaxial graphene bilayer on SiC, grown by atmospheric pressure graphitization in Ar, followed by H_2 intercalation. At the charge neutrality point, the longitudinal resistance shows an insulating behavior, which follows a temperature dependence consistent with variable range hopping transport in a gapped state. In a perpendicular magnetic field, we observe quantum Hall states (QHSs) both at filling factors (ν) multiples of four (ν = 4, 8, 12), as well as broken valley symmetry QHSs at ν = 0 and ν = 6. These results unambiguously show that the quasi-free-standing graphene bilayer grown on the Si-face of SiC exhibits Bernal stacking.

KEYWORDS: Graphene, bilayer, SiC, quantum Hall, Bernal stacking

Low Absorption: Nanoantennas



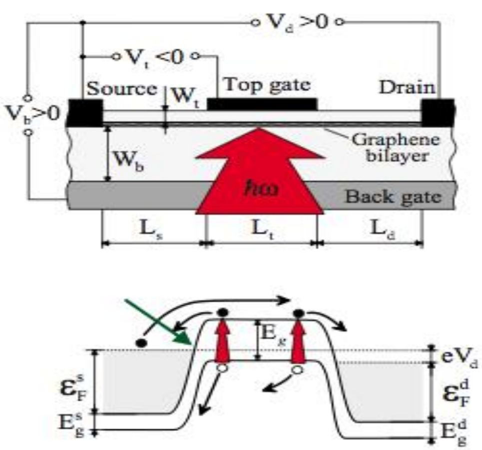


Nanoantenna-Enabled Midwave Infrared Focal Plane Arrays

David W. Peters*, Charles M. Reinke, Paul S. Davids, John F. Klem, Darin Leonhardt, Joel R. Wendt, Jin K. Kim, Sally Samora
Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM, USA 87185-1082

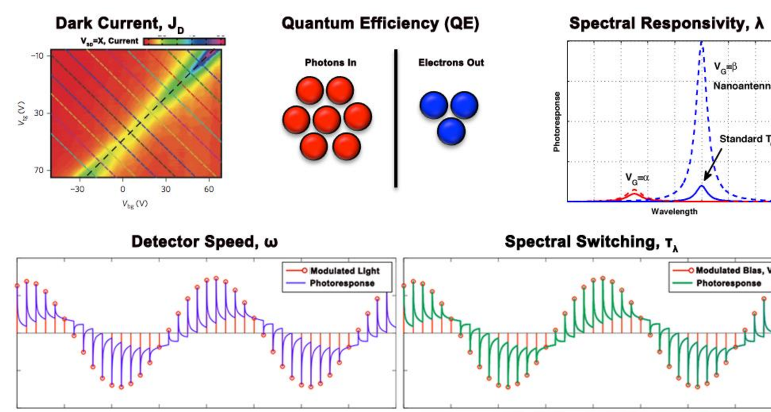
Proc. of SPIE Vol. 8353 83533B-1

Phenomenon: PhotoFET



Ryzhii et al. PRB (79) 245311. 2009

Next Steps: Technology Maturation



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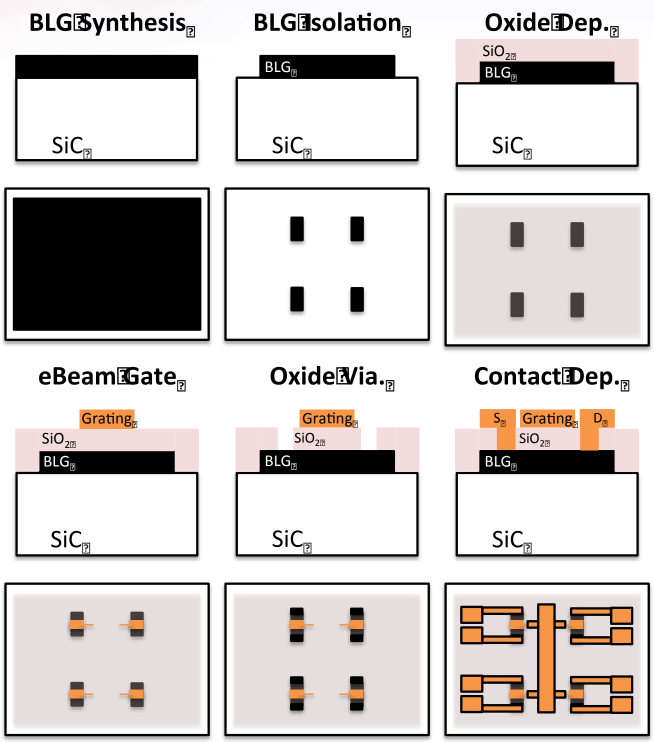
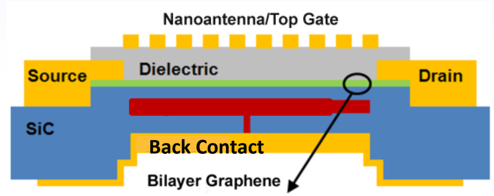
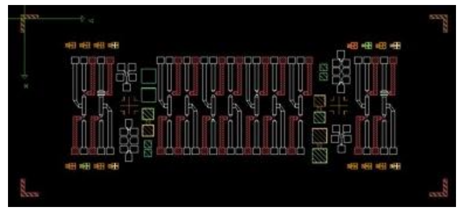
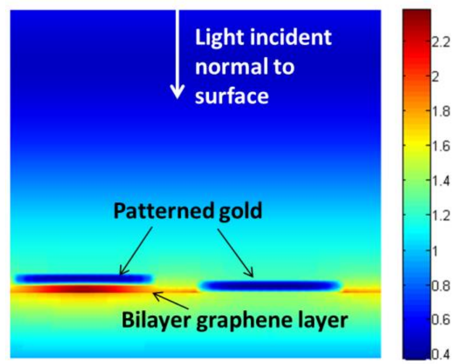
Graphene Detector: Early Fab and Results

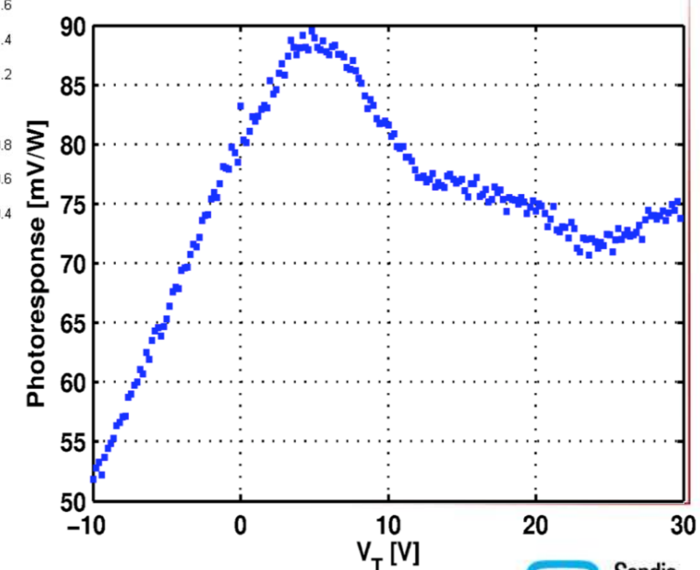








- Scalable fabrication using "standard" techniques
- Multiple operational devices on a chip
- Opens path towards arrays
- Developed an improved understanding of the graphene/SiC interface



Devices show bias dependent tunability with a signal enhanced by nanoantennas.

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Summary

Nanoantennas offer methods of enhancement in traditional and new detector platforms.

- InAsSb detectors in the MWIR.
- Germanium detectors in the Near-IR.
- Graphene detectors that offer new capabilities.