SAND2017-12480PE

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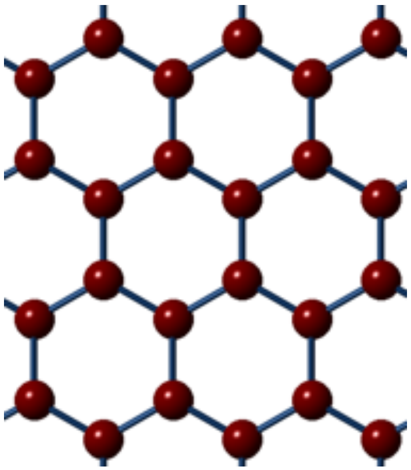  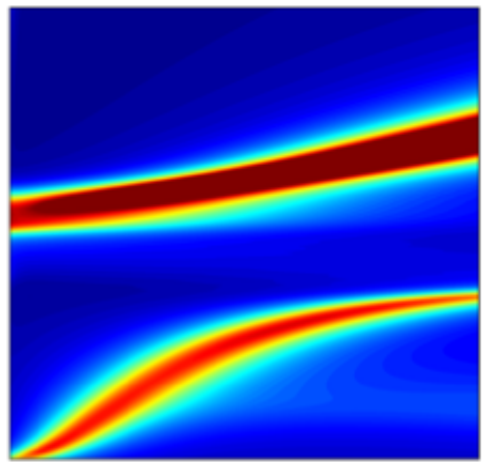 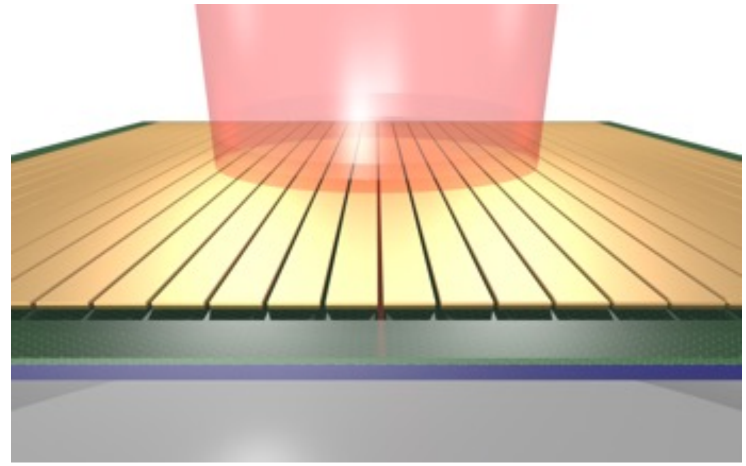

Defining Boundaries:

Designing 2D Systems Using the Materials Surrounding Them

Thomas Beechem

Google Scholar: http://goo.gl/96jGNv

Team:

David Peters
Michael Goldflam
Steve Howell
Joel Wendt
John Nogan
Anthony McDonald
Isaac Ruiz

U.S. DEPARTMENT OF ENERGY · NNSA

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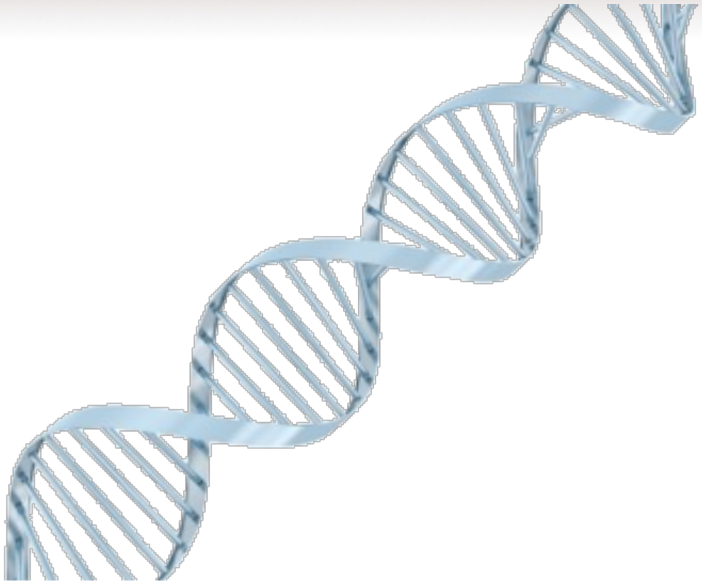
What makes me, me?

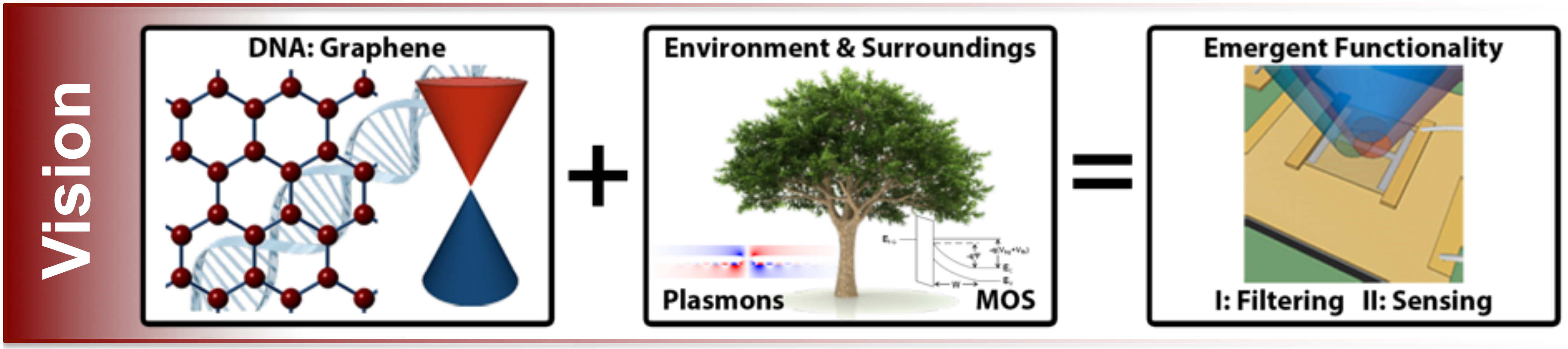
Genetic, Intrinsic



Environment

Takeaway: We are who we are **AND** what we're around.

Vision & Postulates



Postulates

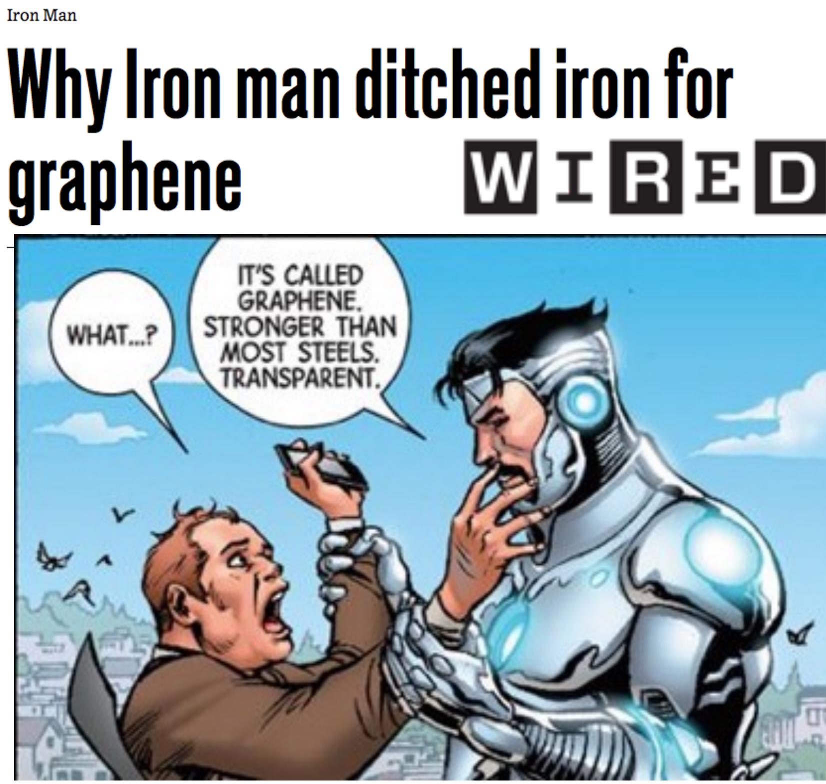
1. Graphene's "DNA" provides functionality traditionally unavailable.
2. Graphene changes when in contact with the real world.
3. These changes are a means of capitalizing on graphene's DNA.

Graphene DNA & the Hype Train


Are we one step closer to being able to use the world's strongest material?


The Washington Post

Why the graphene light bulb could switch on a new era of innovation


Iron Man

Why Iron man ditched iron for graphene

WIRED


Wonder material could harvest energy from thin air


theguardian

Graphene - the new wonder material


Bits The New York Times

Graphene Could Usher in Flexible, Ultra-Slim Gadgets

You've probably never heard of graphene, a carbon-based material, but it might be stuffed into your pocket or wrapped around your wrist in the not-too-distant future.

According to the

Graphene is a fully flexible material.


Graphene can be folded and cut into a microscopic kirigami spring.

The New York Times

Graphene Origami

Graphene is a thin material with tremendous potential. Measuring only an atom-thick, it is harder than diamond, a better electrical conductor than copper, and 200 times as strong as steel.

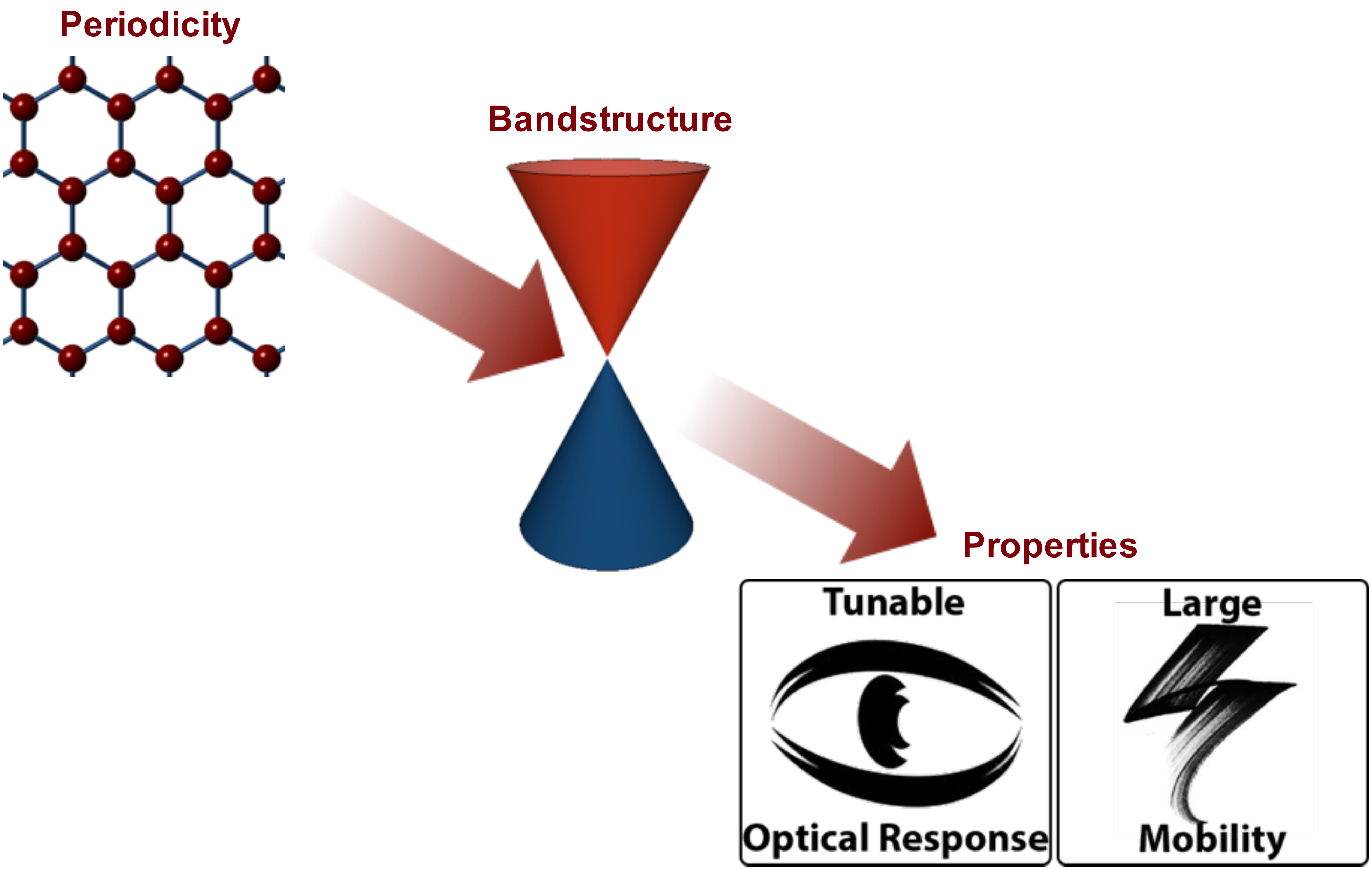
Graphene is so strong that a sheet of it stretched across a coffee-cup should be able to support the weight of a truck bearing down on a pencil point. Some researchers call it a "wonder material" that could be used in everything from batteries and biosensors to computers and condoms.

Now researchers have discovered another one of graphene's feats: It's as flexible as paper. Not only can graphene be crumpled and then perfectly flattened, but it can also be folded like origami, according to a report published Wednesday in Nature.

Using a style of origami that involves cuts and folds called kirigami, the researchers fashioned a sheet of graphene into a tiny spring. According to Nature, researchers may one day use kirigami to craft graphene sheets into microscopic weighing scales or nets small enough to wrap around living cells.

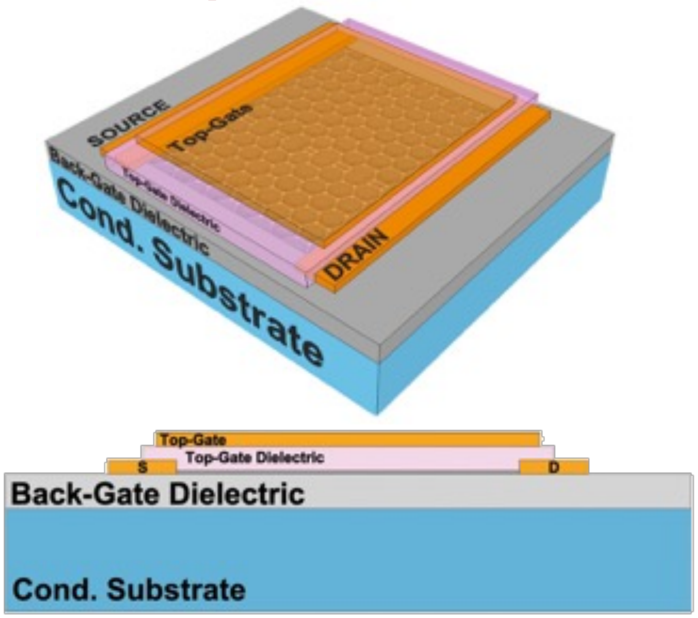
—NICHOLAS ST. FLEUR

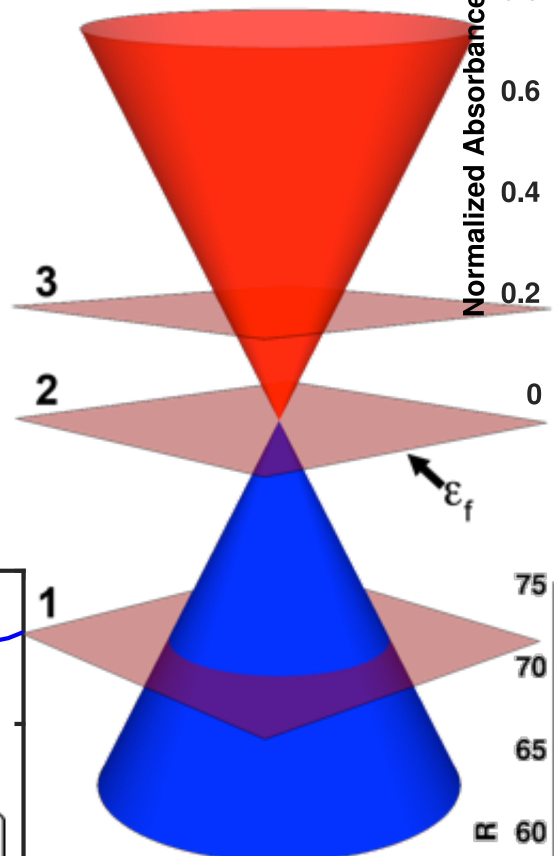
DNA:Origin of Properties



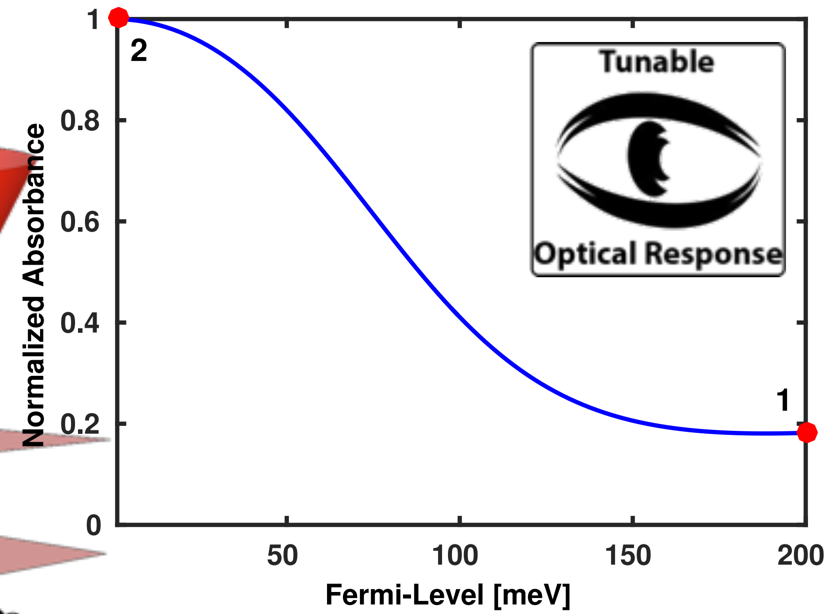
DNA: Graphene Tunability

Graphene Transistor

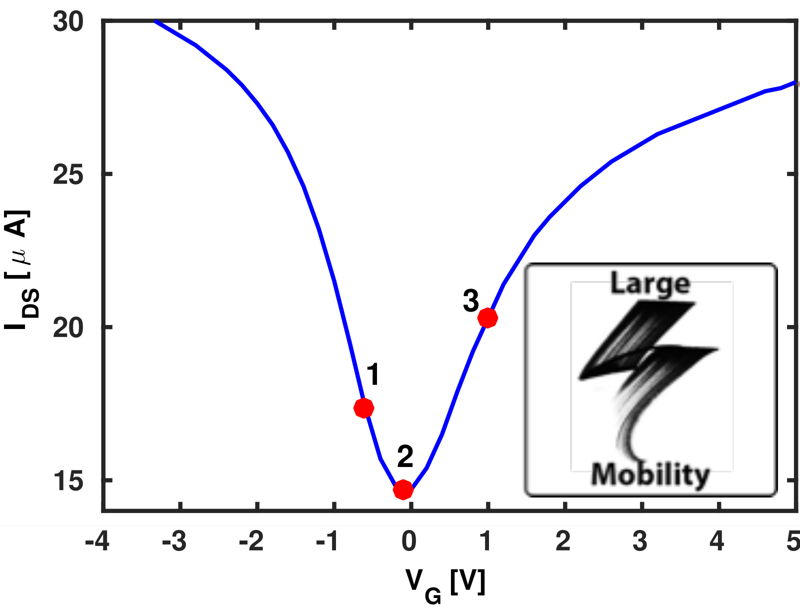




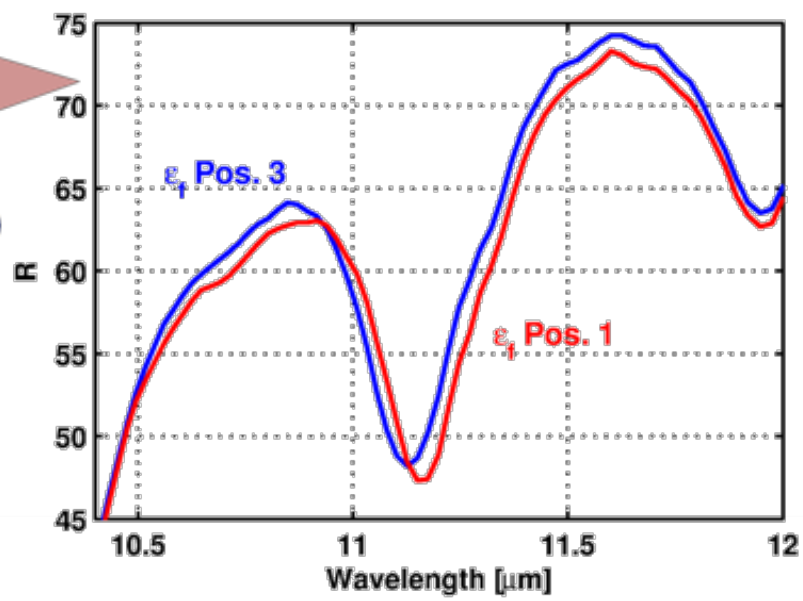
Tunable Absorber



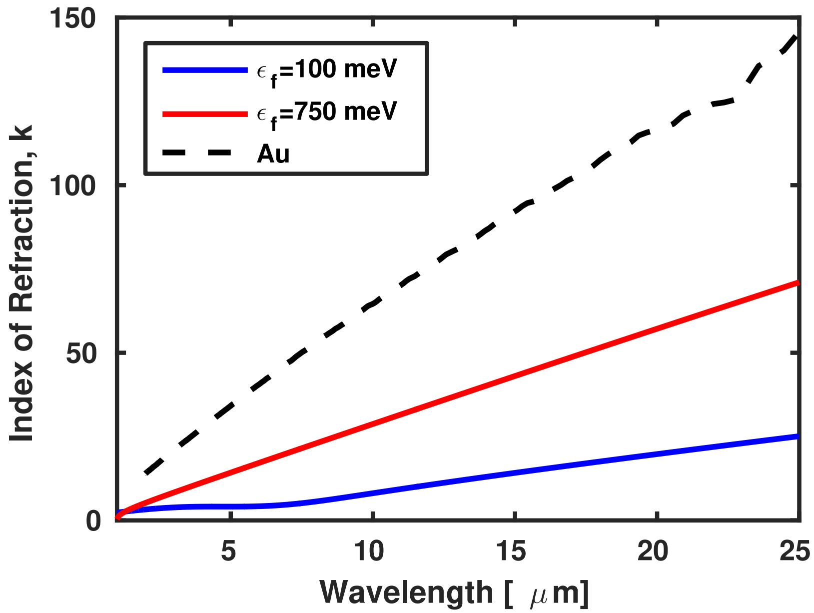
Tunable Resistance

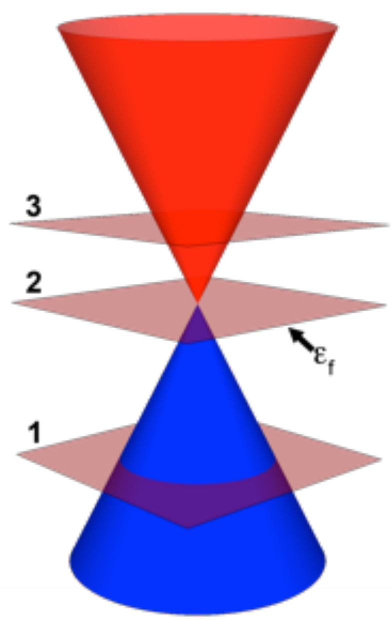


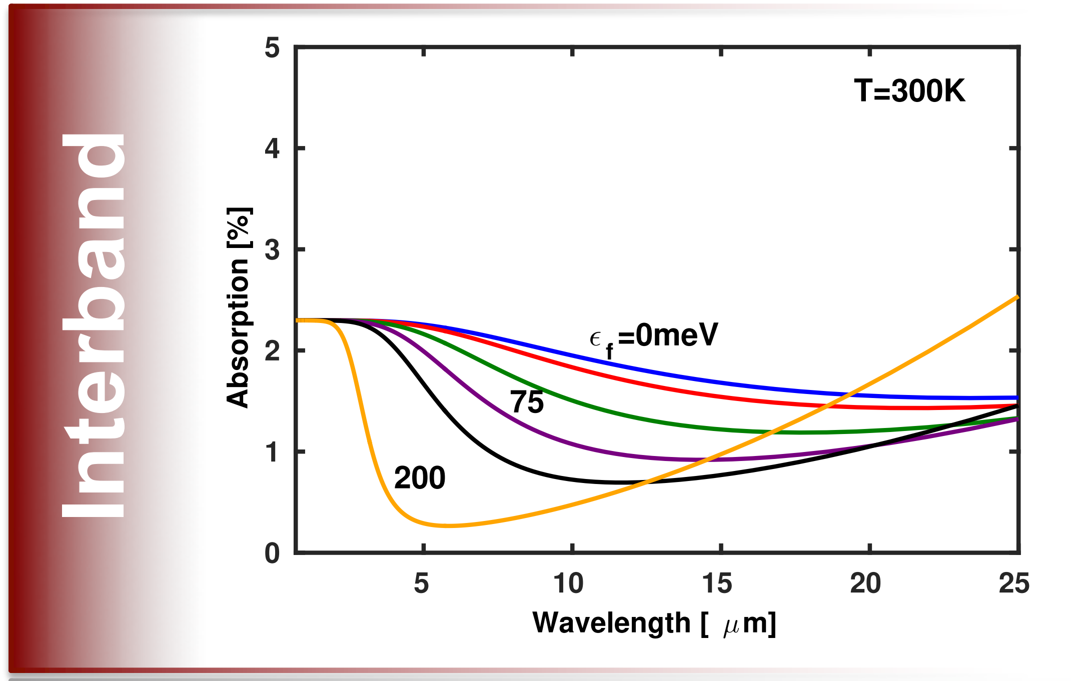
Tunable Nanoantenna

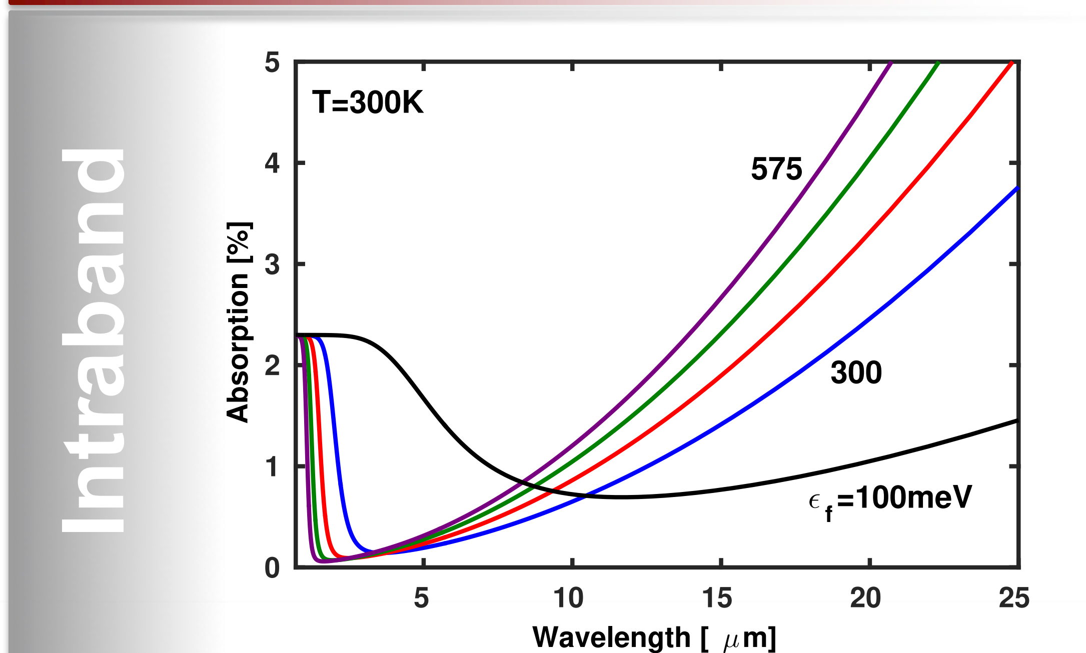


Myth: Graphene Absorbs 2.3%



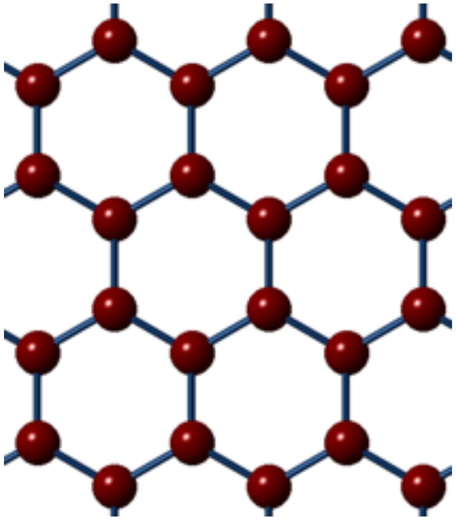


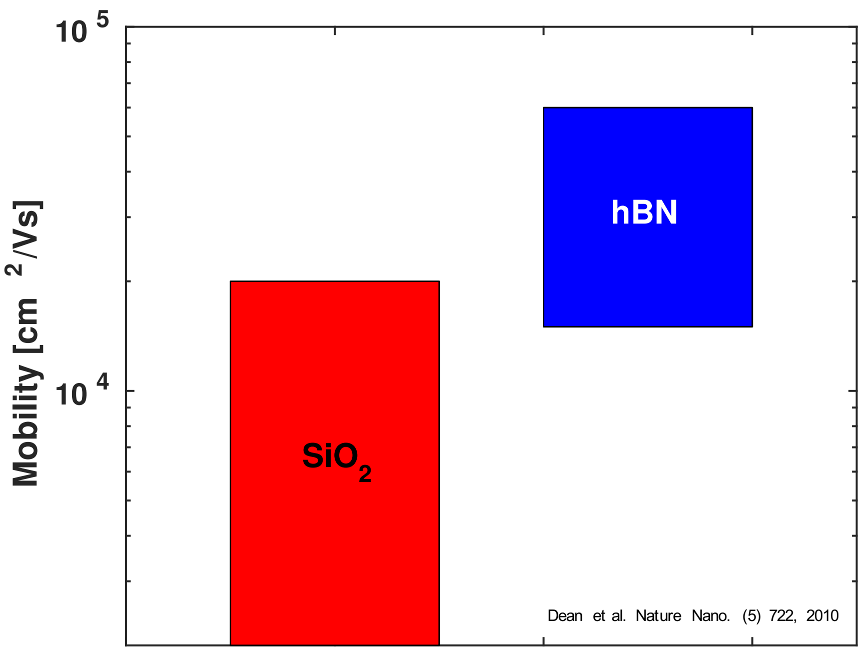


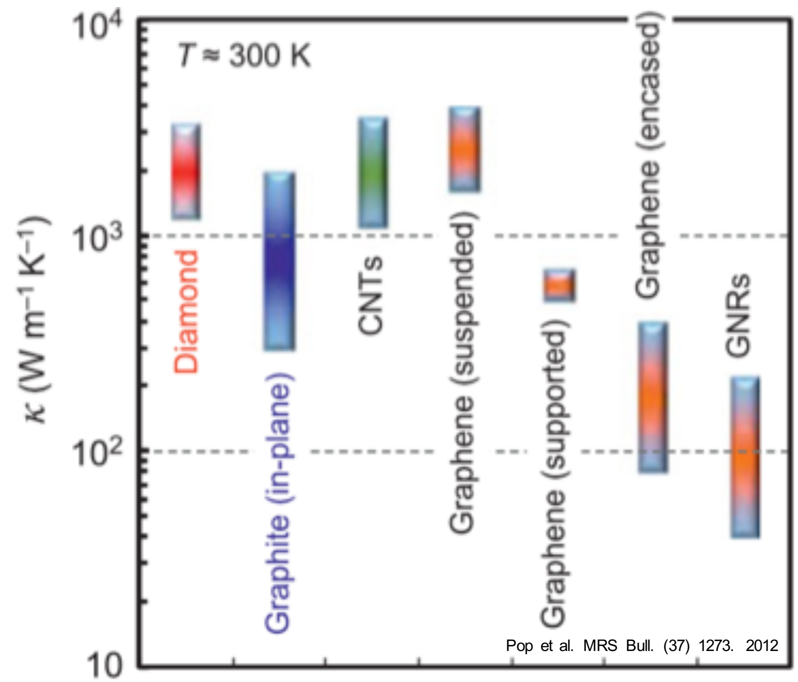


Leonard, Spataru, Goldflam, Peters, Beechem. Sci. Reports. (7) 45873. 2017

Env.:Graphene & Peer Pressure



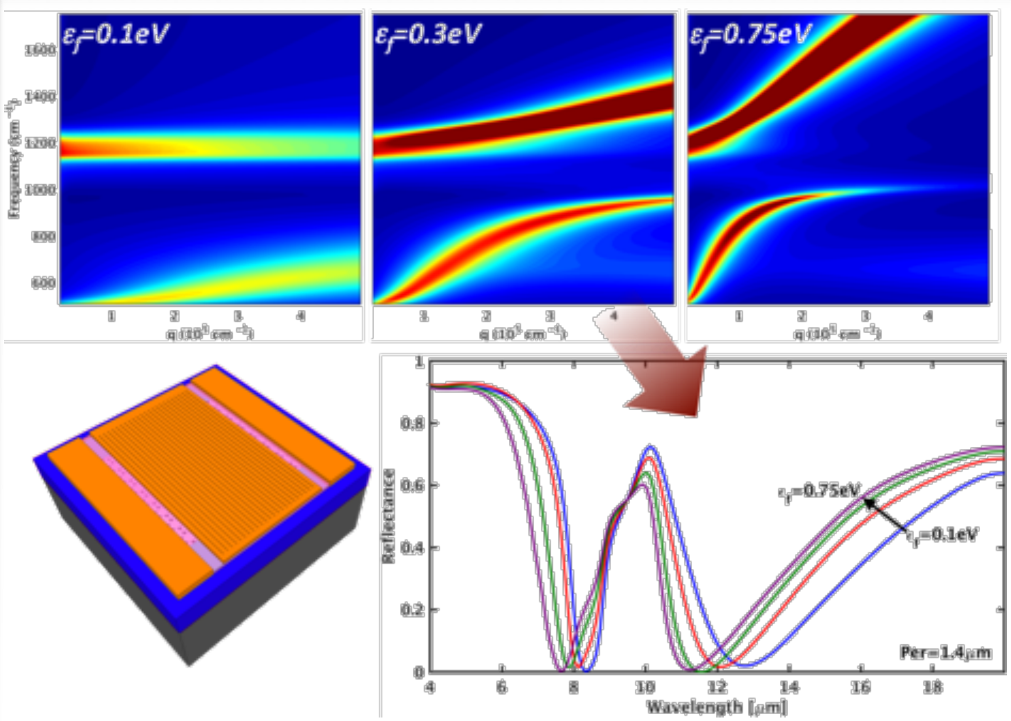




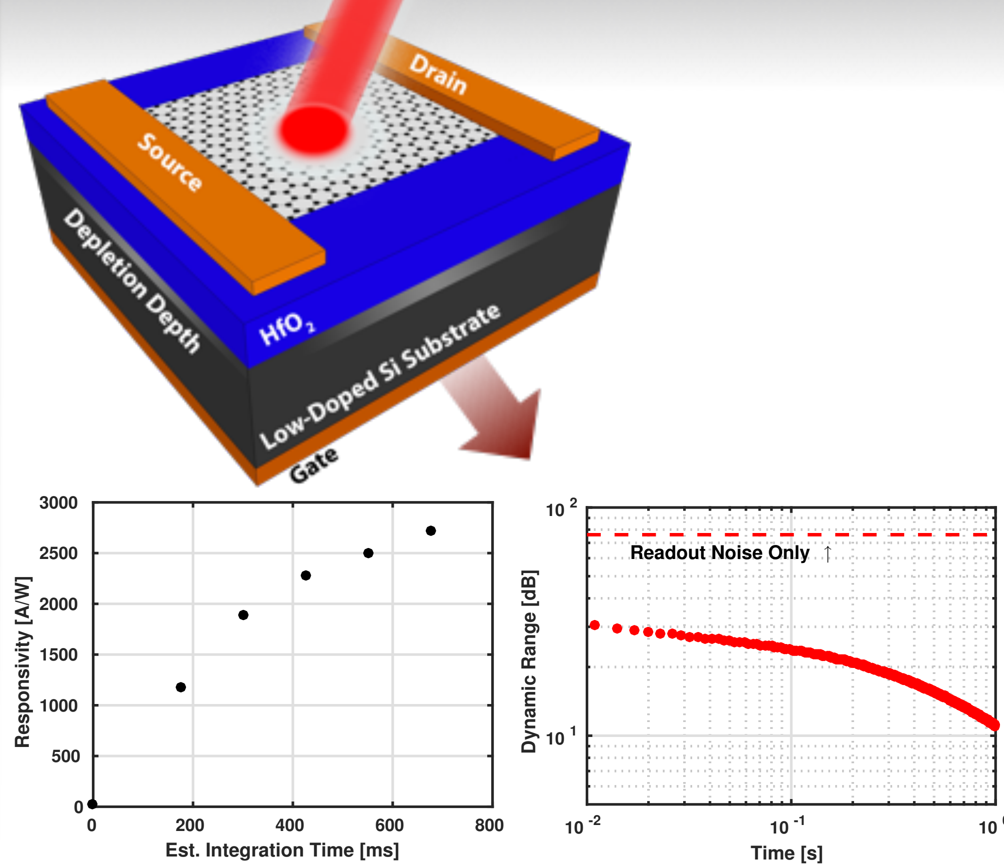
Premise & Path

PREMISE: Leverage materials surrounding graphene to cultivate functionality unavailable with traditional approaches.

Tunable Light Filters



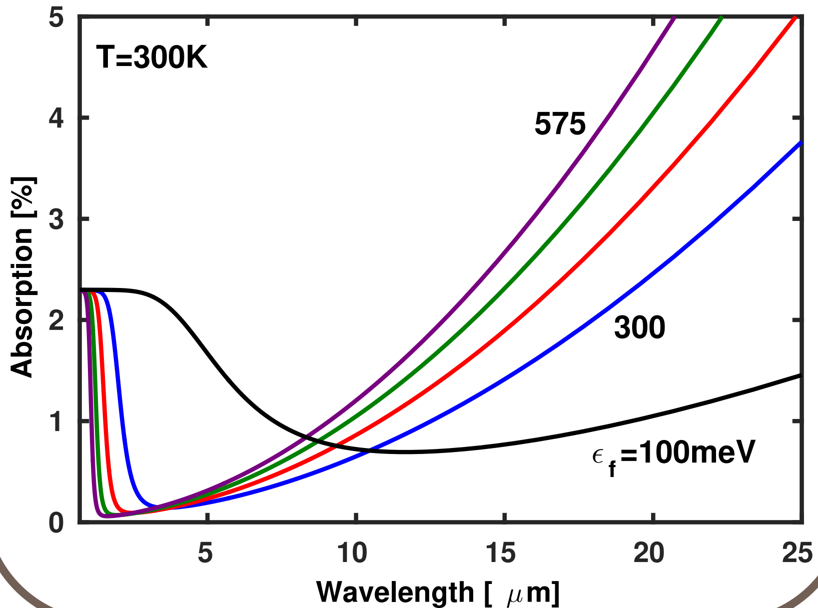
Photodetectors



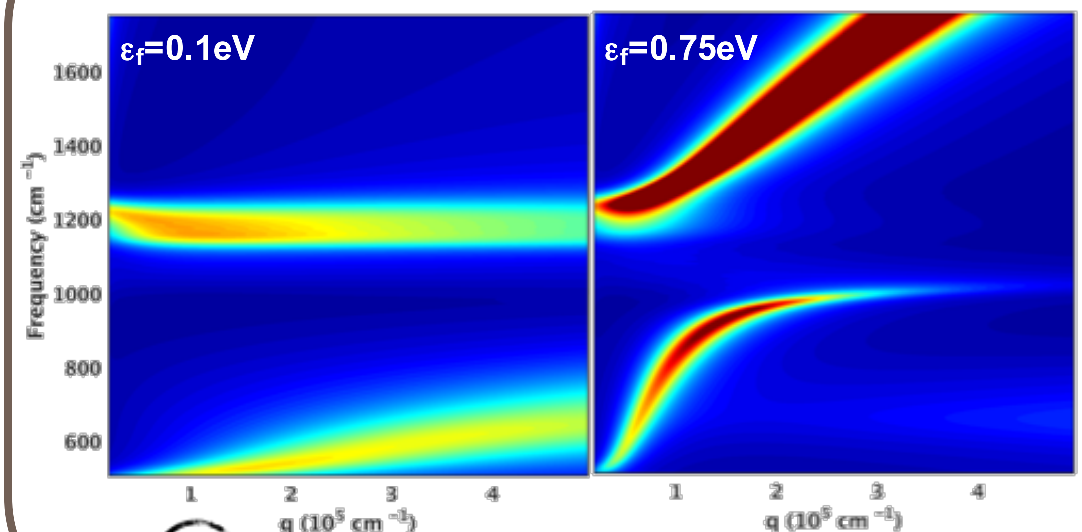
How to increase light-matter interaction?

Objective: Create a tunable IR Filter

Problem: 5% Not Enough



Tool: Graphene Plasmons



Field Confinement + Tunability

Existence Proof: Home Pregnancy Tests…err...Lateral Flow Assays

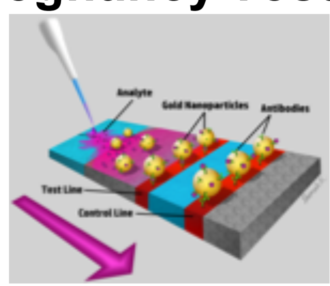
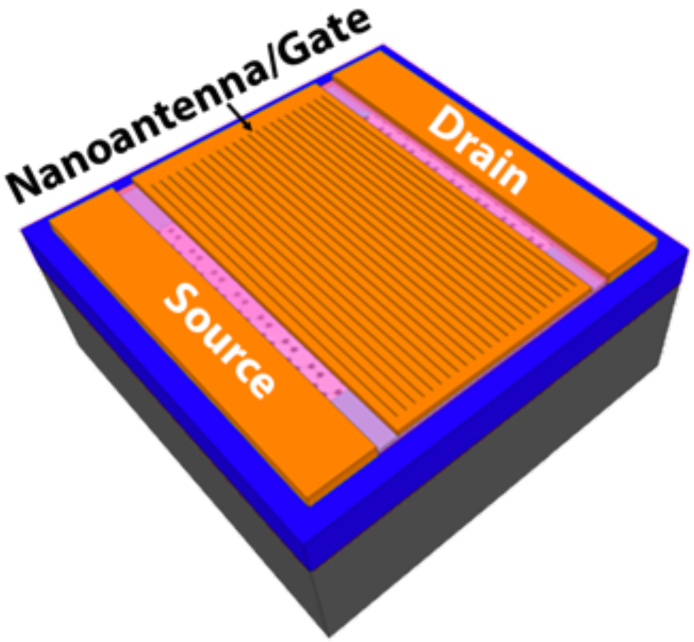
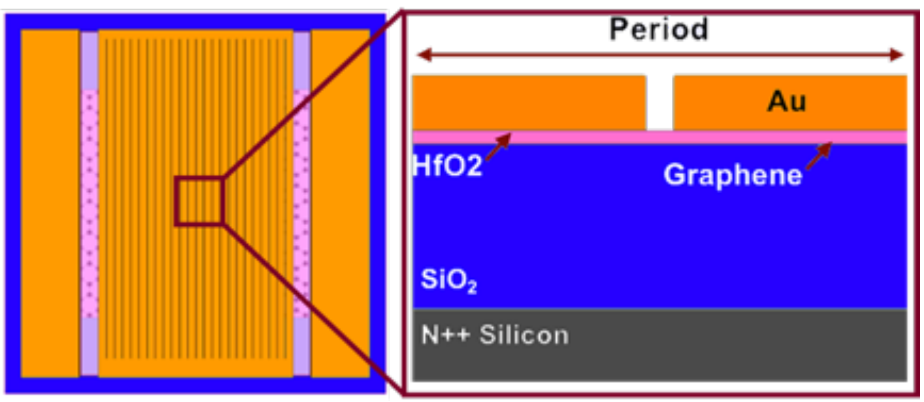


Illustration: nanohybrids. net Image: nanocomsix.com

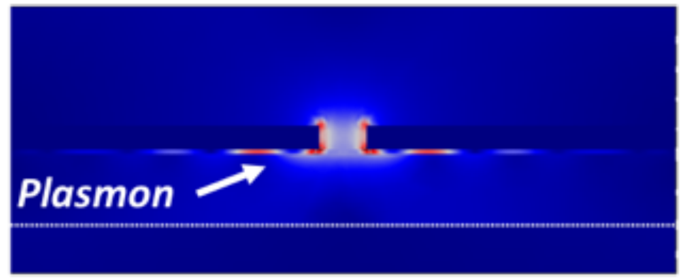
Method & Approach

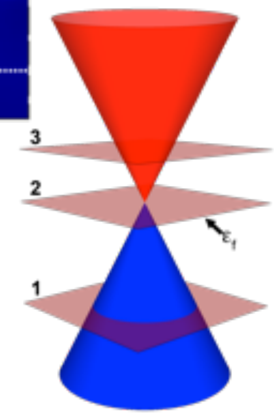
Multiphysics Materials





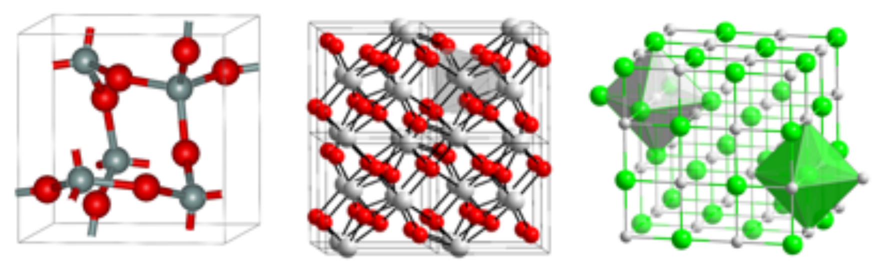
Electromagnetic Modeling



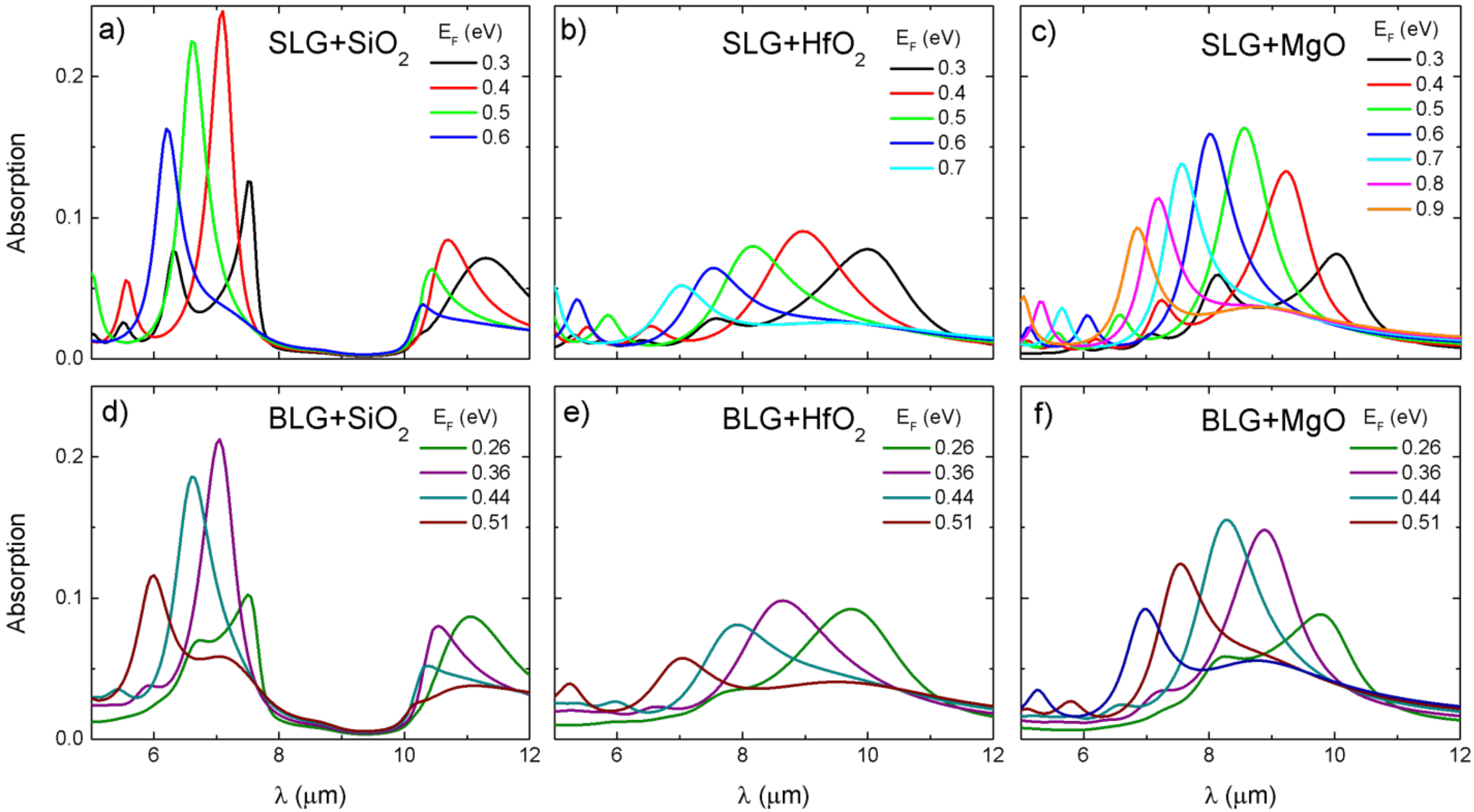


Assess Dielectric Influence

SiO_2 HfO_2 MgO



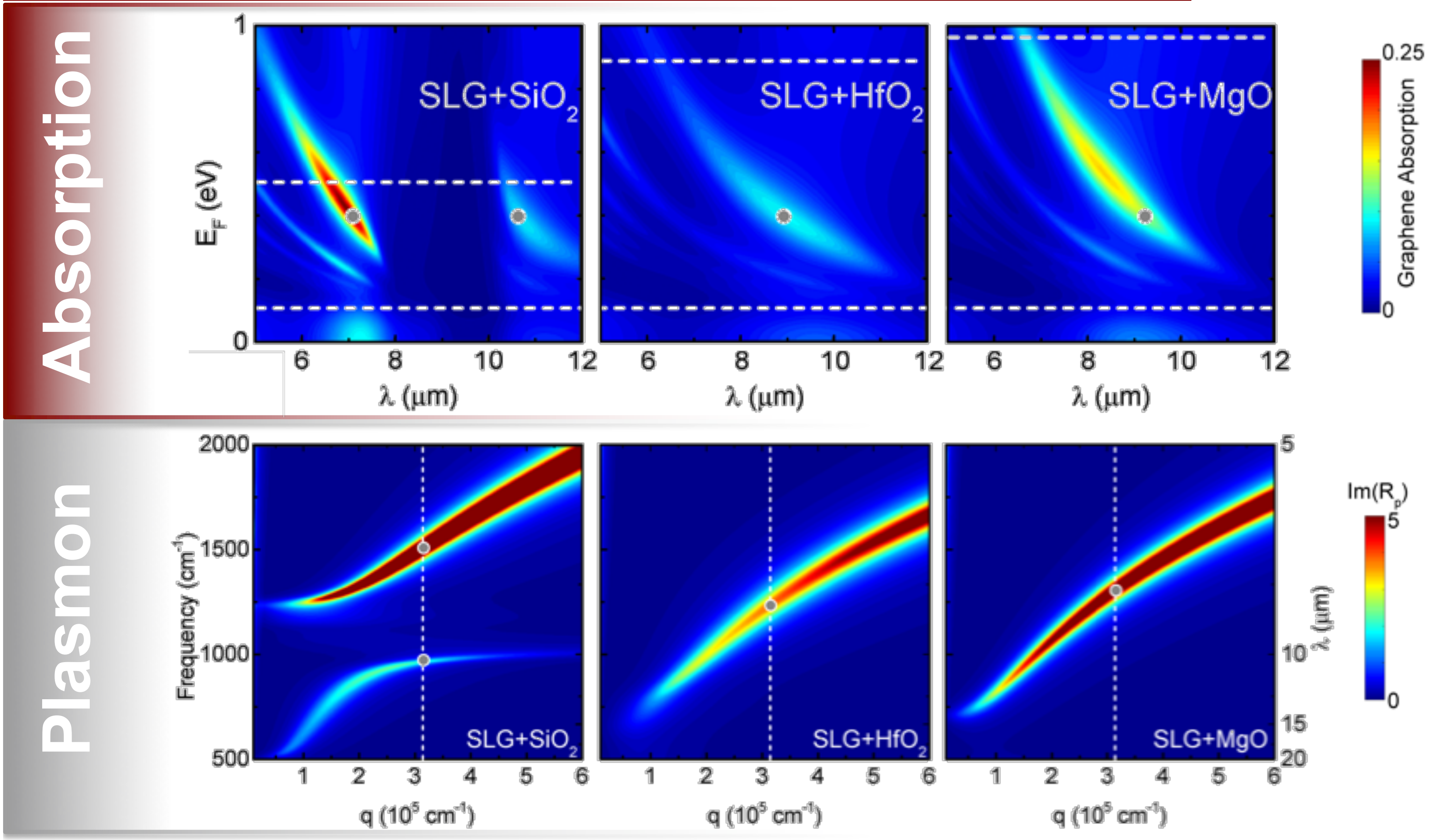
Tunabilty via…. Phonons?



1. **Tunable absorption >10% over micron ranges**
2. **Dielectric defines spectral response**

Phonons determine spectral band of response.

“Surrounding” Absorption



Takeaway: Plasmons drive absorption. Dielectric defines plasmon.

Goldflam, Fei, Ruiz, Howell, Davids, Peters, Beechem. Optics Express (25) 12400. 2017

Phonons & Optical Properties

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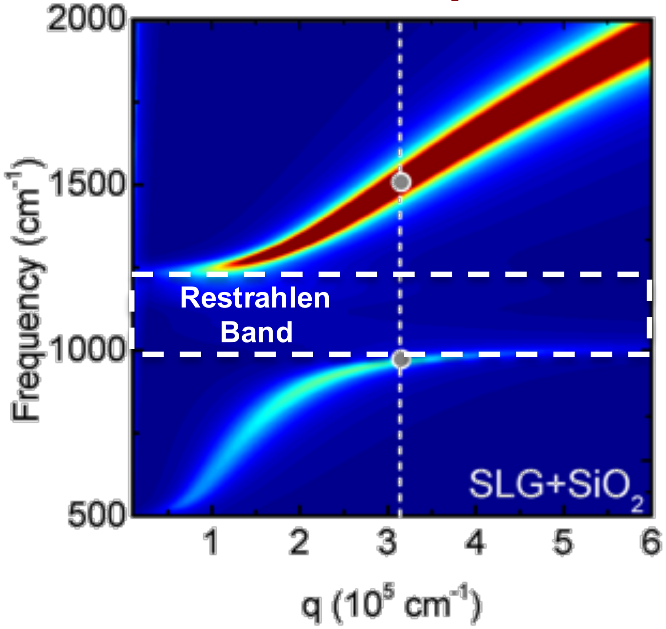
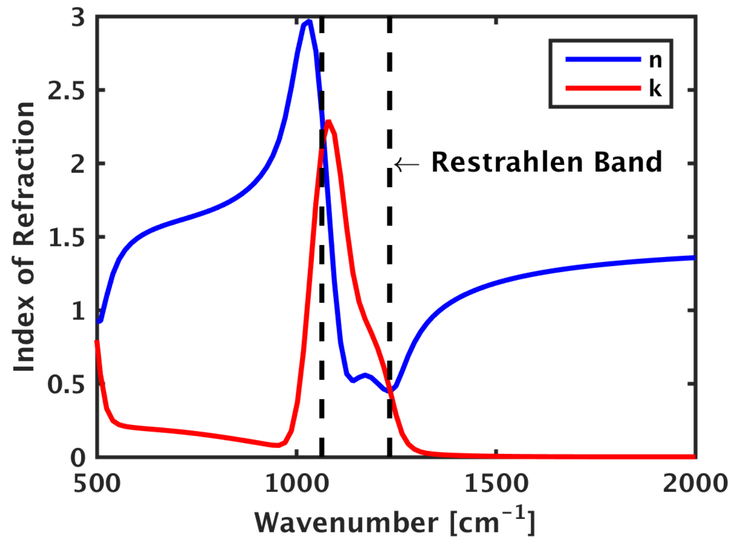
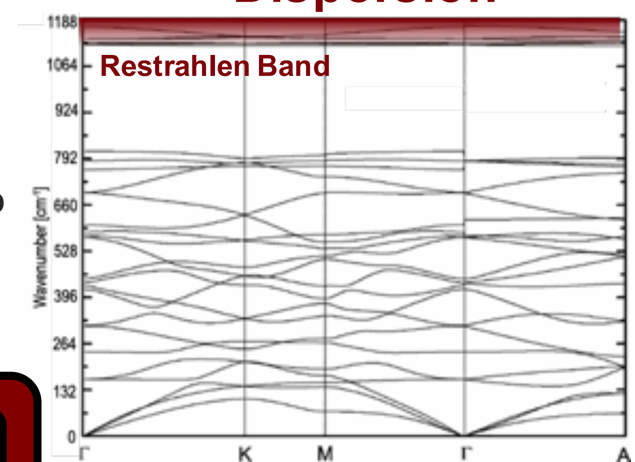
Plasmon Dispersion



SiO_2 Ind. of Refraction



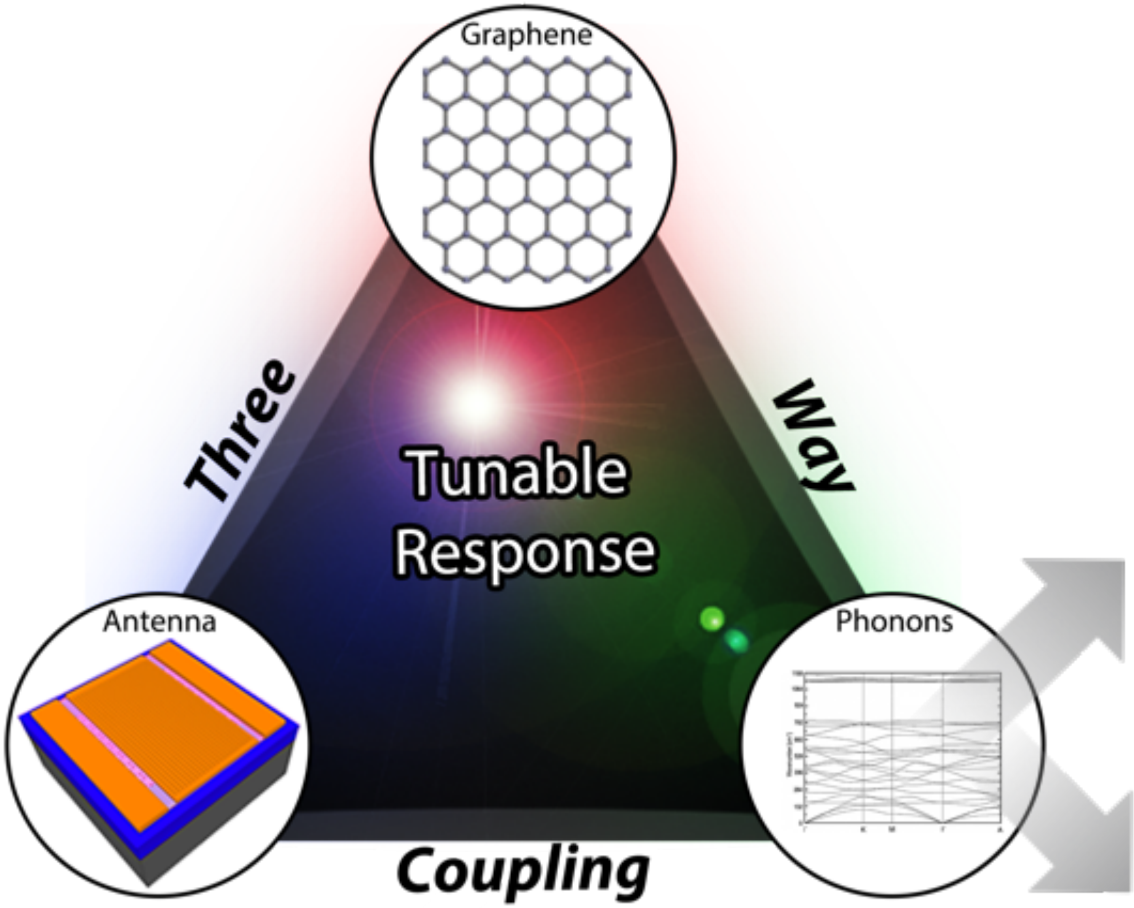
SiO_2 Phonon Dispersion

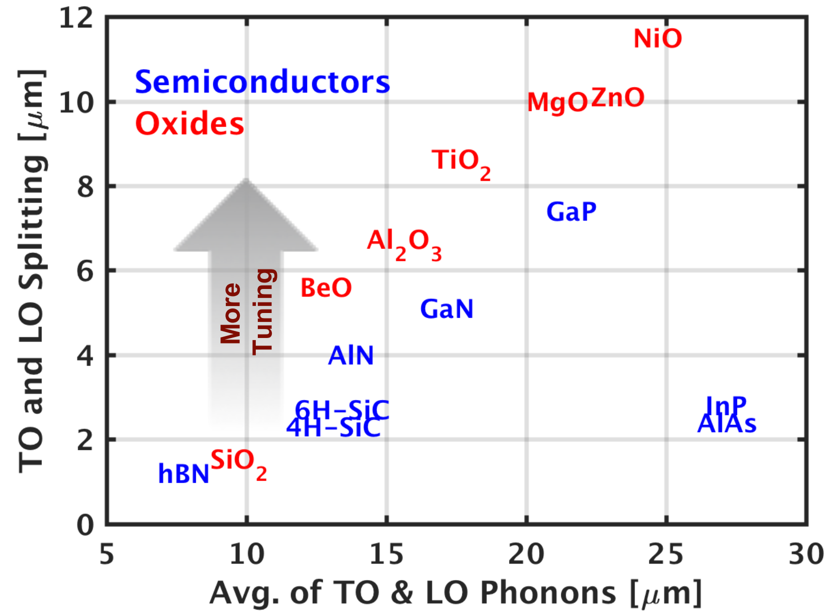


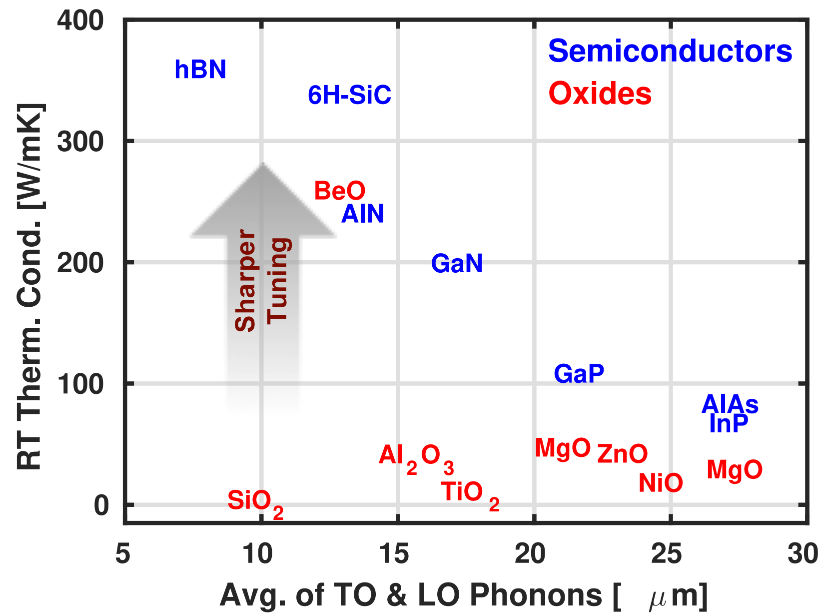
Ma and Garofalini. PRB. (73) 174109. 2006.

Takeaway: Phonons drive optical response

The Phonon Vista…..





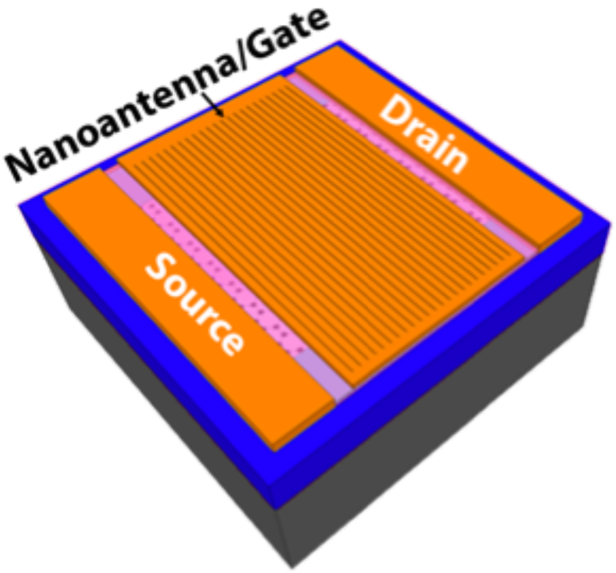


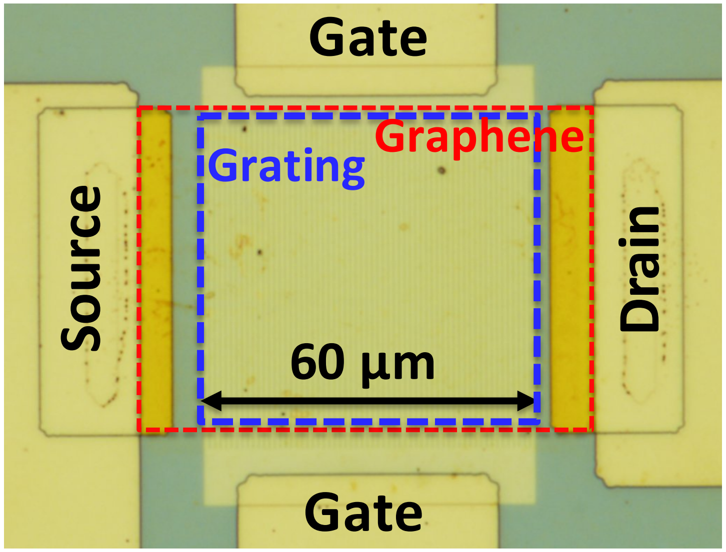
DESIGN QUESTION

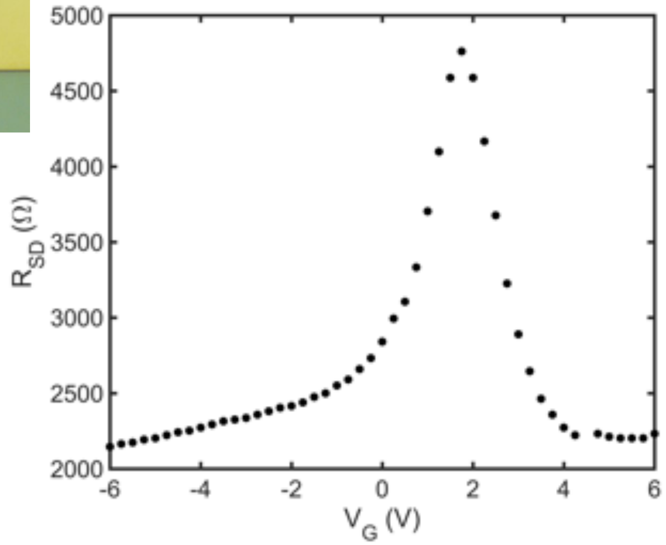
What “phonon” materials are best?

Real-World Demonstration

Objective: Create a tunable IR Filter





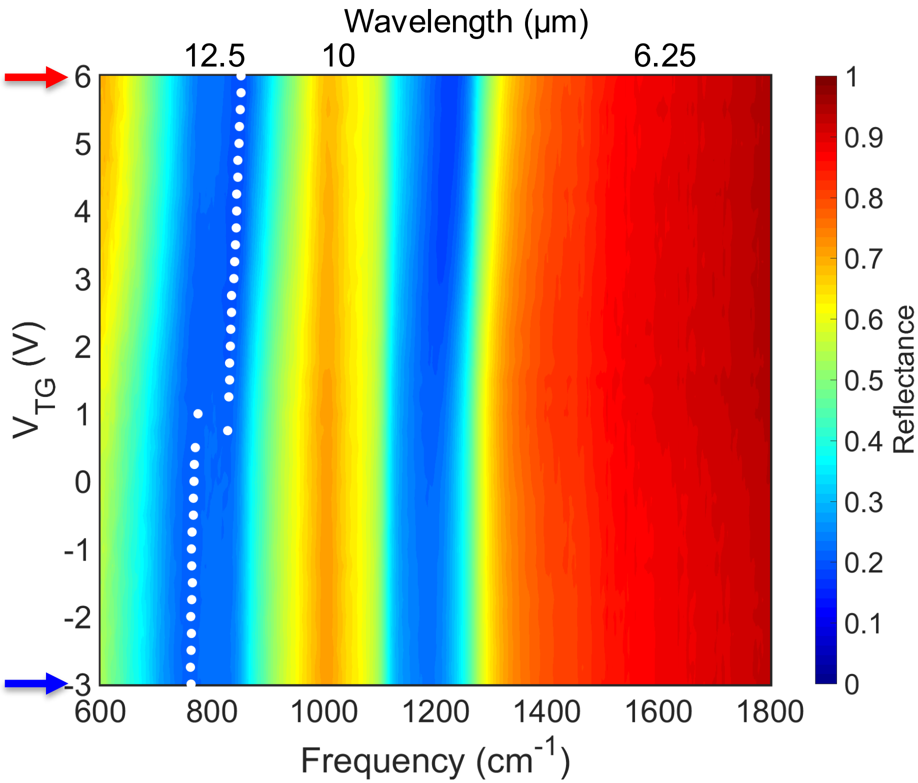


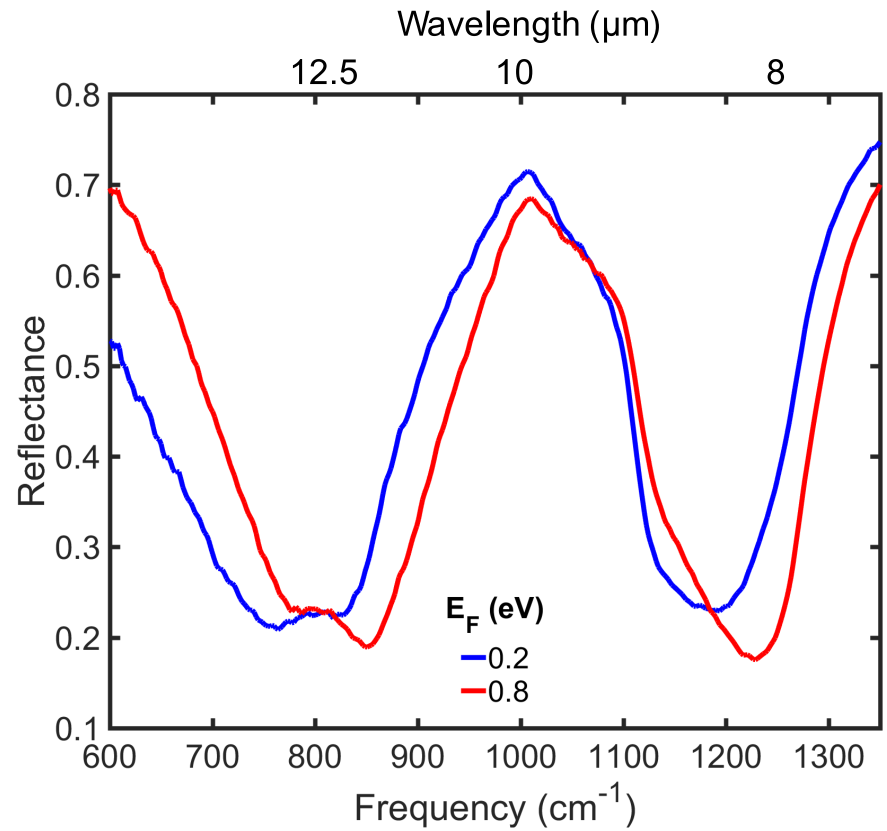
Designing for Utility

1. Scalable (continuous/unpatterned) graphene
2. Protected Graphene
3. No contact to graphene in active area

Goldflam, Ruiz, Wendt, Howell, Beechem. In Preparation.

Gate Tunable Reflectance

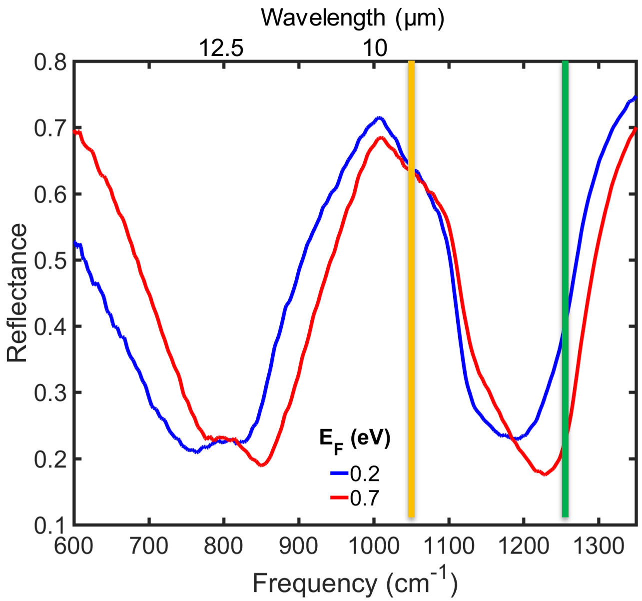


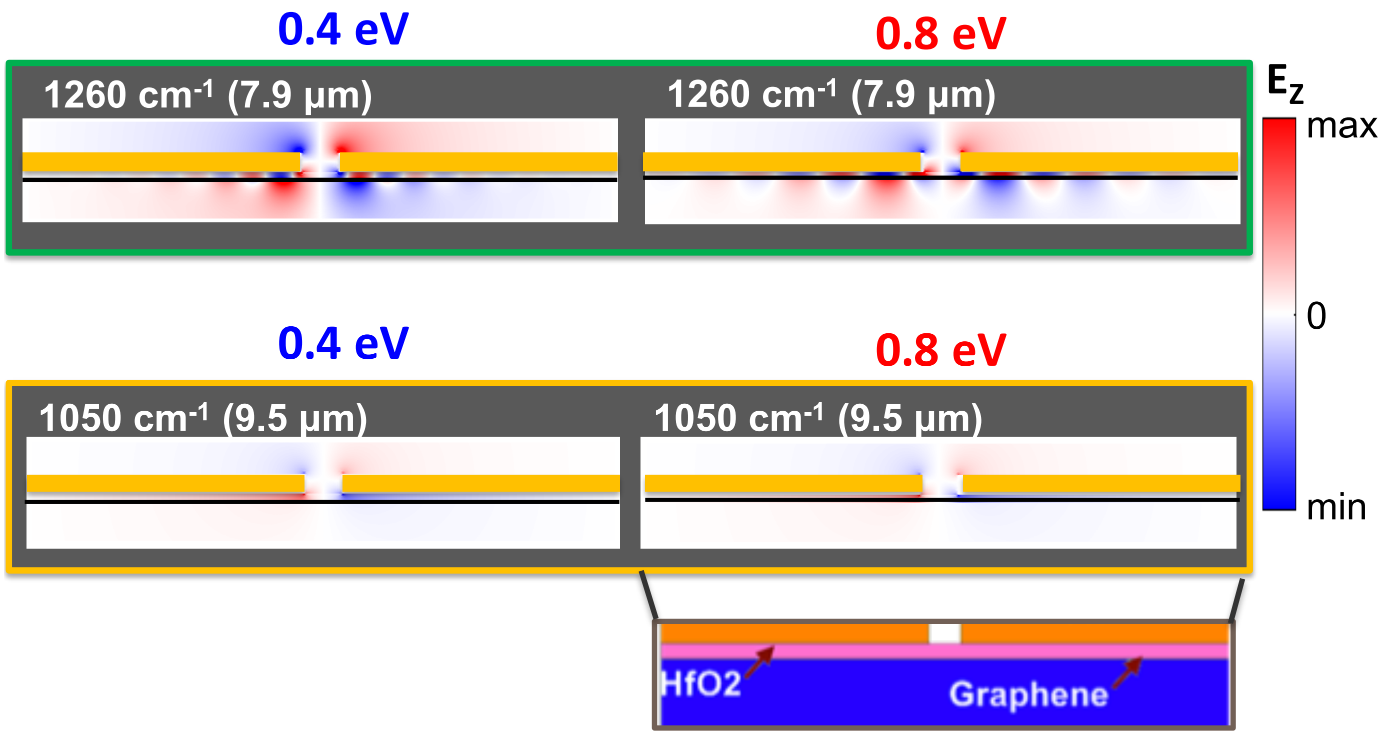


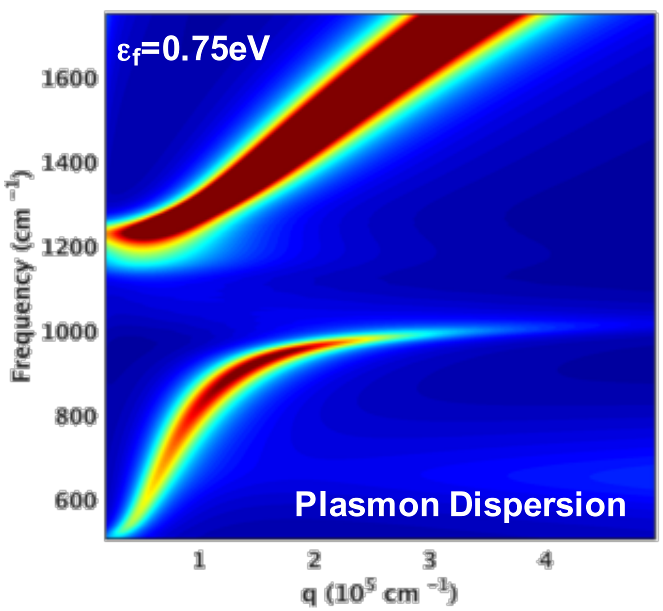
1. **Simultaneous dual-band tuning**
2. **Shifts in excess of 1 μm**

Dependent upon grating, dielectric, and dielectric thickness

Why does it work?







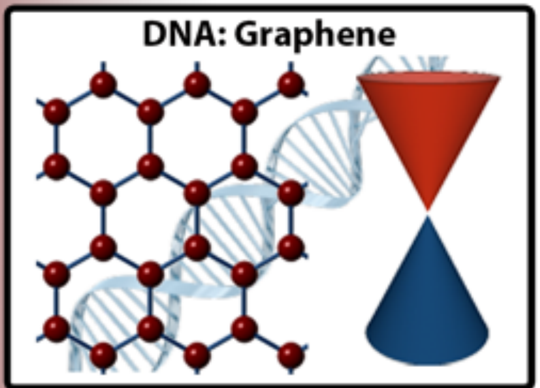
Operational Mechanism

1. Tuning occurs when plasmon is excited
2. Plasmon dispersion defined by surrounding dielectric
3. Spectral selectivity based on dielectric

Goldflam, Ruiz, Wendt, Howell, Beechem. In Preparation.

Vision & Postulates

Vision



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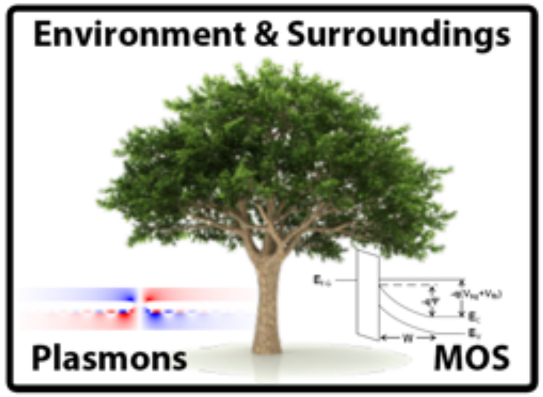

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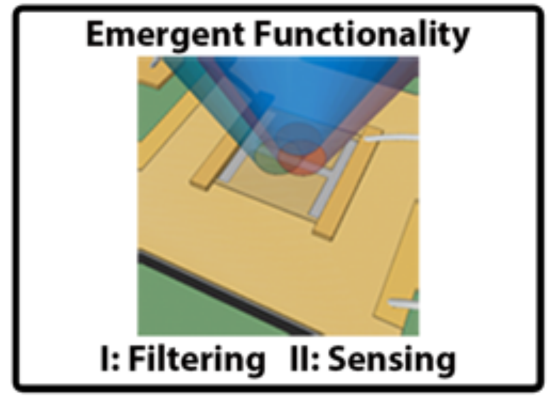

Postulates

Tunable IR Properties

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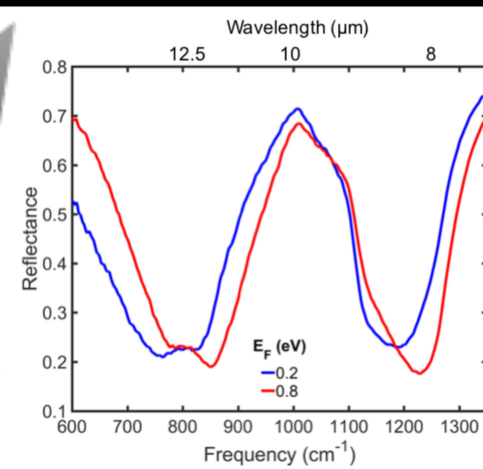
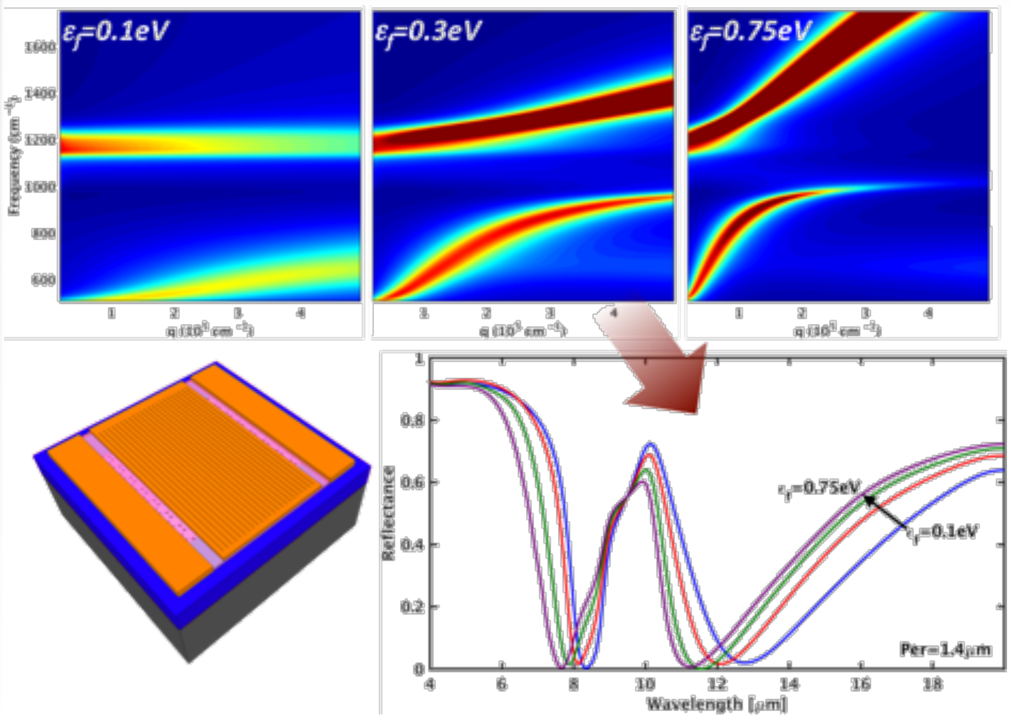
2. Graphene changes when in contact with the real world. → *Plasmons*
3. These changes are a means of capitalizing on graphene's DNA.



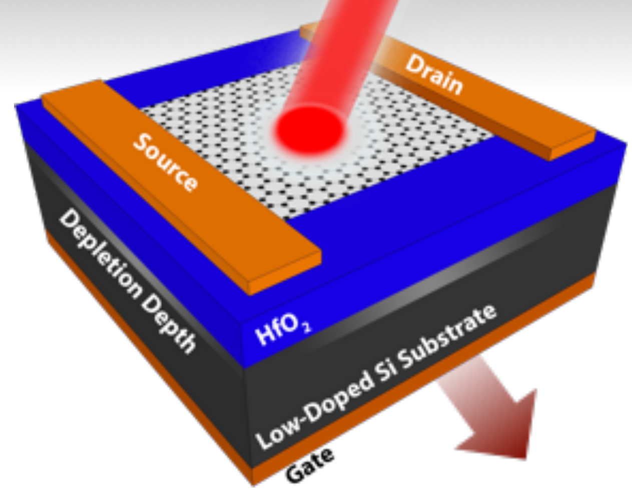
Premise & Path

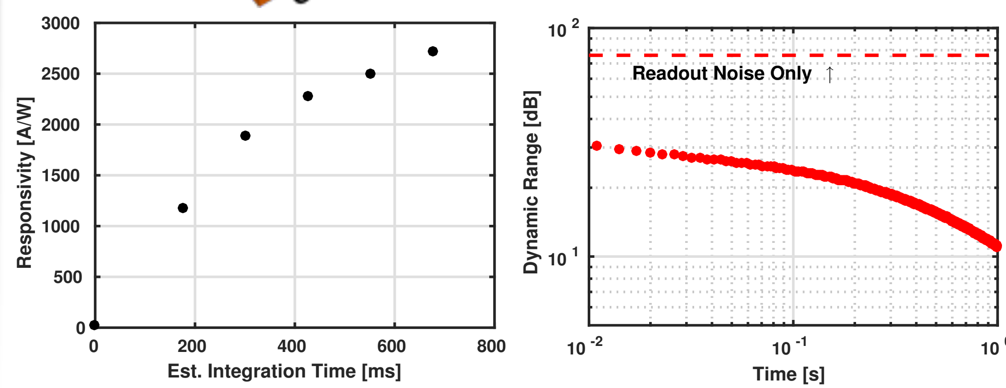
PREMISE: Leverage materials surrounding graphene to cultivate functionality unavailable with traditional approaches.

Tunable Light Filters



Photodetectors





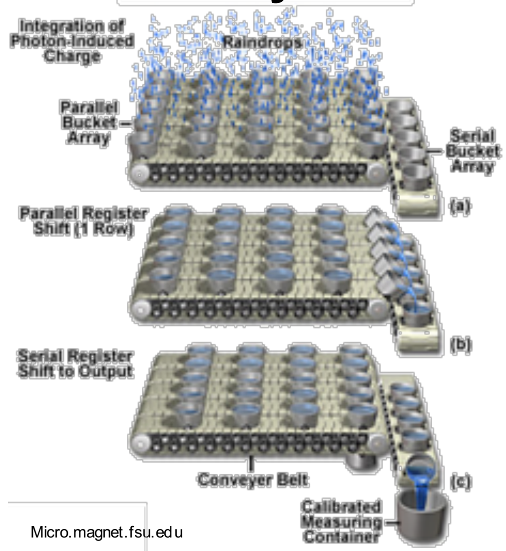
How do photodetectors work?

CCD's

Where you see them…

High Point Scientific

How they work….



Micro.magnet.fsu.edu

Pro

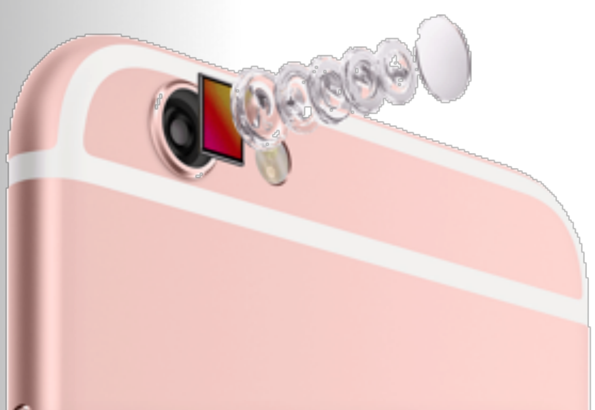
- Full frame exposure
- Large optical area
- Signal integration

Con

- Charge transfer
- Christmas light problem
- Expansion to other materials

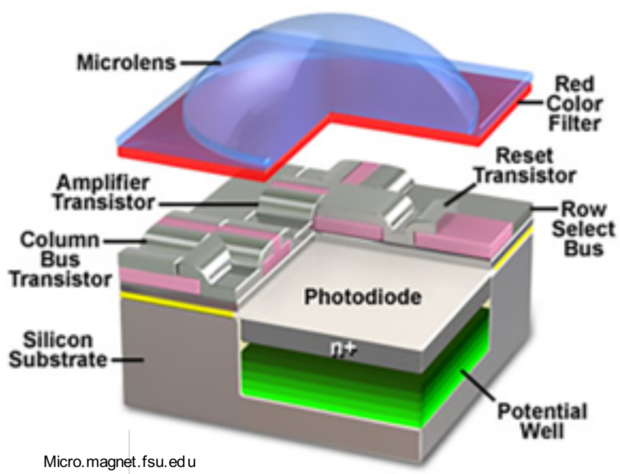
CMOS Sensors

Where you see them…



Cult of Mac

How they work….



Micro.magnet.fsu.edu

Pro

- Speed
- ”Smart” pixels
- Numerous read-out channels

Con

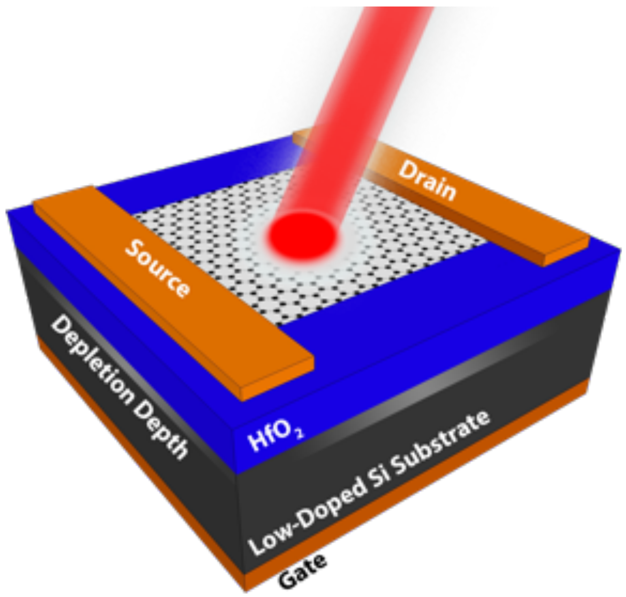
- Small optical area
- Sequential exposure
- Expansion to other materials

How do I get the best of both worlds?

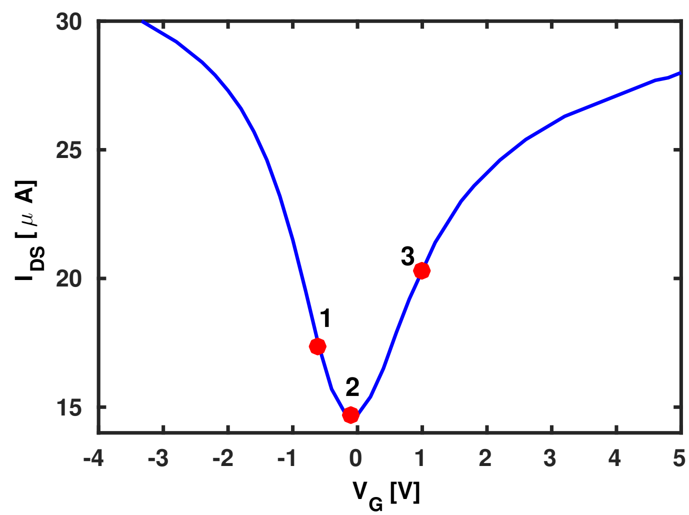
Sandia National Laboratories

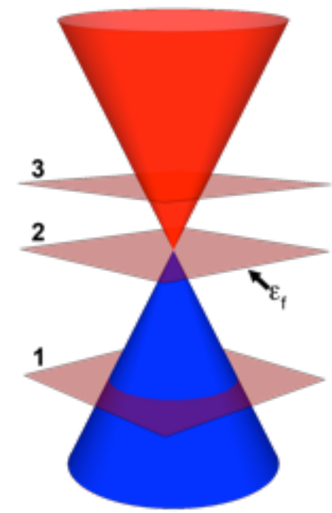
Objective: Photodetector with advantages of both CCD and CMOS

Premise: Transparent Amplifier

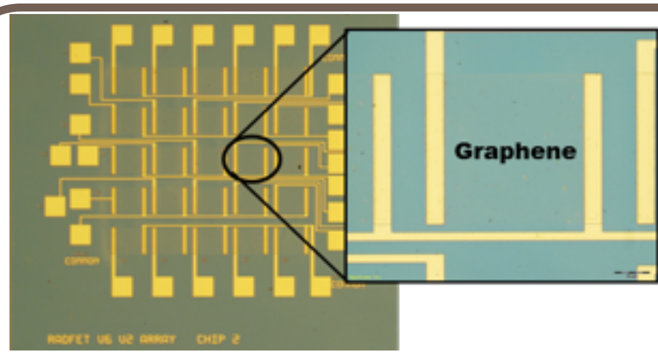


Tool: Graphene Charge Sensor





Graphene does not absorb light



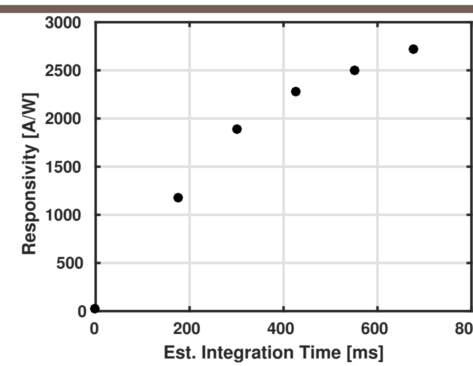
Fabricate

↓

Test (VIS)

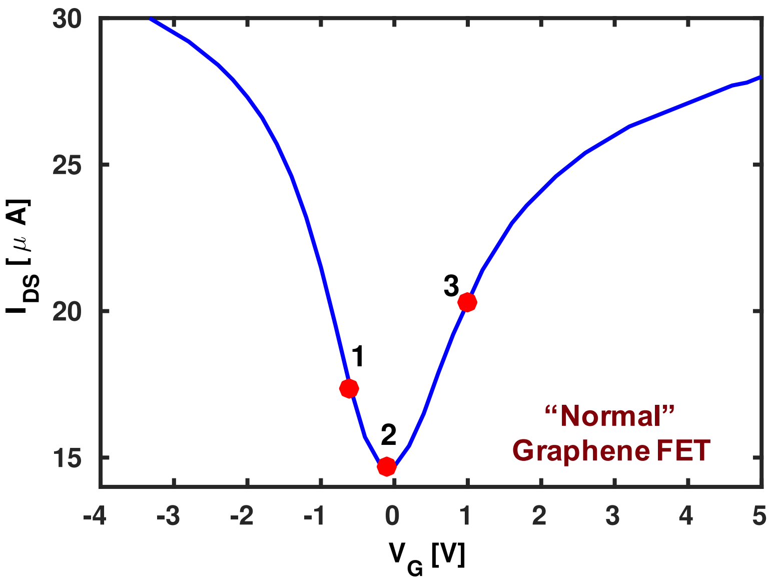
↓

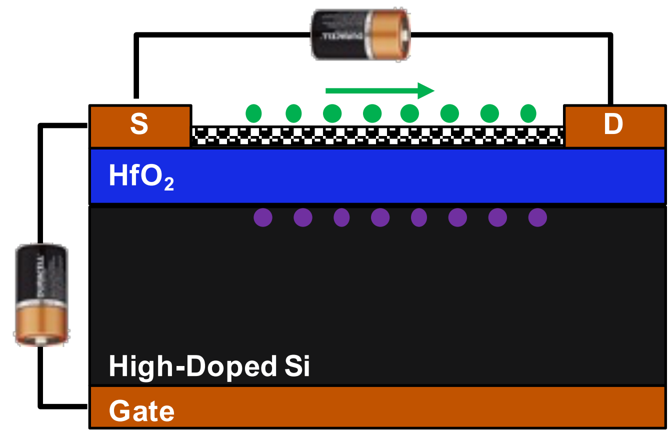
Cull Physics



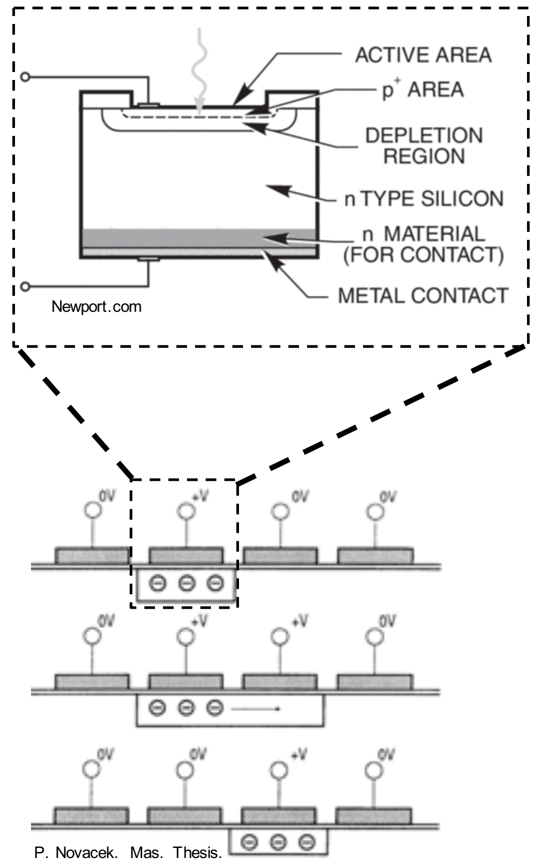
Howell, Ruiz, Davis, Harrison, Smith, Goldflam, Martin, Martinez, Beechem. Scientific Reports. In Press.

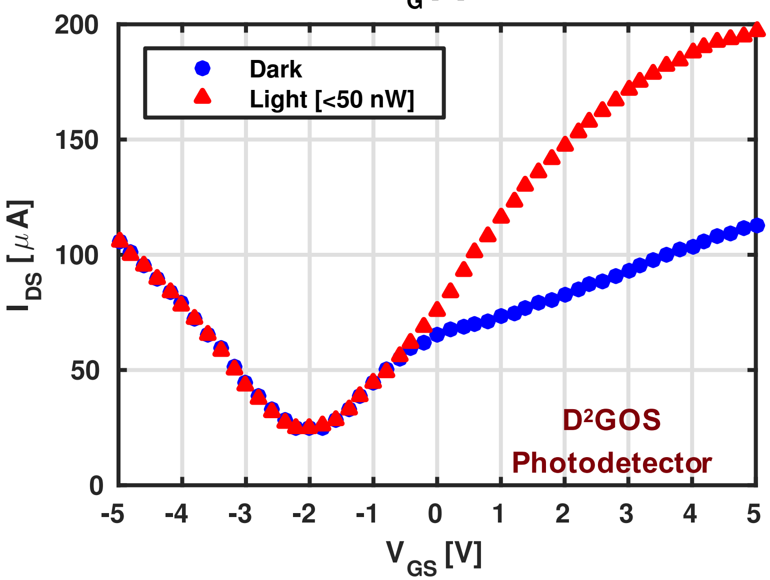
Accumulation vs. Depletion

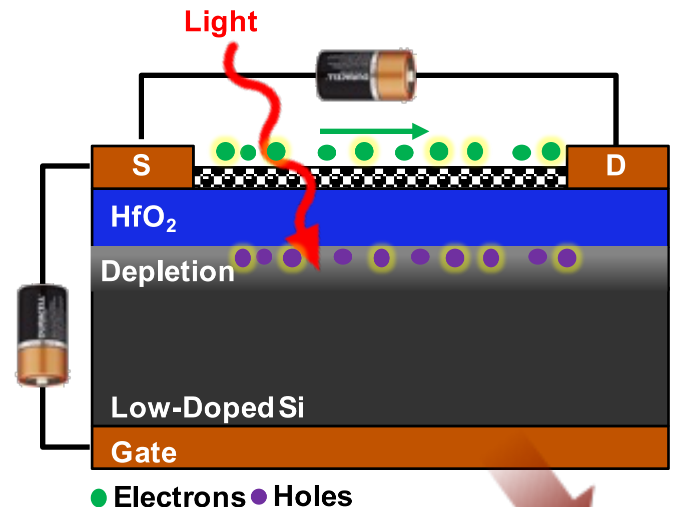




Traditional CCD





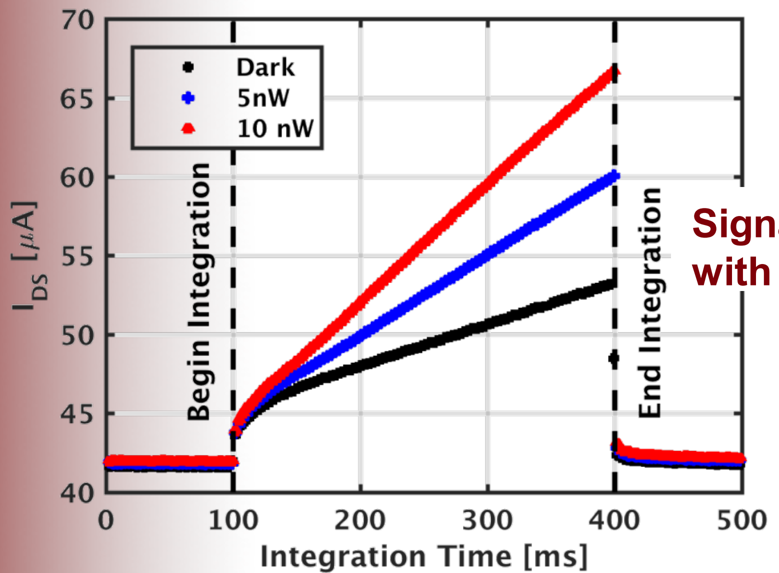


$$I_{ph} = q(\mu n_{ph})\frac{V_{ds}W}{L}$$

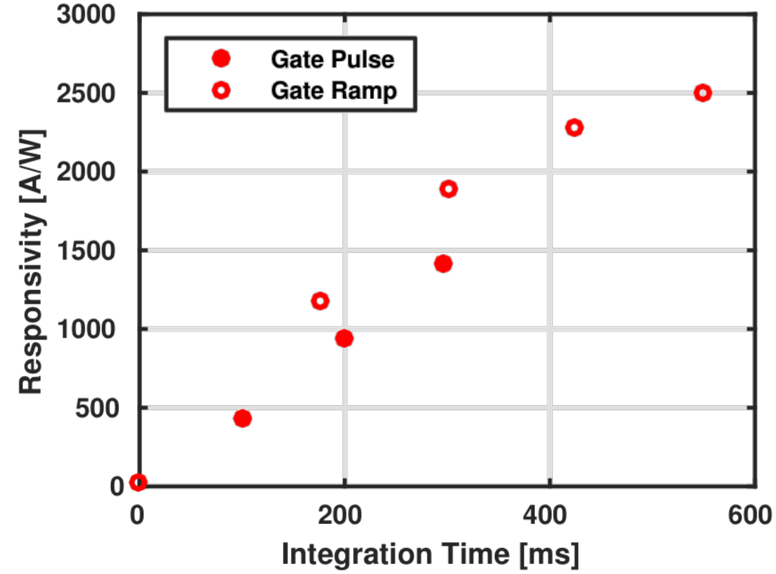
Howell, Ruiz, Davis, Harrison, Smith, Goldflam, Martin, Martinez, Beechem. Scientific Reports. In Press.

How well does it work?

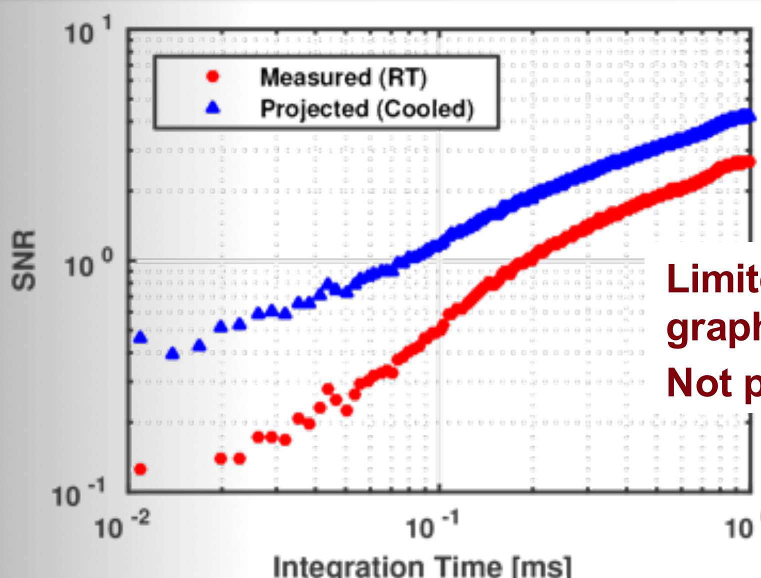
Sensitivity



Signal integration with constant readout

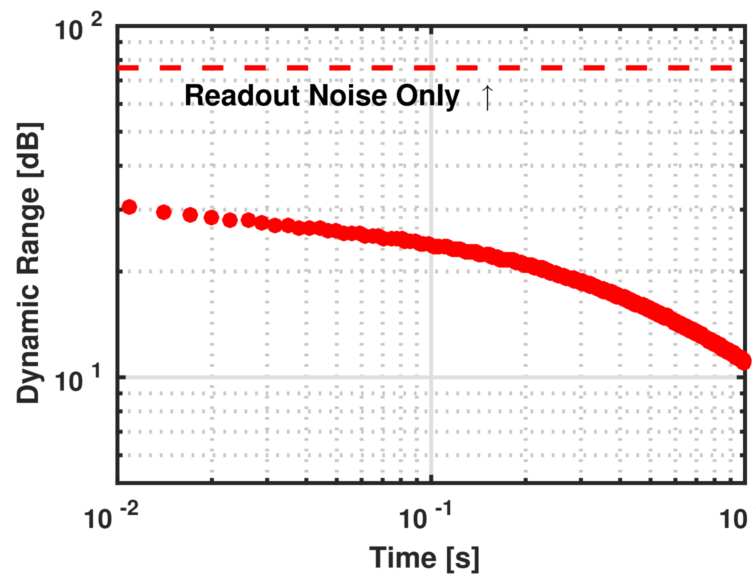


Room Temp. Metrics



Limited by interface and graphene quality…

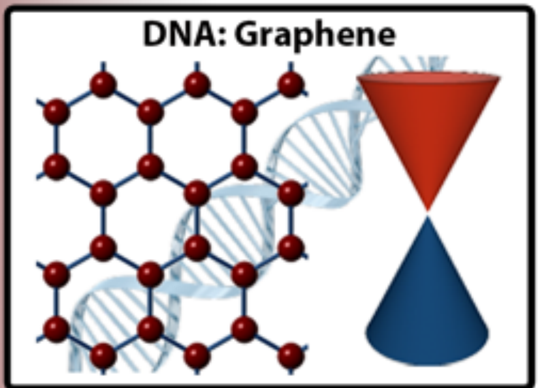
Not physical limits.



Howell, Ruiz, Davis, Harrison, Smith, Goldflam, Martin, Martinez, Beechem. Scientific Reports. In Press.

Vision & Postulates

Vision



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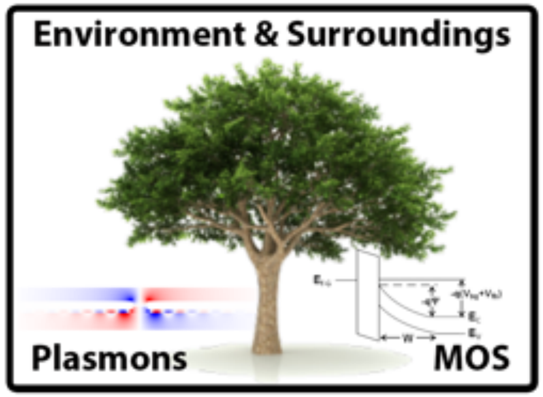

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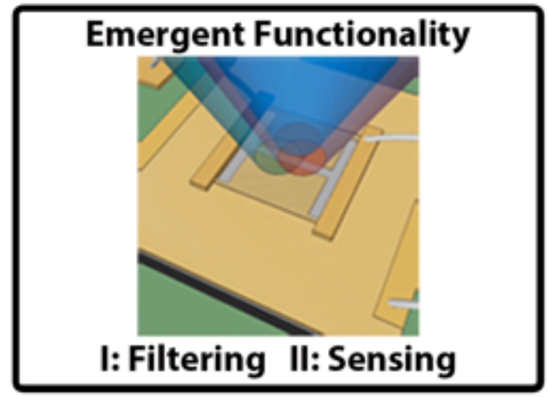
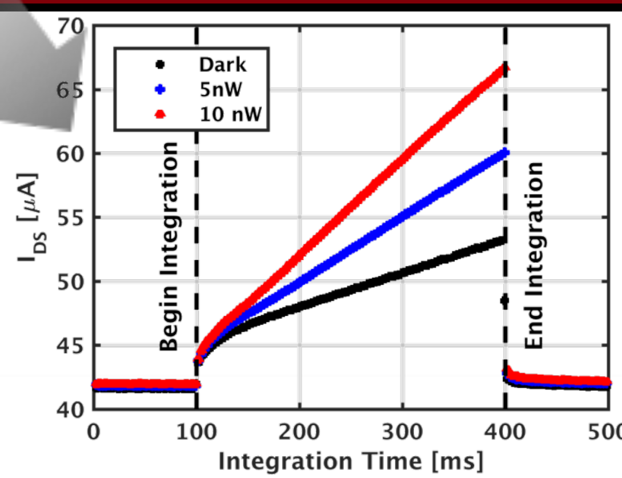


Postulates

Readout with integration

1. Graphene's "DNA" provides functionality traditionally unavailable.
2. Graphene changes when in contact with the real world. → *Photogating*
3. These changes are a means of capitalizing on graphene's DNA.



Look us Up

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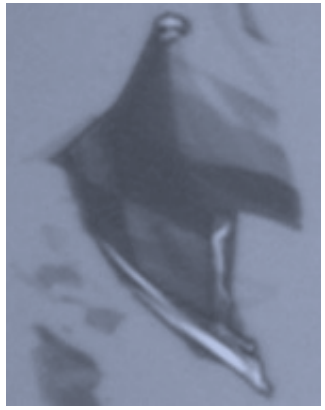
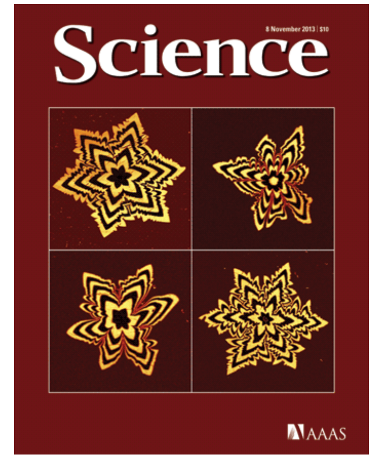
Staff, Post-Doc, Fellowships, Internships and Collaborations

``Brands" of Graphene

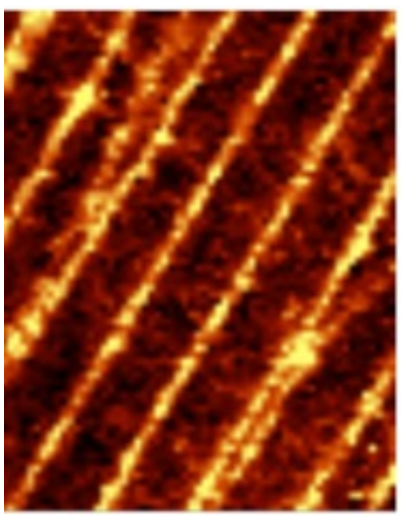
Exfoliated

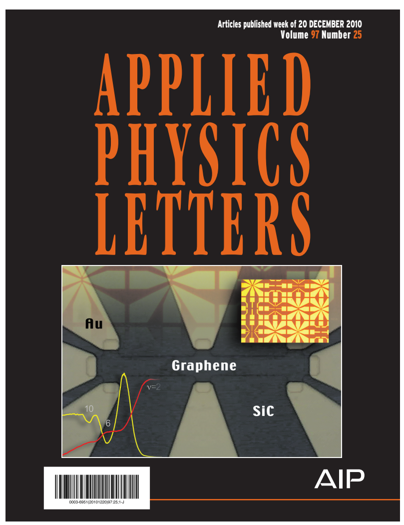


Copper Based CVD

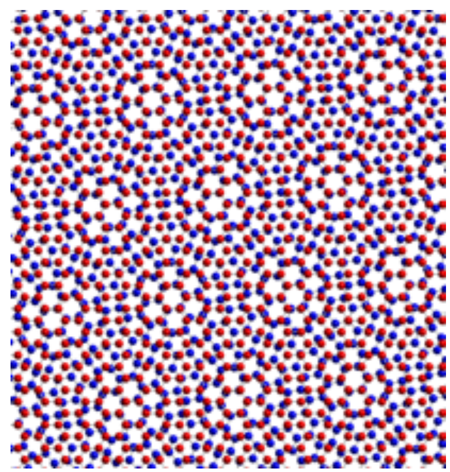


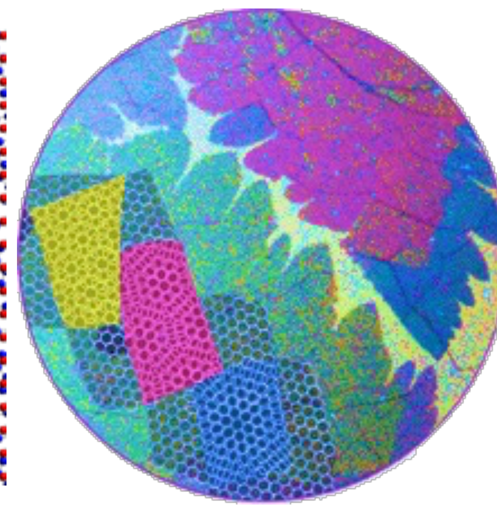
Epitaxial on SiC





Twisted Bilayer Graphene





Epi: Pan, Howell, Ohta, et al. APL (97) 252101. 2010.

CVD: Hao et al. Sci. (342) 720, 2013.