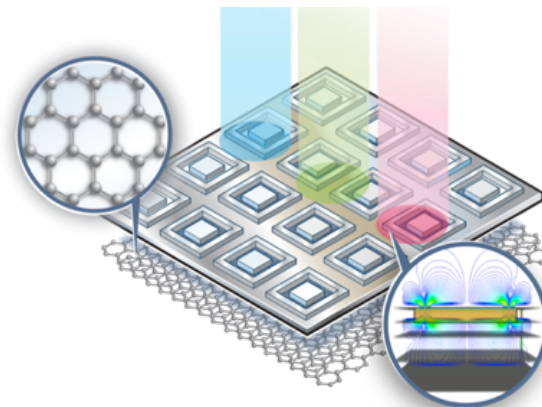
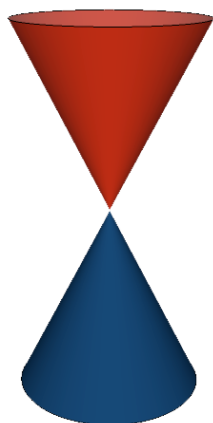
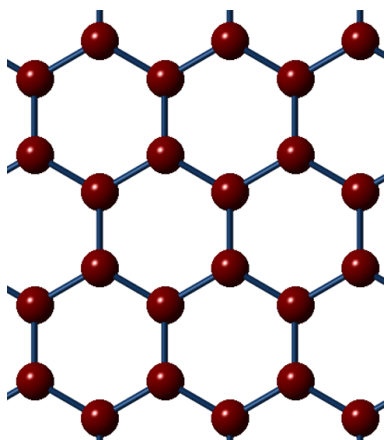


Exceptional service in the national interest



Infrared Chameleon:

Graphene, Phonons, & the Impact of their Interplay on Photodetection

Thomas Beechem

Team:

David Peters

Michael Goldflam

Steve Howell

Taisuke Ohta

John Nogan

Anthony McDonald

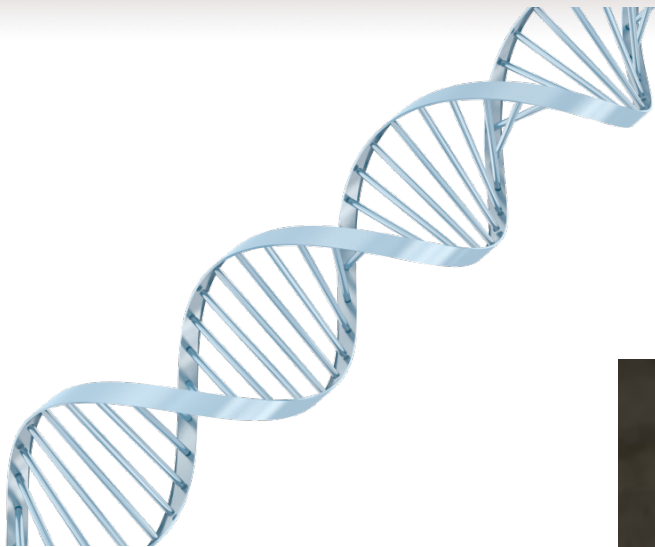
Allister Hamilton

R. Shaffer, I. Ruiz



What makes me, me?

Genetic, Intrinsic



Environment

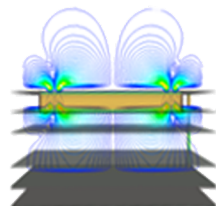
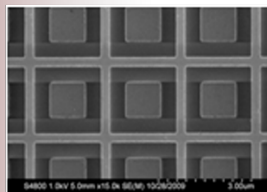


Takeaway: We are who we are **AND** what we're around.

Vision & Challenge

Vision

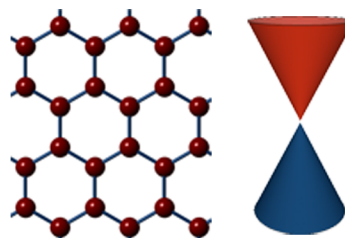
Nanoantenna Field Enhancement



Increased Absorption

+

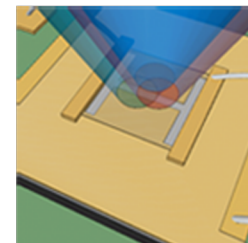
Graphene



Tunable Response

=

Tunable Detector



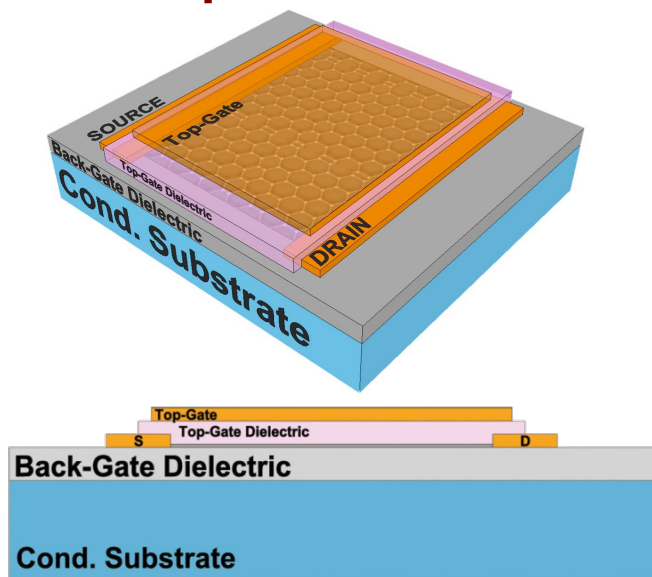
Hyperspectral Pixel

Challenge

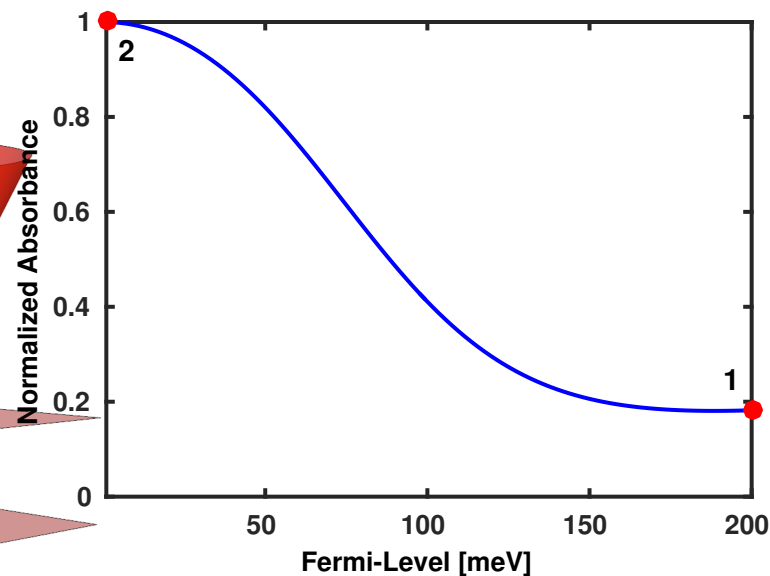
1. Can graphene absorb enough light?
2. Can its absorption be tuned?
3. Can the photogenerated charge be collected?

DNA: Graphene Tunability

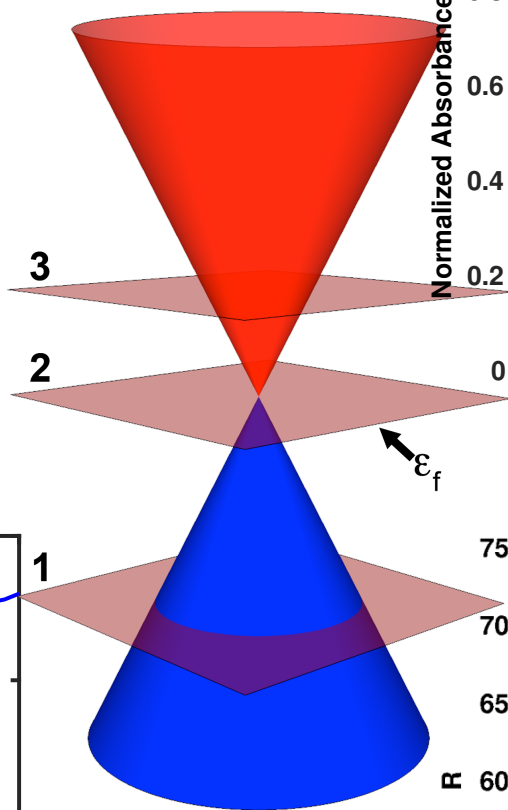
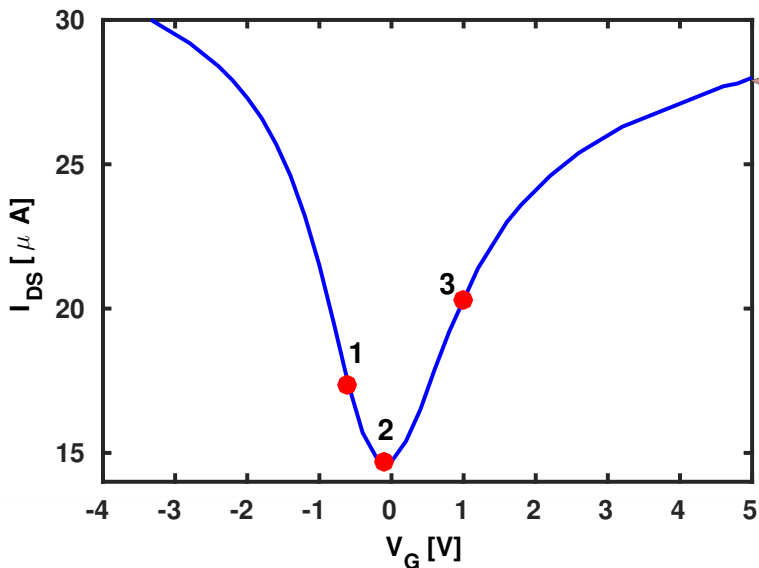
Graphene Transistor



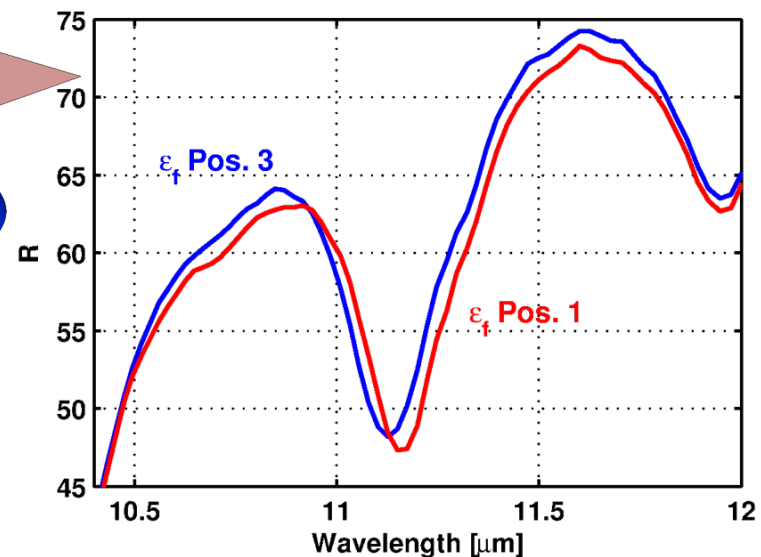
Tunable Absorber



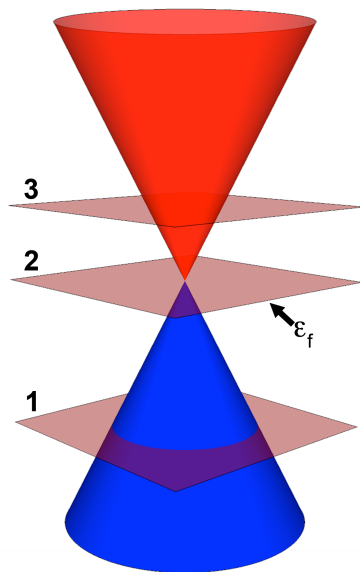
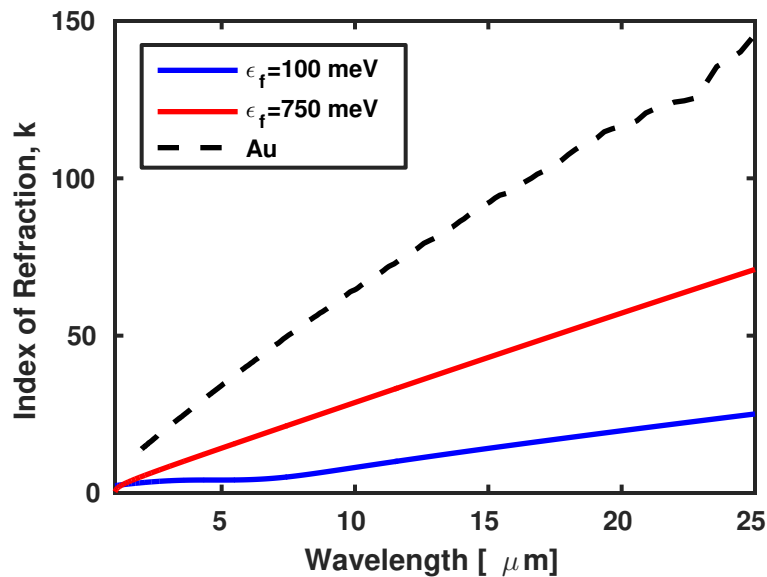
Tunable Resistance



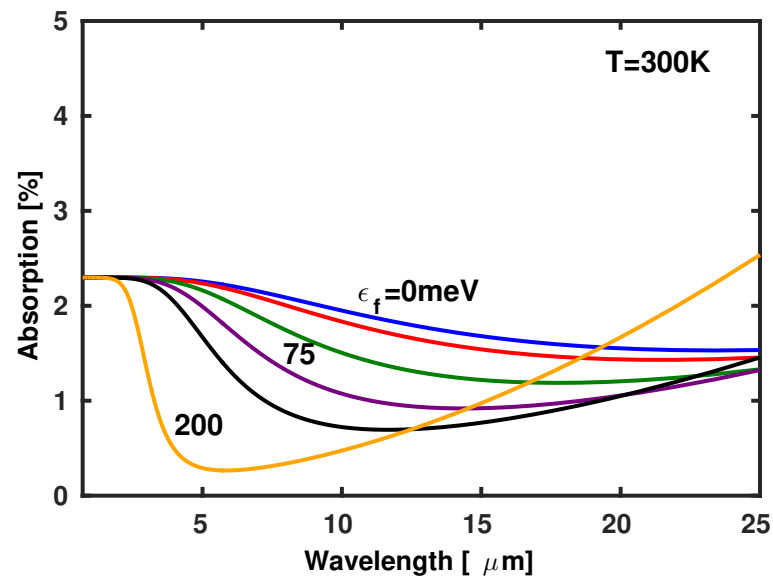
Tunable Nanoantenna



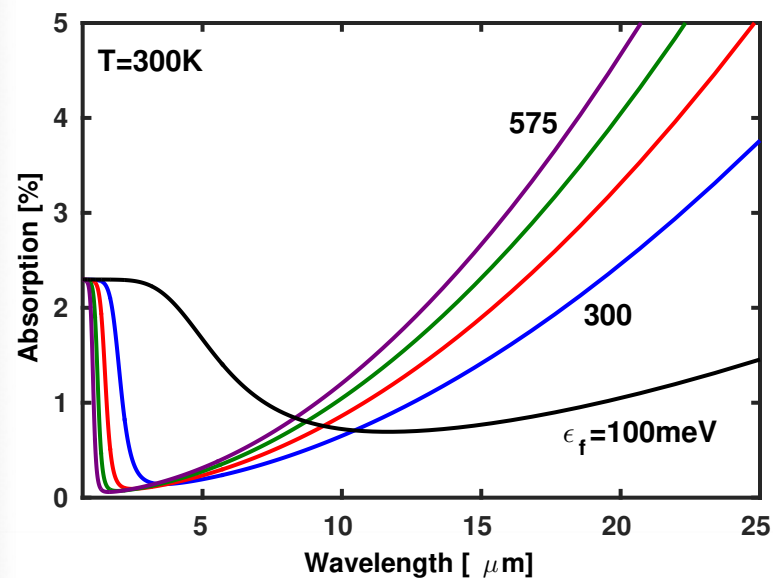
Myth: Graphene Absorbs 2.3%



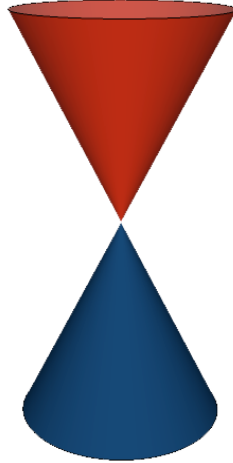
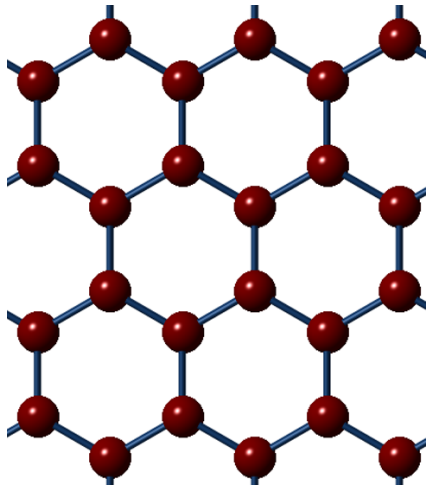
Interband



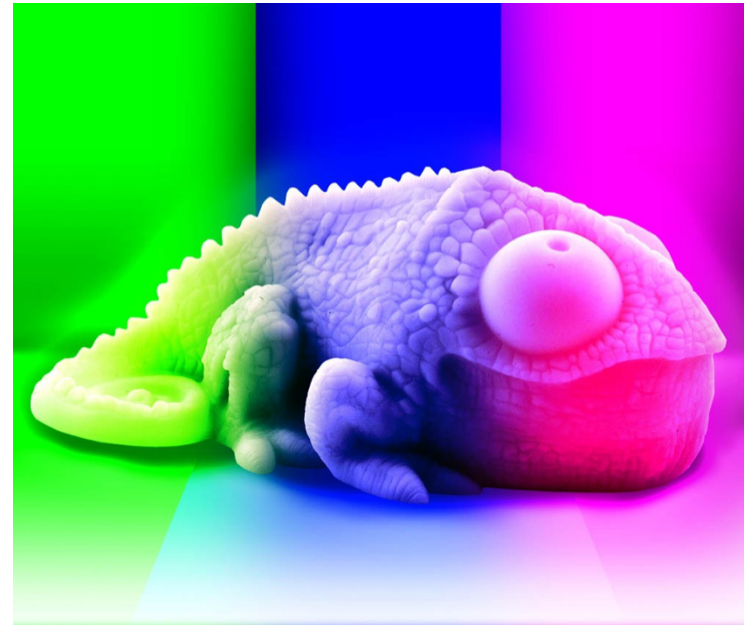
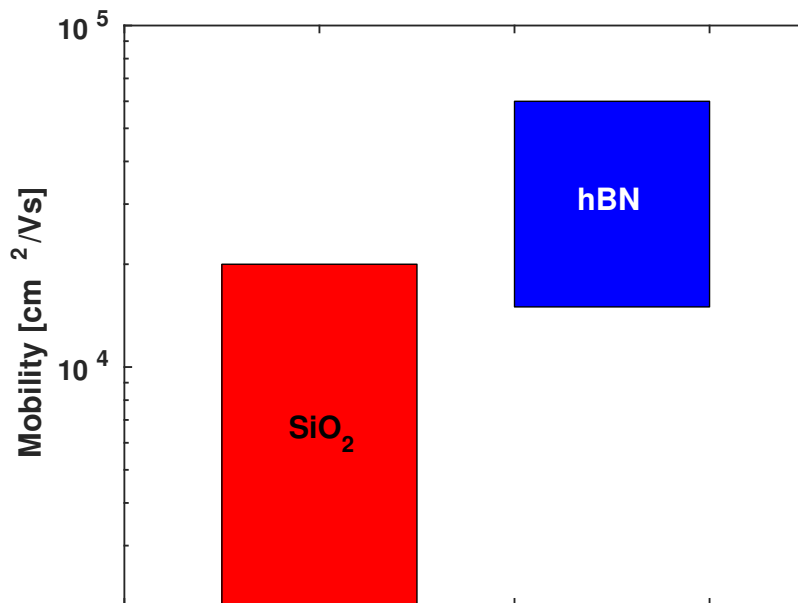
Intraband



Env.: Graphene & Peer Pressure

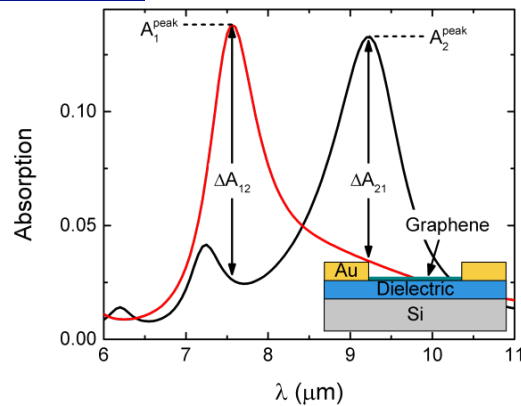
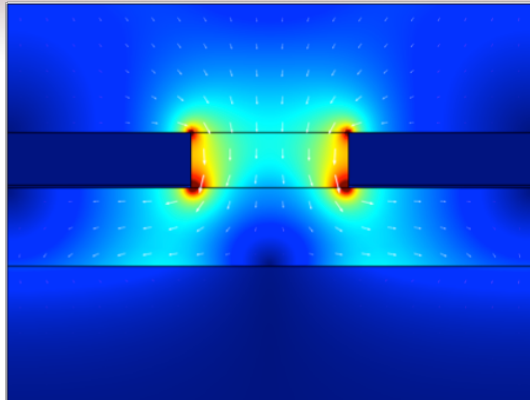


D.A.R.E.®

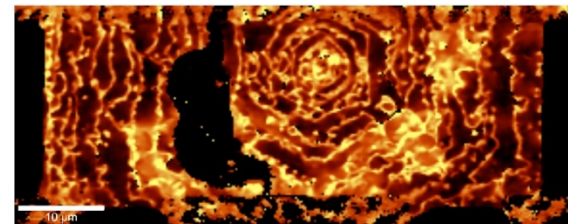
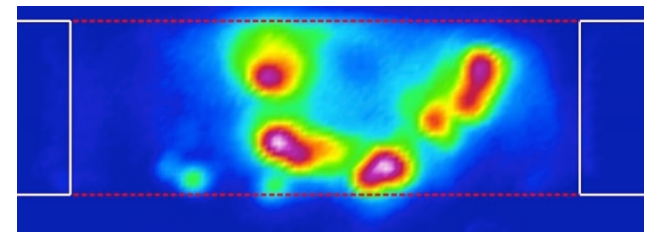
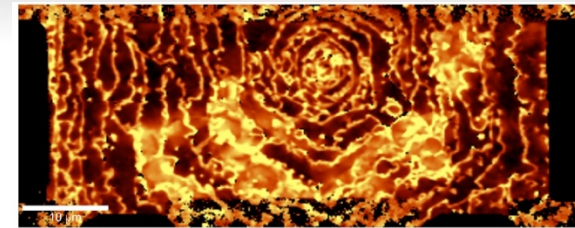


PREMISE: Graphene enabled hyperspectral detection dictated by material itself (DNA) & those adjacent (environment).

Light Absorption

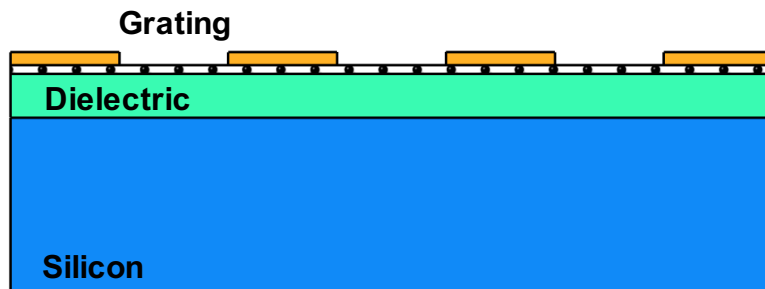
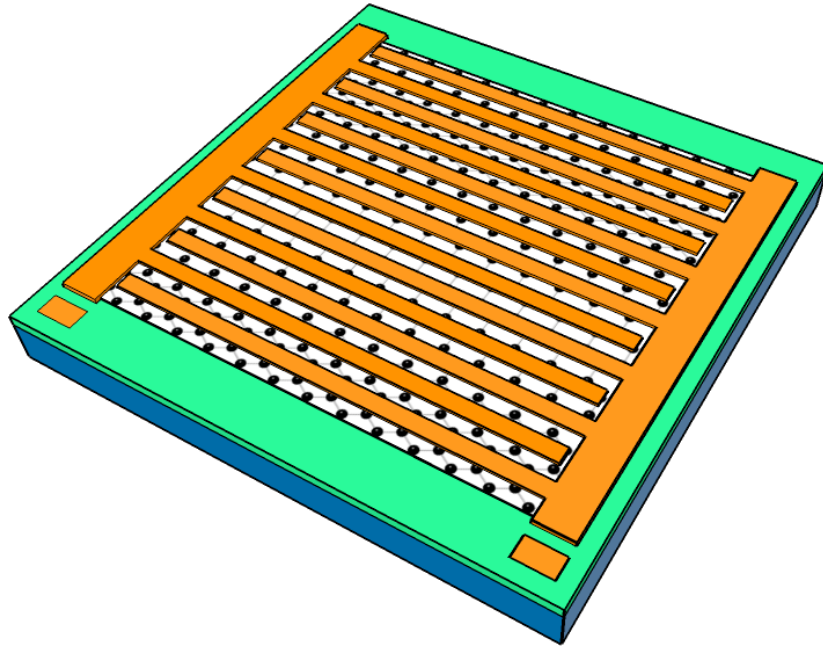


Charge Collection

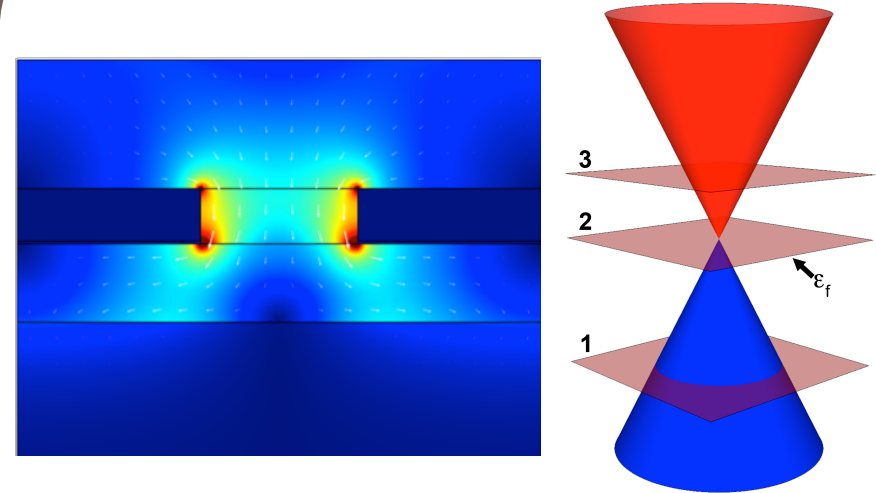


Method & Approach

Architecture & Material Silos

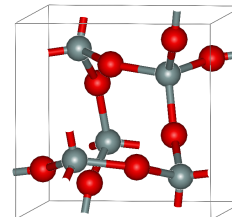


Electromagnetic Modeling

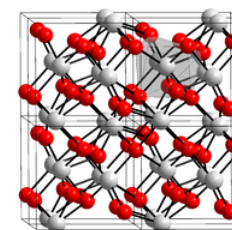


Assess Dielectric Influence

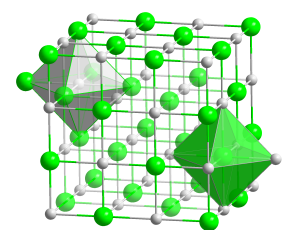
SiO_2



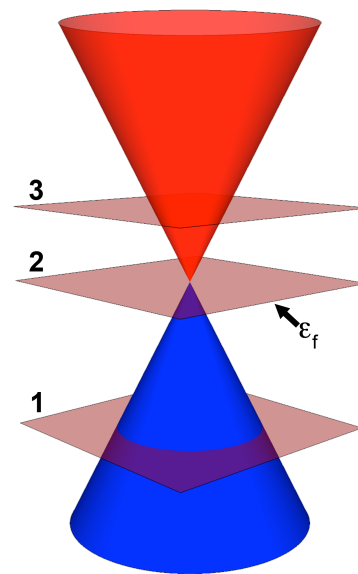
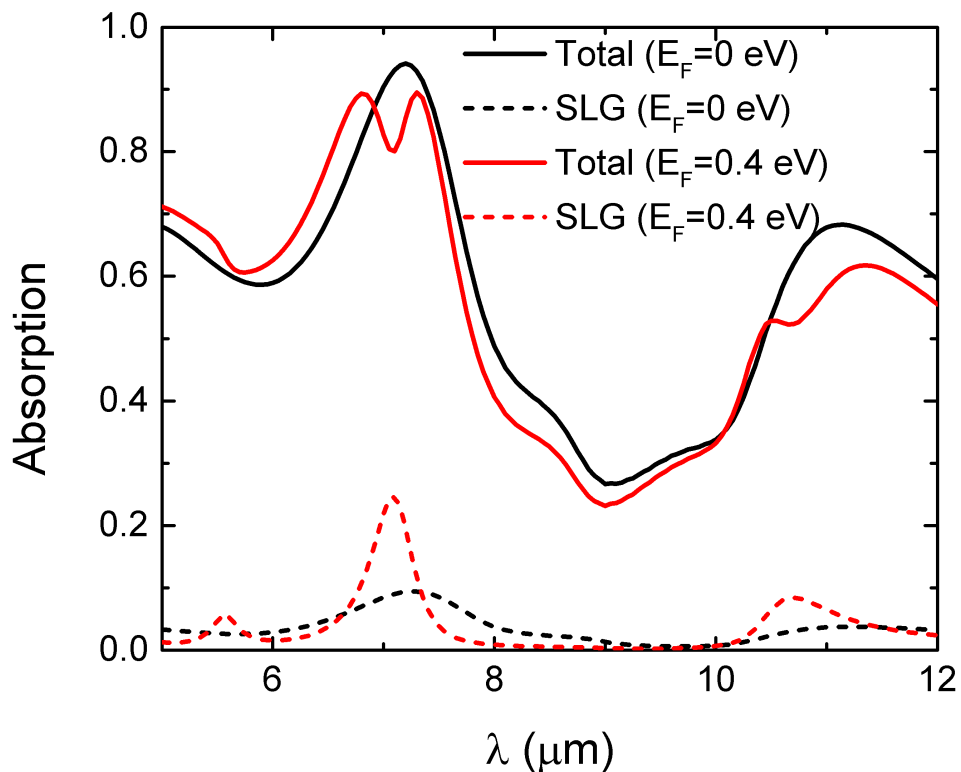
HfO_2



MgO



Does the Antenna Work?



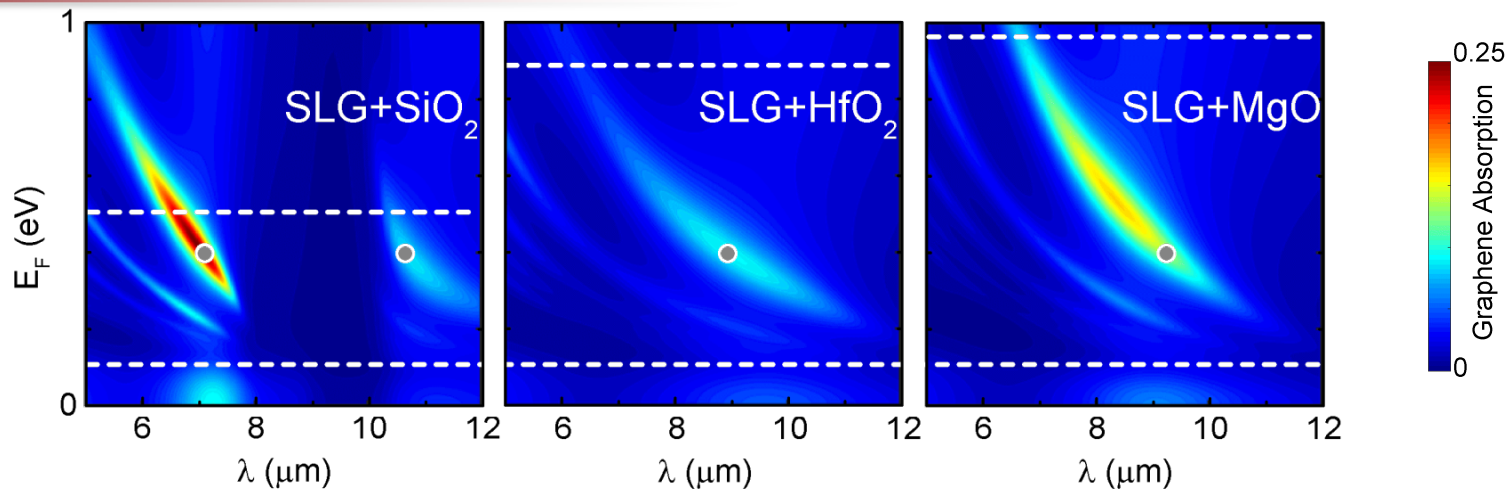
1. 10x increase in absorption over “as is” graphene BUT

2. Most absorption occurs in substrate

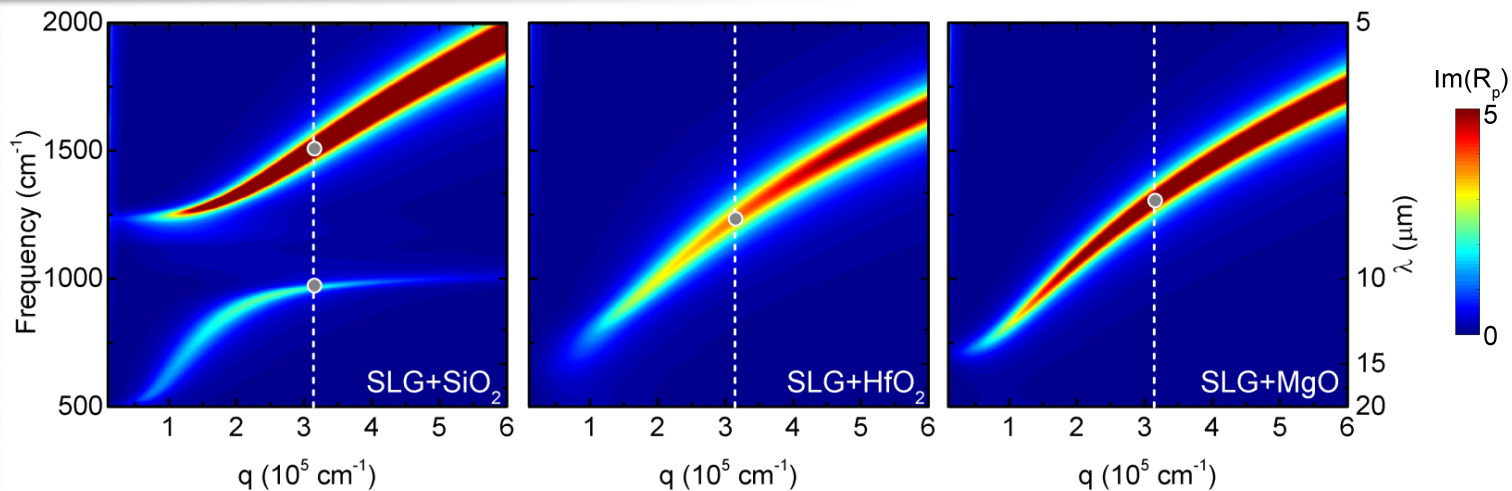
Must design nanoantenna for absorption IN graphene

“Surrounding” Absorption

Absorption



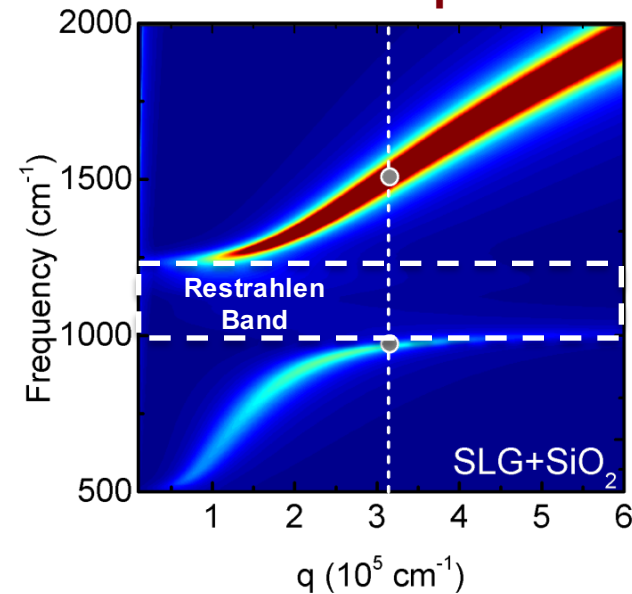
Plasmon



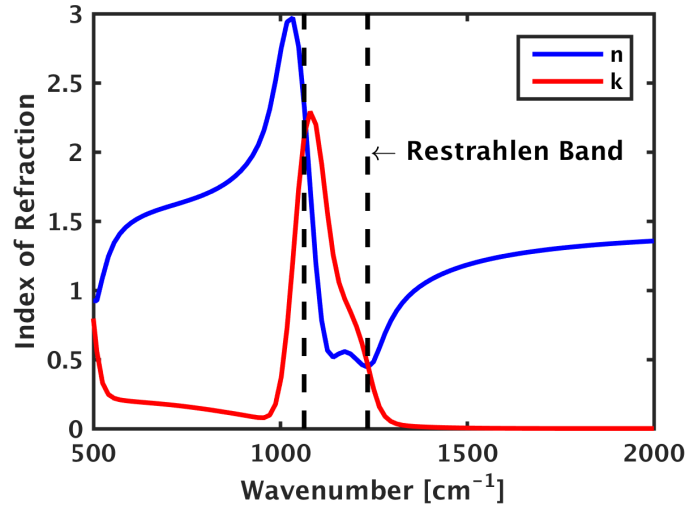
Takeaway: Plasmons drive absorption. Dielectric defines plasmon.

Phonons & Optical Properties

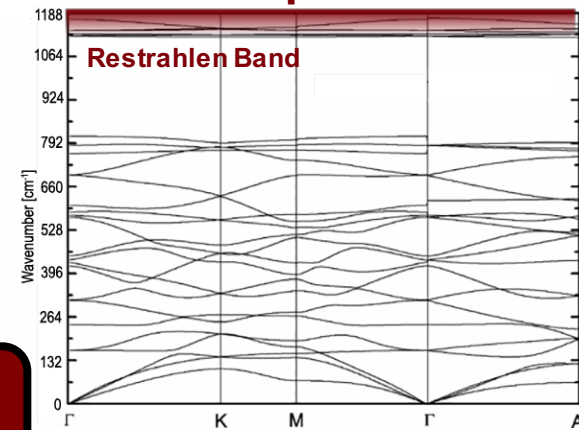
Plasmon Dispersion



SiO₂ Ind. of Refraction

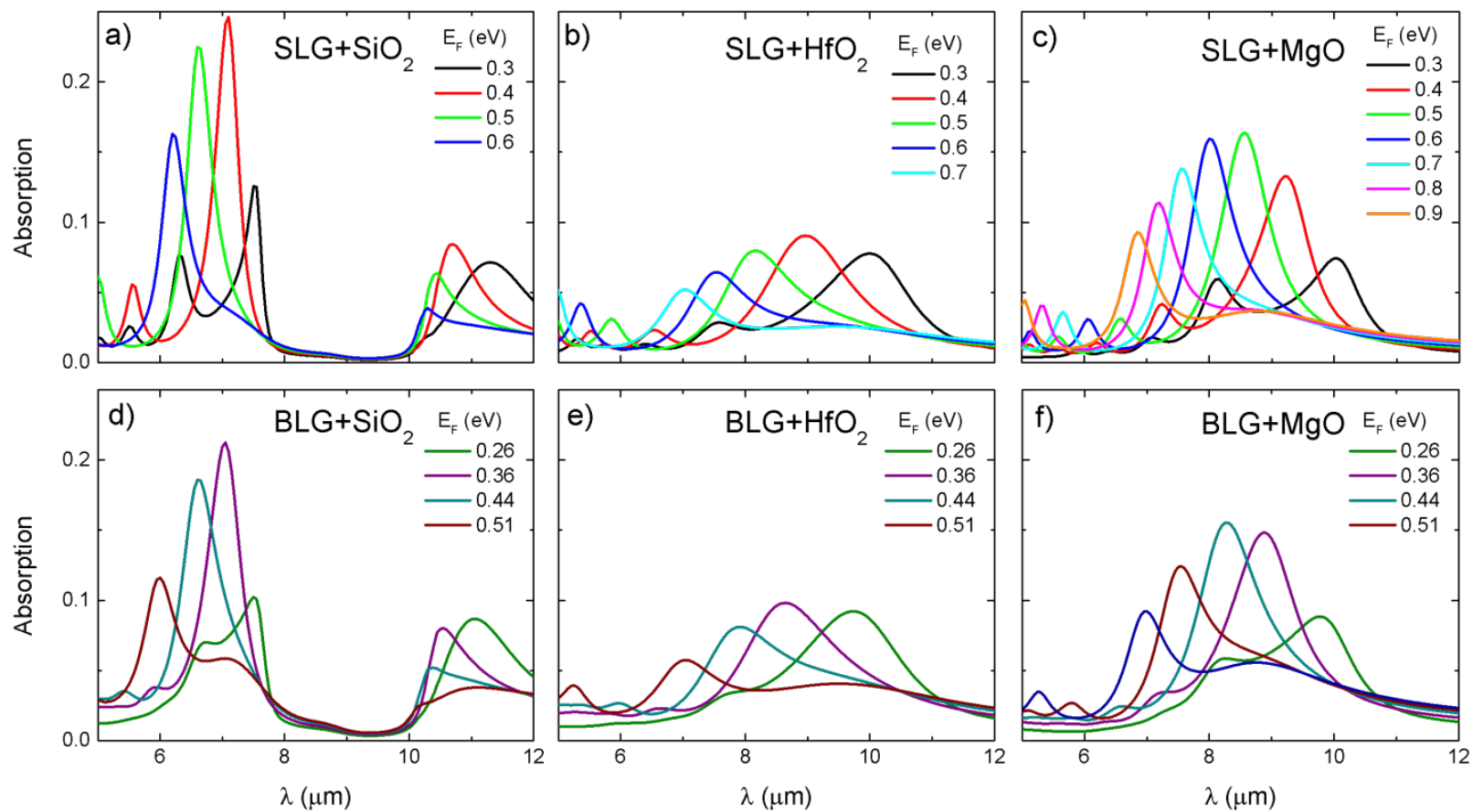


SiO₂ Phonon Dispersion



Takeaway: Phonons drive optical response

Tunability via Phonons



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

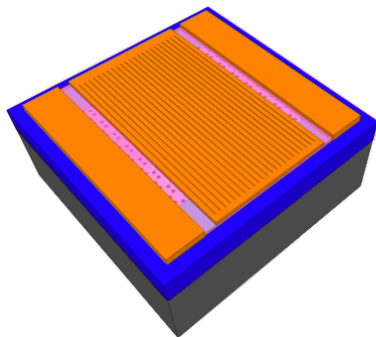
Phonons determine spectral band of response.

Phonons for Filtering

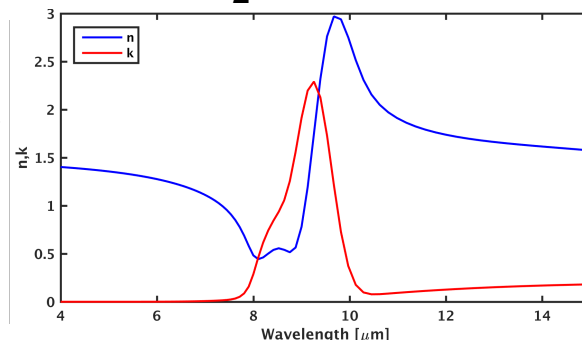
Premise: Couple 2 static resonances with 1 that is tunable

Static
Resonance

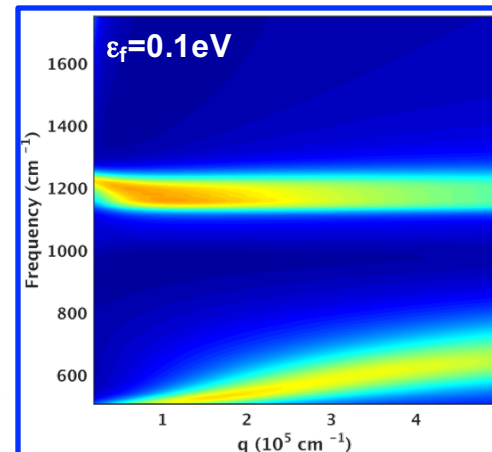
Antenna



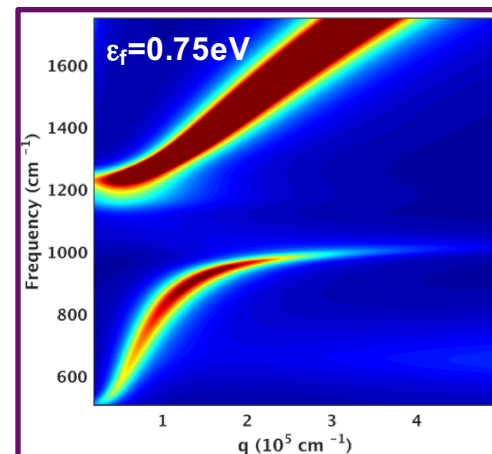
SiO₂ Phonons



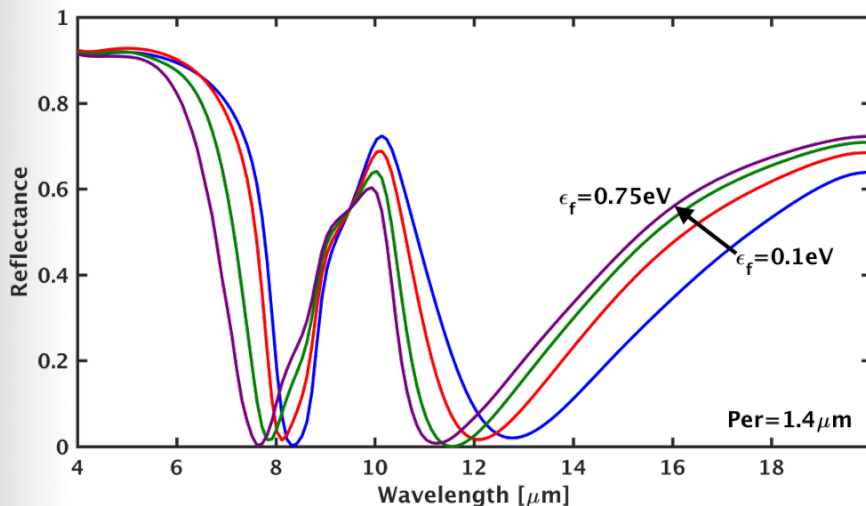
Graphene Plasmon



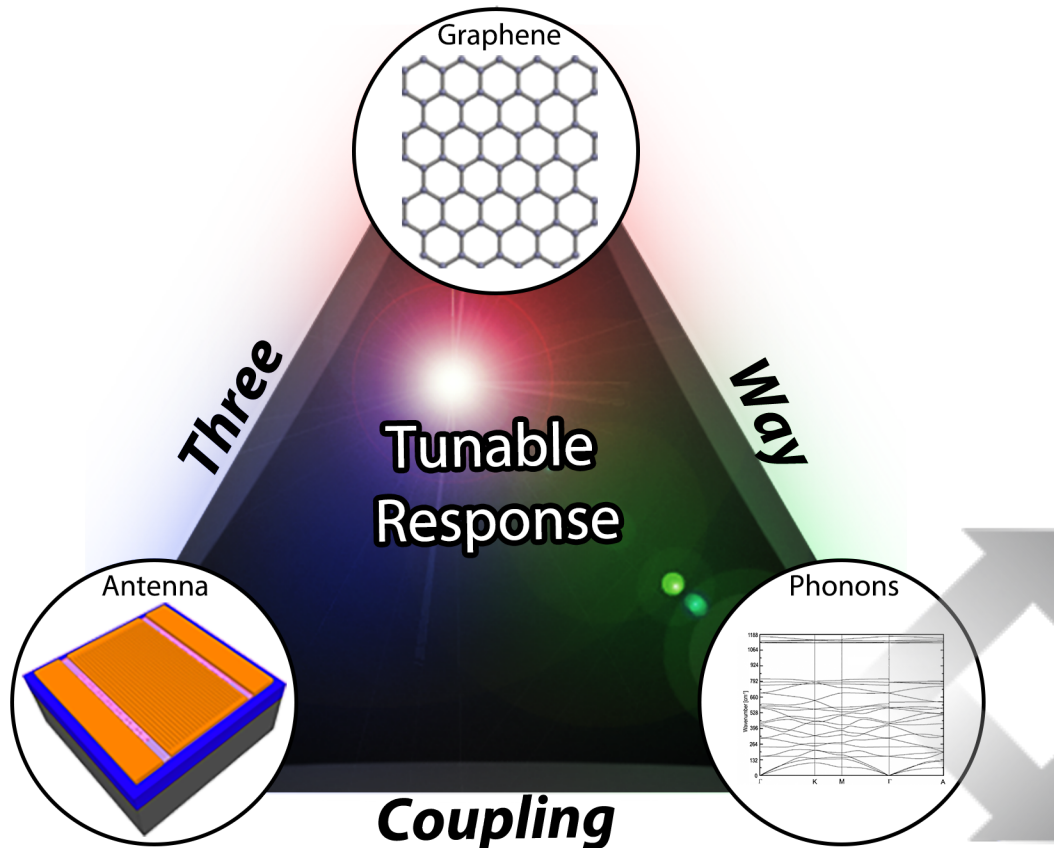
Tunable
Resonance



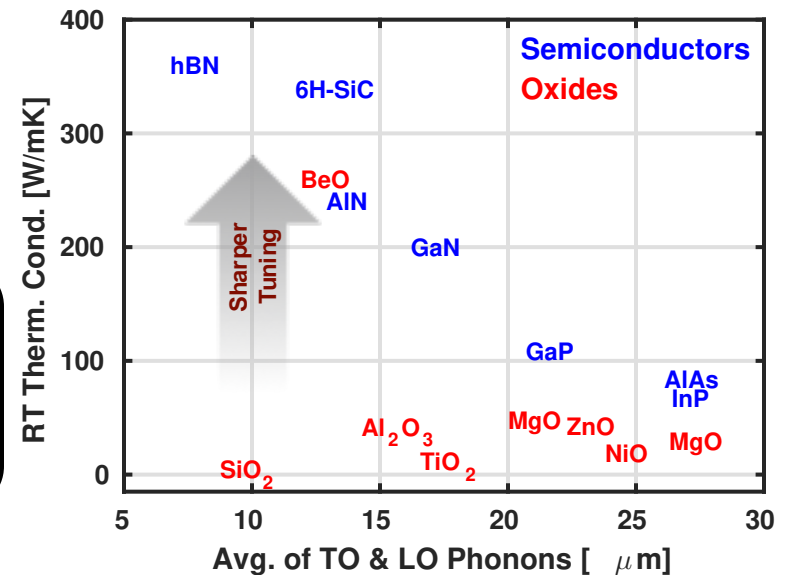
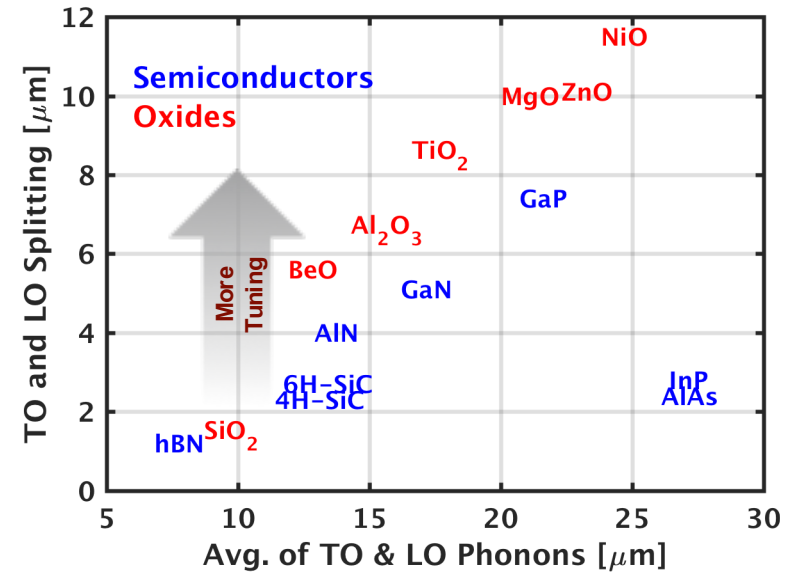
Tunable Perfect
Absorption



The Phonon Vista.....

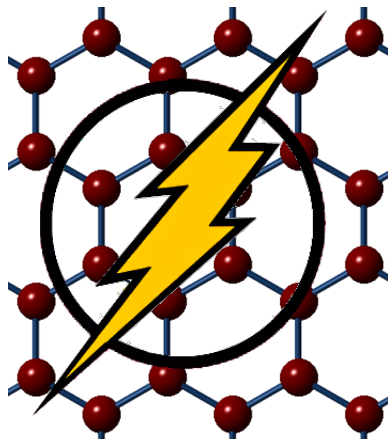


DESIGN QUESTION
What “phonon” materials are best?



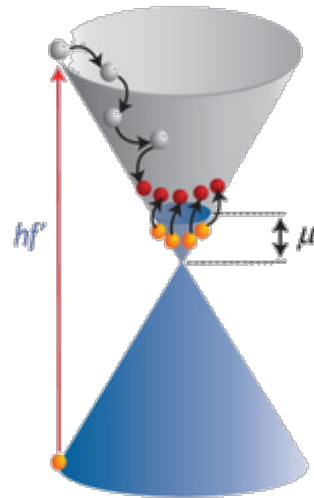
Can we collect the generated charge?

Good News

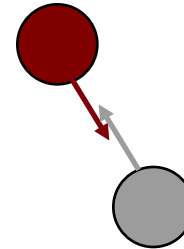


High Mobility

Hot Carrier
Generation



Bad News



Fast
Recombination

Environment

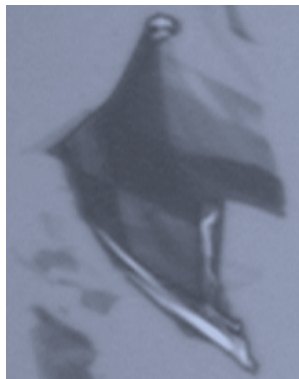


GUIDING QUESTION

What determines charge transport in “real life”?

“Brands” of Graphene

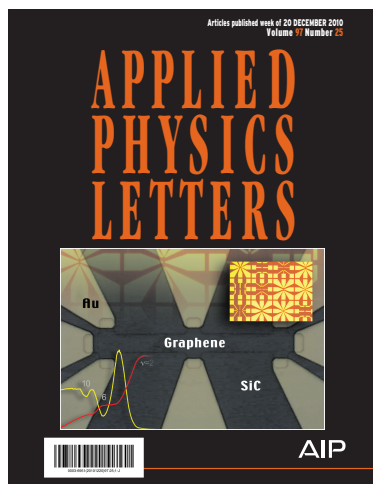
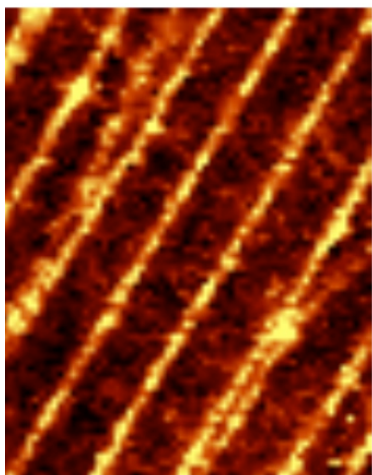
Exfoliated



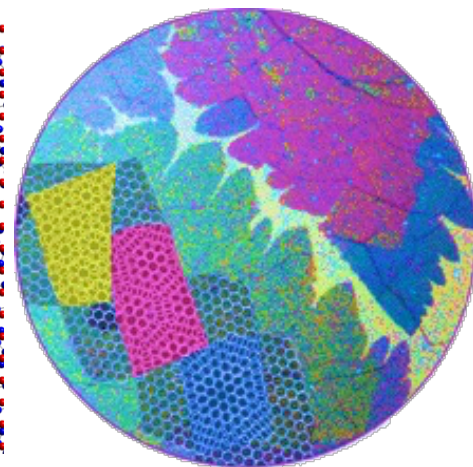
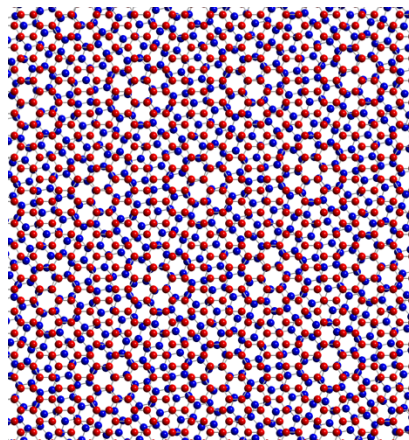
Copper Based CVD



Epitaxial on SiC

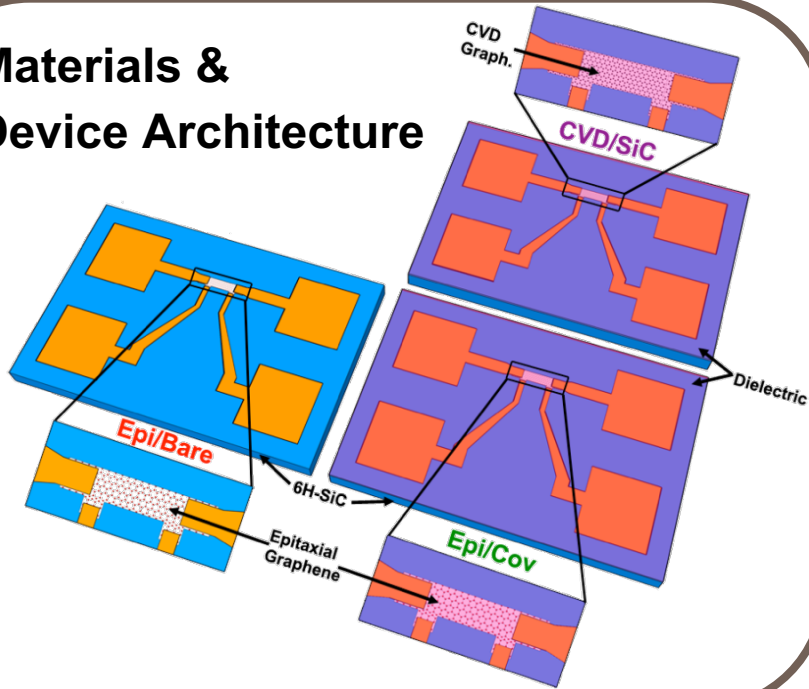


Twisted Bilayer Graphene

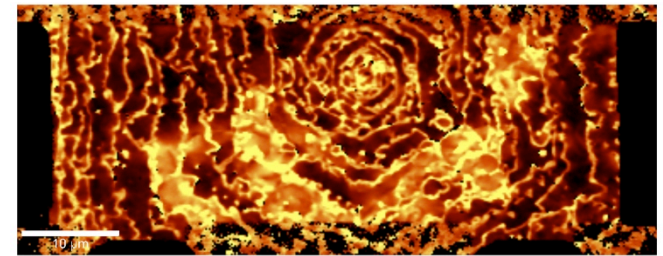
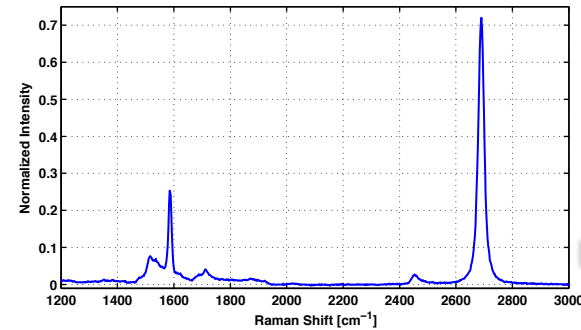


Method & Approach

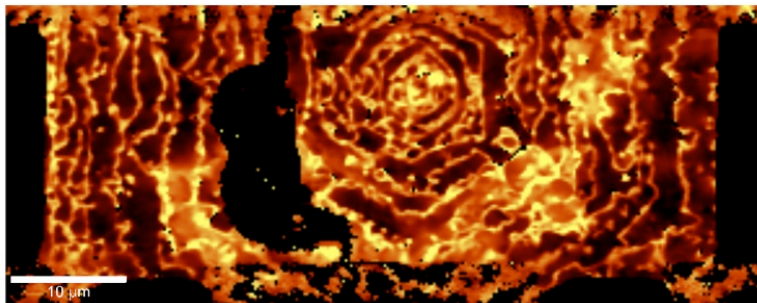
Materials & Device Architecture



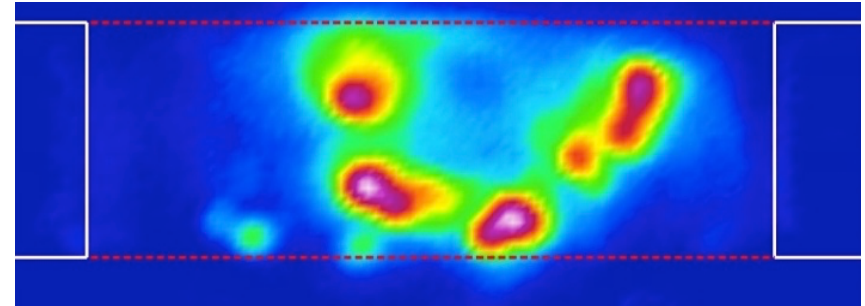
1. Pre-Raman Imaging



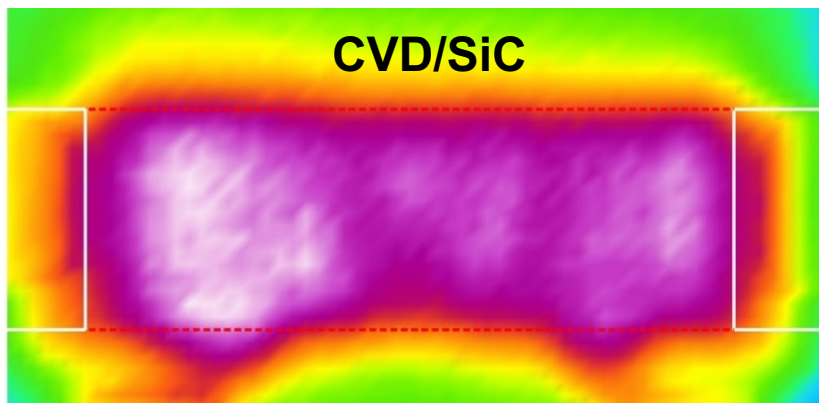
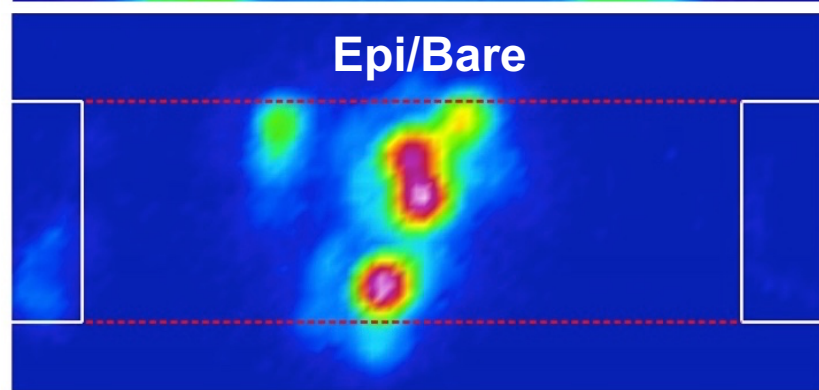
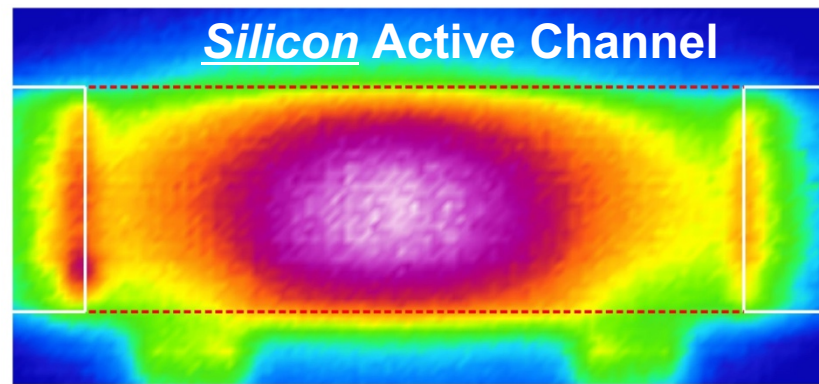
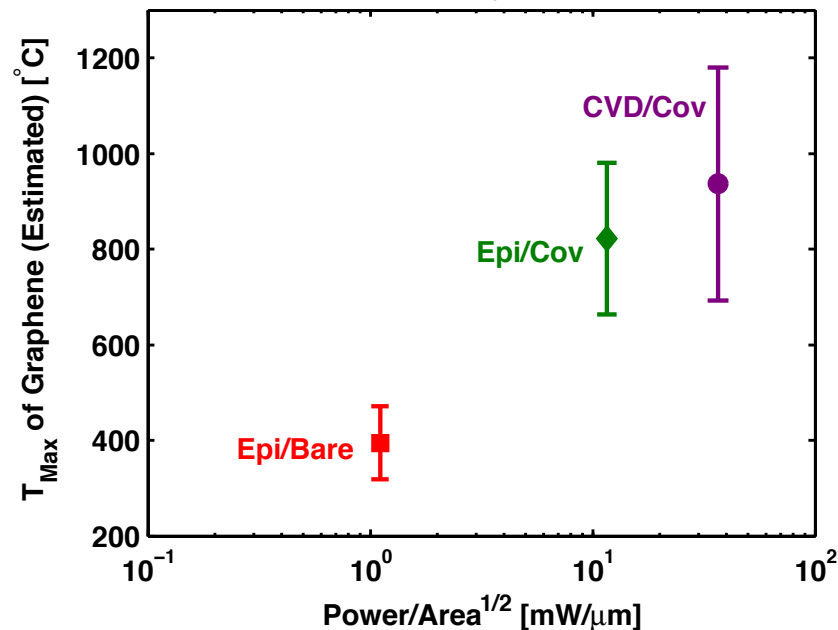
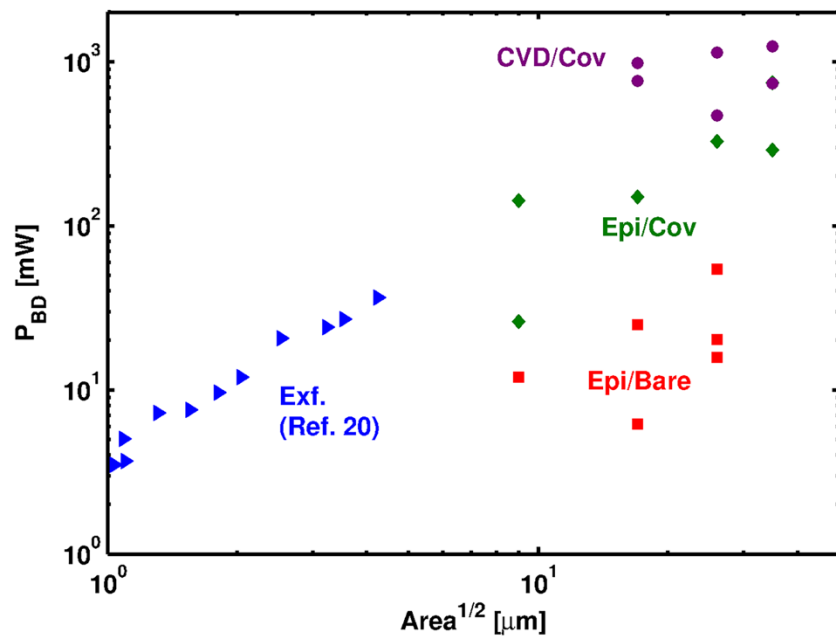
3. Post-Raman Imaging



2. Infrared Thermography

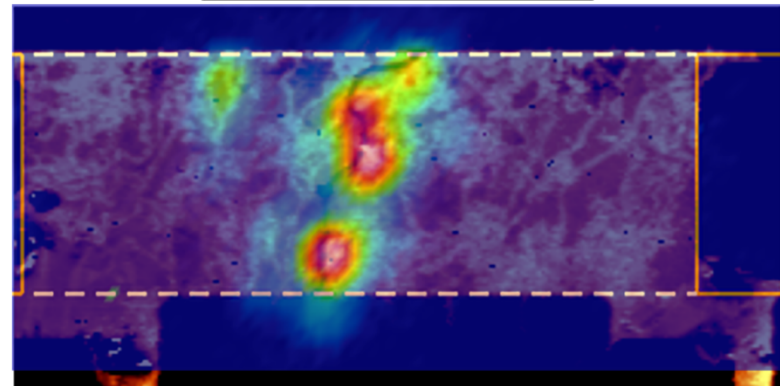
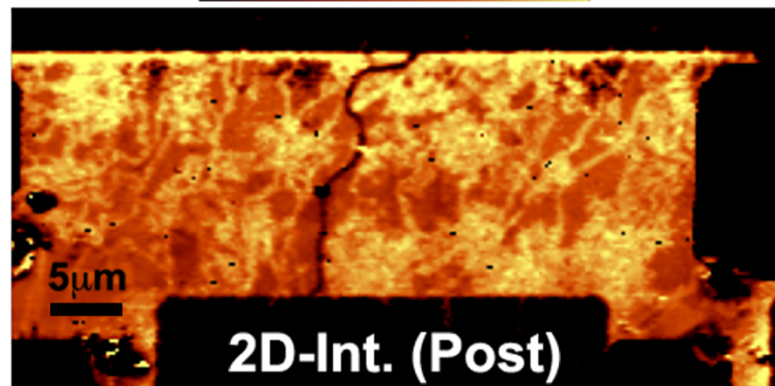
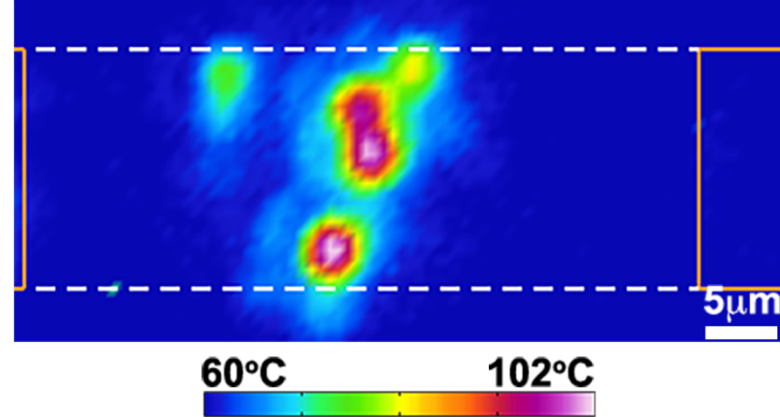
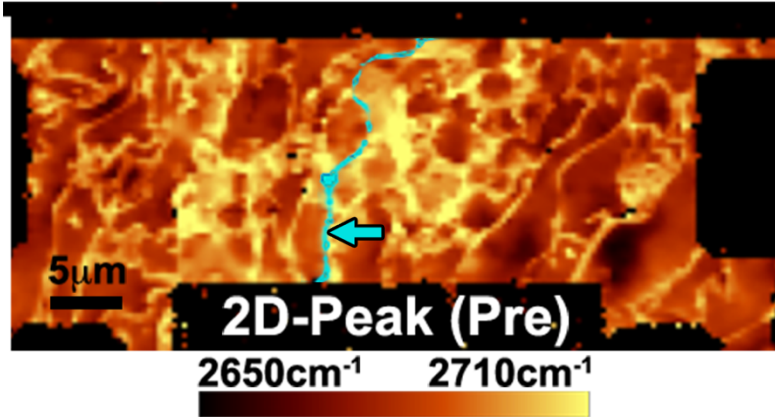
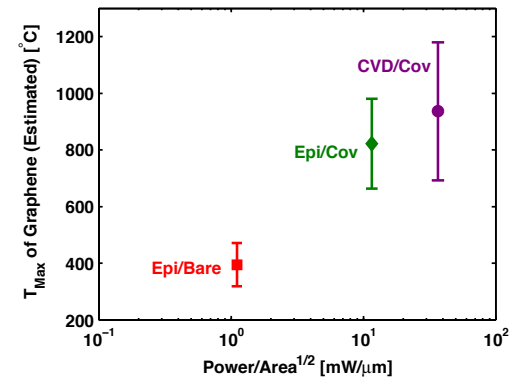
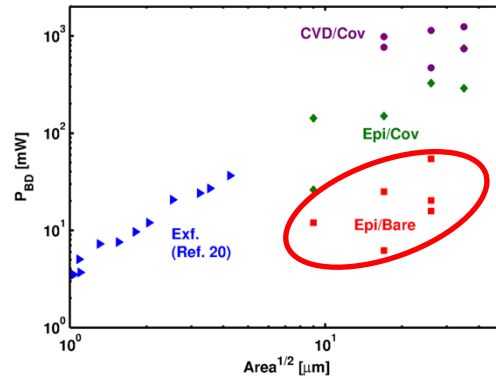
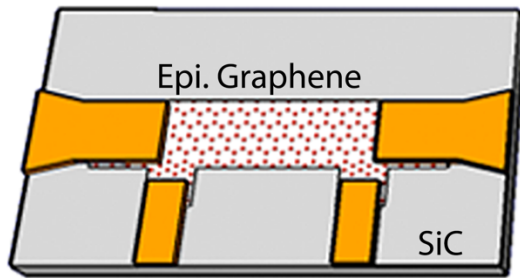


Graphene Dependent Failure



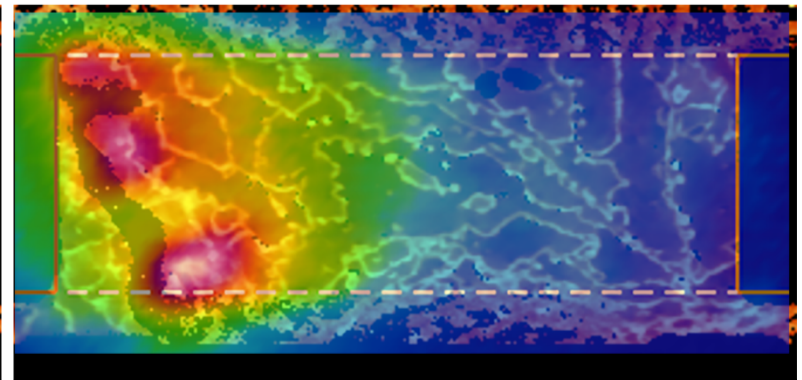
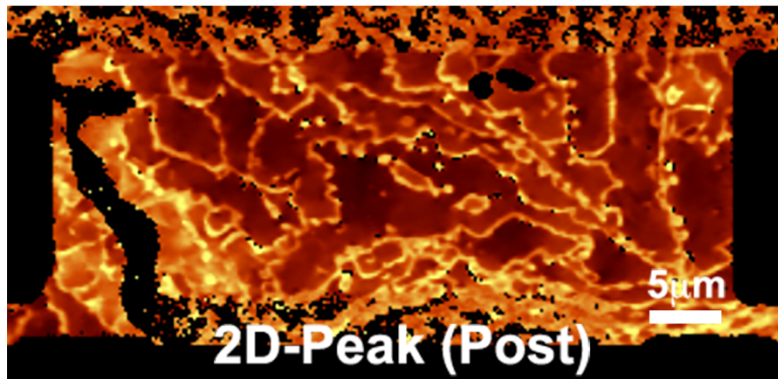
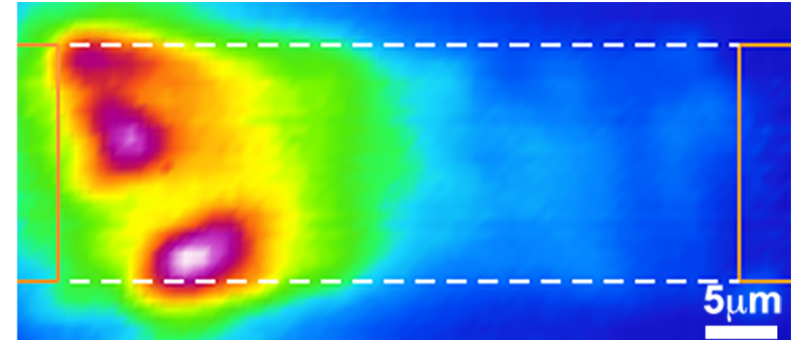
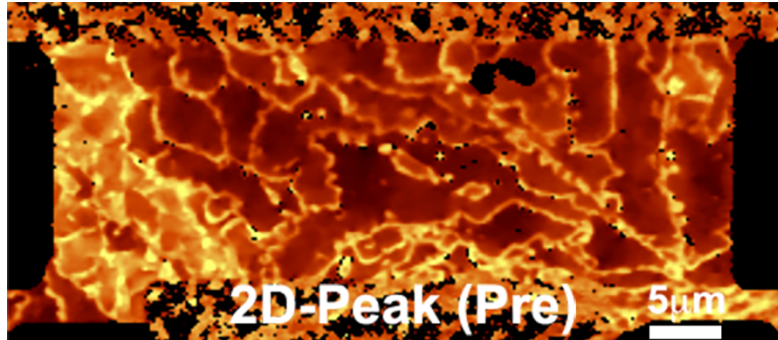
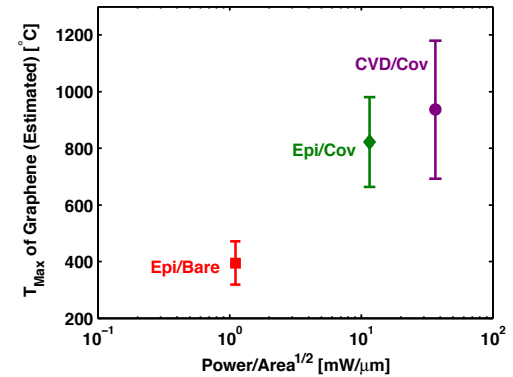
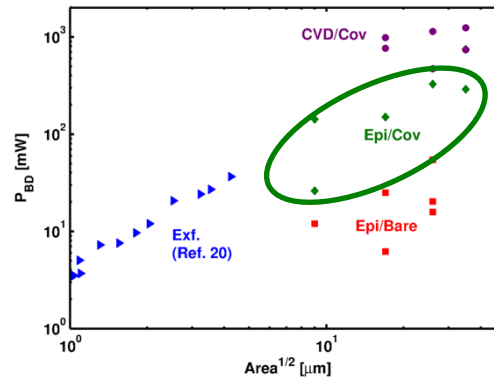
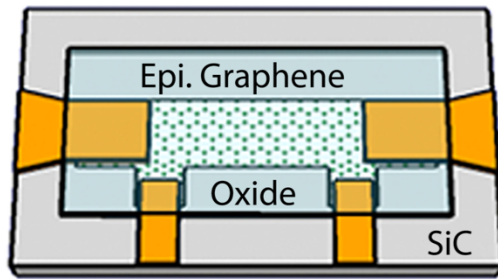
Epi/Bare: Low Power Failure

Epi/Bare



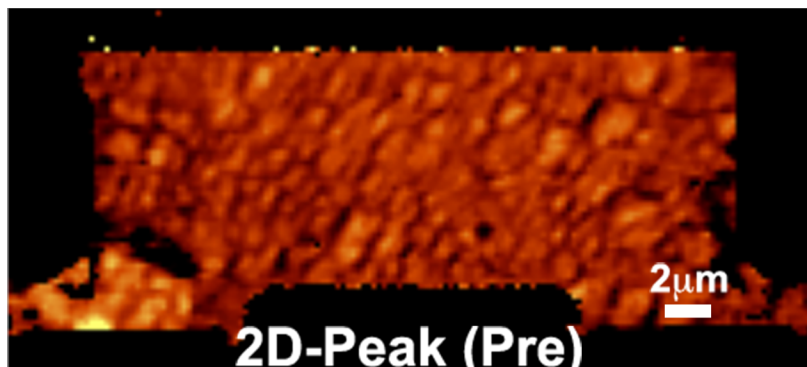
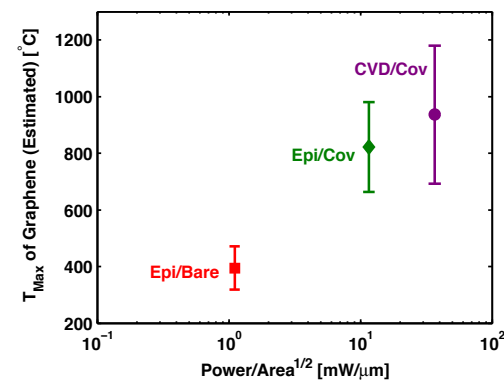
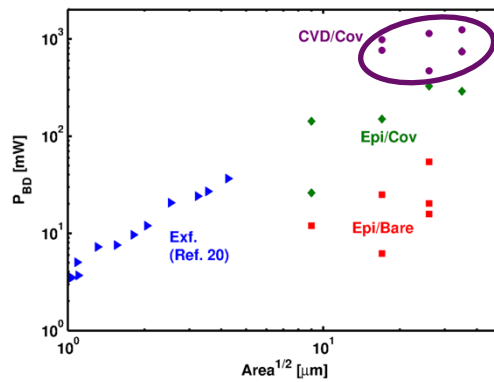
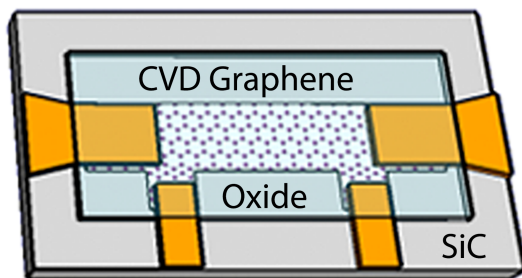
Epi/Cov: Middling Power Failure

Epi/Cov

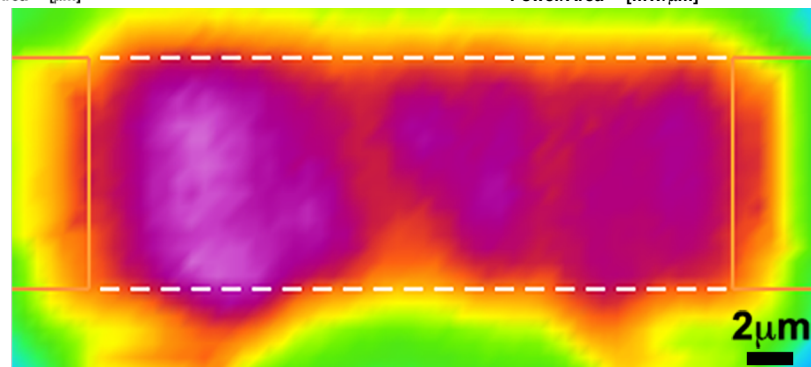


CVD/Cov: High Power Failure

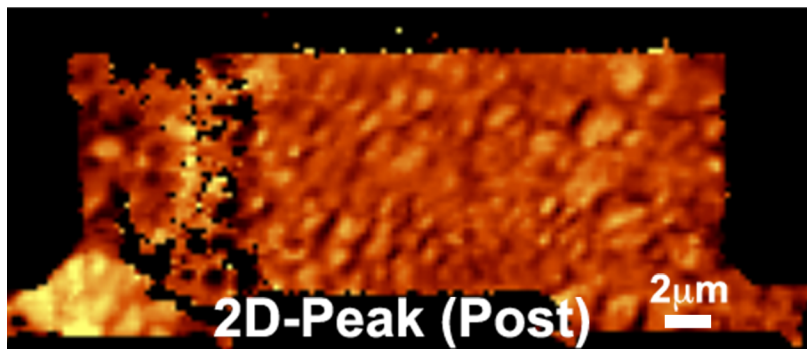
CVD/Cov



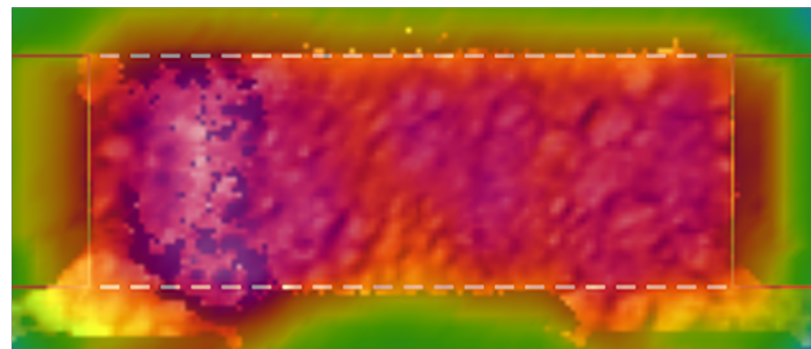
2675 cm^{-1} 2695 cm^{-1}



60 $^{\circ}C$ 300 $^{\circ}C$

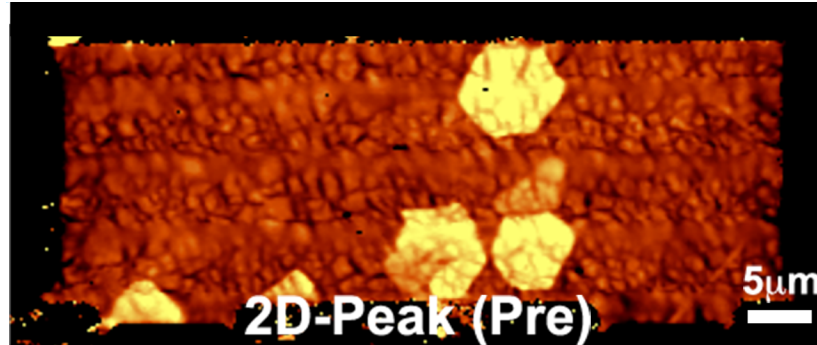
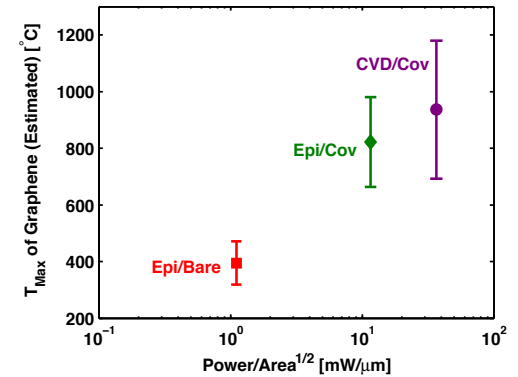
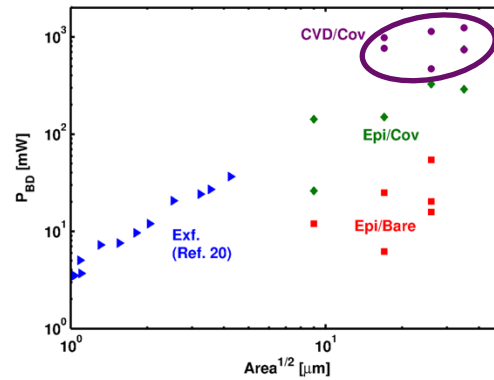
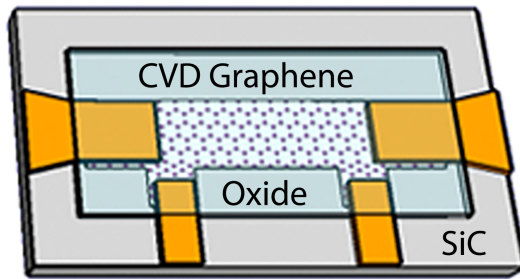


2D-Peak (Post)

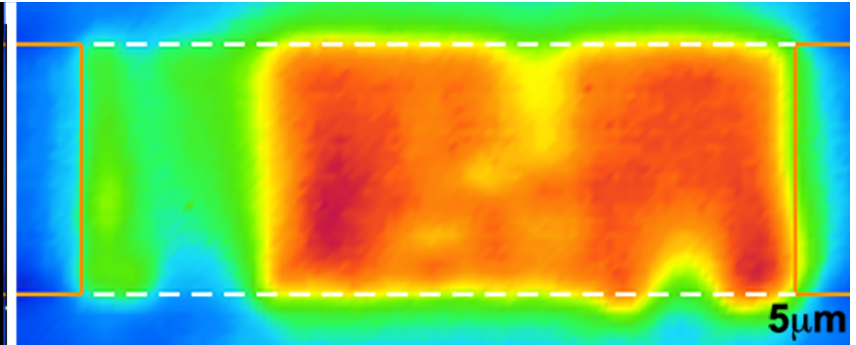


CVD/Cov: High Power Failure

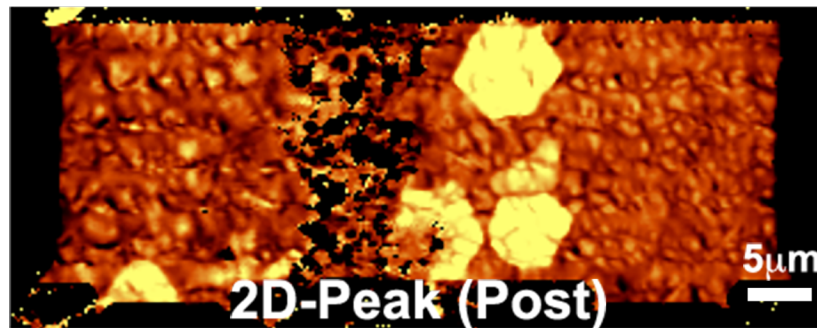
CVD/Cov



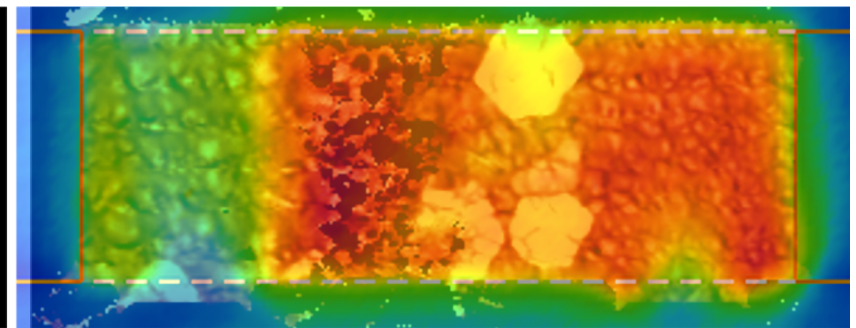
2675cm⁻¹ 2695cm⁻¹



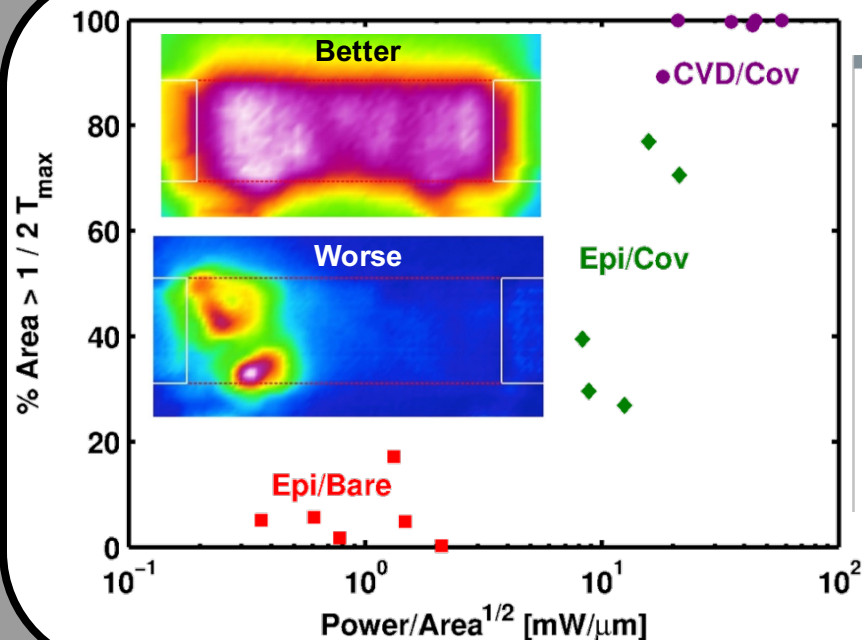
60°C 280°C



2D-Peak (Post)



Take Home Message



SCIENTIFIC REPORTS

OPEN Self-Heating and Failure in Scalable Graphene Devices

Thomas E. Beechem, Ryan A. Shaffer, John Nogan, Taisuke Ohta, Allister B. Hamilton, Anthony E. McDonald & Stephen W. Howell

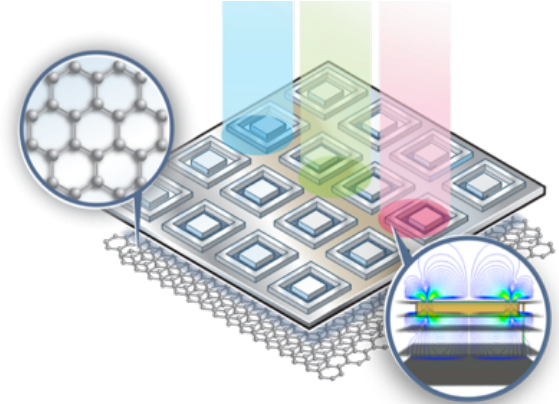
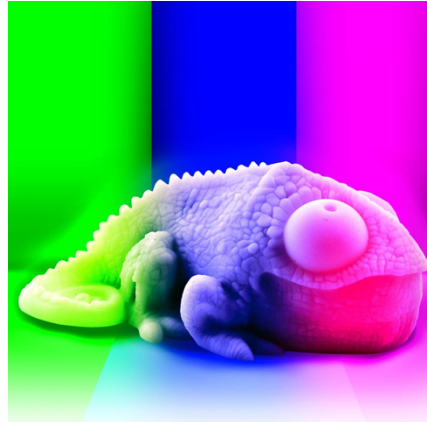
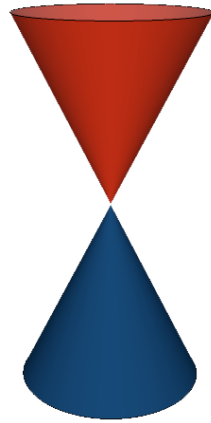
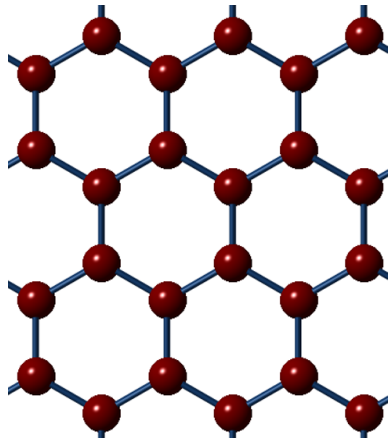
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Published: 09 June 2016

Self-heating induced failure of graphene devices synthesized from both chemical vapor deposition (CVD) and epitaxial means is compared using a combination of infrared thermography and Raman imaging. Despite a larger thermal resistance, CVD devices dissipate $>3\times$ the amount of power before failure than their epitaxial counterparts. The discrepancy arises due to morphological irregularities implicit to the graphene synthesis method that induce localized heating. Morphology, rather than thermal resistance, therefore dictates power handling limits in graphene devices.

1. Power handling determined by ability to uniformly Joule-heat.
 2. Joule-heating distribution determined by morphology of graphene.
- Interlayer Interactions determine morphology.**



Takeaway: Hyperspectral graphene based detection promising.
Surroundings as important to photodetection as graphene itself.

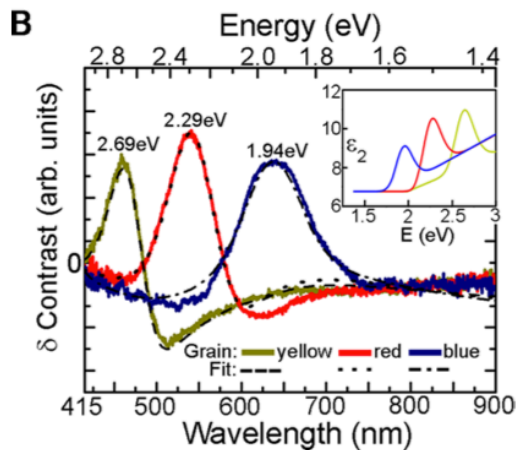
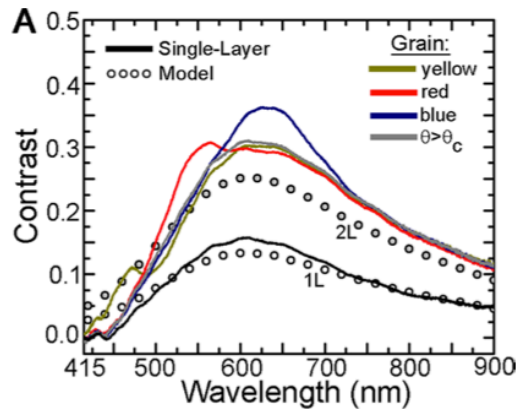
Why does the G-mode get so big?

Increased Absorbance

Electronic Hybridization of Large-Area Stacked Graphene Films

Jeremy T. Robinson,^{†,*} Scott W. Schmucker,[†] C. Bogdan Diaconescu,[‡] James P. Long,[†] James C. Culbertson,[†] Taisuke Ohta,[‡] Adam L. Friedman,[‡] and Thomas E. Beechem[†]

[†]Naval Research Laboratory, Washington, D.C. 20007, United States and [‡]Sandia National Laboratories, Albuquerque, New Mexico 87185, United States



Quantum Interference

ARTICLE IN PRESS

LETTER

doi:10.1038/nature09866

Controlling inelastic light scattering quantum pathways in graphene

Chi-Fan Chen¹, Cheol-Hwan Park¹, Bryan W. Boudouris^{2,3}, Jason Horng¹, Baisong Geng¹, Caglar Girit¹, Alex Zettl^{1,3}, Michael F. Crommie^{1,3}, Rachel A. Segalman^{2,3}, Steven G. Louie^{1,3} & Feng Wang^{1,3}

