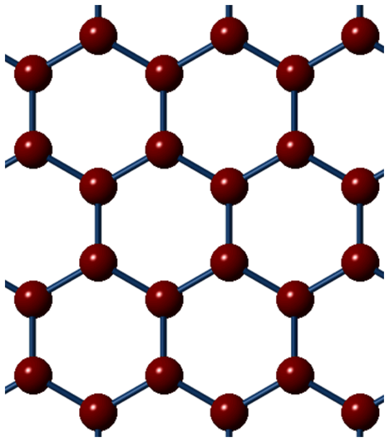
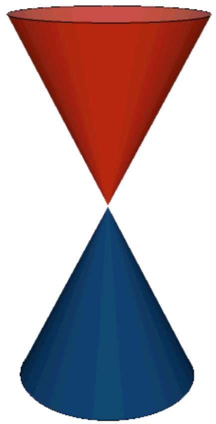
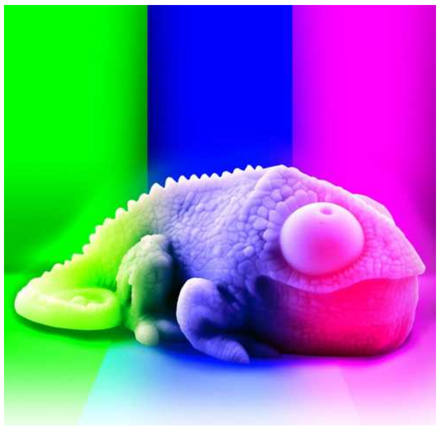
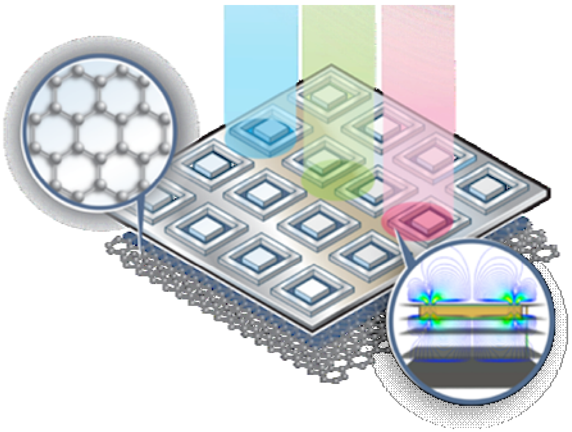
SAND2016-12414PE

Infrared Chameleon:
Graphene, Surrounding Materials, and the Primacy of Their Interaction on Photodetection

Thomas Beechem

Team:
David Peters
Michael Goldflam
Steve Howell
Taisuke Ohta
John Nogan
Anthony McDonald
Allister Hamilton
R. Shaffer, I. Ruiz

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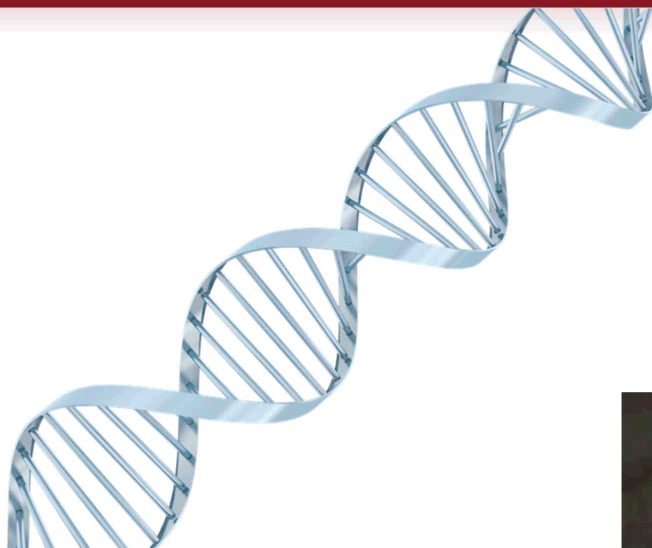
What makes me, me?

Genetic, Intrinsic



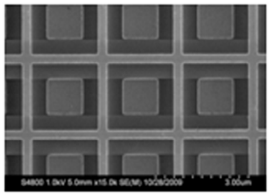
Environment

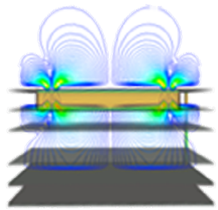
Takeaway: We are who we are AND what we're around.

Vision & Challenge

Vision

Nanoantenna Field Enhancement

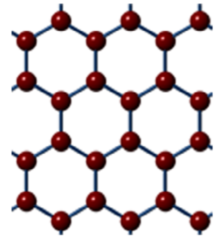




Increased Absorption

+

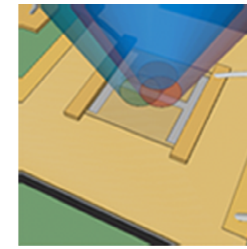
Graphene



Tunable Response

=

Tunable Detector



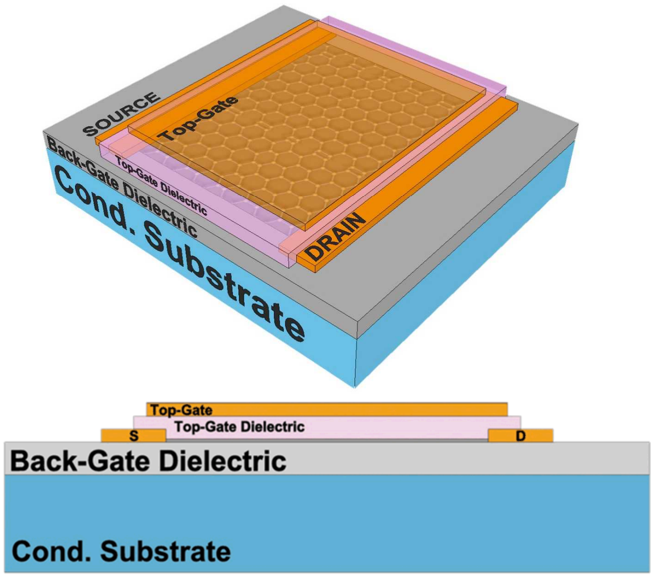
Hyperspectral Pixel

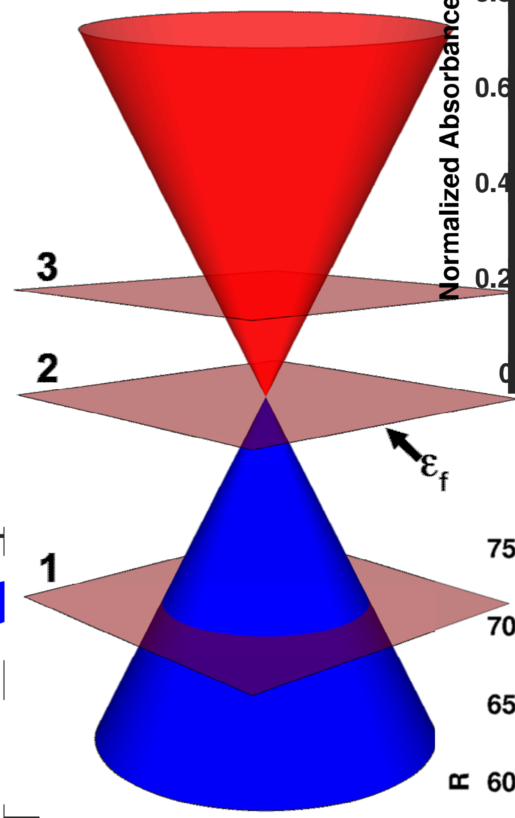
Challenge

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

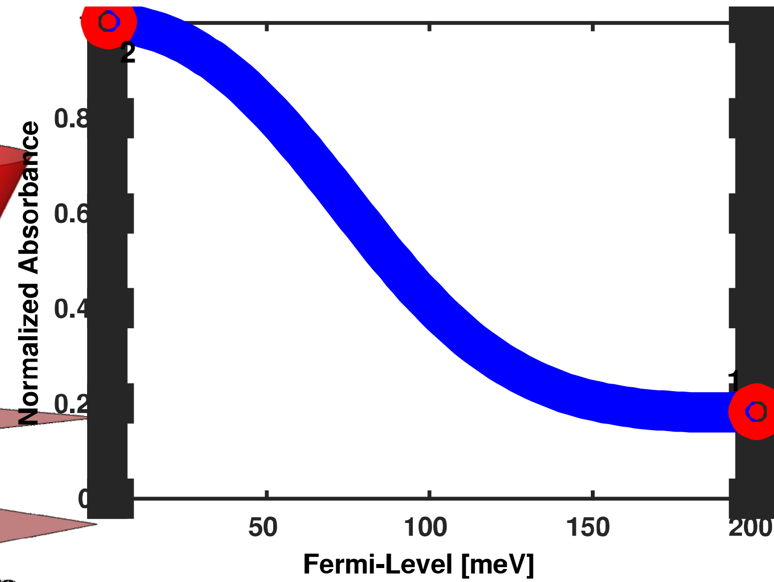
DNA: Graphene Tunability

Graphene Transistor

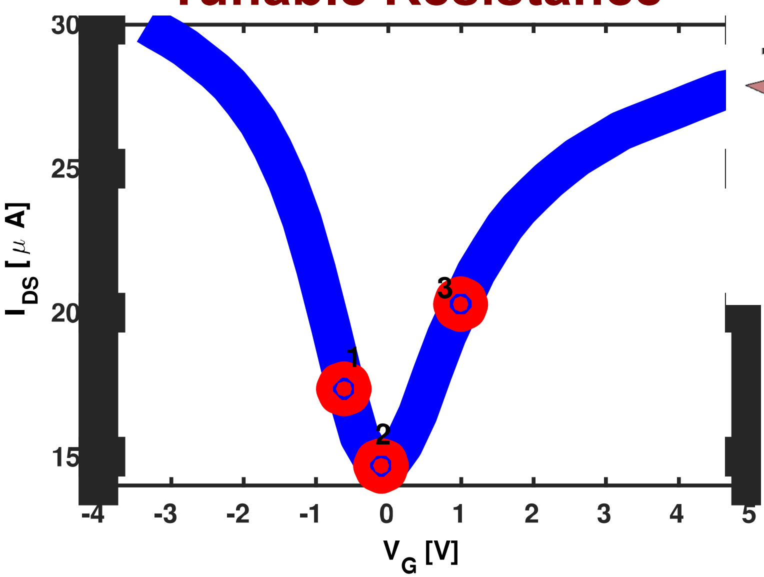




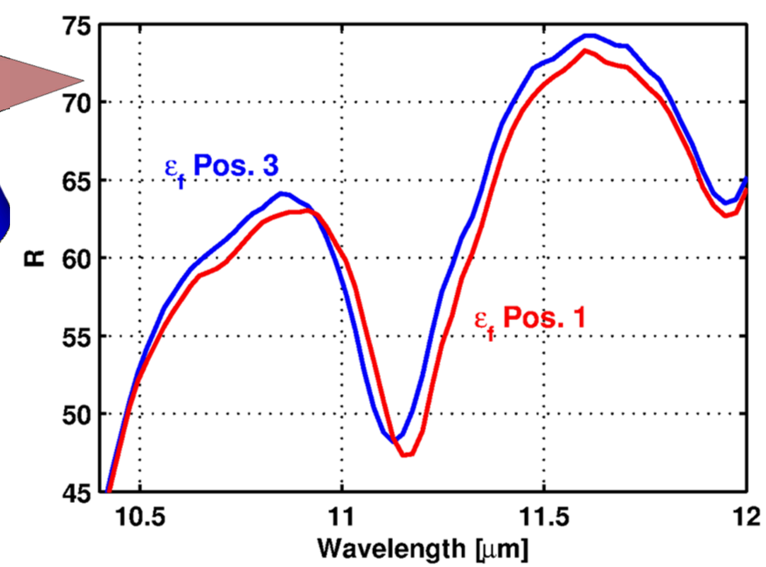
Tunable Absorber



Tunable Resistance



Tunable Nanoantenna



Myth: Graphene Absorbs 2.3%

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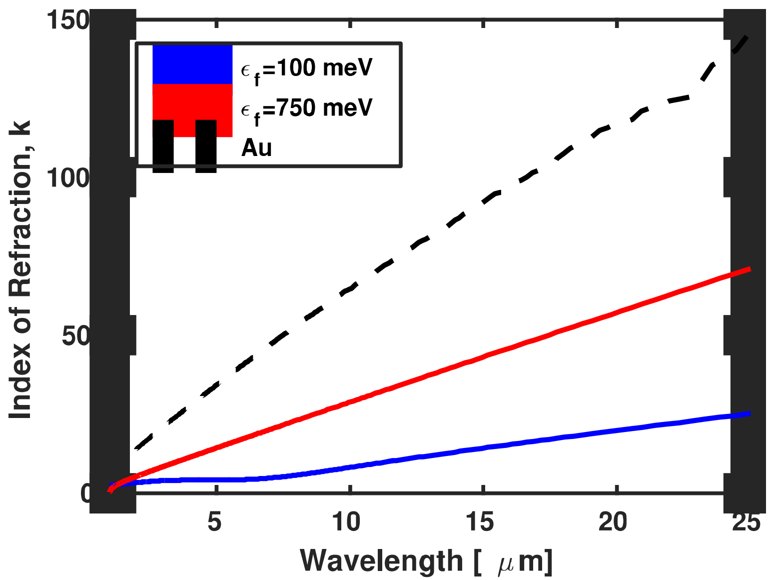
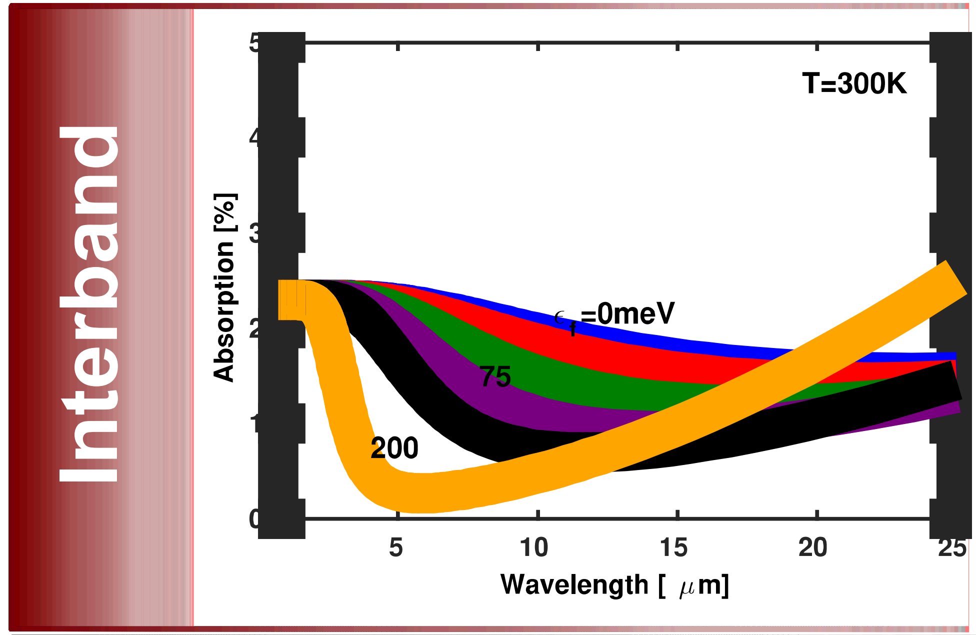
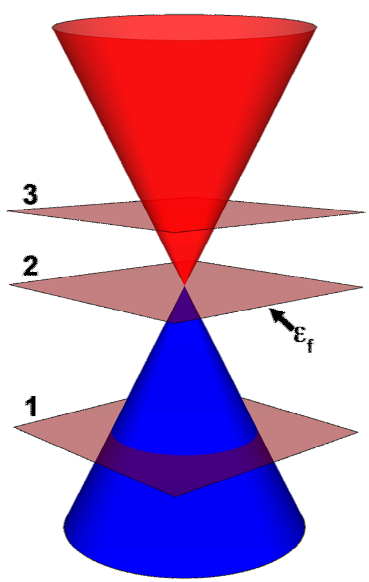
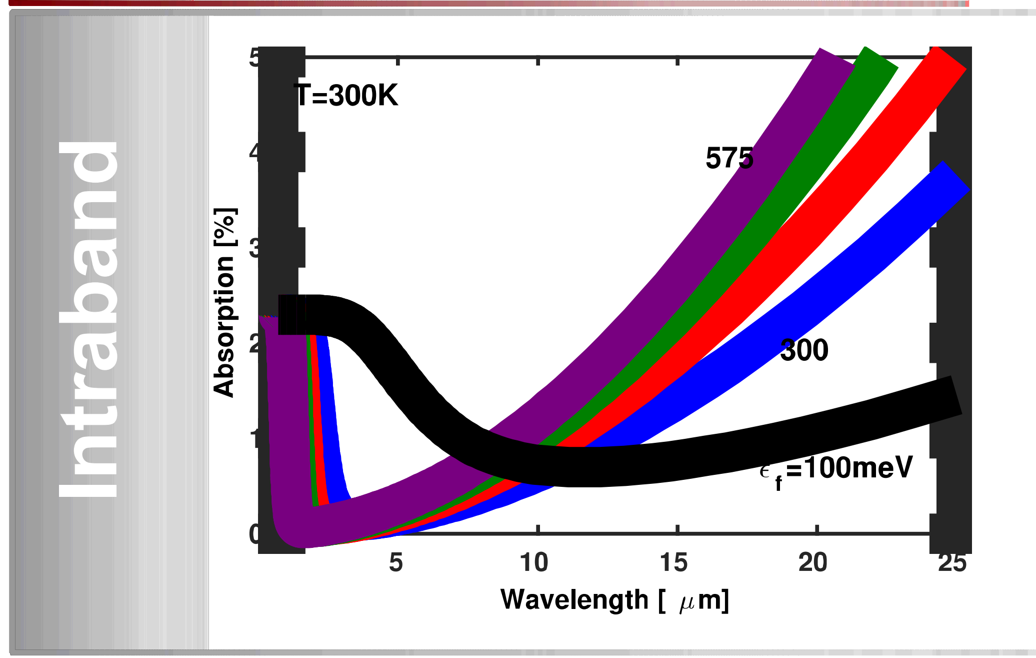
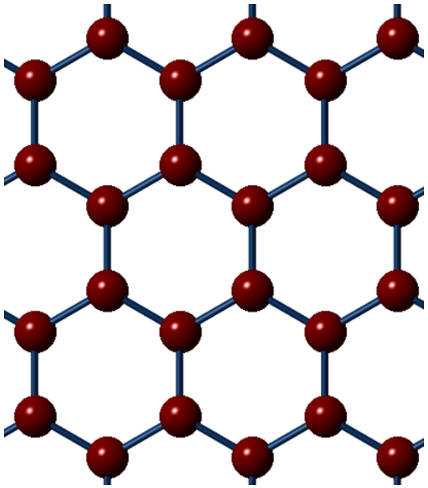


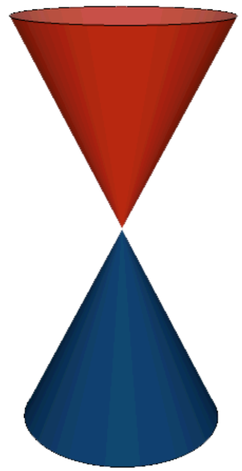




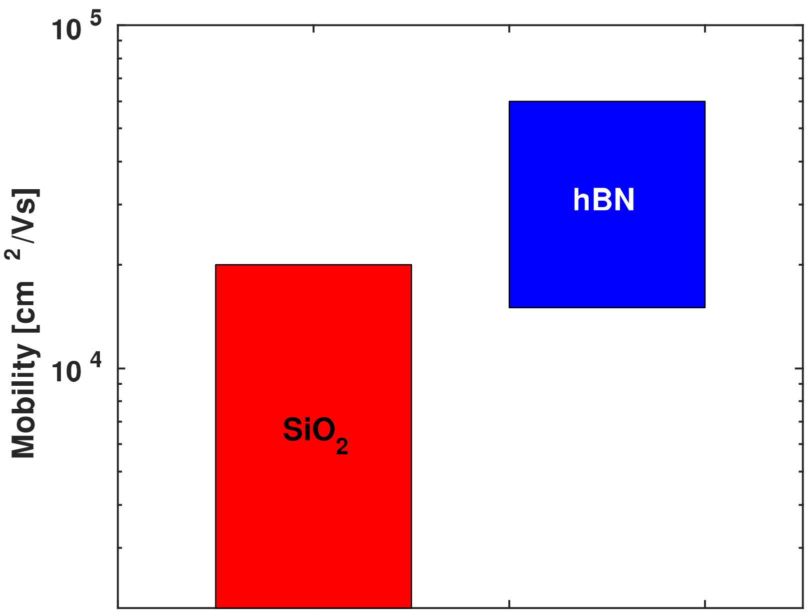


Env.:Graphene & Peer Pressure





D.A.R.E.®

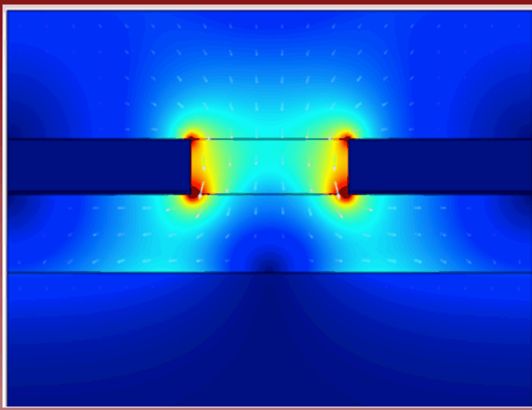


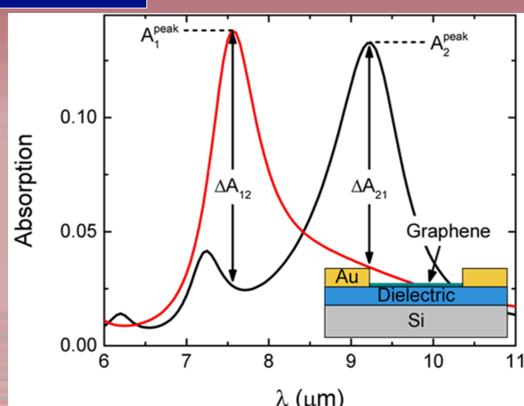
Mobility: Dean et al. Nature Nano. (5) 722, 2010

Premise & Path

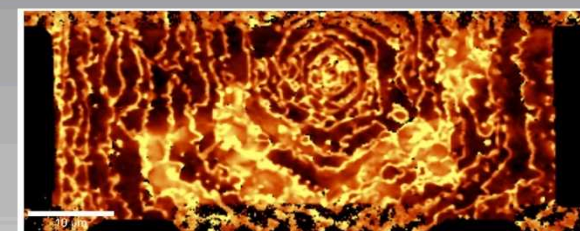
PREMISE: Graphene enabled hyperspectral detection dictated by material itself (DNA) & those adjacent (environment).

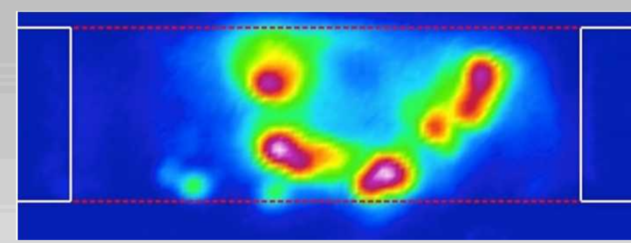
Light Absorption

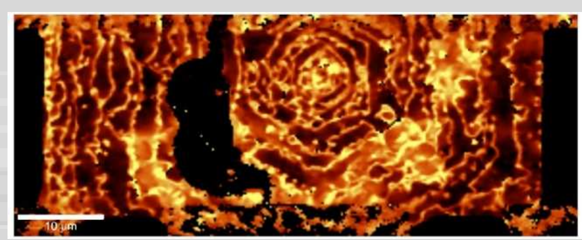




Charge Collection

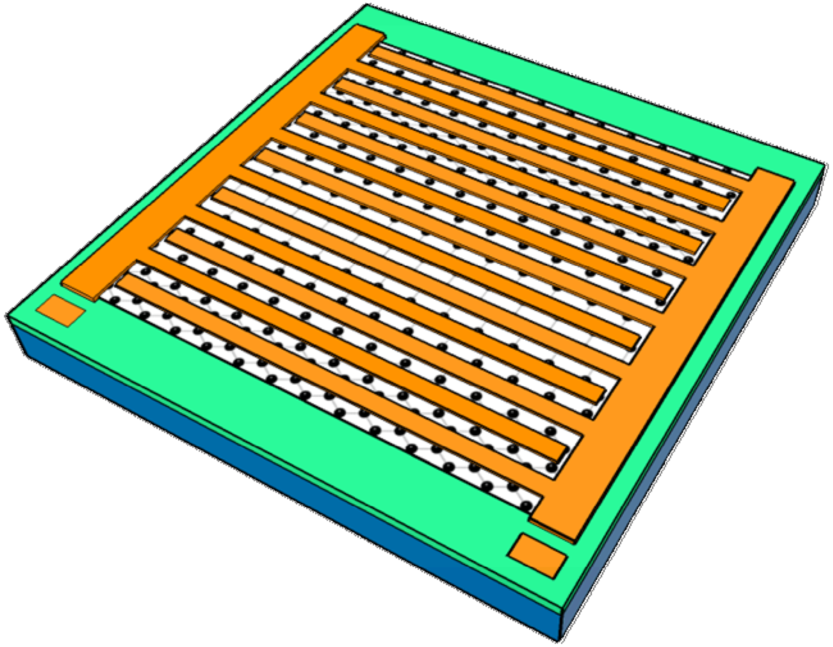


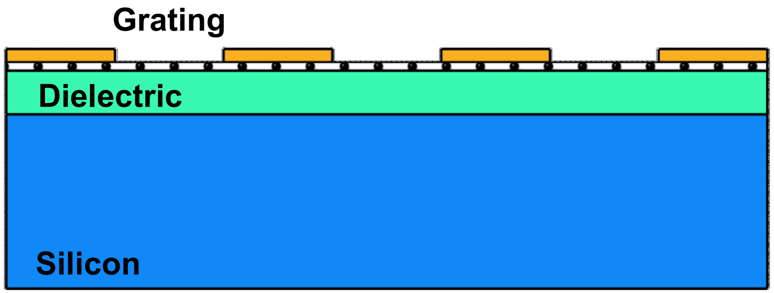




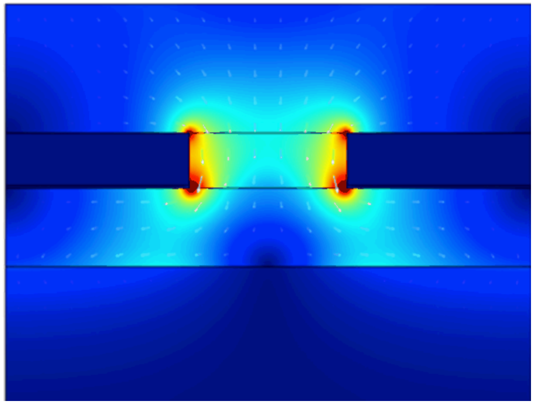
Method & Approach

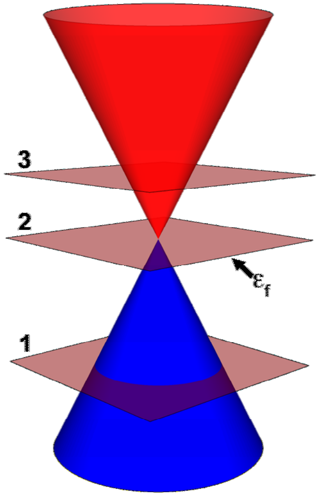
Architecture & Material Silos





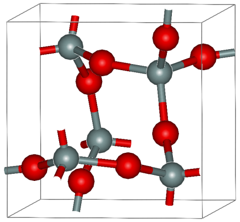
Electromagnetic Modeling



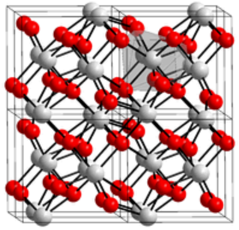


Assess Dielectric Influence

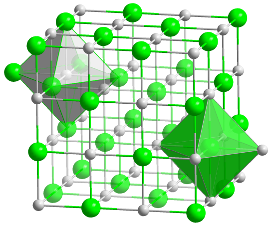
SiO_2



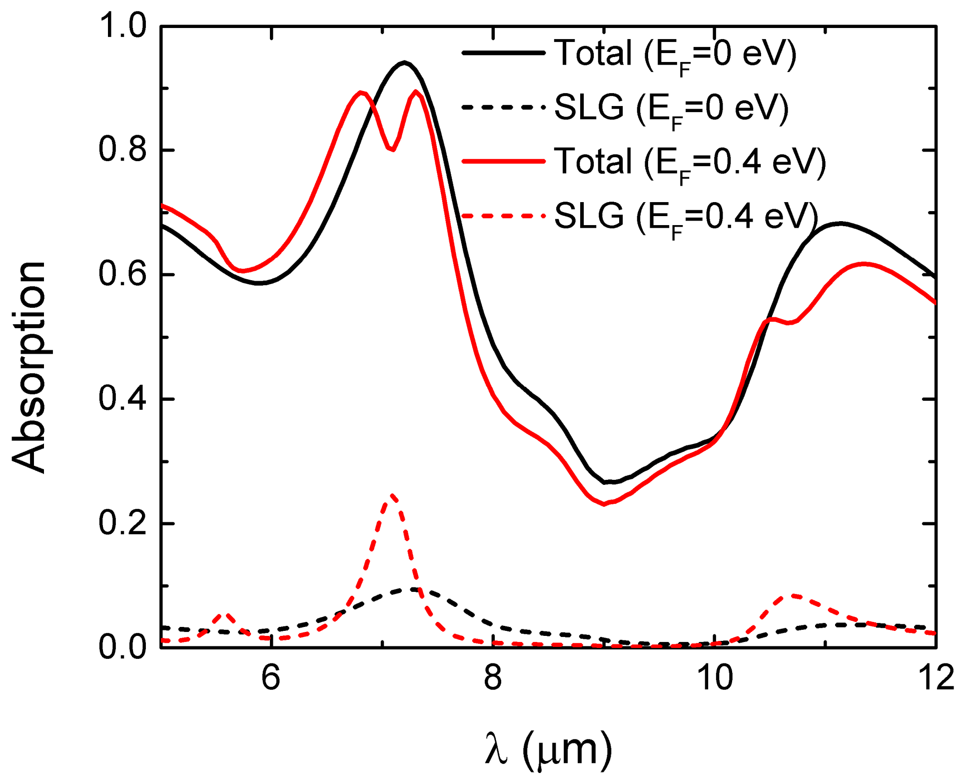
HfO_2

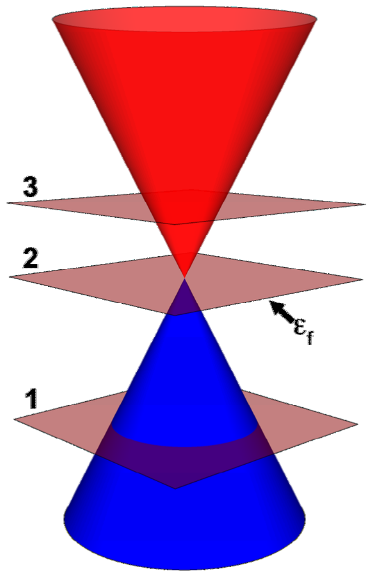


MgO



Does the Antenna Work?





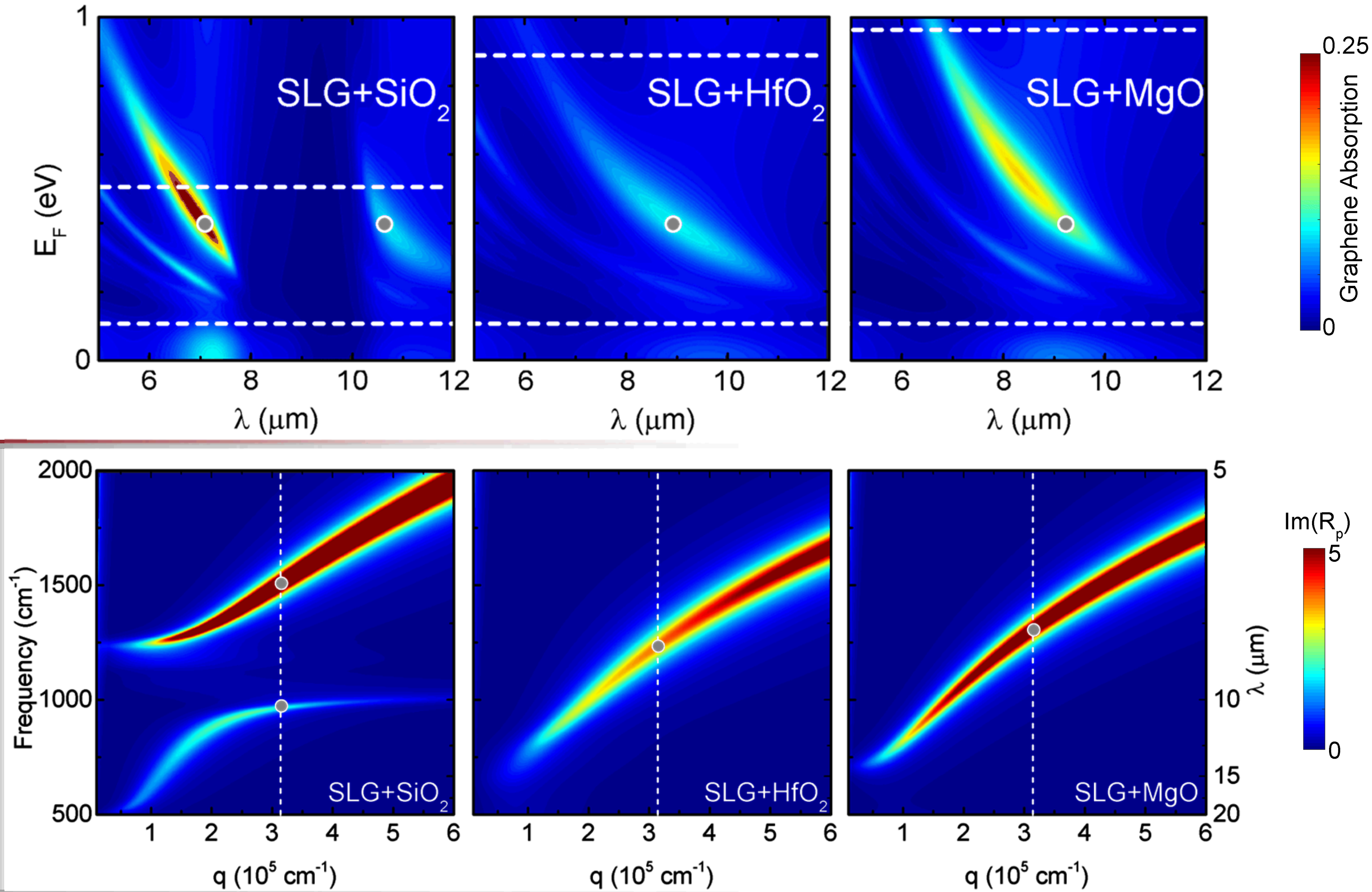
1. 10x increase in absorption over “as is” graphene BUT
2. Most absorption occurs in substrate

Must design nanoantenna for absorption IN graphene

"Surrounding" Absorption

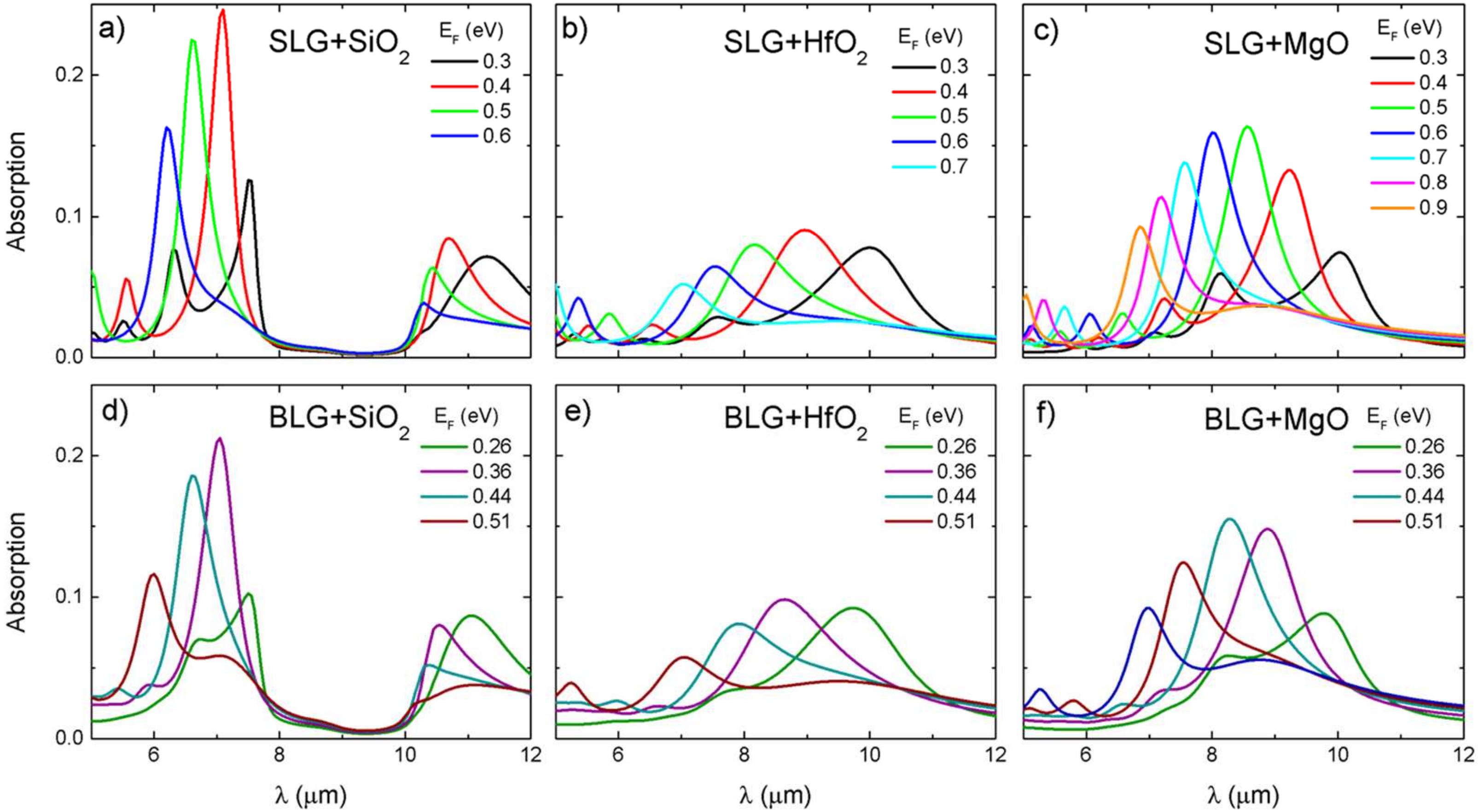
Absorption

Plasmon



Takeaway: Plasmons drive absorption. Dielectric defines plasmon.

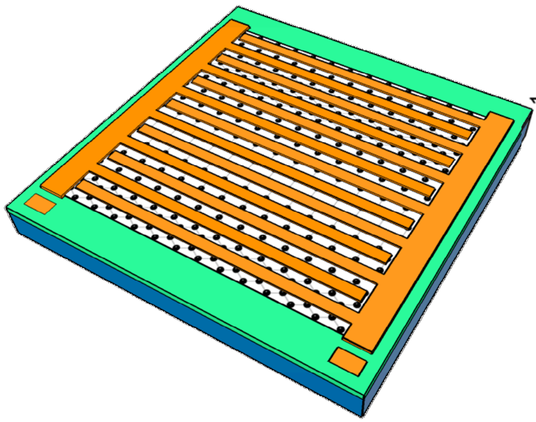
Tunabilty via Plasmon Excitement

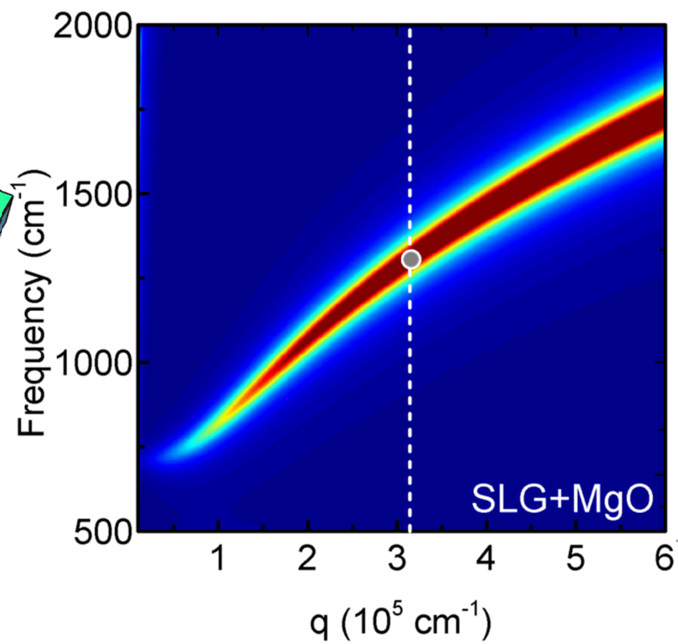


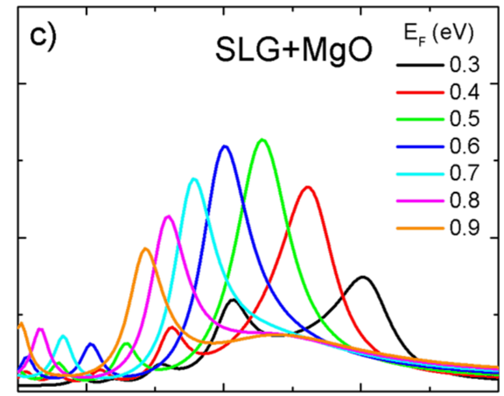
1. **Tunable absorption >10% over micron ranges**
2. **Dielectric defines spectral response**

Bilayer graphene provides little to no advantage

Take Home Points







1. **Plasmon excitement creates large graphene absorption.**
2. **Plasmon dispersion defined by surrounding medium.**

Absorption can be tuned over microns.

Can we collect the generated charge?

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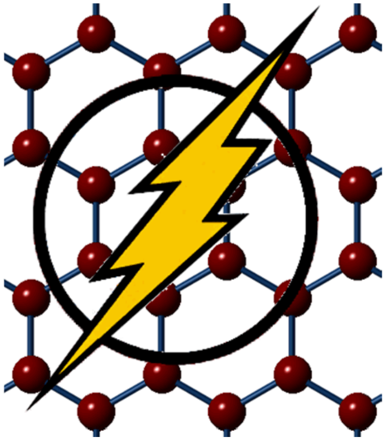
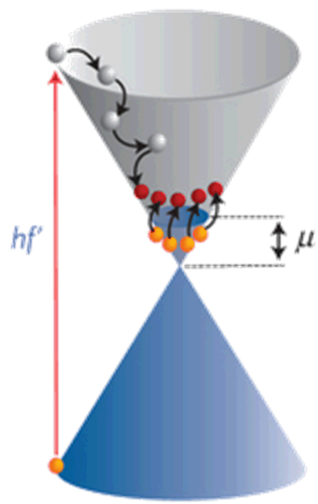
Good News

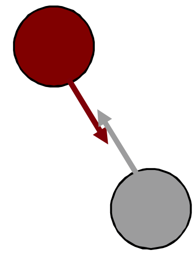


High Mobility

Hot Carrier Generation



Bad News



Fast Recombination

Environment

GUIDING QUESTION

What determines charge transport in "real life"?

Hot Carrier: Tielrooij et al. Nat. Phys. (9) 248. 2013.

``Brands” of Graphene

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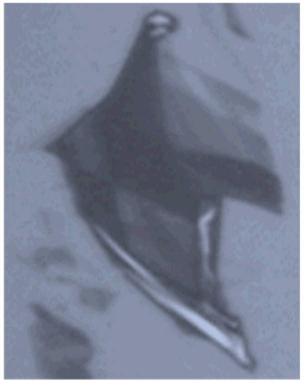
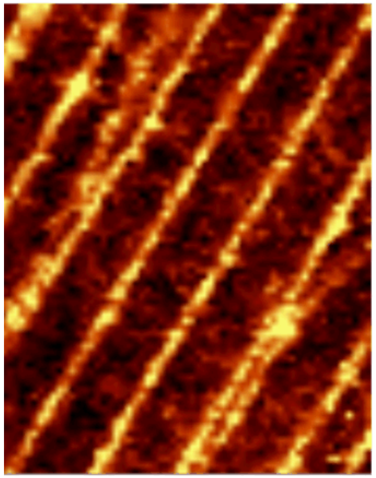
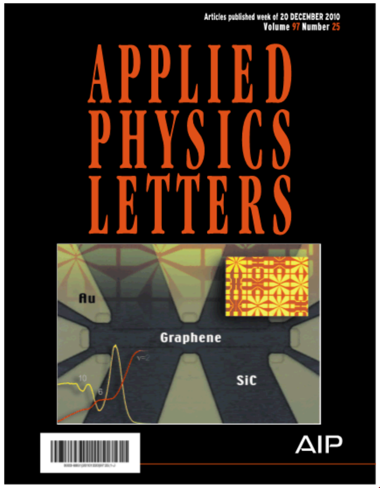
Exfoliated



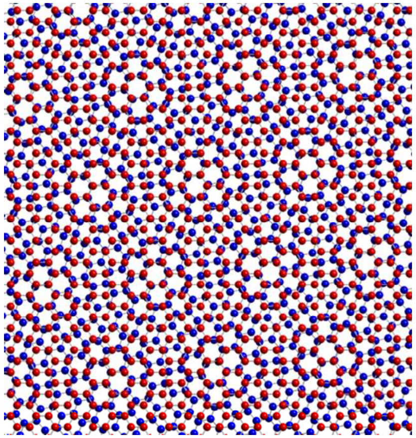
Copper Based CVD

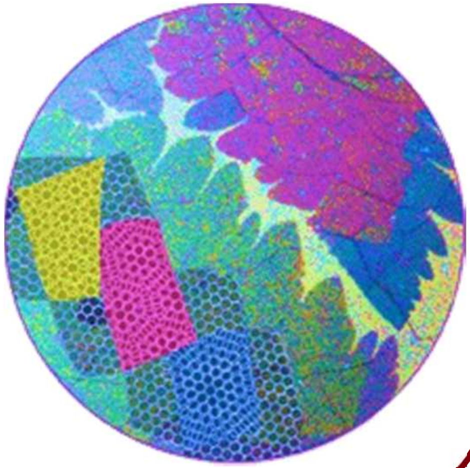
Epitaxial on SiC





Twisted Bilayer Graphene



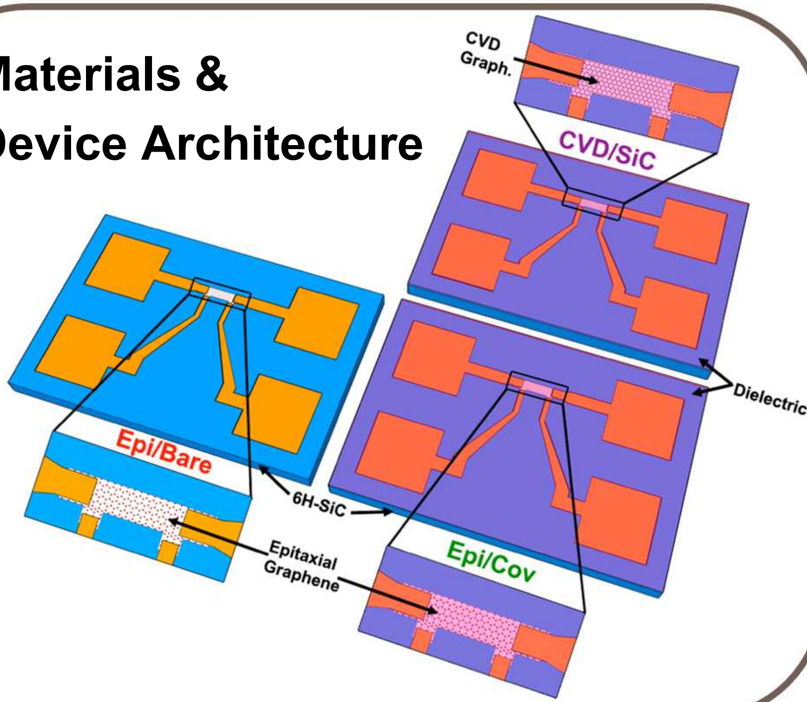


Epi: Pan, Howell, Ohta, et al. APL (97) 252101. 2010.

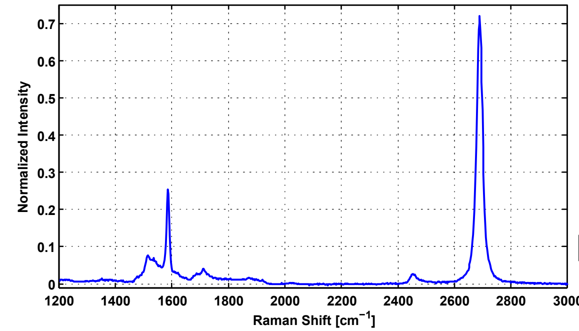
CVD: Hao et al. Sci. (342) 720, 2013.

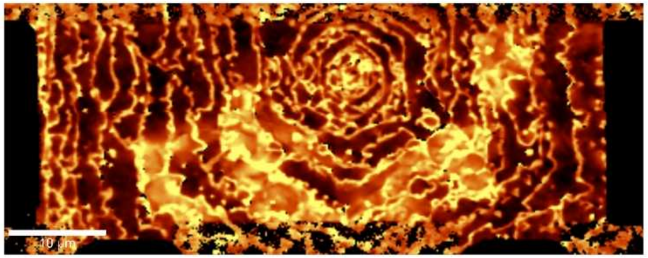
Method & Approach

Materials & Device Architecture

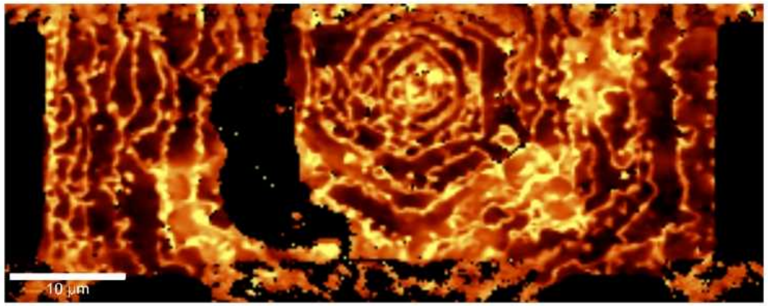


1. Pre-Raman Imaging

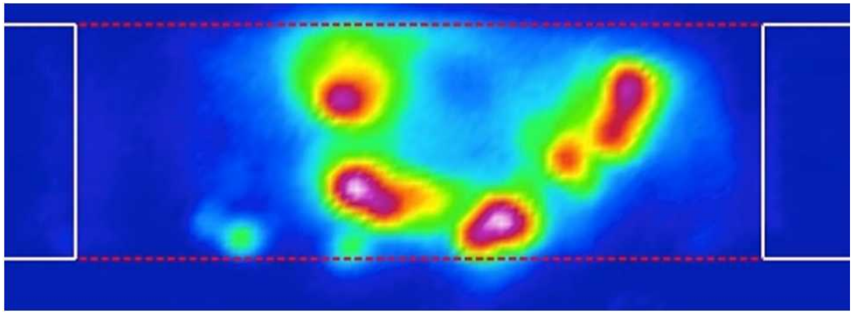




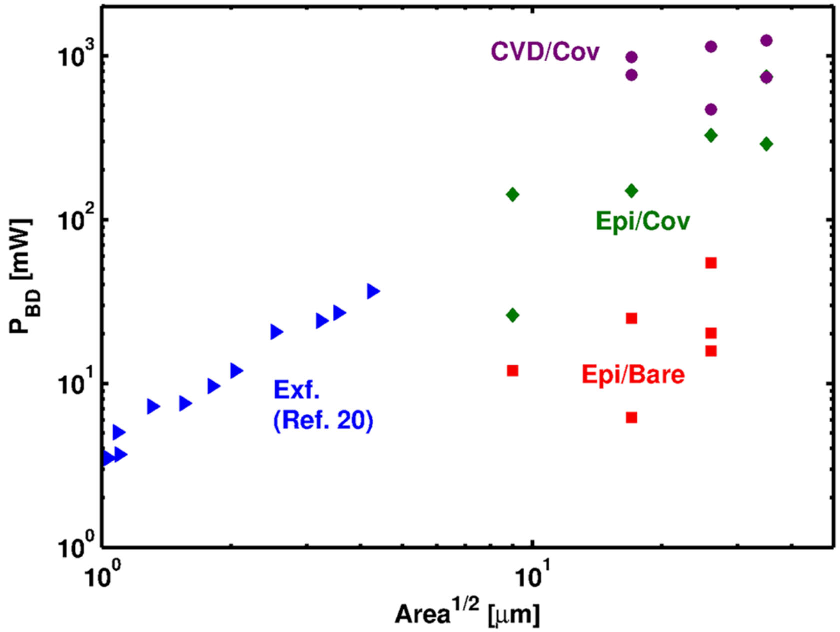
3. Post-Raman Imaging

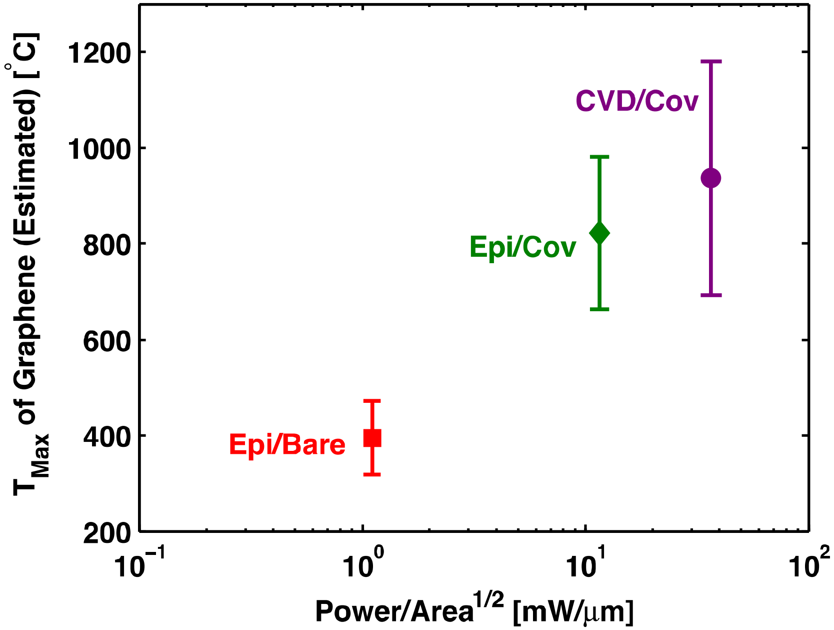


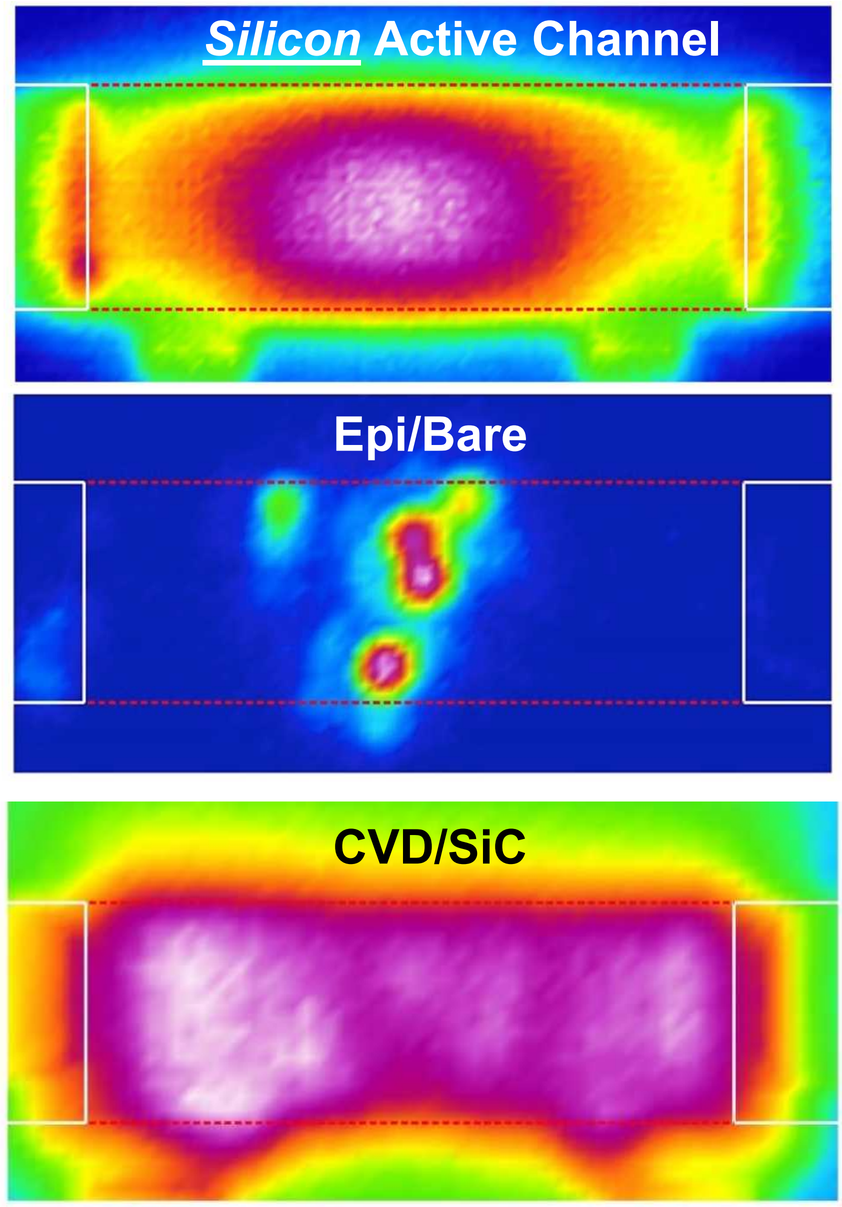
2. Infrared Thermography



Graphene Dependent Failure

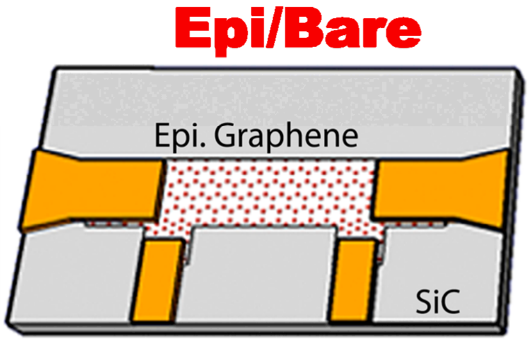


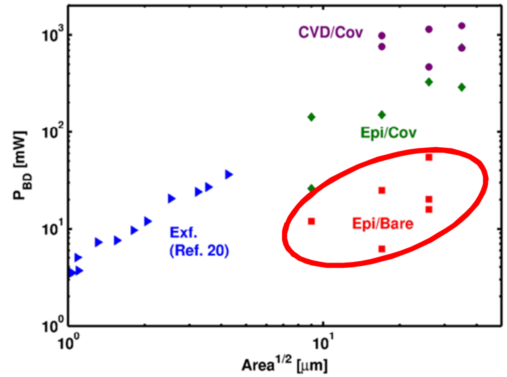


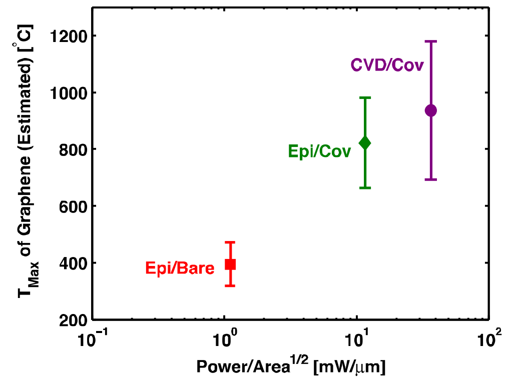


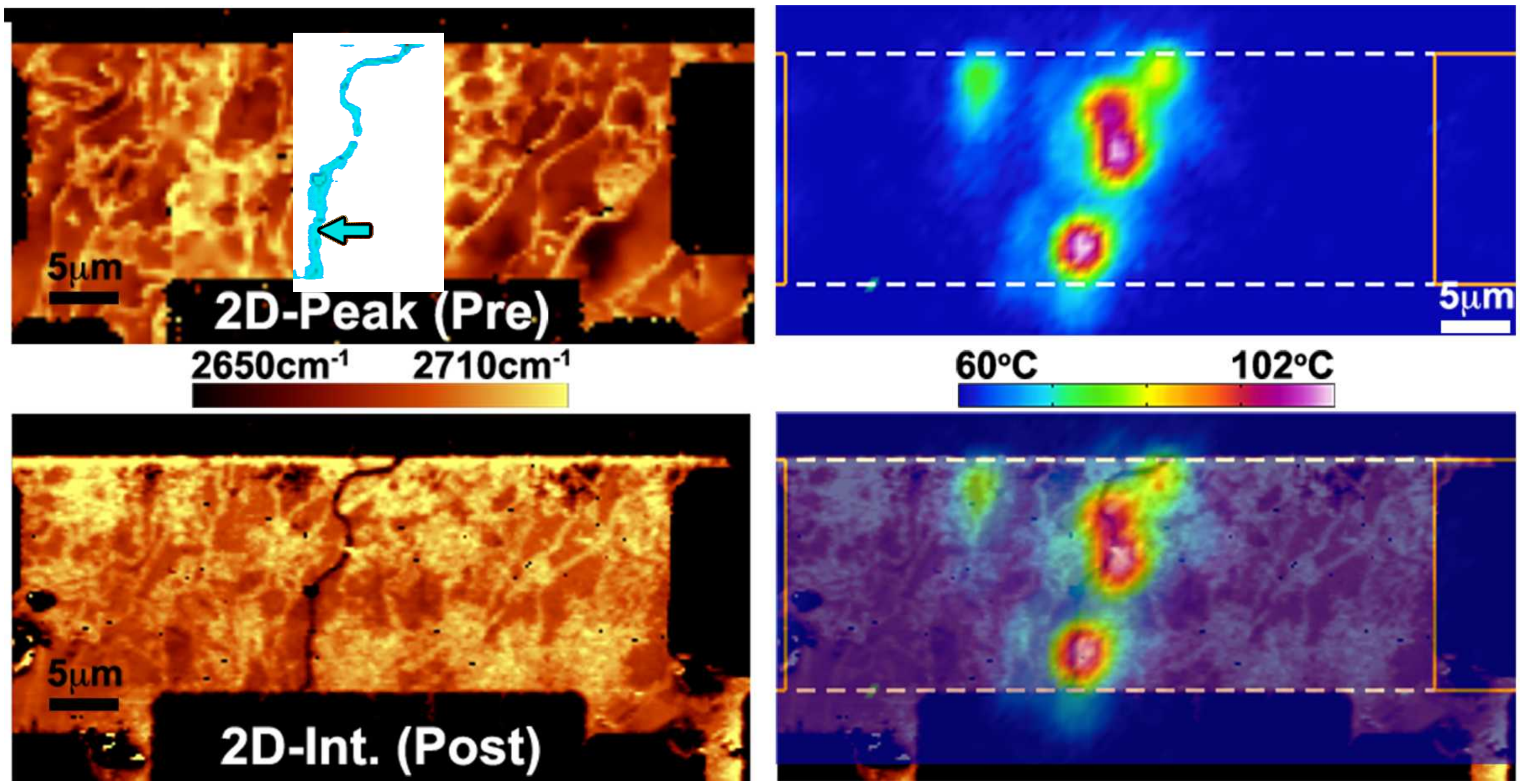
Exf./Bare Ref. 20: Liao et al. PRL. (106) 256801. 2011

Epi/Bare: Low Power Failure

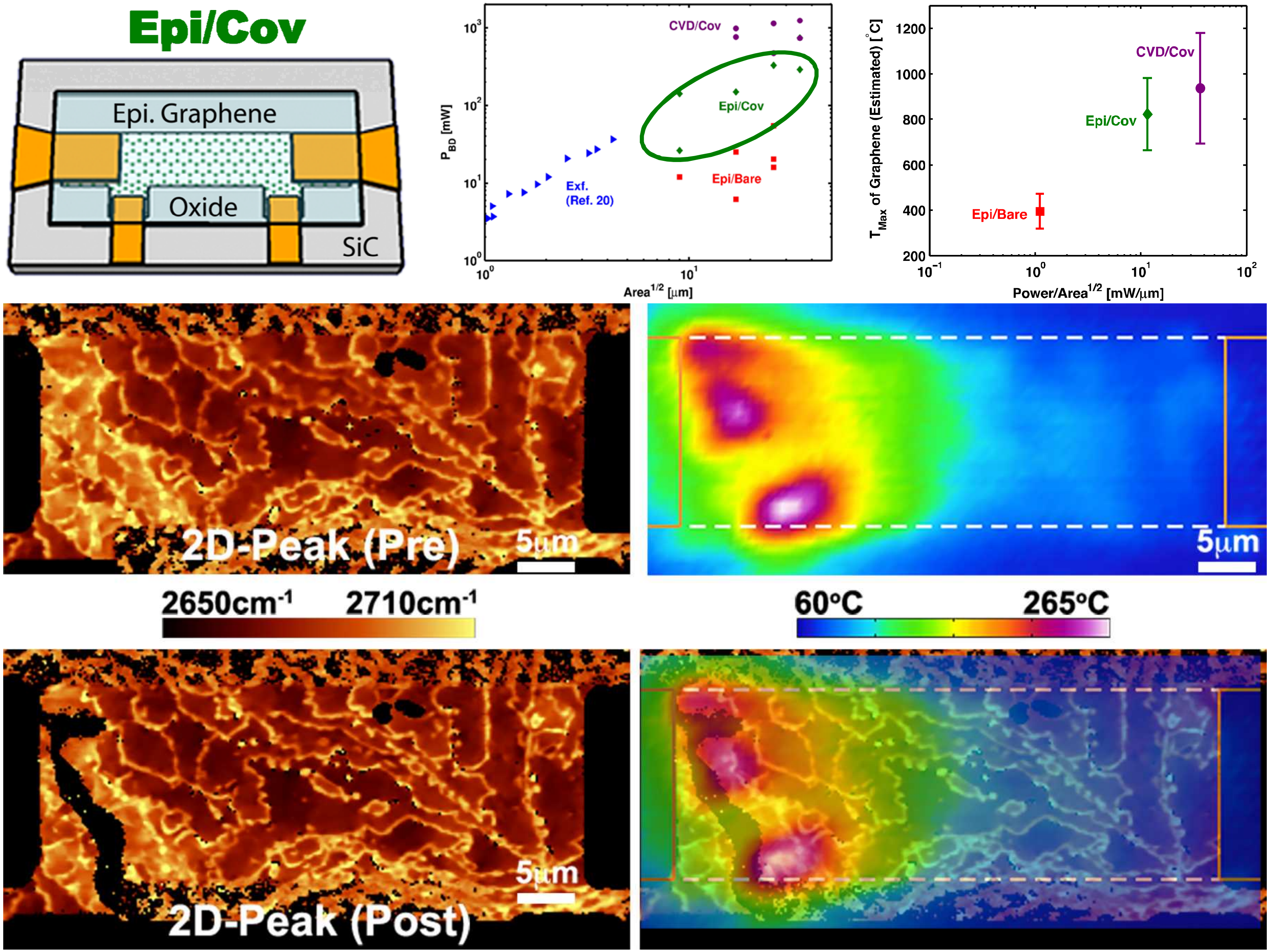




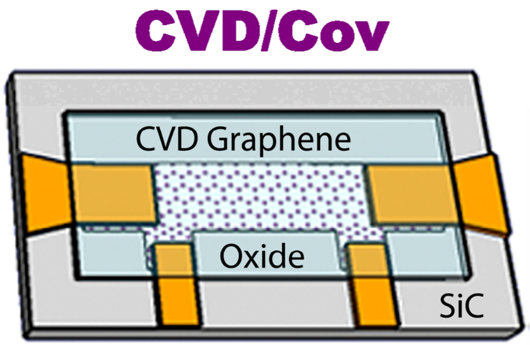


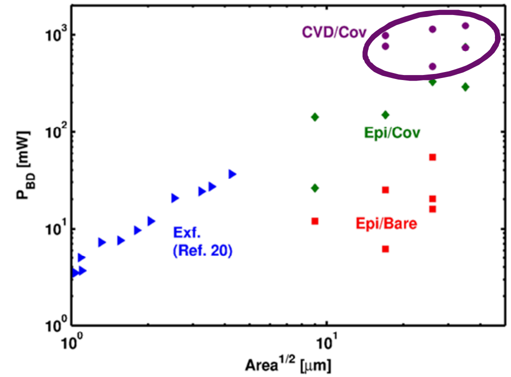


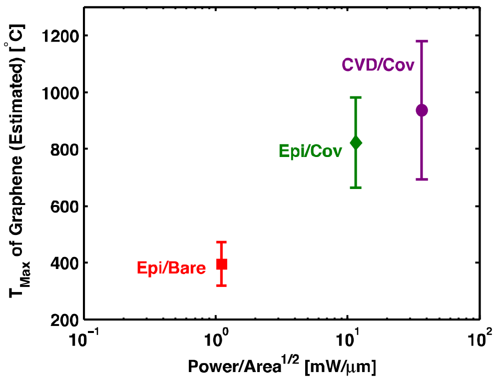
Epi/Cov: Middling Power Failure

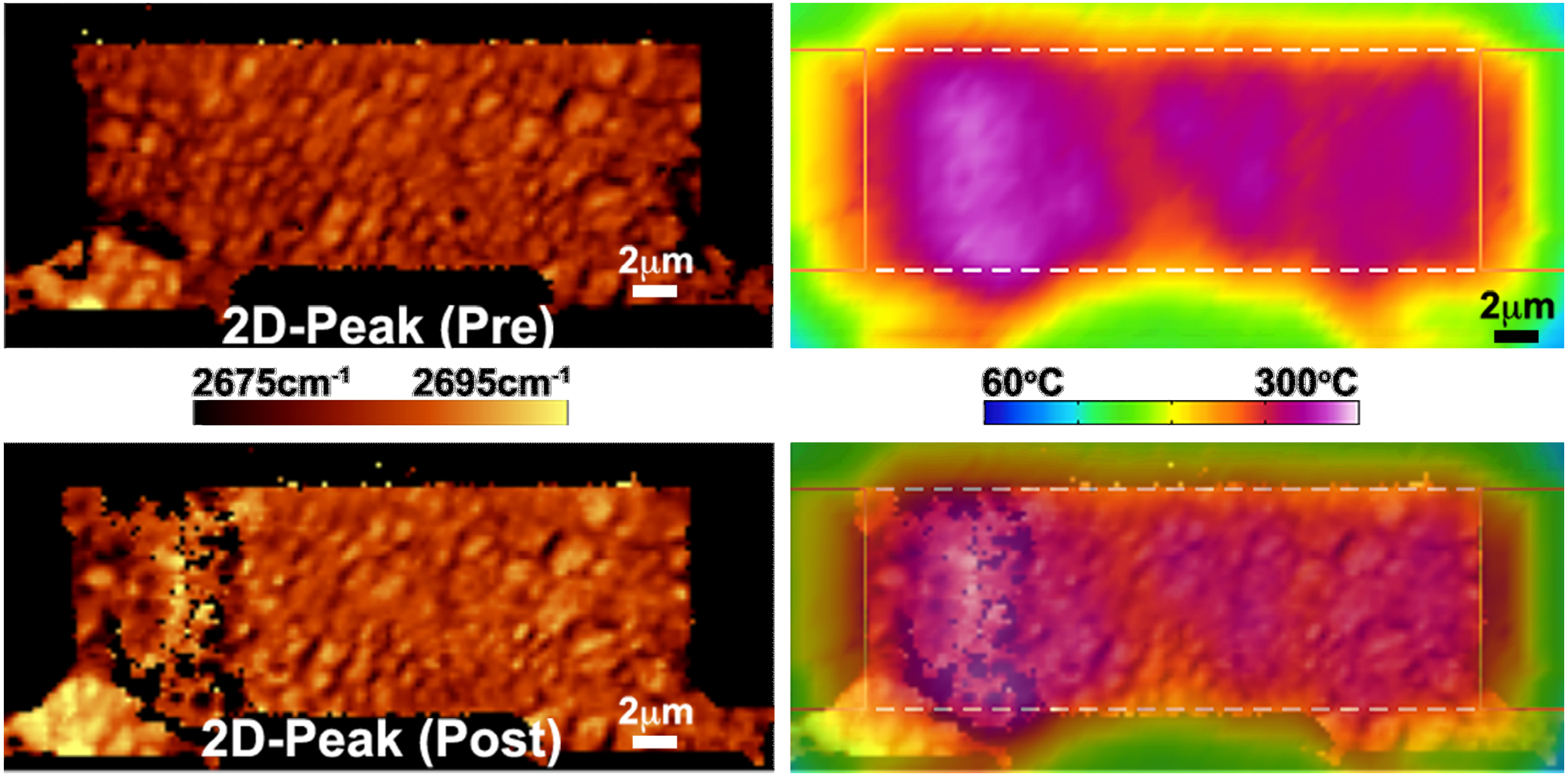


CVD/Cov: High Power Failure



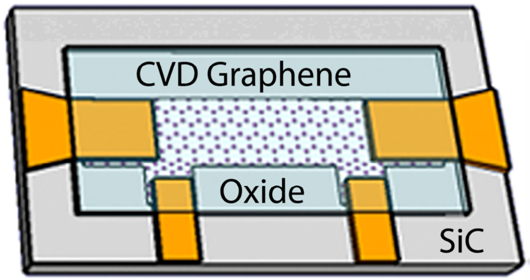


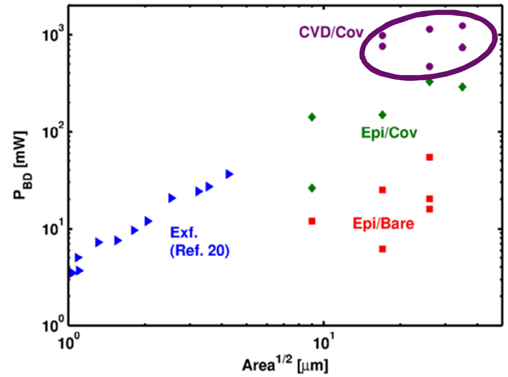


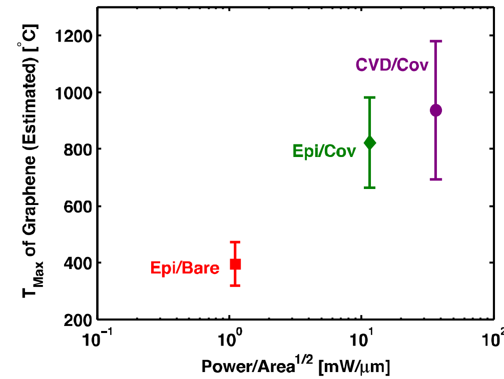


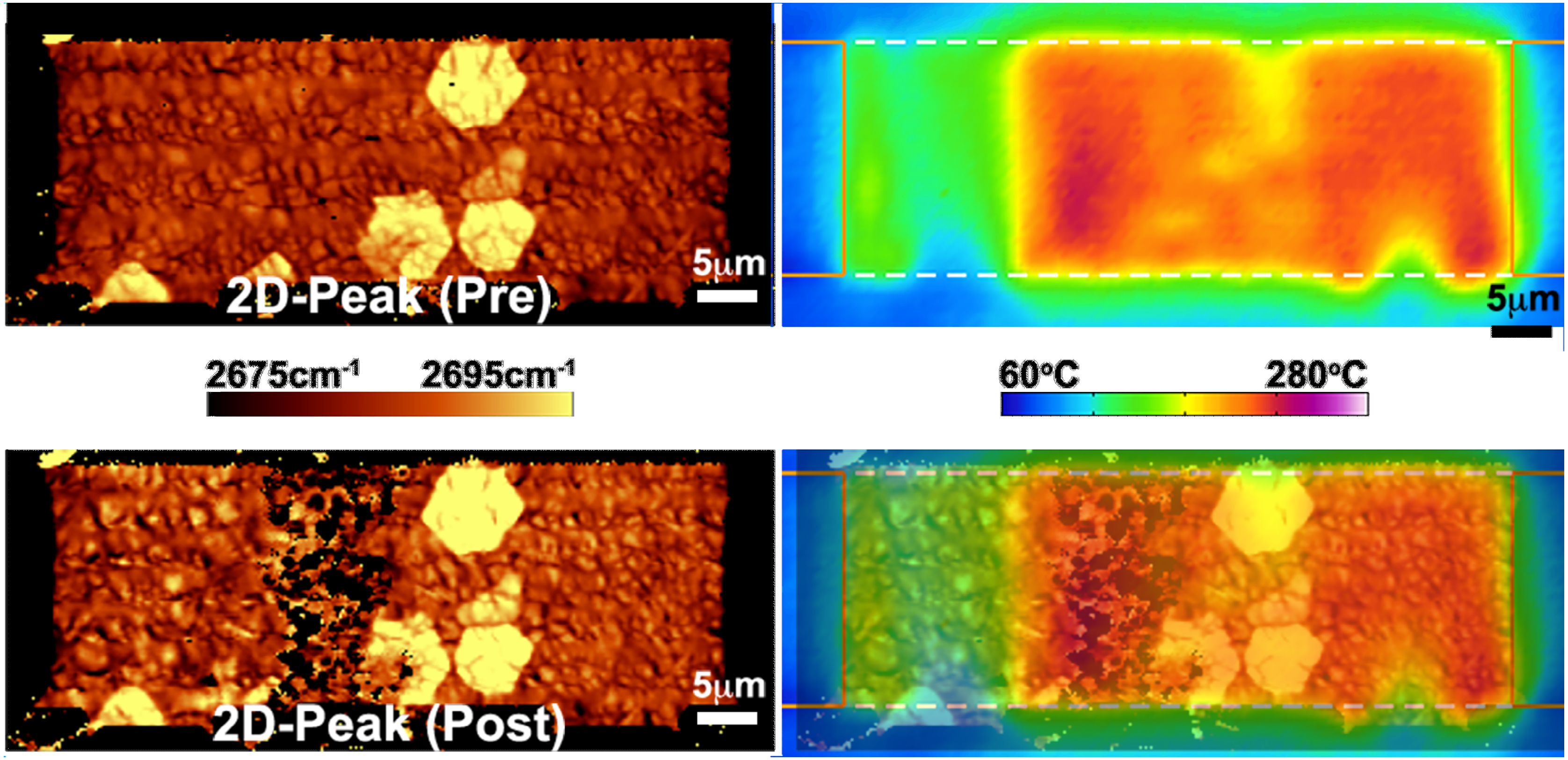
CVD/Cov: High Power Failure

CVD/Cov

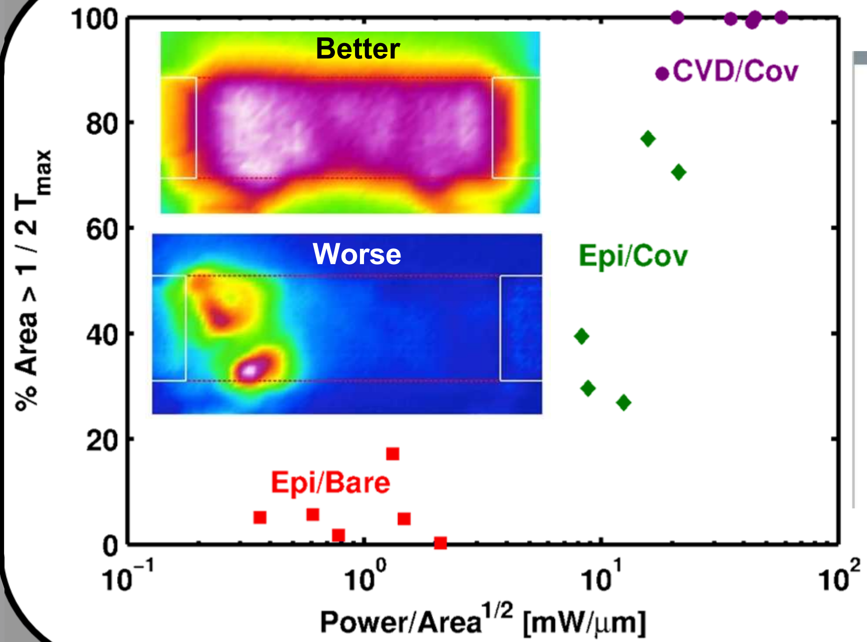


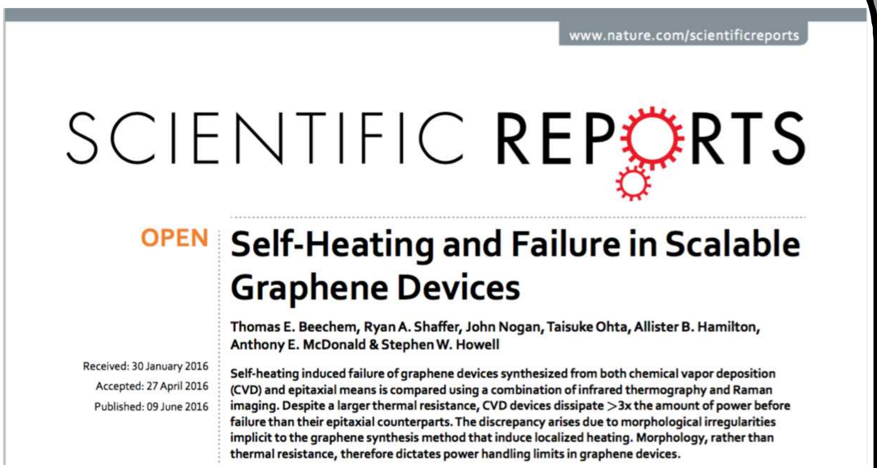






Take Home Message

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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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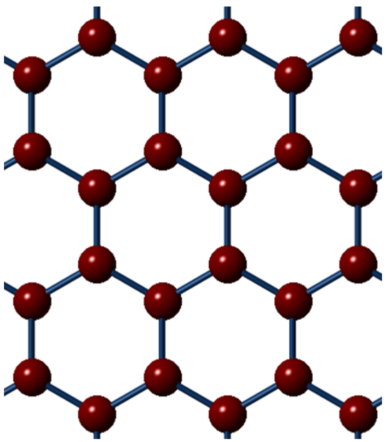
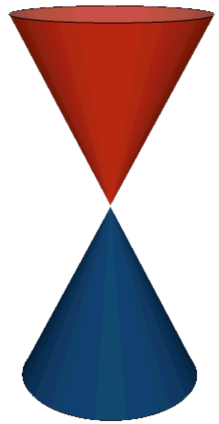
Self-heating induced failure of graphene devices synthesized from both chemical vapor deposition (CVD) and epitaxial means is compared using a combination of infrared thermography and Raman imaging. Despite a larger thermal resistance, CVD devices dissipate >3x the amount of power before failure than 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.

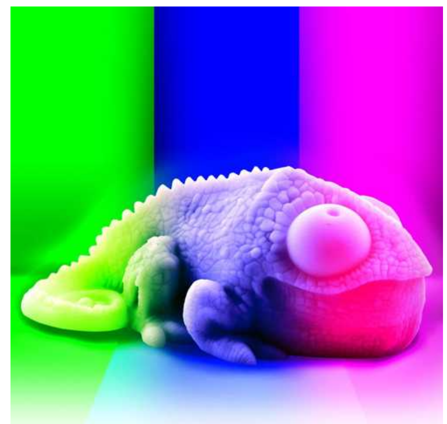
1. **Power handling determined by ability to uniformly Joule-heat.**
2. **Joule-heating distribution determined by morphology of graphene.**

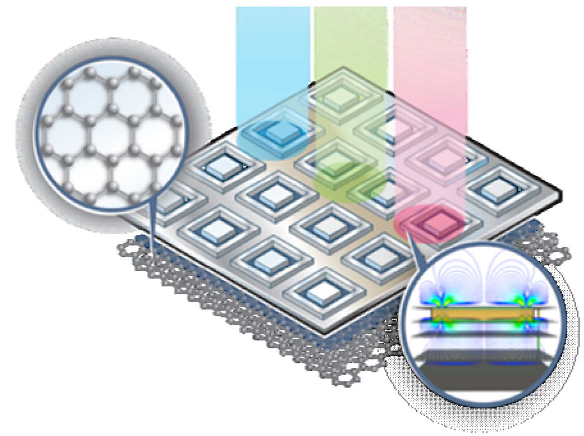
Interlayer Interactions determine morphology.

Bottom Line









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