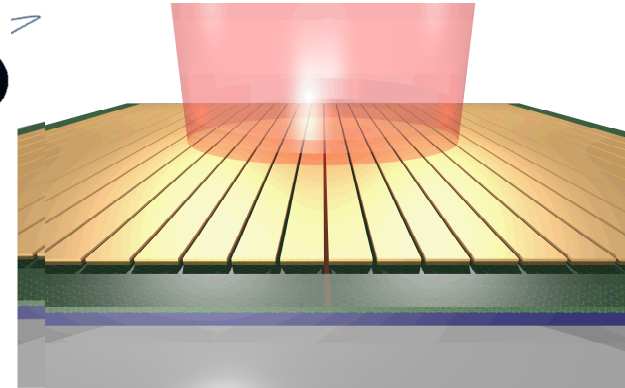
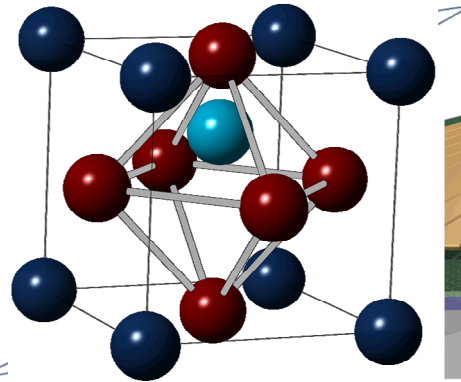
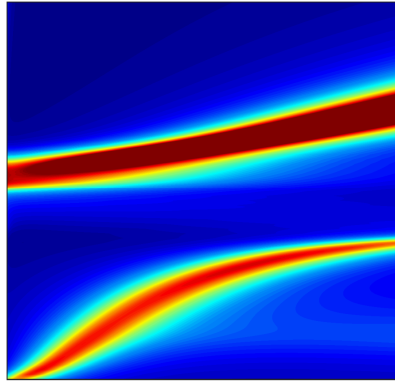
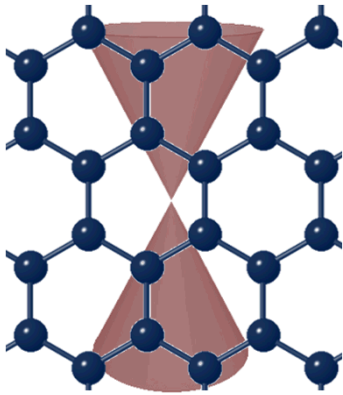


Phonon Light Switches: Leveraging Vibrations for Tunable Infrared Filters



Phonon Light Switches

Leveraging Vibrations for Tunable Infrared Filters

Thomas Beechem

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



Team:

David Peters

Michael Goldflam

Steve Howell

Joel Wendt

John Nogan

Anthony McDonald

Isaac Ruiz

Jon Ihlefeld

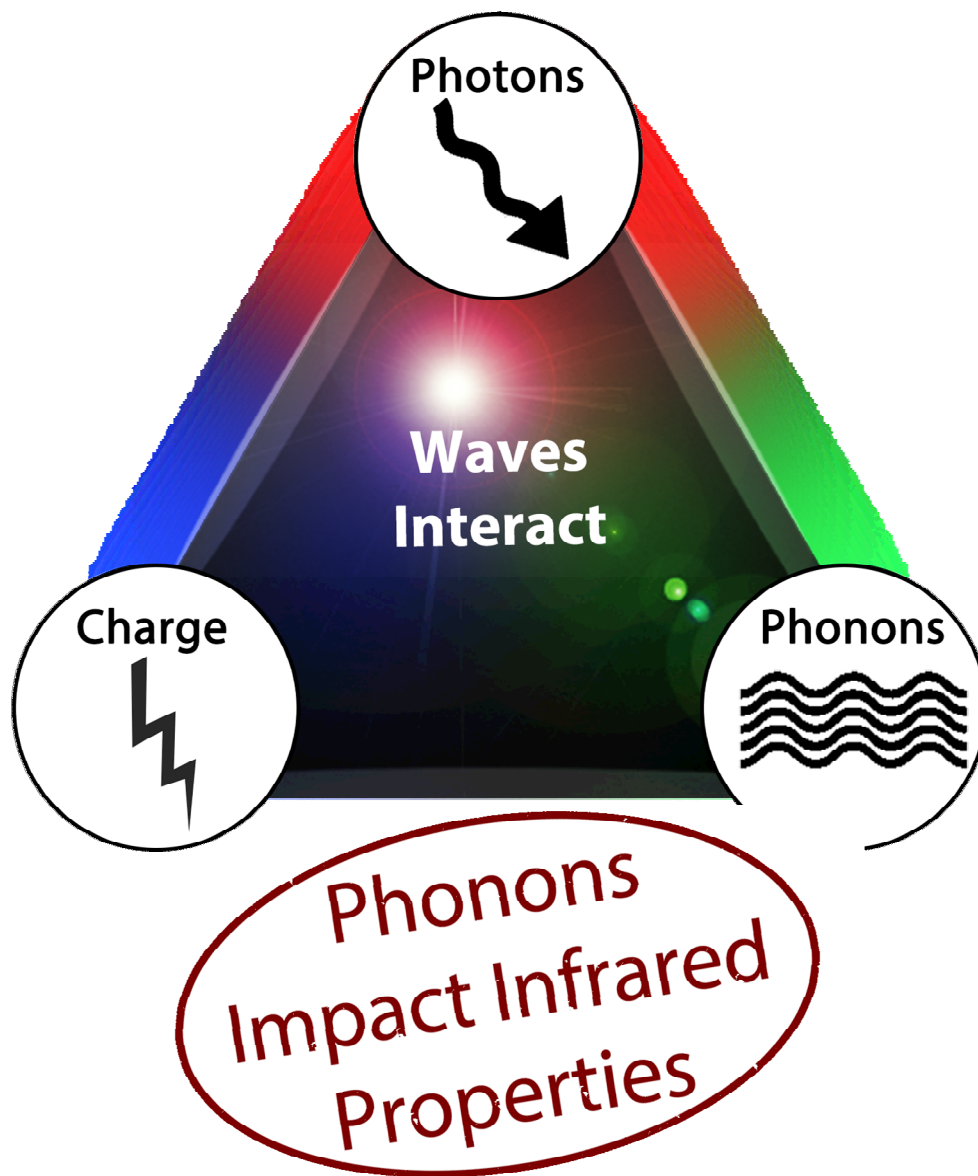




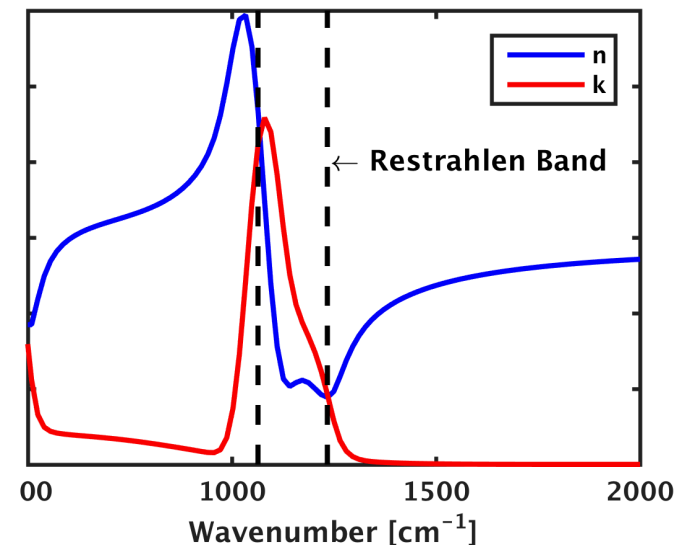
Phonon



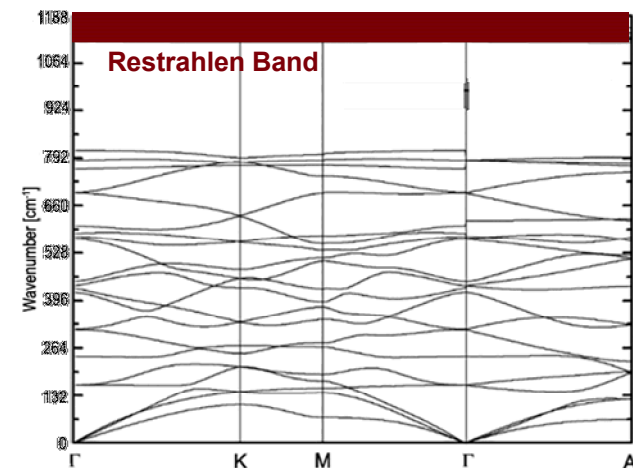
Waves are Waves are Waves



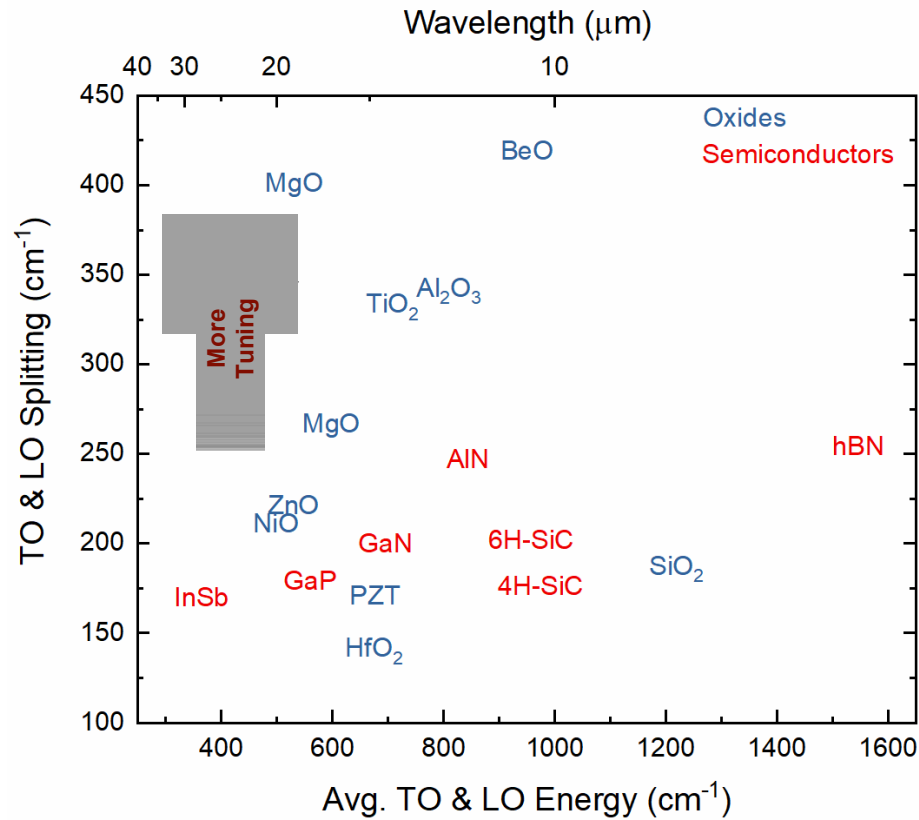
SiO₂ Ind. of Refraction



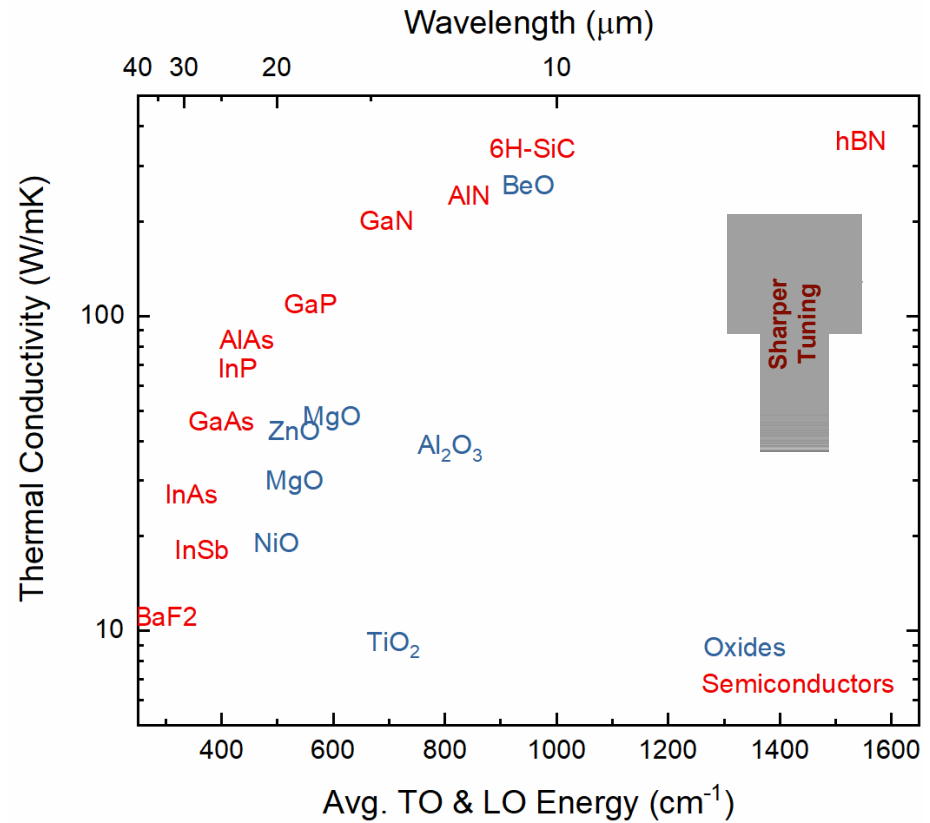
SiO₂ Phonon Dispersion



Phonon's Optical Vista



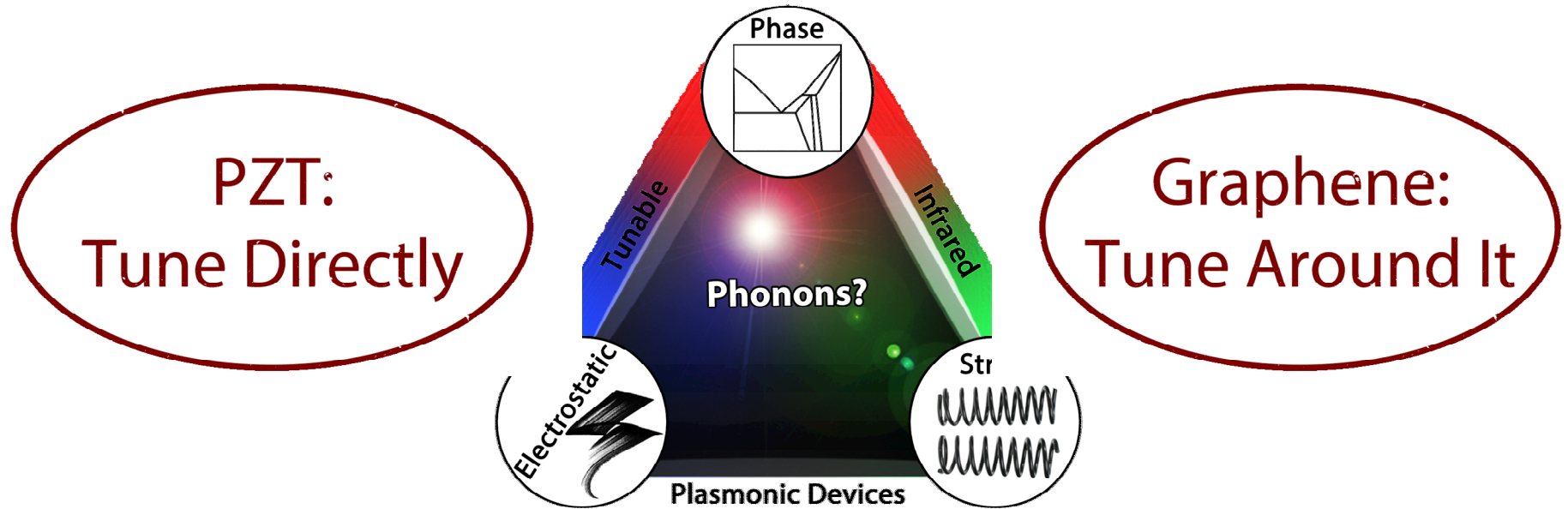
Many Materials
Many Bands



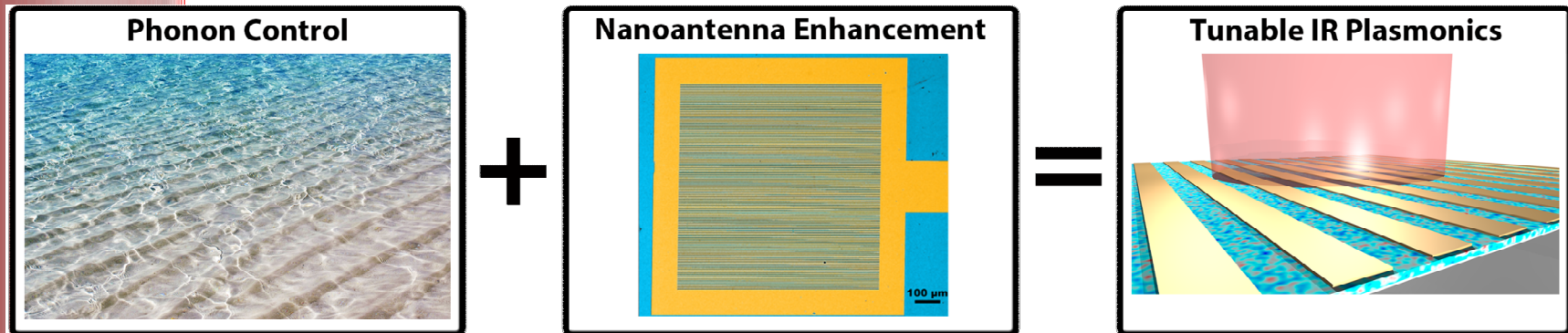
How do we
"use" it?

Phonons for Infrared Tuning

Premise: Leverage phonons for reconfigurable plasmonic devices

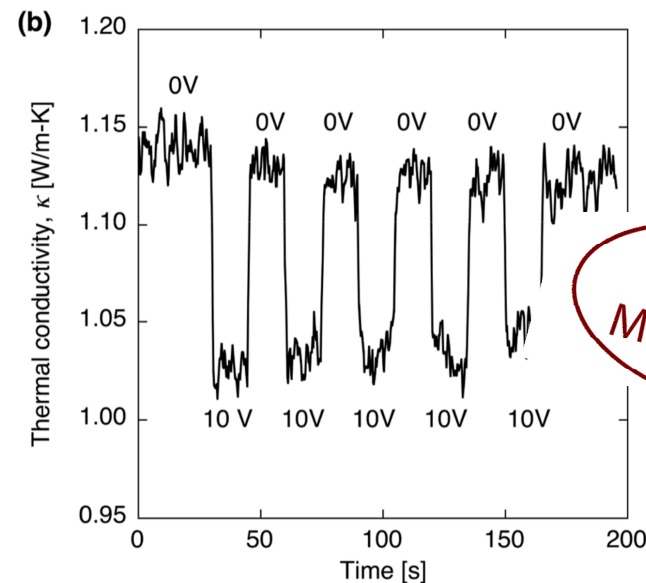
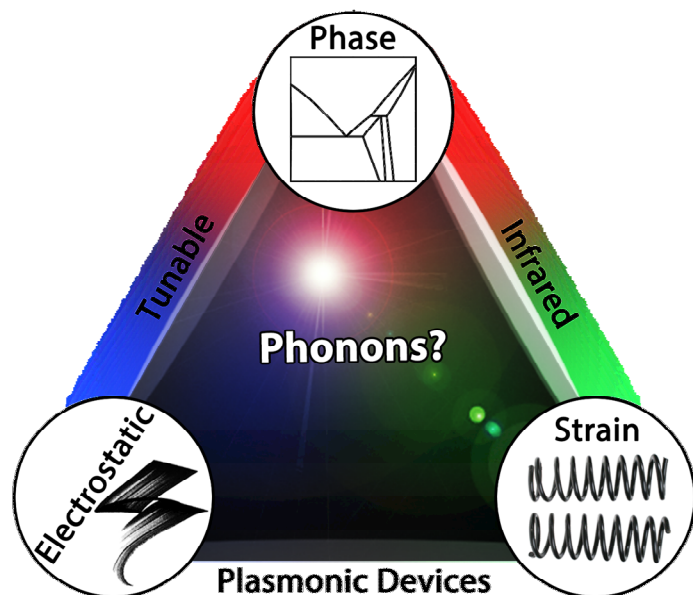


Path

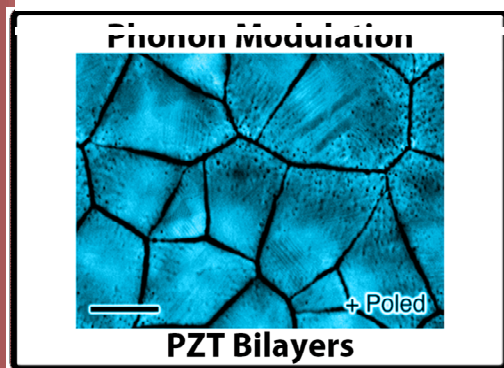


PZT: Direct Phonon Tuning

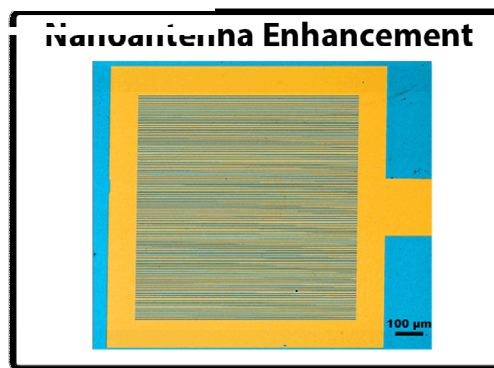
Premise: Leverage phonons for reconfigurable plasmonic devices



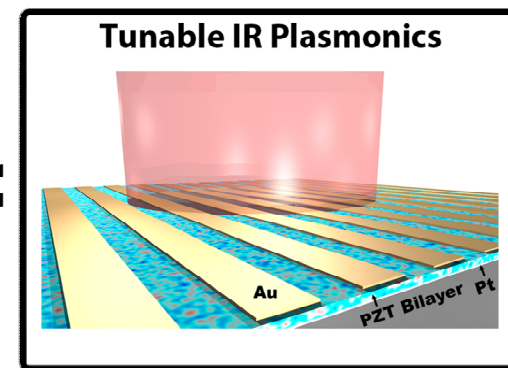
Path



+

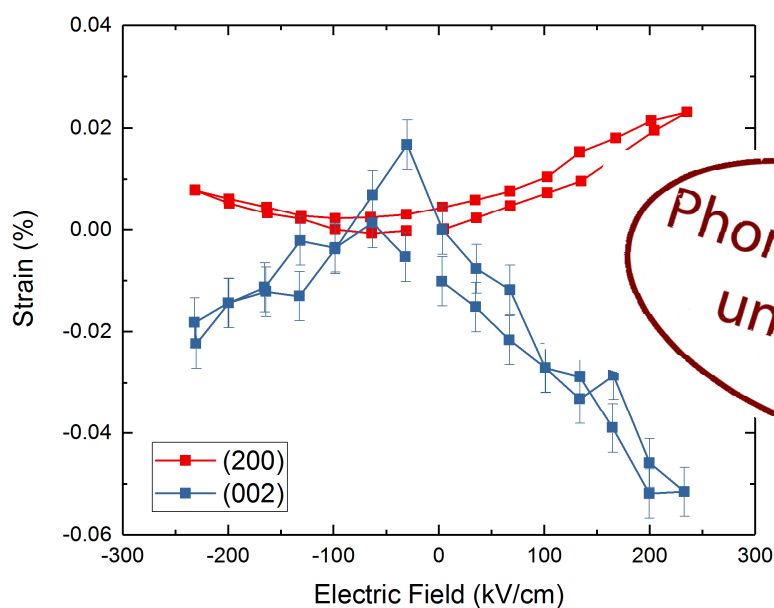
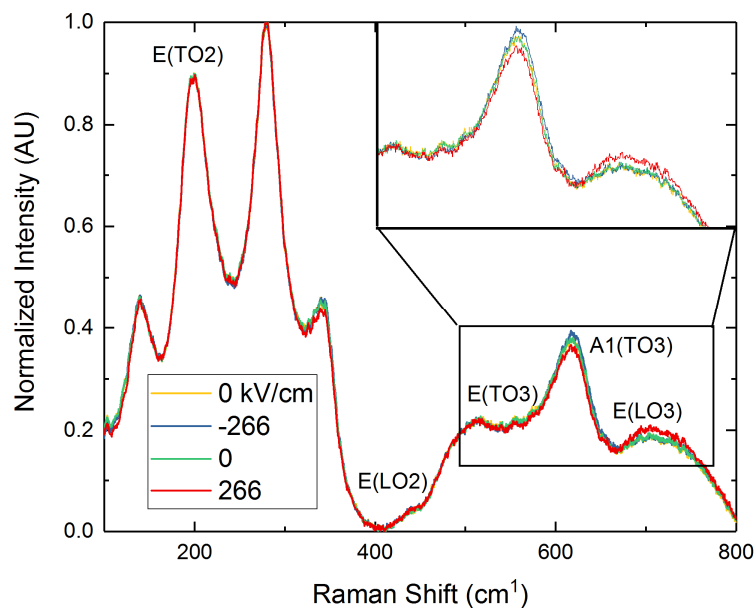
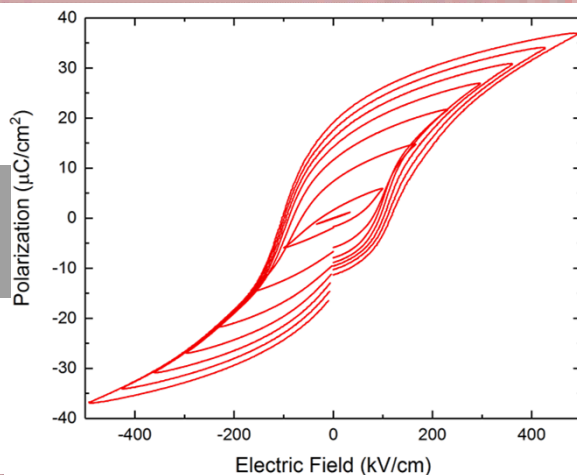
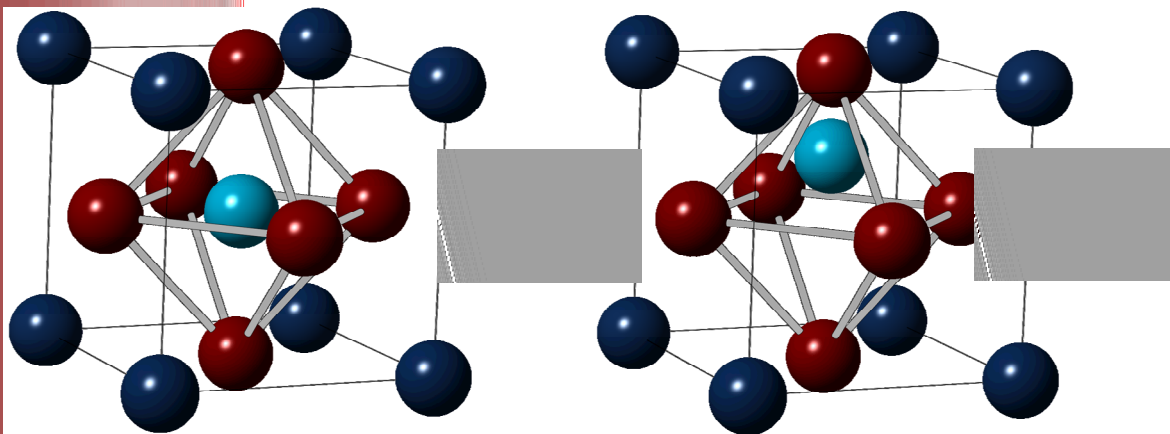


=



Modulating Phonons in PZT

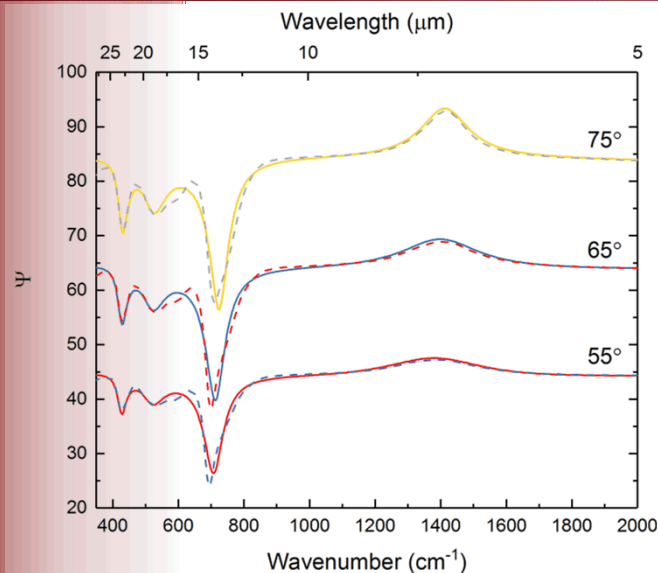
Affects
Phonons?



Phonons change
under field

PZT's Optical Response, Phonons?

PZT Optical Properties

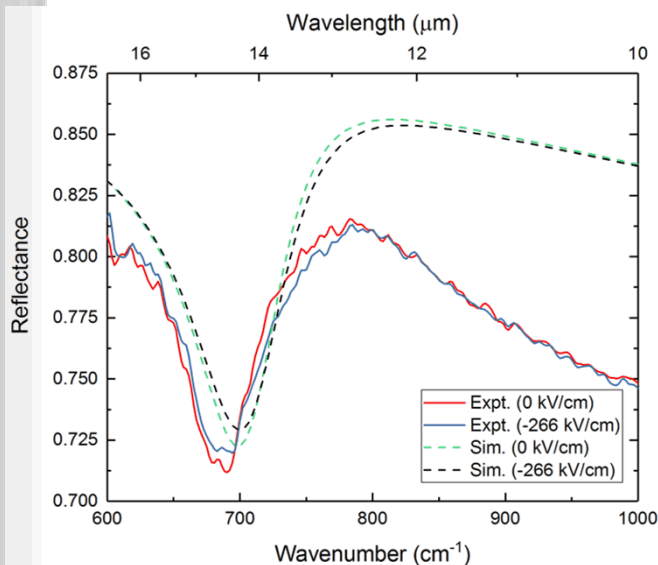


$$\epsilon(\omega) = \epsilon_{\infty} \prod_{i=1}^2 \frac{\omega_{i,LO}^2 - \omega^2 + i\Gamma_{i,LO}\omega}{\omega_{i,TO}^2 - \omega^2 + i\Gamma_{i,TO}\omega}$$

- Optical properties in IR determined by **phonon energies & their scattering**.

Field (kV/cm)	$\omega_{E(TO2)}$	$\Gamma_{E(TO2)}$	$\omega_{E(LO2)}$	$\Gamma_{E(LO2)}$	$\omega_{E(TO3)}$	$\Gamma_{E(TO3)}$	$\omega_{E(LO3)}$	$\Gamma_{E(LO3)}$
0	214	21	426	33	533	87	702	72

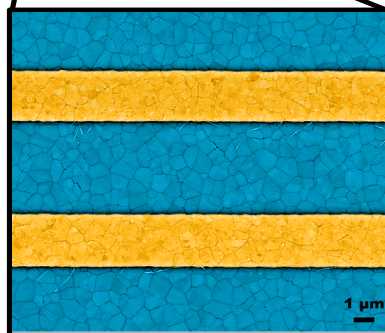
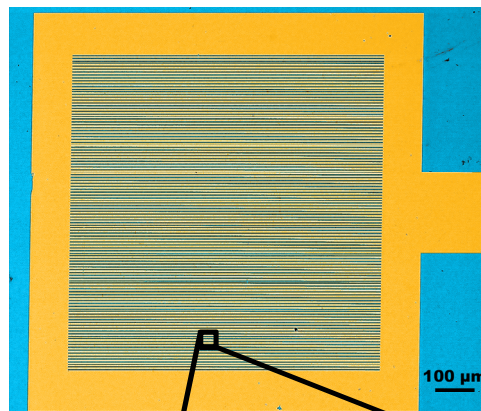
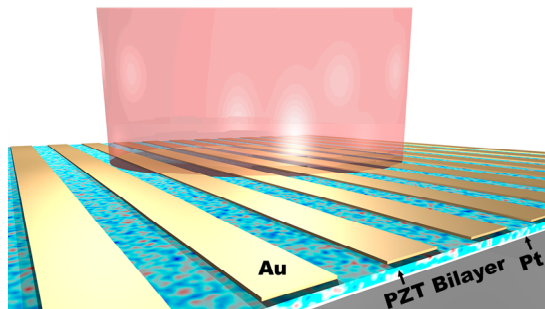
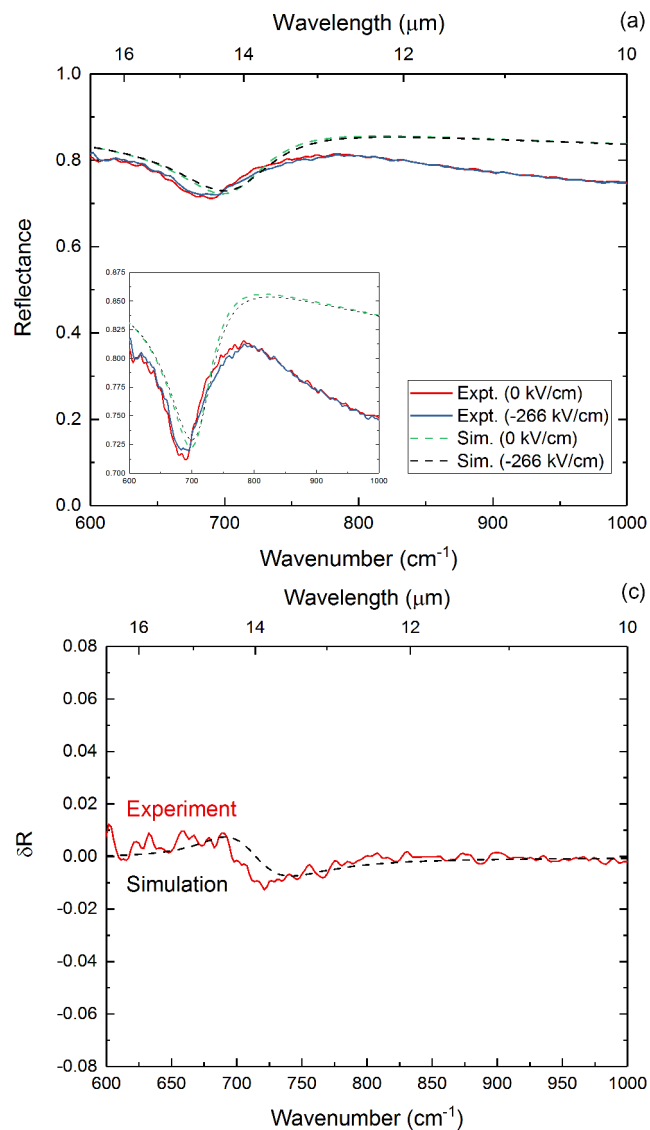
Optical Response Under Field



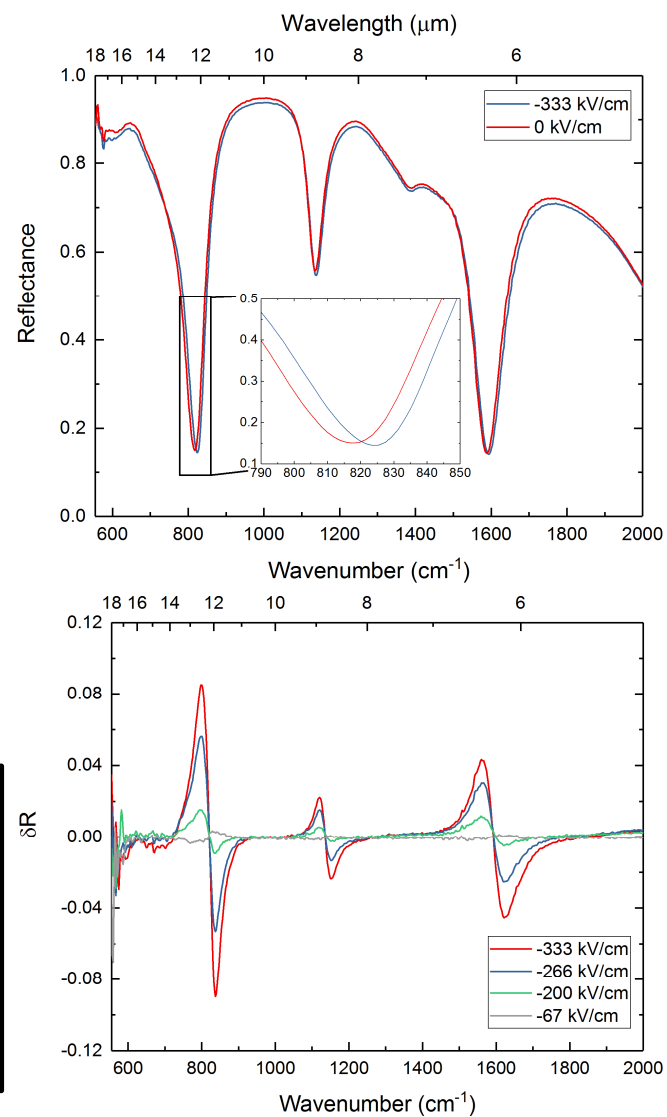
Small change?
Can it be bigger?

Exciting Plasmons in PZT

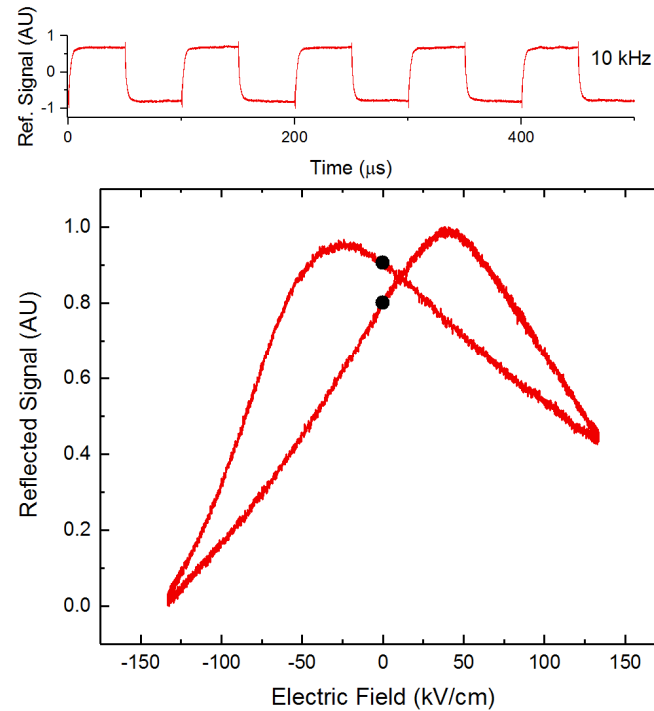
Unpatterned Device



Patterned (Plasmonic) Device



Tunability: Consequence



Ferroelectric Advantage

Low-Power

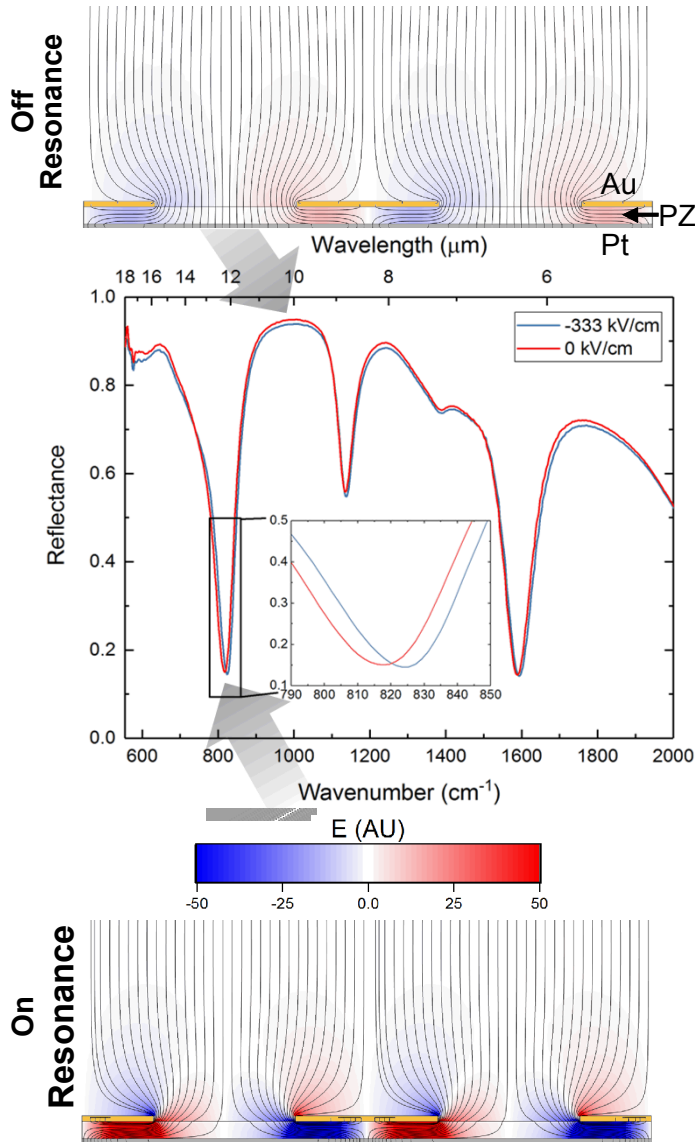
Switching Speed

Latchable

Scalable Fabrication

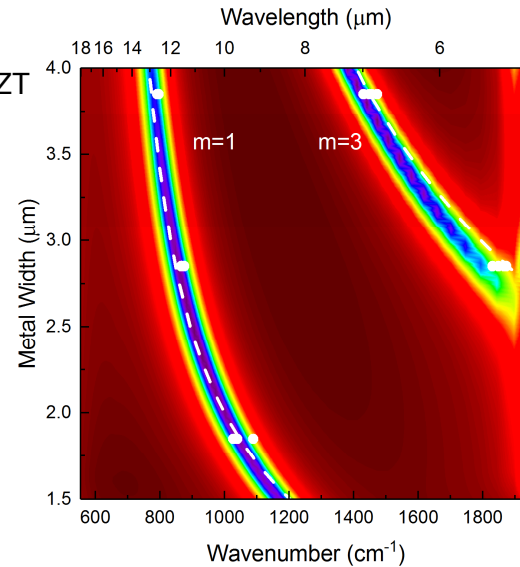
- No other approach offers this suite of capability.
- May enable tunable phonon-polaritons

Tunability: Cause

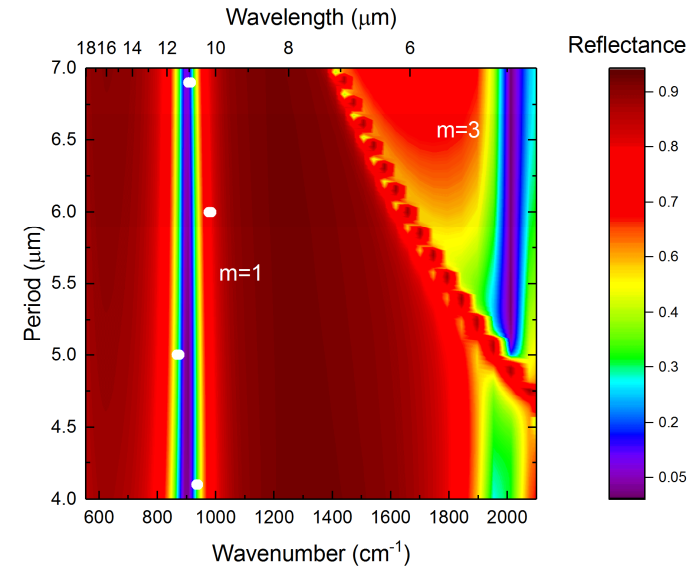


Where do the standing waves come from?

Constant Period



Constant Finger Width



Gap-Plasmon
Fabry-Perot

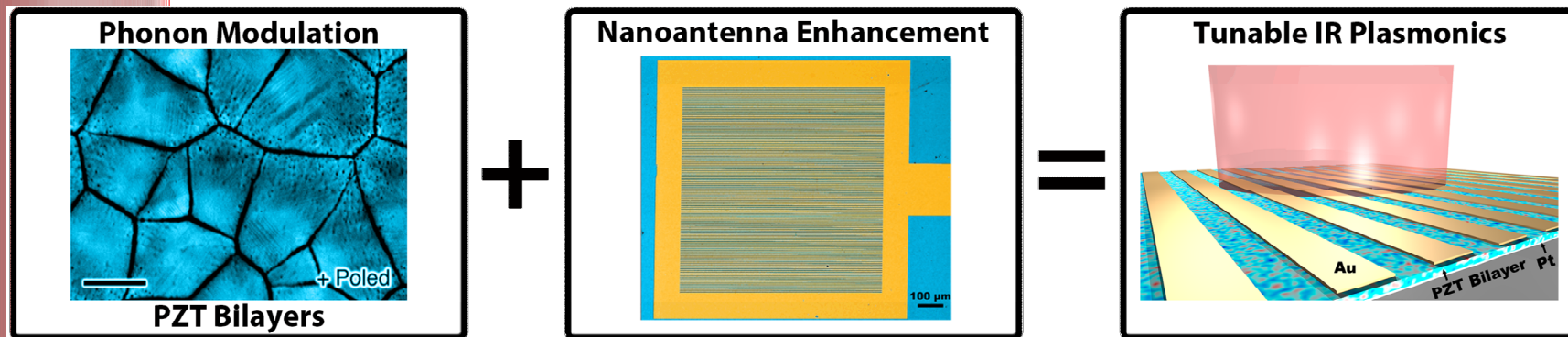
$$\frac{4\pi w_m n_{eff}}{\lambda_{res}} + 2\phi = 2m\pi$$

Depends on optical properties of PZT

- Optical properties depend on phonons
- Field induced modifications of phonons tune plasmon

Take Home Message

Path



Takeaways

- IR-active phonons change with domain reconfiguration
- Phonon changes alter optical properties
- Changes amplified in plasmonic systems. **Phonons** for tuning.

What makes me, me?

Genetic, Intrinsic



Environment



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

Graphene DNA & the Hype Train



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

By Nicola Davidson, CNN
Updated 8:53 AM ET, Fri January 13, 2017

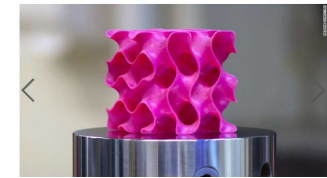


Photo: iStockphoto.com. These materials could change the world.
Graphene again - Researchers at the Massachusetts Institute of Technology have designed a new material that is 30 times stronger than steel.

Recommended for you

- Chicago judge killed outside home
- Ex-MLB player Chris Nelson found safe

The Washington Post

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

By Dominic Basulto April 2 Follow @dominicbasulto



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home science

Physics

Graphene - the new wonder material

Scientific interest rolls in for a material that is more solid than steel and a better conductor than copper

David Larousseire

Friday 22 November 2013 10:45 GMT

Most popular in US

- British spies were first to spot Trump team's links with Russia
- Arizona Sky Village's residents have one rule: Turn off your 'goddamned lights'
- United States' first female Muslim judge, Shifa Abdul-Salam, found dead in New York

Iron Man

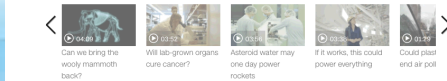
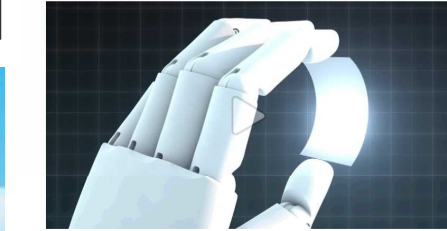
Why Iron man ditched iron for graphene

WIRED



Wonder material could harvest energy from thin air

By Peter Shatloft, video produced by Curtis Brown and Jackson Lo, CNN
Updated 9:59 AM ET, Tue November 3, 2015



Story highlights

Researchers in the UK say a discovery involving wonder material graphene could revolutionize batteries.

Graphene is 200 times stronger than steel and a million times thinner than a human hair.

The material, which has the same atomic structure as the lead in pencils, is impermeable to atoms and molecules.

Scientists found that positively charged hydrogen atoms could pass through it with implications for fuel cell efficiency.

Editor's Note: Originally published December 2014, updated November 2, 2015.

CNN — Bold claims for new battery technology have been around since the invention of the lead-acid battery more than 150 years ago.

But researchers at Manchester University in the UK say their latest discovery involving the new wonder material graphene could be the most revolutionary advance in battery technology yet.

According to a study published in the journal Nature,

Top stories

- News anchor learns her husband died in story she's reporting
- Chicago judge killed outside home

Bits The New York Times

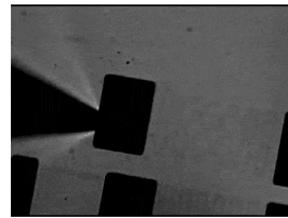
Graphene Could Usher in Flexible, Ultra-Slim Gadgets

By NICK BILTON OCTOBER 12, 2012 5:54 PM 24

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.



Graphene is a fully flexible material. Ji Hye Hong



Graphene can be folded and cut into a microscopic kirigami spring. Cornell University/McEuen Group

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.

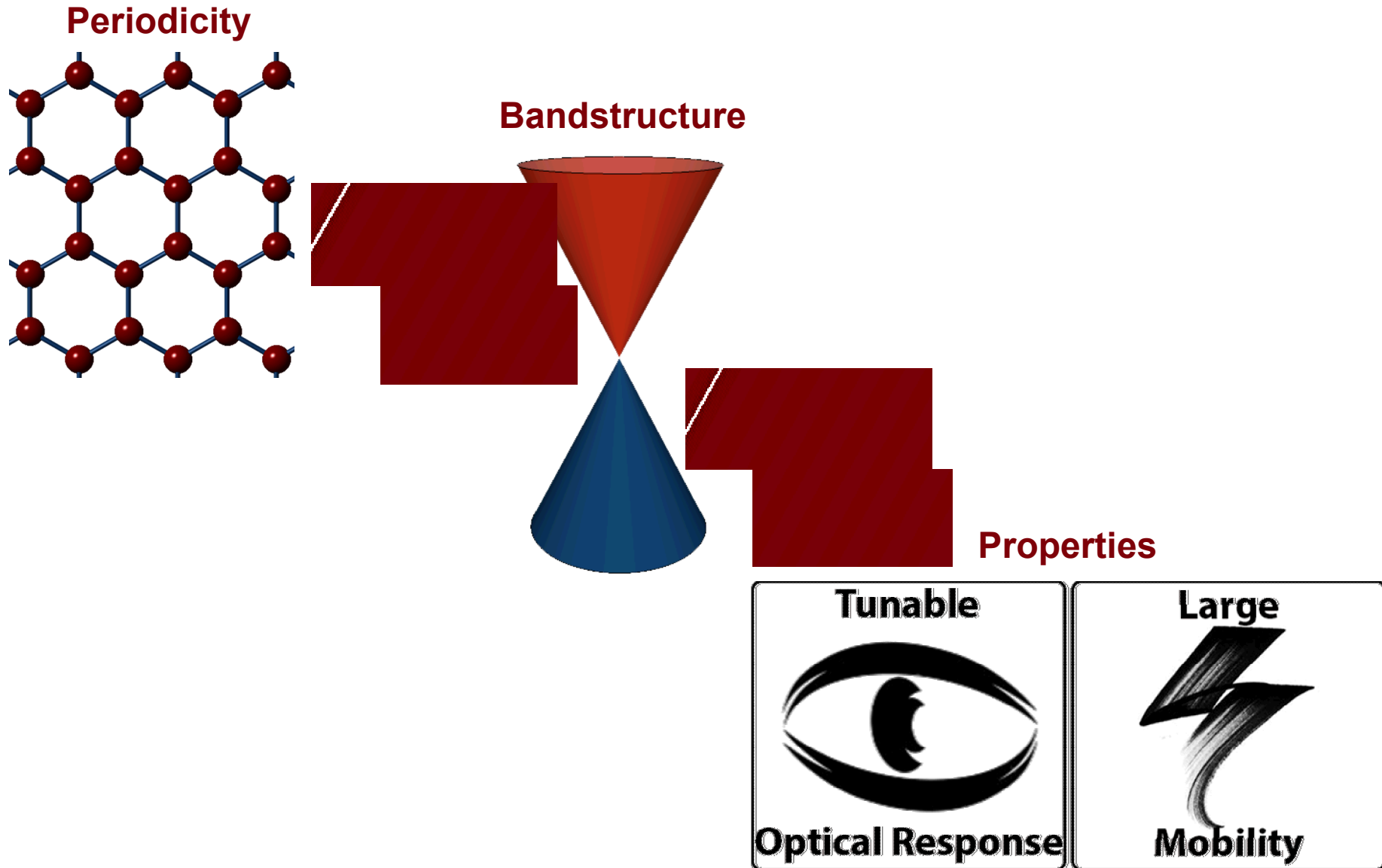
Graphene is so strong that a sheet of it stretched across a coffee-cup should be able to support the weight of a truck bearing down on a pencil point. Some researchers call it a "wonder material" that could be used in everything from batteries and biosensors to computers and condoms.

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.

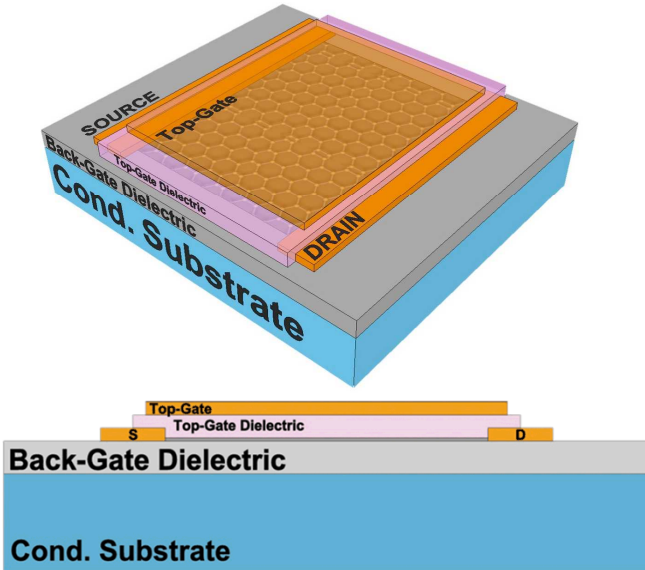
—NICHOLAS ST. FLEUR

DNA: Origin of Properties

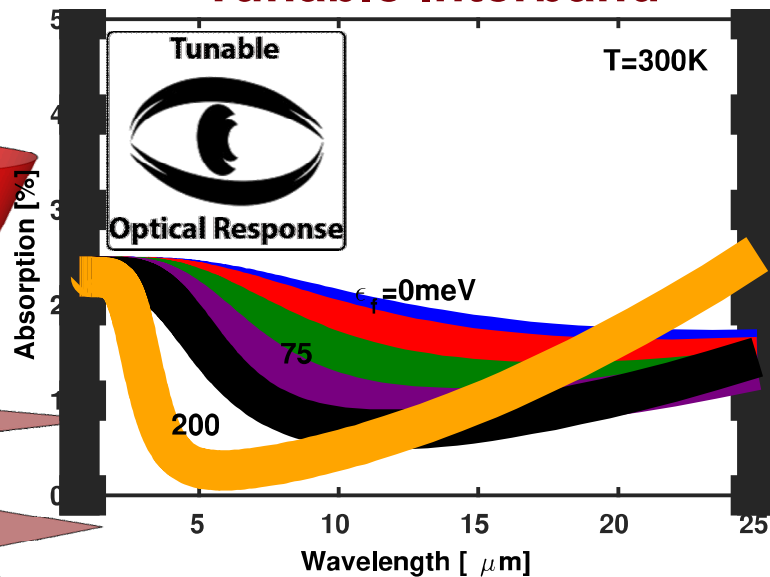


DNA: Graphene Tunability

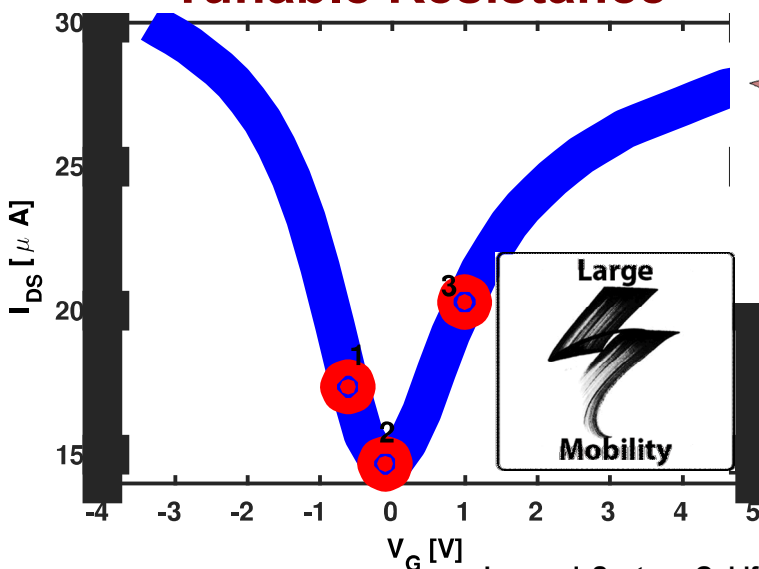
Graphene Transistor



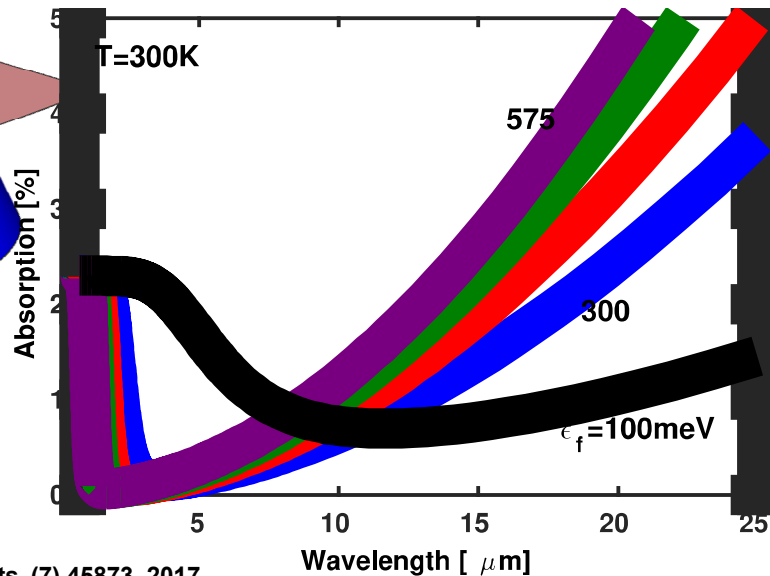
Tunable Interband



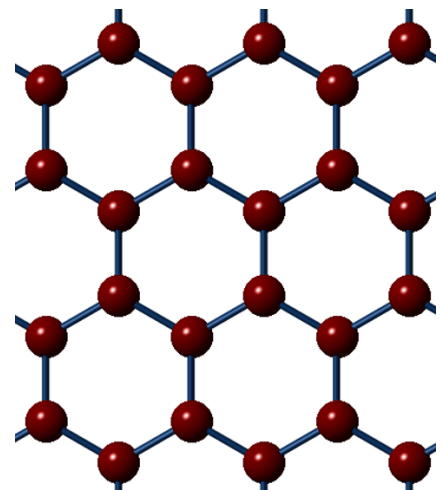
Tunable Resistance



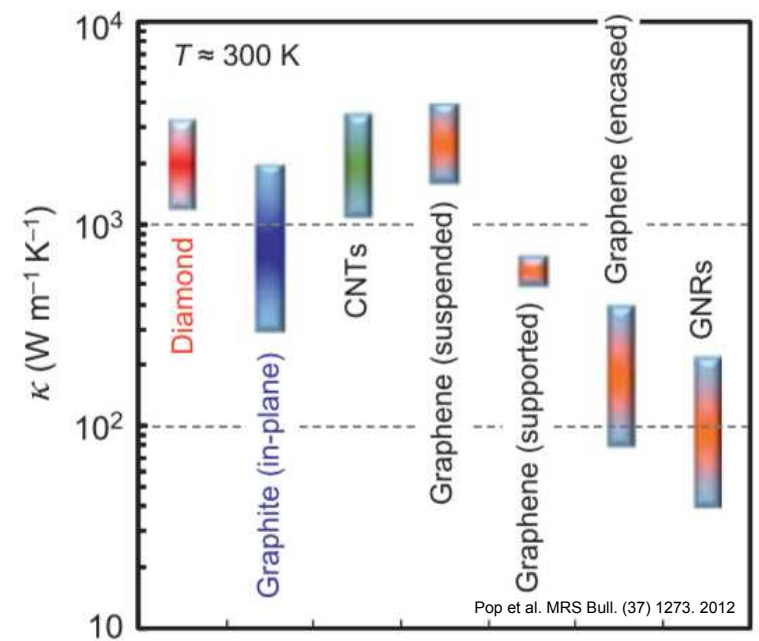
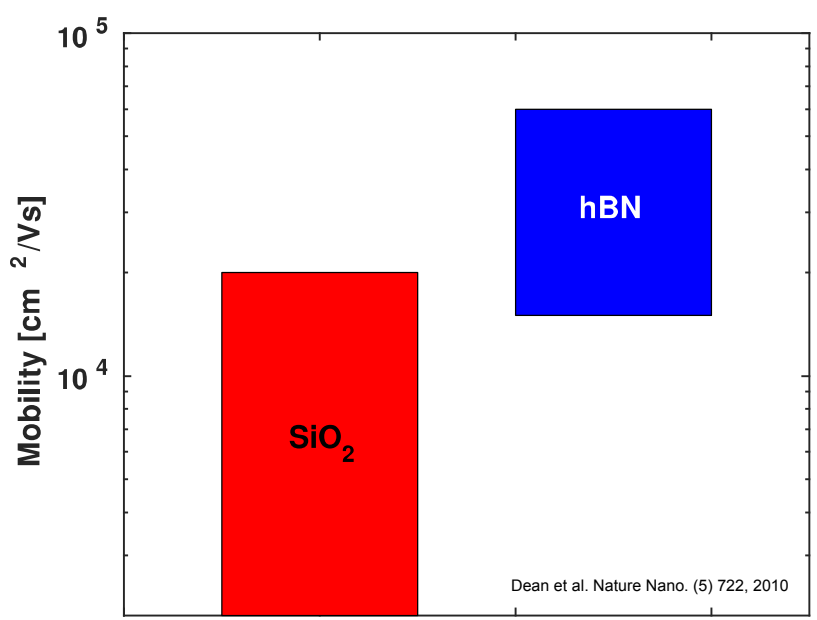
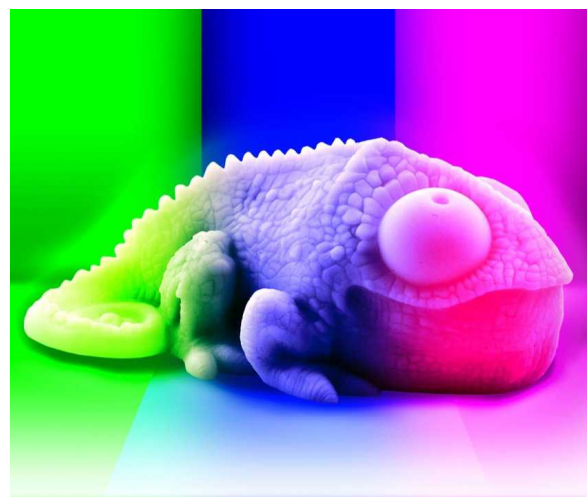
Tunable Intraband



Env:Graphene & Peer Pressure



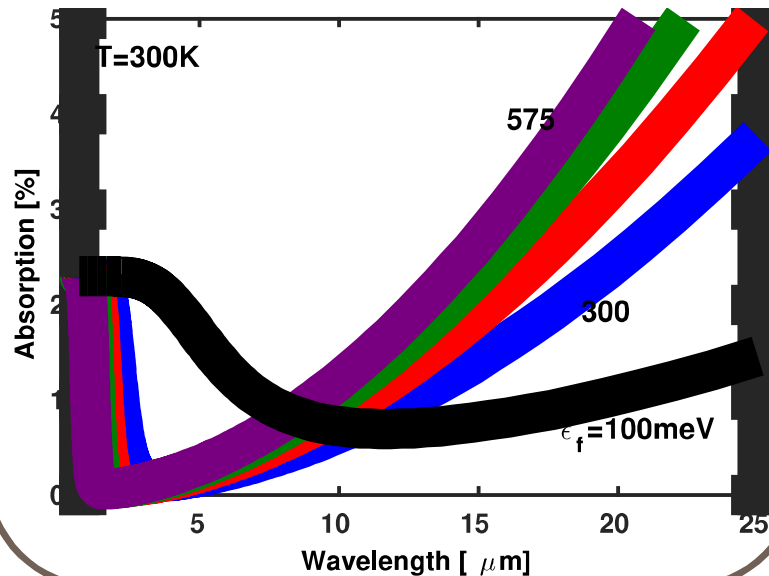
D.A.R.E.[®]



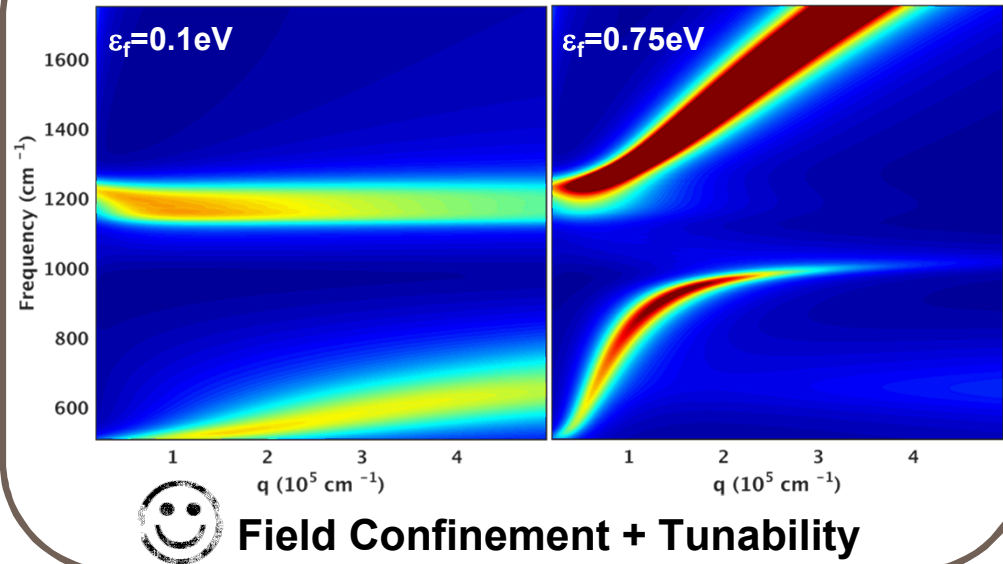
How to increase light-matter interaction?

Goal: Create a tunable IR filter

Problem: 5% Not Enough

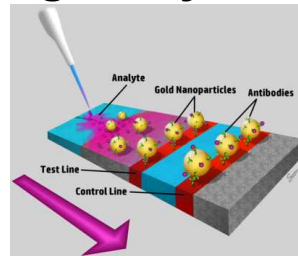


Tool: Graphene Plasmons



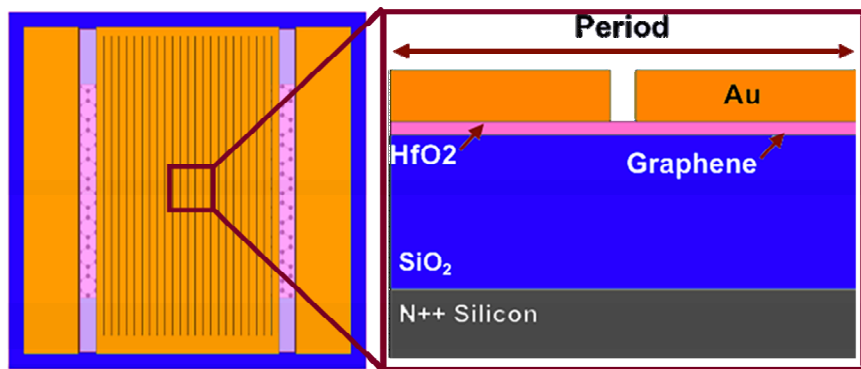
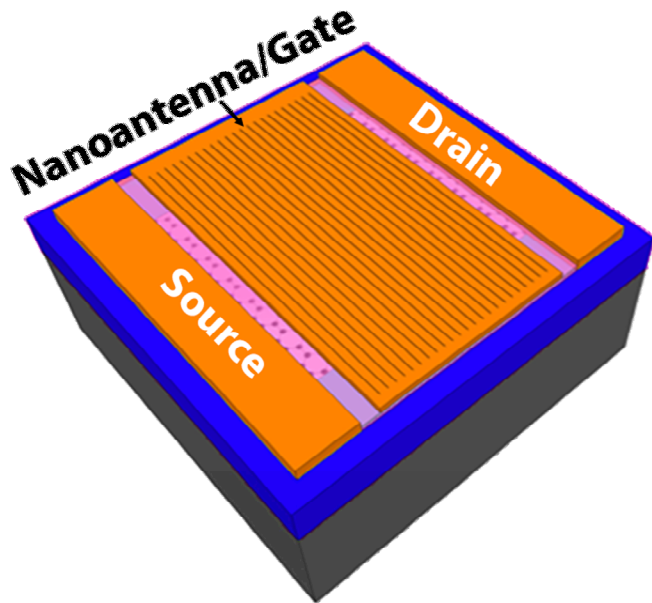
Field Confinement + Tunability

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

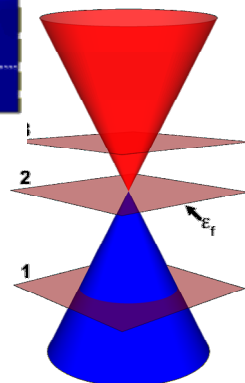
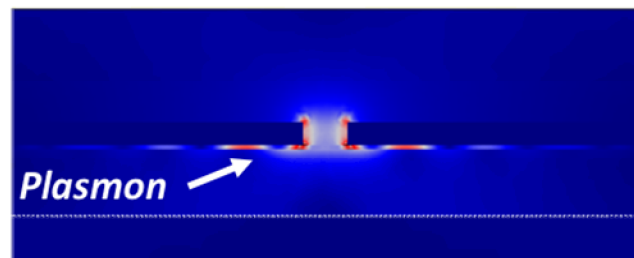


Method & Approach

Multiphysics Materials

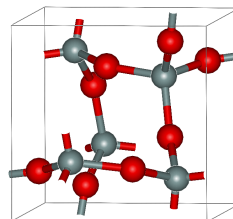


Electromagnetic Modeling

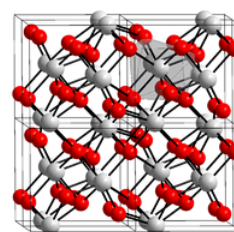


Assess Dielectric Influence

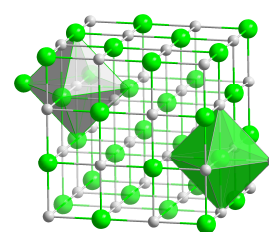
SiO_2



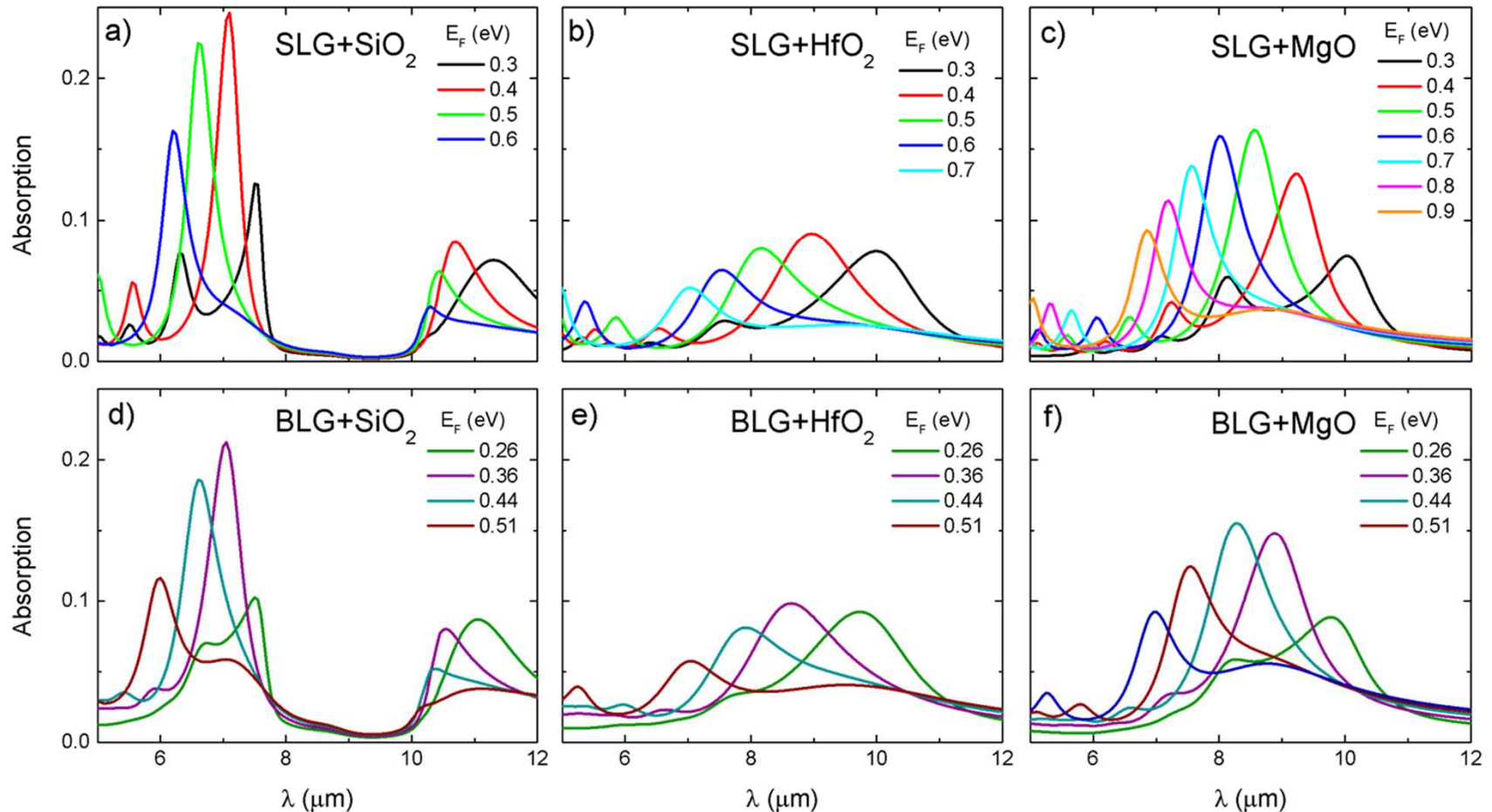
HfO_2



MgO



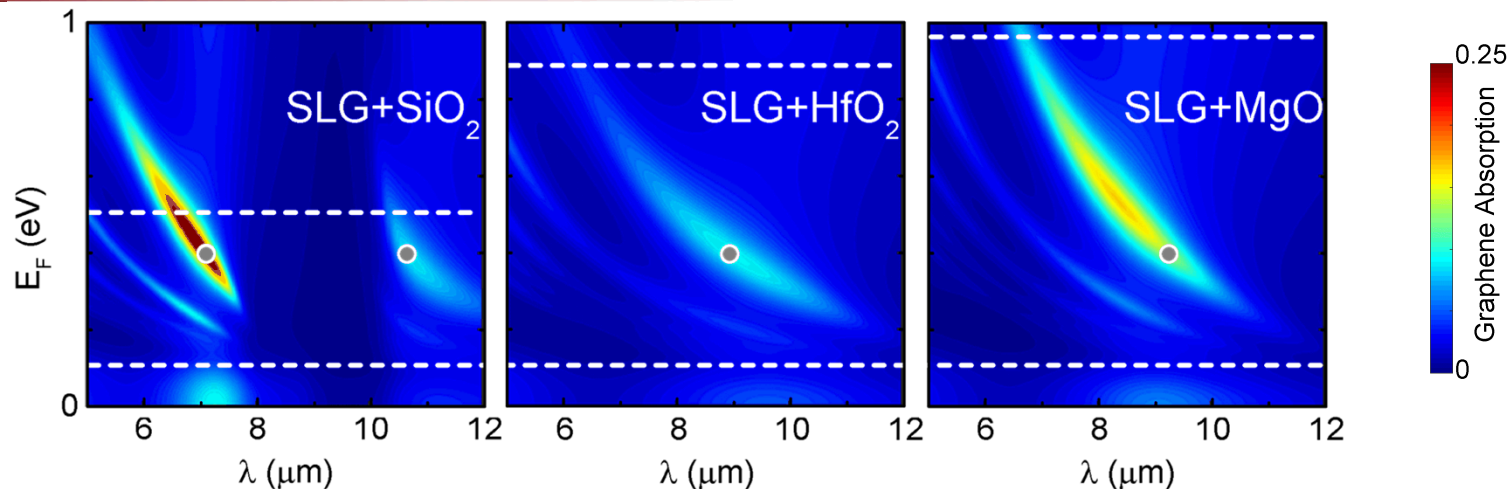
Tunability via Graphene and...?



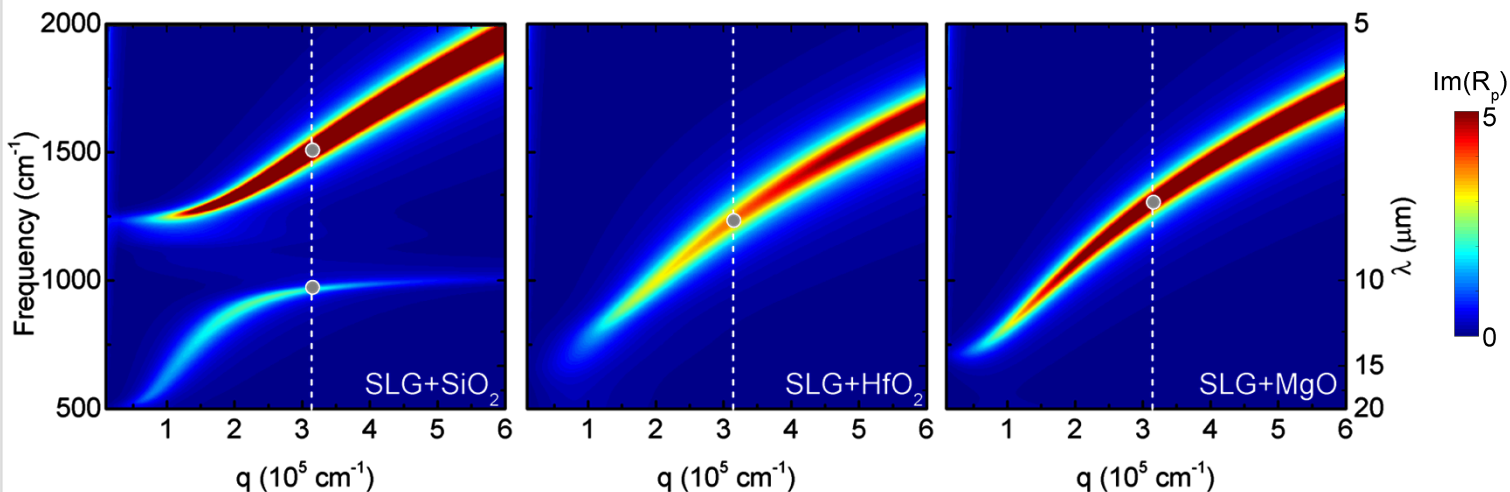
Takeaway: Graphene absorption can be tuned. Dielectric dictates.

“Surrounding” Absorption

Absorption



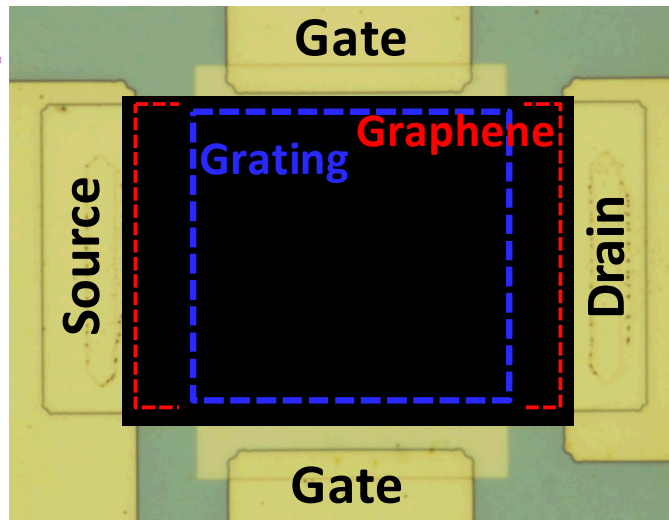
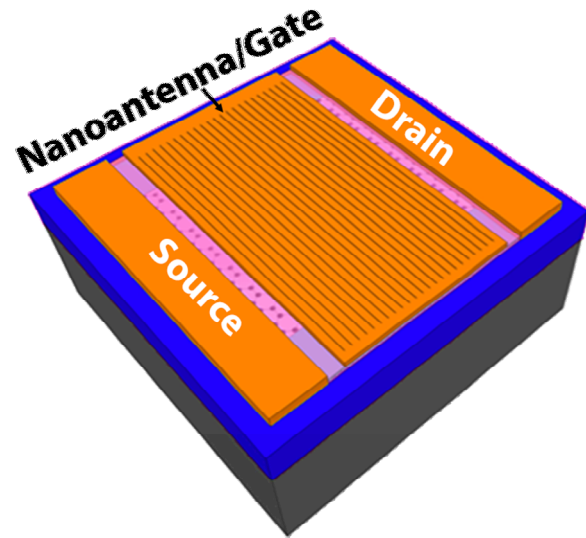
Plasmon



Takeaway: Plasmon defines absorption. Dielectric **PHONON** defines plasmon.

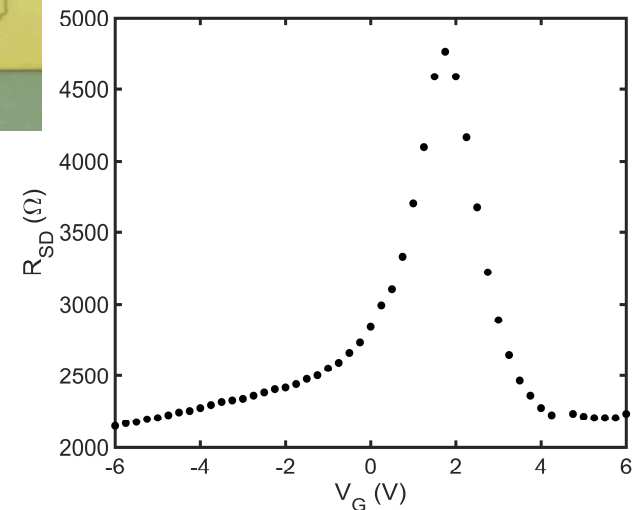
Real-World Demonstration

Goal: Create a tunable IR filter

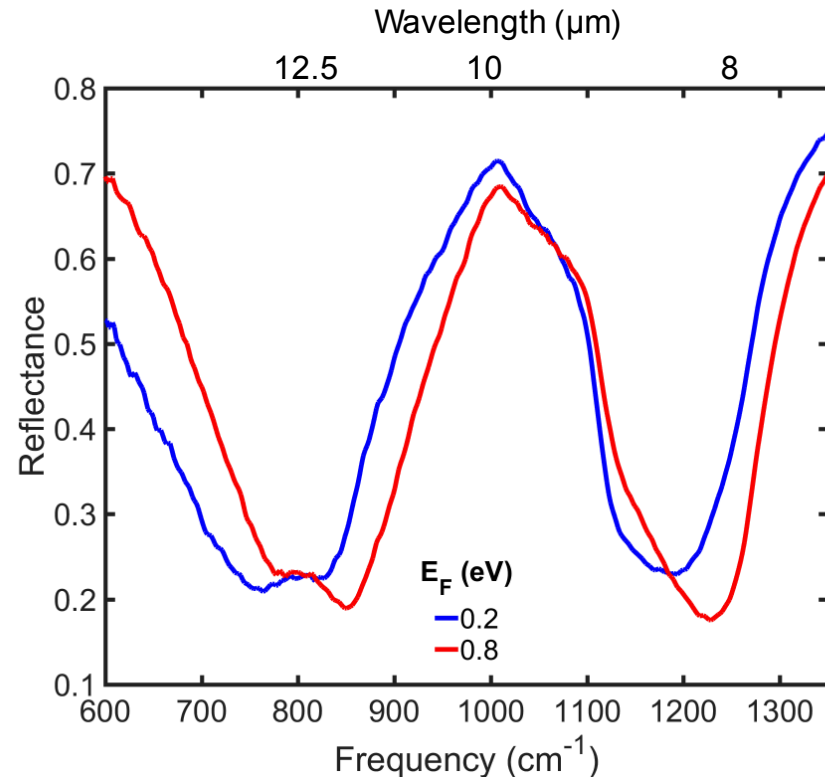
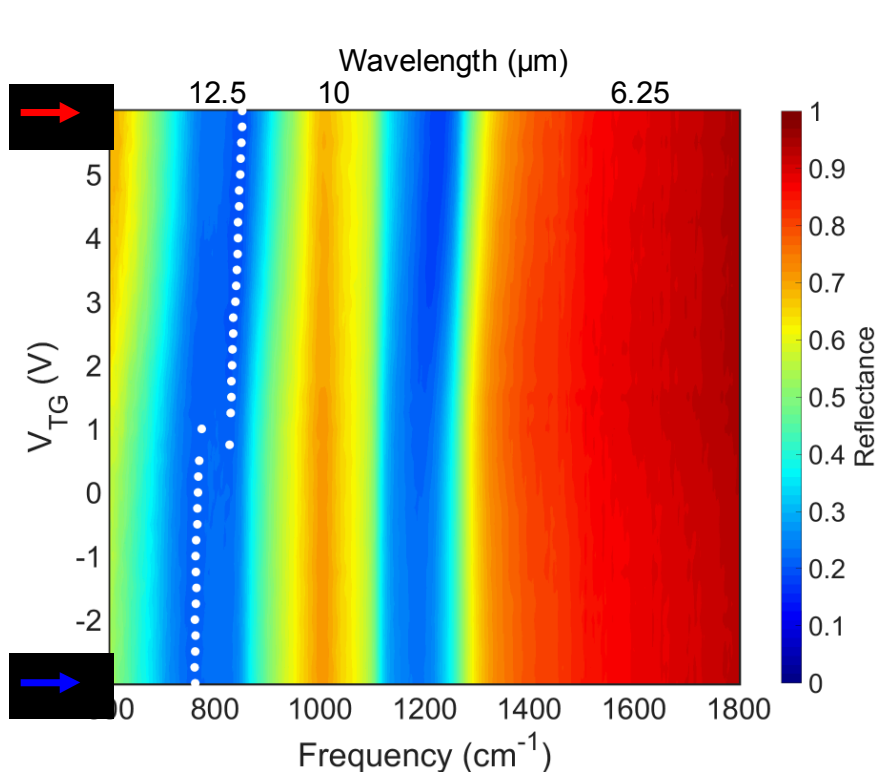


Design Rules

- Scalable (continuous/unpatterned) graphene
- Protected graphene
- No contact to graphene in active area



Gate Tunable Reflectance

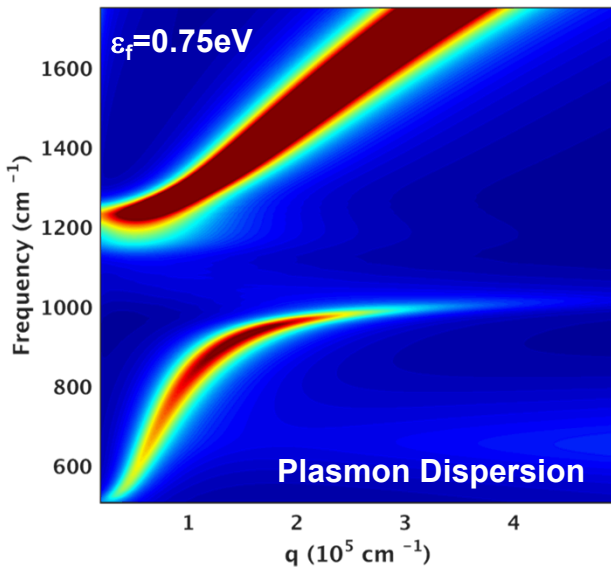
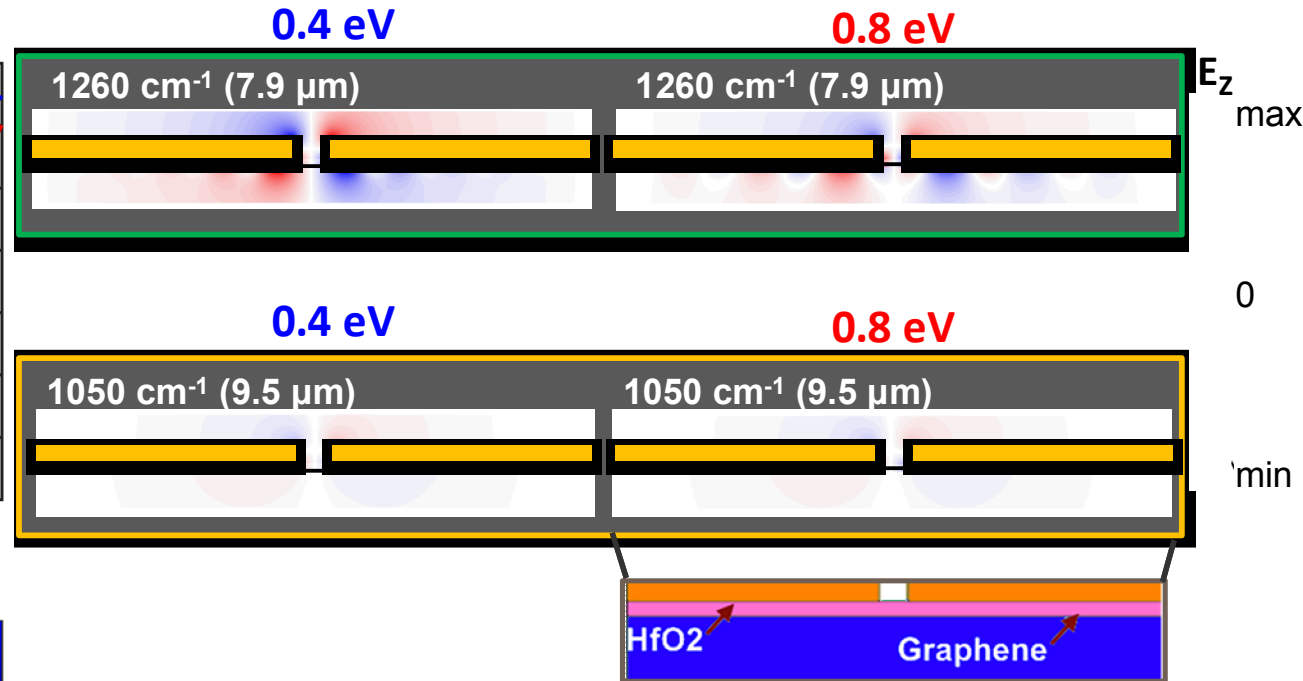
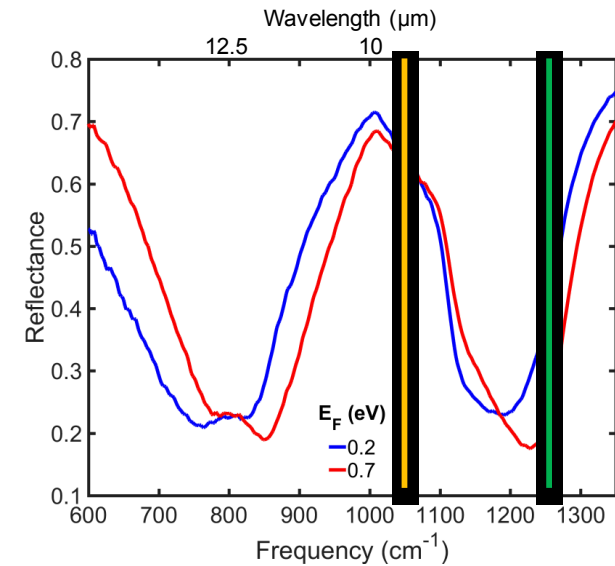


Dual-Band
Tuning

Shifts $>$
 $1 \mu\text{m}$ (90 cm^{-1})

Dependent upon
Dielectric phonon

Why does it work?

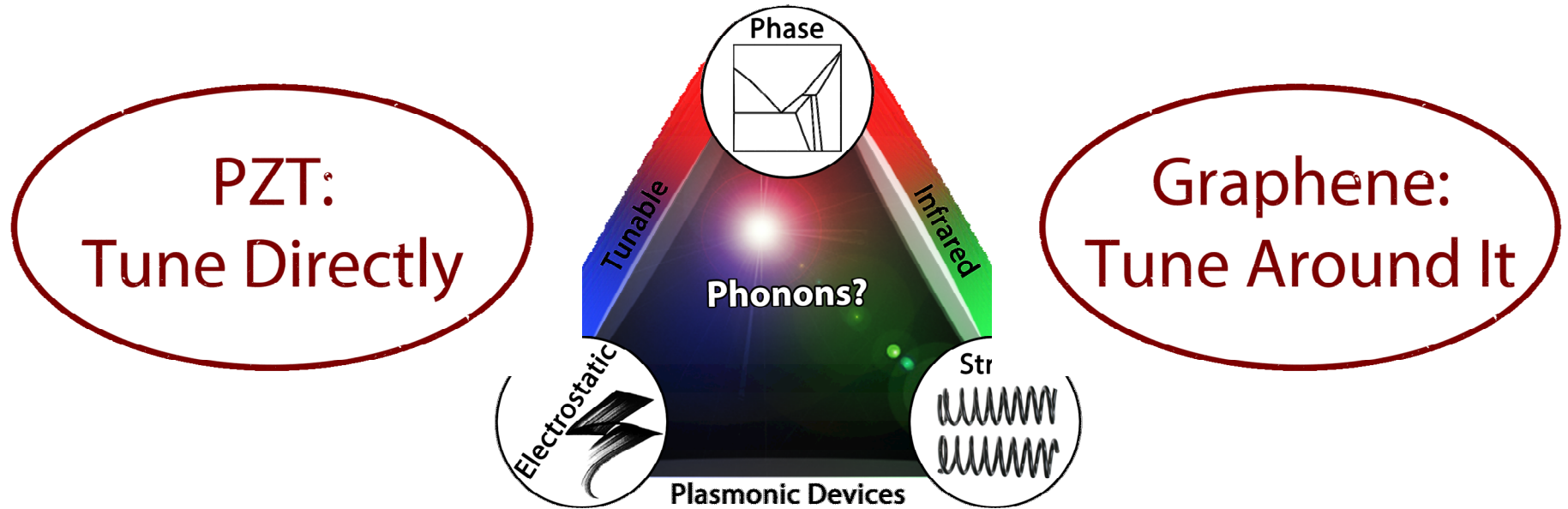


Operational Mechanism

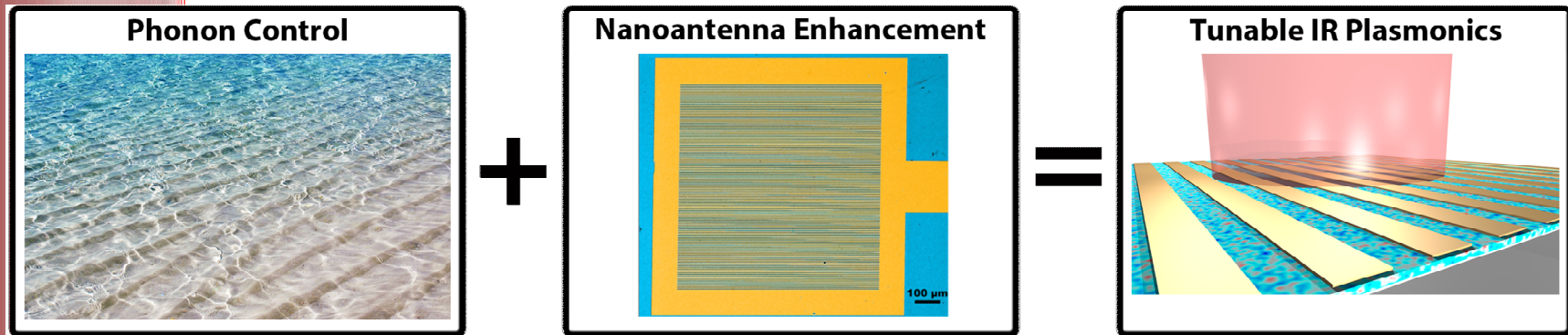
- Tuning occurs when plasmon is excited
- Plasmon dispersion defined by surrounding dielectric
- Spectral selectivity based on dielectric phonons

Phonons for Infrared Tuning

Premise: Leverage phonons for reconfigurable plasmonic devices



Path





Sandia National Laboratories

Thomas Beechem

Google Scholar: <http://goo.gl/96jGN>

tebeech@sandia.gov

505-284-3503

sandia.gov/careers

Staff, Post-Doc, Fellowships, Internships
and Collaborations

Wanted:
Thermal Physics
Post-Docs

Wanted:
Optical Physics
Post-Docs