FUSING LIGHT WITH HEAT

Polaritons for Nanoscale Thermal Transport & Sensing

Thomas Beechem

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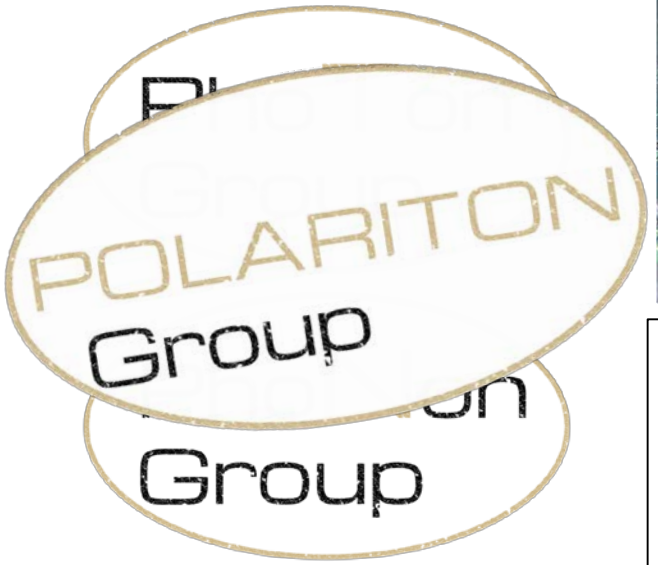
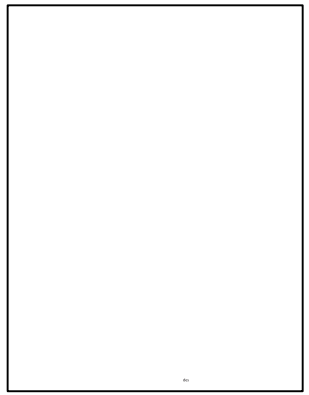
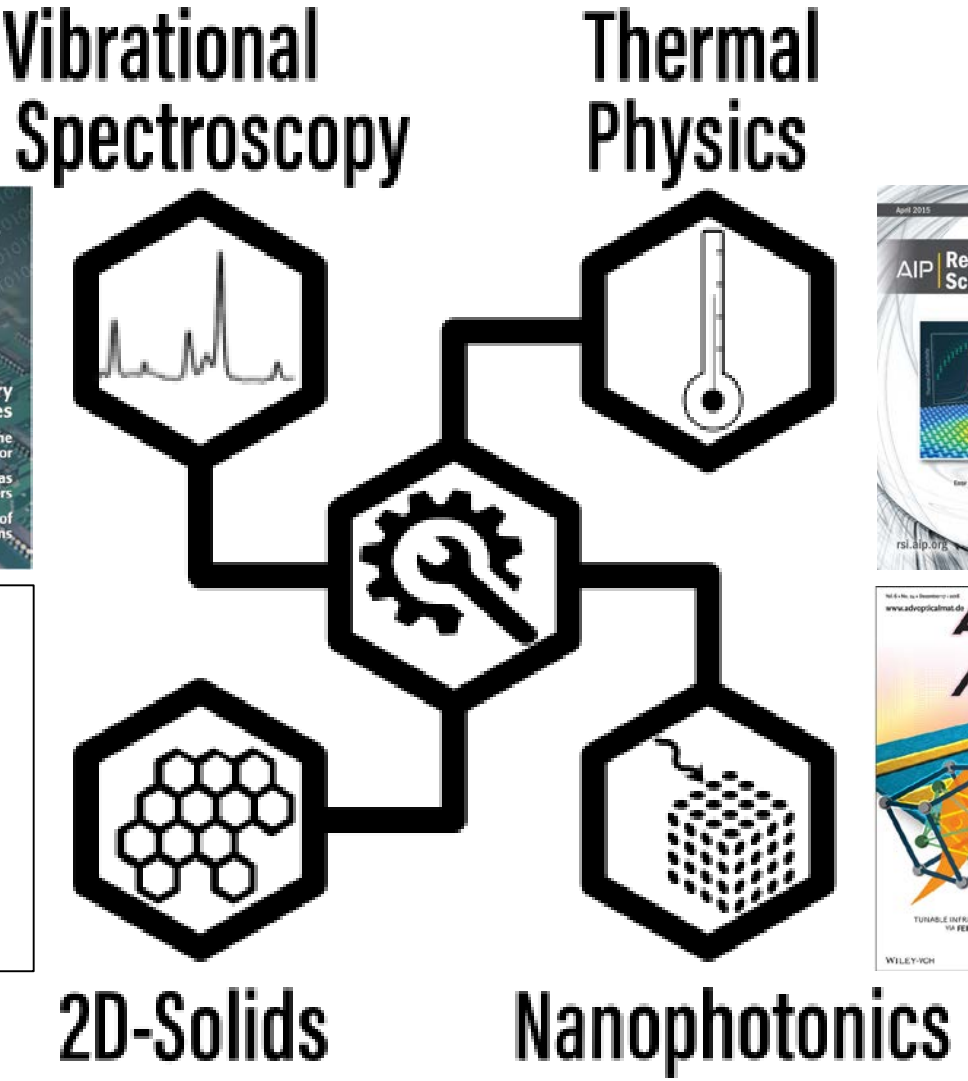
Specere

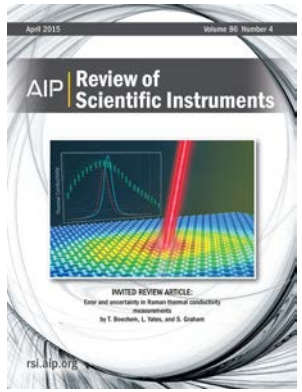
Our Perspective…

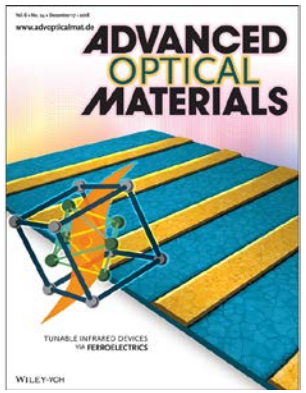
Specere











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Message: Polaritonic Energy Transport

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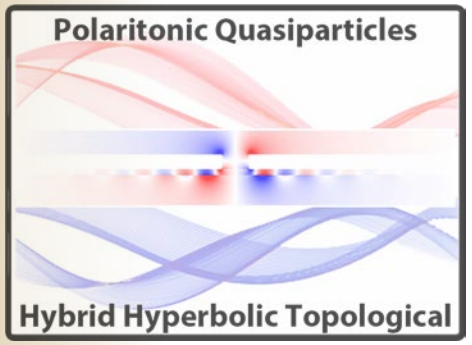
Problem

Phonons and Electrons “bad” in small spaces (< 1µm) & at interfaces.

Premise



Fundamentally different energy carrier needed.

Polaritons are the carrier.

Reason

Polaritons get **better** in smaller spaces.

Dispersion Engineering of polaritons is doable.

Polaritons can be **dynamically tuned**.

Polariton: The Wave Duet

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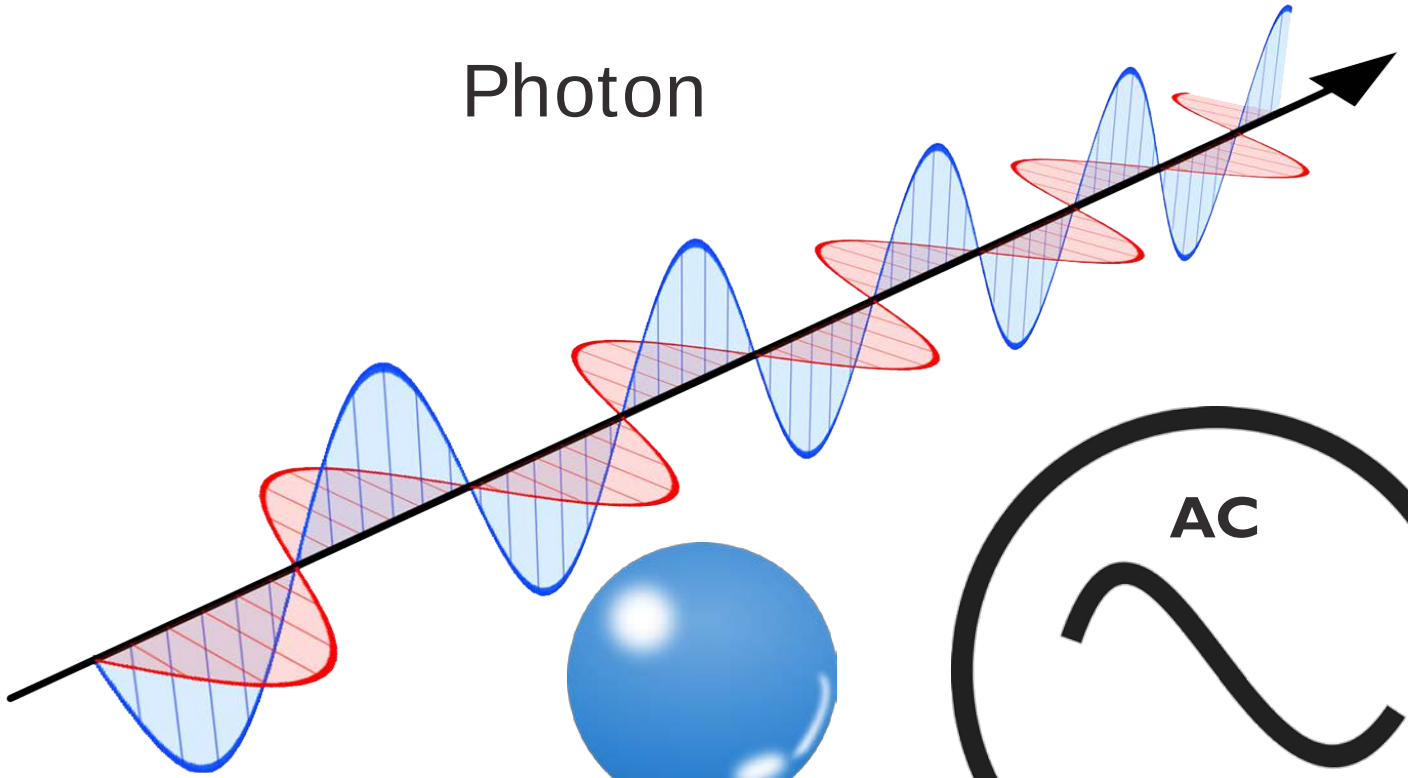
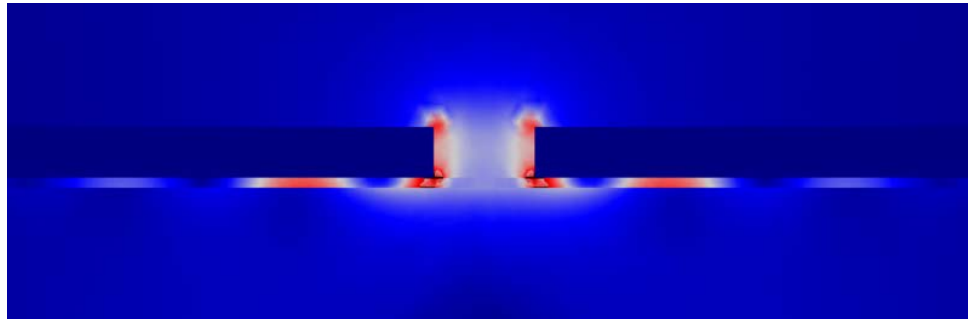
Photon

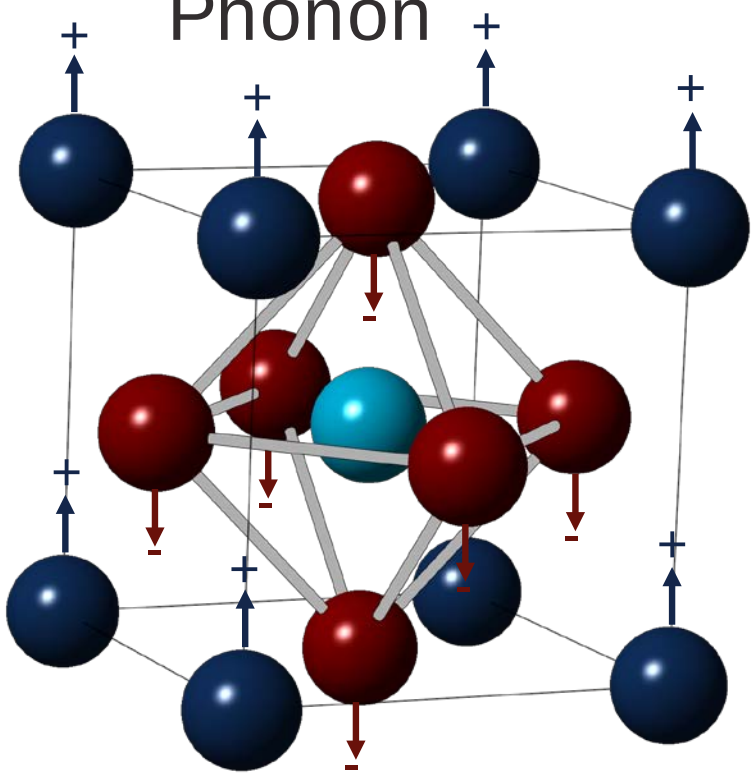


Exciton

Plasmon

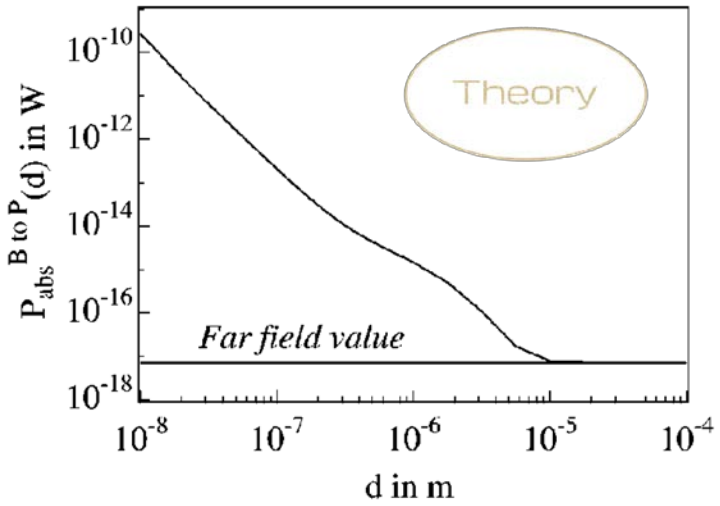


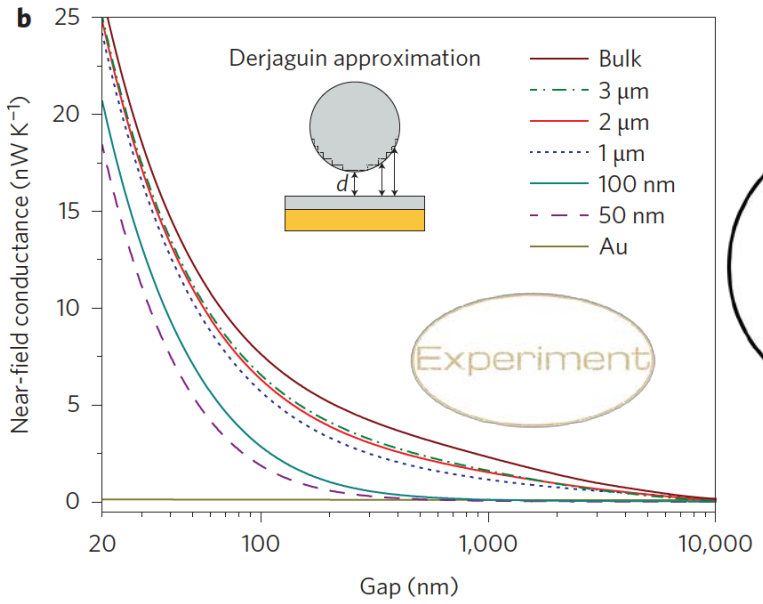
Phonon



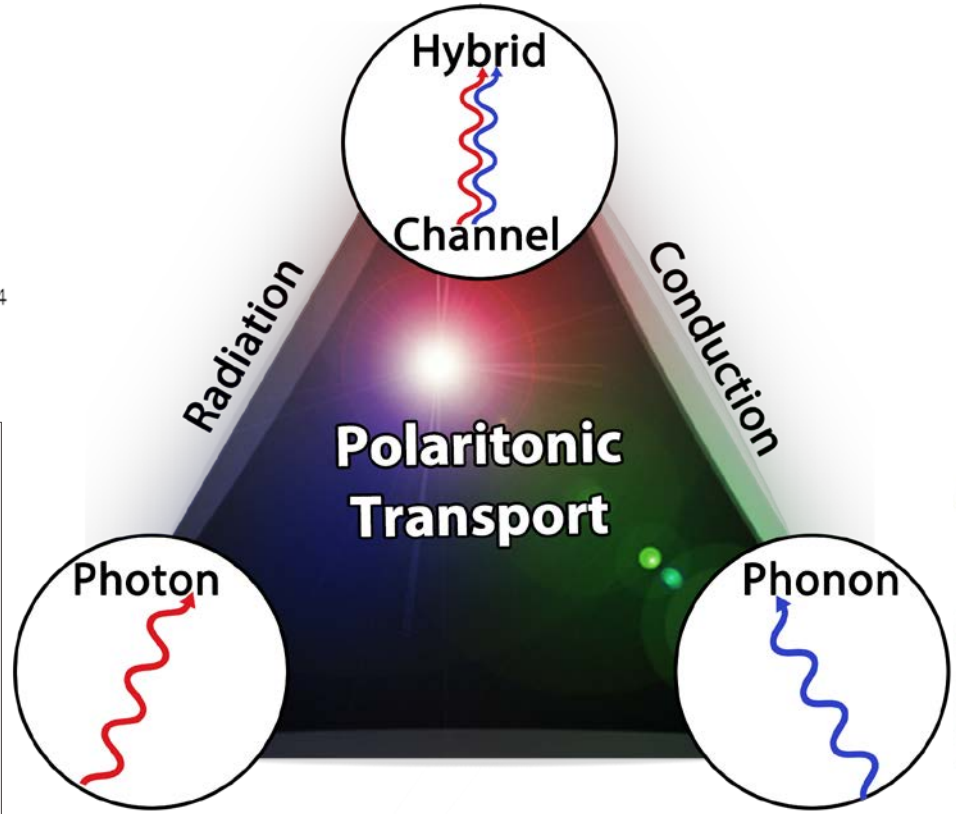
Polaritons carry heat.

Theory: Mulet et al. APL (78) 293. 2001

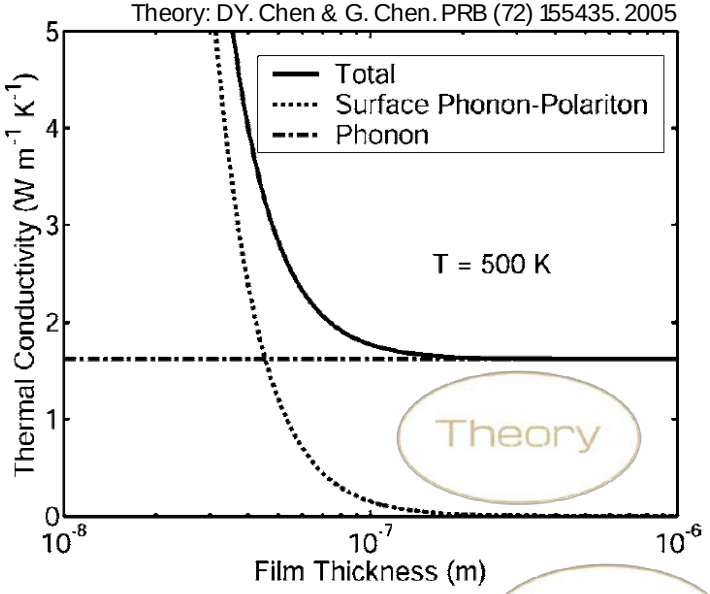


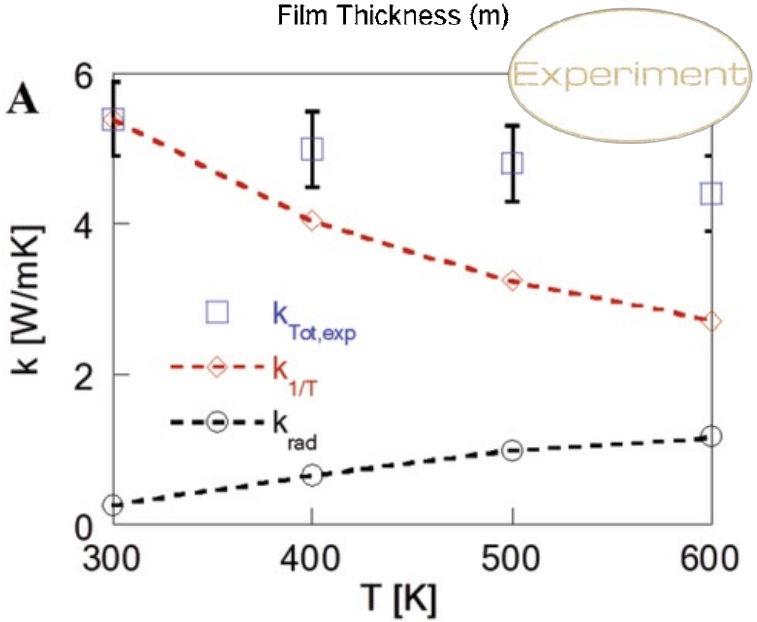


Expt: Song et al. Nat. Nano (10) 253. 2015.



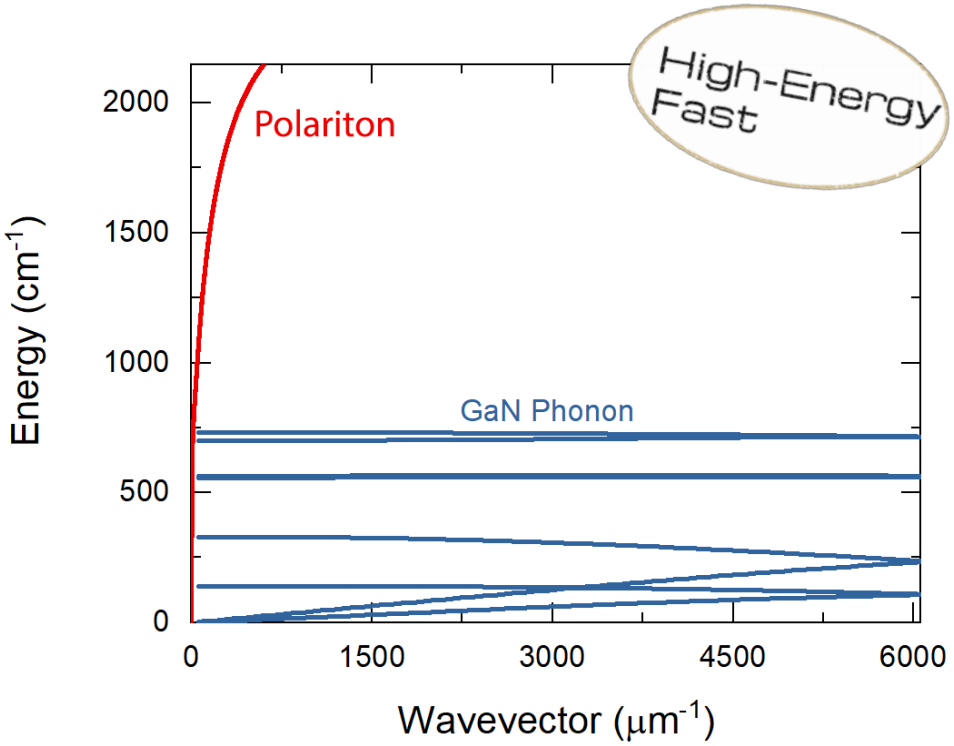
Theory: DY. Chen & G. Chen. PRB (72) 155435. 2005



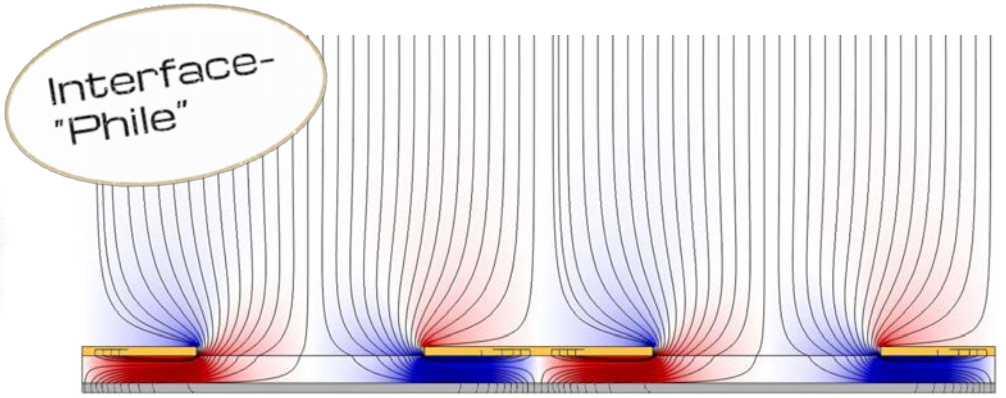


Expt: Salihoglu..Xu. Adv. Fun. Mat. 1905830. 2019.

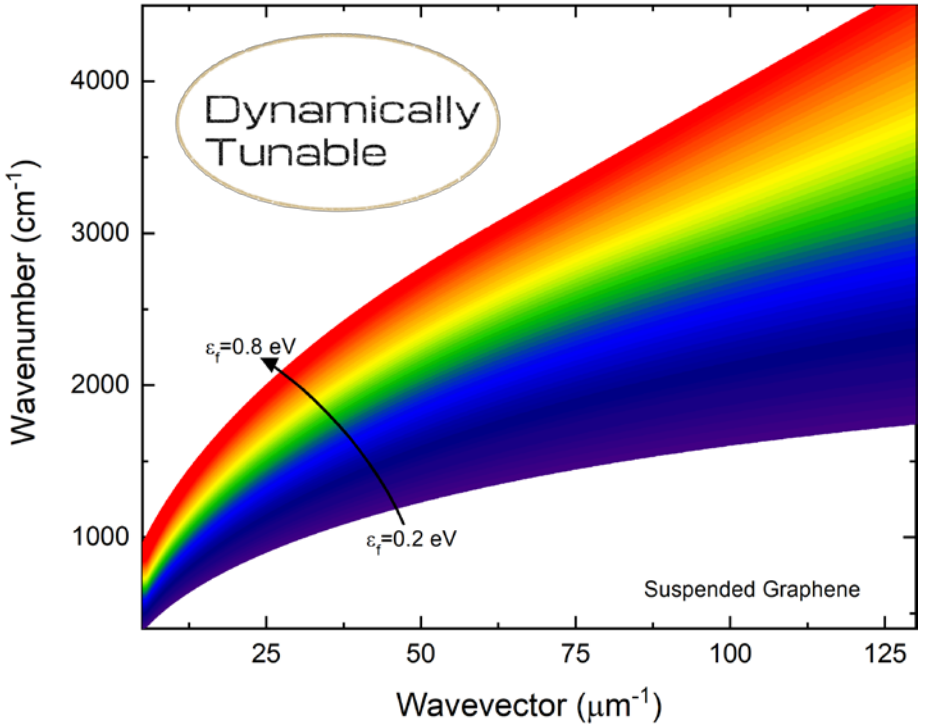
But Why Polaritons for Nanoscale Heat Transport?



Maxwell (μm)
over
Newton (Å)



Details: T. Beechem et al. Adv. Opt. Mat. 14, 1800062. (2018).



Details: A. Jarzembski…Beechem et al. Phys. Rev. Appl. 14, 034044 (2020).

Problem: Solutions aren't scaling

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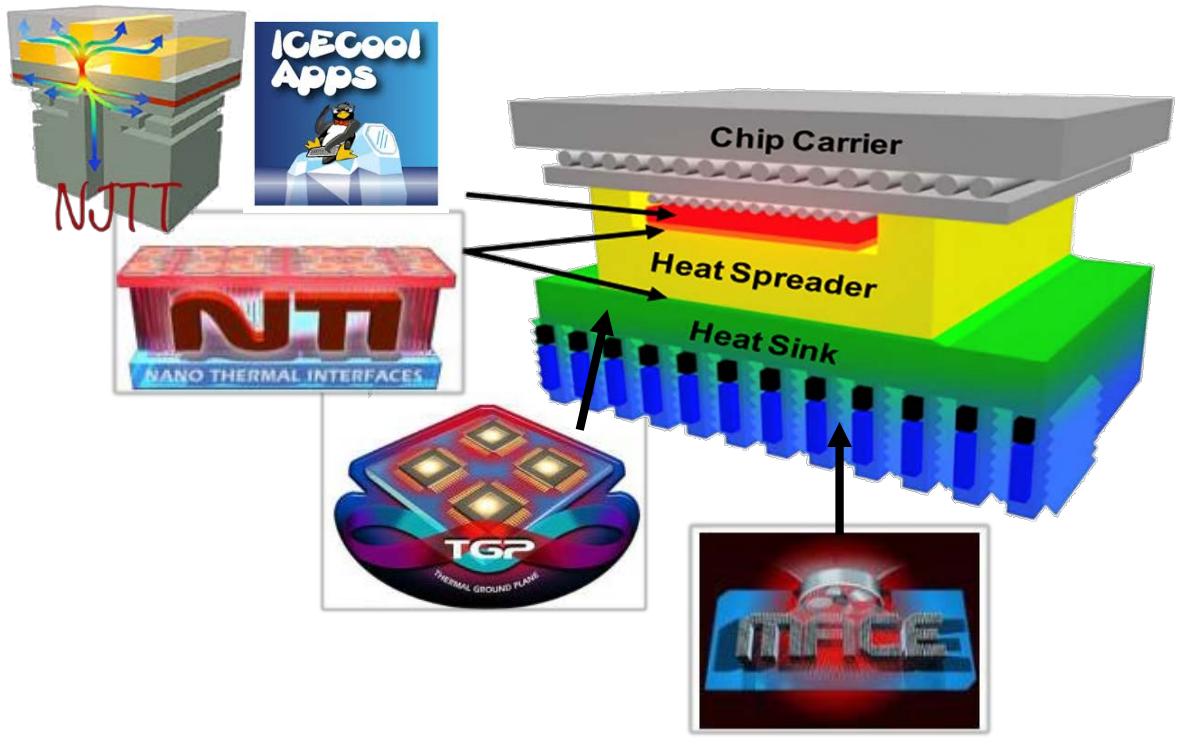
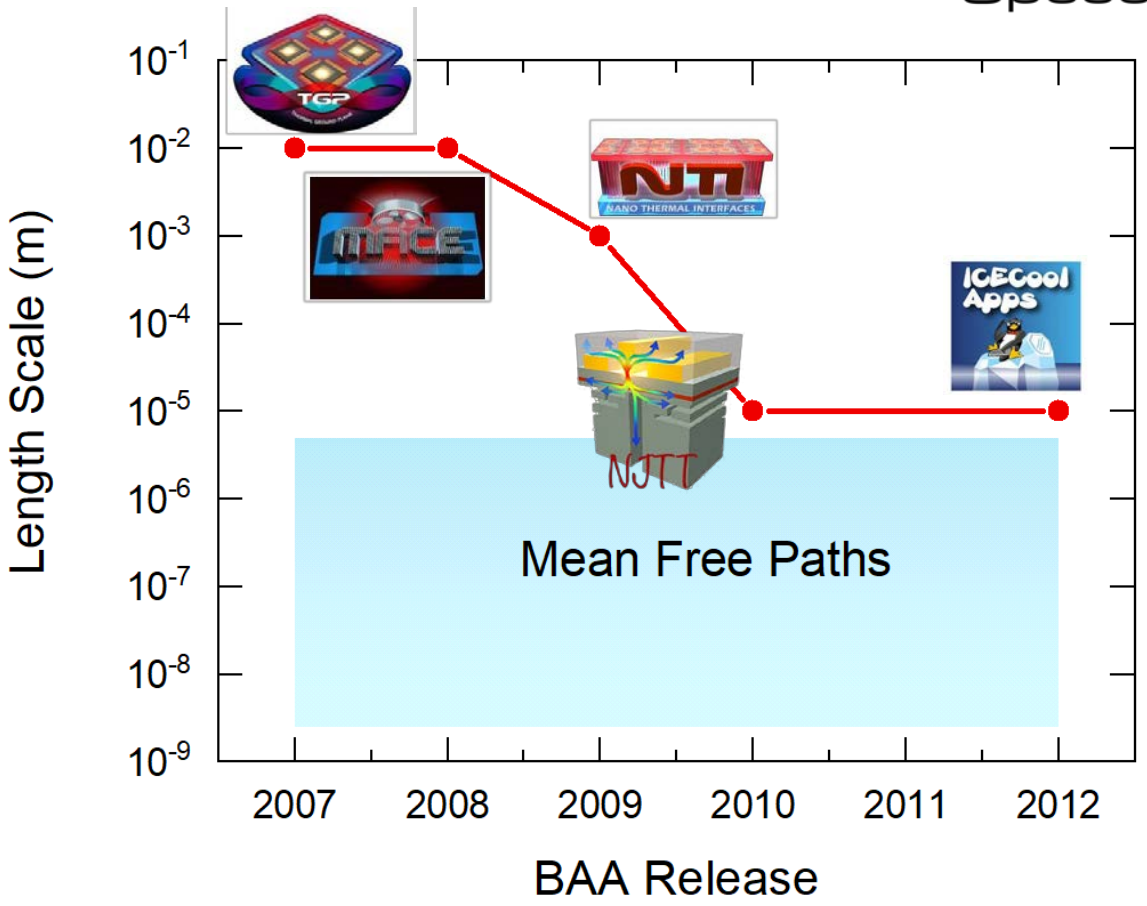
Frozen Approach ➠ Throw cold at the device

Images: Disney, HiFlux, Parker Hannifin, Advanced Thermal Solutions





Paradoxical

Need solutions closer to source ➞ Gotta get smaller.

NJTT Graphic: K. Goodson Semi-Therm 2019 (nanoheat.stanford.edu). Others: A. Bar-Cohen. ModSim 2015.

Problem 1: Phonons Less Efficient in Small Places

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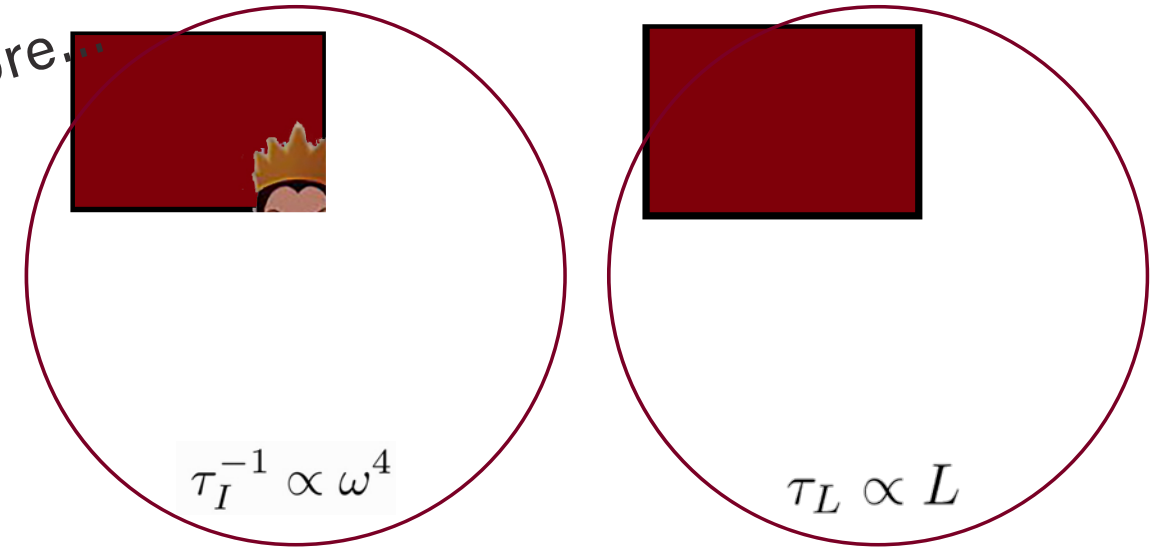
Phonon Gas (PG) Model RTA

$$k_{PGM} = \frac{1}{VN_o} \sum_{\mathbf{q},s} (\hbar\omega) \frac{df_{\mathbf{q},s}}{dT} v^2_{\mathbf{q},s} \tau_{\mathbf{q},s}$$

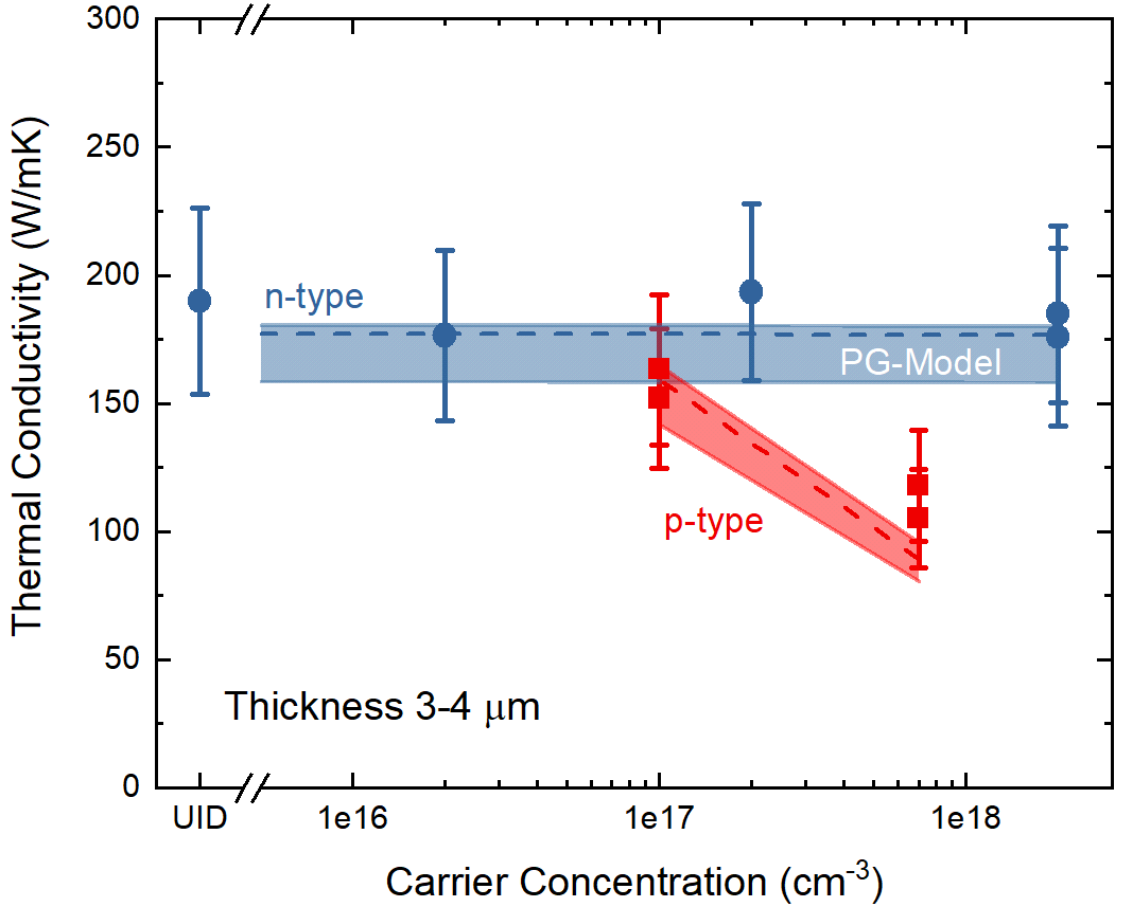
Question: What matters more… size or "bad stuff" ?



Dislocations

$\tau_D^{-1} \propto \omega^3$

GaN Thermal Conductivity

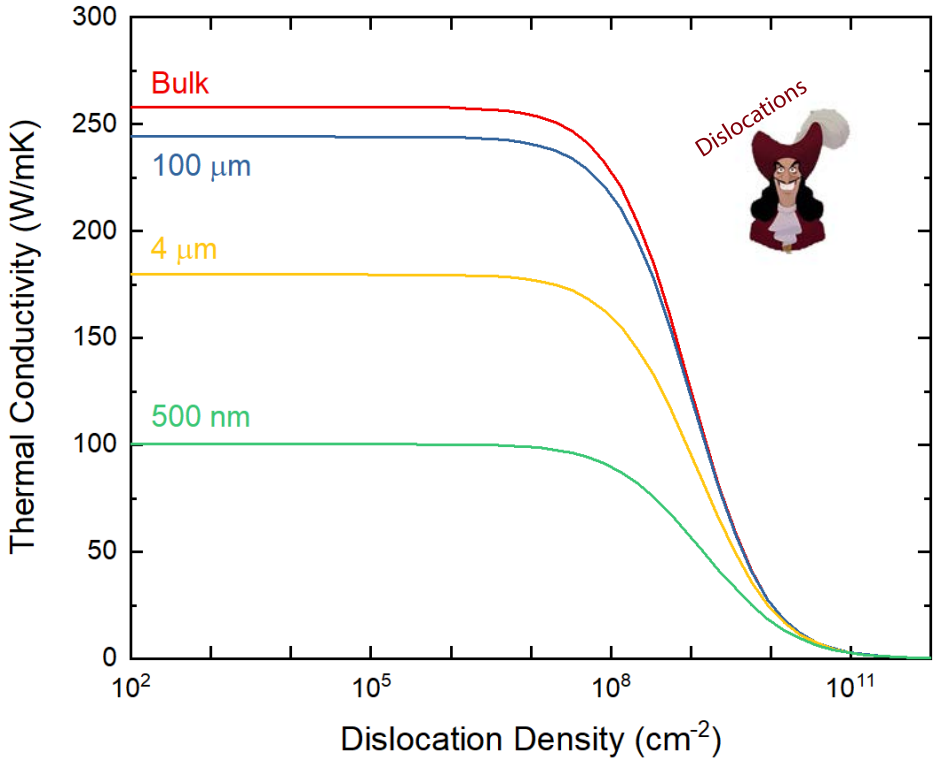


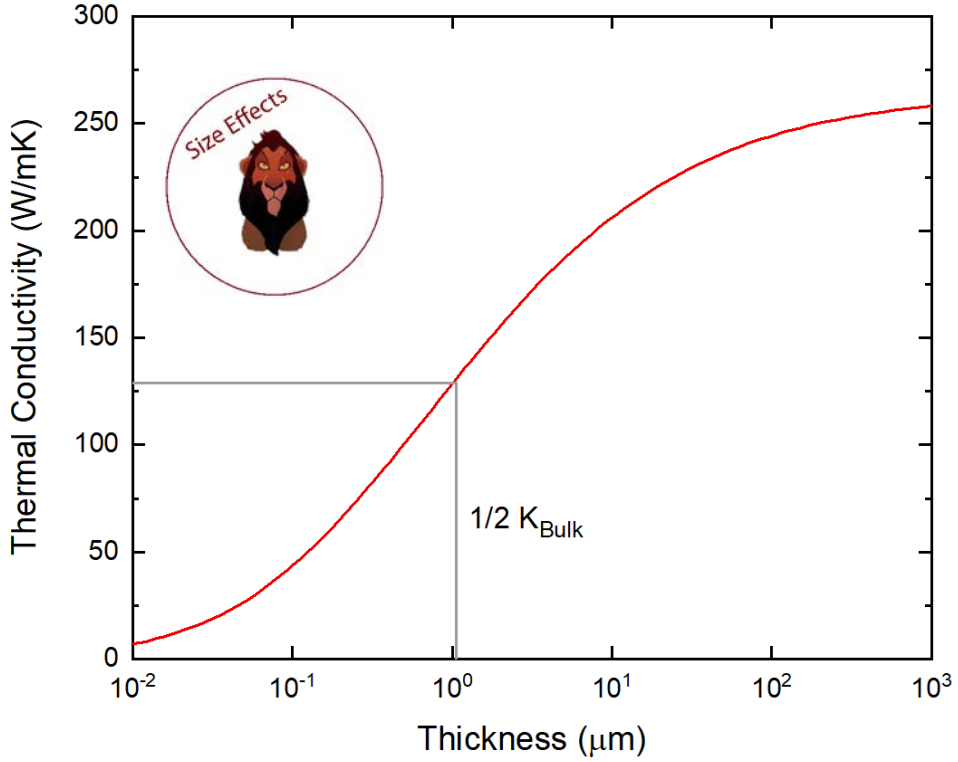
p-type Sensitive

n-type Immune?

Details: Beechem et al. JAP. (120) 095104. 2016

Phonon Gas Model: Probing the "Pain Points"





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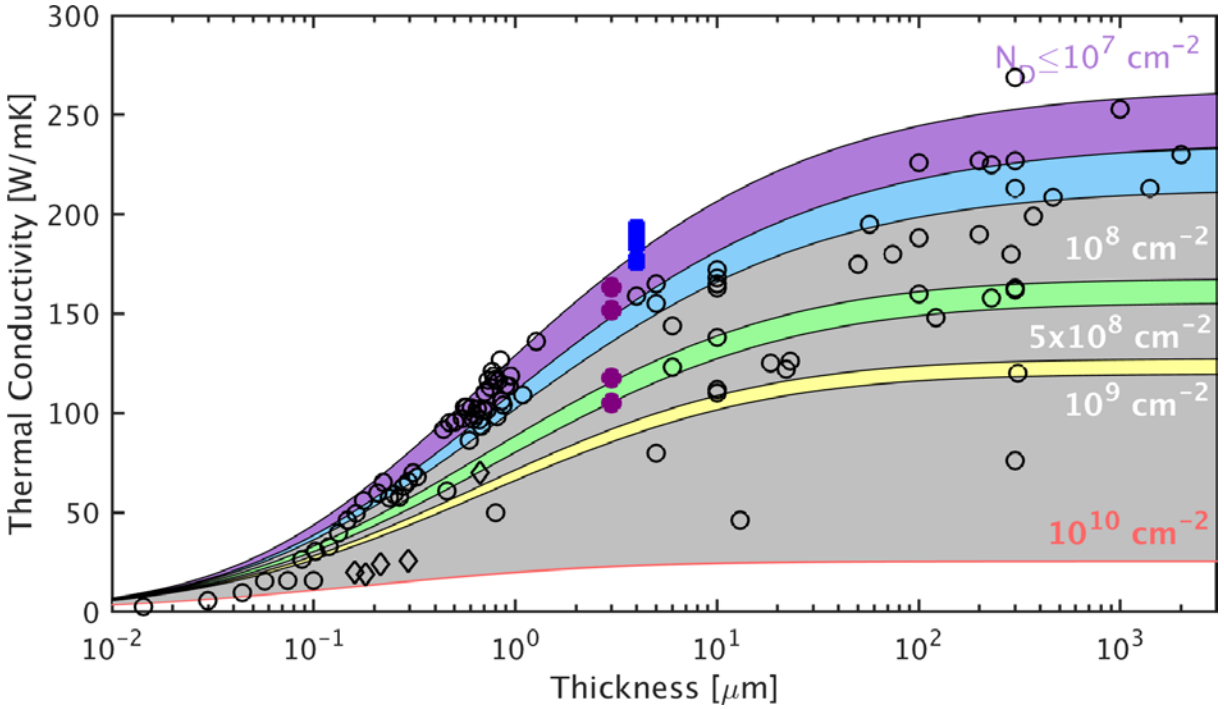
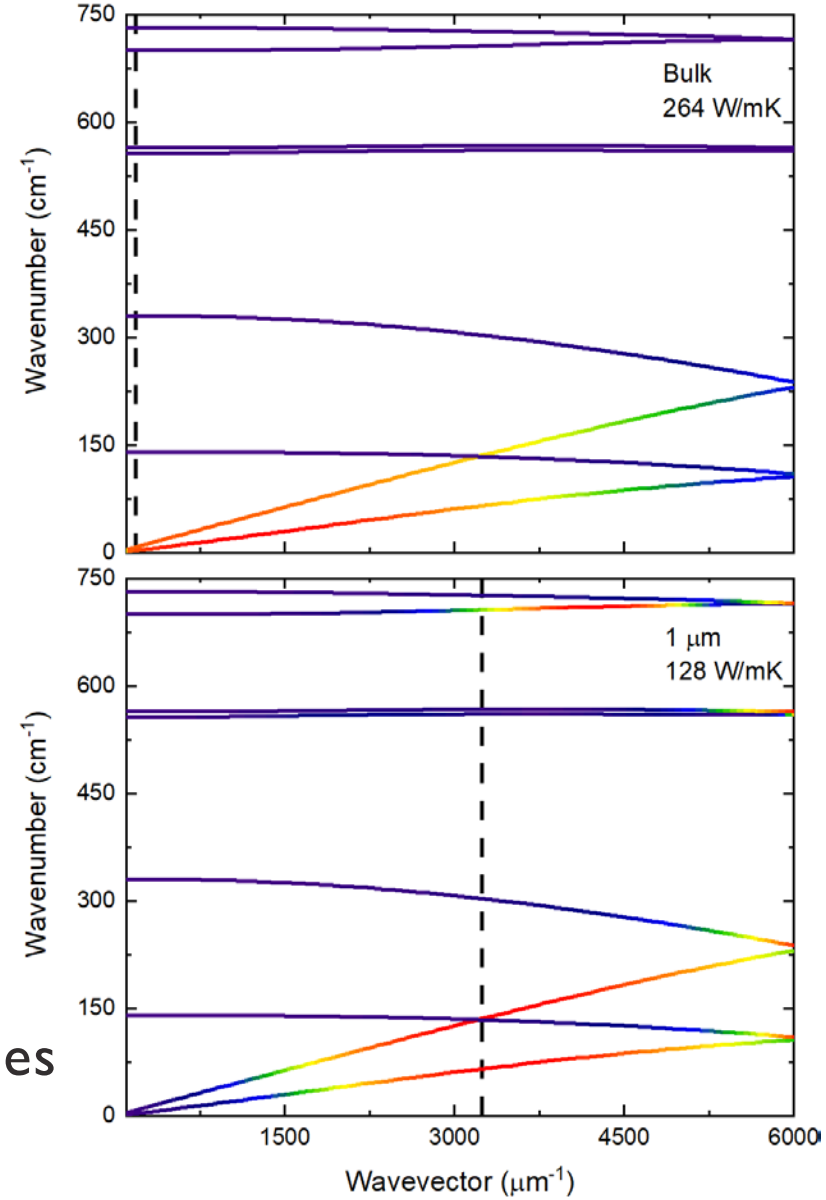
Details: Beechem et al. JAP. (120) 095104. 2016

Size Dictated Thermal Conductivity of GaN



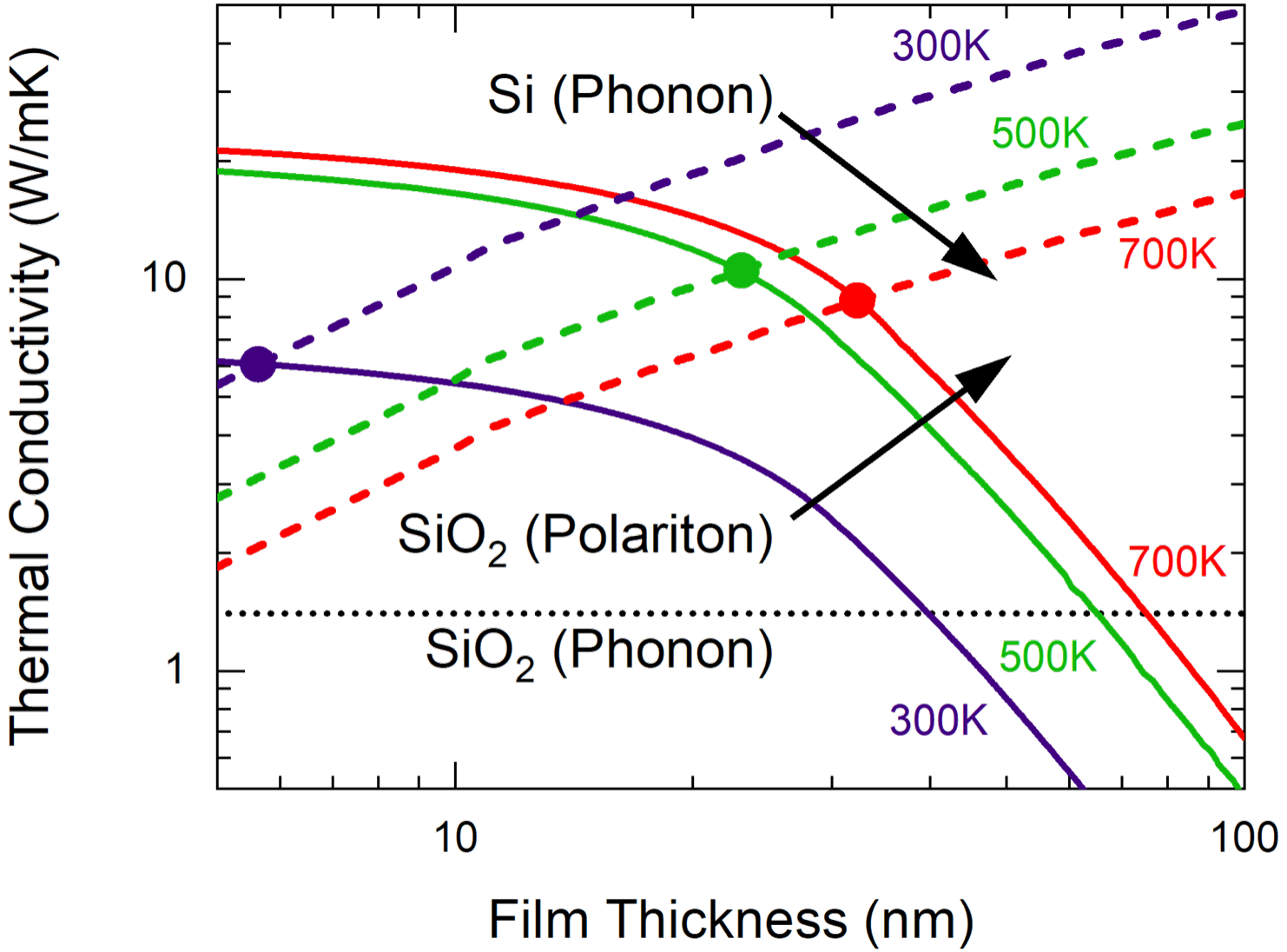


Takeaway Textbook values don't exist in devices

Takeaway Phonon transport scales opposite to devices

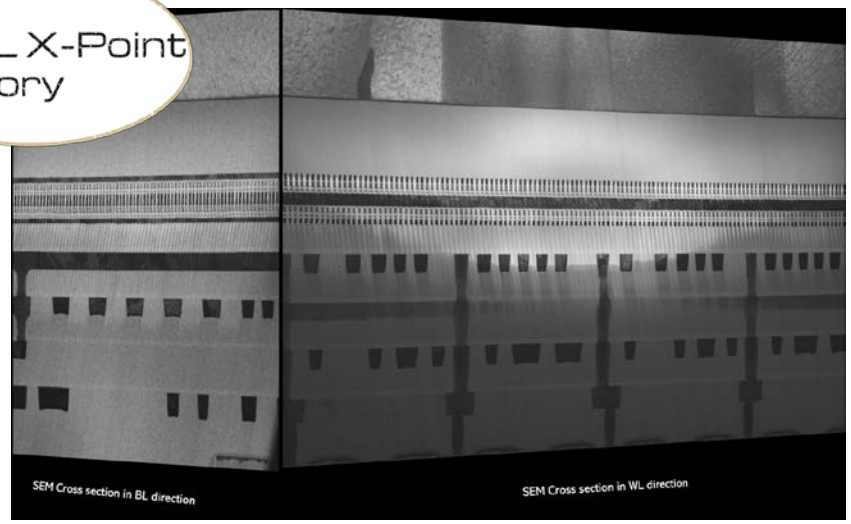
Details: Beechem et al. JAP. (120) 095104. 2016

Polaritonic Transport Scales with Device Size

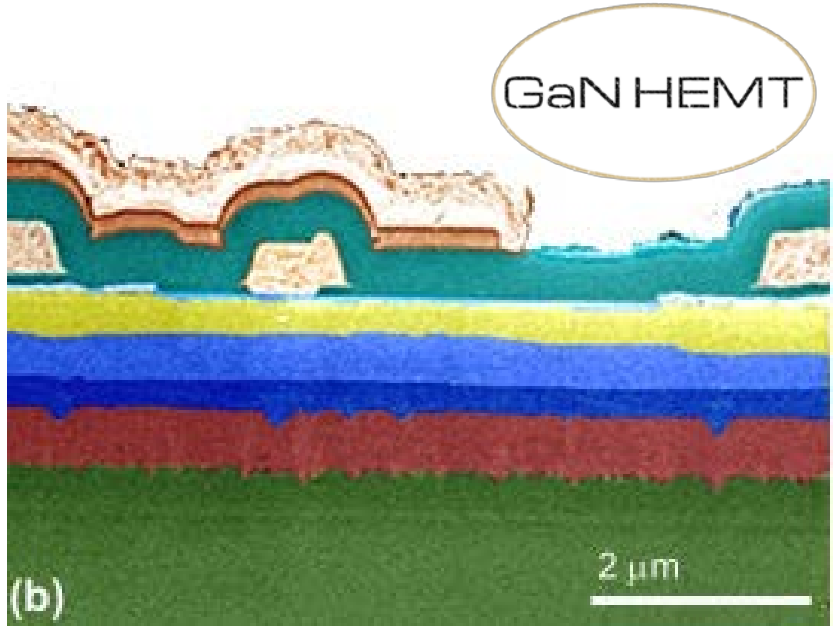


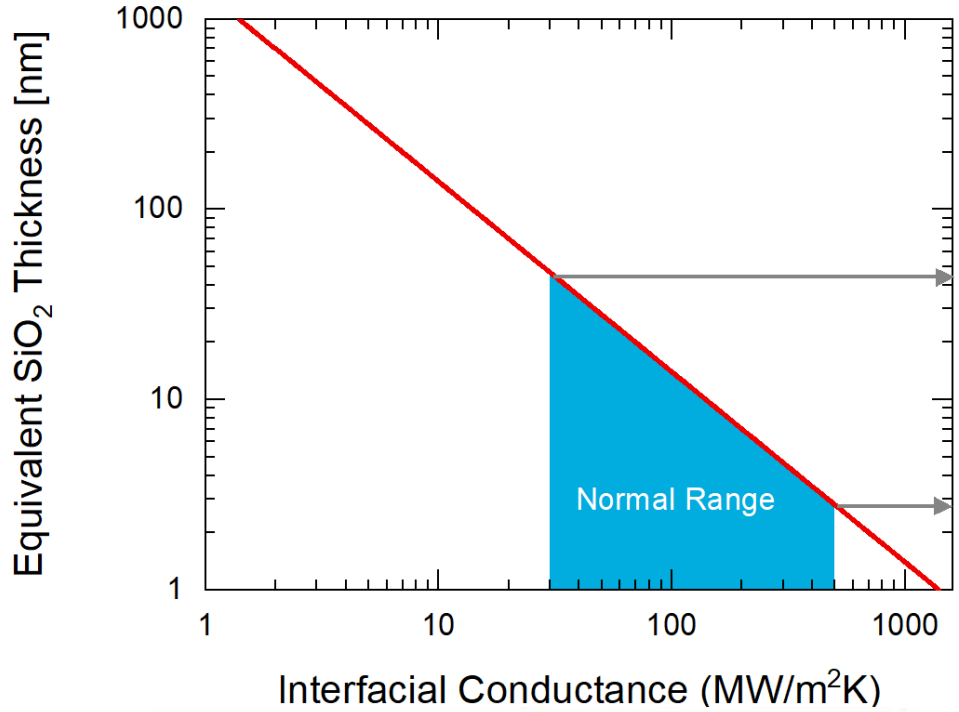
Polariton Calculations: Ordona-Miranda et al. JAP (113) 084311 2013

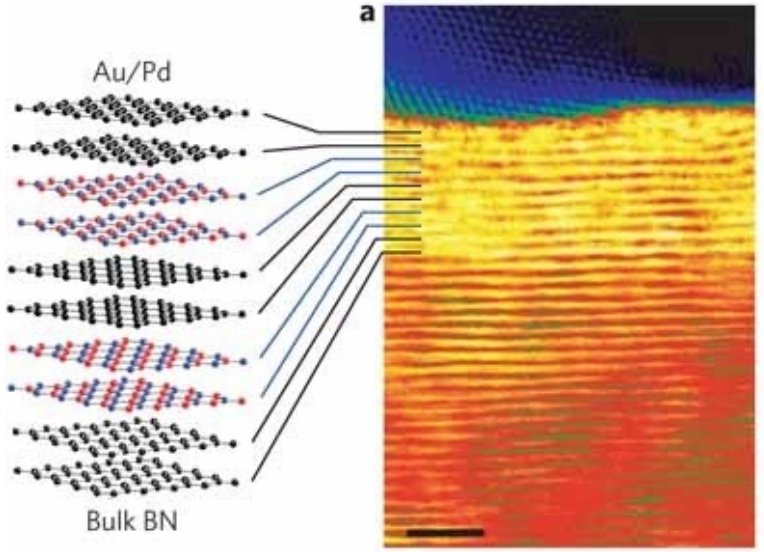
Problem2: Interfaces are everywhere ..and Bad!



www.anandtech.com



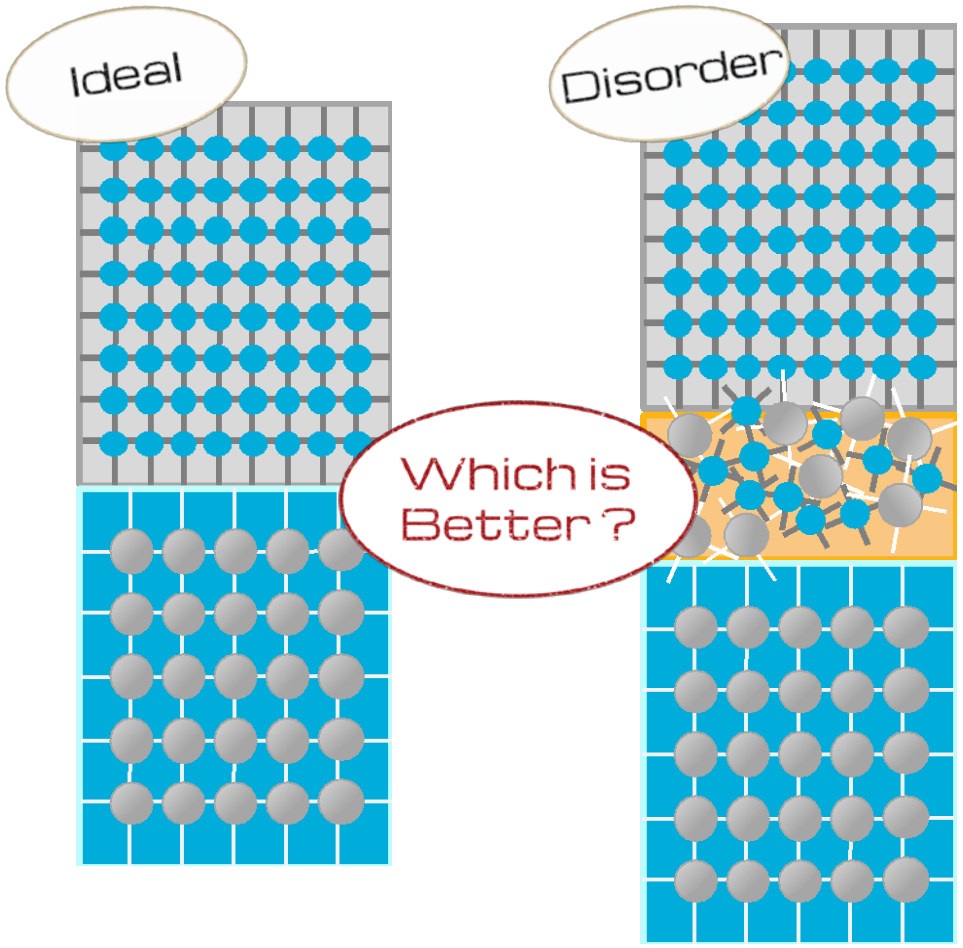


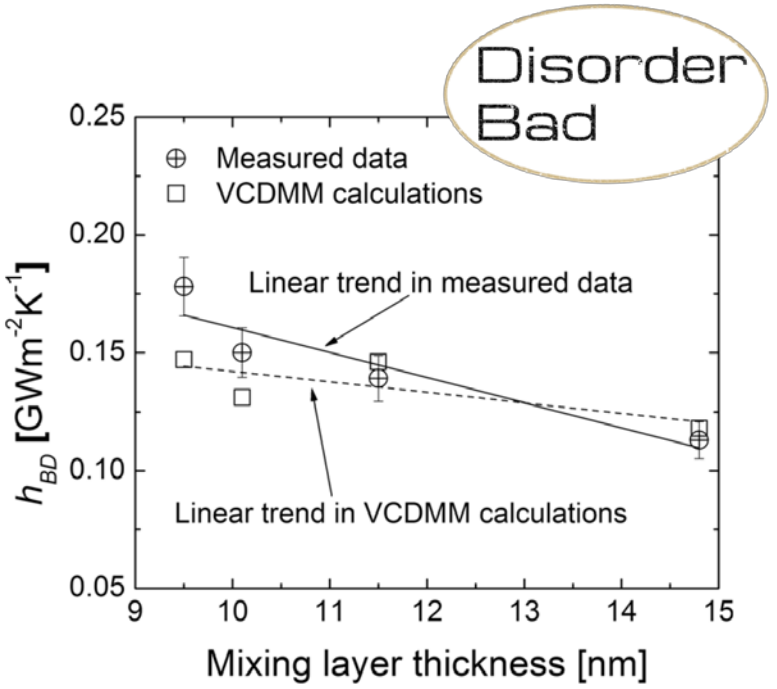


2D-Devices

Haigh et al. Nat. Mat. (11) 764. 2012.

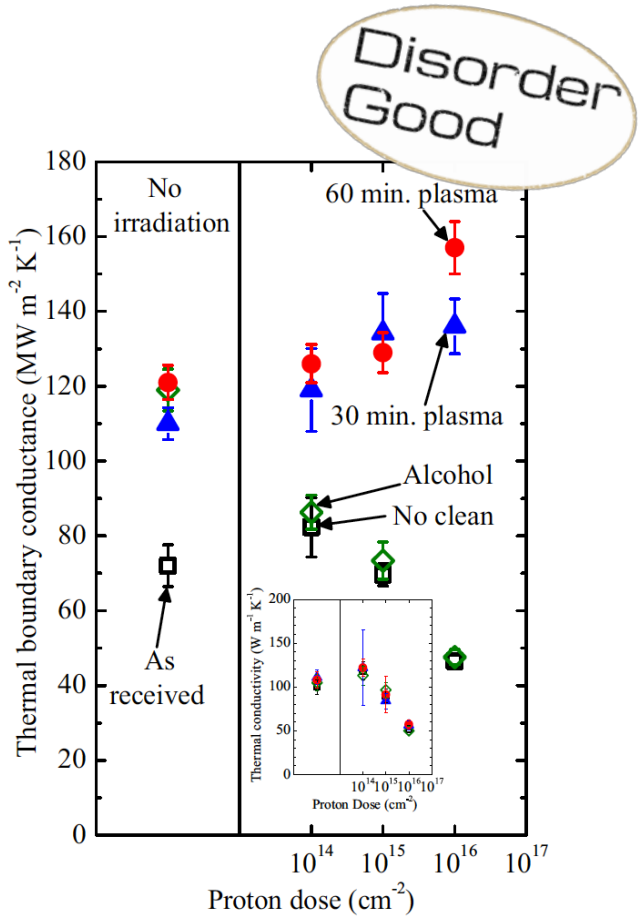
Interfaces Remain Confounding (Phonons)





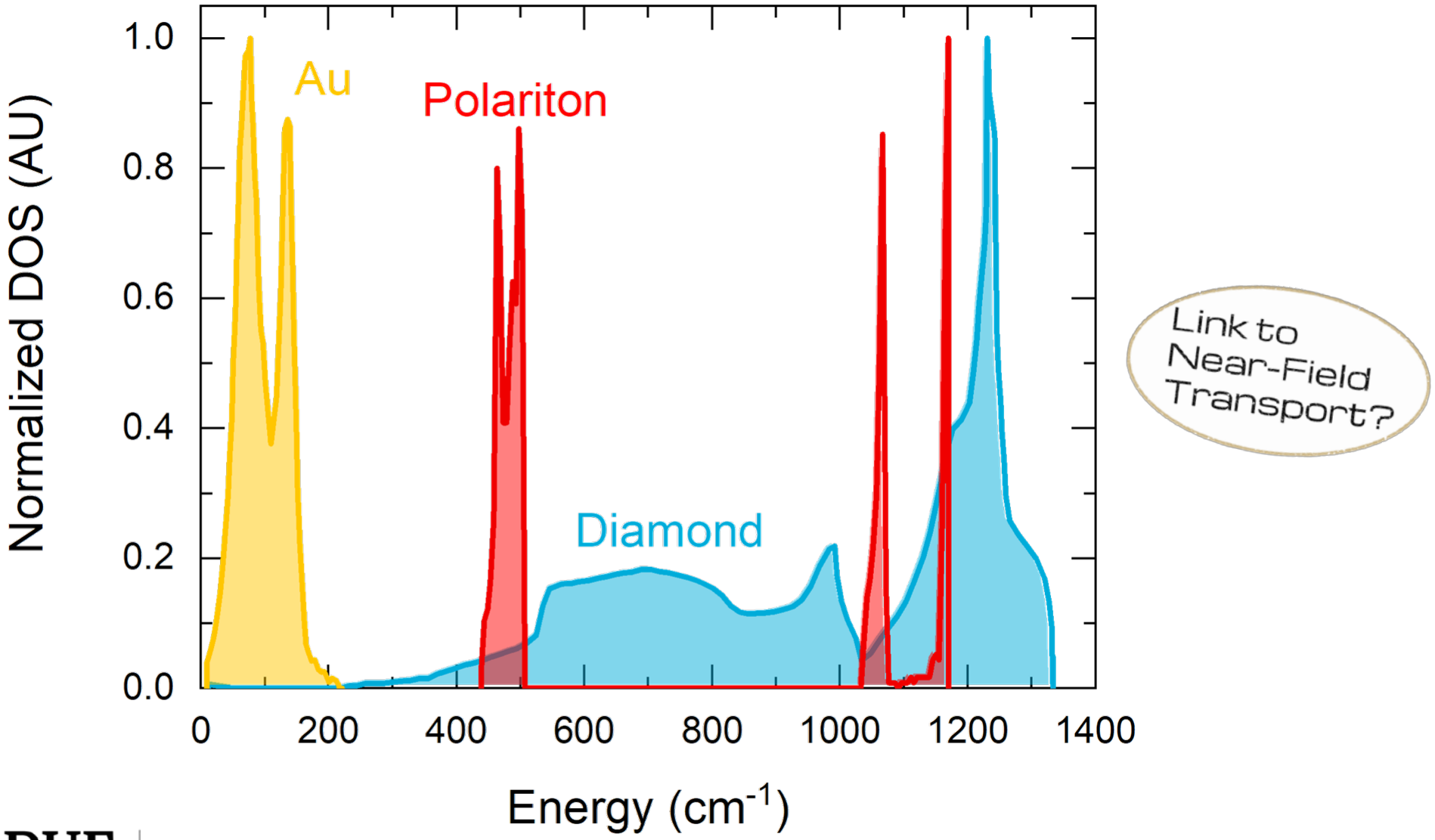
Expt. Details: Hopkins…Beechem…Graham. JHT (130) 0624402. 2008.

Theory Details: Beechem…Hopkins…Graham. APL (90) 054104. 2007.



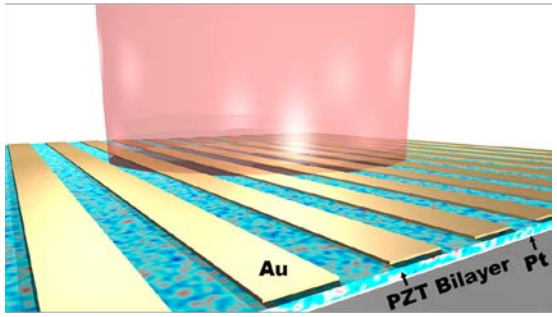
Details: Gorham…Beechem…Hopkins et al. PRB. (90) 024301. 2014.

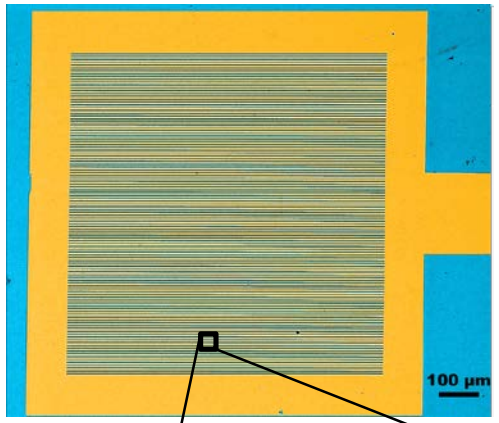
Polaritons at Interfaces…"Translating" Heat?

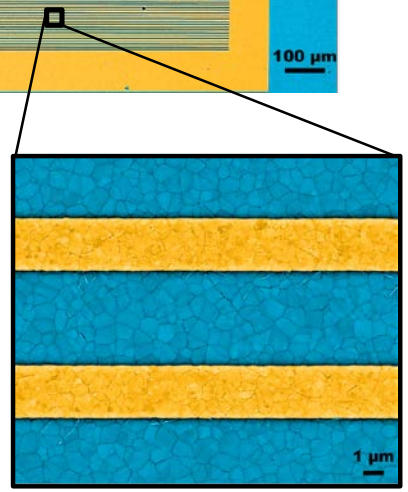


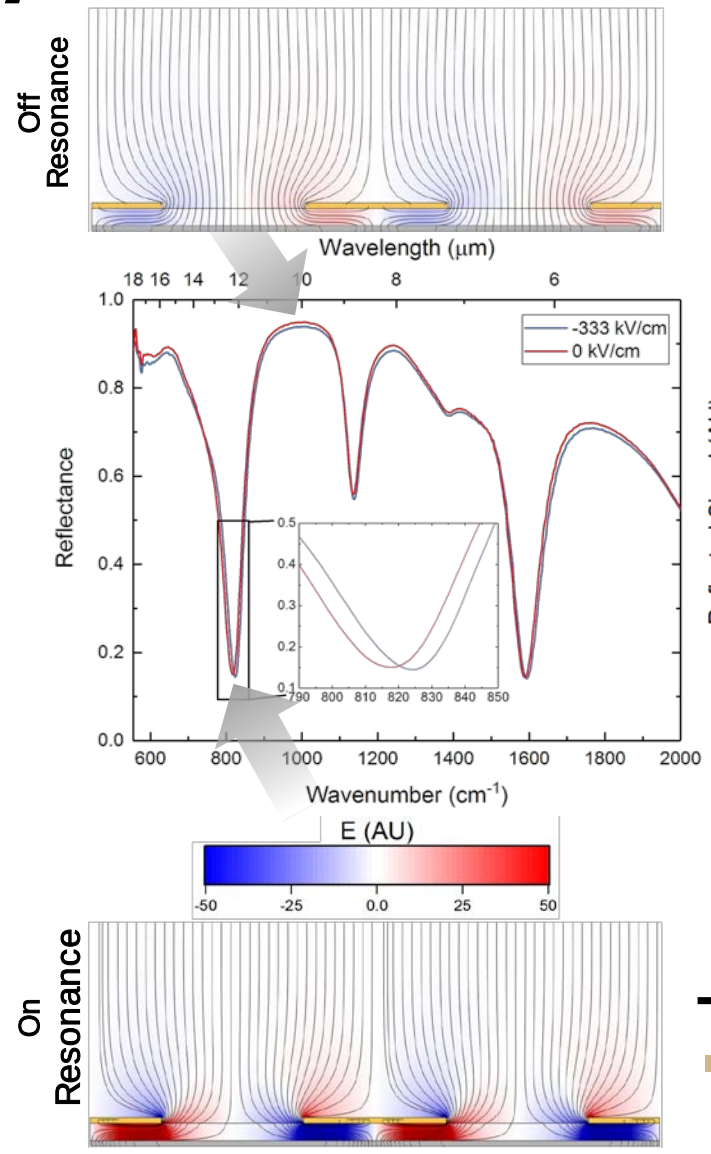
Link to Near-Field Transport?

Interfacial Transport via Polaritonic Hybridization?

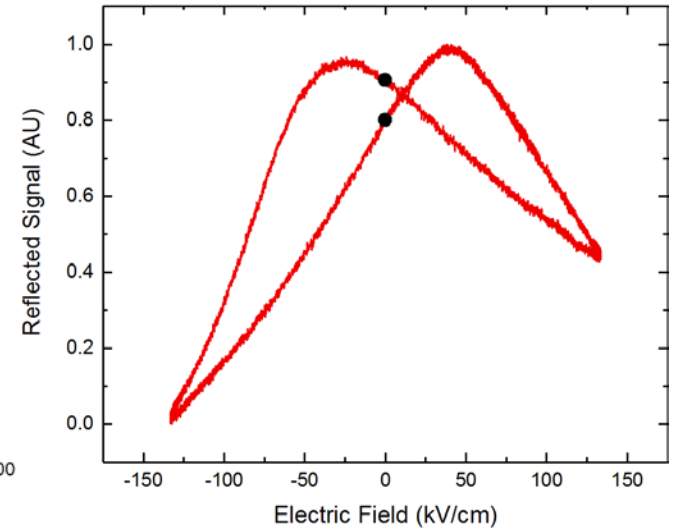


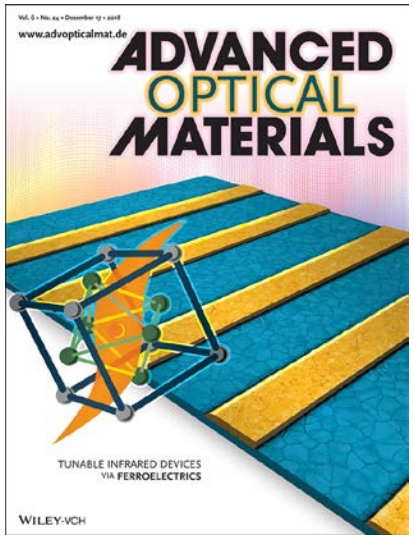






Details: Beechem et al. Adv. Opt. Mat. (6) 1800062. 2018.





Opportunity for heat transfer!

Takeaway Polariton coupling links boundaries

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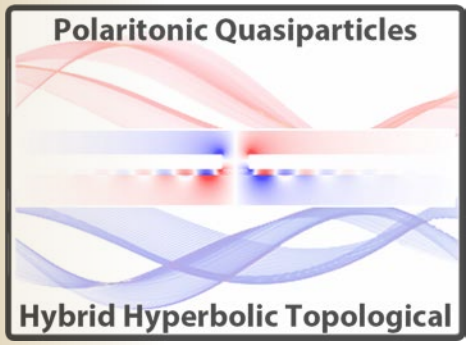

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Reason

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WARNING Graphene Ahead

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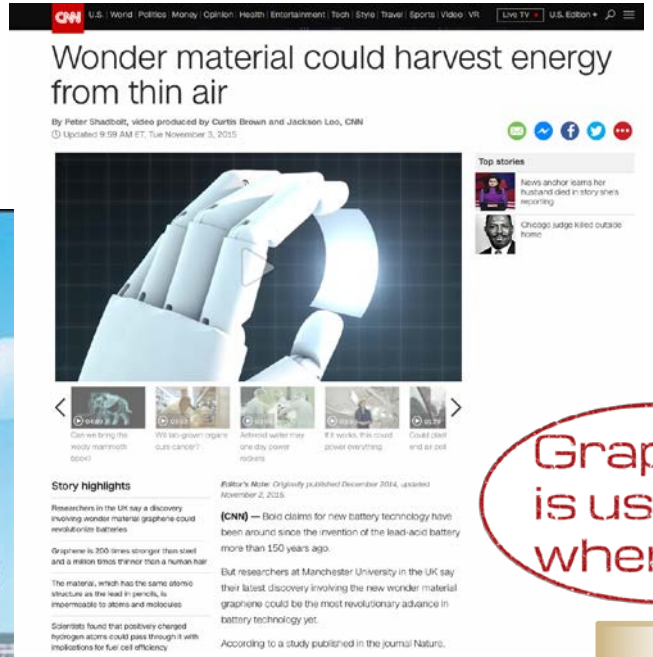
Iron Man

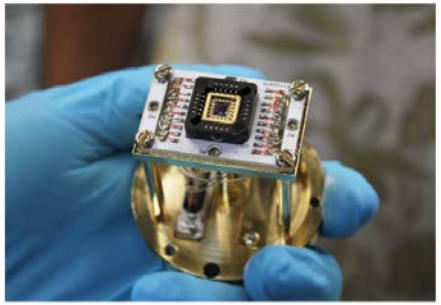
Why Iron man ditched iron for graphene



Graphene is useful when...

- Tuning (2DOS)
- Form & flexibility
- Heterogeneous integration

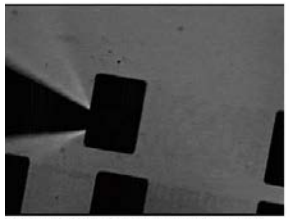
2D "Win"



A Physics Magic Trick: Take 2 Sheets of Carbon and Twist

The study of graphene was starting to go out of style, but new experiments with sheets of the ultrathin material revealed there was much left to learn.

A device containing an unusual form of carbon: two one-atom-thick sheets pressed together with the lattice of one rotated slightly. Experiments by Dmitri Efetov and his colleagues show that this material can exhibit different electronic properties, including superconductivity. ICFO – The Institute of Photonic Sciences



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

The New York Times

JULY 30, 2015

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.

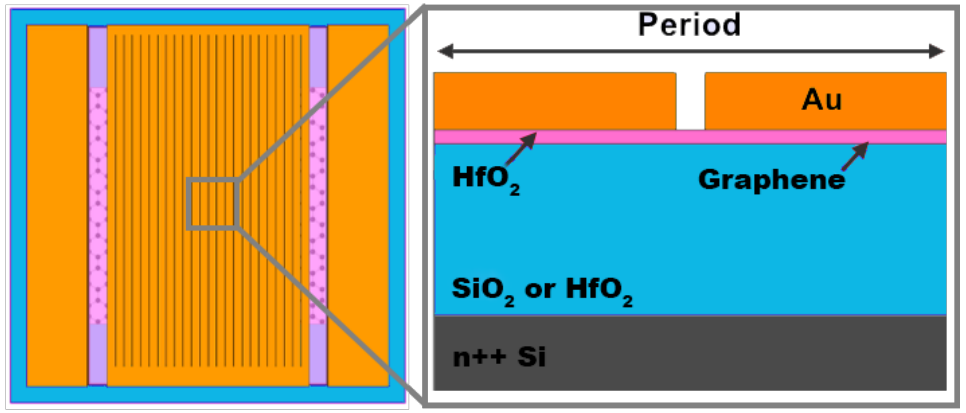
Graphene is so strong that a sheet of it stretched across a coffee-cup should be able to support the weight of a truck bearing down on a pencil point. Some researchers call it a "wonder material" that could be used in everything from batteries and biosensors to computers and condoms.

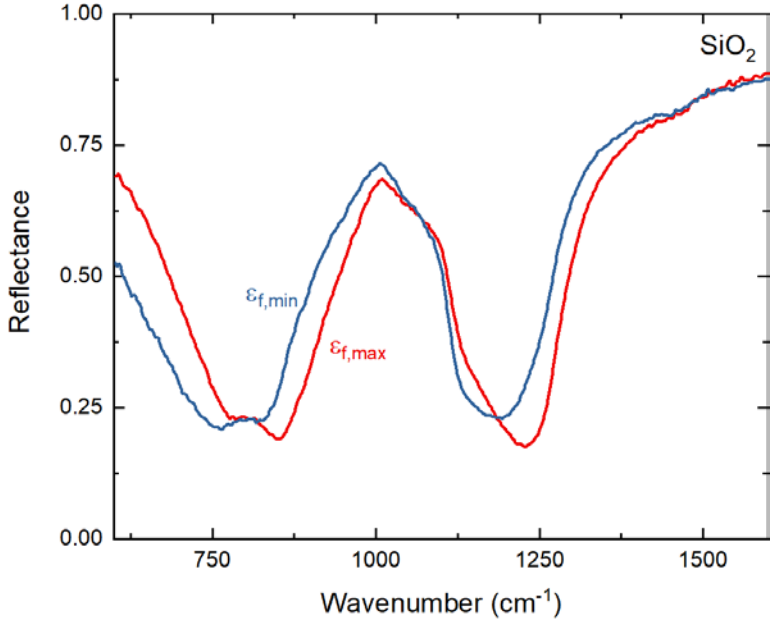
Now researchers have discovered another one of graphene's feats: It's as flexible as paper. Not only can graphene be crumpled and then perfectly flattened, but it can also be folded like origami, according to a report published Wednesday in Nature.

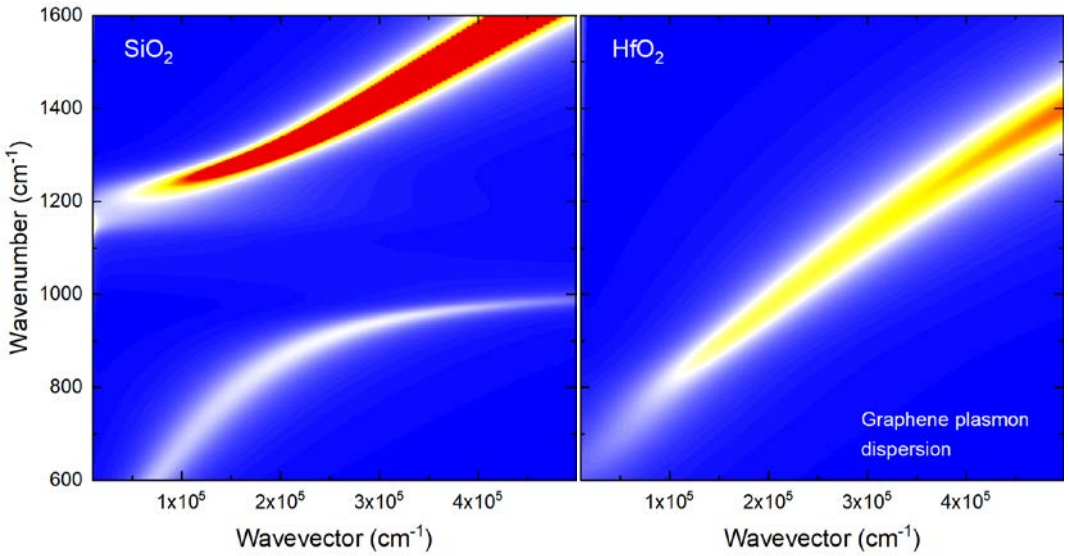
Using a style of origami that involves cuts and folds called kirigami, the researchers fashioned a sheet of graphene into a tiny spring. According to Nature, researchers may one day use kirigami to craft graphene sheets into microscopic weighing scales or nets small enough to wrap around living cells.

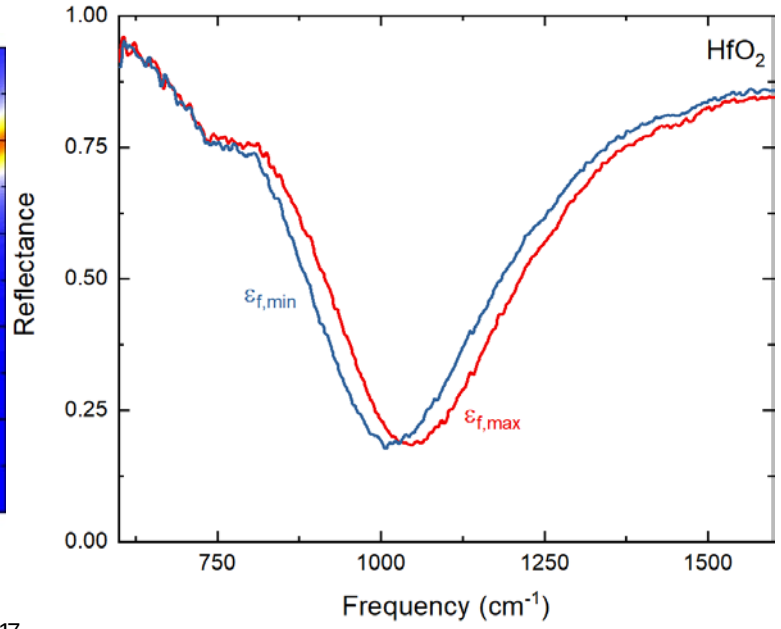
—NICHOLAS ST. FLEUR

Polariton Tailoring…"Easy" Dispersion Engineering





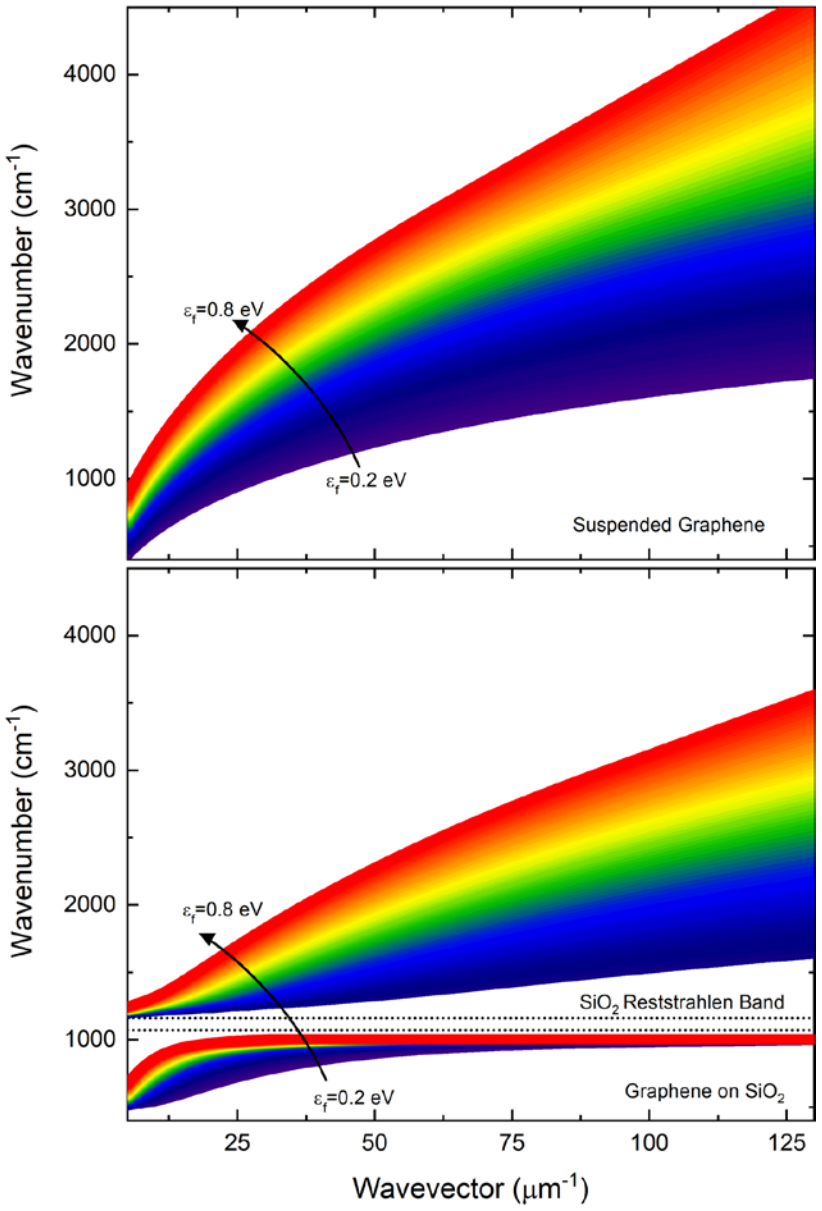




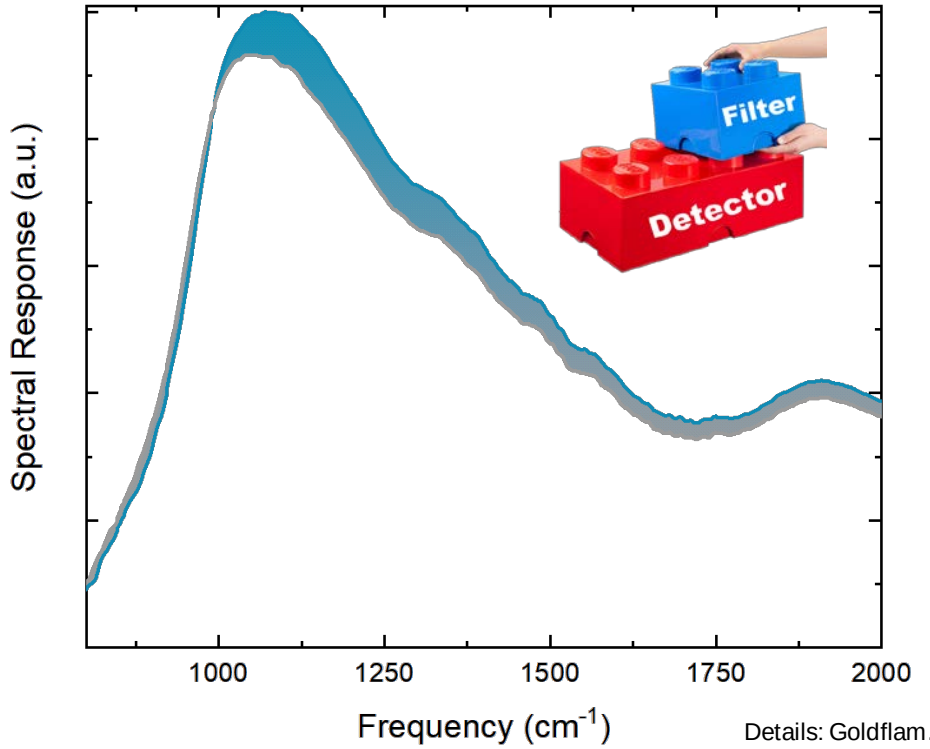
Dispersion Change with Substrate

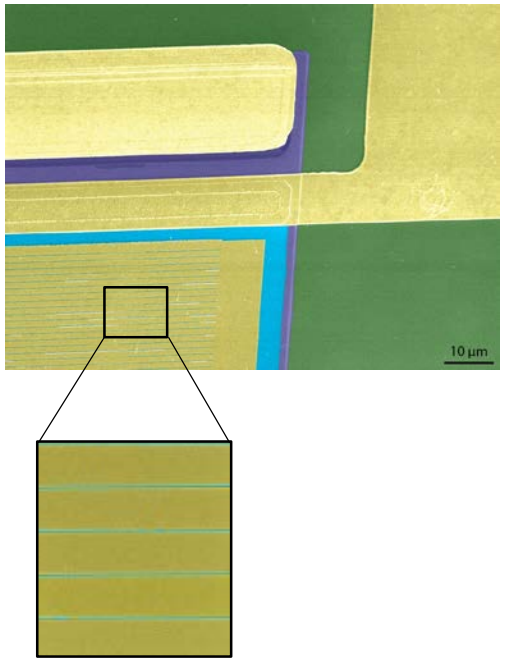
Details: Goldflam…Beechem Opt. Exp. (7) 8532. 2018, Goldflam…Beechem Opt. Expt. (25) 12400. 2017

Polariton Tuning: "Push Button" Thermal Transport?



Details: A. Jarzembski…Beechem et al. Phys. Rev. Appl. 14, 034044 (2020).





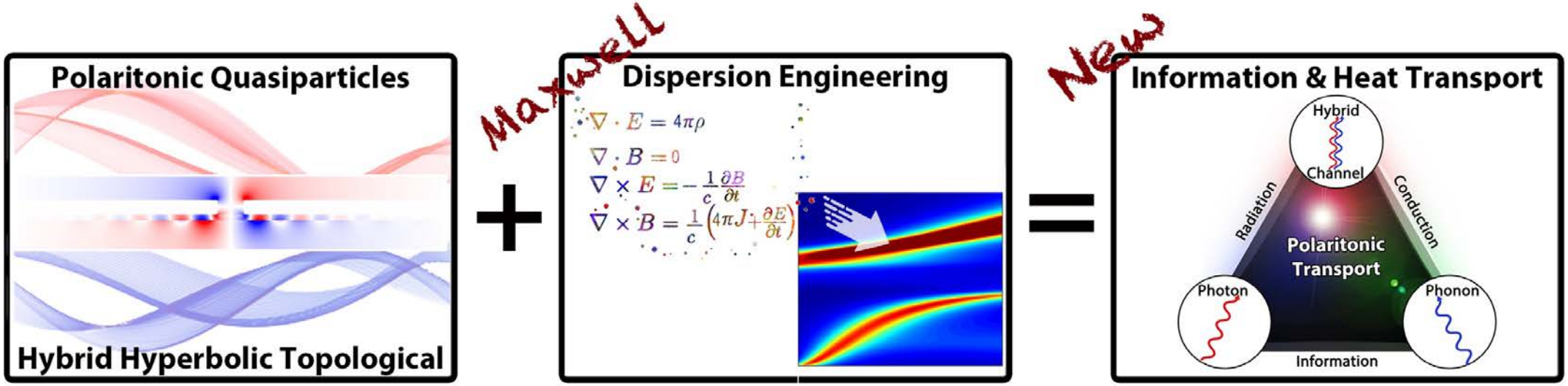
Details: Goldflam…Beechem et al. APL (116) 191102. 2020

Opportunity for heat transfer!

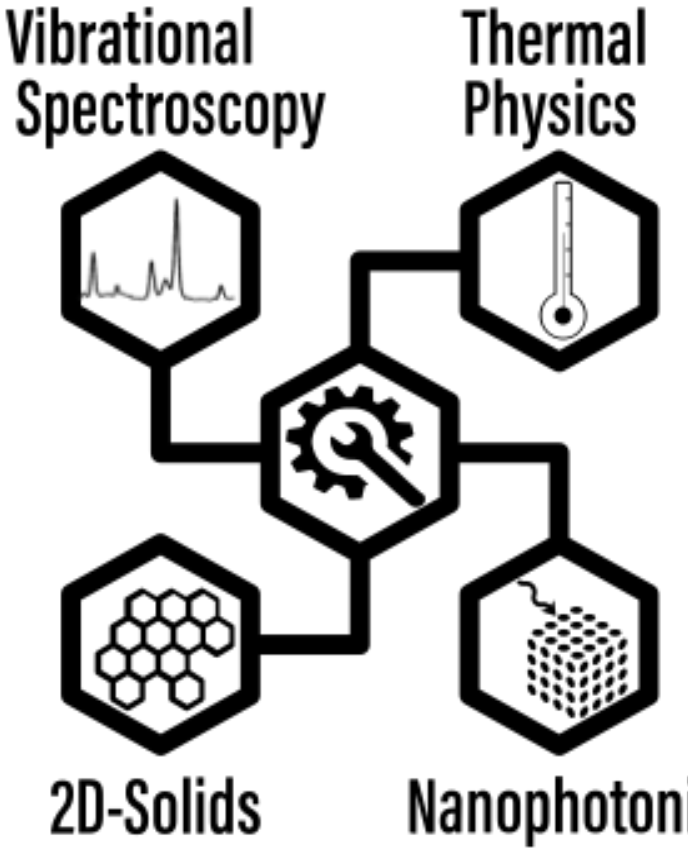
Takeaway Polariton dispersions can be engineered

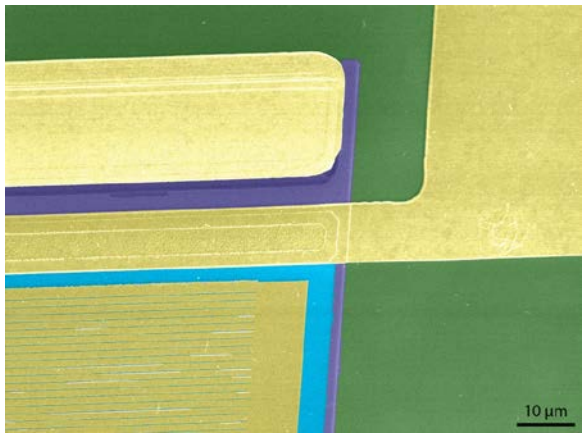
Takeaway Polariton dispersions can be switched.

Polaritonic Energy Transport: The Path



Polaritonic Energy Transport: The Tools





Details: Goldflam…Beechem. APL (116) 191102. 2020.

Beyond Heat... Polaritons for Spectroscopy

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Problem #1
Spectrometers are too big

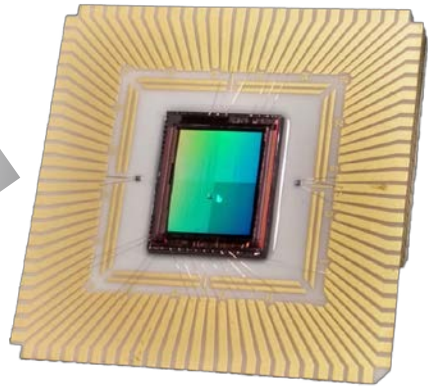
Problem #2
Spectrometers are too general purpose.

Problem #3
Momentum

STUCK ON THE LIGHT LINE

Γ

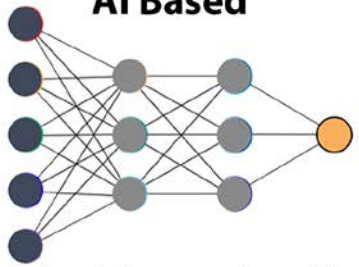
Beyond Heat…Polaritons for Spectroscopy



Metasurface Filters

+

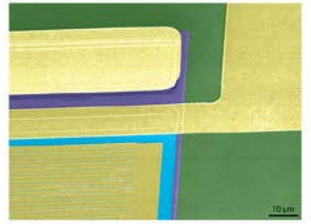
AI Based



Spectral Reconstruction

"More" Momentum || Made to Order

Chip-Based



Spectroscopy

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A light lab employing infrared physics to create thermal, spectroscopic and sensing solutions.

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