Annual Exam for PhD students
Second Year

October 20, 2020

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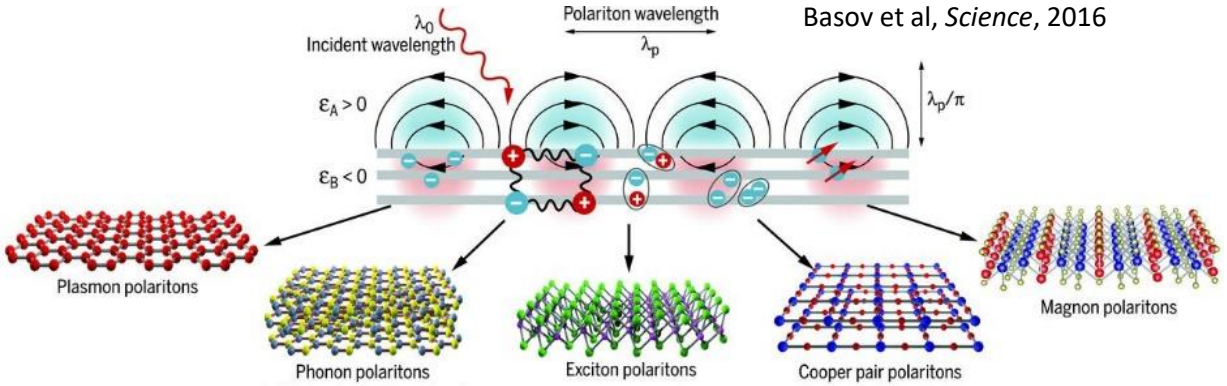
Supervisor: Alessandro Tredicucci

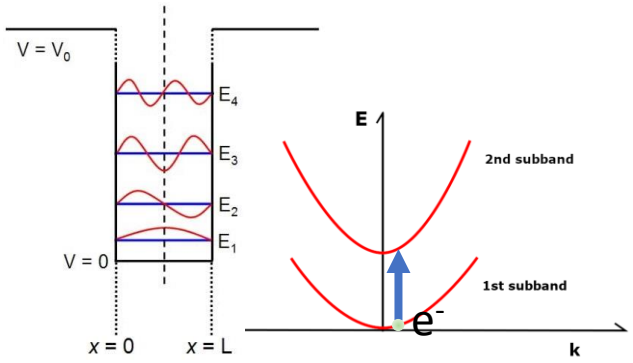
Introduction



Basov et al, *Science*, 2016

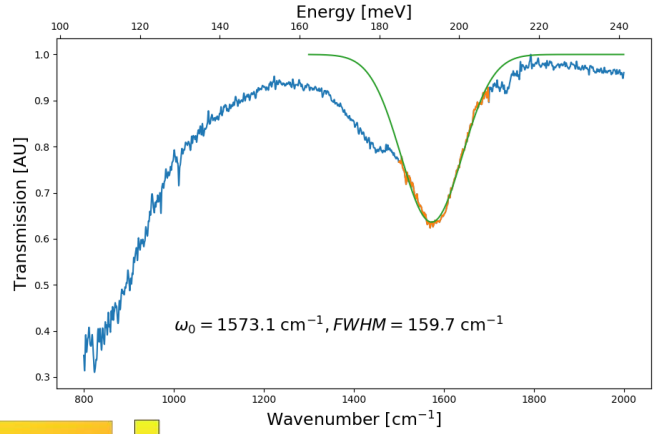
Surface Polaritons

- Out-of-plane component of the electric field
- Large confinement factor $\eta_0 \sim 10^2$
- Increased energy density



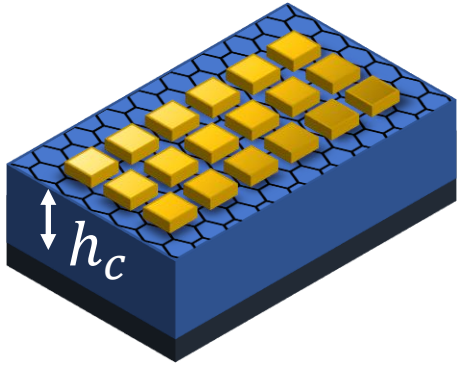
Intersubband transitions

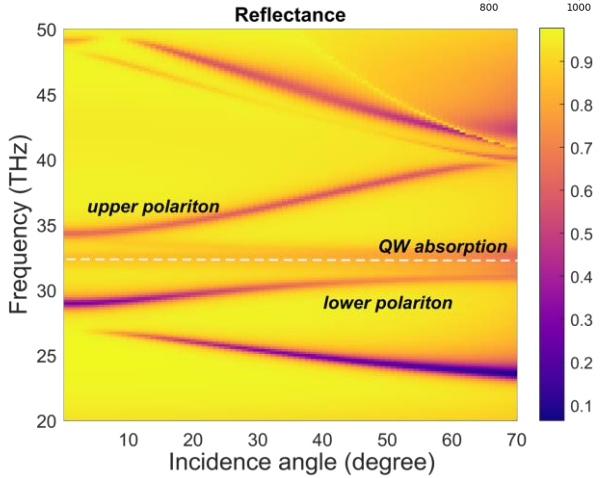
- Delta like linewidth
- III-V heterostructures
- Recently observed in 2D materials



Critical coupling

Cavity effect





Strong coupling

Resonant effect

Summary

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Intersubband Transitions and Surface Polaritons

Critical Coupling driven by Graphene Plasmons

Whispering Gallery Modes in Graphene Microdisks

Non-local intersubband transitions

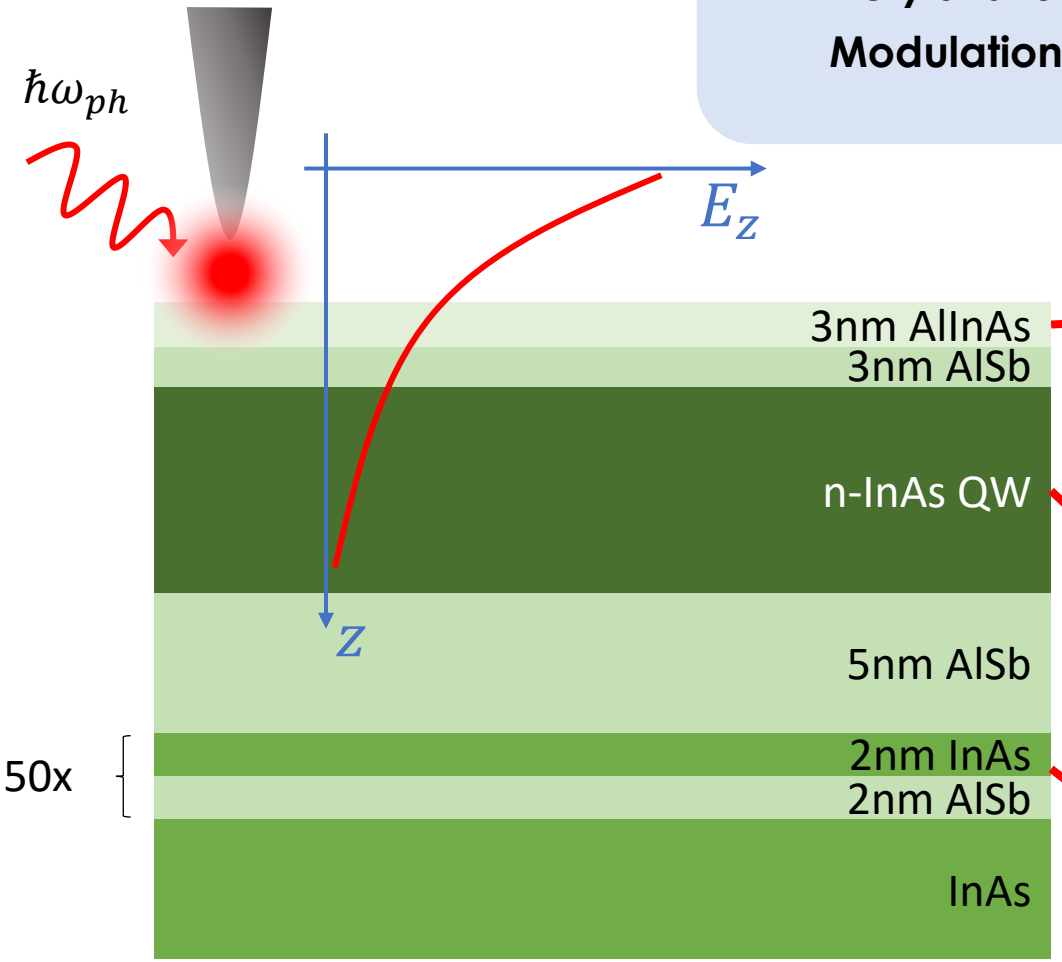
Structure of our Quantum Well

Measuring intersubband transitions with a s-SNOM

Beyond diffraction limit with near field to detect local thickness fluctuations

Very shallow Quantum Well is required for the near field to leak in

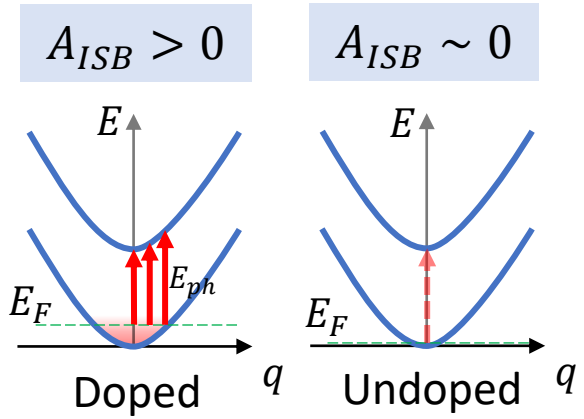
Modulation of the charge density necessary to isolate resonant absorption



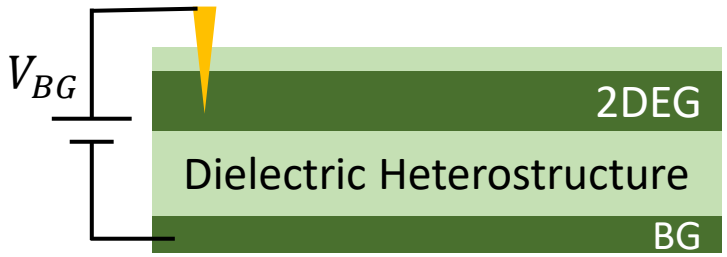
Cap layer to match surface energy pinning to crystal E_F

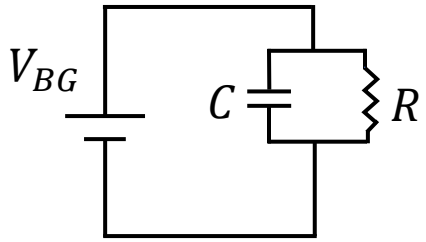
QW Active region
Transition frequency depends on thickness

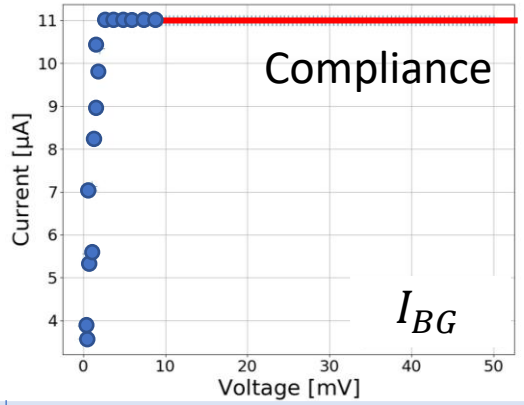
Heterostructure due to InAs-AlSb lattice mismatch



Issues in backgating the sample



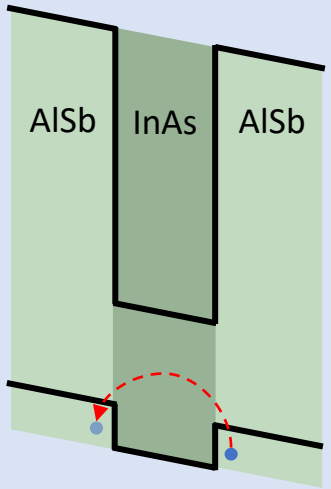




$R \sim 50\ \Omega$
Ohmic behaviour between 2DEG and BG

Possible Causes

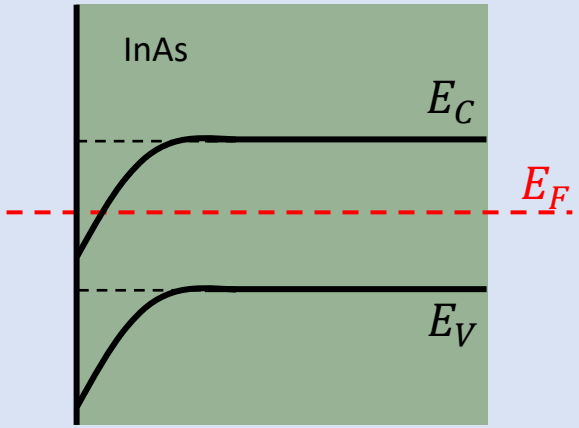
Hole transport



Possible Solution:

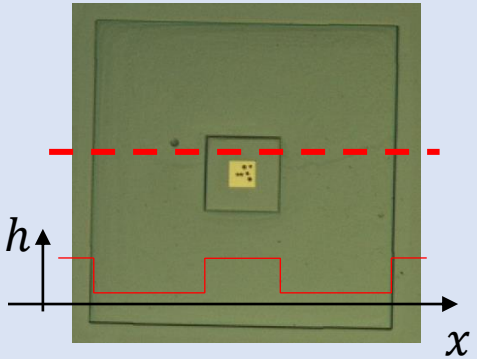
Low T measurement

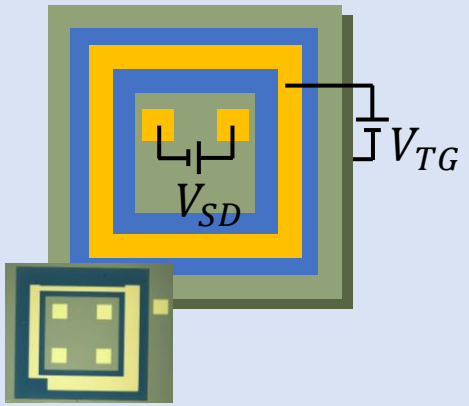
Surface Fermi Pinning



Possible Solutions:

Etching pillars to increase surface resistance





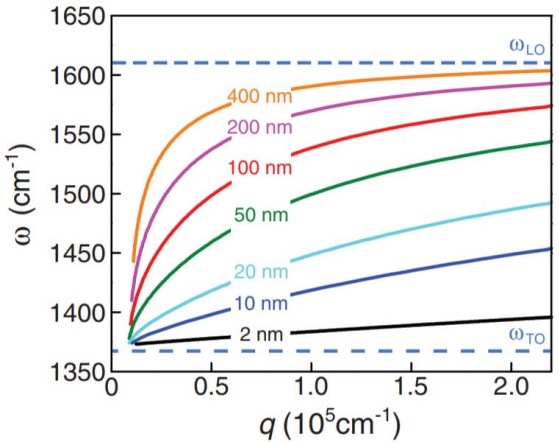
Creating a ‘guard ring’ to isolate 2DEG from lateral surfaces

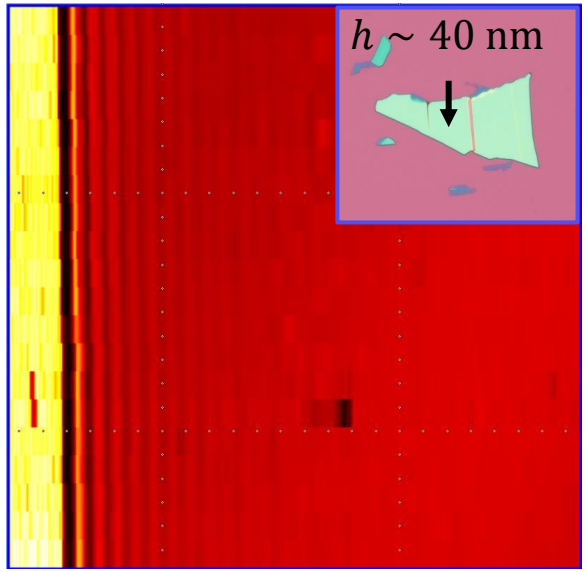
Coupling with Phonon Polaritons

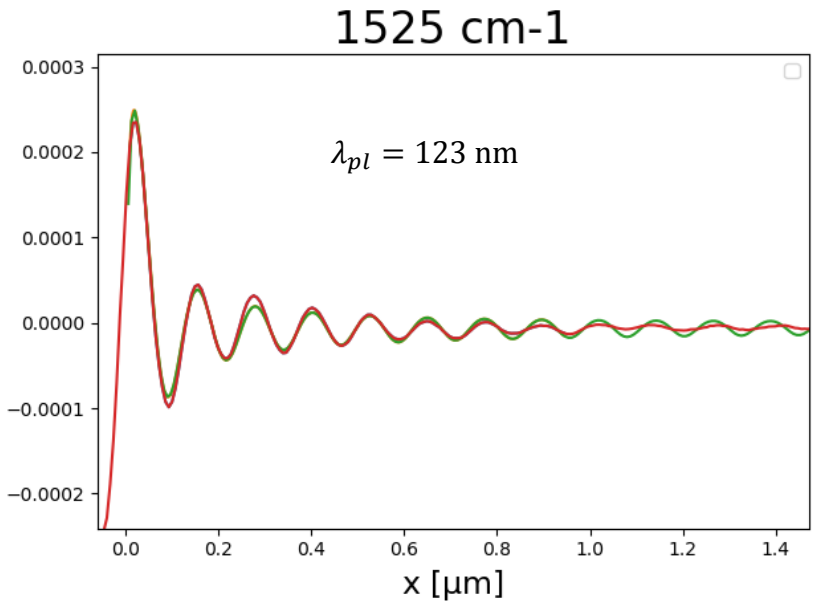
Phonon Polaritons in hBN are surface polaritons

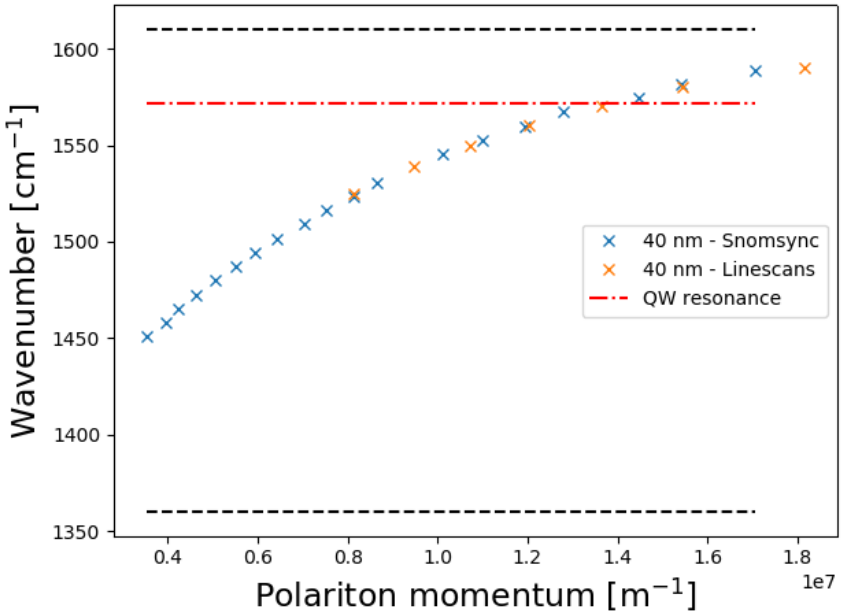
- Phonon polaritons can be excited in **hBN Reststrahlen Band**
- Dispersion is **thickness dependent**
- **No charge carrier involved**: electrical tuning is not crucial

Basov *et al*, *Science 2014*









In collaboration with Dr. F. Koppens' group @ICFO, Castelldefels (BCN)

Critical Coupling driven by plasmons

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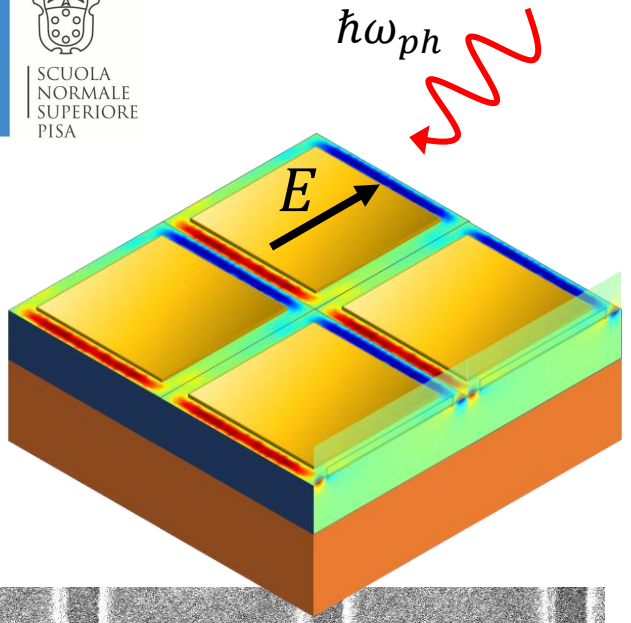
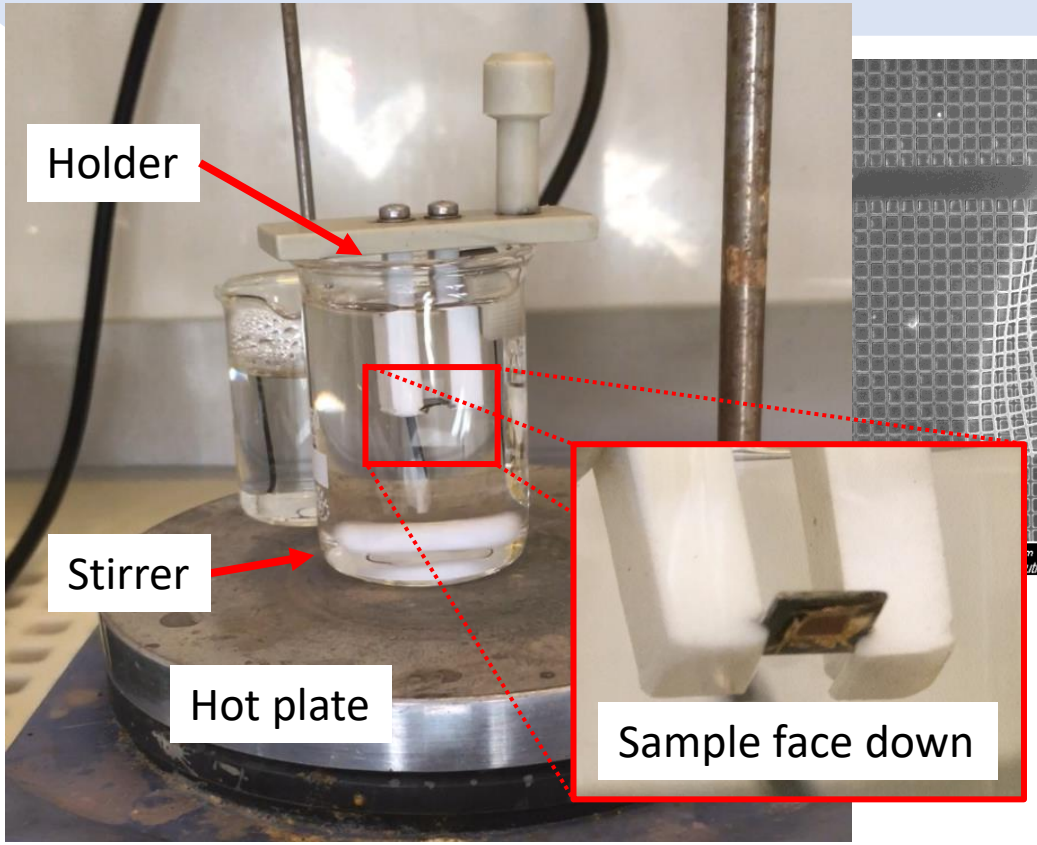
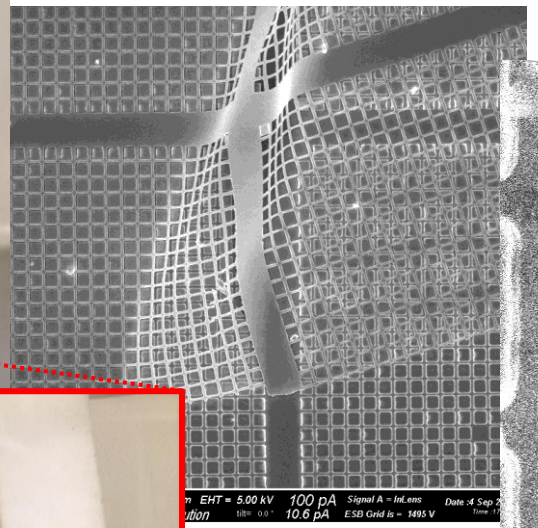
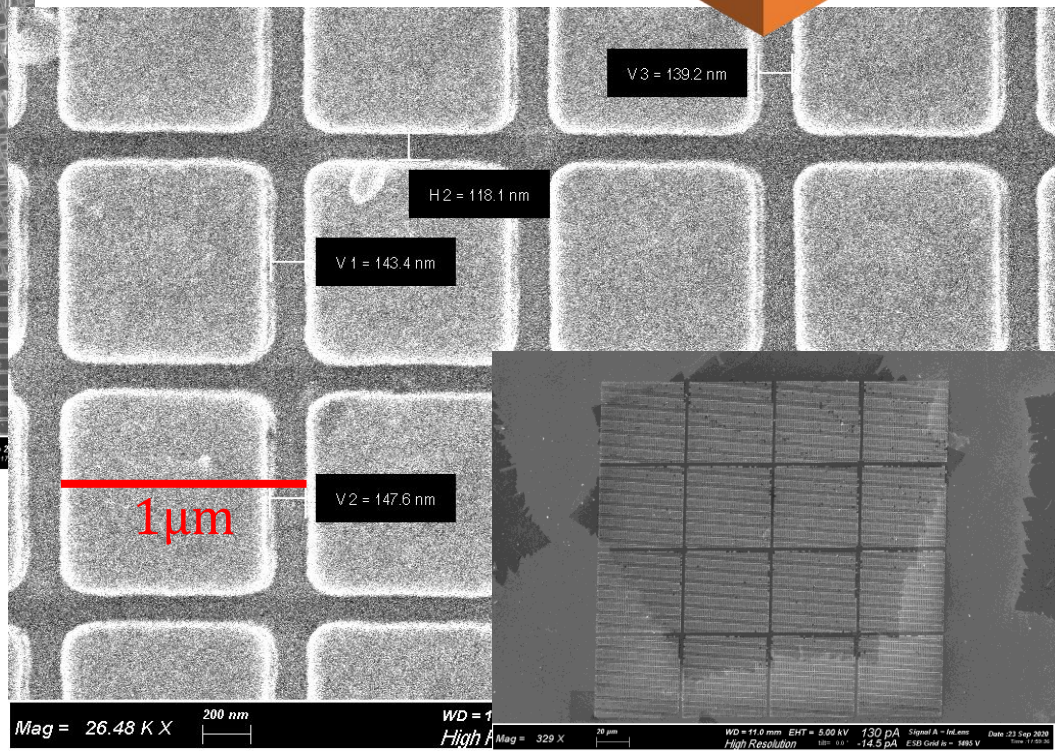
Resonant condition for $h_c = \frac{\lambda}{4}$ where ~ 100% of light is absorbed

- **Gold antennas on Graphene** (CVD grown, prov. by Dr. C. Coletti's group)
- **Large-area pattern** of few microns gold squares for FTIR
- Development of a **technique** for fast but reproducible fabrication









Critical Coupling driven by plasmons

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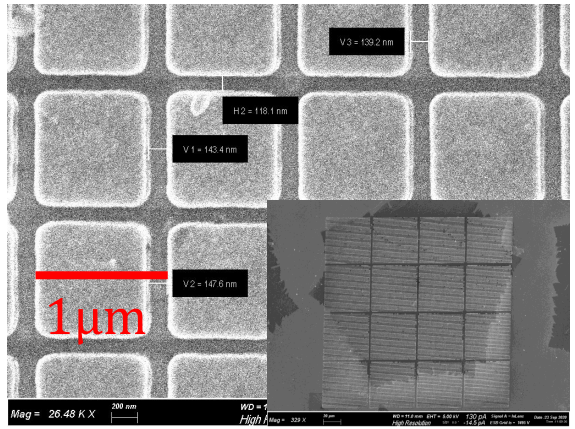
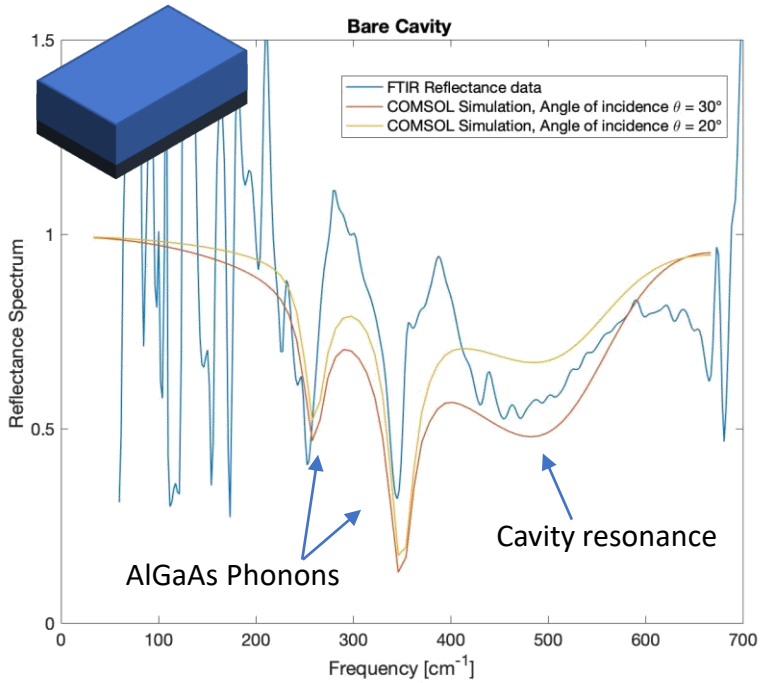
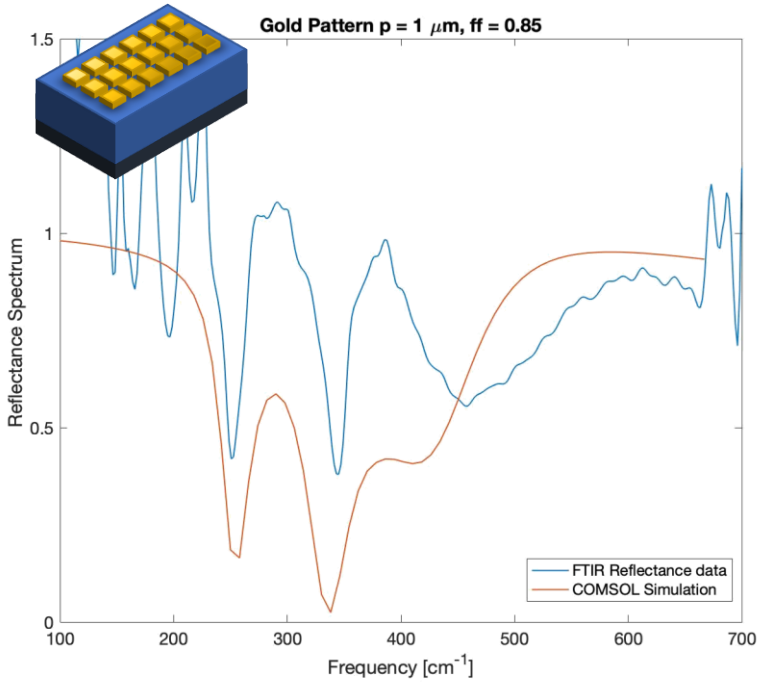
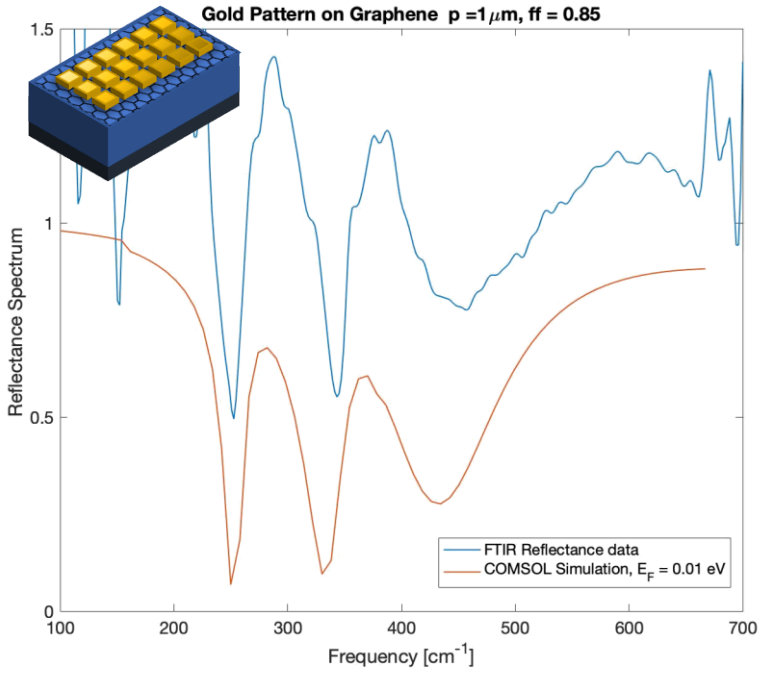
Three samples: bare cavity, gold pattern and gold pattern with graphene

- **Bare cavity absorption** shows weak and broad absorption
- Gold patterned sample is expected to show a **shifted peak**
- Graphene **narrows the resonance** even at low E_F





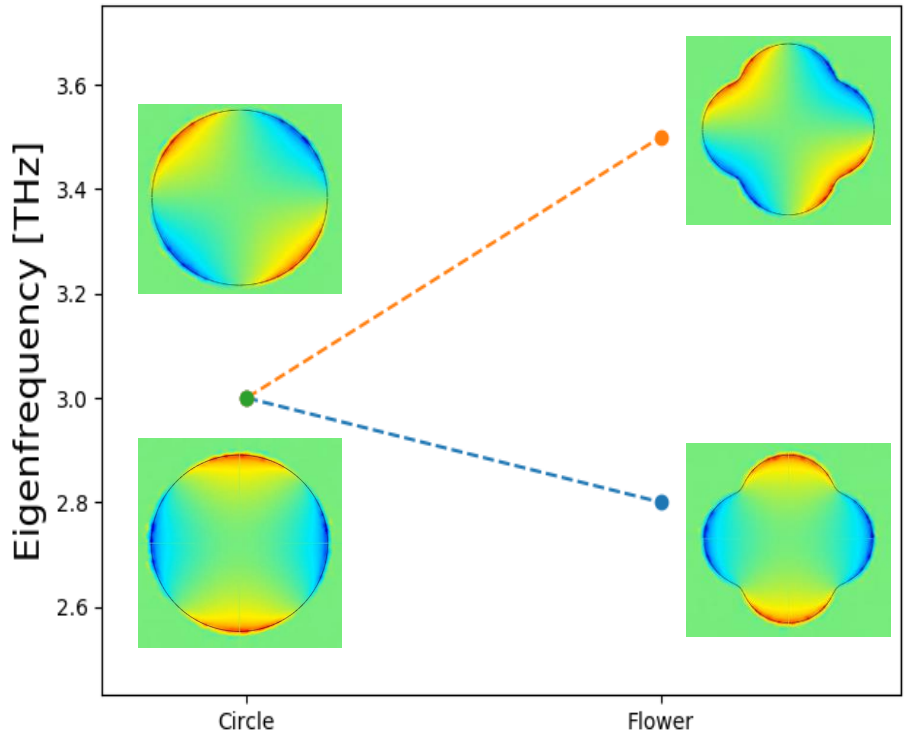


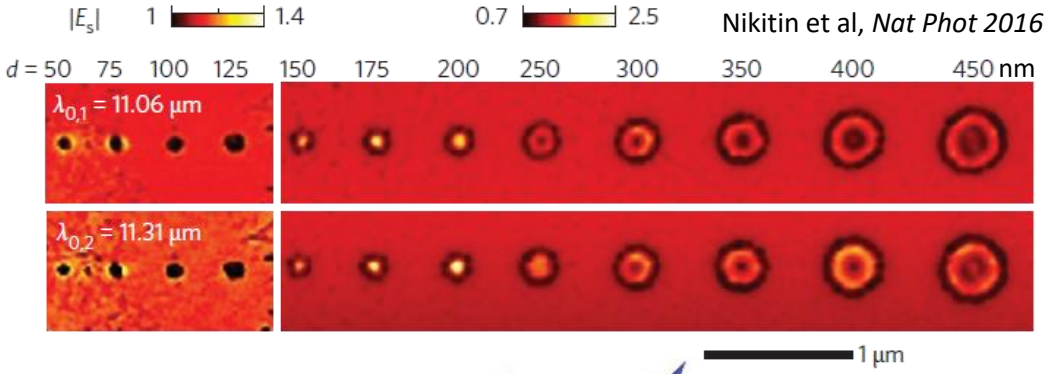


Whispering Gallery Modes (WGMs) in Graphene

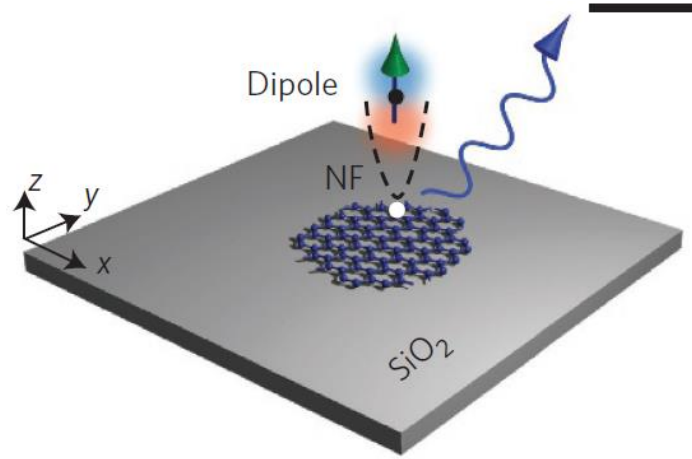
Modes living at the edge of a circular cavity

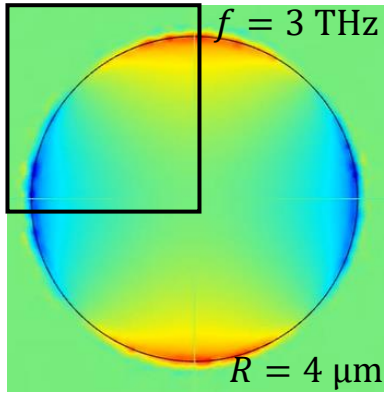
- Due to rotational symmetry, WGMs are **degenerate in phase**
- **Breaking the symmetry** could lead to a lift of the degeneracy
- Comsol simulations performed to confirm observability with a s-SNOM

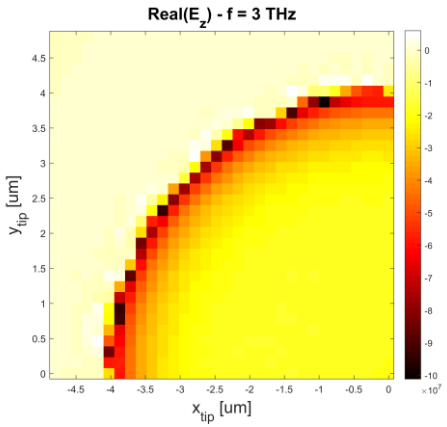




Nikitin et al, *Nat Phot 2016*







Non-local Intersubband transitions

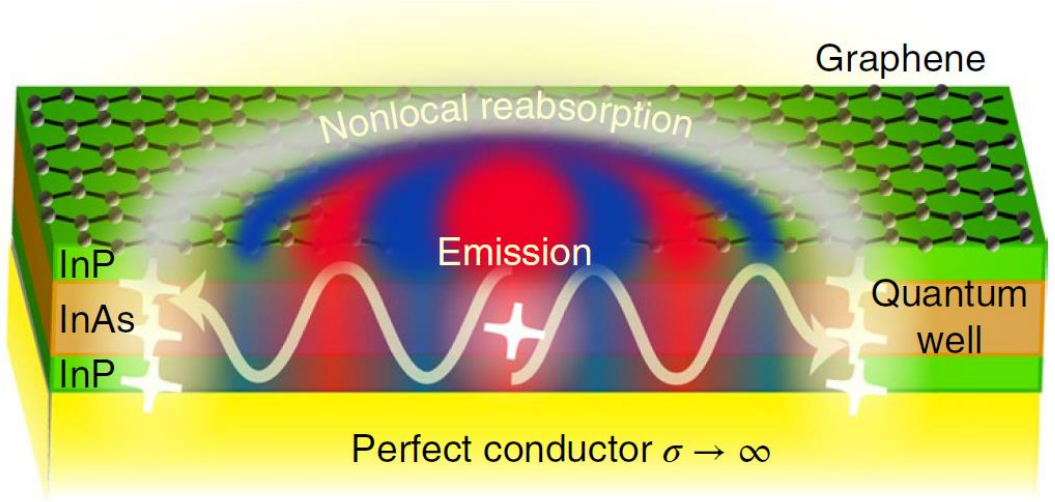
Coupling in a Metal-Insulator-Graphene cavity

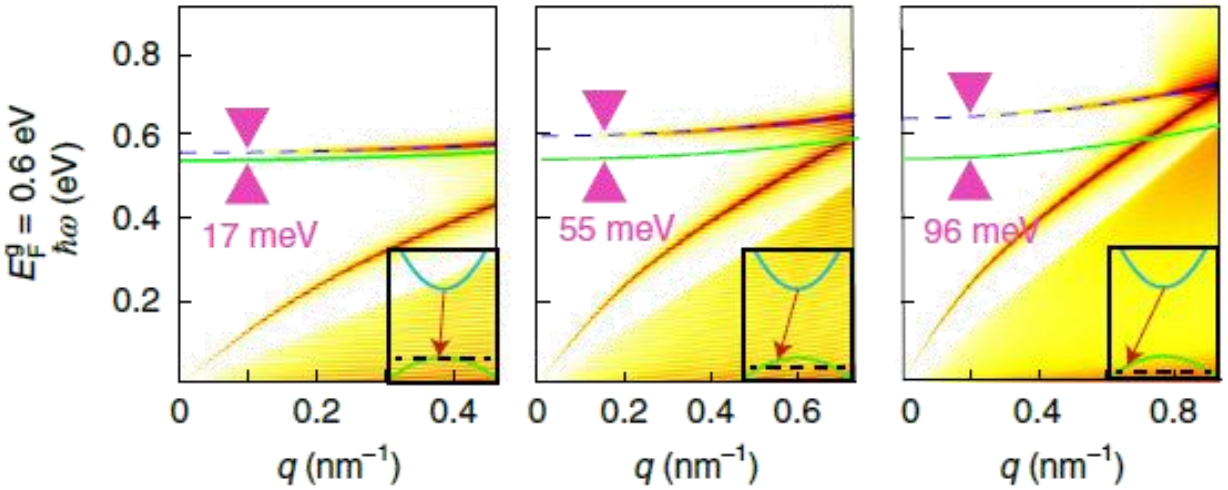
So strong a coupling it **changes the properties** of the crystal

Bandgap renormalization depending on Fermi energy of the crystal

We want to explore the effects of the coupling in this system **on ISB transitions**

Kurman et al, *Nat Phys 2020*





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Thank you for your attention!