Intersubband Polariton

Francesco Pisani

Outline

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    - Surface Plasmon
    - Intersubband transition
    - Intersubband Polaritons
- Polariton Emission
- Improving the polariton generation
    - High Q-factor cavities & parabolic QWs
    - Graphene grating
    - Critical Coupling
- Magic Windows

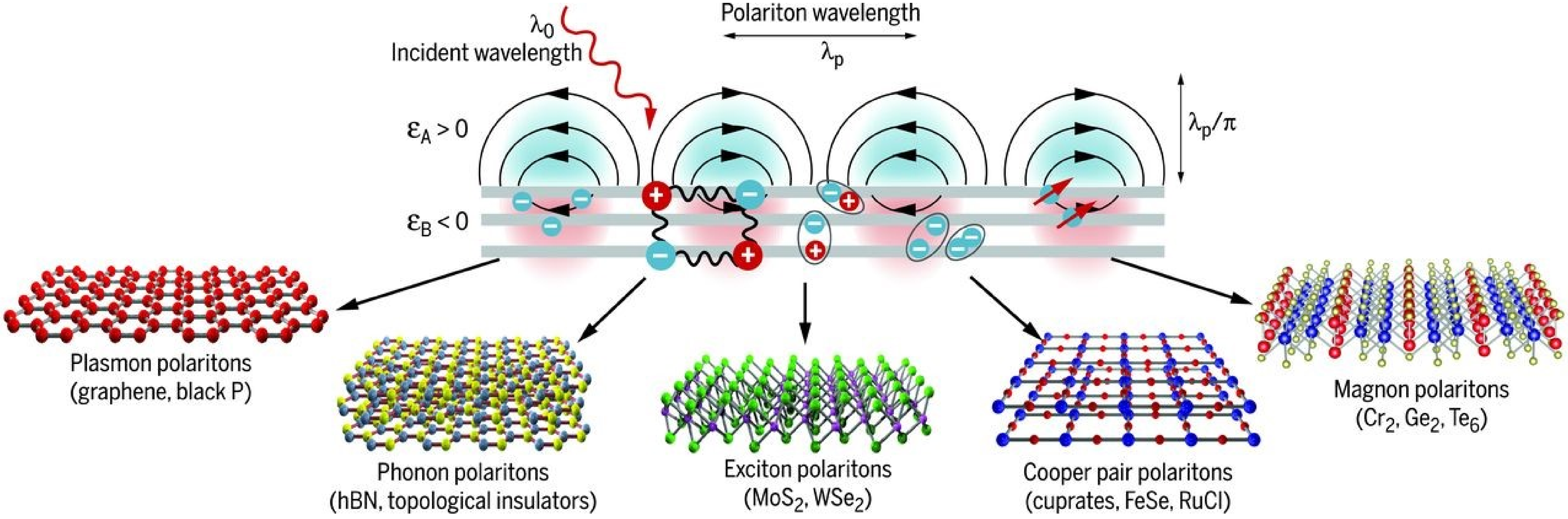
MIR-BOSE

Mid- and far-IR optoelectronic devices based on Bose-Einstein condensation

Intersubband Polariton Laser

Polaritons

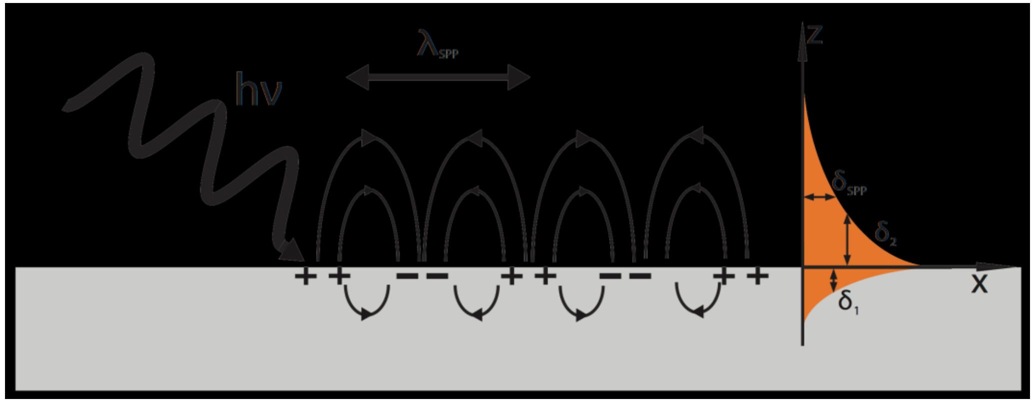
are **bosonic quasiparticles** resulting from strong coupling of electromagnetic waves with an electric or magnetic dipole-carrying excitation.



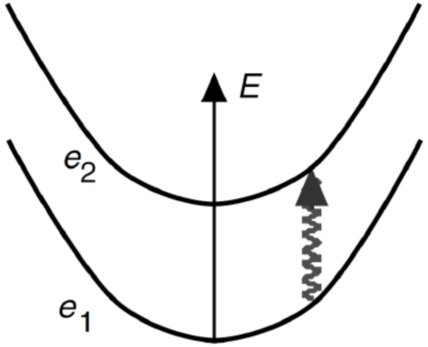
Polaritons

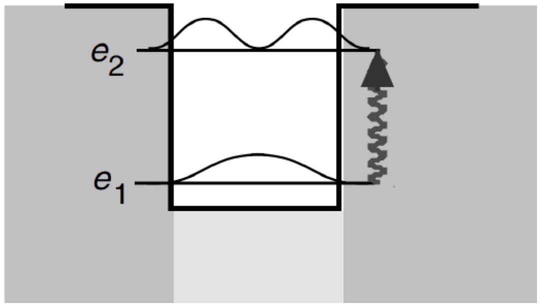
are **bosonic quasiparticles** resulting from strong coupling of electromagnetic waves with an electric or magnetic dipole-carrying excitation.

- **Photonic resonance**: Surface Plasmon



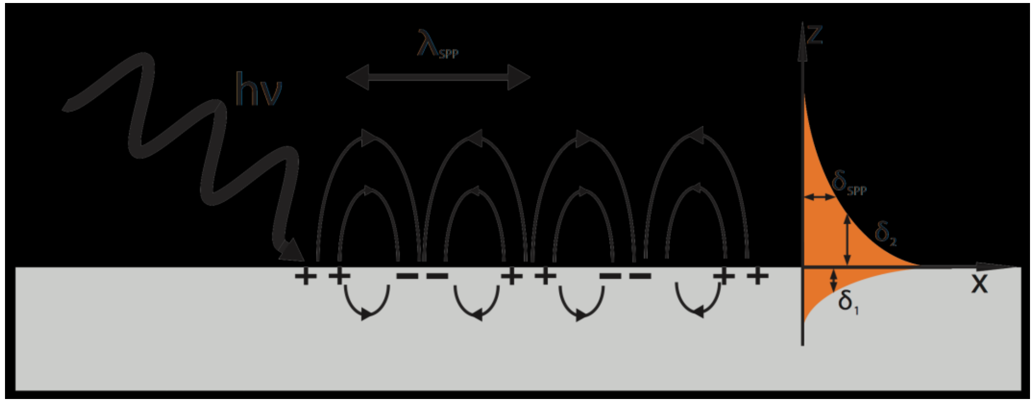
- **Material resonance**: Intersubband transitions

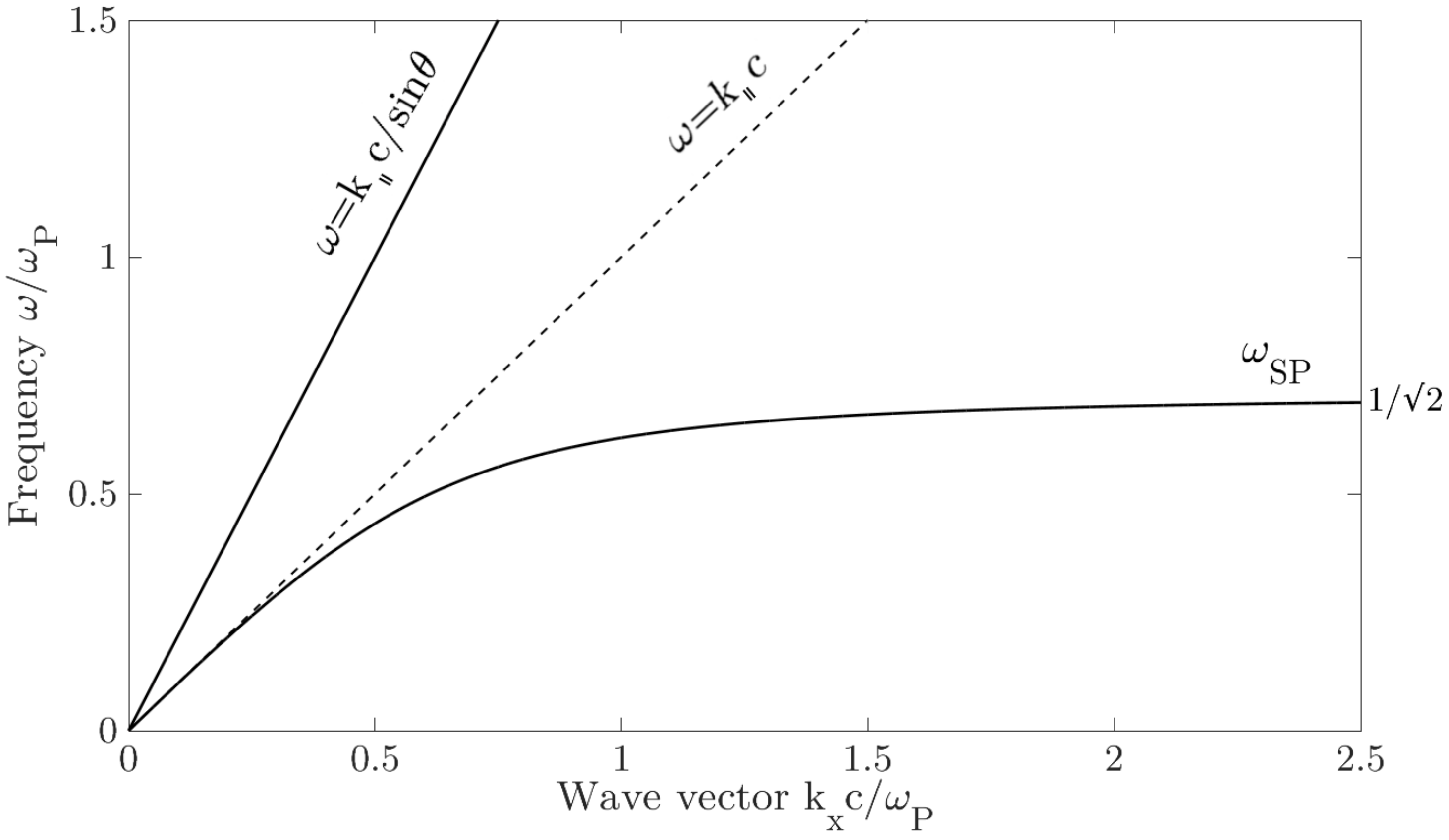




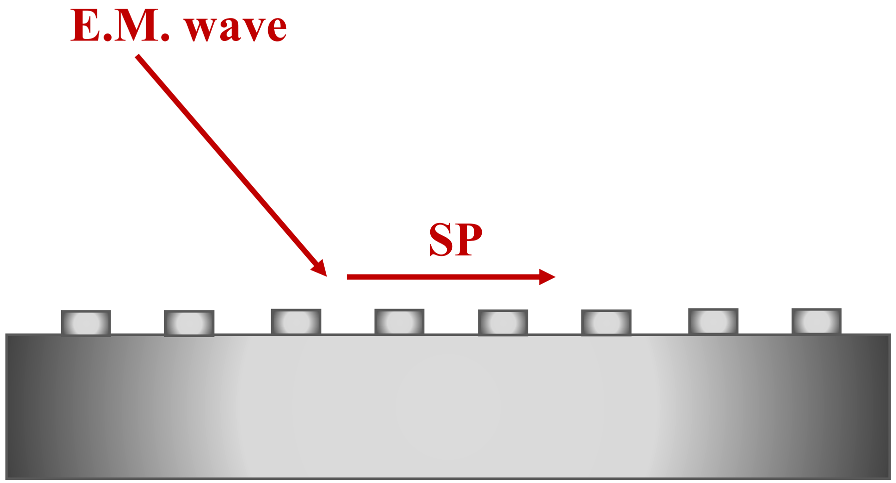
Surface Plasmons

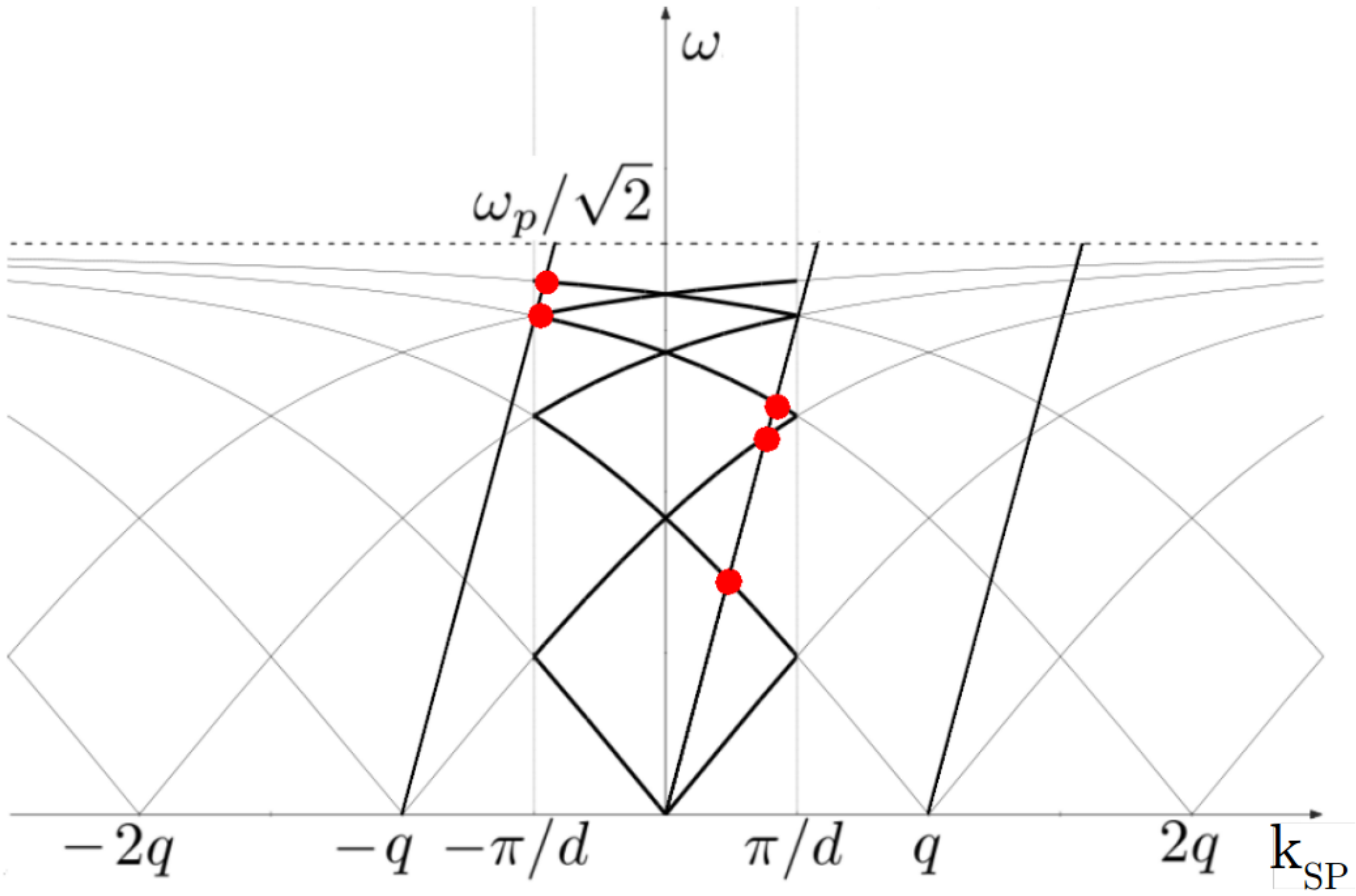
are collective oscillation of electrons in the metal, driven by an electromagnetic wave.





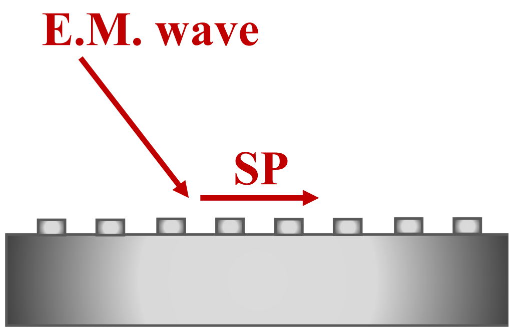
Surface Plasmons can be excited thourgh a grating coupler

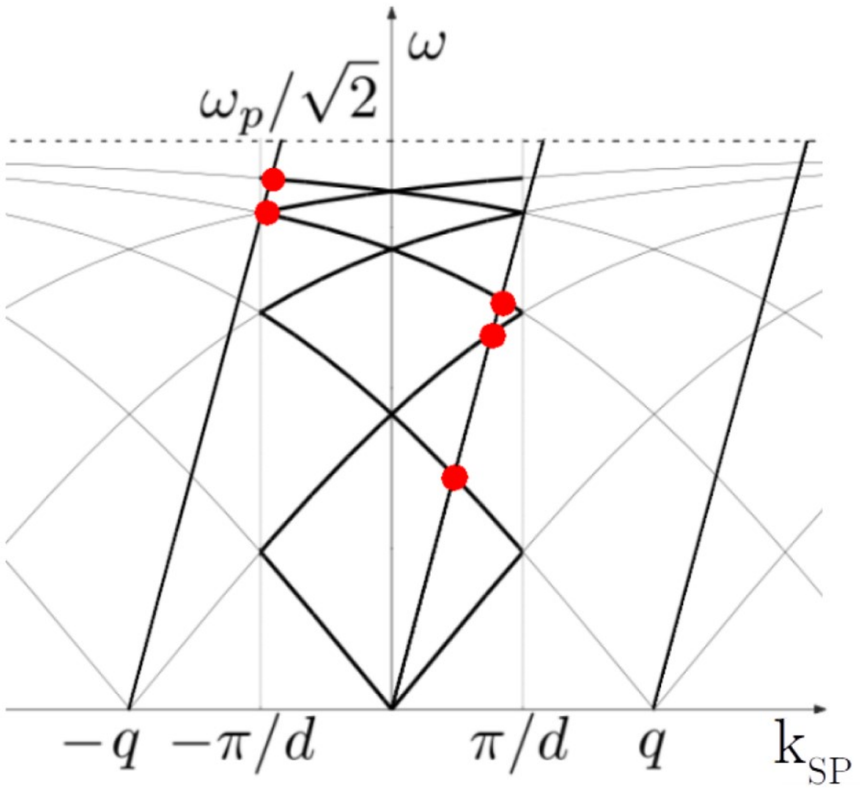


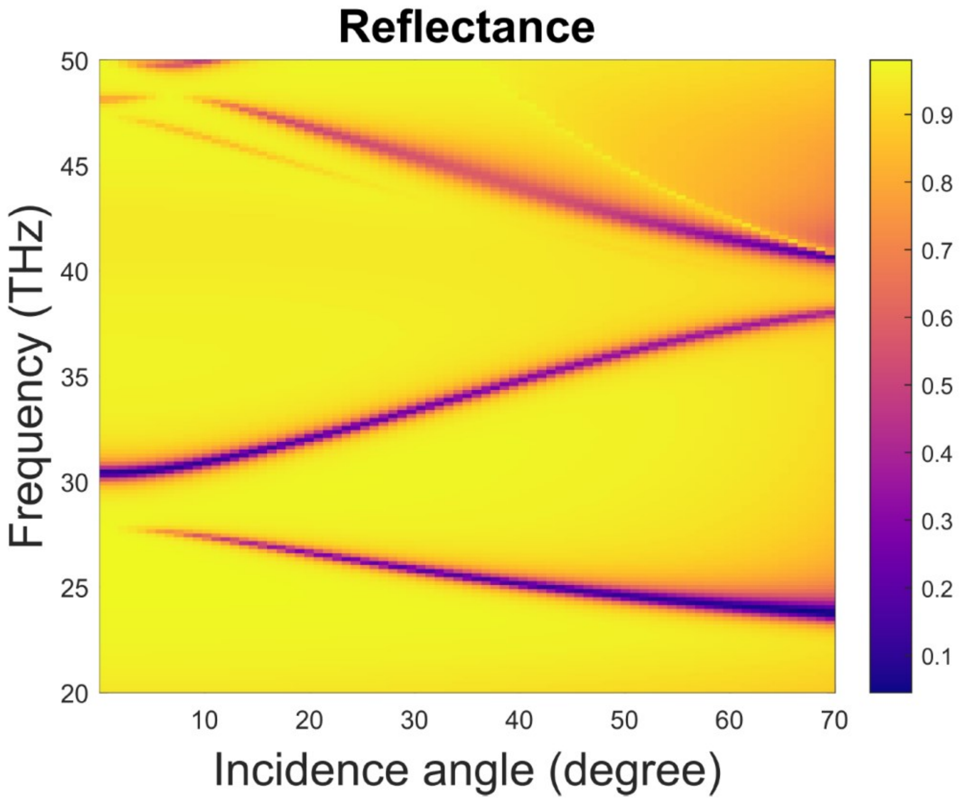


The dispersion folds in the F.B.Z

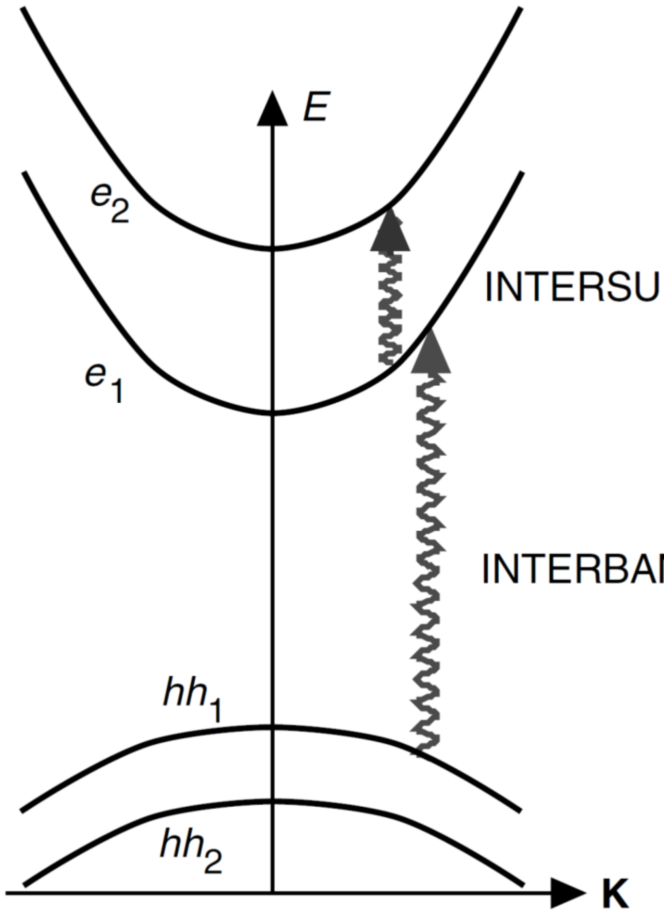
Surface Plasmons can be excited through a grating coupler

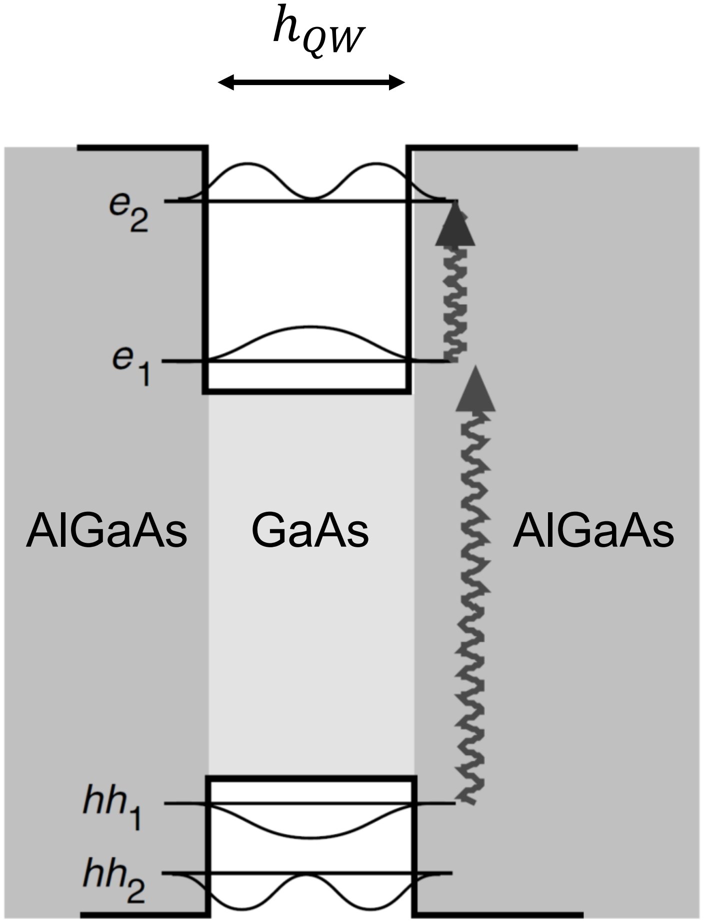






Intersubband Transitions

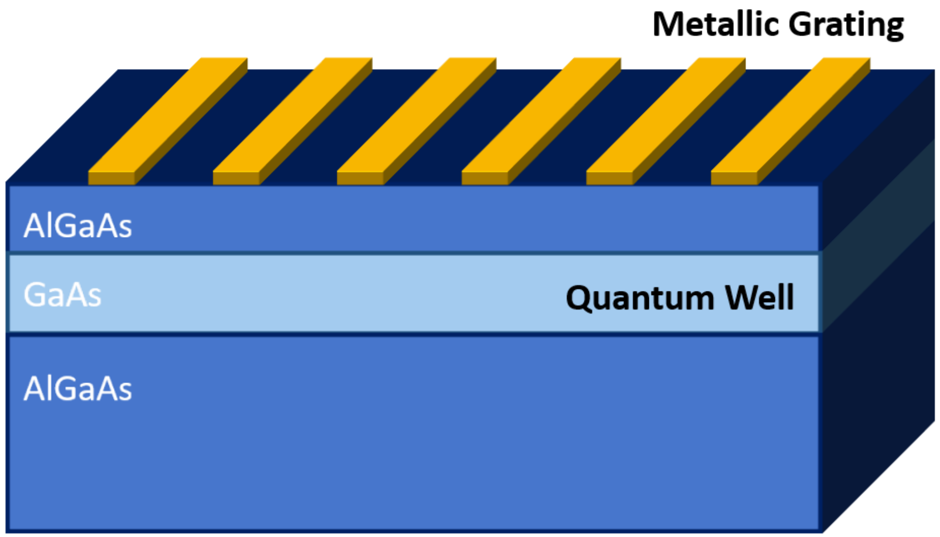


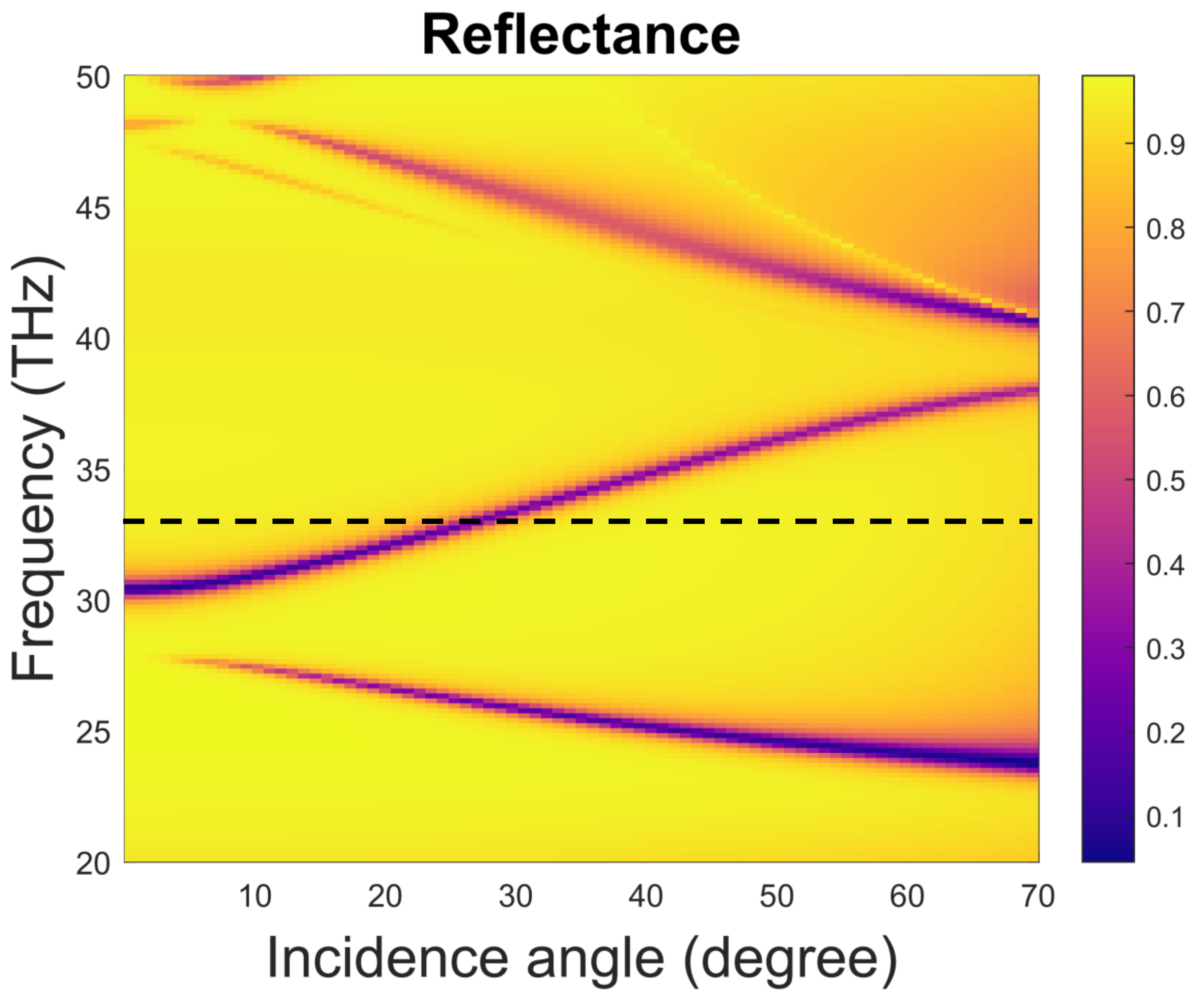


The transition frequency can be tuned with the QW thickness.

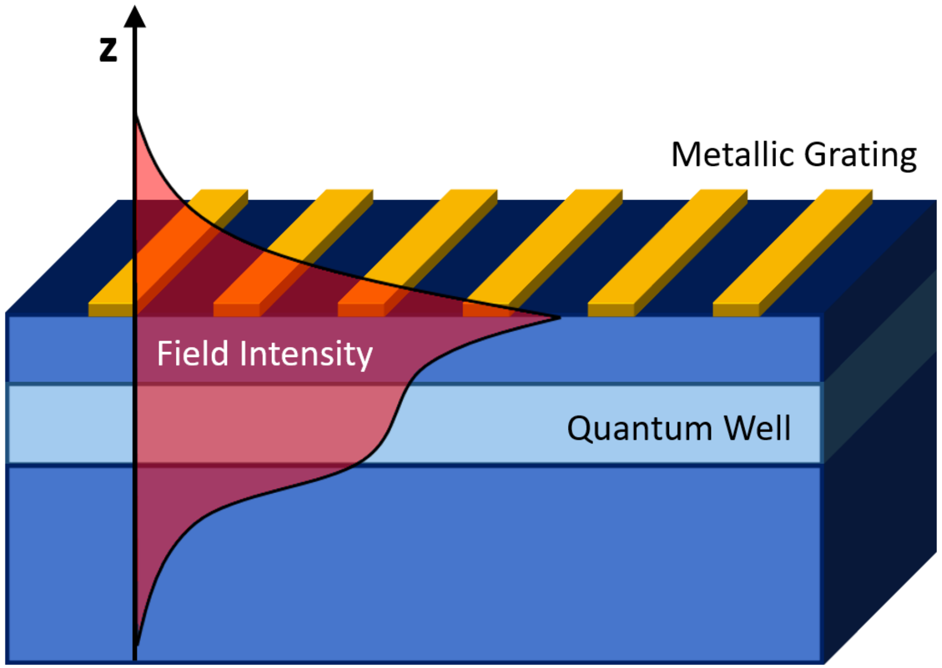
The absorbed polarization is in the growth direction.

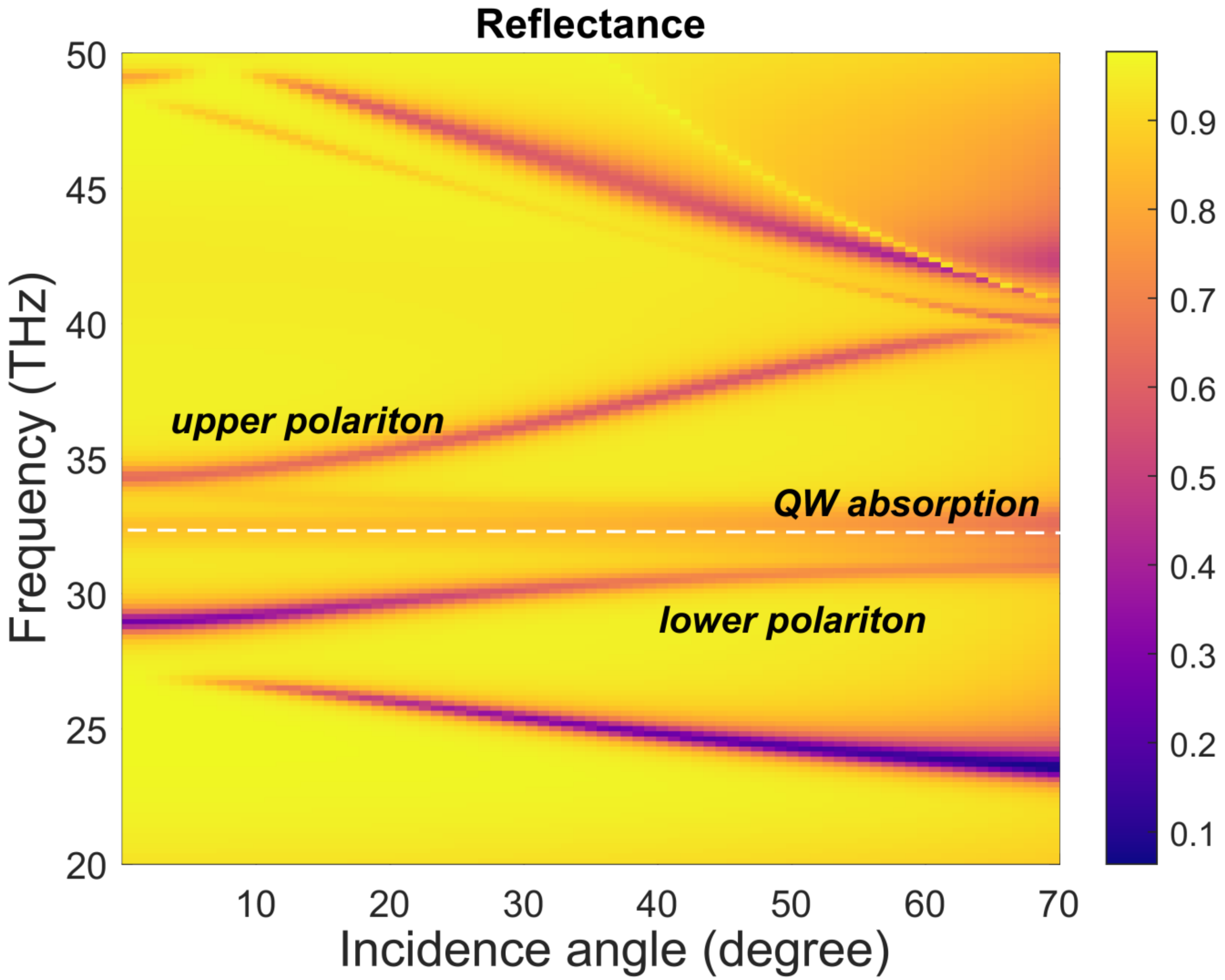
The strong coupling between the two resonances generates the Intersubband Polariton



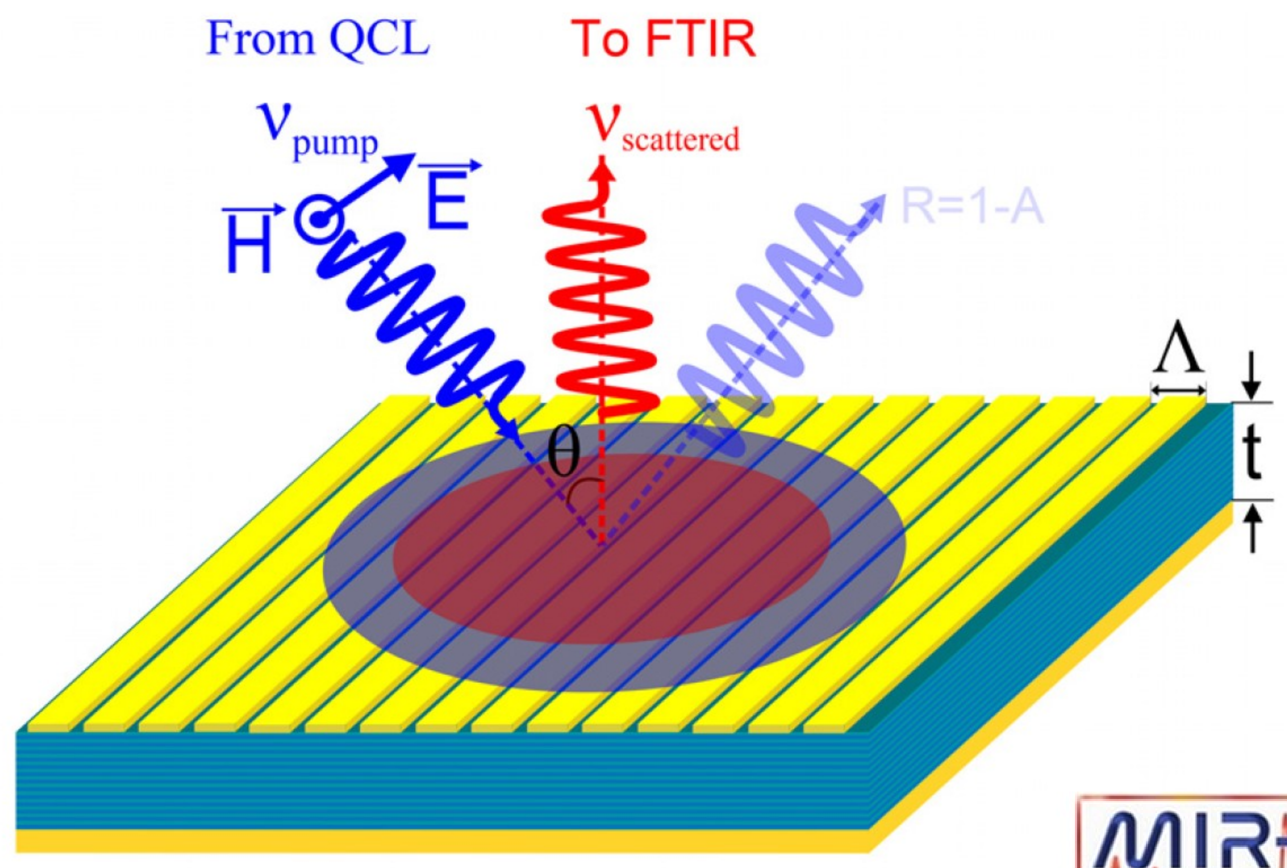


The strong coupling between the two resonances generates the intersubband Polariton

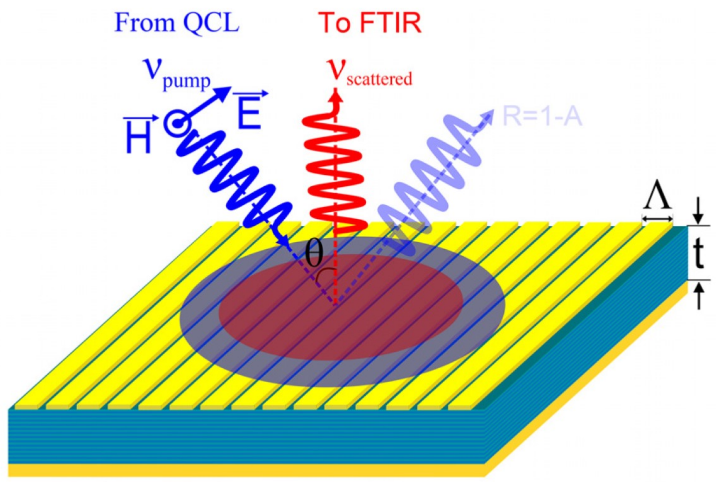




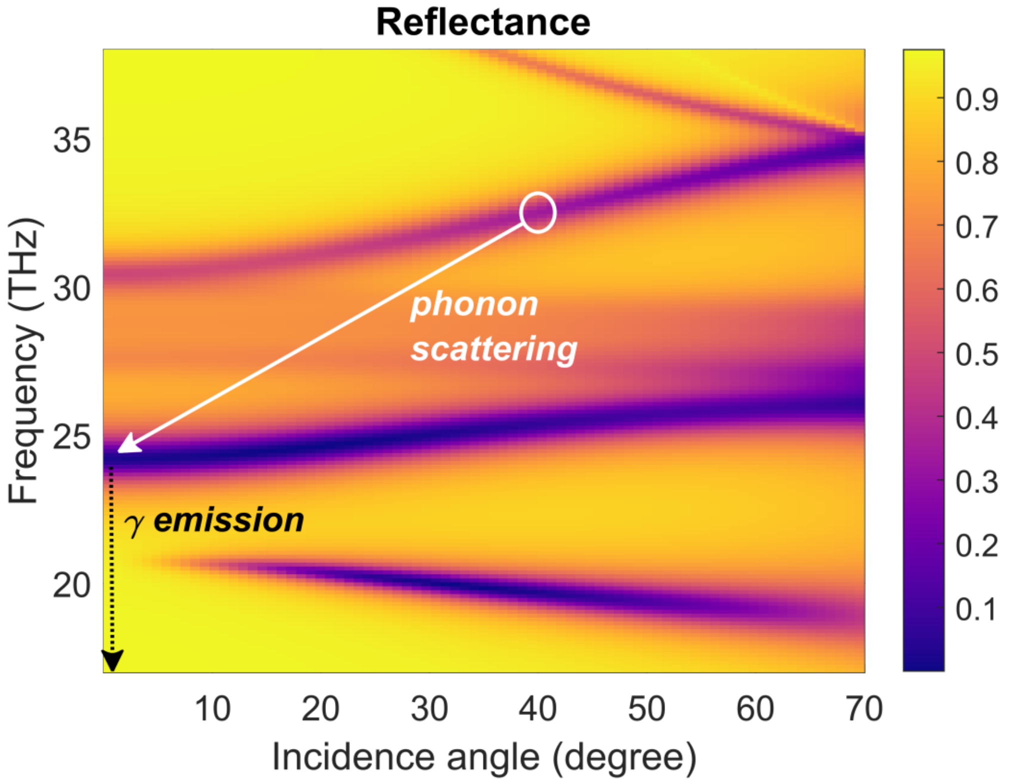
Polariton Emission



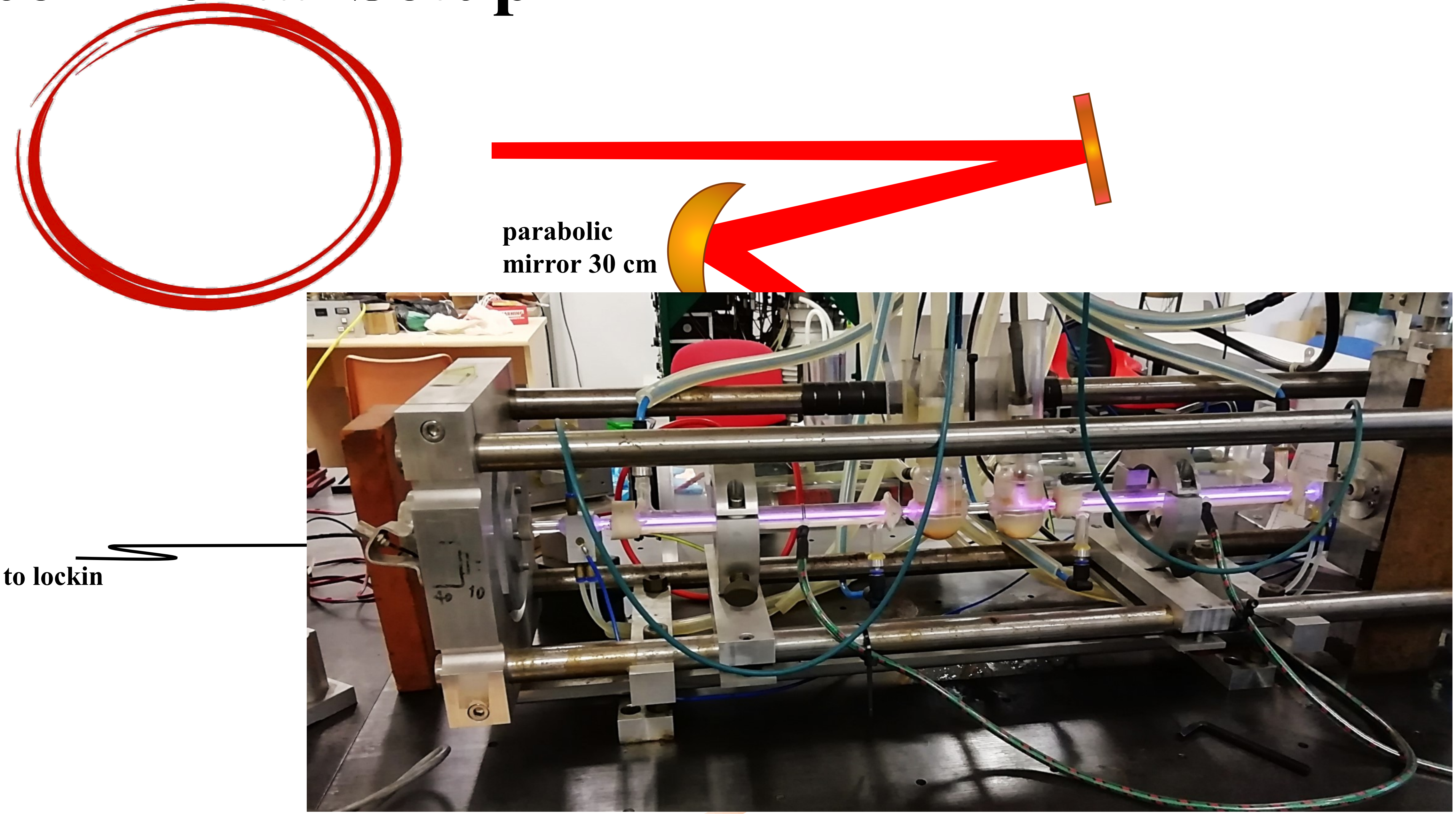
Polariton Emission



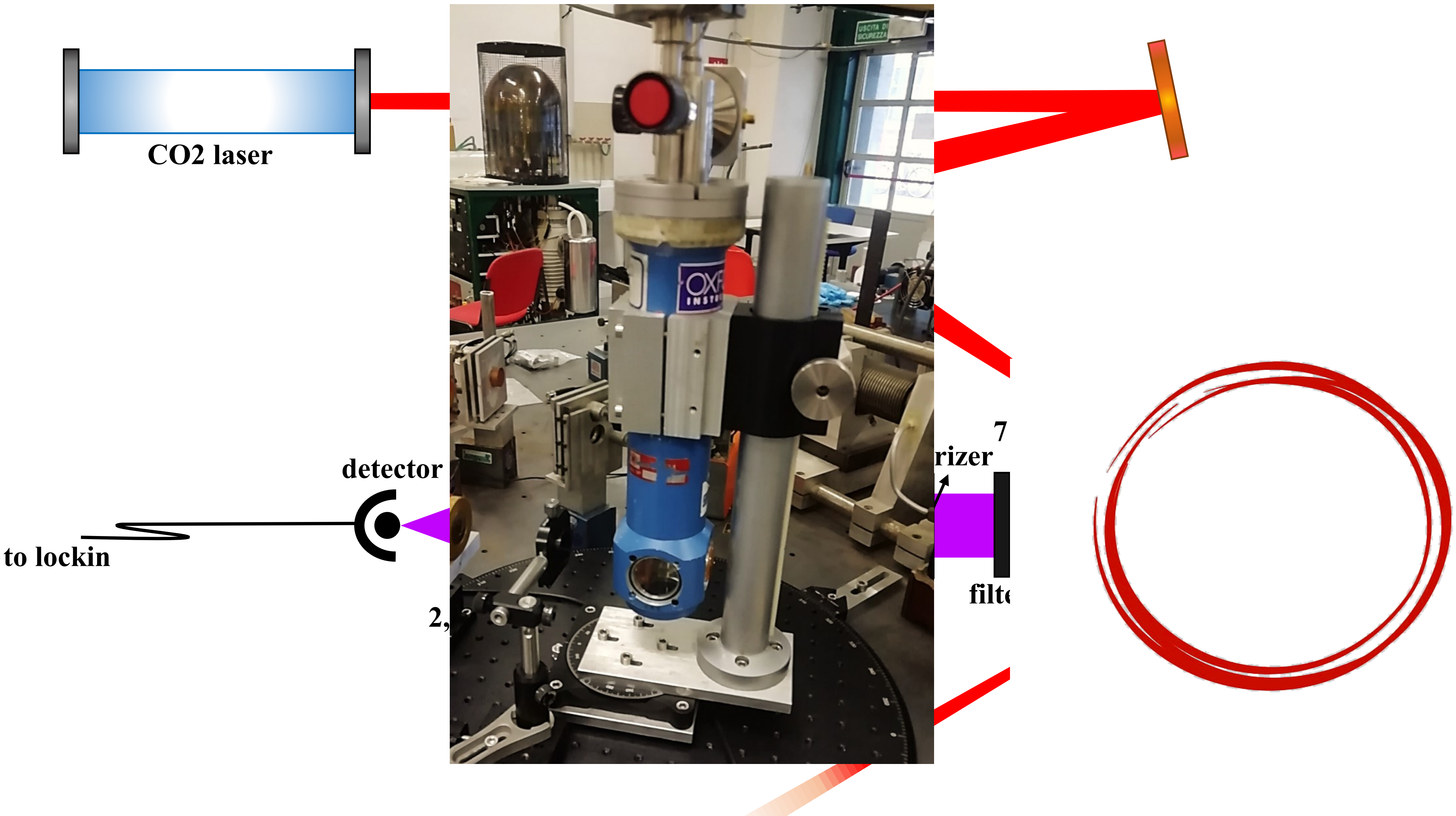
- Metallic back for better field distribution
- SP resonance tailored by the grating pitch
- 35 QWs with high doping
- LO-phonon energy 36.3 meV



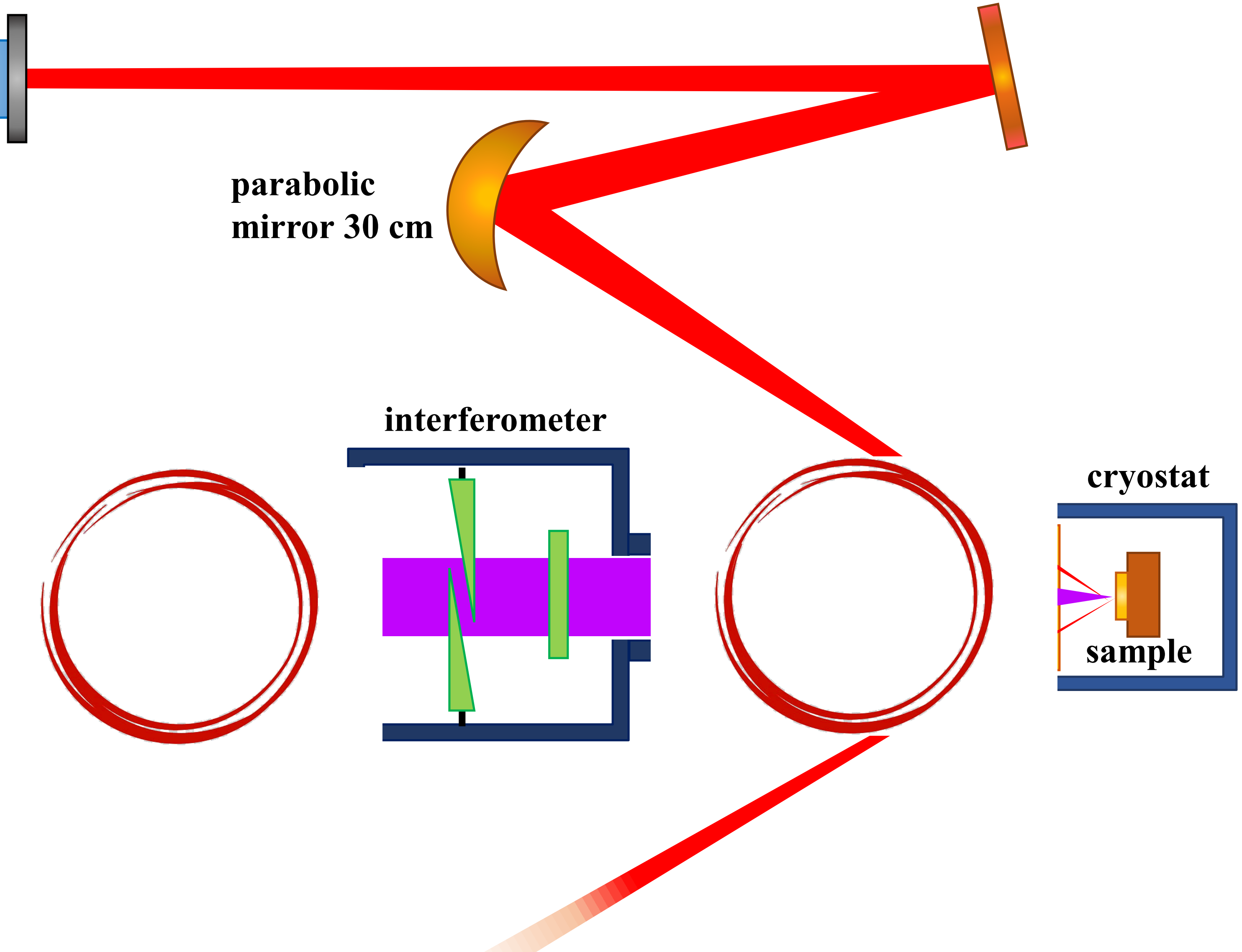
Experimental Setup



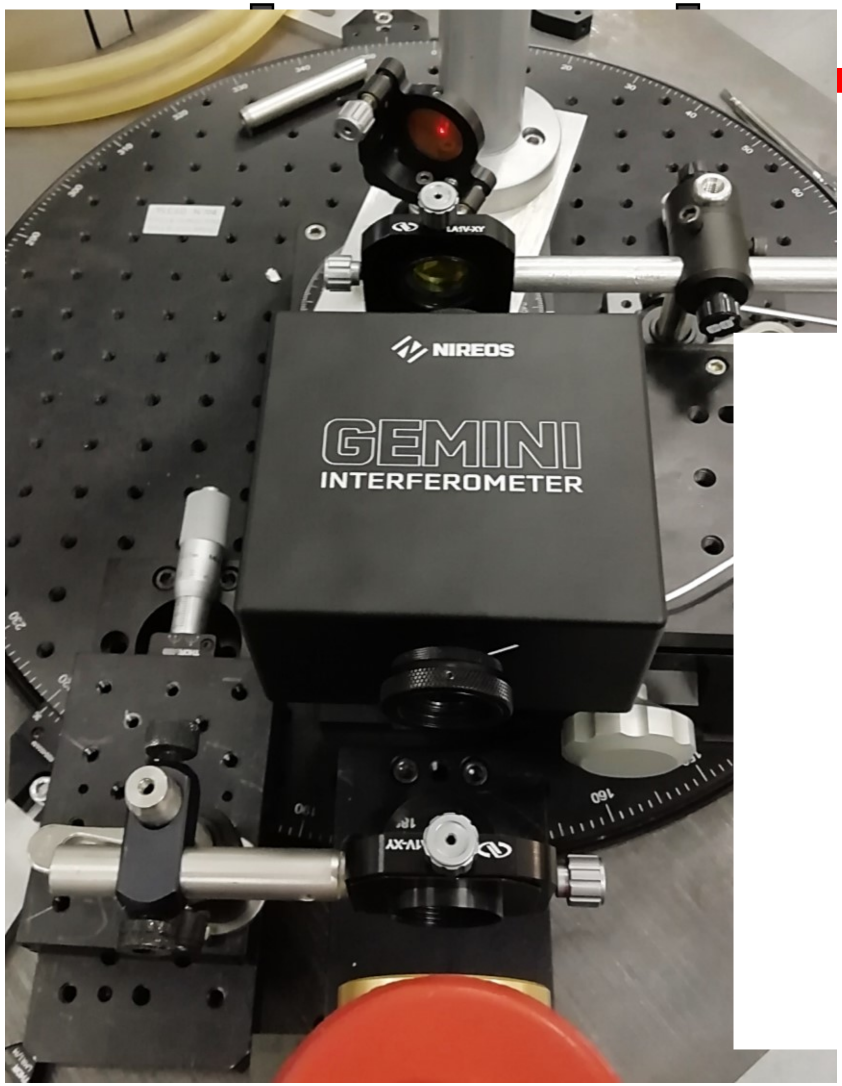
Experimental Setup

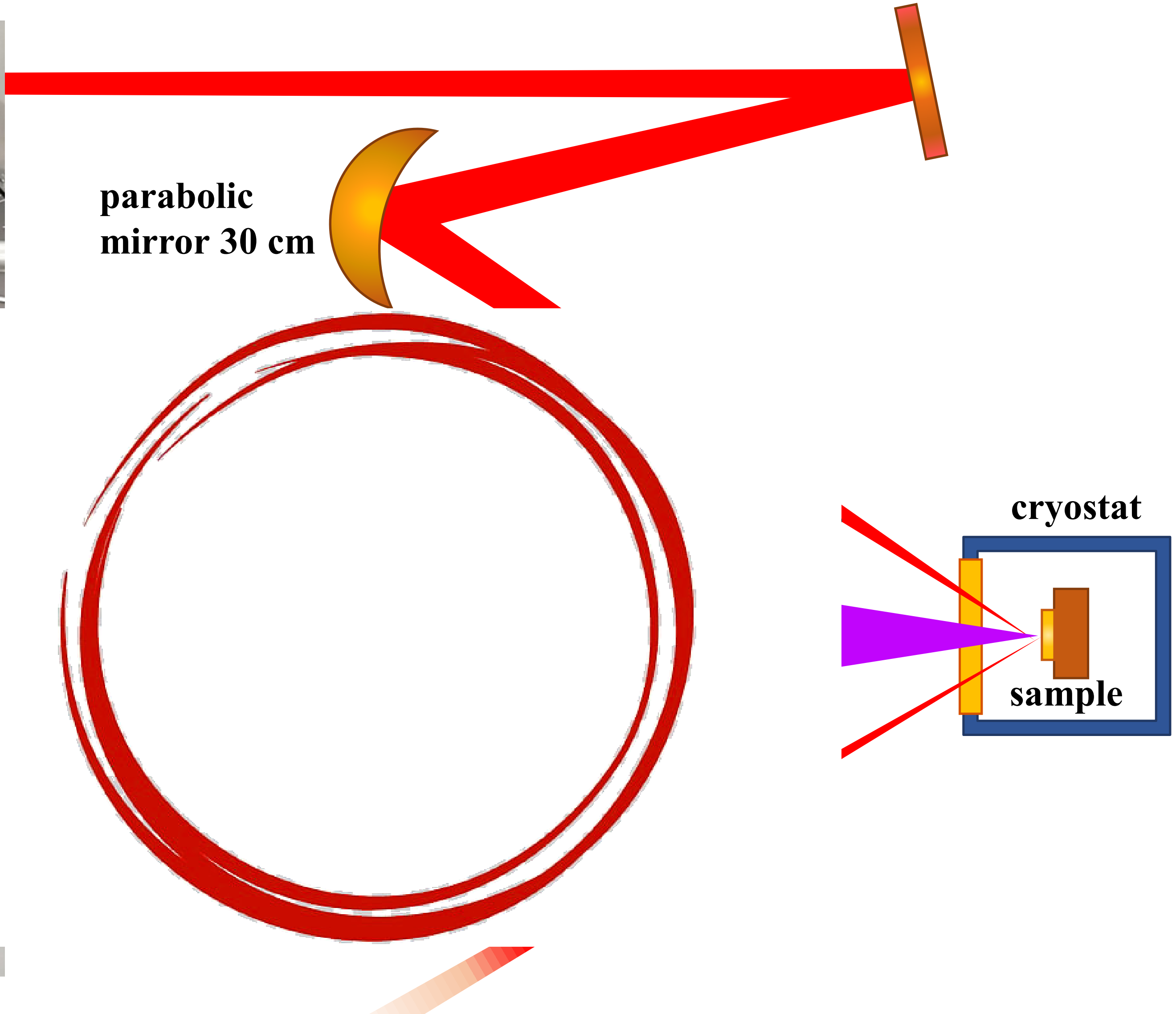


Experimental Setup

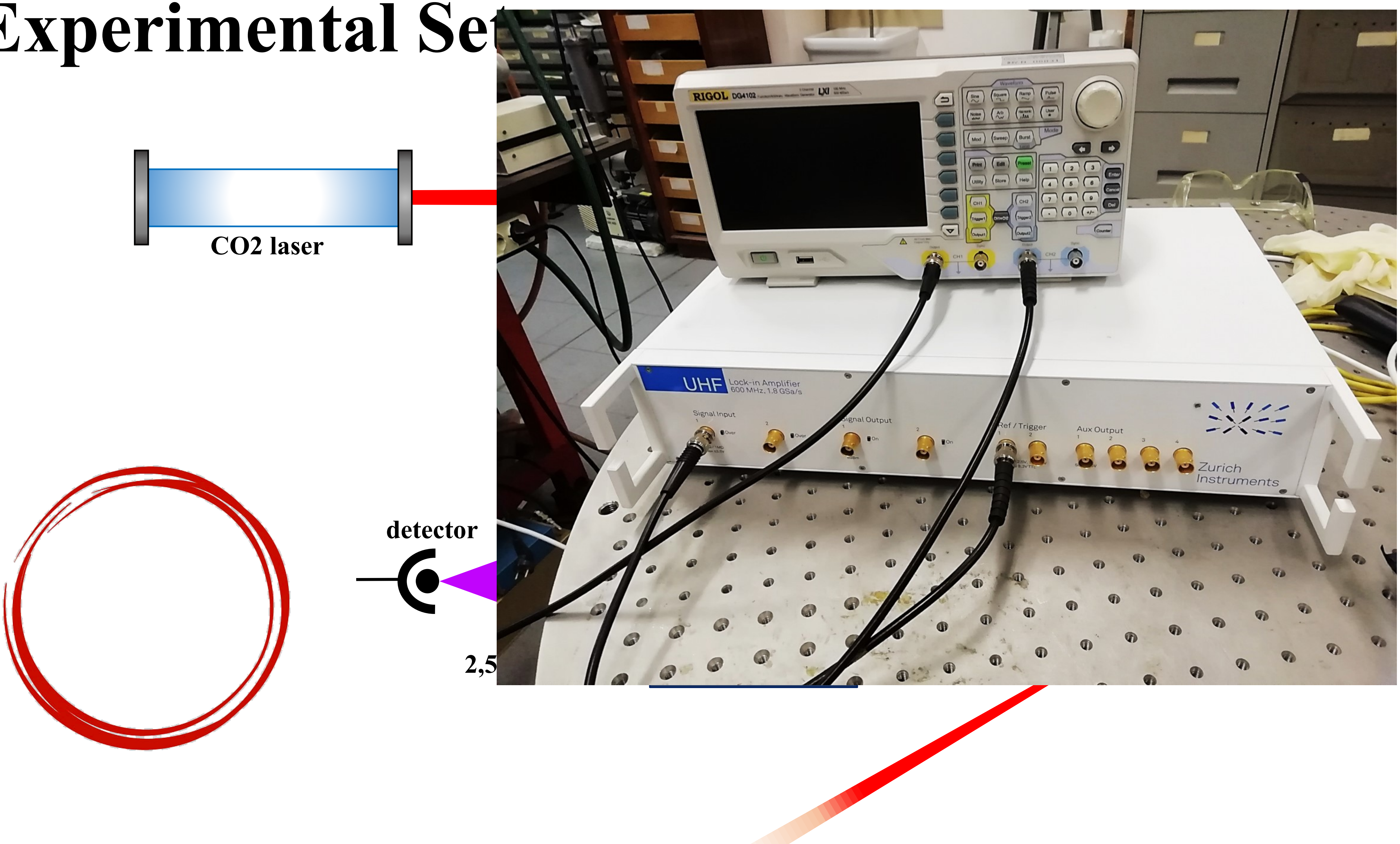


Experimental Setup

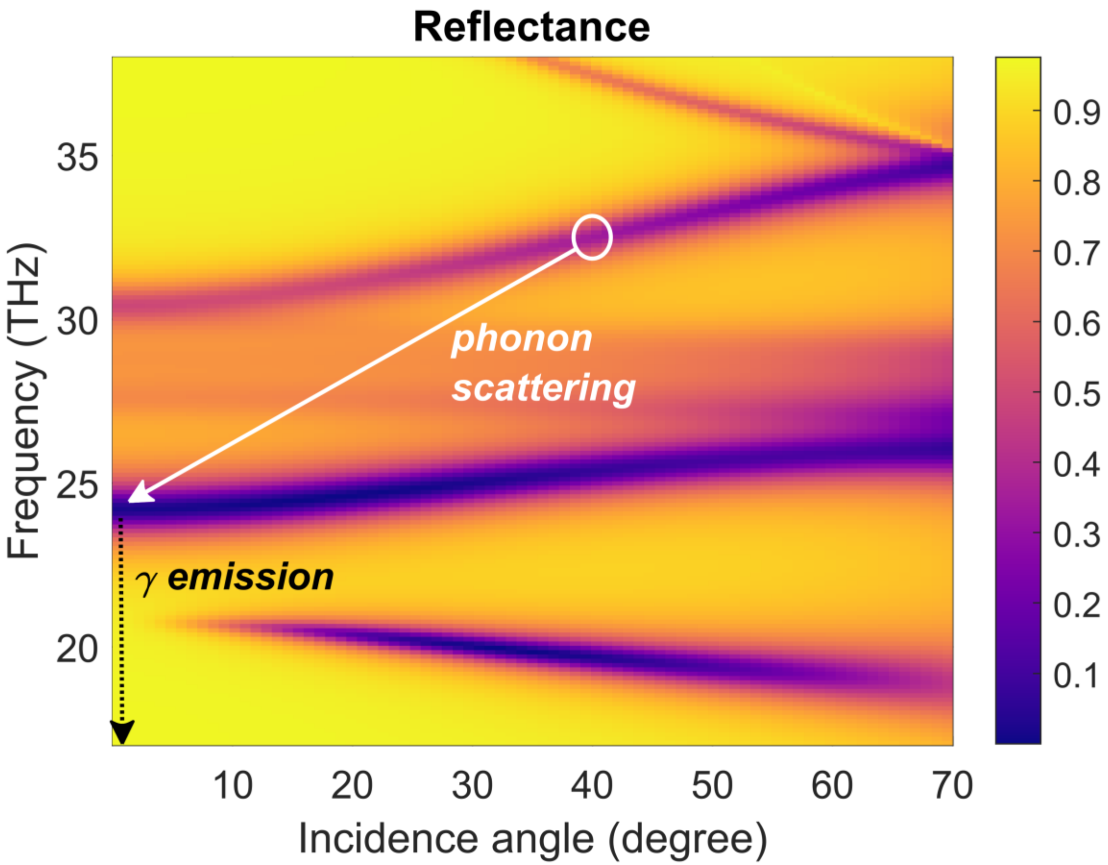


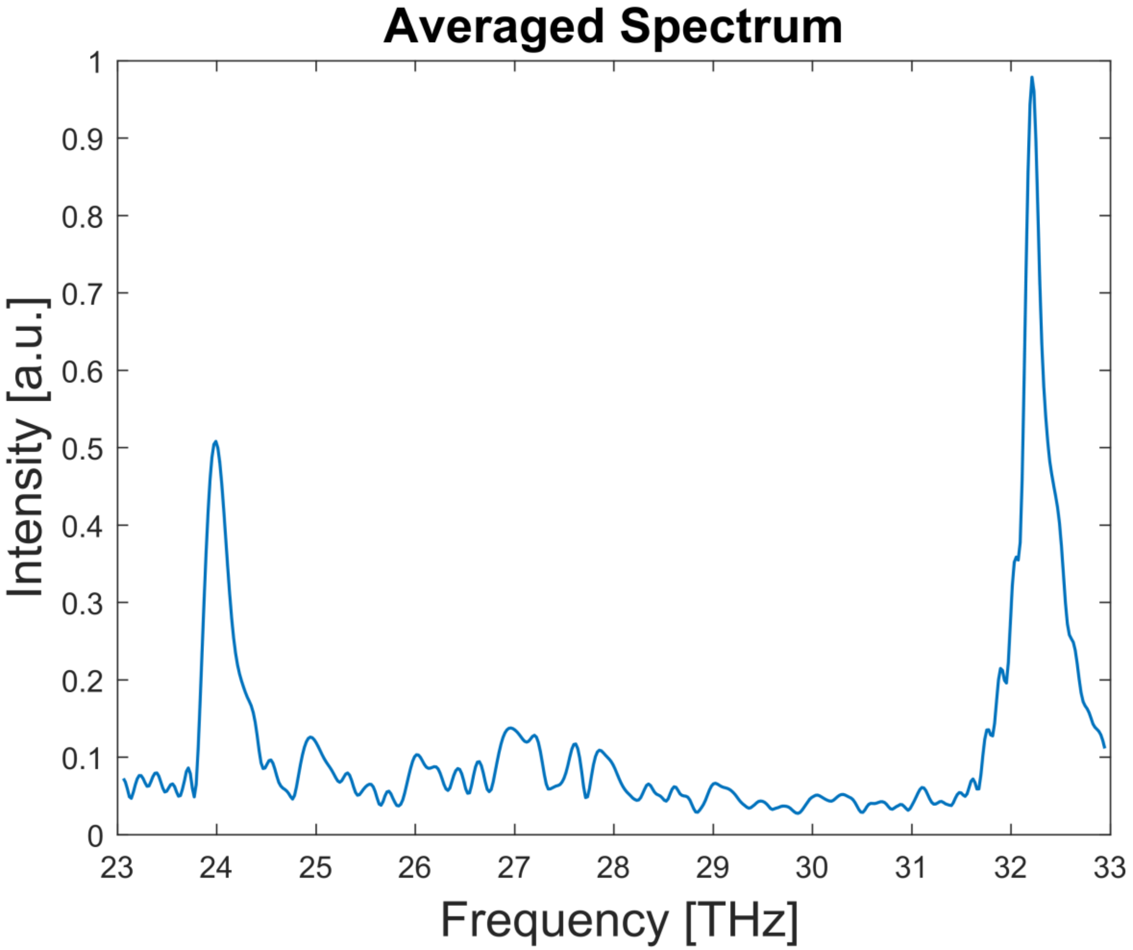


Experimental Set



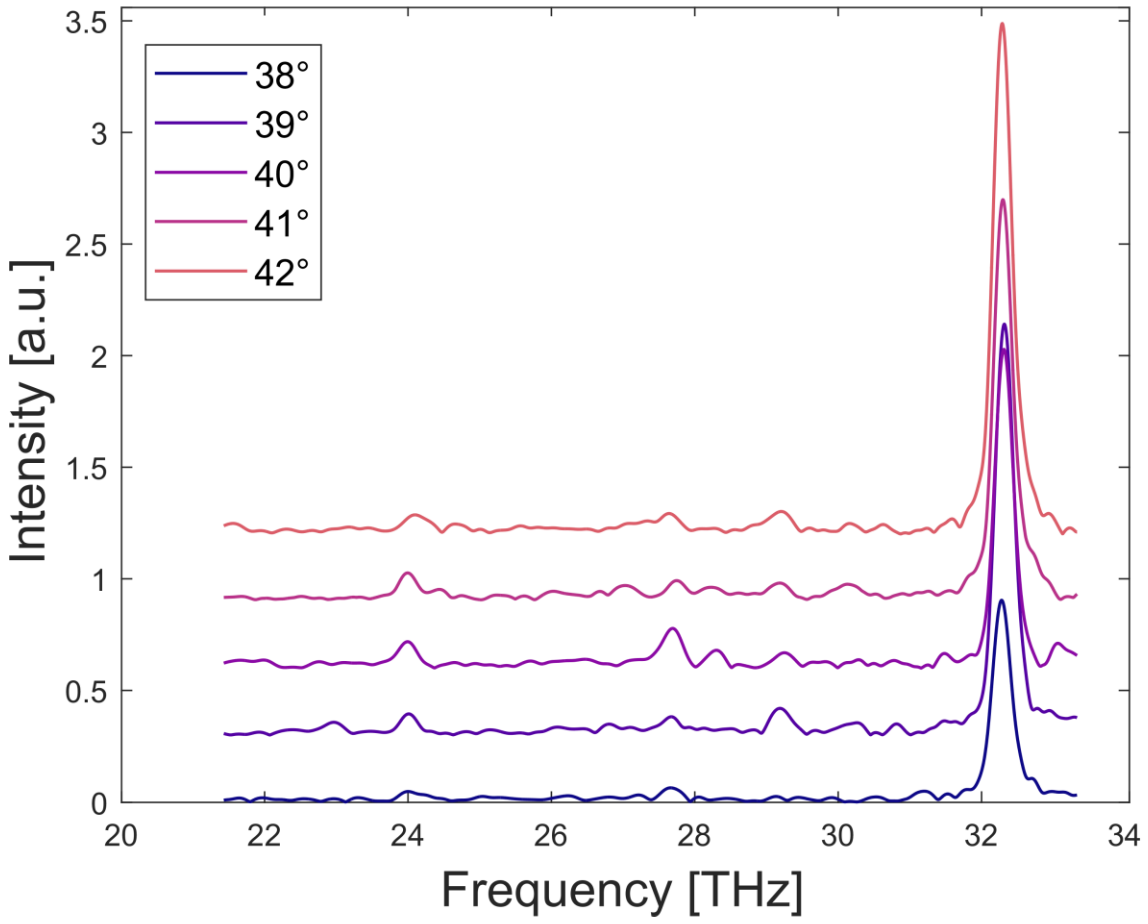
The polariton emission is revealed from the spectra

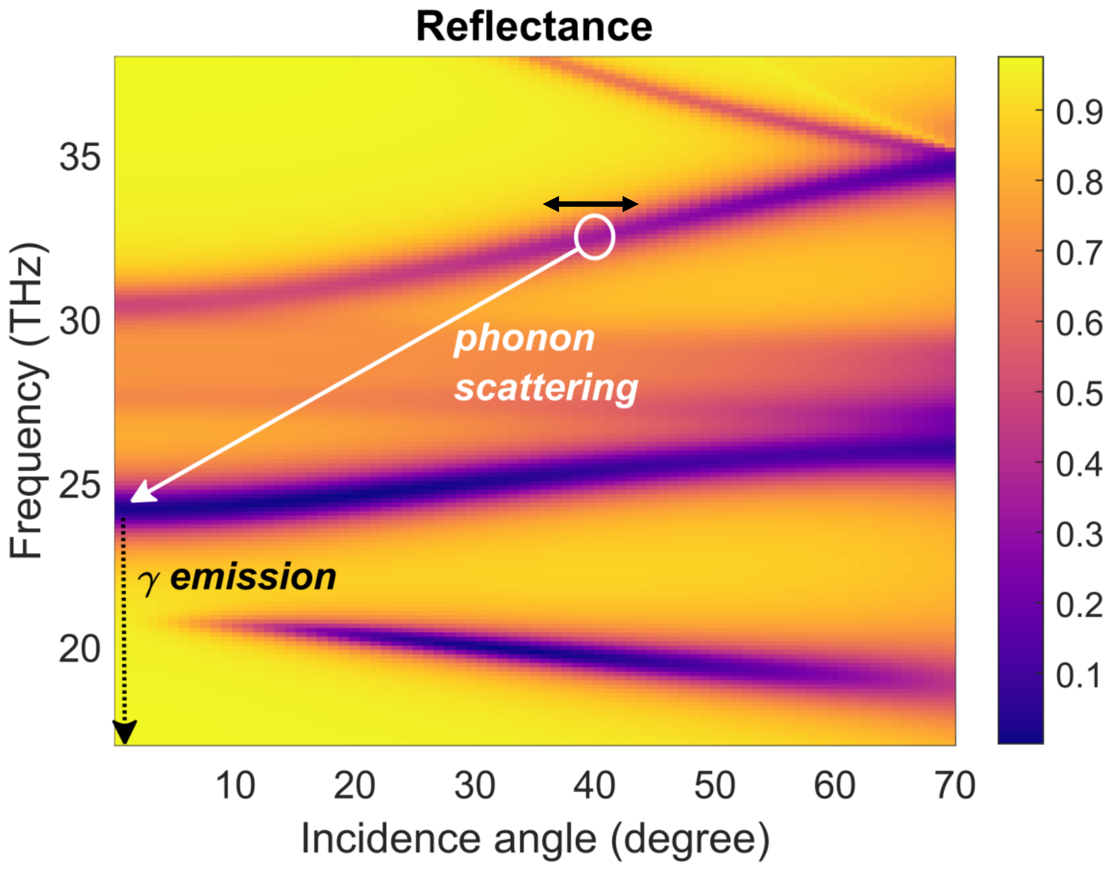




The polariton emission is revealed from the spectra

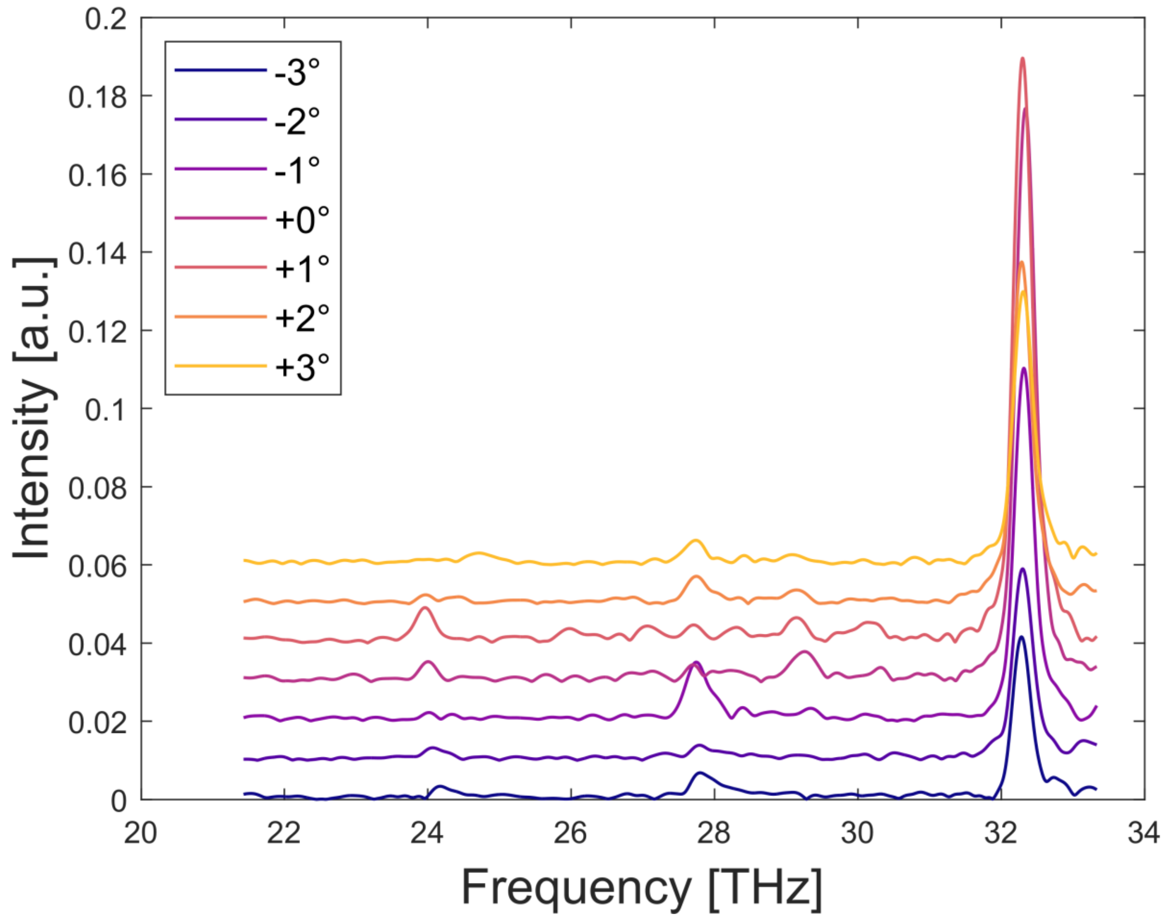
Pumping angle dependence

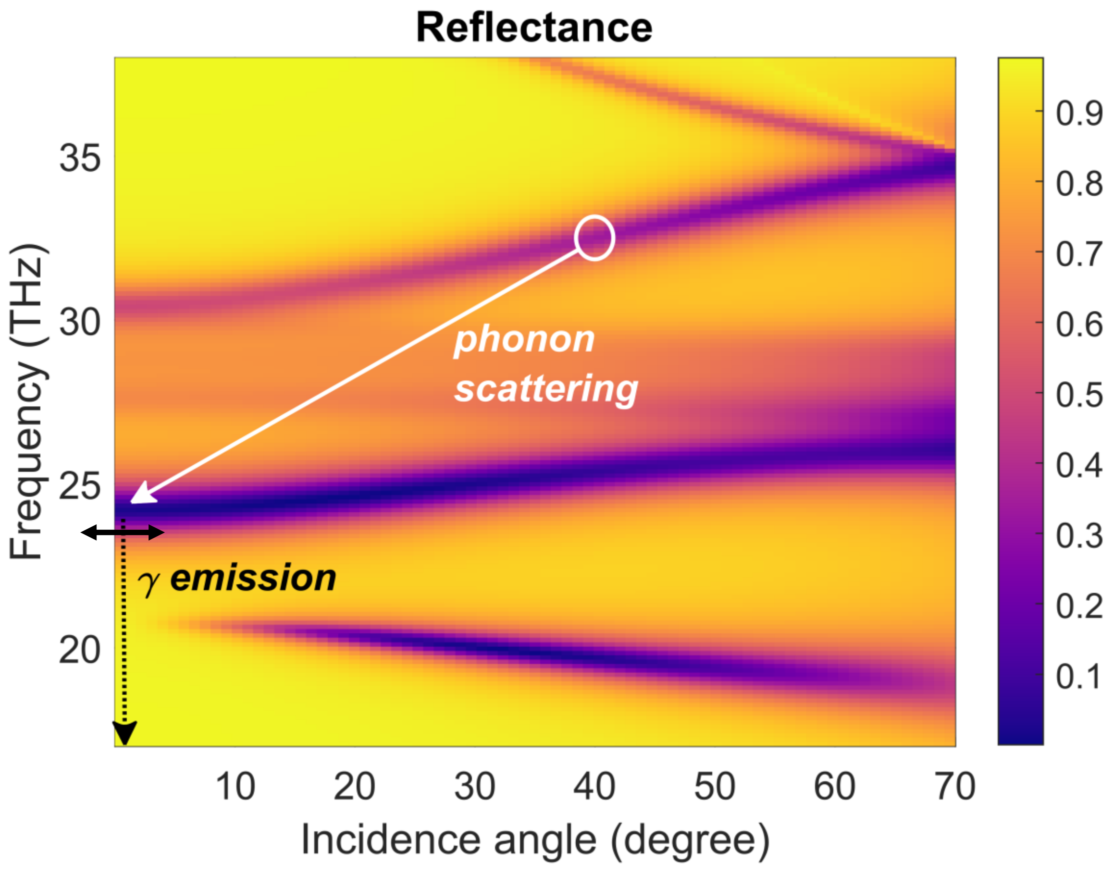




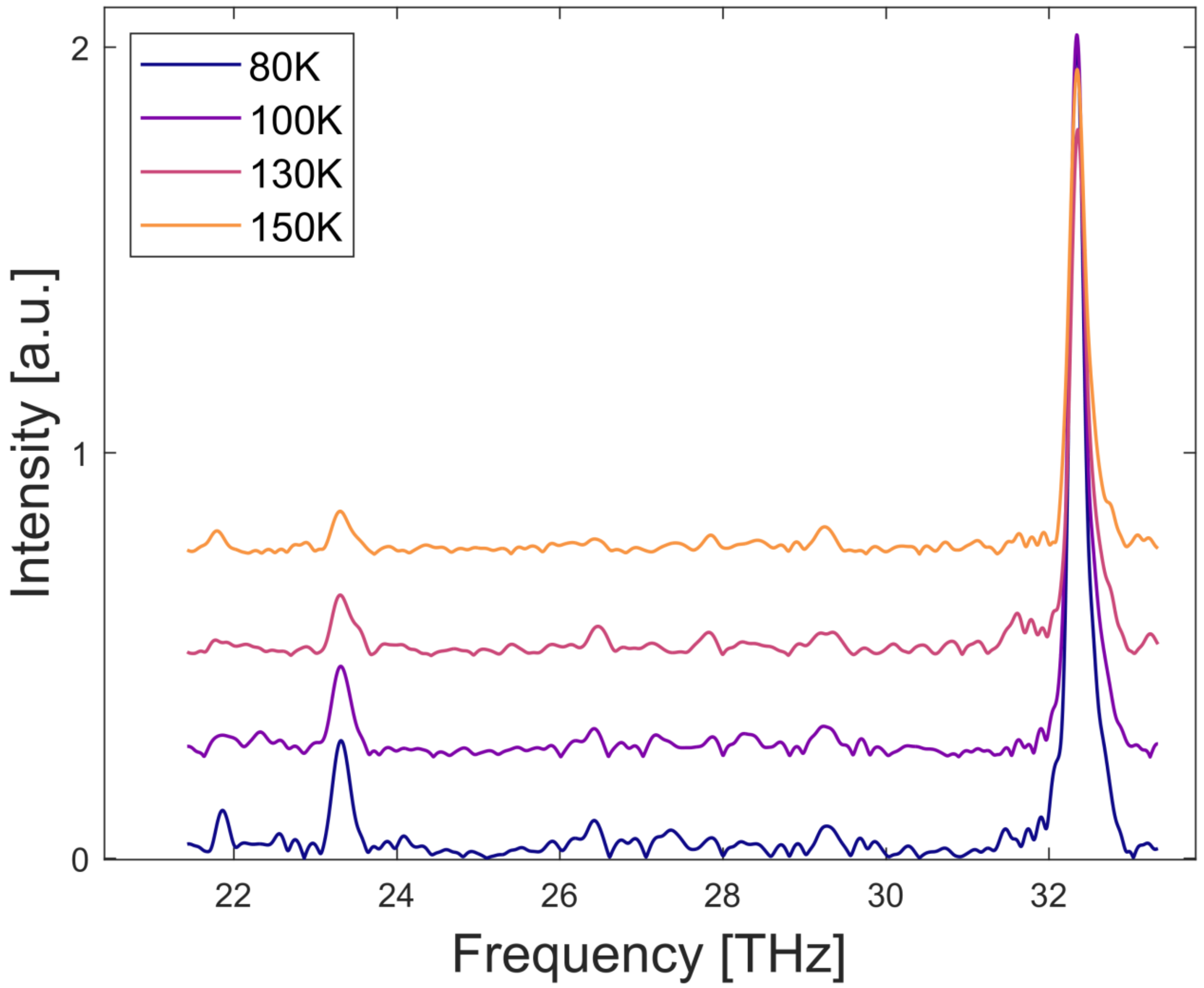
The polariton emission is revealed from the spectra

Detection angle dependence





The polariton emission is revealed from the spectra

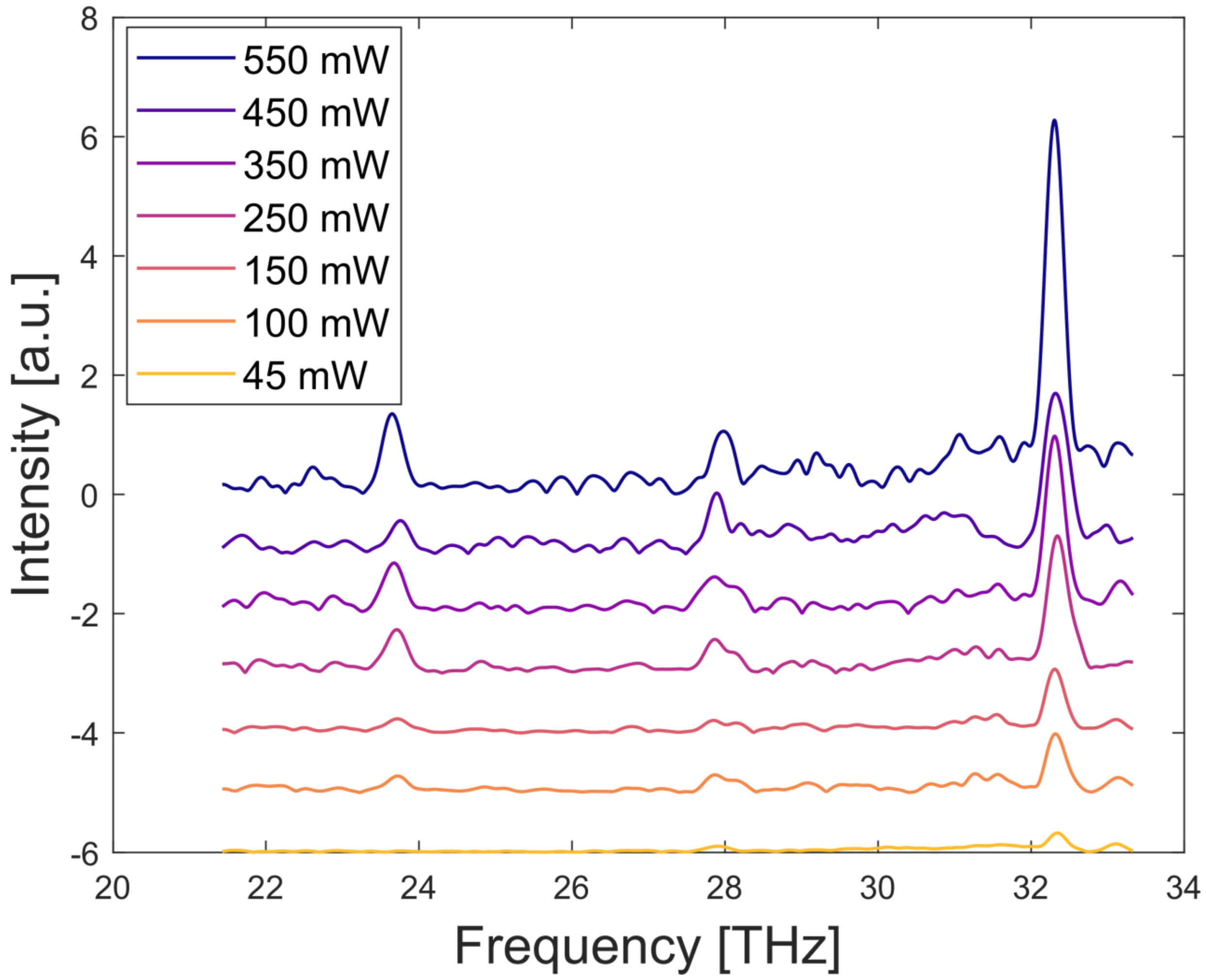


Temperature dependence

- Maximum at the lowest temperature
- Nitrogen cooled

- **Helium?**

The polariton emission is revealed from the spectra



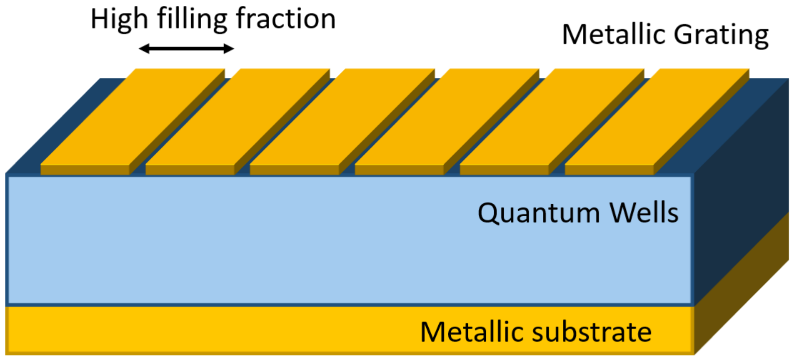
Pumping power dependence

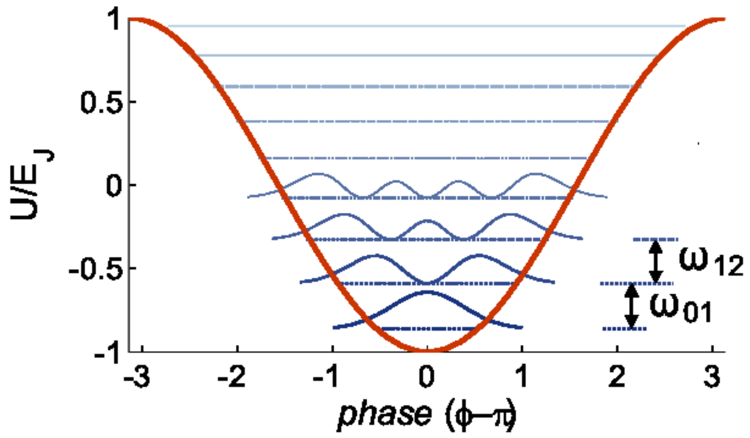
- Maximum at the highest power
- Emission "linear" with power

- **No lasing yet!**

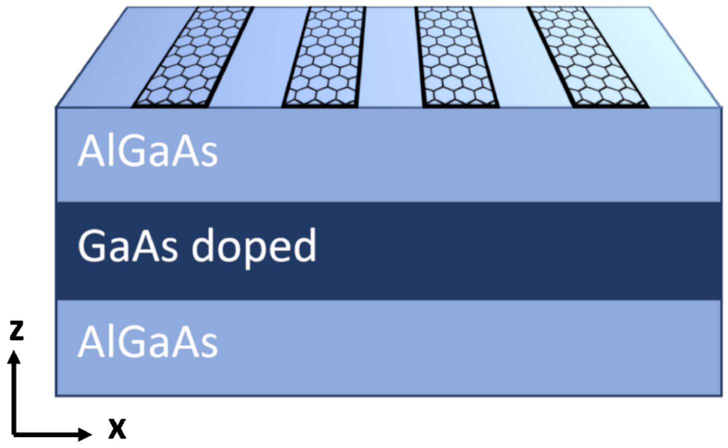
Improving the polariton generation

High Q-factor cavities



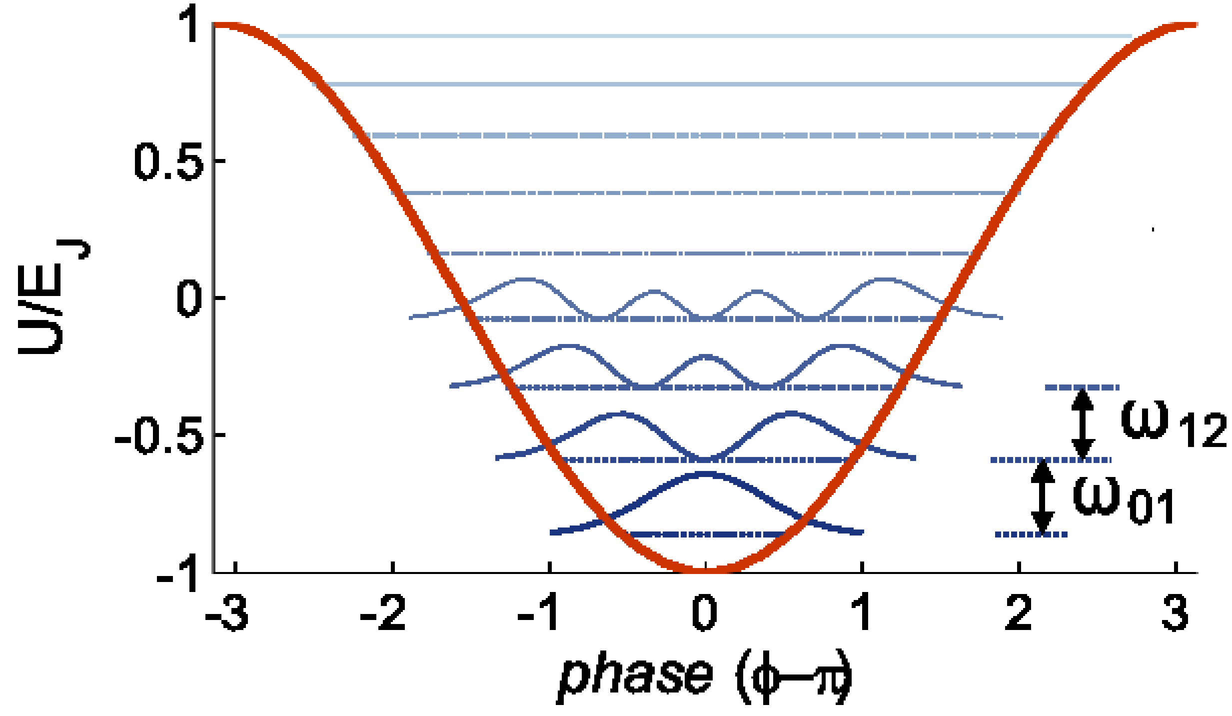


Parabolic QWs



Graphene grating

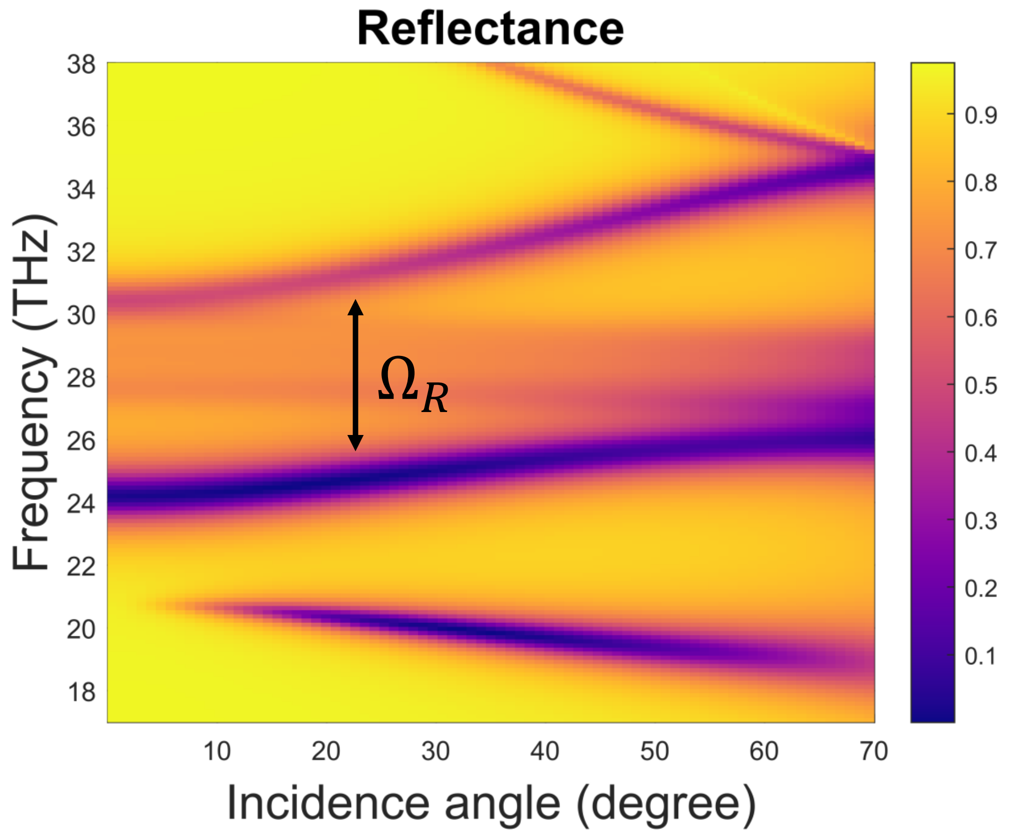
The levels in a PQW are equally spaced in energy

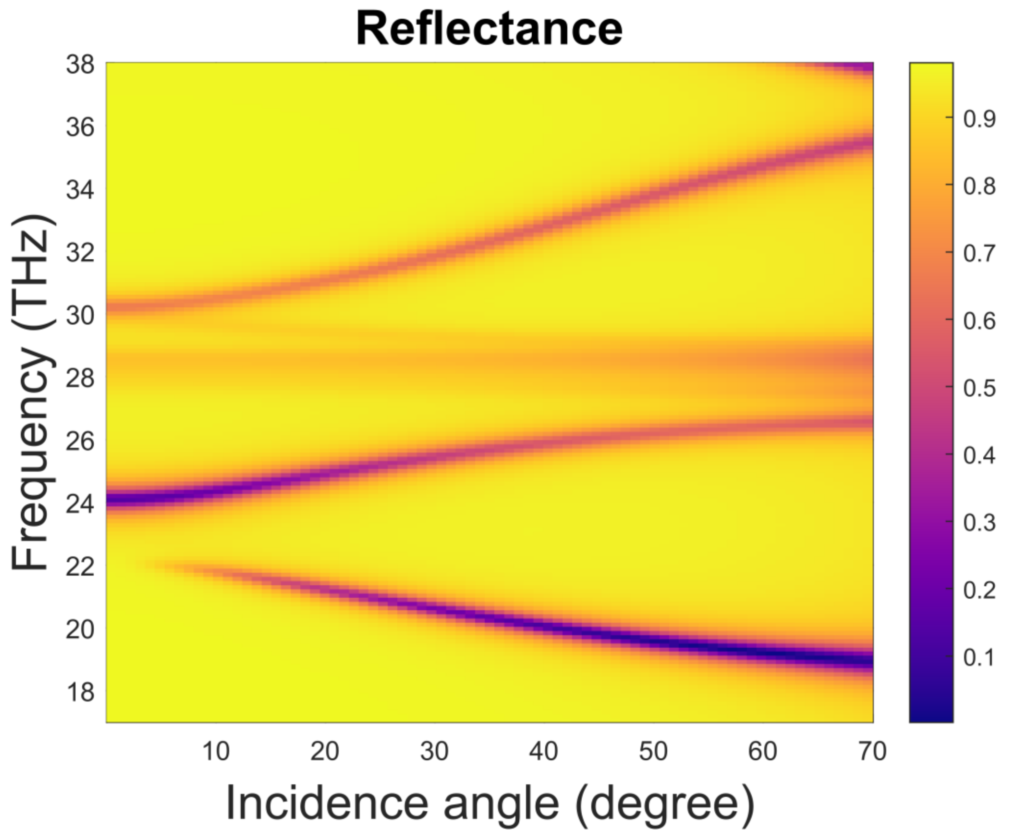


- Higher doping
- Working at room temperature
- Lower frequencies

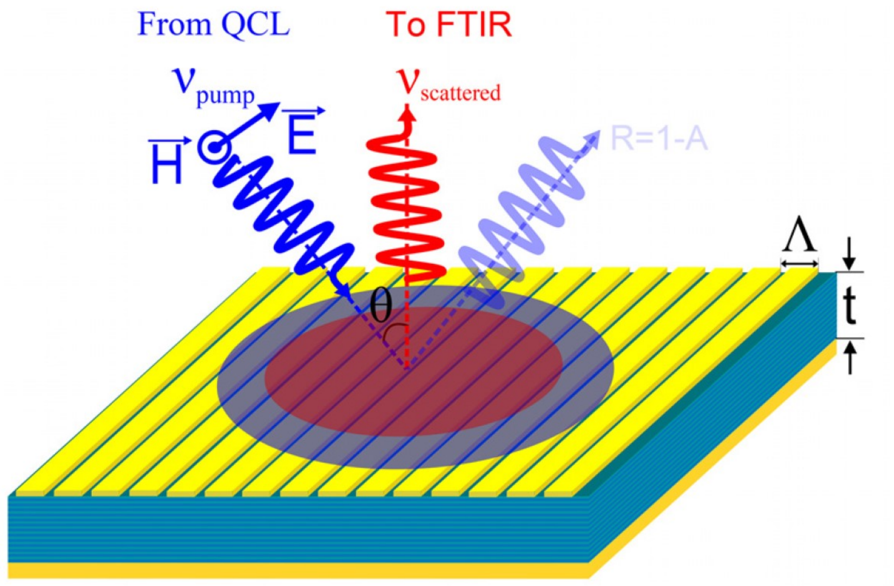
Objective: increase the coupling strength and Q-factor

$$g = \frac{\Omega_R}{\omega_c} \qquad g \propto \sqrt{\frac{n_{QW}}{\omega_c V}} \qquad Q = \Omega_R/\bar{\gamma}$$

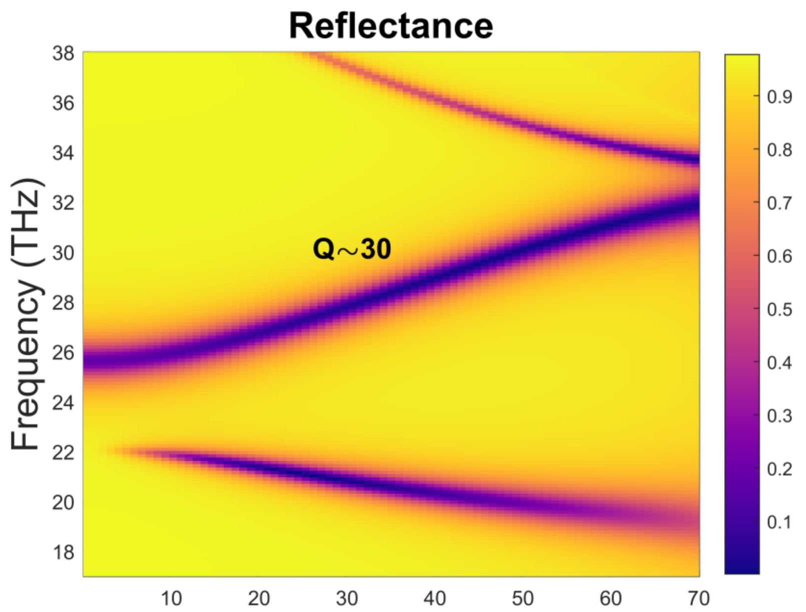


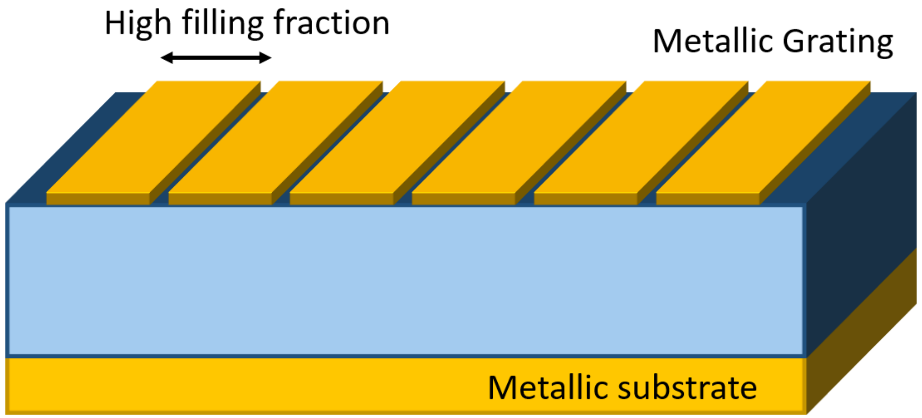


Decreasing the losses to increase the Q-factor

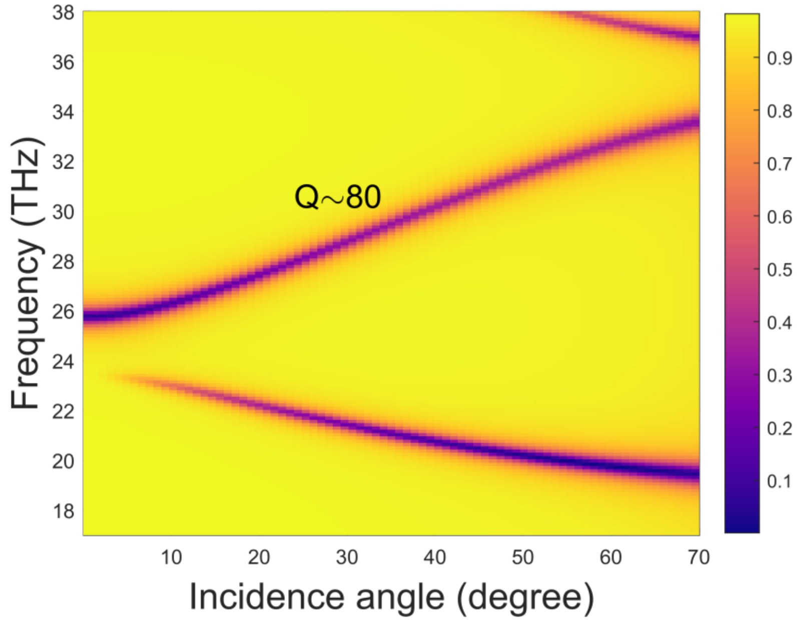


$ff = 78\%$





$ff = 95\%$



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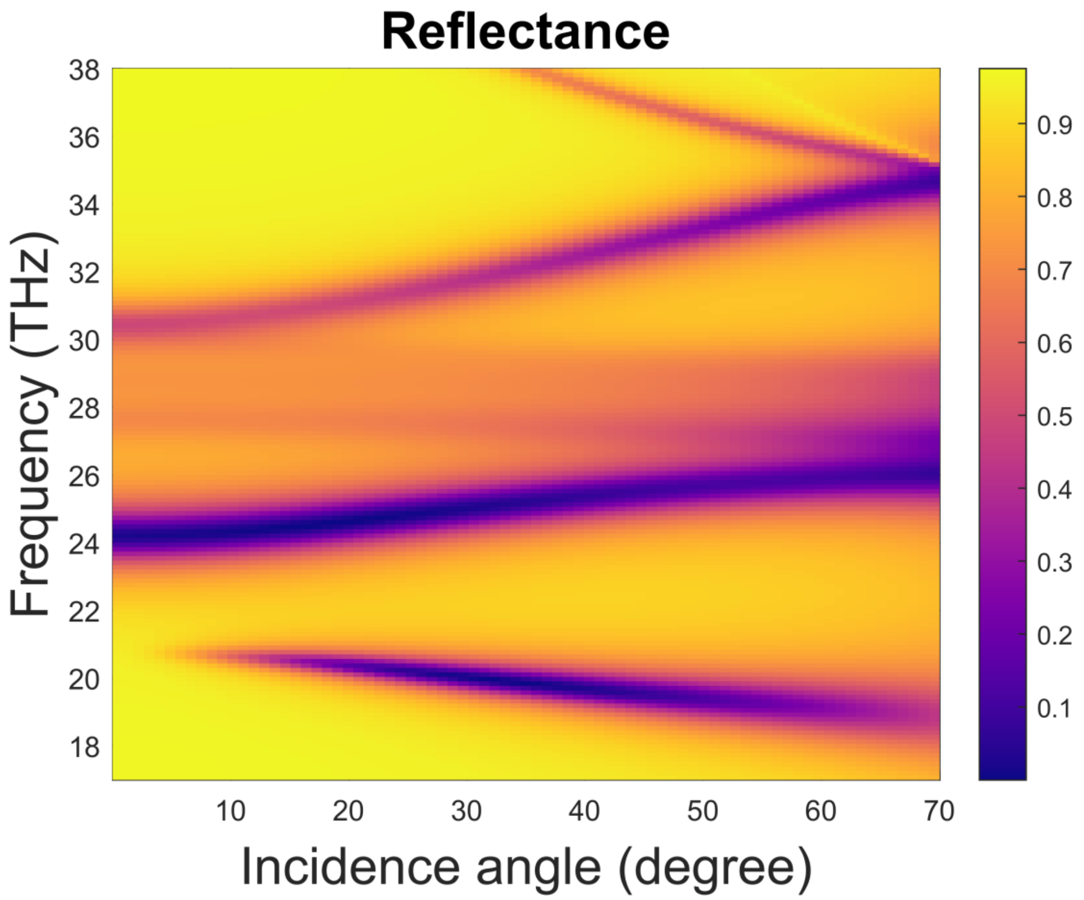
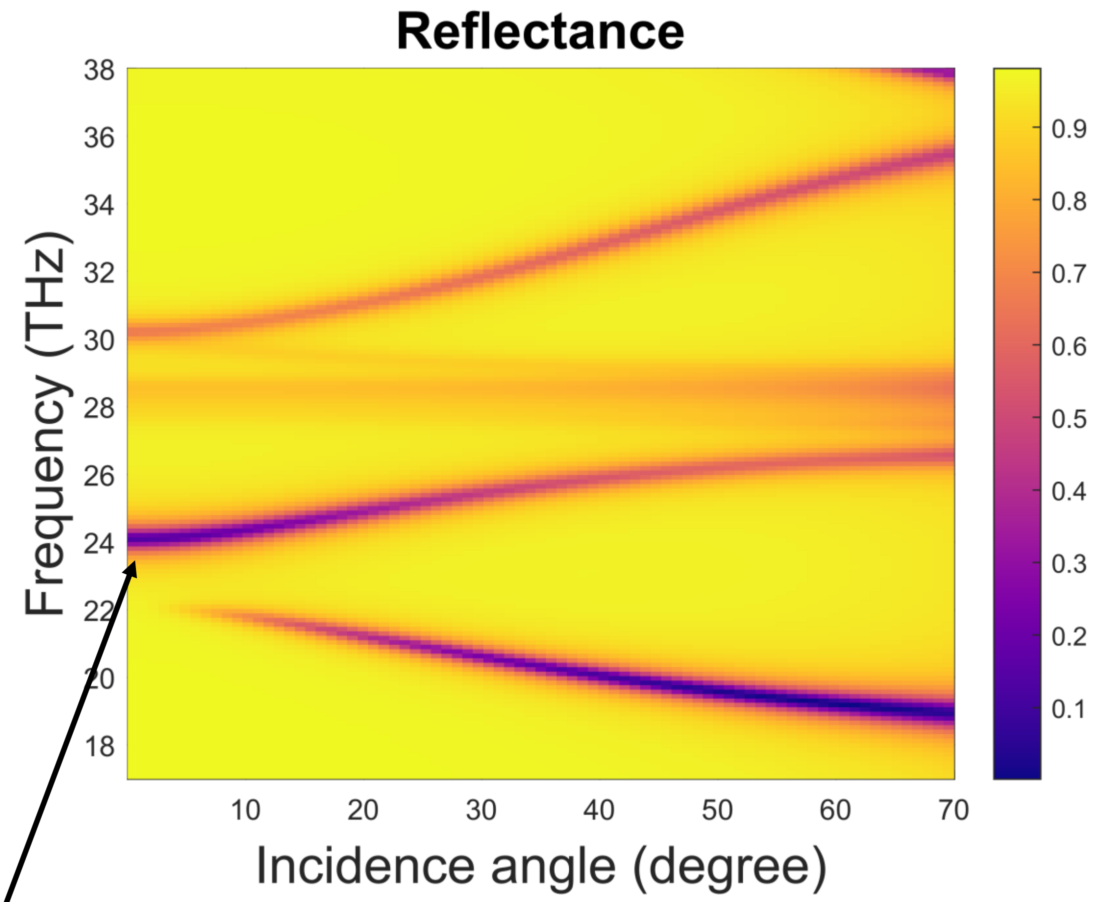
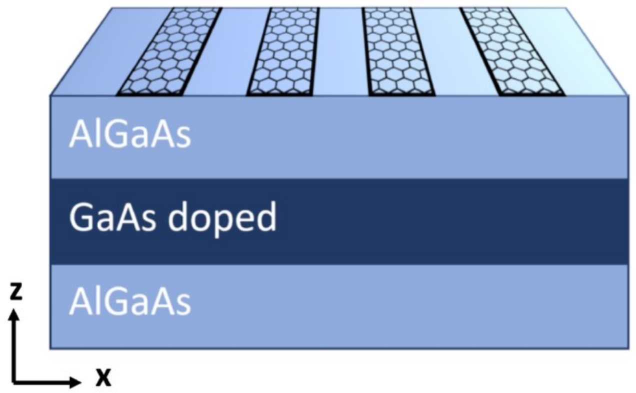


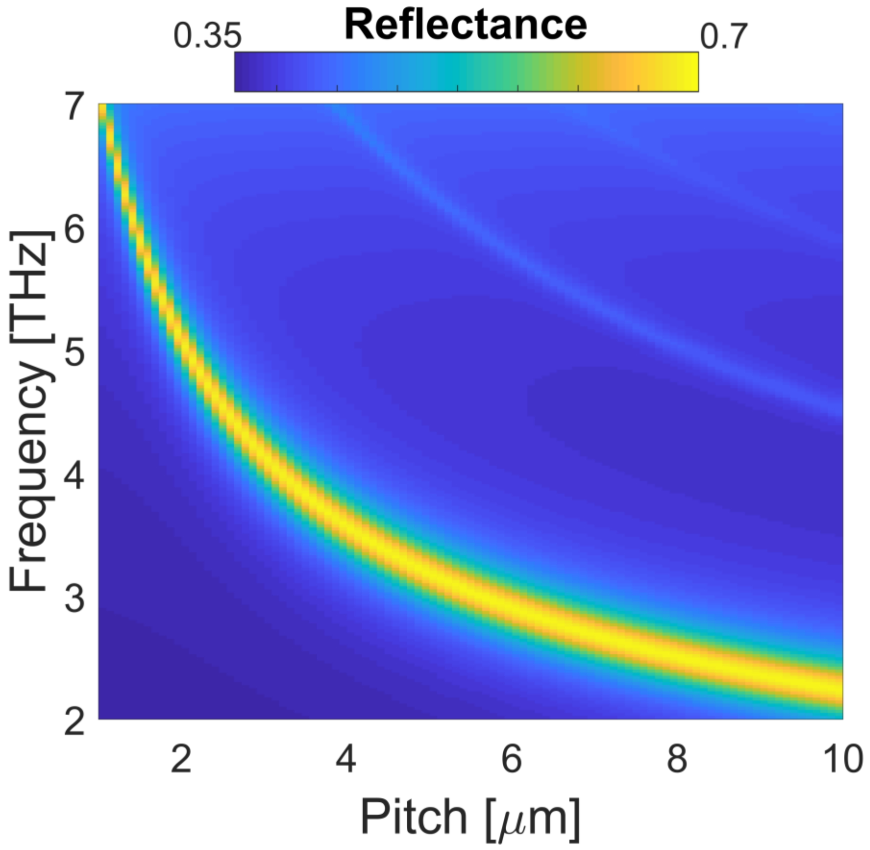


Higher polariton **lifetime**

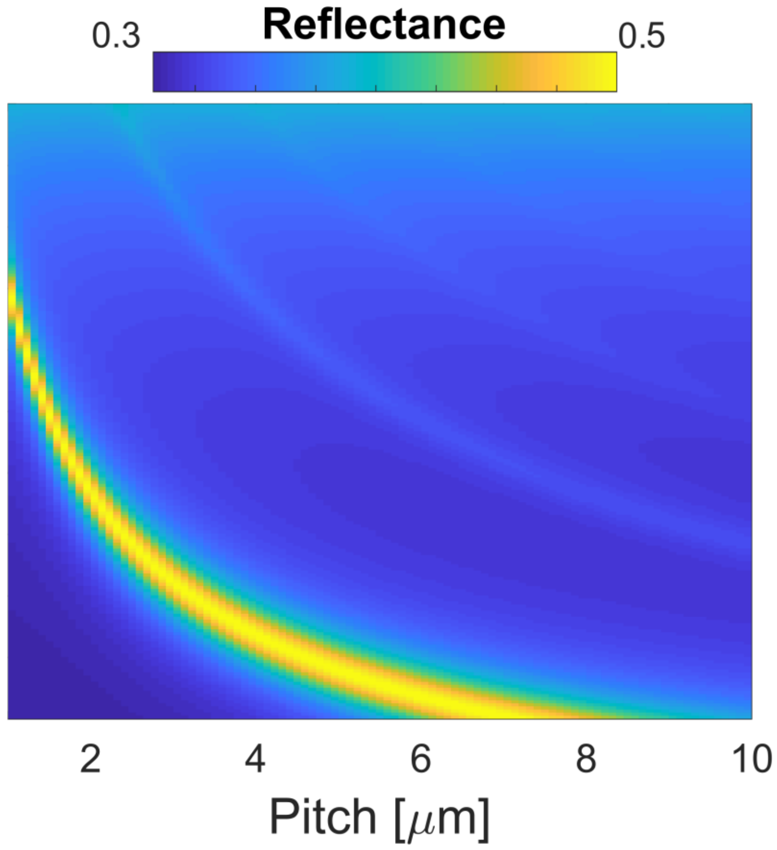
Graphene for high confinement & tunable resonance



$$\frac{\lambda_{SP}}{\lambda_0} \propto \frac{1}{\varepsilon+1}\frac{E_F}{\hbar\omega_0} \sim \frac{1}{100}$$

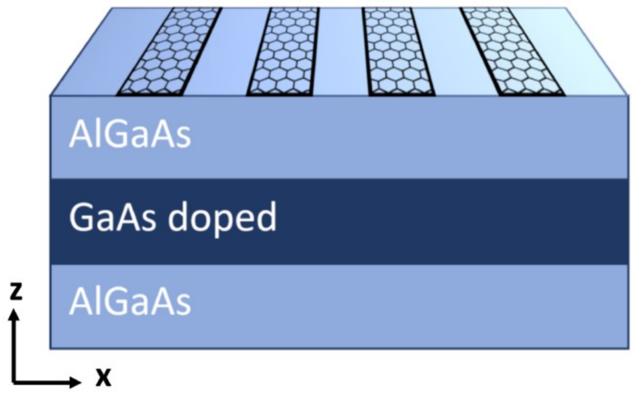


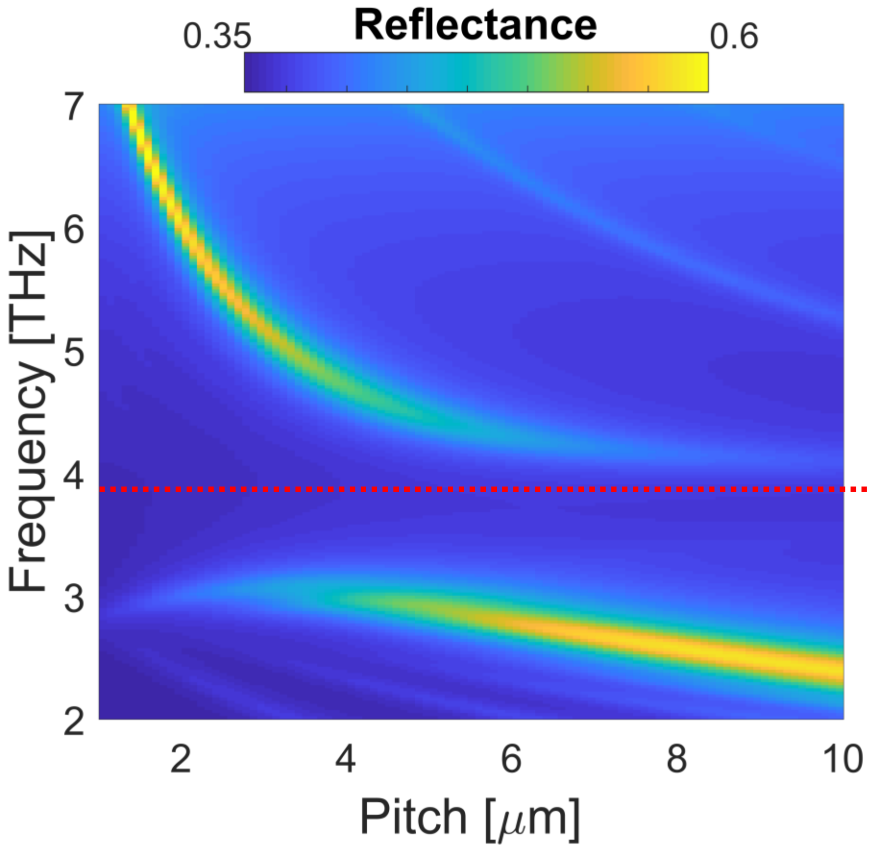
$E_F = 0.35\ meV$



$E_F = 0.25\ meV$

Graphene for high confinement & tunable resonance





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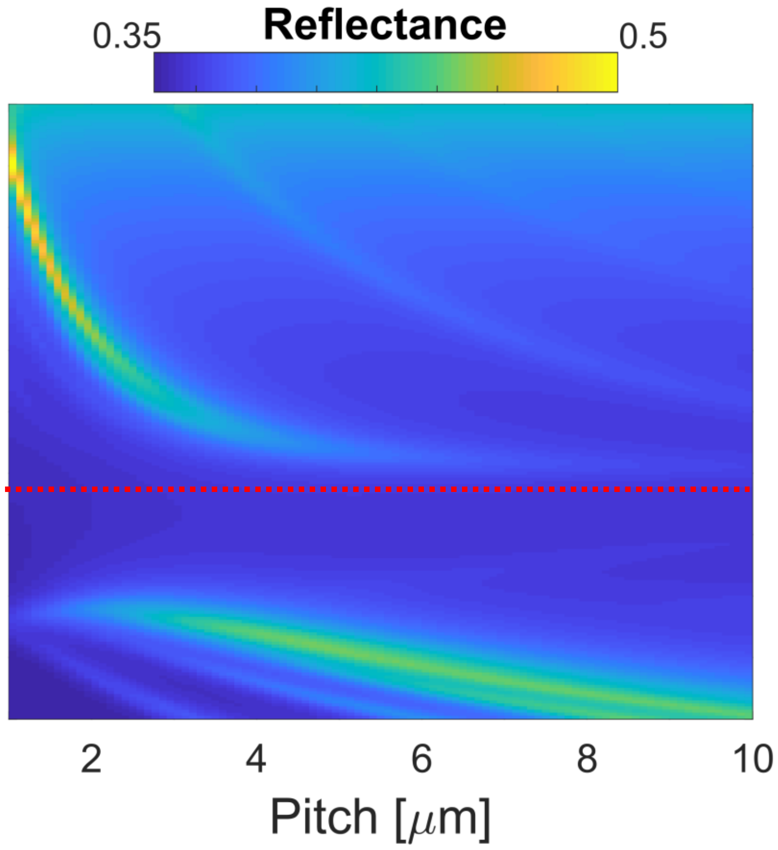

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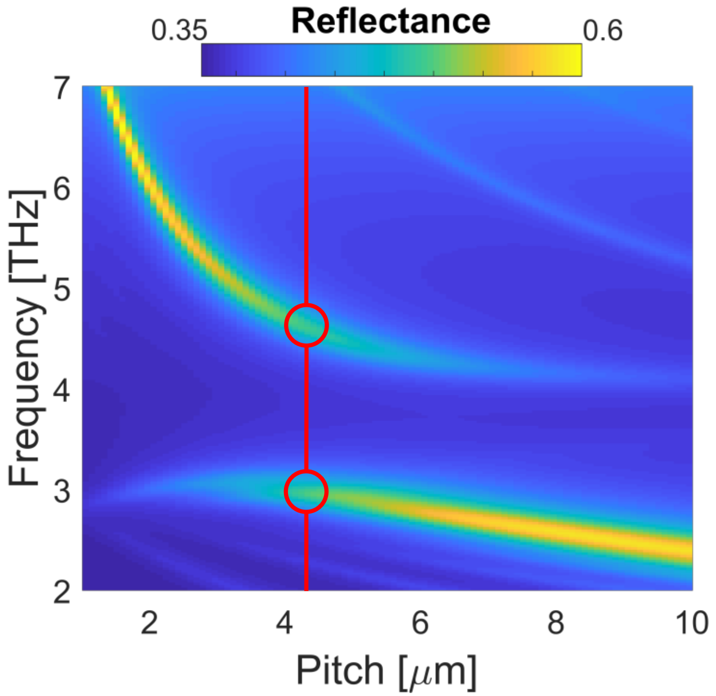
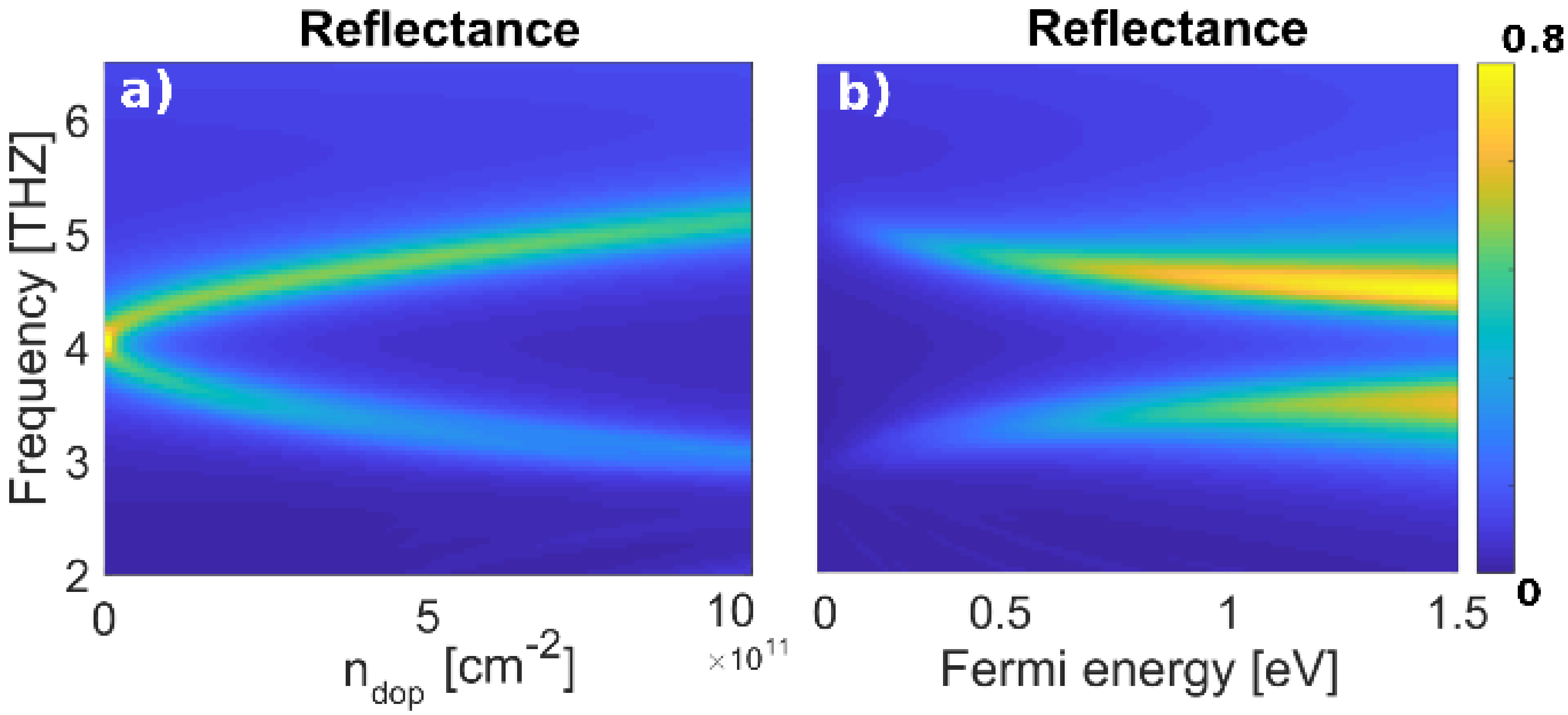
$$\frac{\lambda_{SP}}{\lambda_0} \propto \frac{1}{\varepsilon + 1} \frac{E_F}{\hbar\omega_0} \sim \frac{1}{100}$$

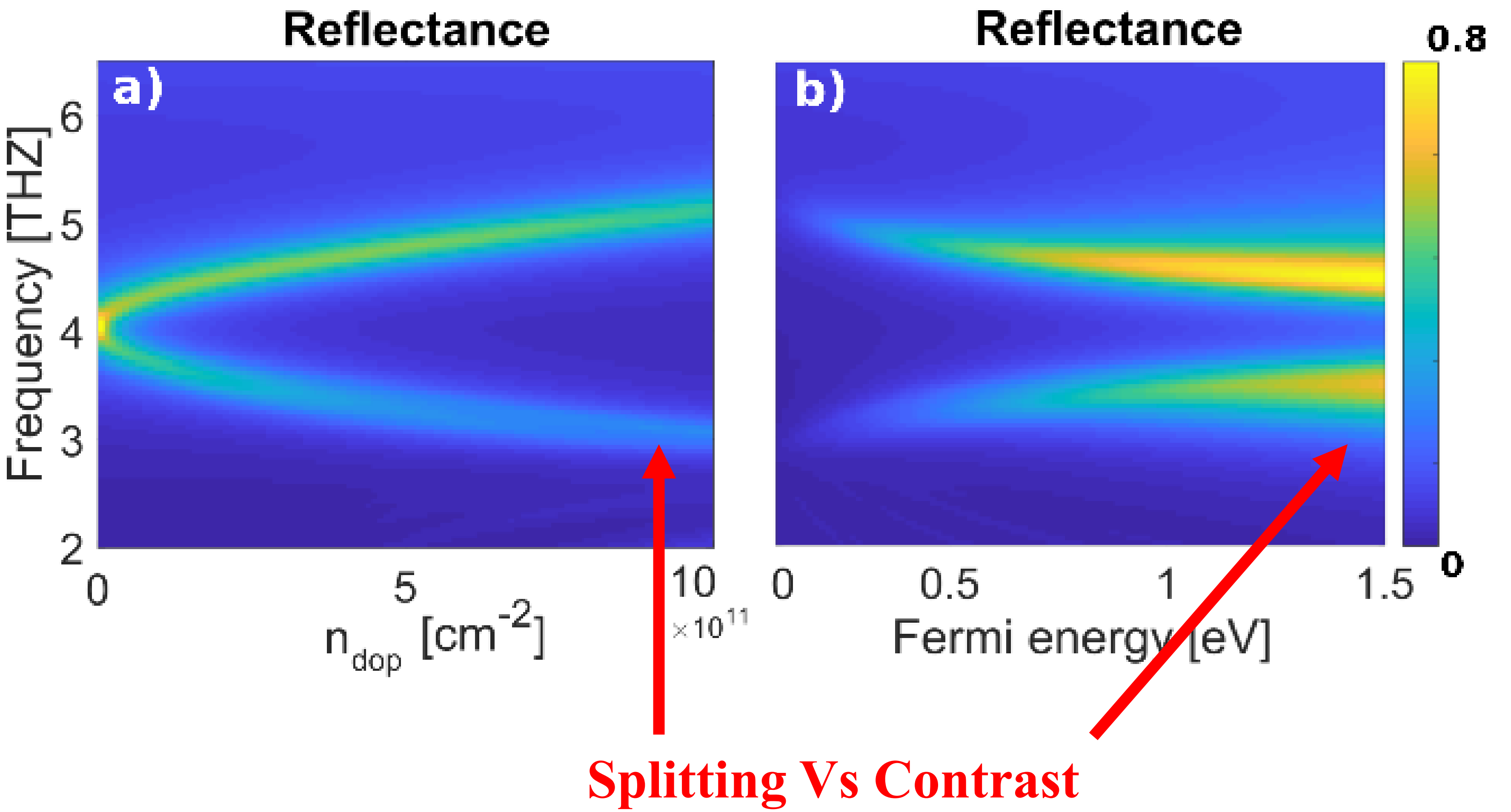
The polariton generation can be enhanced tuning the QW & graphene doping



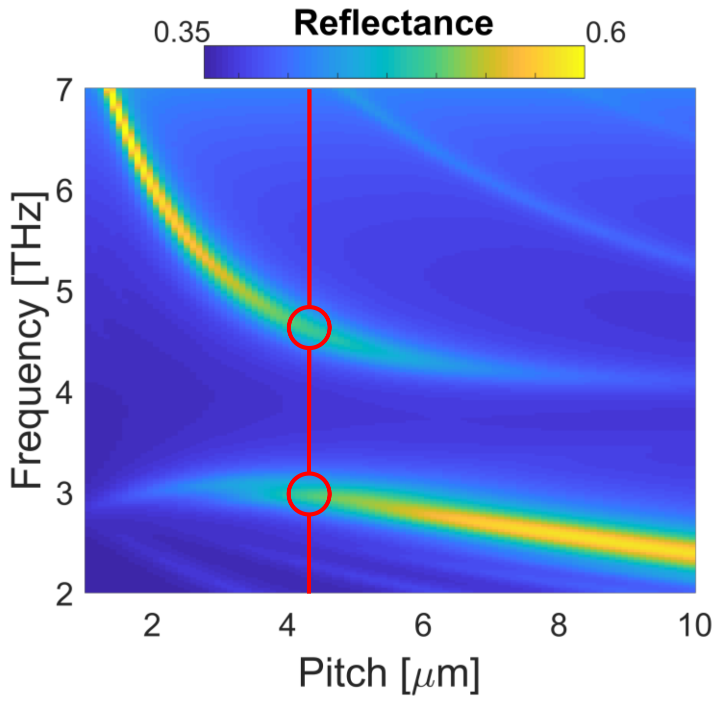


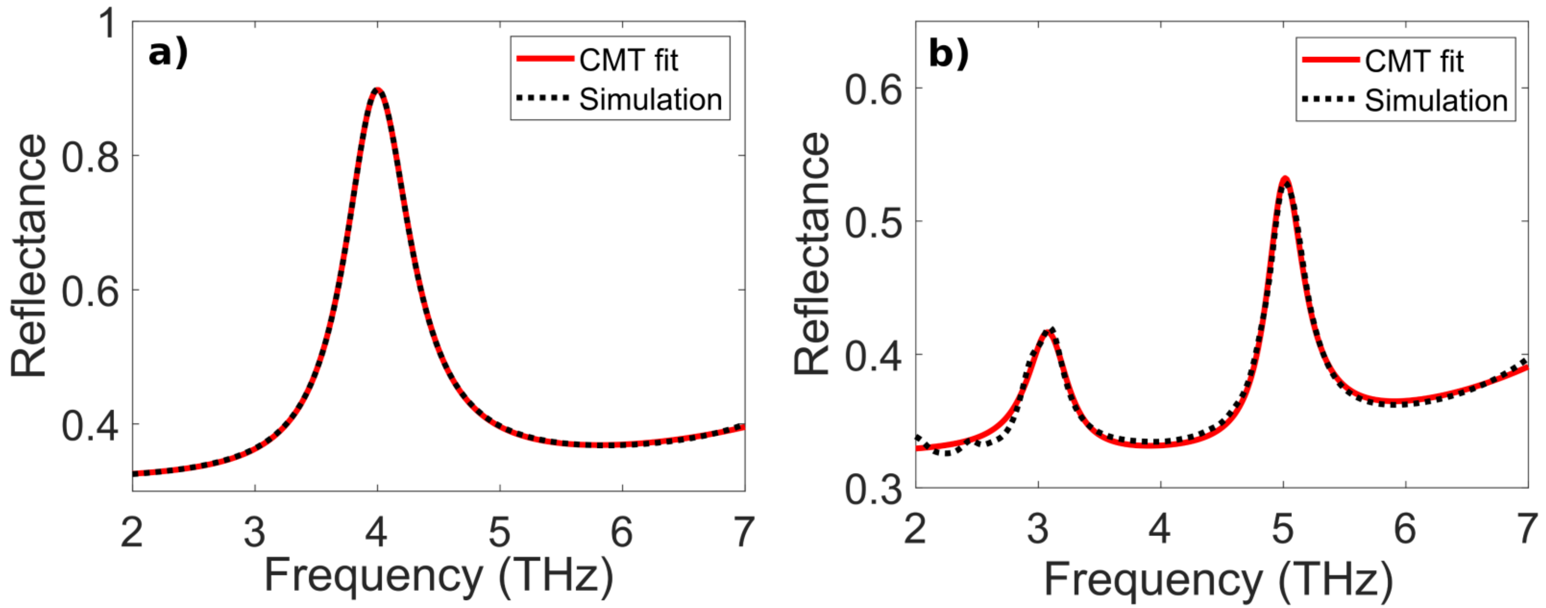
The polariton generation can be enhanced tuning the QW & graphene doping

- $g = \frac{\Omega_R}{\omega_c}$
- $g \propto \sqrt{\frac{n_{QW}}{V}}$
- $\lambda_{SP} \propto E_F$
- $Q = \frac{\Omega_R}{\bar{\gamma}}$



Fitting the reflectance to characterize the resonance



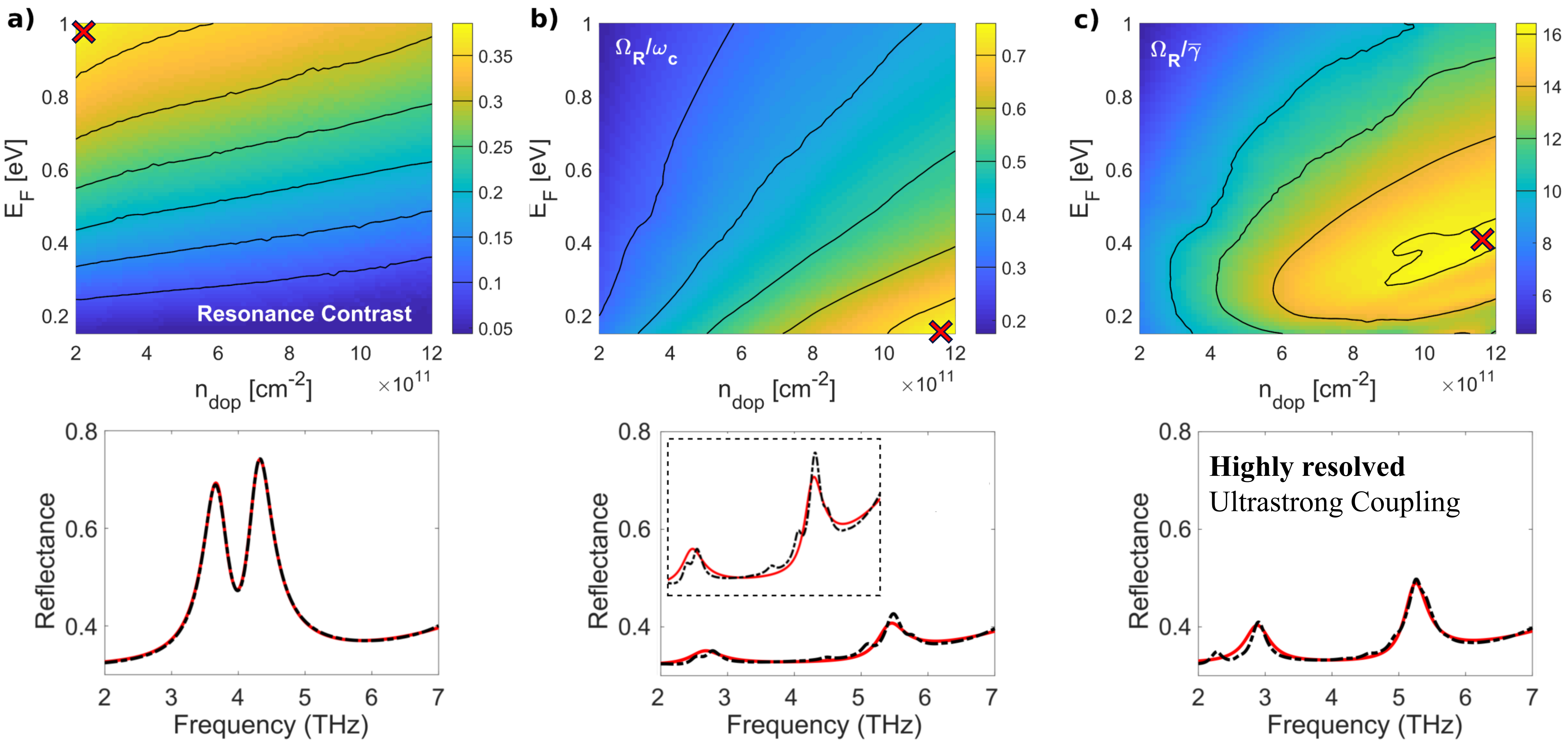


Coupled Mode Theory:

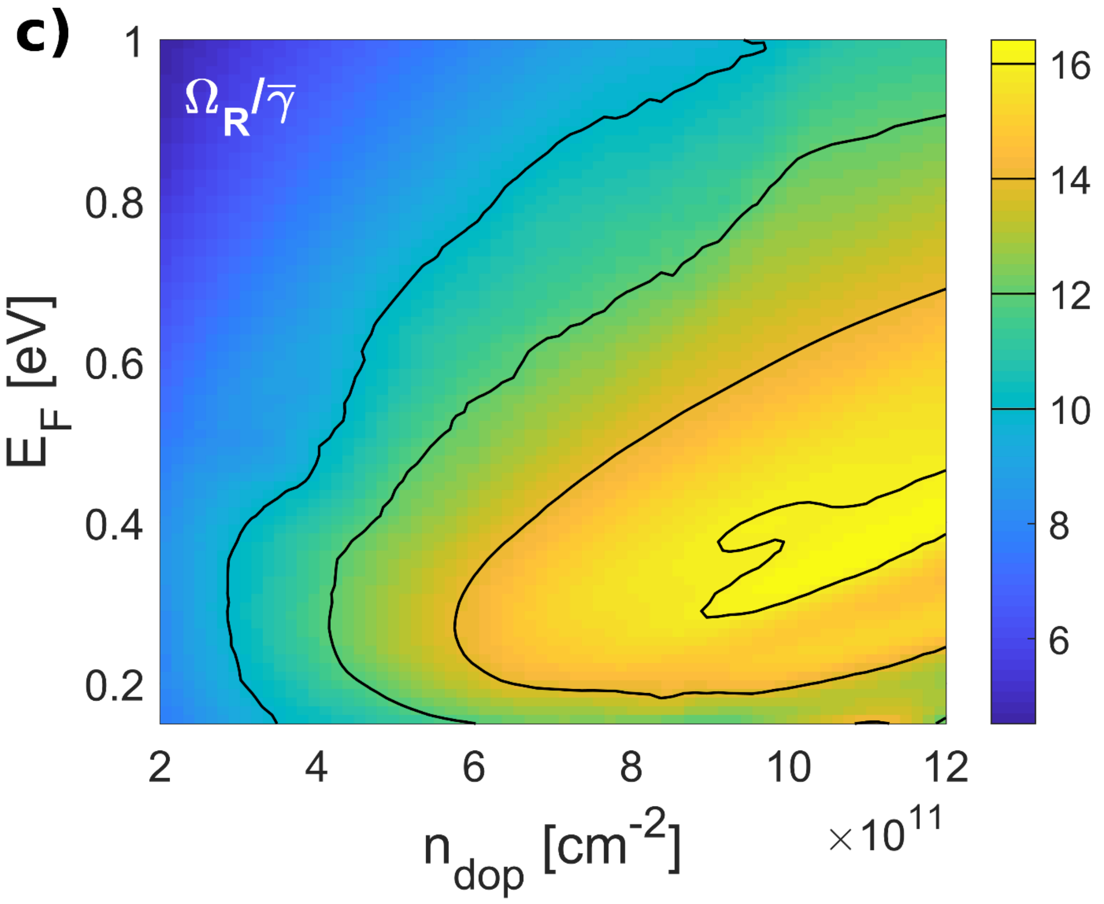
$$R = R(\omega, \omega_c, \omega_{12}, \Omega_R, \bar{\gamma})$$

$$\bar{\gamma} = \gamma_{12} + \gamma_r + \gamma_{nr}$$

Fitting the right parameters to maximize the Q-factor

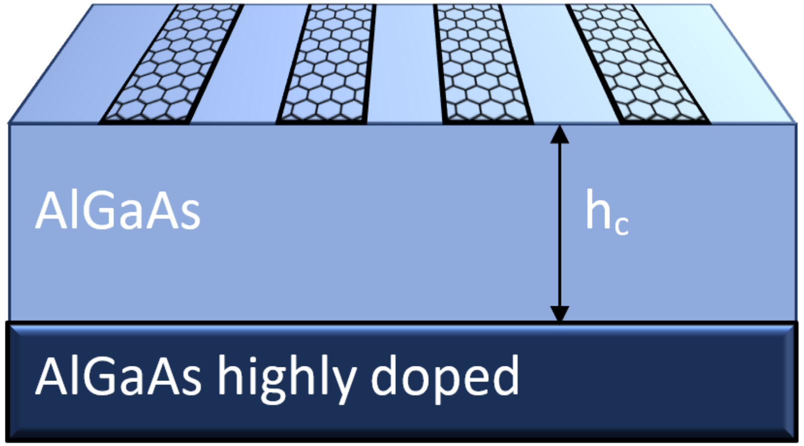


Too easy with the simulations

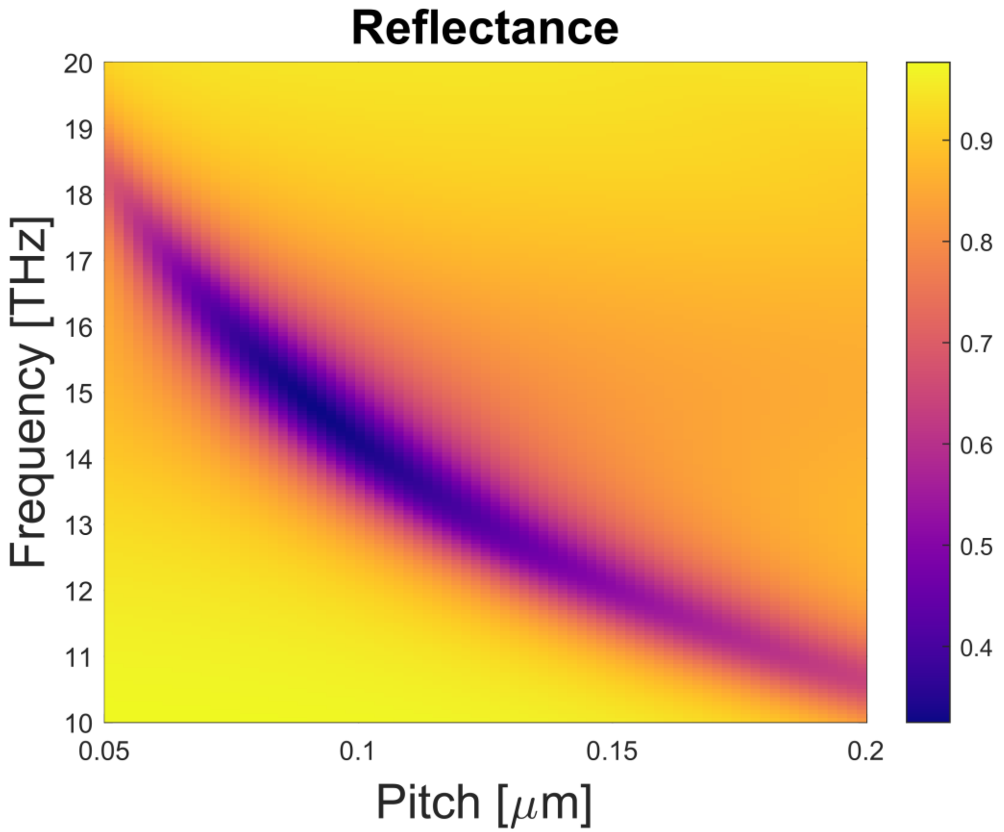


- $E_F \sim 0{,}4\ eV$
- $\mu = 20000\,\frac{cm^2}{Vs}$
- $n_{dop} \sim 1 \times 10^{12} cm^{-2}$

With the critical coupling we can lower the requirements

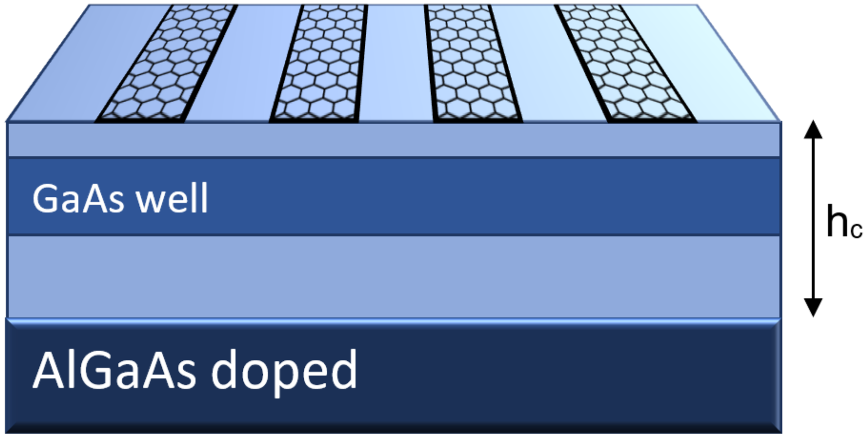


$$h_c = \frac{\lambda}{4n_D}$$



$$E_F \sim 0{,}2\ eV \qquad \mu = 5000\,\frac{cm^2}{Vs}$$

With the critical coupling we can lower the requirements



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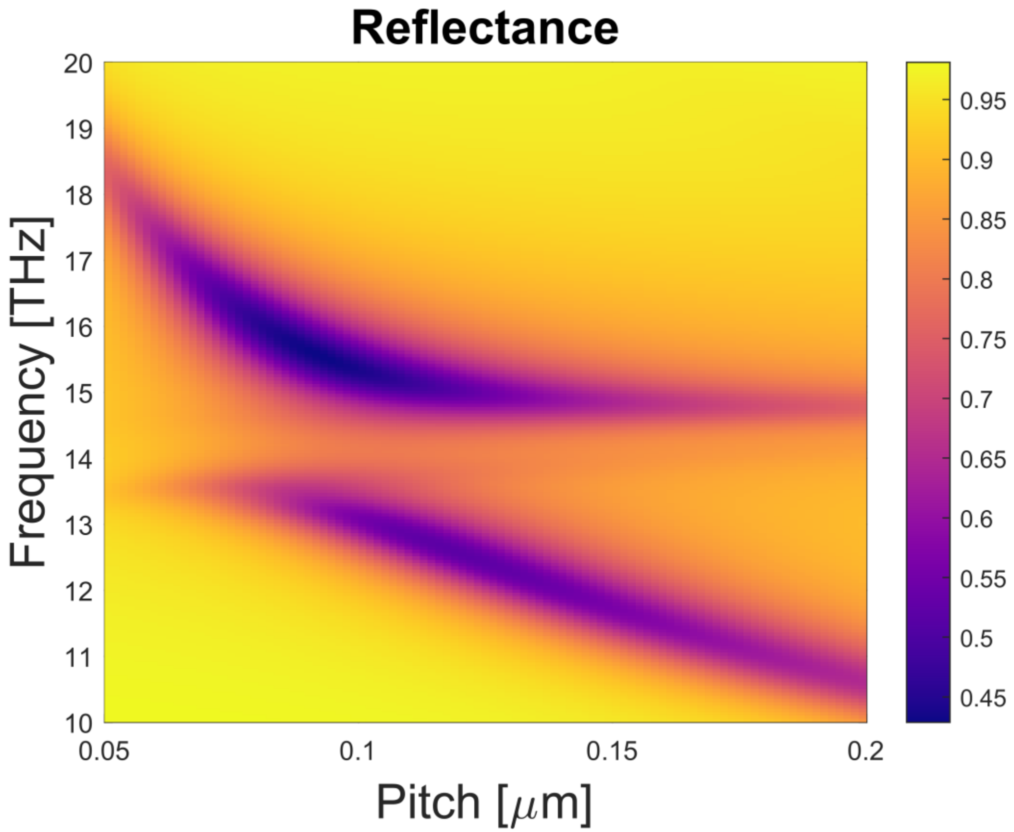
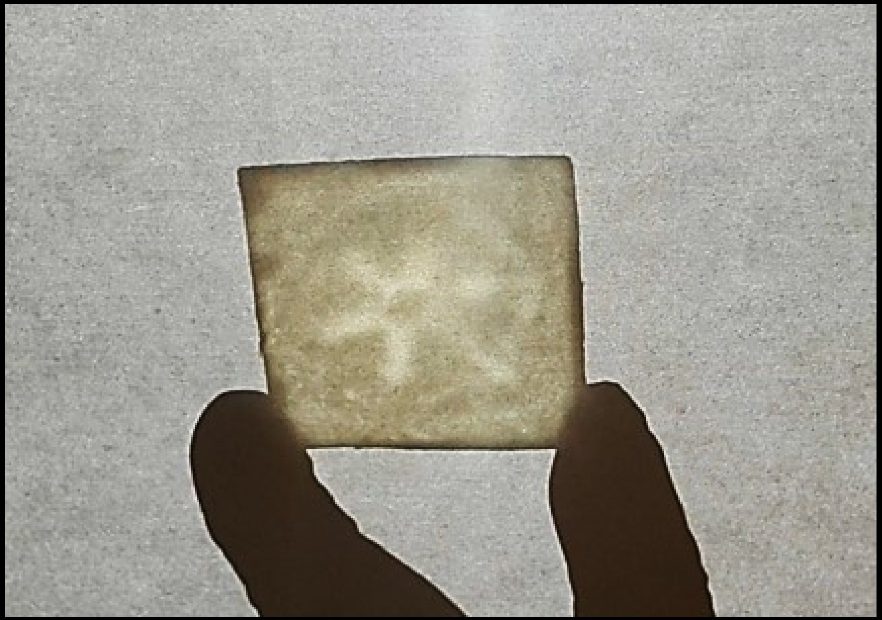


$$E_F \sim 0{,}2\ eV \qquad \mu = 5000\frac{cm^2}{Vs}$$

$$n_{dop} = 5 \times 10^{11} cm^{-2}$$

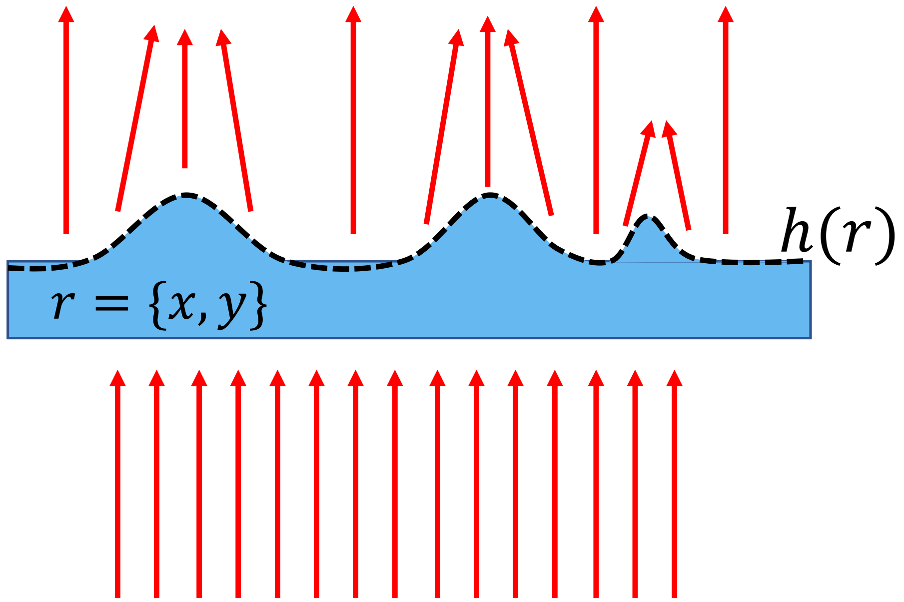
Magic windows

The **chinese magic mirror** projects the pattern engraved on the back



The **magic window** projects a specific image

Bumps on the surface deflect the light



Desired image

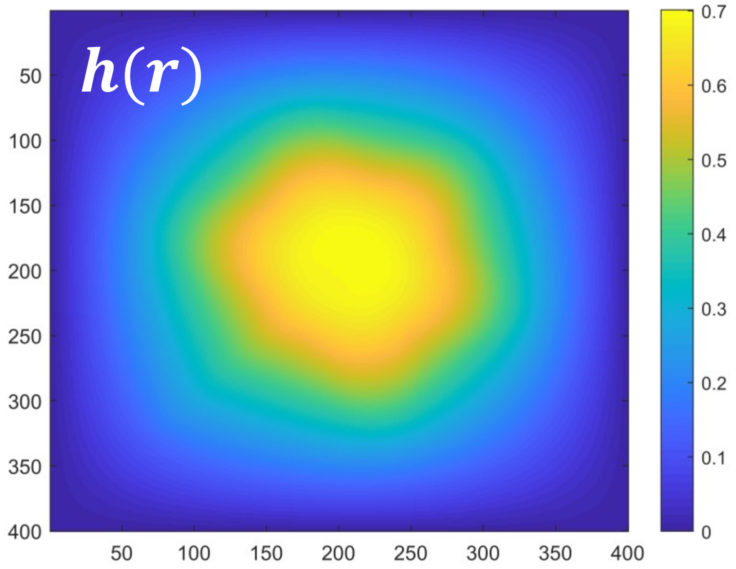
$$\nabla^2 h(r) = \frac{I(r) - 1}{z(1-n)}$$

Focal distance

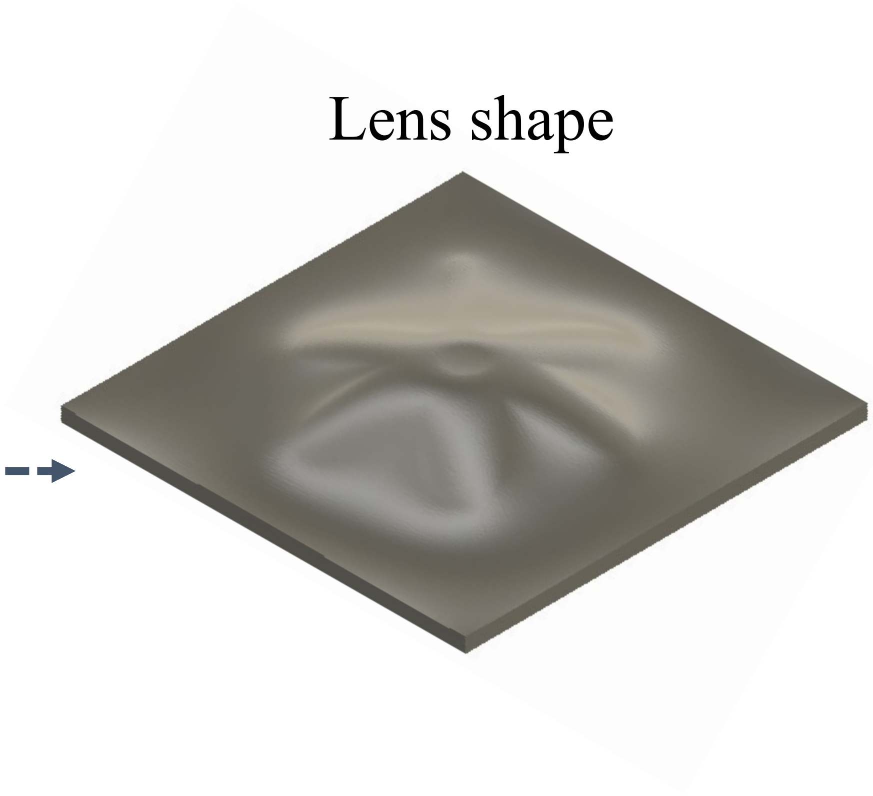
From the image to the window

Image to project

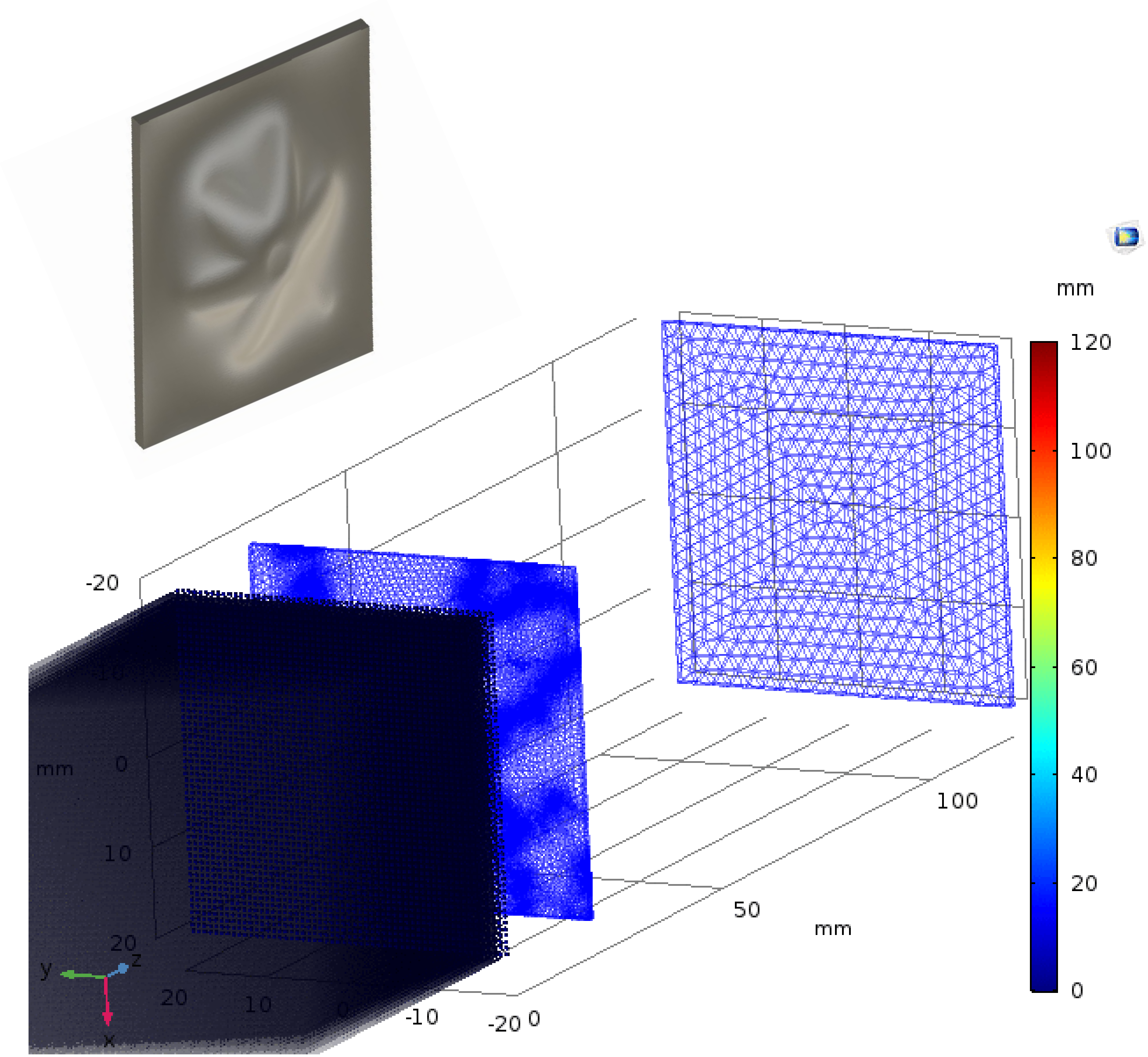
Height profile

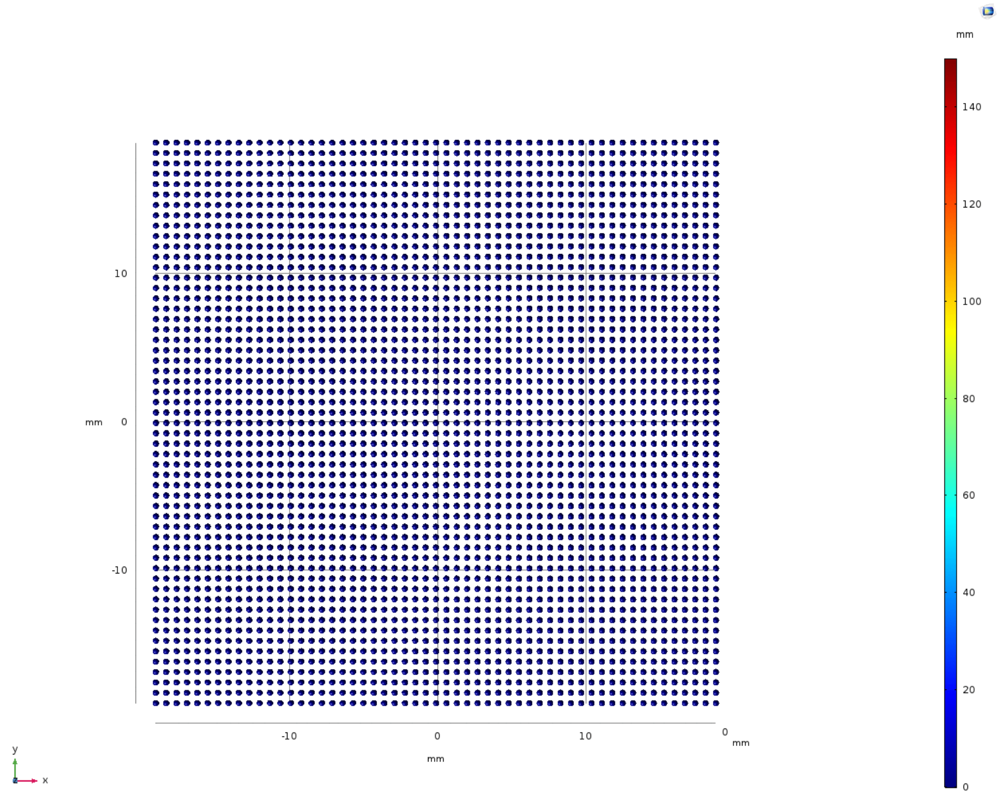


Lens shape

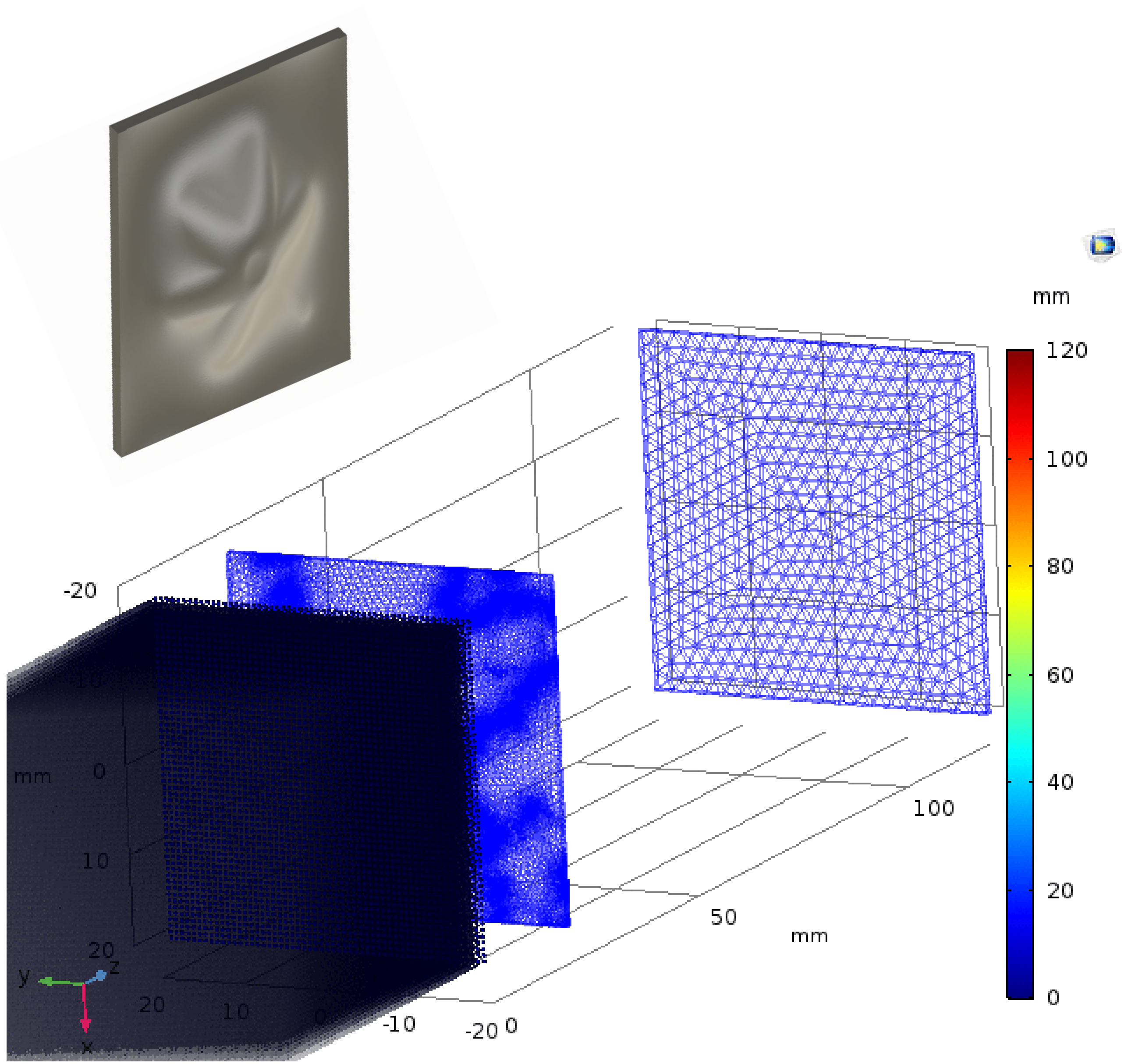


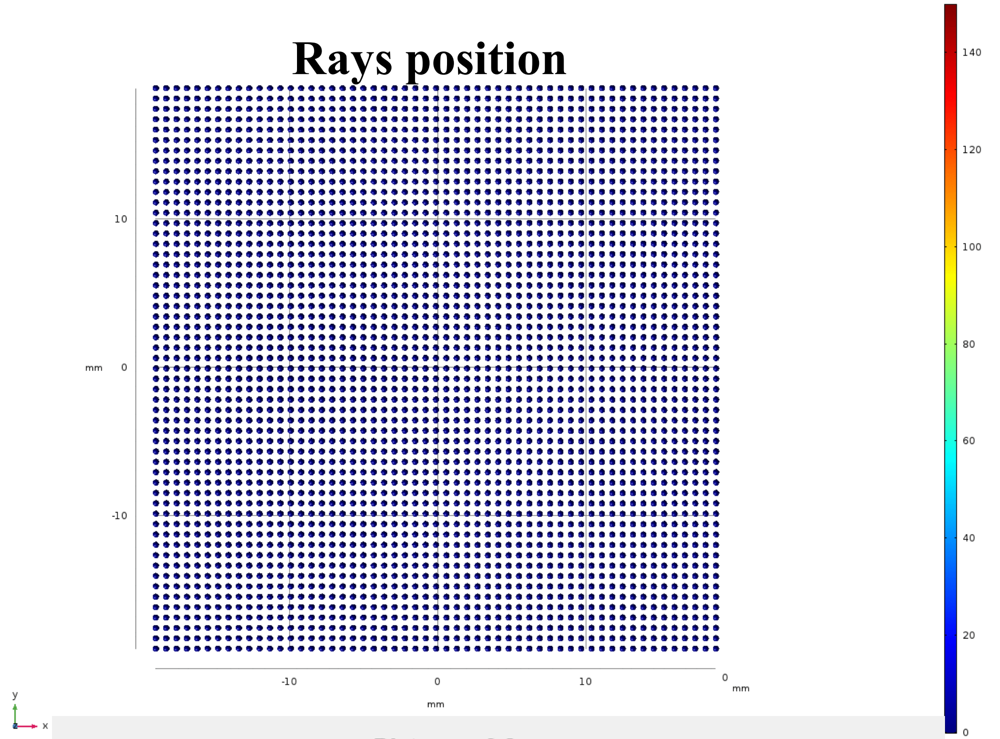
Testing the lens with ray tracing

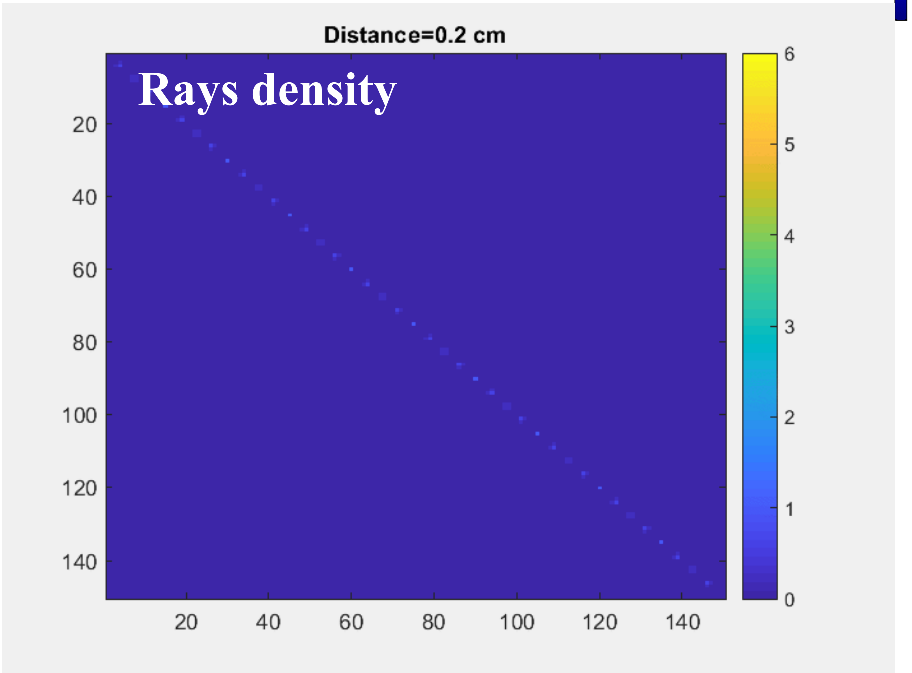




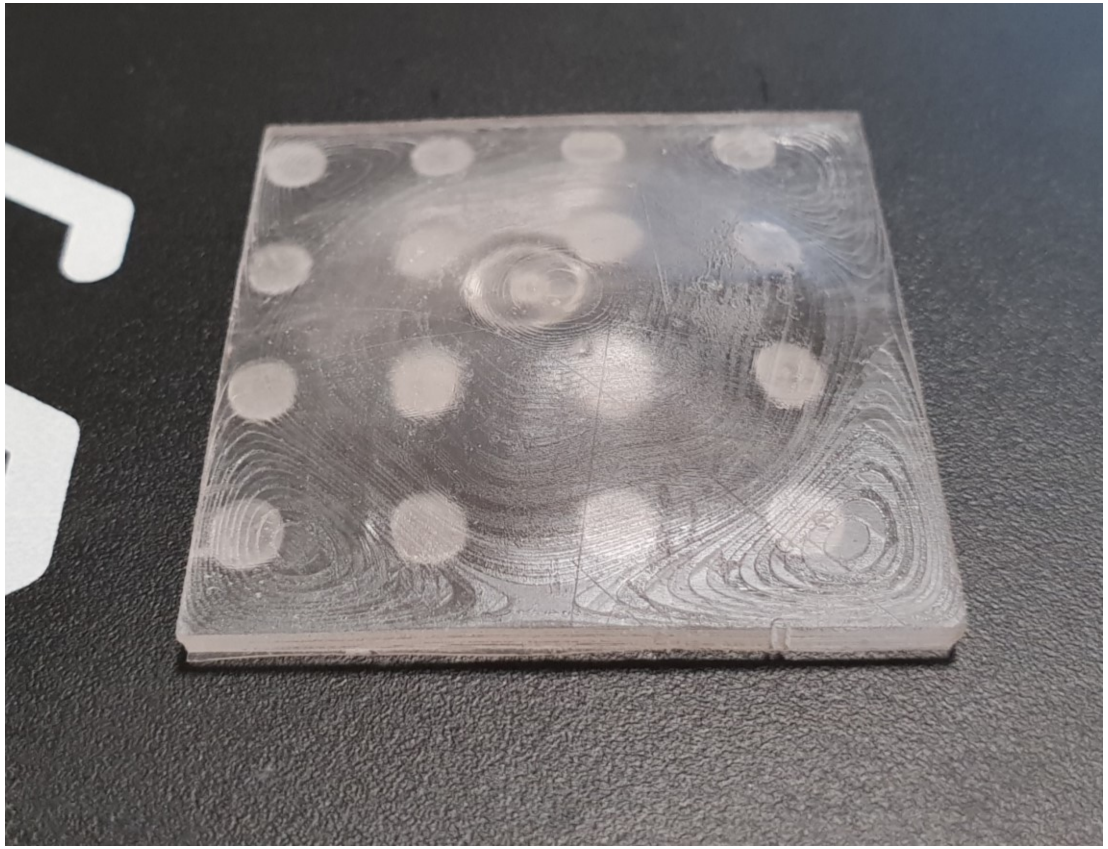
Testing the lens with ray tracing

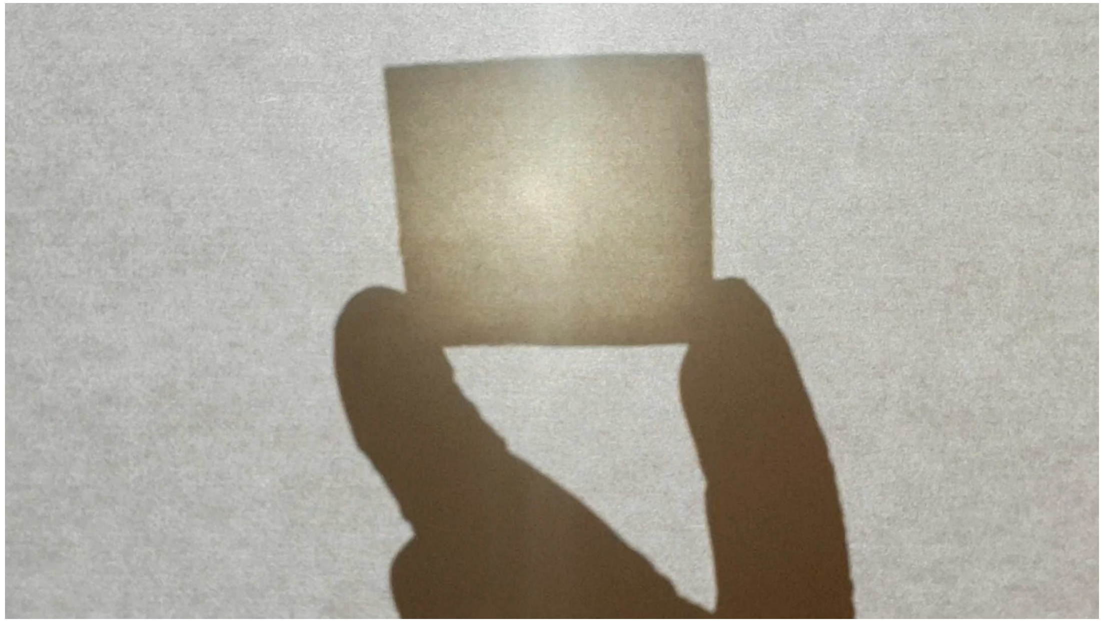




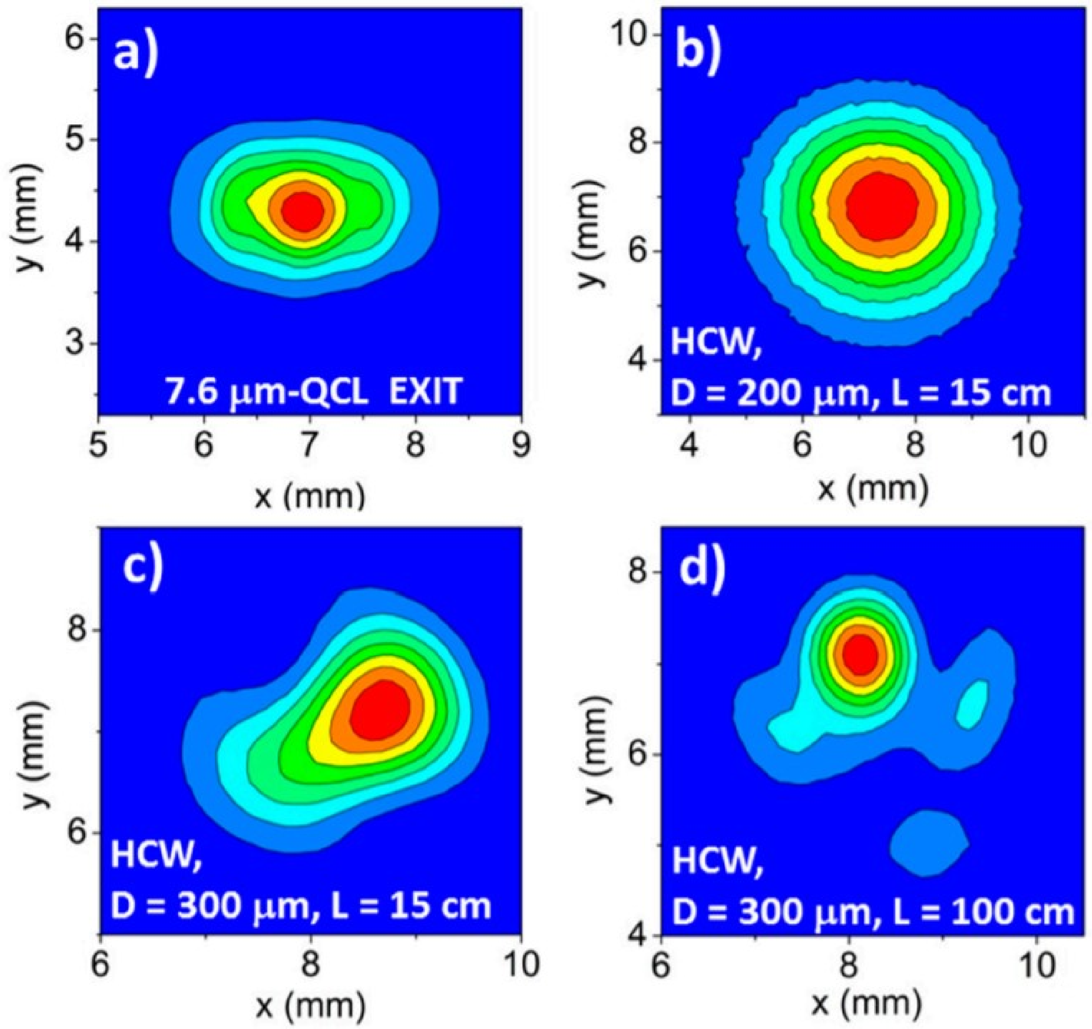


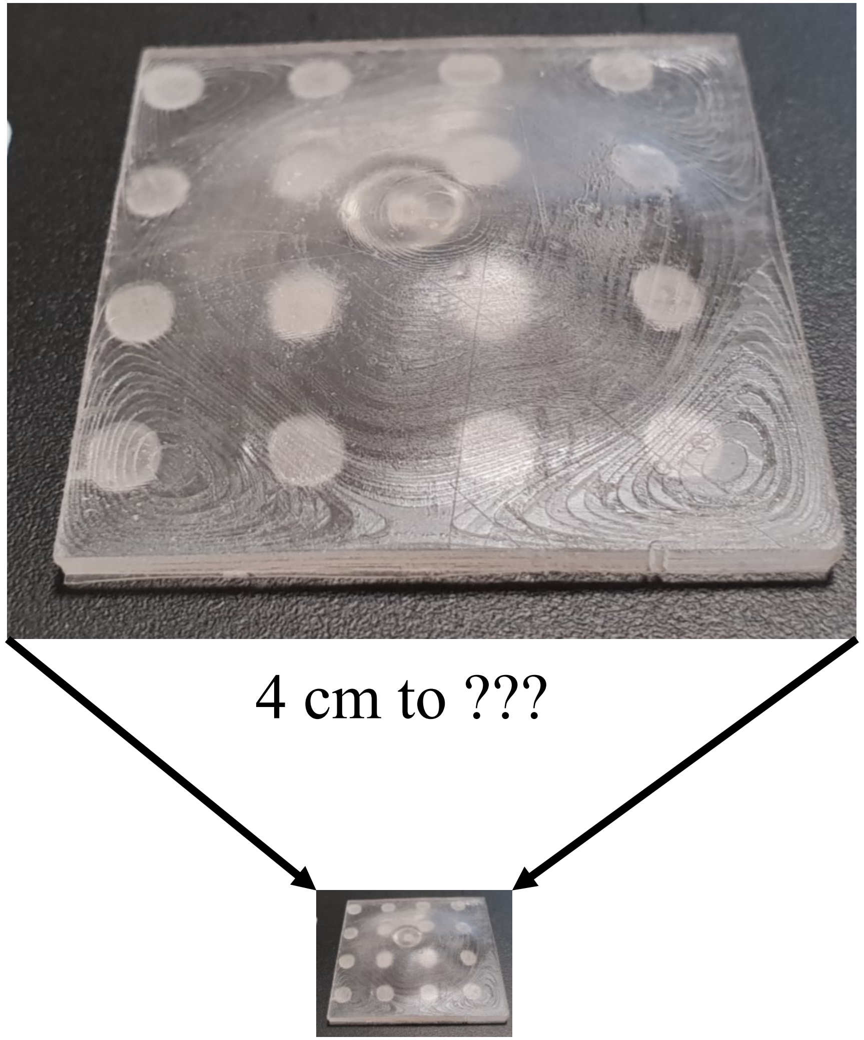
3D-printed windows



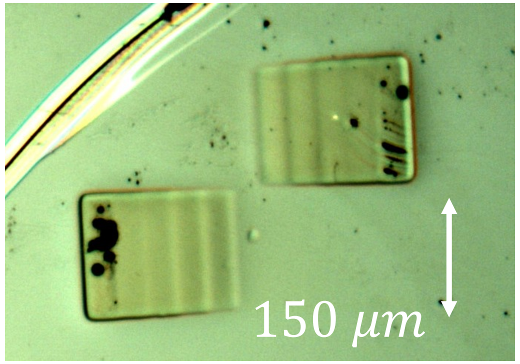


We can use the windows to adjust distortions

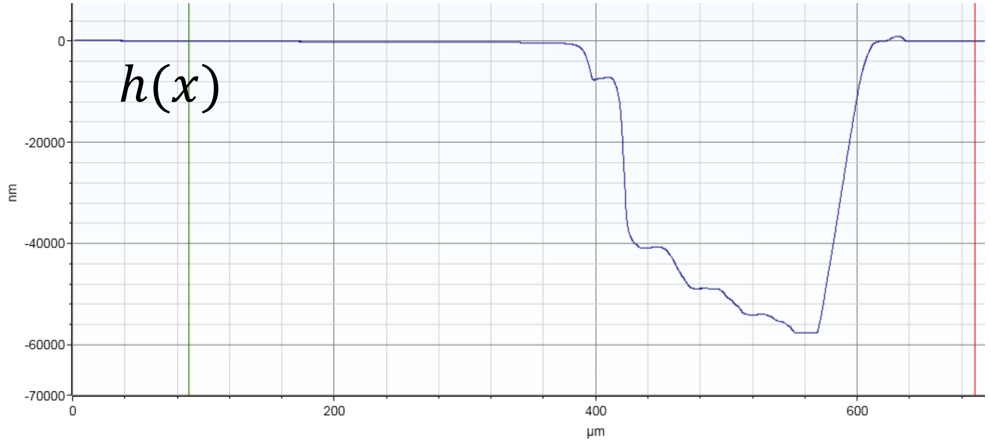


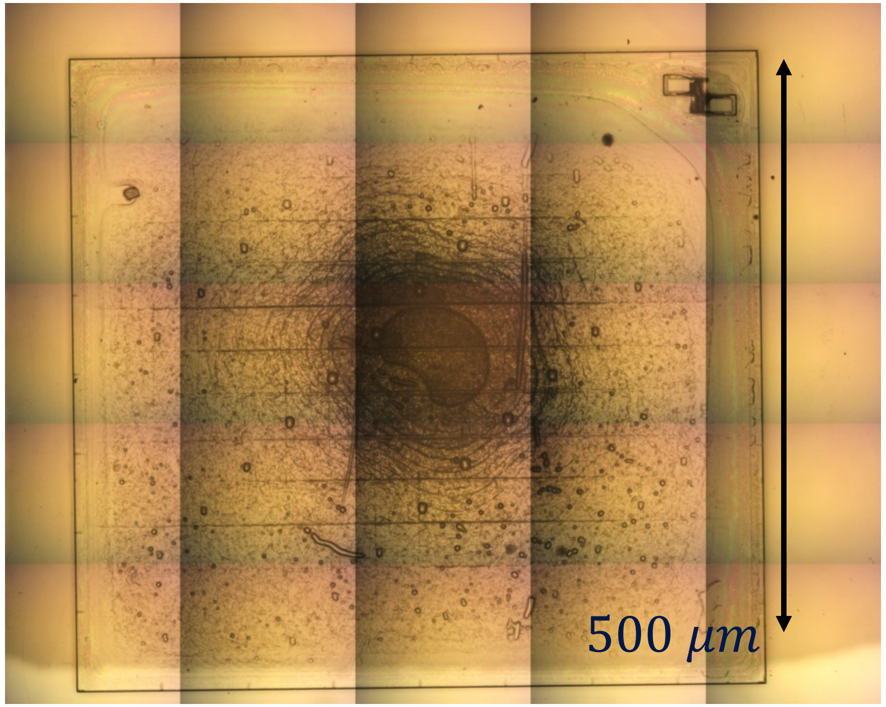


Laser Writer lithography: firsts tests towards the micrometer range



Dose array

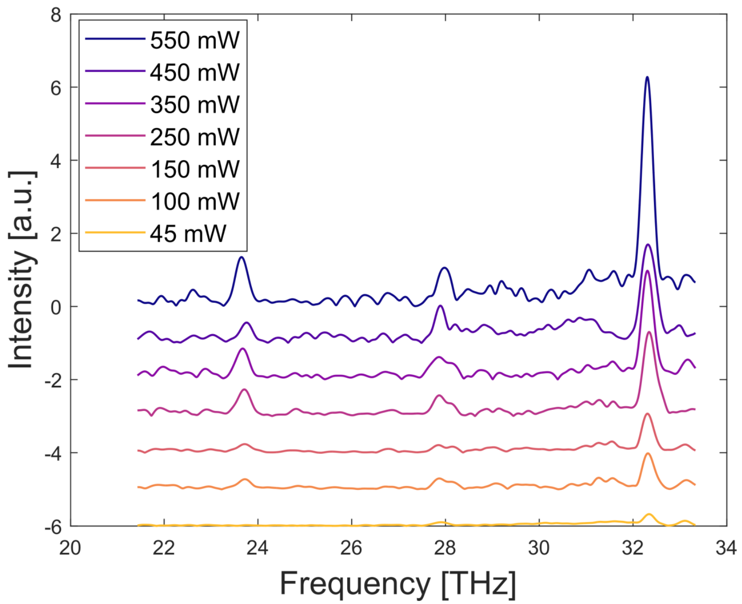




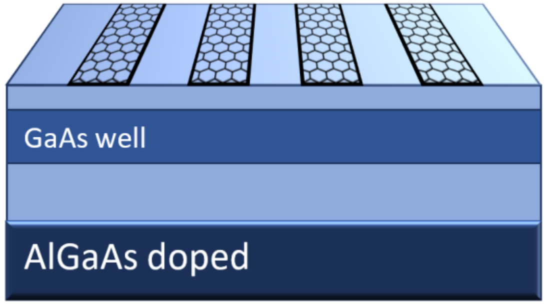
Lens shape

Conclusions

- Polariton Emission
  - Preliminary results
  - Future directions



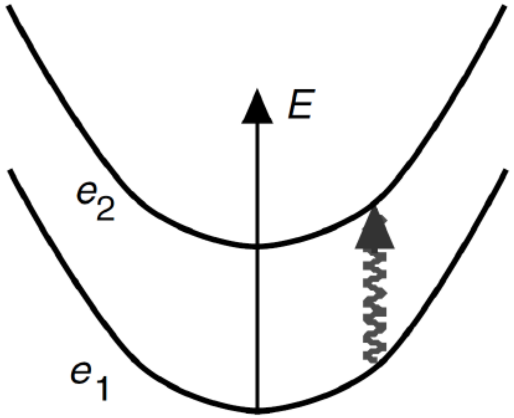
- Improving the polariton generation
  - High Q-factor cavities & parabolic QWs
  - Graphene grating
  - Critical Coupling

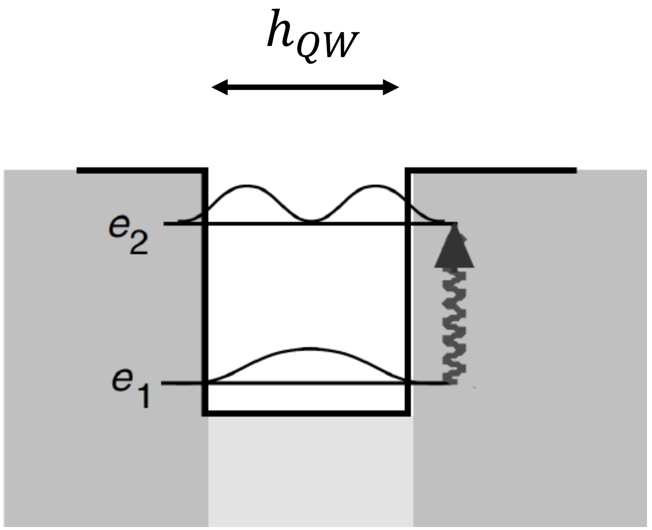


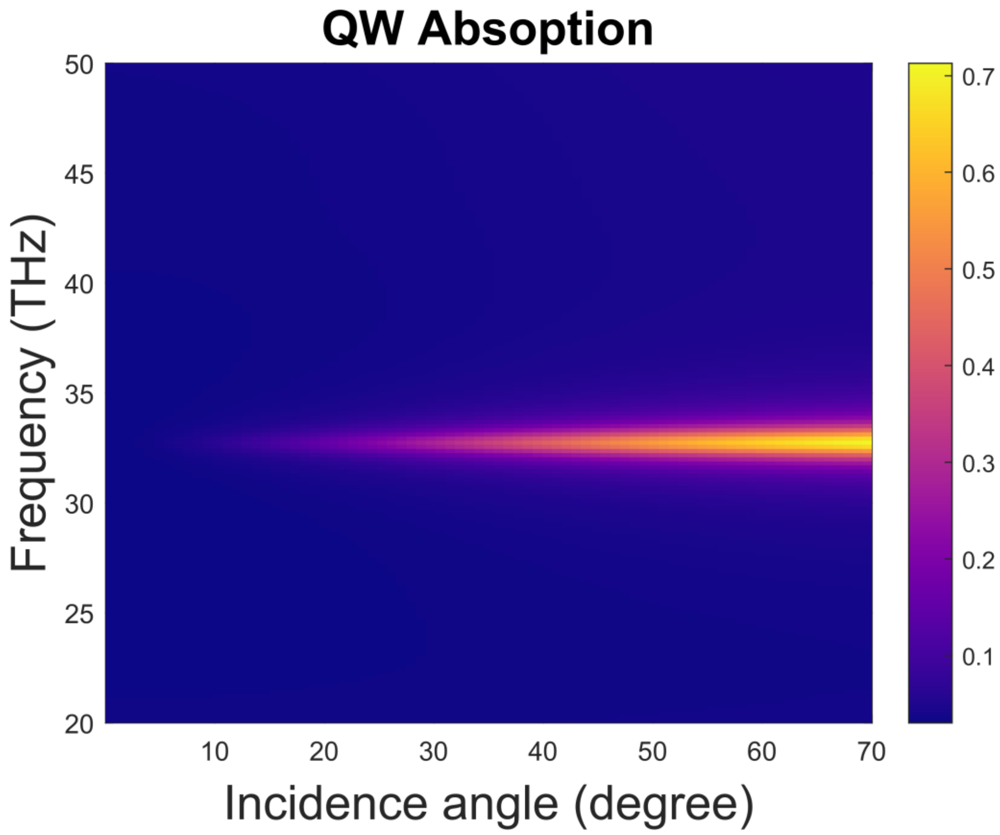
- Magic Windows
  - Printed Windows
  - Laser Writer

Back up

The transition frequency can be tuned with the QW thickness

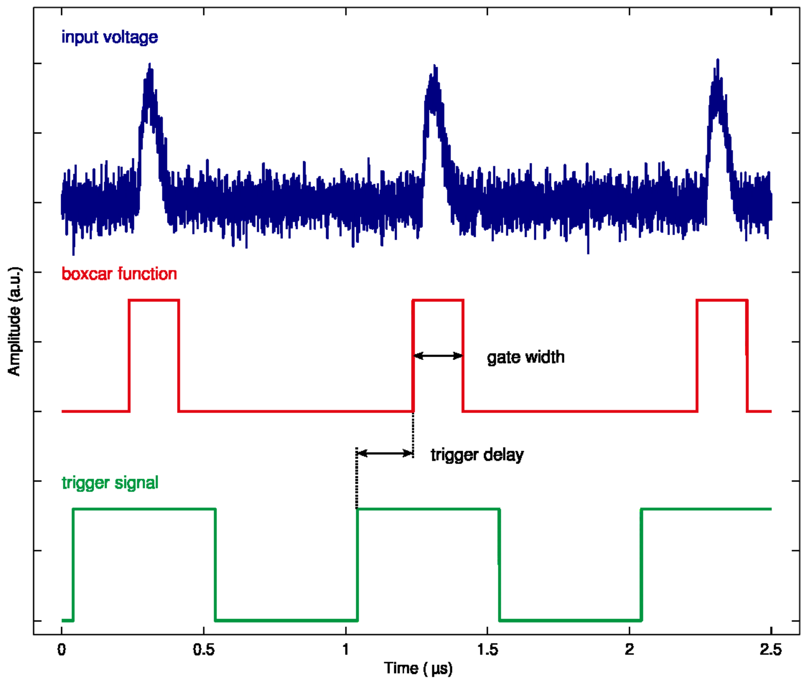






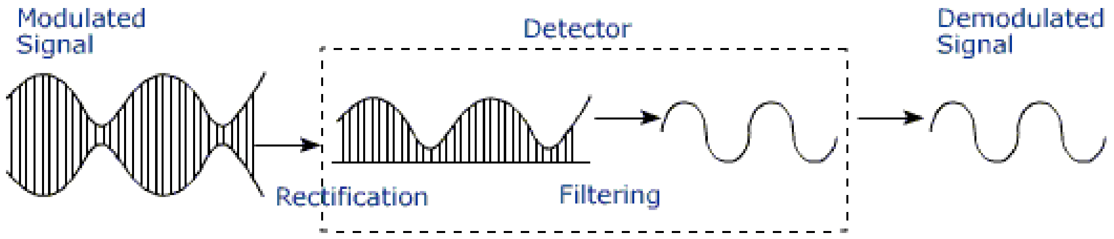
Three signals at the same time
(UHF lock-in)

Boxcars



Demod 1

Demod 2



Filter order 8

Filter order 4

A gold grating can be taylored on the PQWs resonance