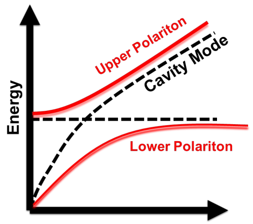
THE STRANGE CASE OF LIGHT-MATTER STRONG COUPLING REGIME

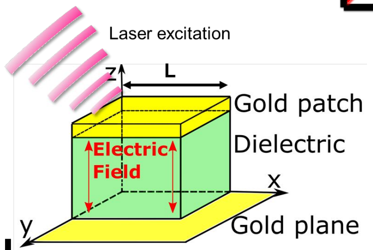
Simone Sotgiu

SUMMARY

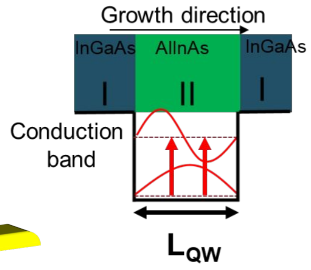
- Light-Matter Strong Coupling Regime



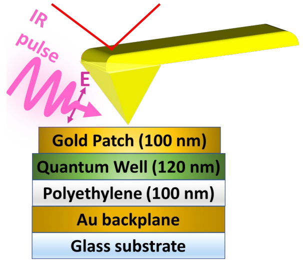
- Optical Cavity: Patch antenna



- Intersubband Transition in a quantum well



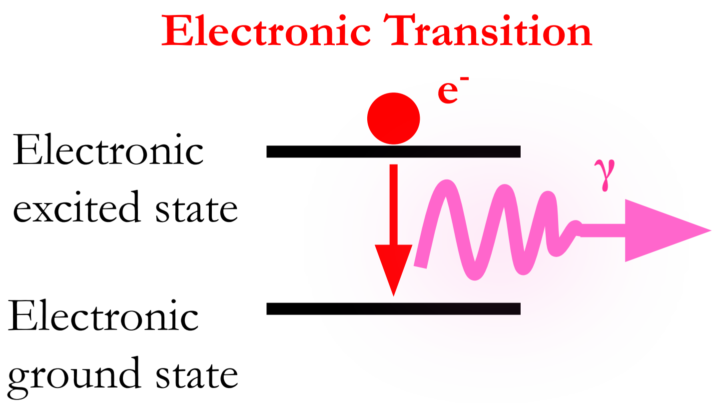
- Experimental Technique: AFM-IR



- Experimental Results

Light-Matter Strong Coupling Regime

In the **light-matter strong coupling regime** a photon is absorbed and re-emitted by an **electronic transition** inserted into an **optical cavity**.



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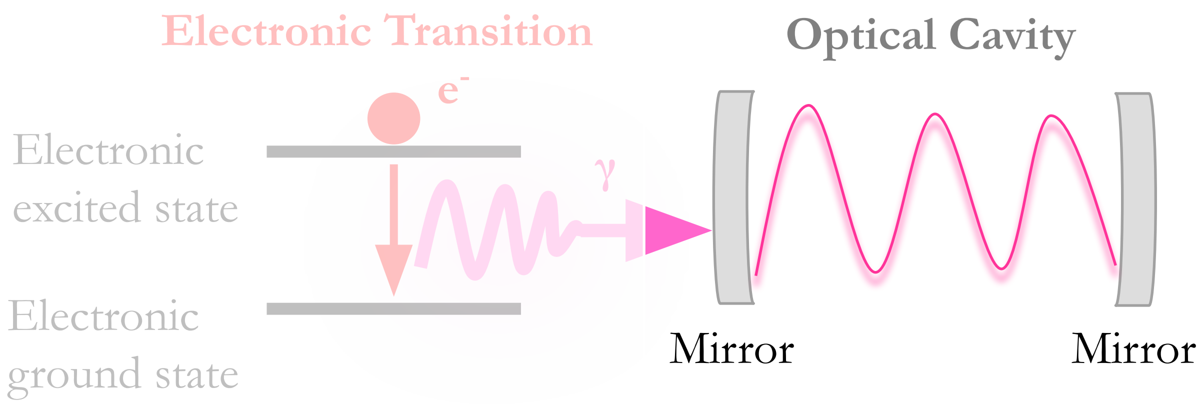

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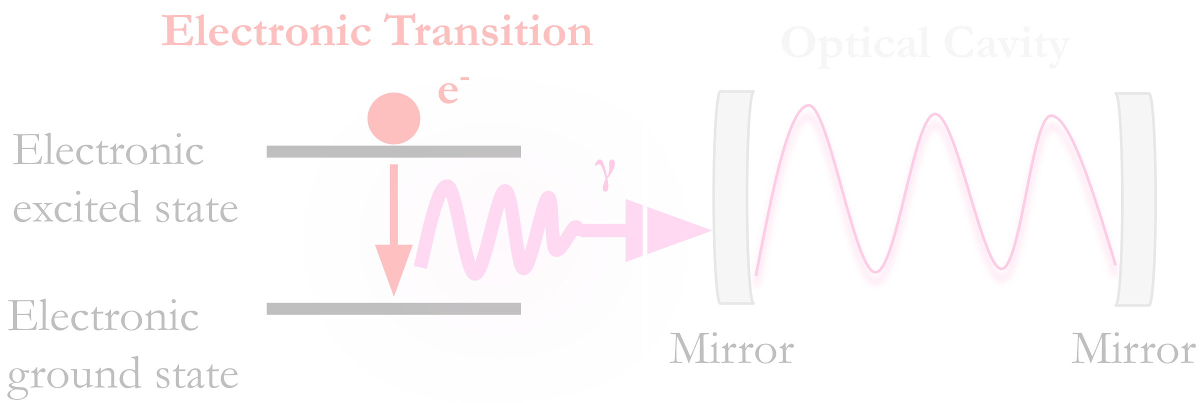

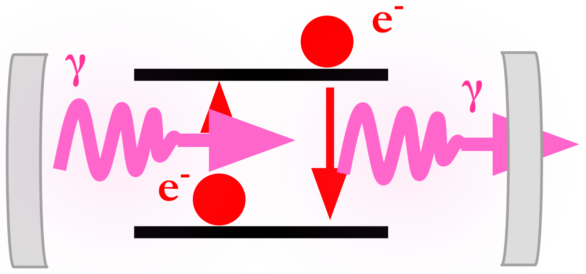

As soon as the energy of the electronic transition and the energy of the photonic cavity mode approach each other, the system can no longer be described by the two excitations singuralry as they become inextricably linked. Two new hybrid systems are created, called ***Polaritons*** which are mixed states between light and matter

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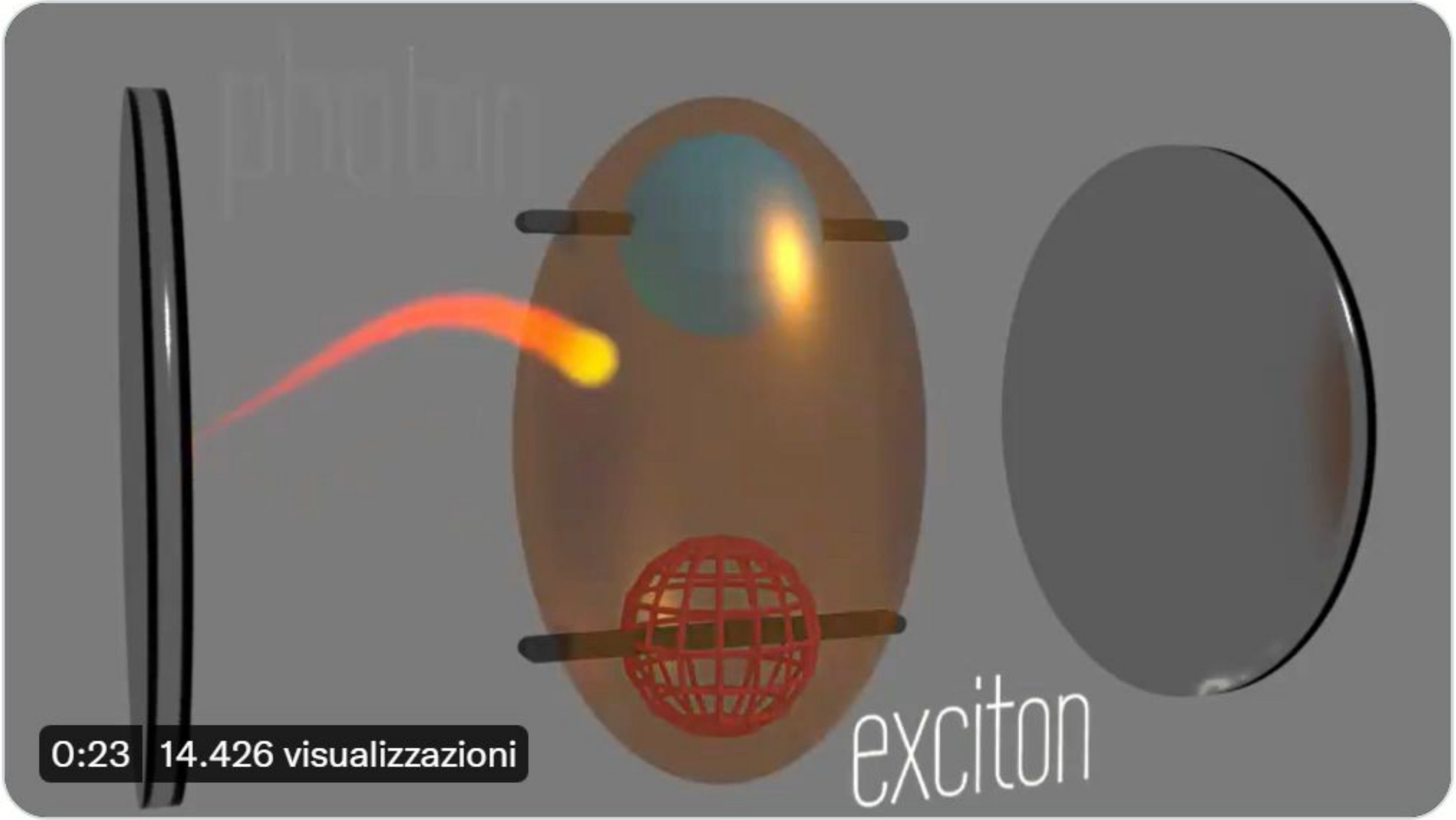

https://twitter.com/lagoudakis_p/status/1377535517076643840?s=20&t=m3opkmPnIkW_9HopN9cikA

Light-Matter Strong Coupling Regime

How can we describe polaritons?

How can we understand if we have reached the light-matter strong coupling regime?

Light-Matter Strong Coupling Regime

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How can we understand if we have reached the light-matter strong coupling regime?

We can write the total Hamiltonian consisting in the electronic part, the light part, and their interaction

$$H = \hbar\omega_c(a^\dagger a + 1/2) + \hbar\omega_{12} b^\dagger b + \frac{i\hbar\omega_P}{2} \times \sqrt{f_w \frac{\omega_c}{\omega_{12}}}(a - a^\dagger)(b + b^\dagger) + \frac{\hbar\omega_P^2}{4\omega_{12}}(b + b^\dagger)^2.$$

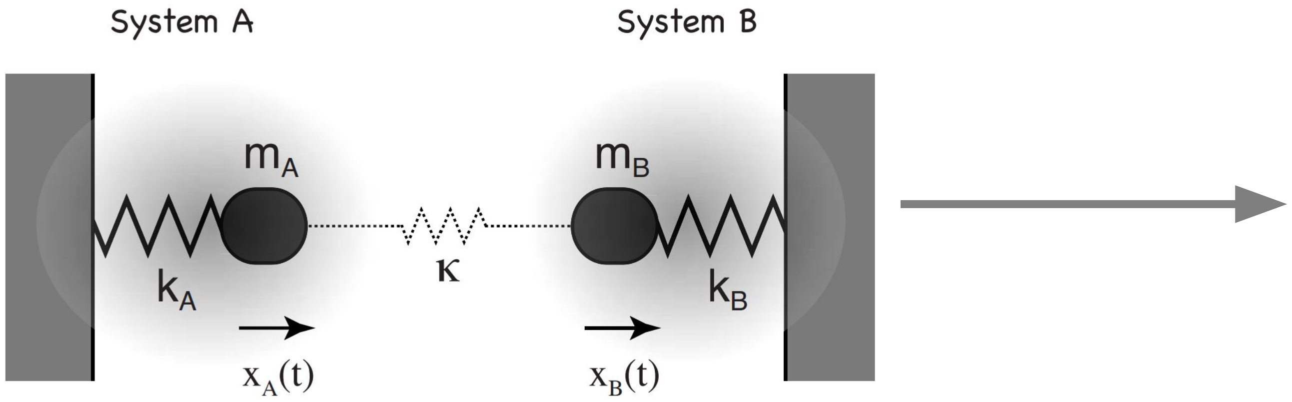
Let us diagonalize it…

Light-Matter Strong Coupling Regime

….maybe the next time!

You have a physics degree…it is substantially a degree on springs!

Let us consider the two excitations as…two springs! And the interaction? Another spring!

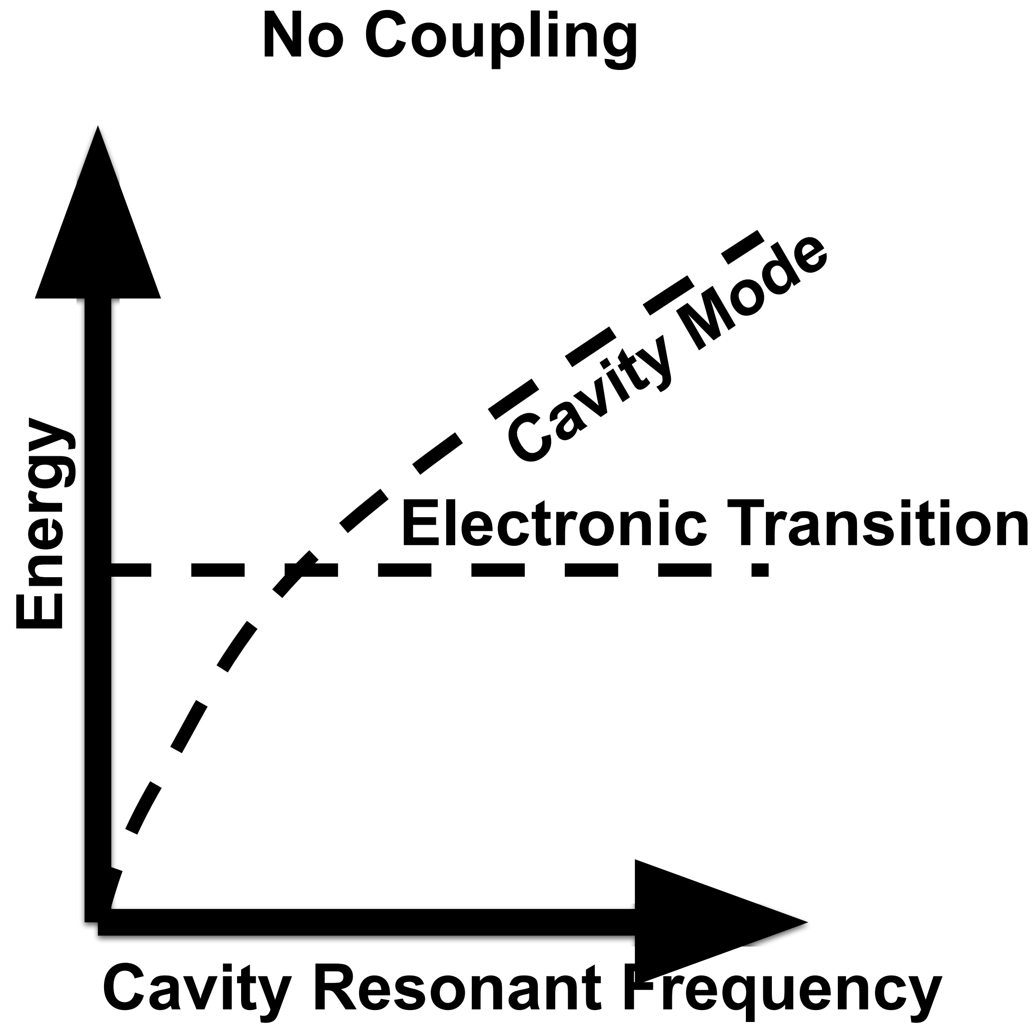


$$m_A\ddot{x}_A + k_A x_A + \kappa(x_A - x_B) = 0$$

$$m_B\ddot{x}_B + k_B x_B - \kappa(x_A - x_B) = 0.$$

A lot easier and it gives very satisfying informations!

Light-Matter Strong Coupling Regime



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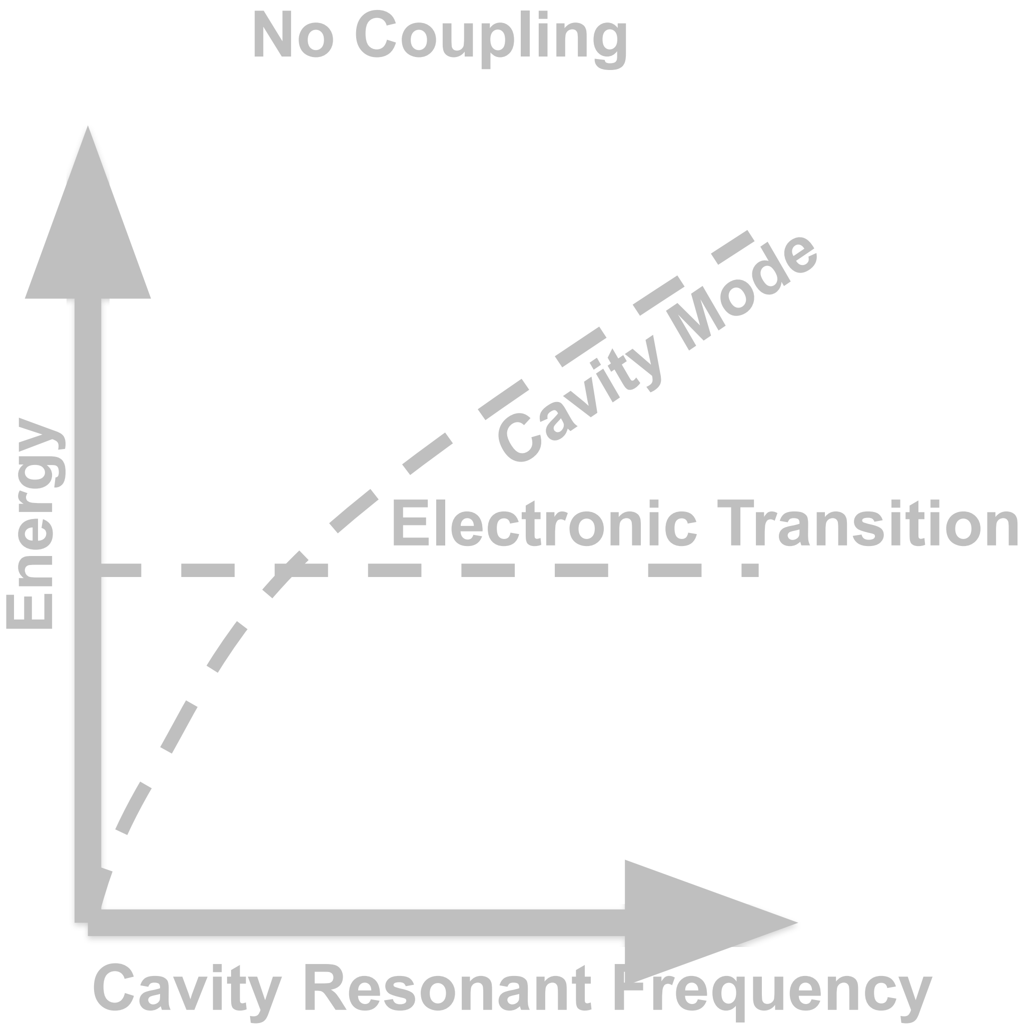
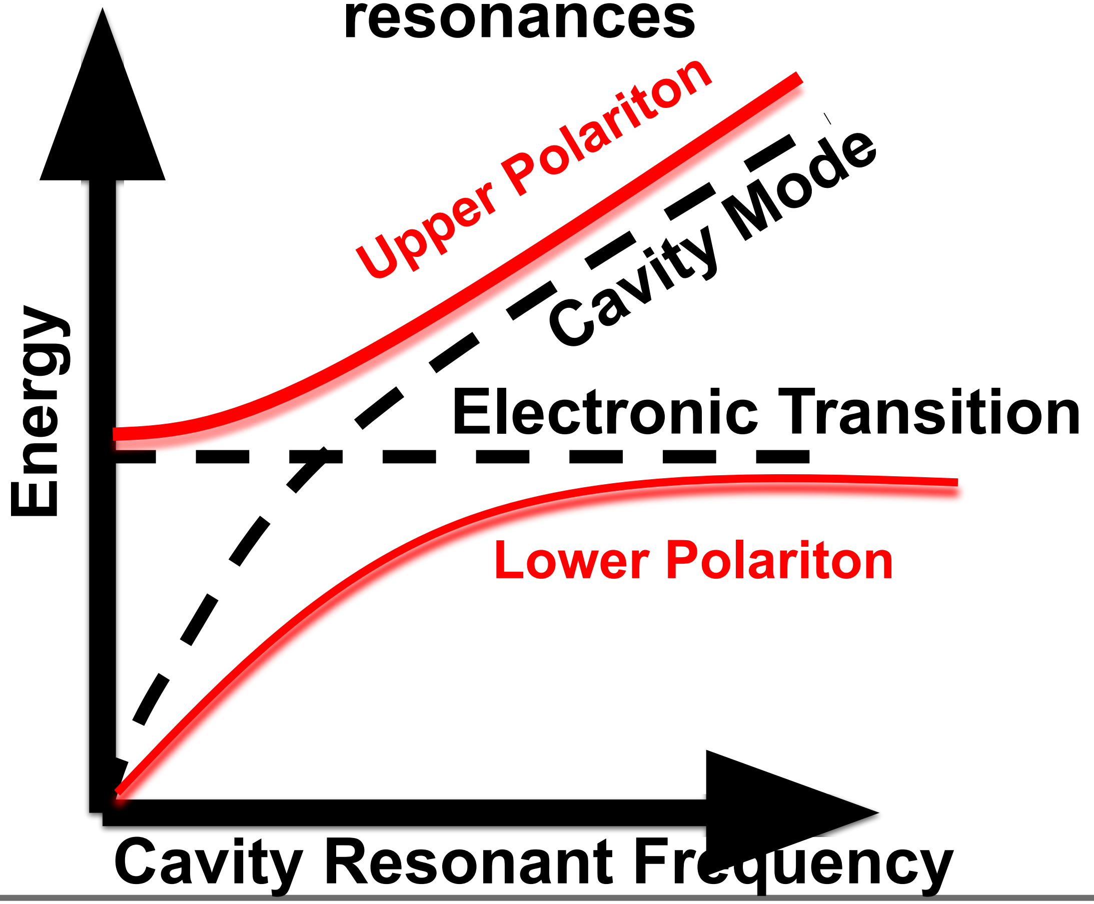
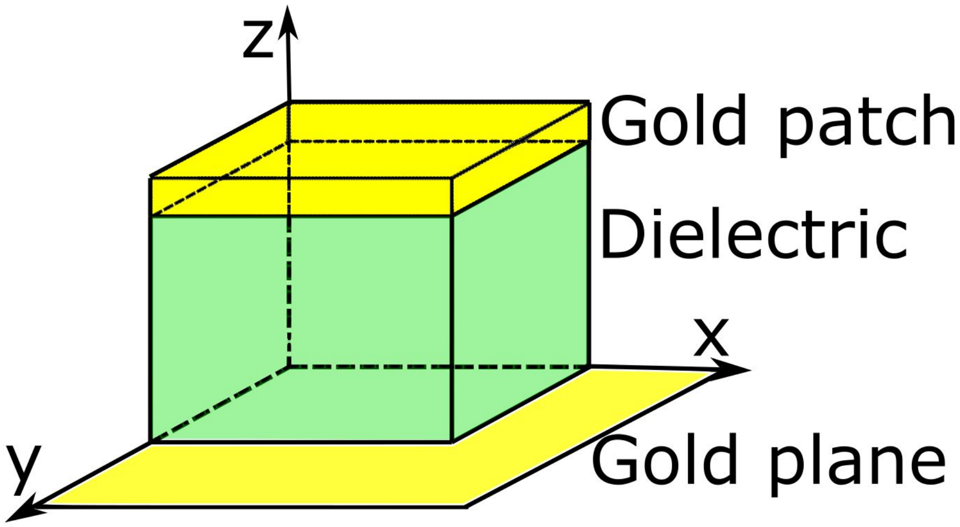


Strong Coupling: splitting of the resonances



Optical Cavity: patch antenna



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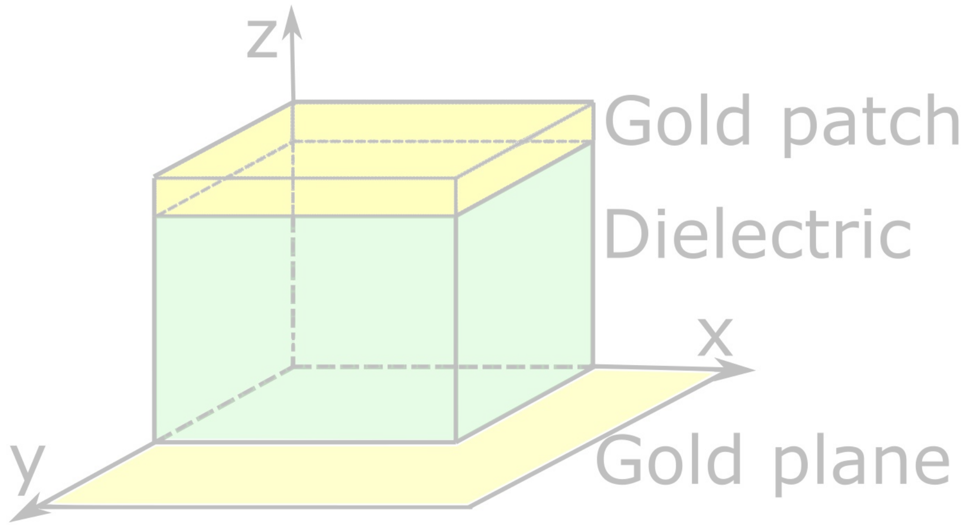
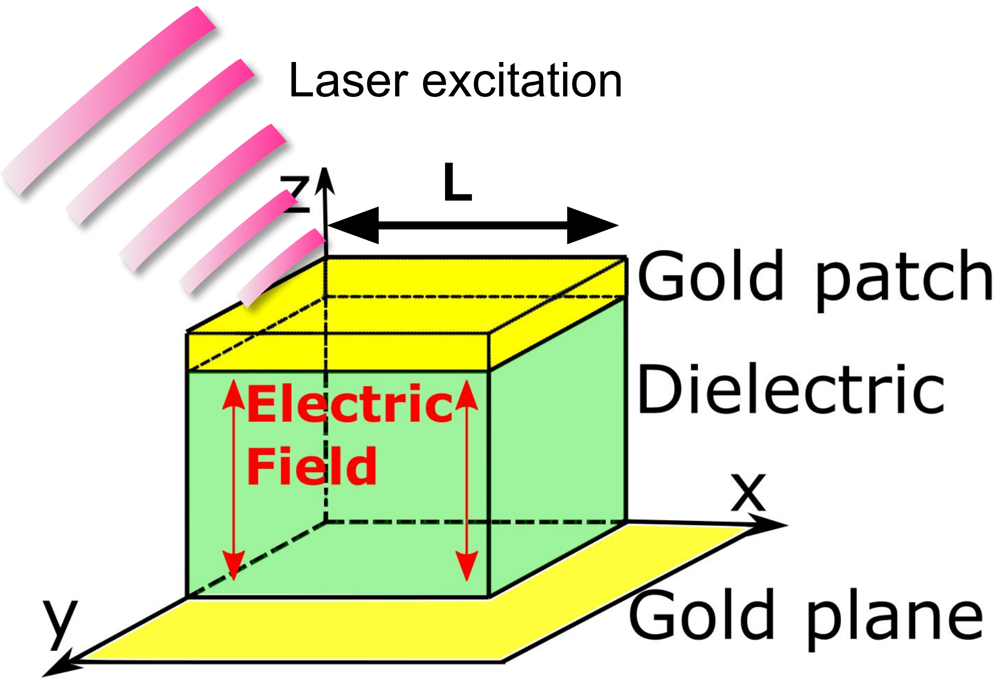




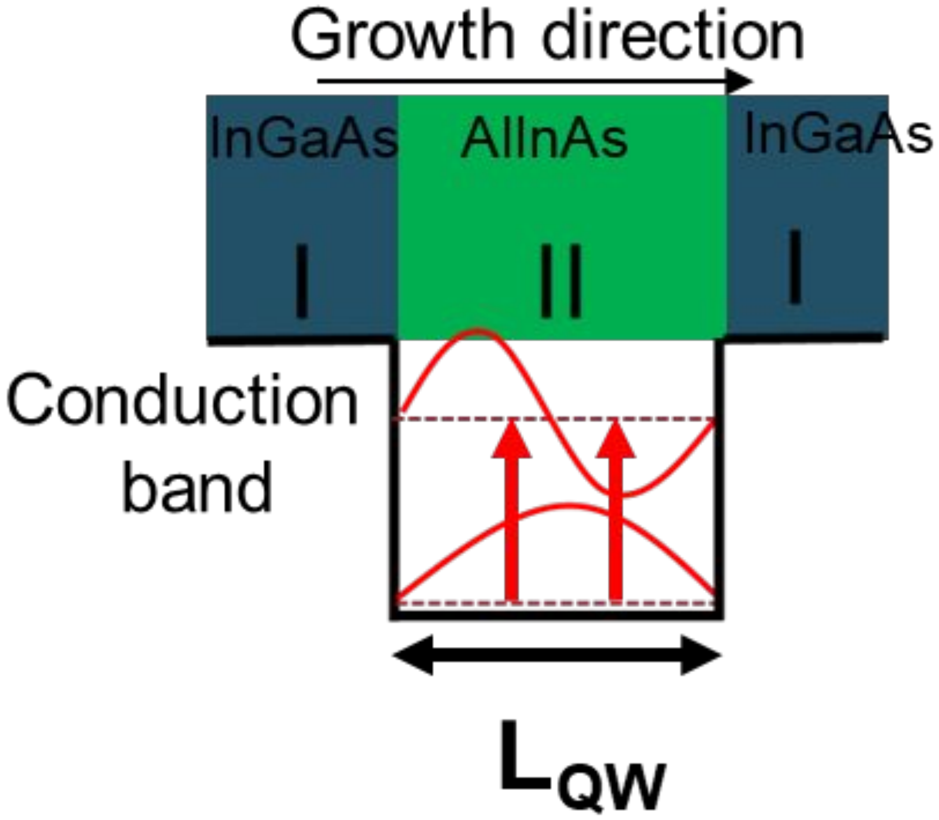
When the antenna is excited at its resonant frequency, a strong electric field is created inside the cavity

The resonant frequency is proportional to the side of the patch antenna

$$\omega_{res} \sim L^{-1}$$

Electronic Transition: Intersubband transition in a quantum well

Quantum well: Heterostructures of semiconductor with different energy gap



The spatial confinement leads to the discretization of the energy levels inside the well

An electronic transition between these new electronic levels is called **Intersubband Transition**

Experimental Technique: AFM-IR

We couple the tip of a **Atomic Force Microscope (AFM)** to a **Quantum Cascade Laser (QCL)** emitting in the **mid-IR** (900-1800 cm^{-1}) so to measure at the **single resonator level** (**subwavelength resolution)**

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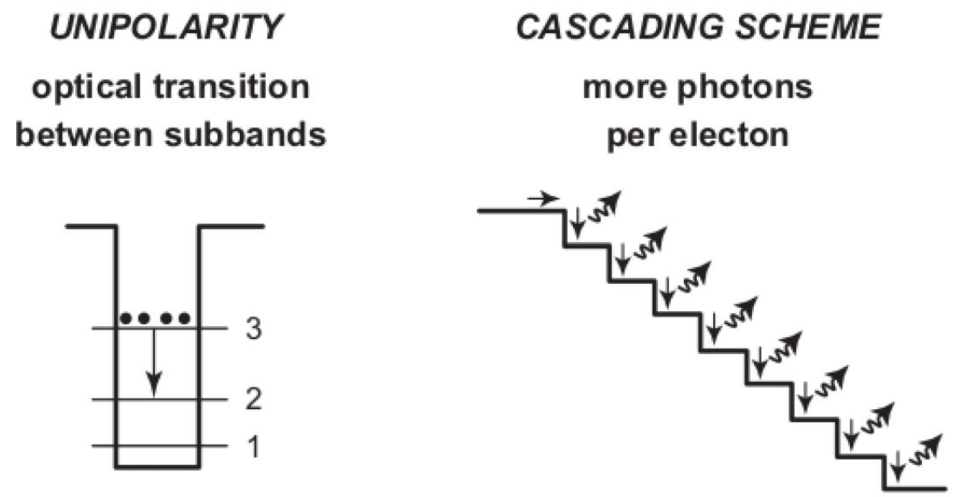
QCL

Exploiting intersubband transition in quantum wells to tune the emission energy and a cascade scheme to laser



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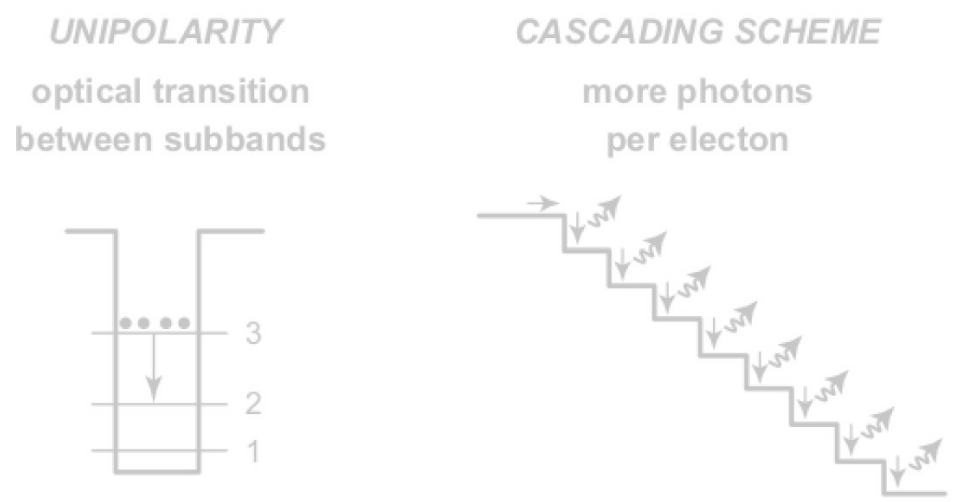
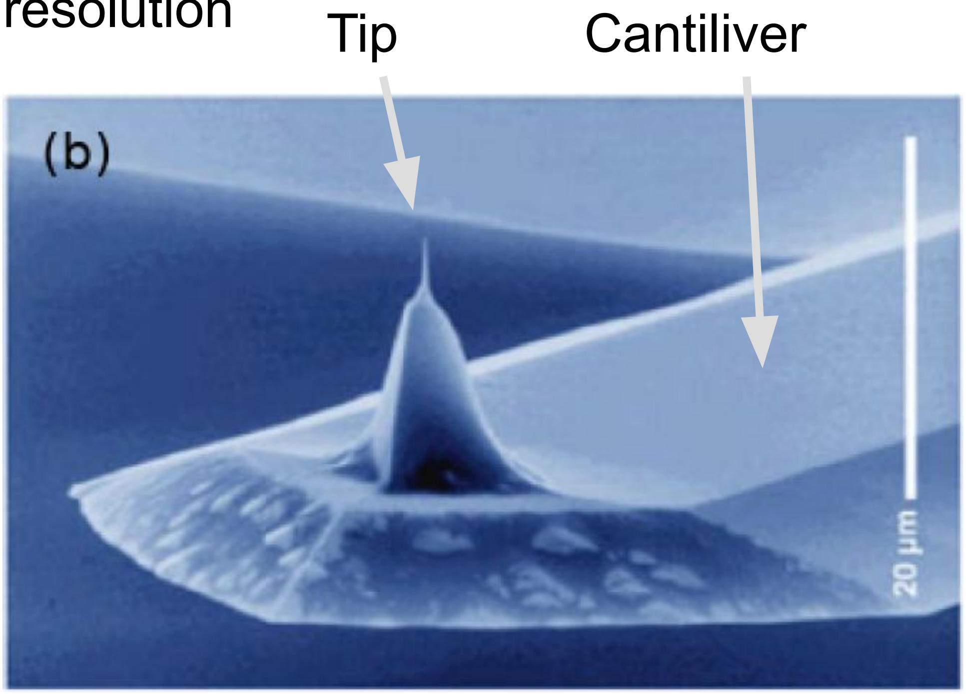


AFM

Cantiliver plus a tip reaching nanometric resolution



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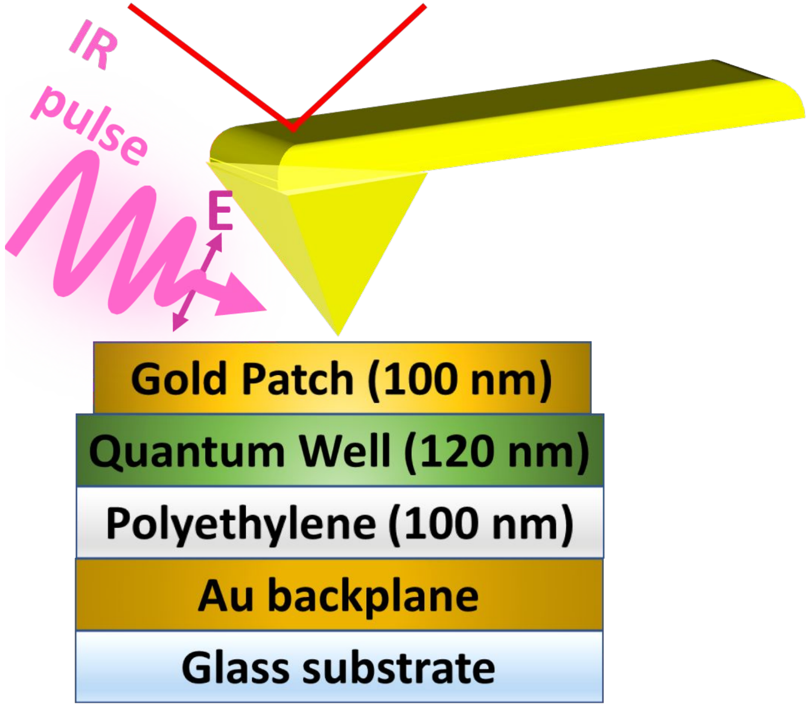
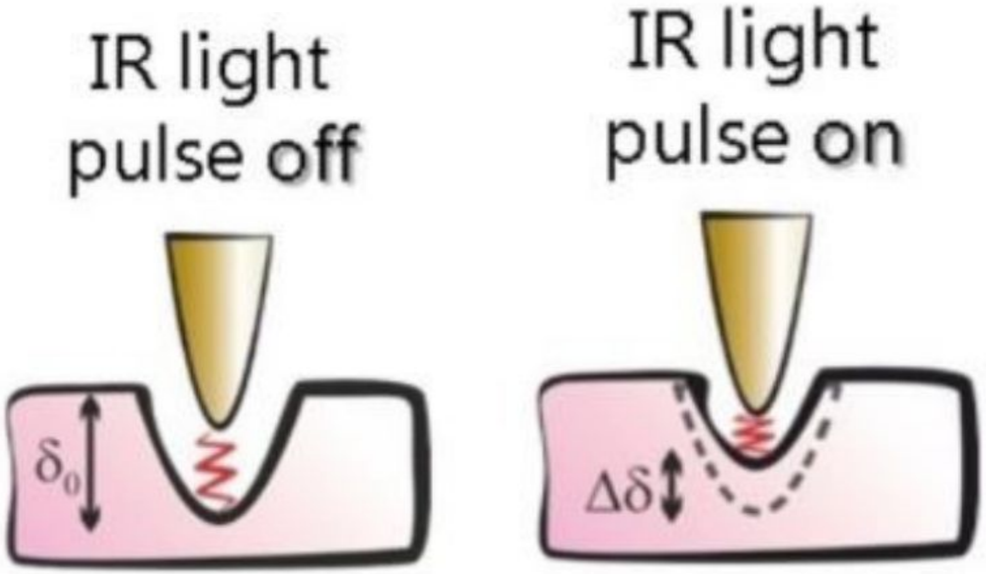
We shine the sample with Infrared Radiation using the QCL. **IF** the sample absorbs it photoexpands. We can detect the photoexpansion with the tip of the AFM with nanometric resolution!





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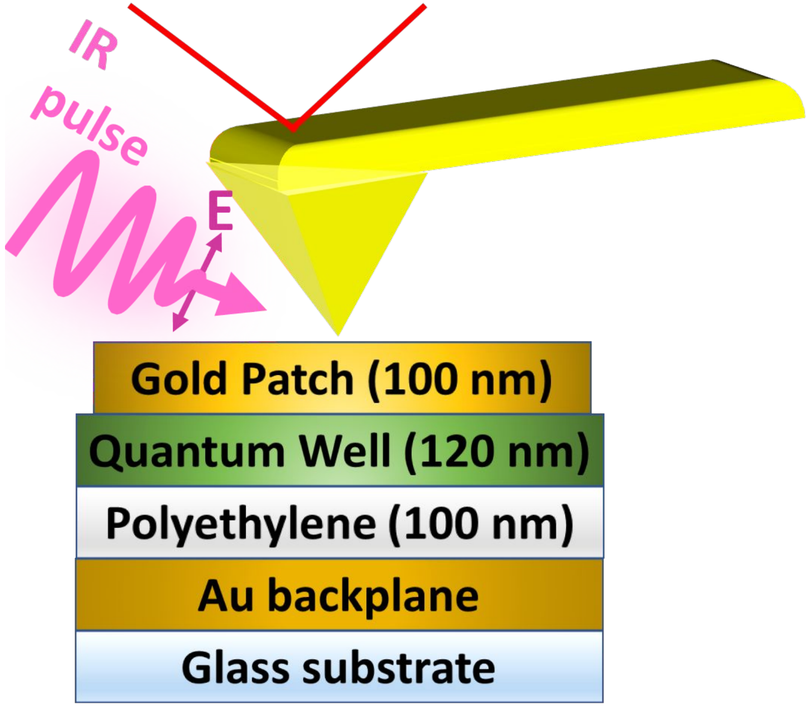
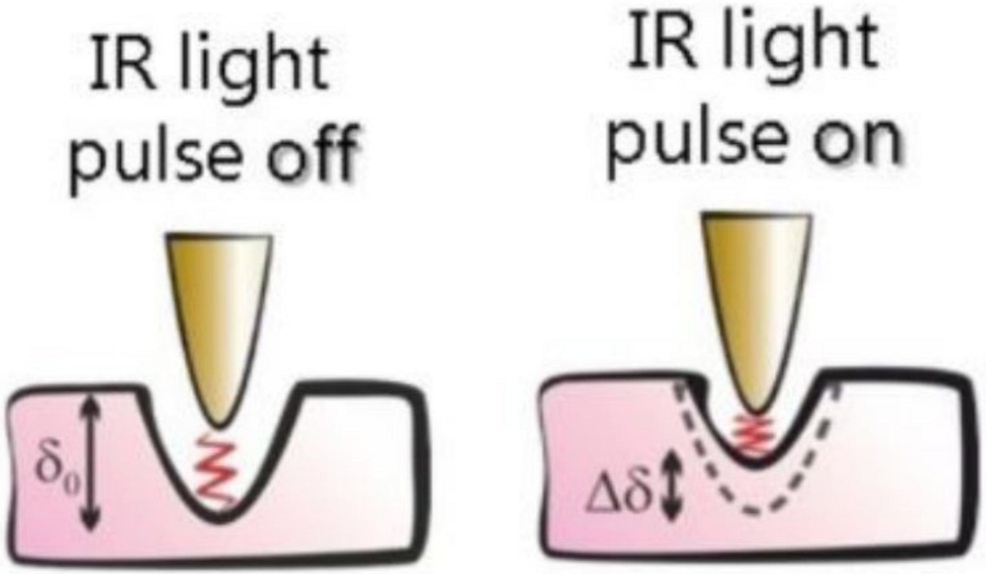
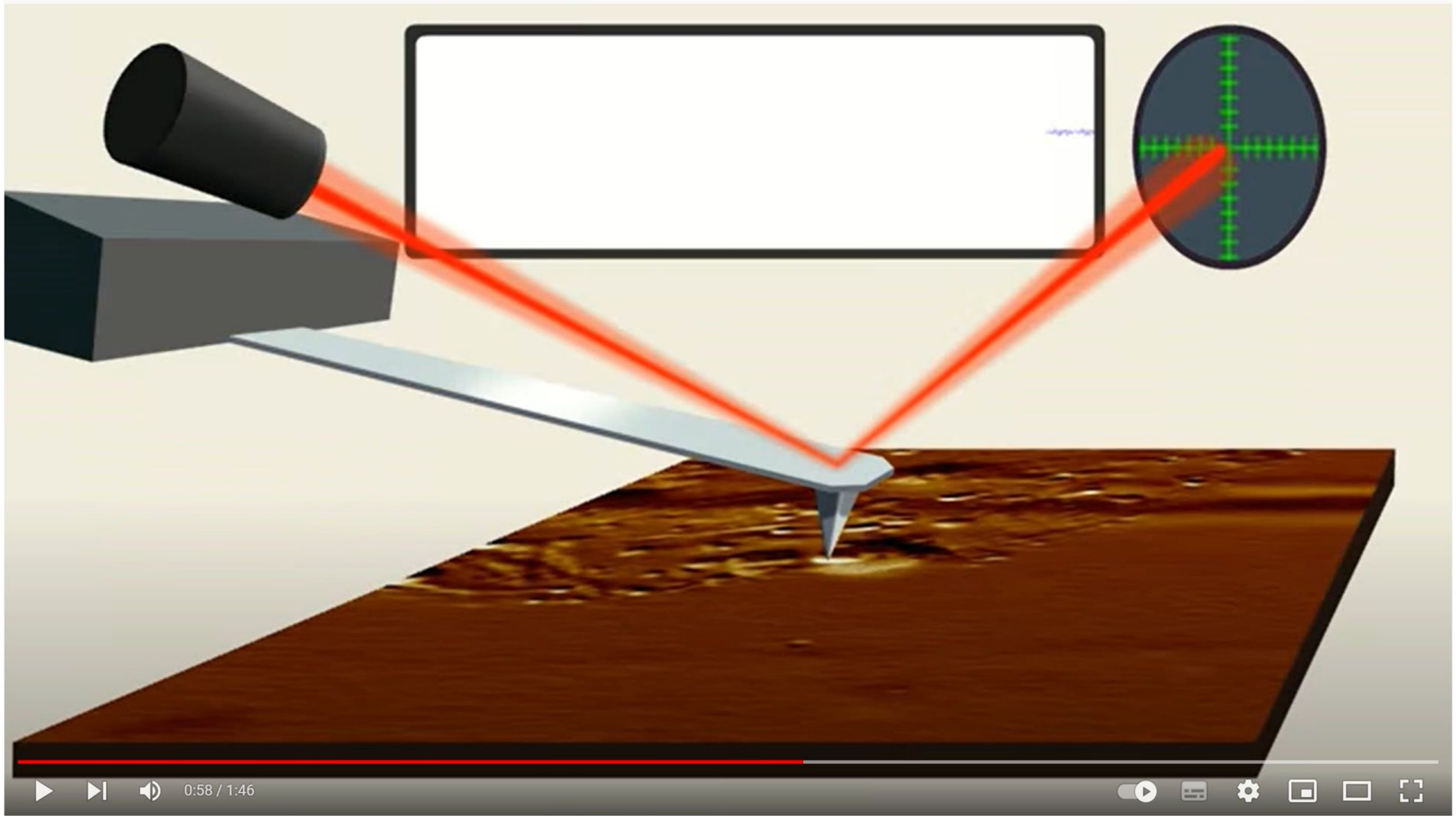




We inserted inside the cavity a layer of polymer which is almost transparent in this regime. It only acts as a **thermal and mechanical transducer**

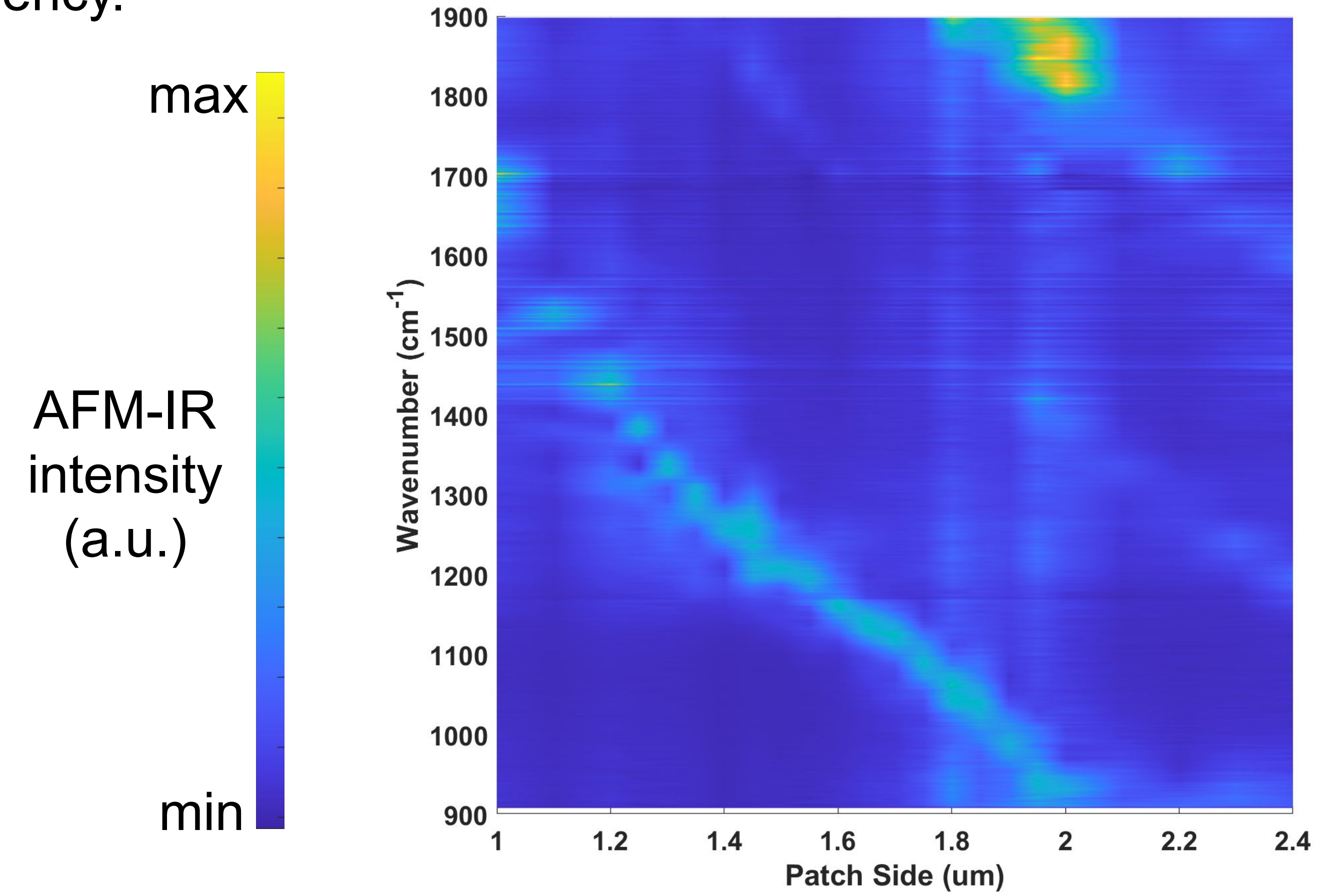
Experimental Technique: AFM-IR

https://www.youtube.com/watch?v=3jM68P0LZHc



Experimental Results: No Coupling

We focus on antennas with undoped quantum wells (no electronic transition avaible!) hence no strong coupling expected. We acquire absorption spectra changing the antenna side, so that tuning the resonant frequency.



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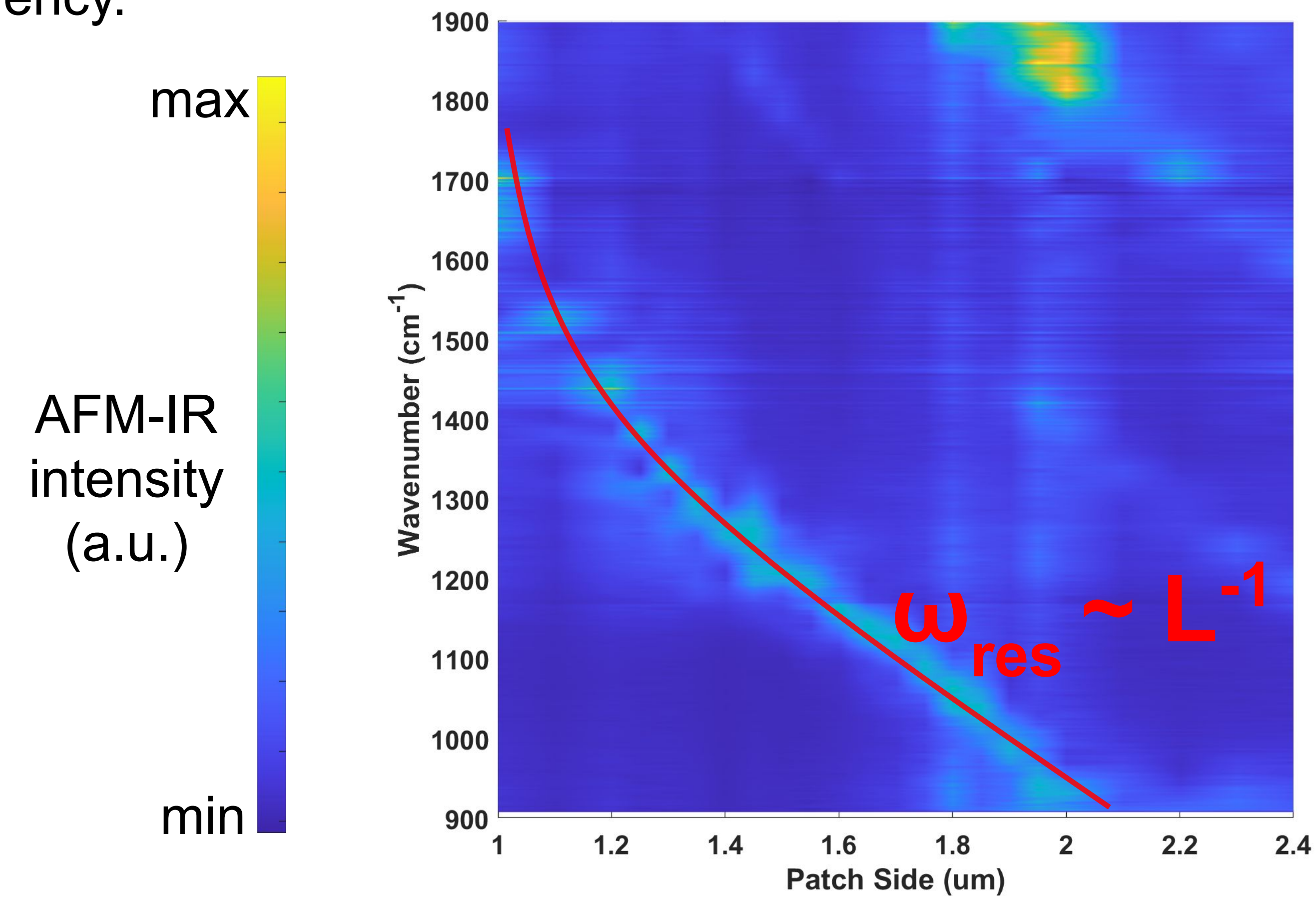
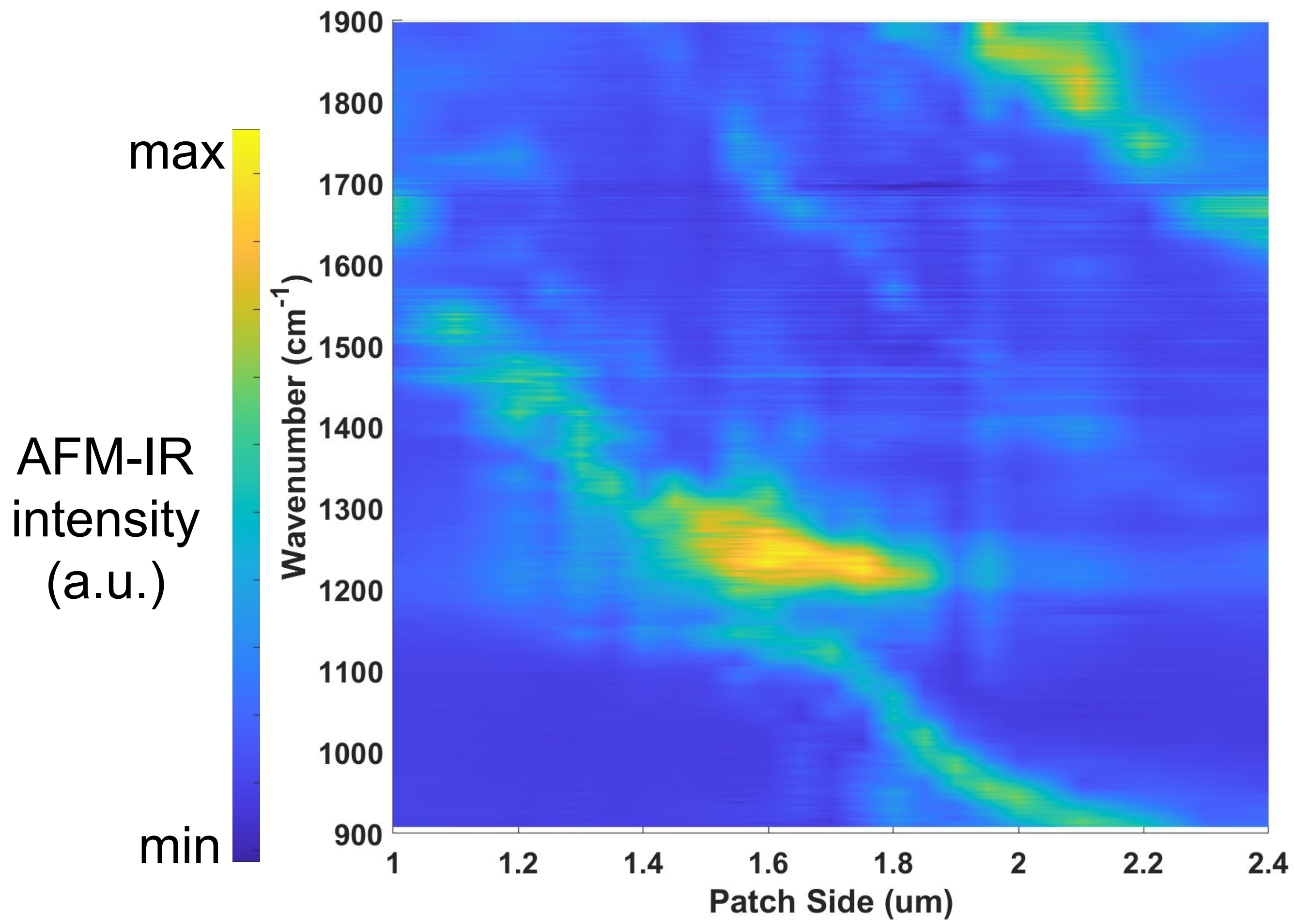


We observe the (hyperbolic) resonant frequency of the patch antenna

Experimental Results: Strong Coupling!

Then we move to doped antennas to reach the light-matter strong coupling regime, the things change!



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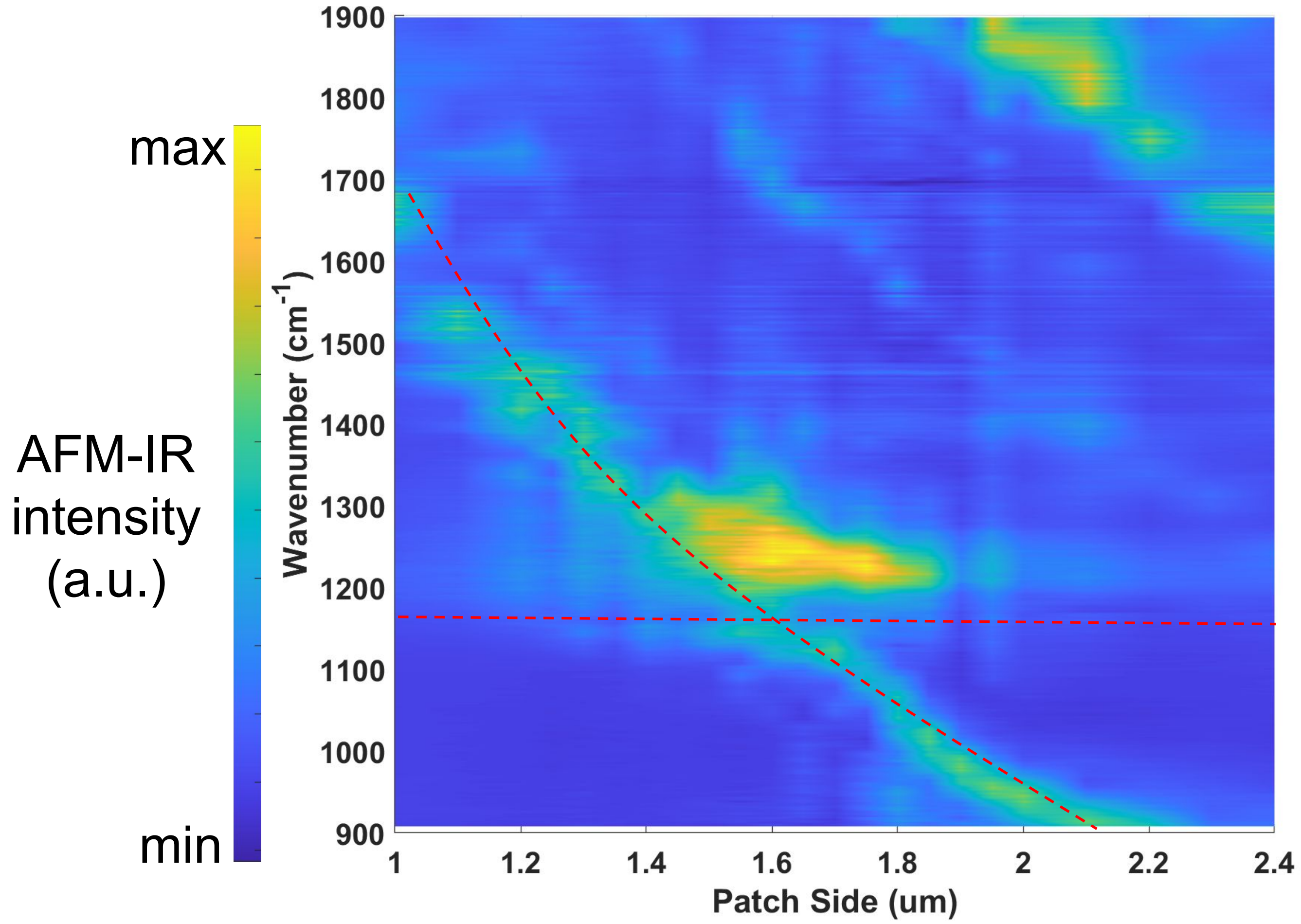

The spectra now cannot be described by the antenna resonance and the electronic transition alone!

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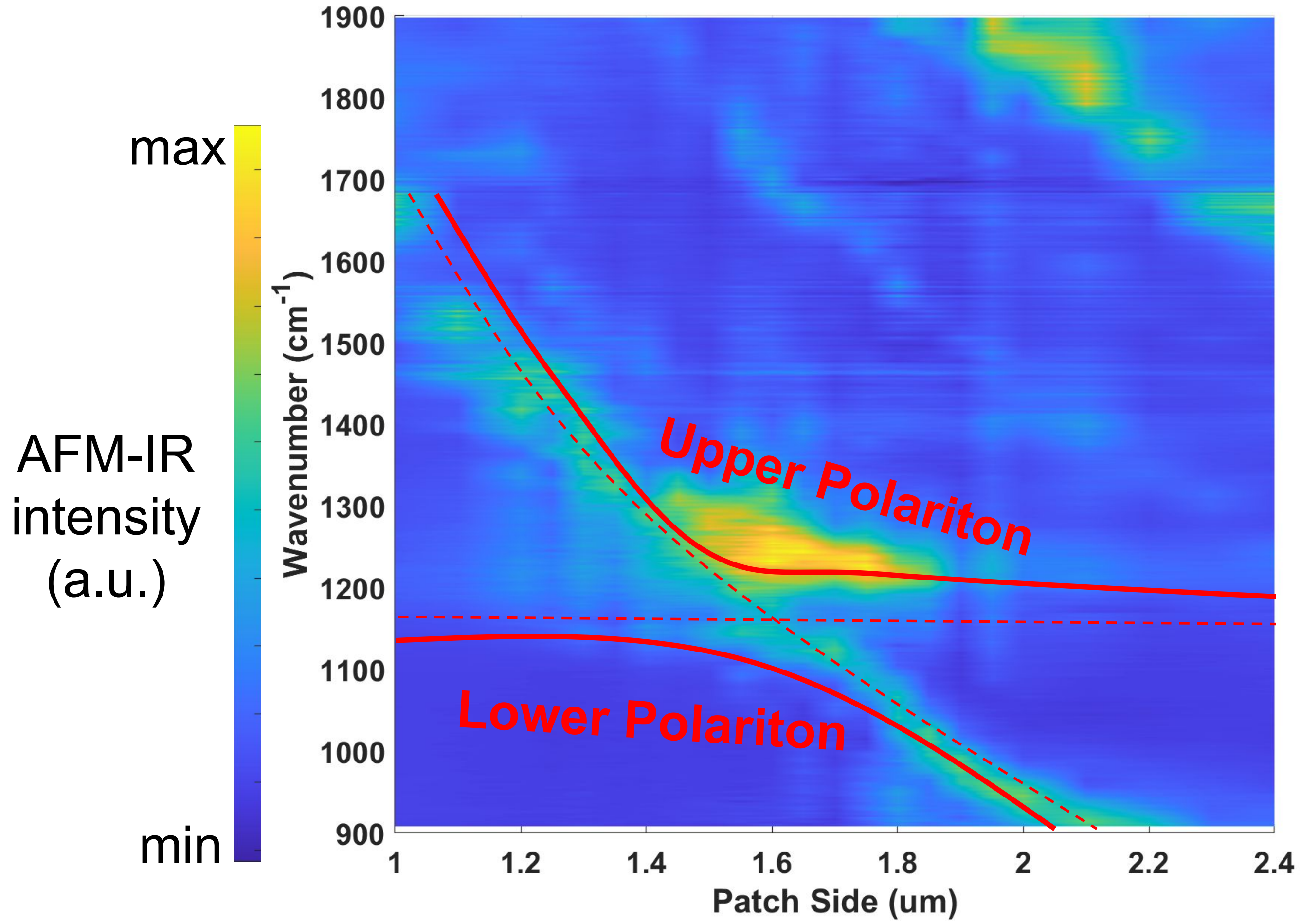

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We reached the light-matter strong coupling regime probing the single antenna!

Acknowledgments…

Infrared Spectroscopy Group

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Thank you all for your attention!