Critical Coupling in Polaritonic Metasurfaces

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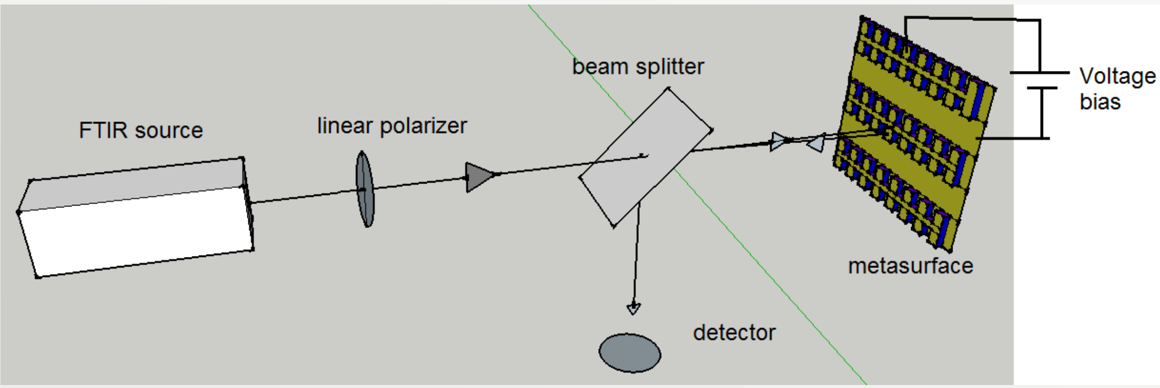
Problem and Context

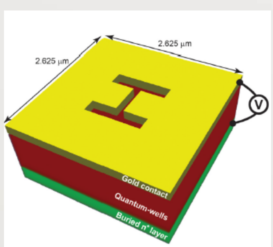
- Metasurfaces are flat, thin optical components that can introduce abrupt changes to the properties of incident light.
- Goal: Change the reflection of a mid-infrared beam with a voltage bias.
- Can be used as a modulator

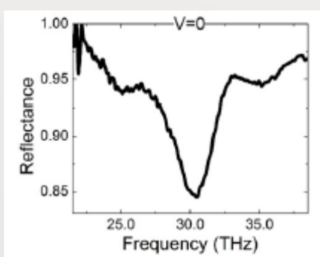


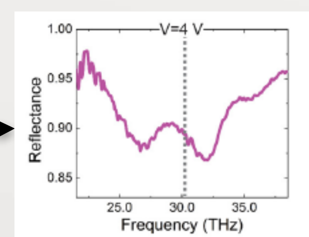
- Critical coupling and no reflection when there is no voltage bias across the metasurface.
- Increase reflection with a voltage bias.

Previous work:

- A metasurface made with a pattern of H shaped openings.
- See a reflection change going from 0V to 4V

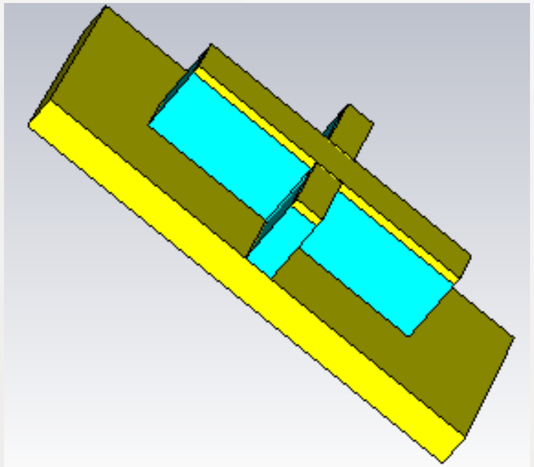


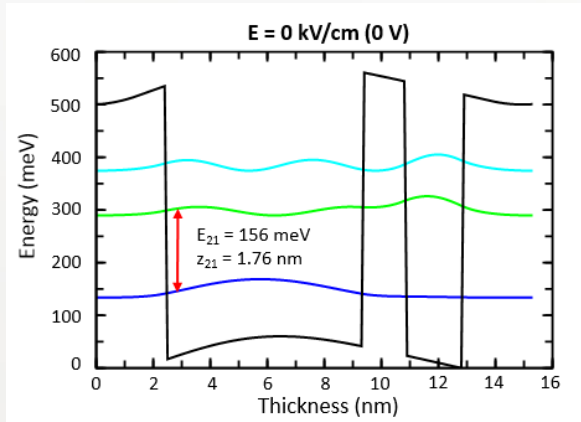


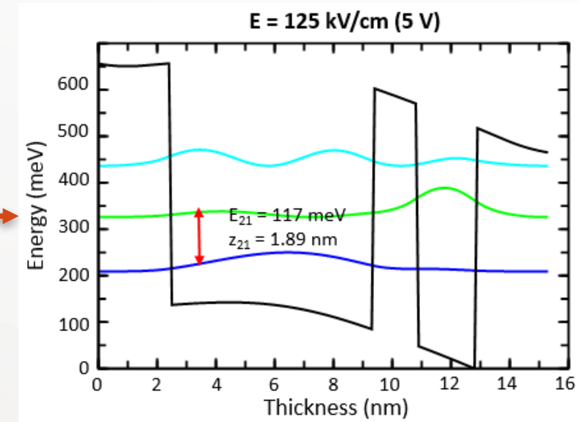


Benz, A., Montaño, I., Klem, J. F., & Brener, I. (2013). Tunable metamaterials based on voltage controlled strong coupling. *Applied Physics Letters*, *103*(26).

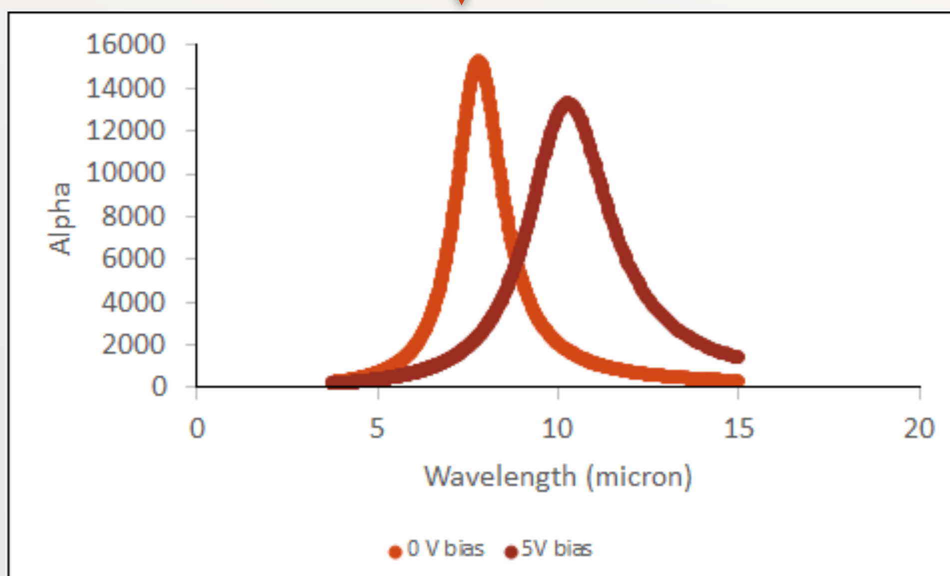
Theory



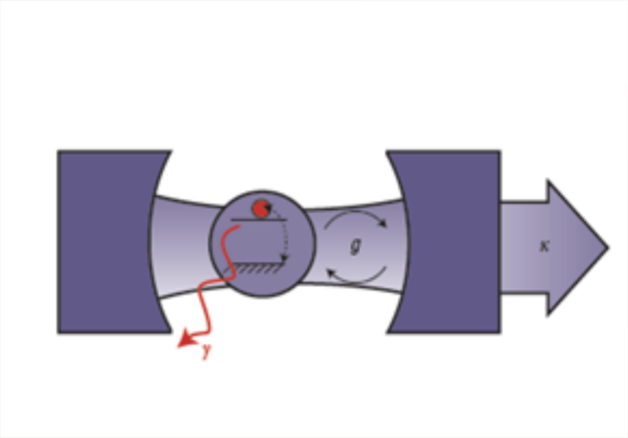




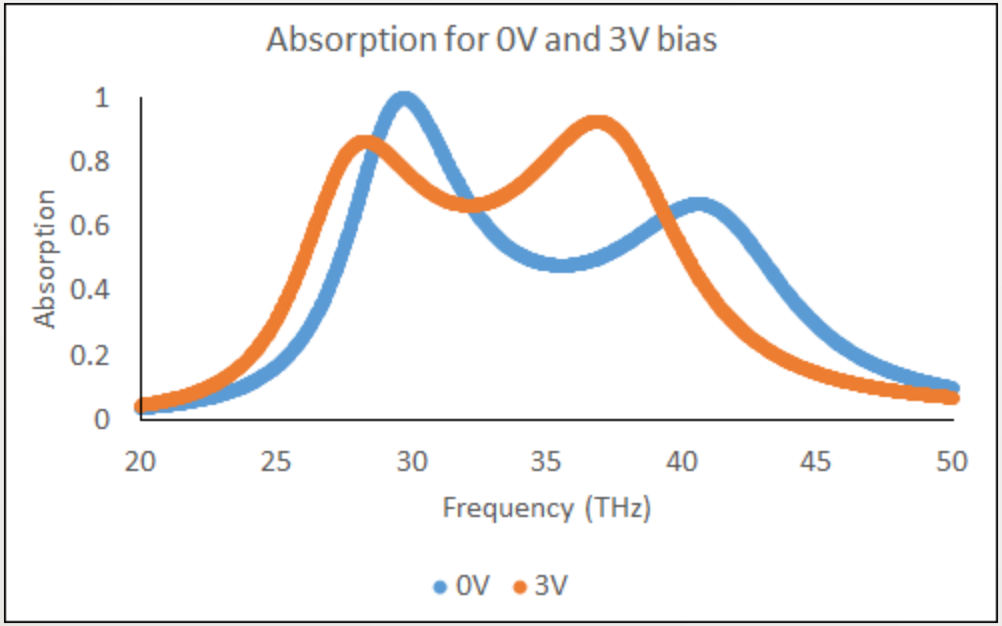
- The gold dipole acts as an optical cavity which, at the resonance frequency, confines light inside a subwavelength volume.
- The MQW acts as a two level system, whose absorption can be tuned by a voltage bias.



Theory continued



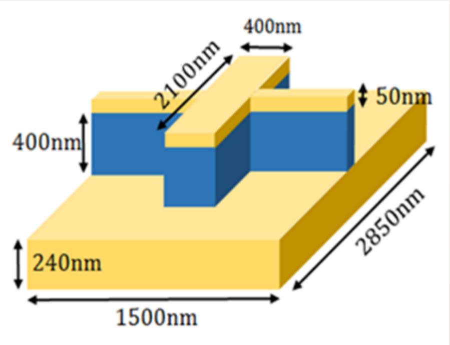
- Coupling an optical cavity to an IST forms a polariton
- A polariton exhibits two energies, which is observed in a dampening and splitting of the absorption spectrum.

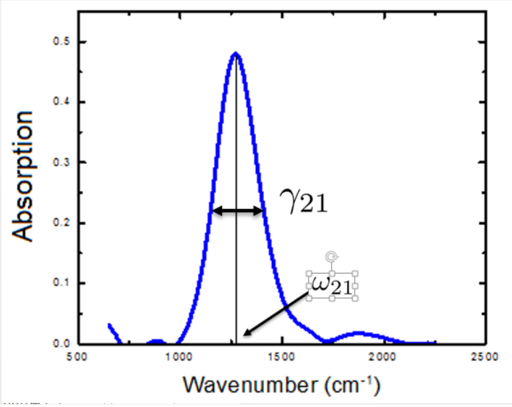


Khitrova, G., Gibbs, H. M., Kira, M., Koch, S. W., & Scherer, A. (2006). Vacuum Rabi splitting in semiconductors. *Nature Physics*, *2*(2), 81–90.

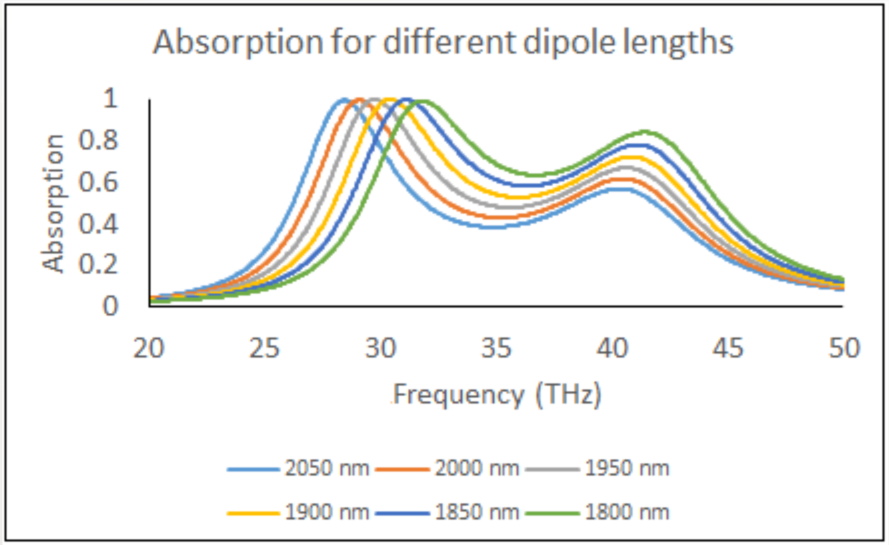
Design and Simulation

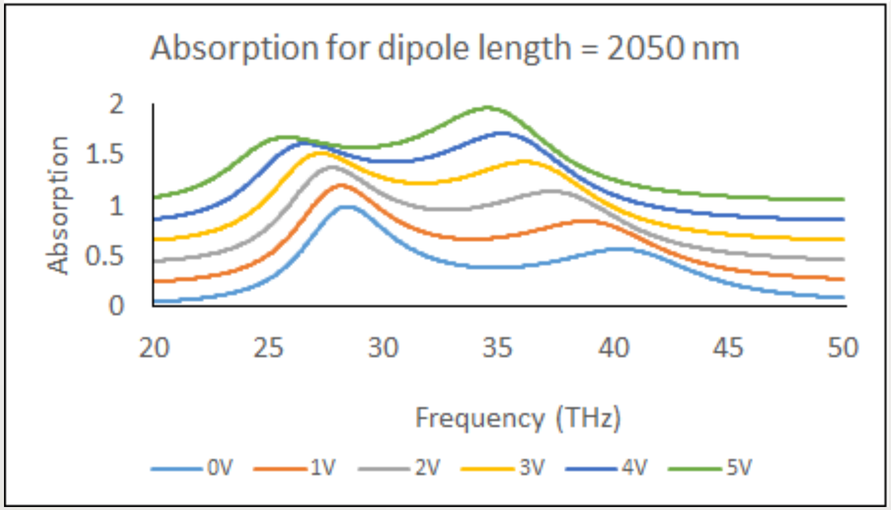
- The unit cell is constructed in CST simulation software.
- Electric permittivity values are calculated and the optical response is observed for different dipole lengths to look for largest absorption change under a voltage bias





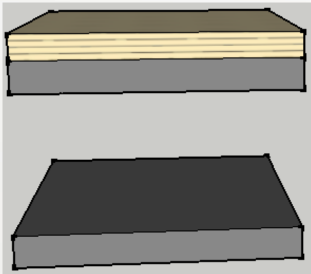
$$\epsilon_\perp(\omega) \approx \epsilon_{core}(\omega) + \frac{N_e(ez_{12}^2)}{\epsilon_0\hbar((\omega_{21}-\omega)-i\gamma_{21})}$$



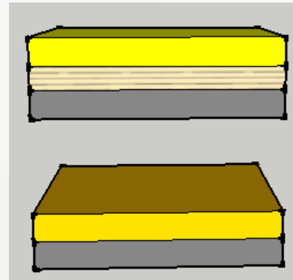


Fabrication

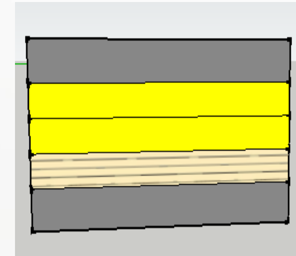
Starting set up



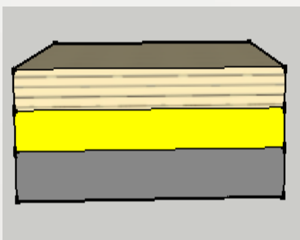
Deposit AU 120 nm



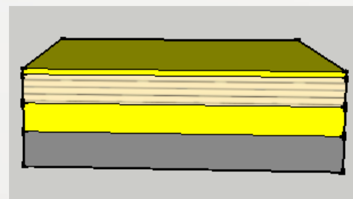
Wafer bond



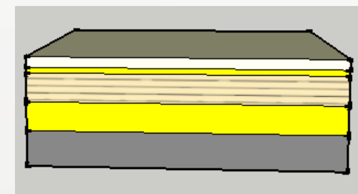
Polish and wet etch



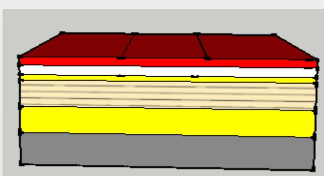
Deposit Au 50 nm



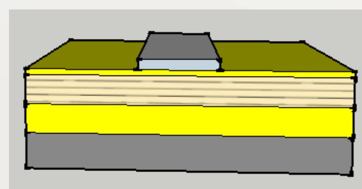
Deposit SiN 200 nm



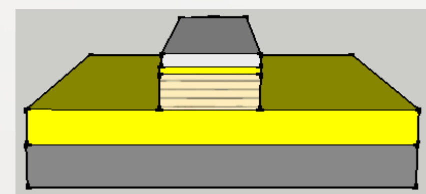
E-beam litho



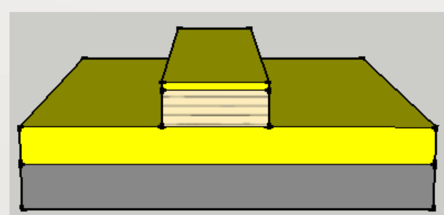
RIE etching and apply Acetone



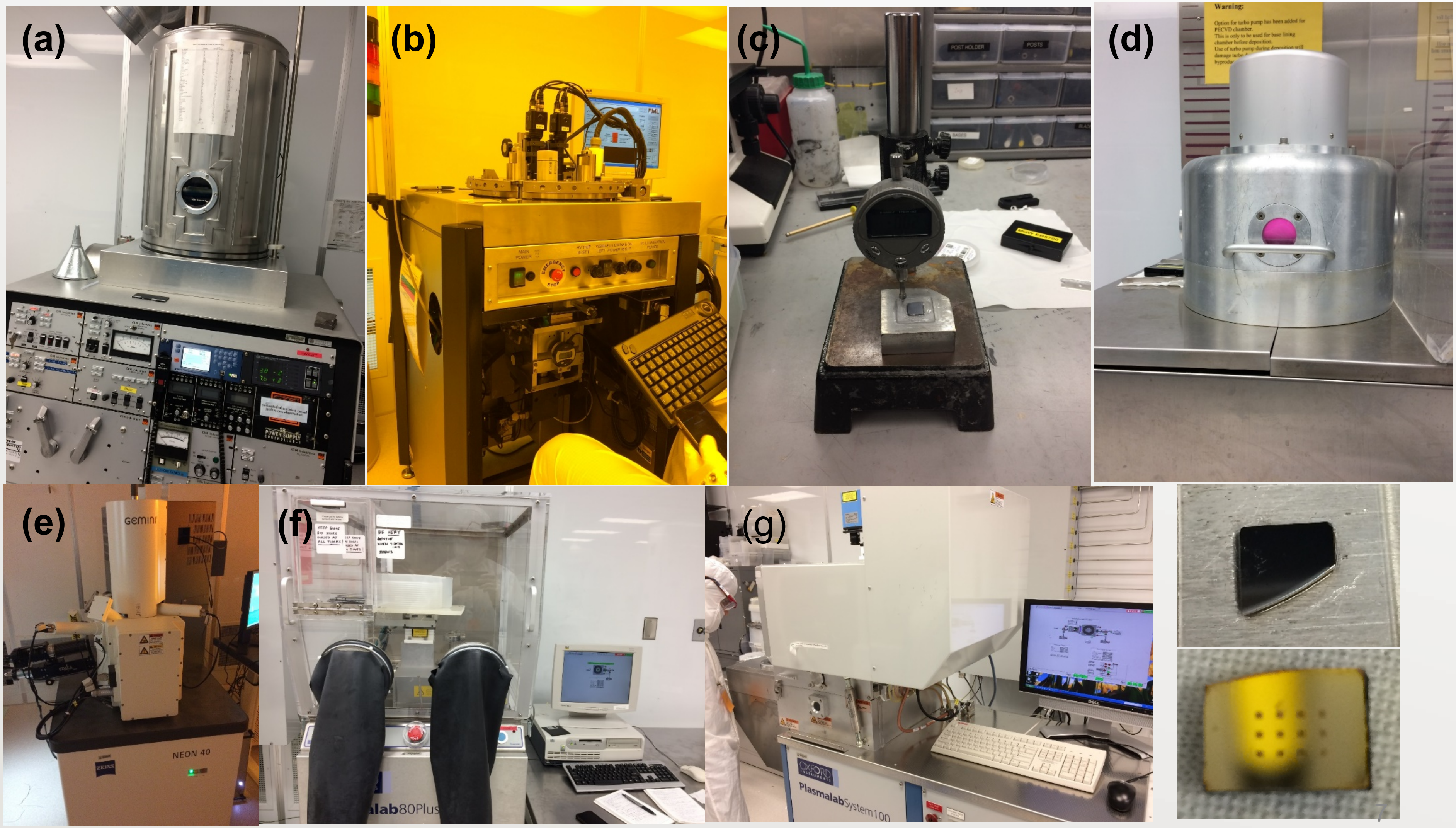
ICP etching



Apply HF

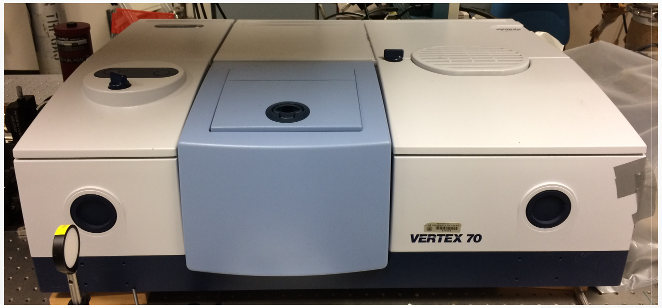


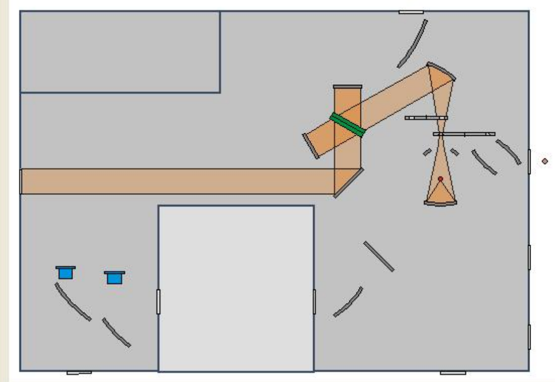
(a) e-beam evaporator metal deposition → (b) wafer bond → (c) polish and wet etch → (d) PECVD SiN deposition → (e) EBL → (f-g) RIE and ICP plasma etch



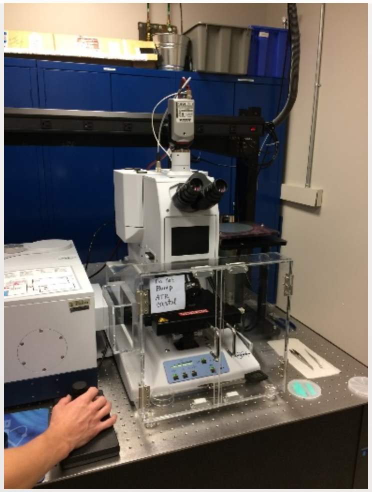
Absorption Measurements

- FTIR – Fourier Transform Infrared Spectroscopy
- A broadband source is sent into an interferometer.
- Reflection results are converted from reflection per mirror position to reflection per frequency.

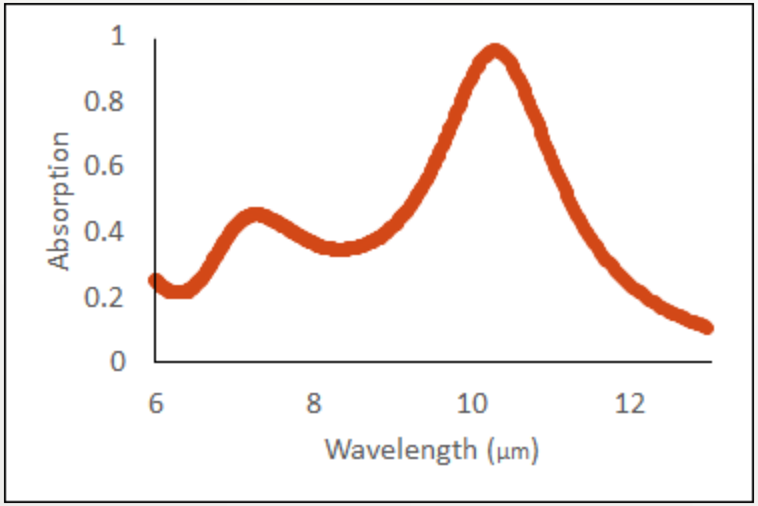




- FTIR signal is outsourced into an infrared microscope objective.

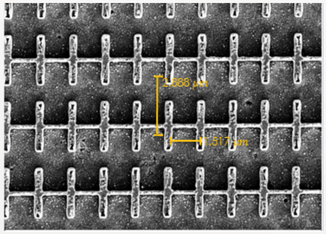


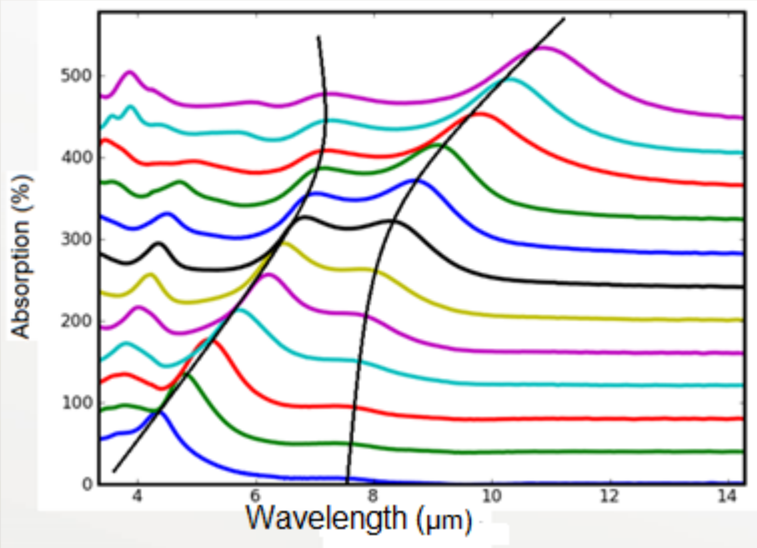
Critical Coupling



Experimental results for a dipole length of 2300 nm. Absorption peak of 96% at ~ 10.3 μm.

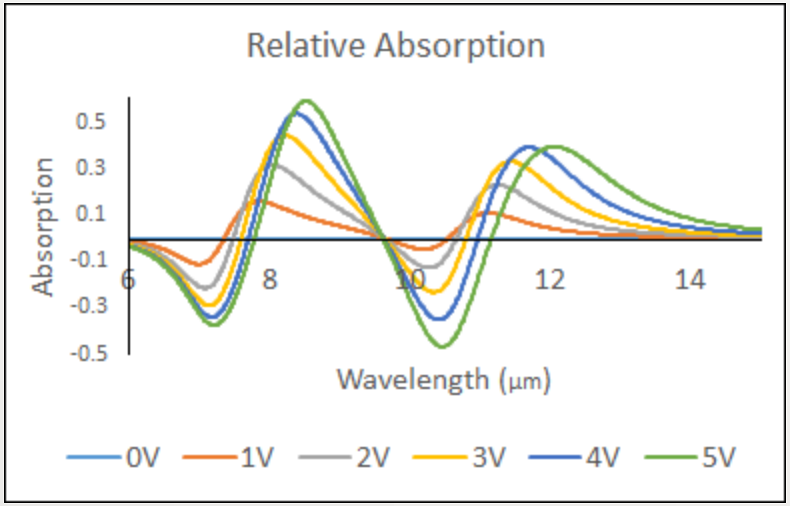
- A total of 12 patterns with dipole lengths ranging from 1300- 2400 nm were made.
- Critical Coupling was achieved with up to 97% absorption.





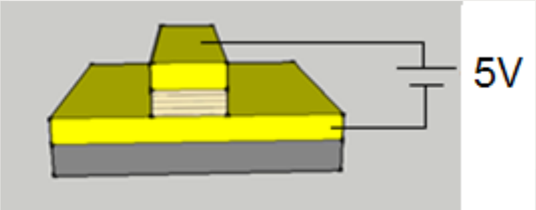
Experimental results for dipoles with mask lengths 1300 – 2400 nm. Results are offset by 40% for clarity.

Simulation Results for applying different DC bias voltages.



Future Work and Applications

- We plan to apply a voltage bias to contacts on the gold surface and ground plane to demonstrate an electrically tunable metasurface operating in the mid-infrared spectral range.
- Stark Tunable metasurfaces have already been demonstrated before. For this project, we hope to achieve a larger absorption change in designing for critical coupling in the unbiased case.
- Potential applications include an electrically tunable optical filter or laser modulator.



Acknowledgements

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