Dielectric Response of Novel LC Resonant Metamaterial using THz impedance spectroscopy

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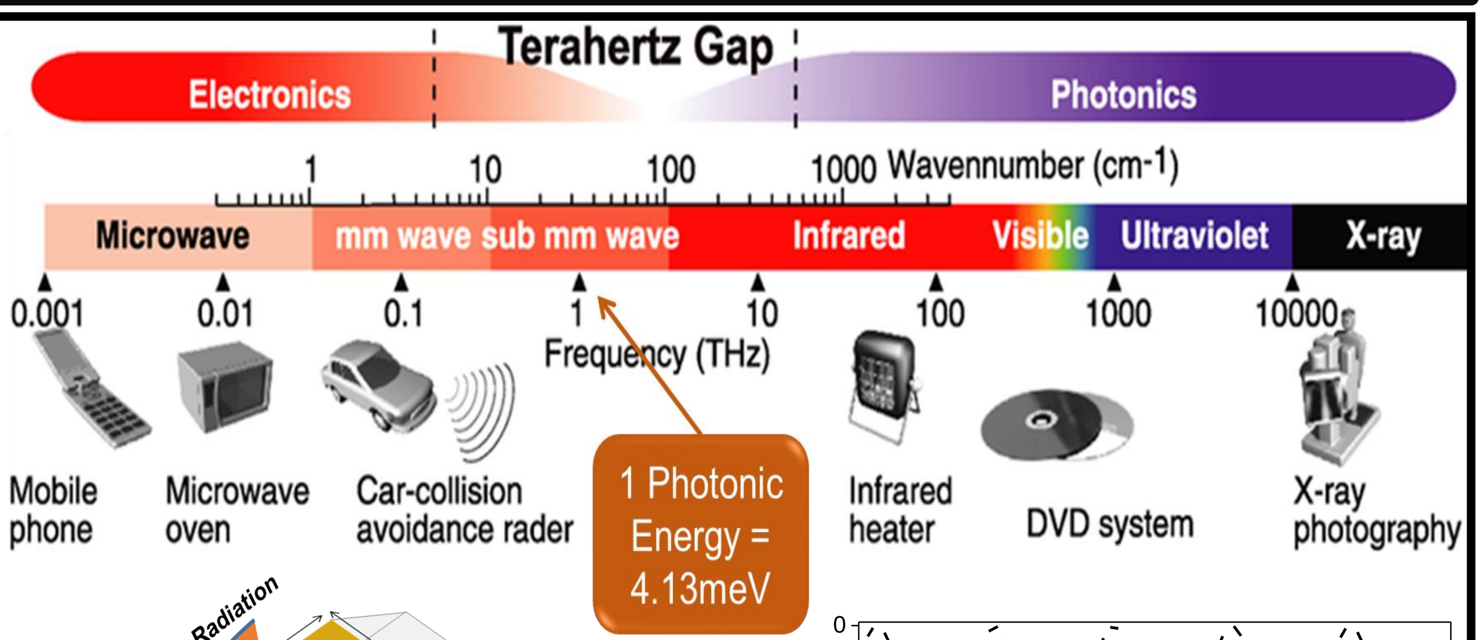
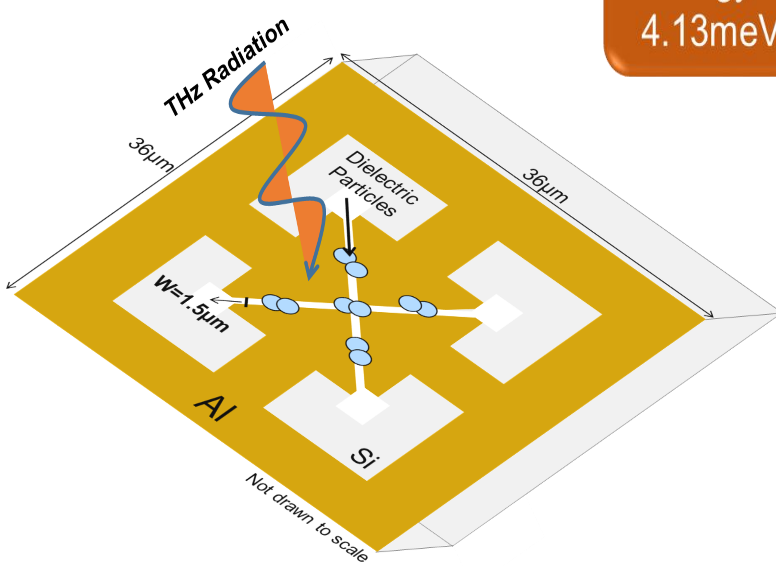
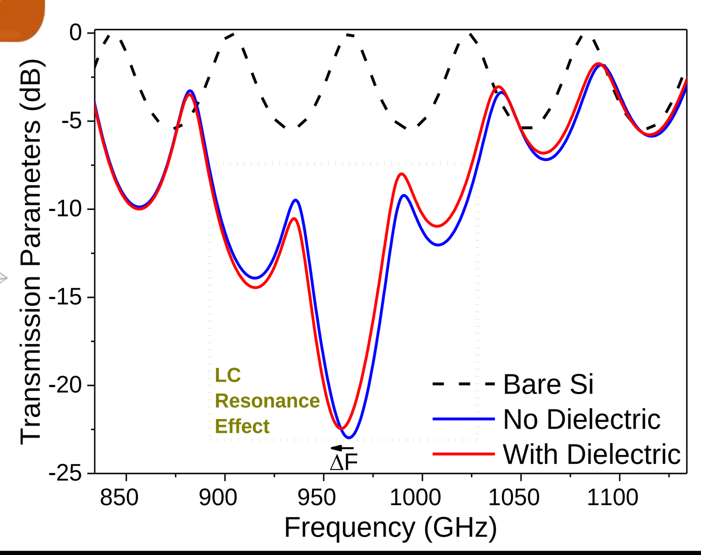
ABSTRACT

A change in terahertz (THz) metamaterials (M.M) resonance frequency (F_0) can be brought by any foreign substance deposited in the capacitive-gap region, thereby changing the effective dielectric constant (ε_{eff}) and thus the capacitance, resulting in a redshift in the resonance frequency (ΔF) with respect to the pristine LC circuit in the array. The dielectric response is maximized by proper engineering and optimization of the M.M geometry and material so that we can extract the maximum ΔF for lower concentration of dielectrics. Moreover, the Fabry-Perot (FP) oscillations of the substrate interacts with the M.M. resonance which results in increment/decrement of the electric and magnetic field coupling to the M.M; thus give rise to strong/weak coupling of FP-M.M resonances, depending on the thickness and material of the substrate. Thus, the dielectric response can be maximized by proper engineering and optimization of the M.M (including substrate) geometry and material so that we can extract the maximum ΔF for lower concentration dielectrics.







LC RESONANT METAMATERIAL

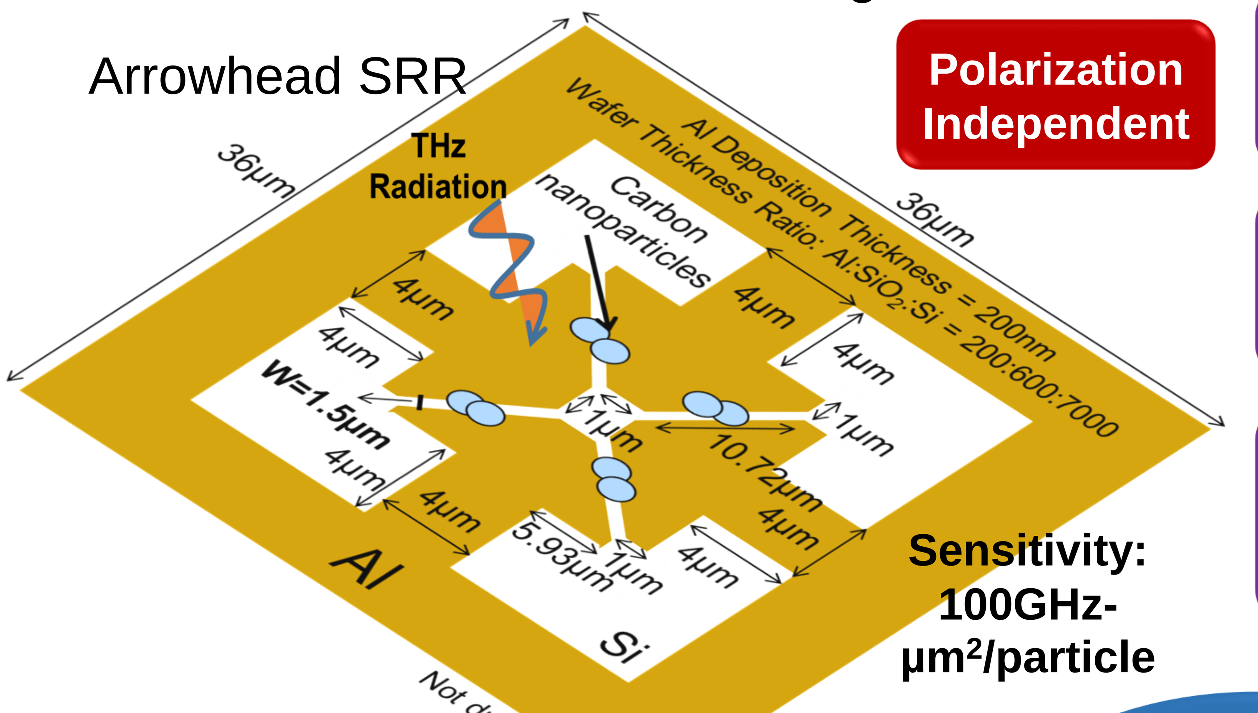
WORKING PRINCIPLE

- **LC resonant M.M consists of an inductive (L) and capacitive (C) element, with natural resonant frequency F_0.**
- **Any dielectric particle introduced in the capacitive gap area, changes the effective dielectric constant and hence the resonating frequency of the M.M.**
- **This dielectric response of M.M structure is characterized by a red-shift of the M.M resonant frequency, which is captured at resonance by THz impedance spectroscopy.**

DETECTOR STRUCTURE – NOVEL DESIGN

1. Metamaterial Architecture Design

Arrowhead SRR



Polarization Independent

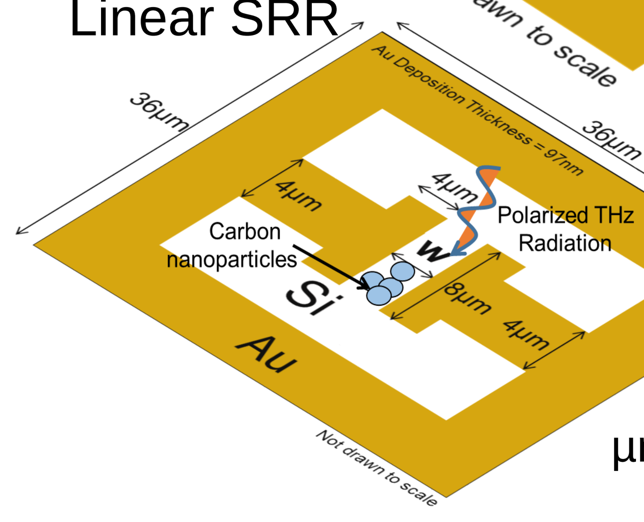
Larger Capacitive Areas

Higher Sensitivity

More effective for nanoparticles

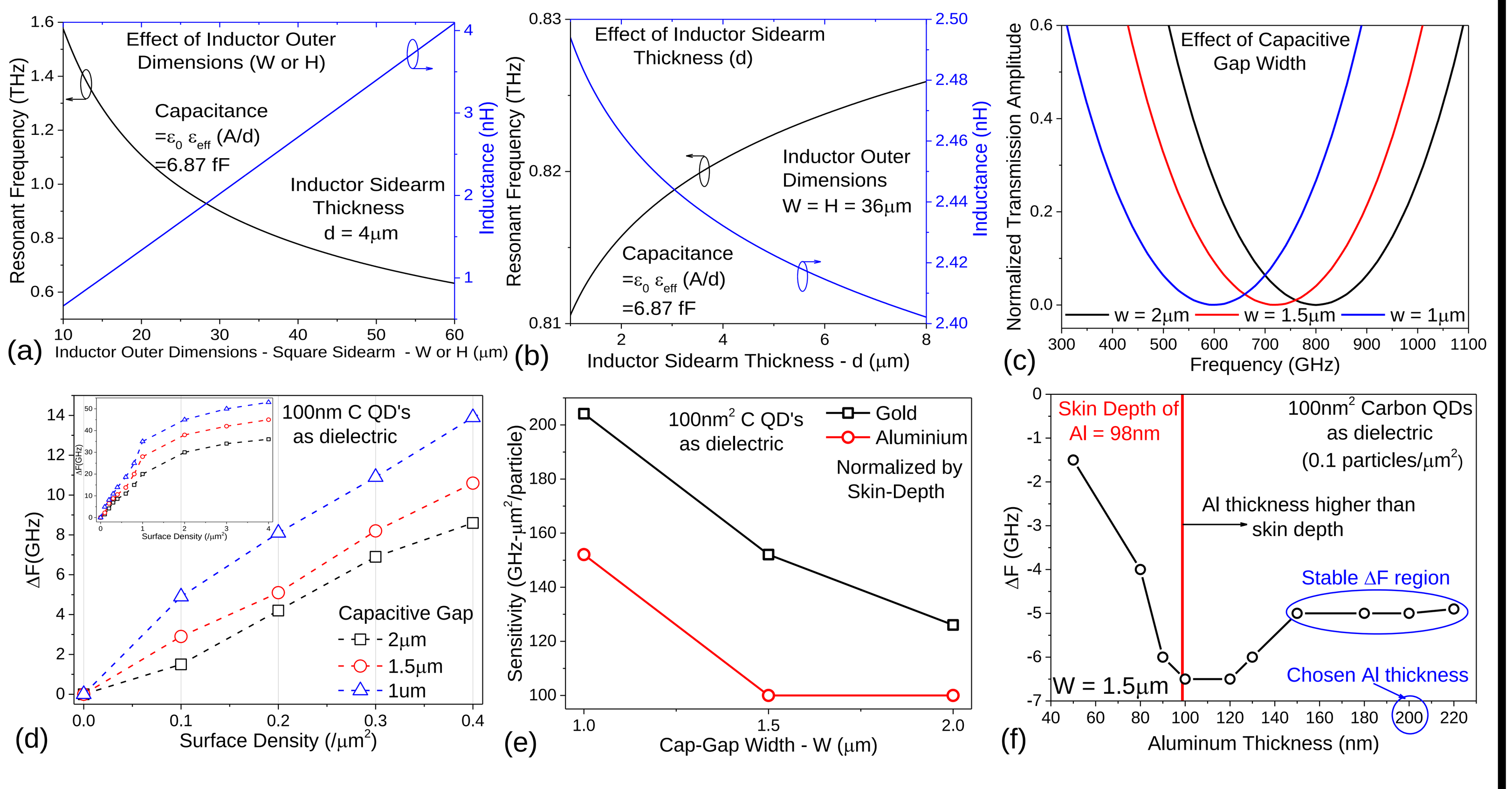
Sensitivity: 100GHz-µm²/particle

Linear SRR

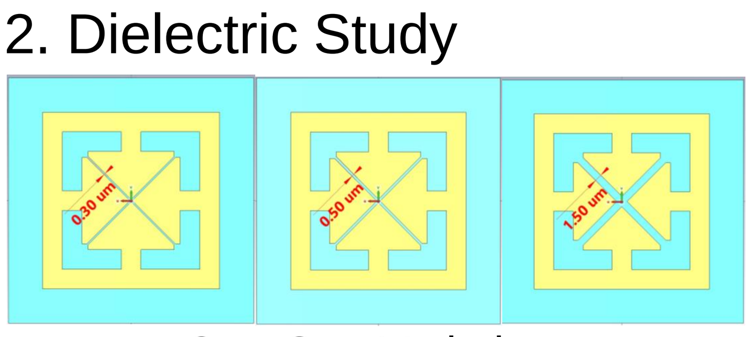


Sensitivity: 20GHz-µm²/particle [4]

5X Enhancement in Sensitivity compared to Linear SRR



2. Dielectric Study

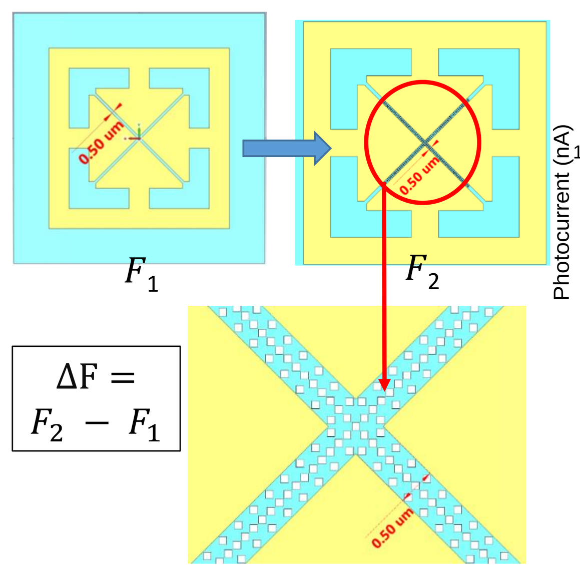


Cap-Gap Variations

$$F_0 = \frac{1}{2\pi\sqrt{LC}}$$

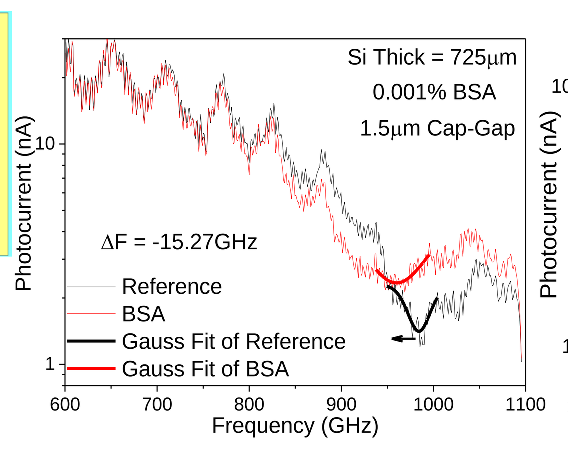
$$C = \varepsilon_0 \varepsilon_{eff} \frac{A}{W}$$

$$F_0 \propto \frac{1}{\varepsilon_{eff}}; F_0 \propto A$$

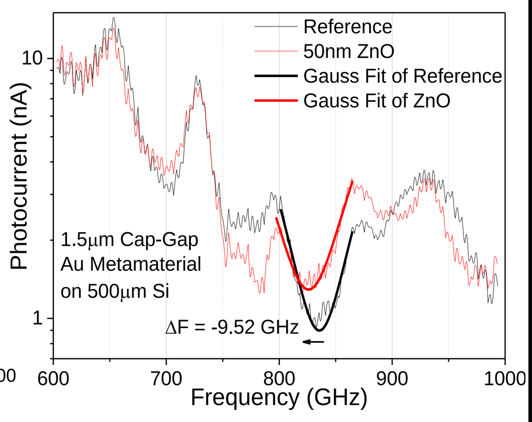


$$\Delta F = F_2 - F_1$$

Resonance Frequency Shift

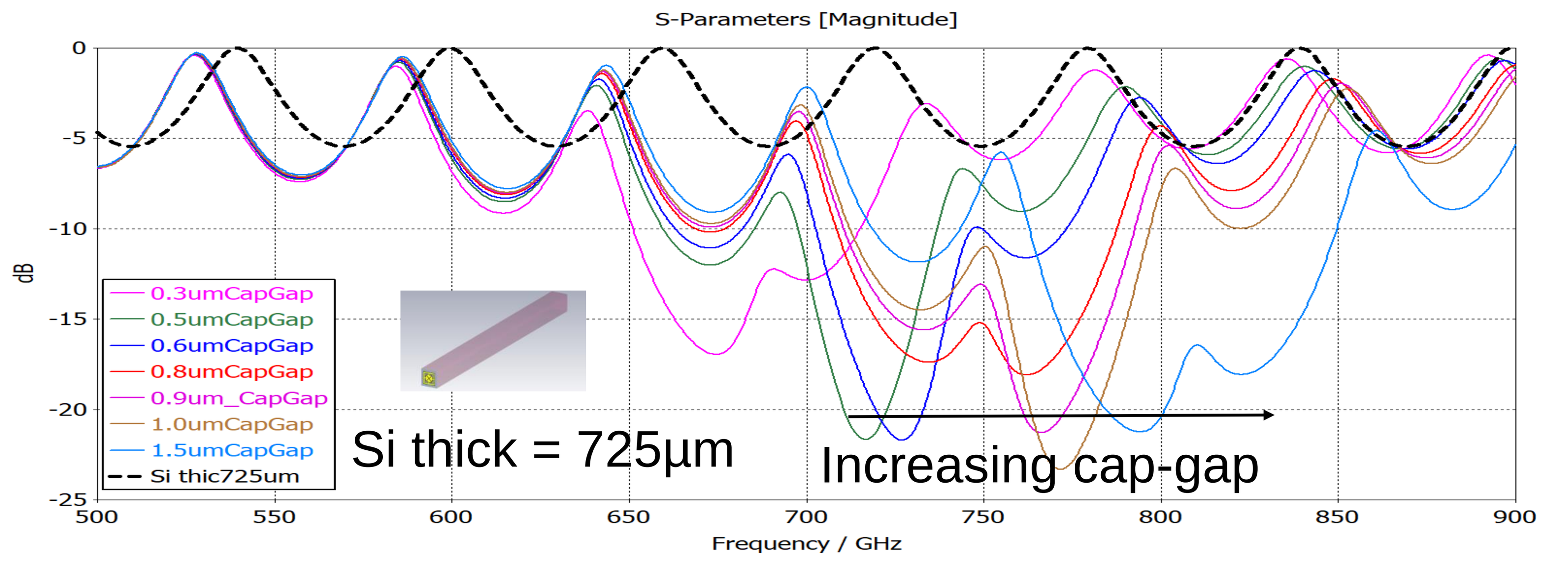


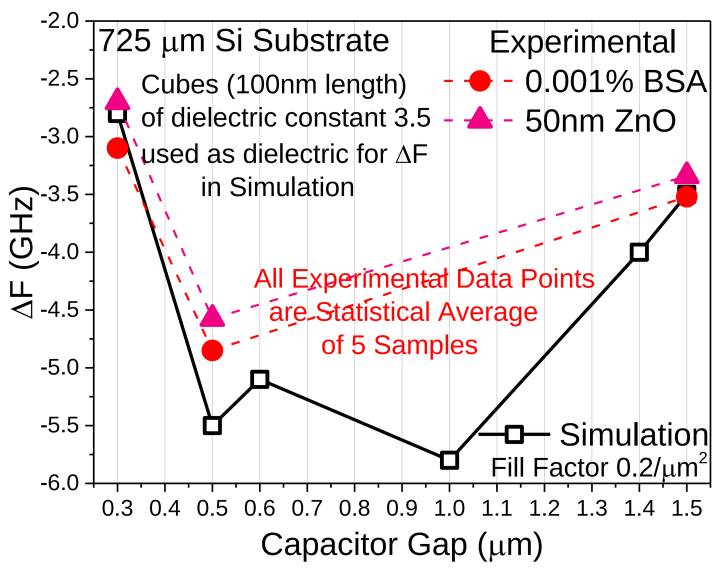
Experimental ΔF for Organic nano-particles (Bovine Serum Albumin – BSA)

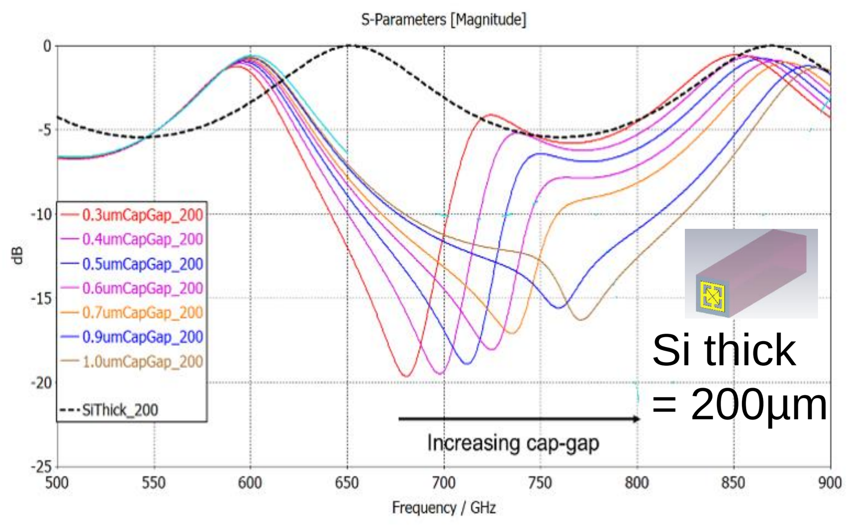


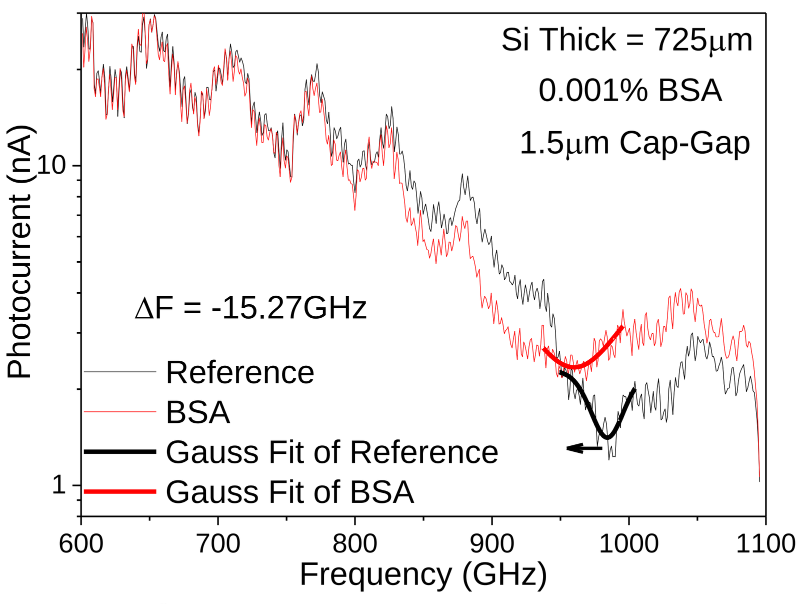
Experimental ΔF for Inorganic nano-particles (Zinc Oxide – 50nm)

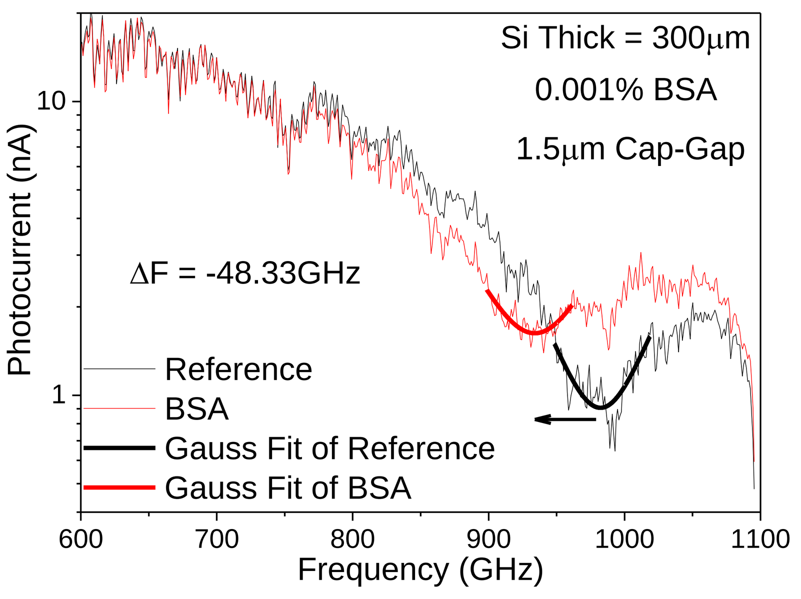
FABRY-PEROT (FP) COUPLING WITH M.M

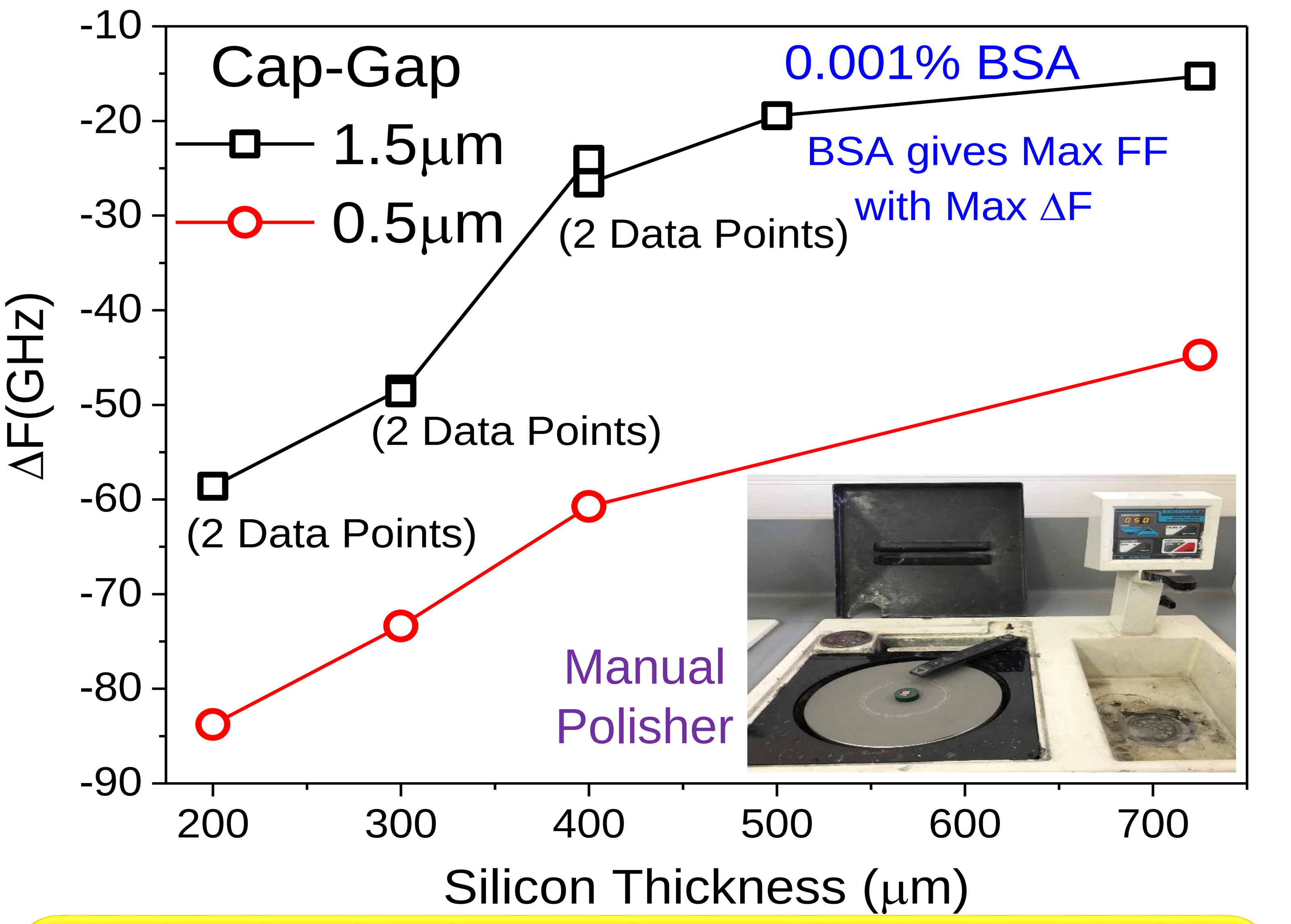












De-Coupling MM from FP Resonance

- Reduction in Silicon (substrate) thickness reduces ε_{eff} and also widens F.P. oscillations.
- ΔF increases by 5X, hence enabling ultra-sensitive detection.
- Promising to use in virus detection.

REFERENCES

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4) Park, S. J.; Cha, S. H.; Shin, G. A.; Ahn, Y. H. Sensing Viruses Using Terahertz Nano-Gap Metamaterials. Biomed. Opt. Express 2017, 8 (8), 3551. https://doi.org/10.1364/boe.8.003551.