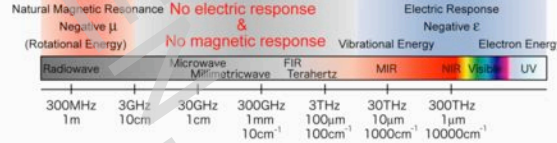
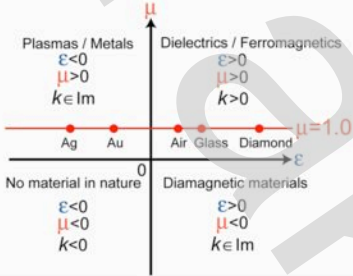


Plasmonic metamaterial

No material in nature has magnetic responses in the optical frequency region.

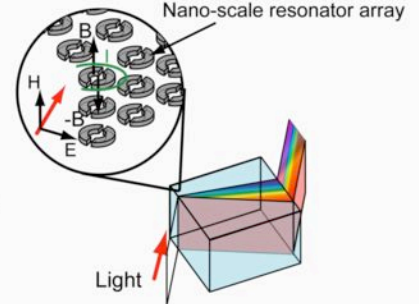
Magnetic permeability is always unity.



Why is there no magnetic materials in optical frequency region?

Spin of electrons and atoms can not follow the high frequency oscillation.

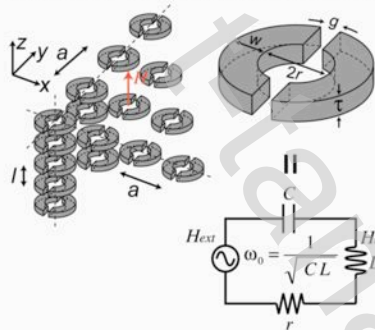
Control both ϵ and μ by plasmonic oscillation of free electrons inside metal nano structures
Element size & spacing $\ll \lambda$ to avoid diffraction



Plasmonic Metamaterial

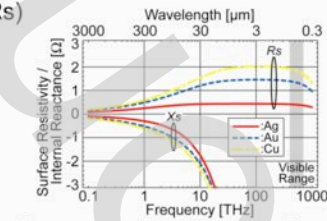
Magnetic response of plasmonic metamaterials

Plasmonic Split Ring Resonators (SRRs)



Effective permeability of the SRRs:

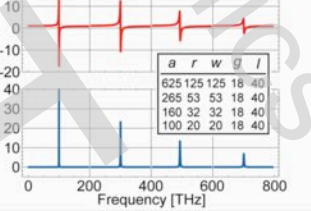
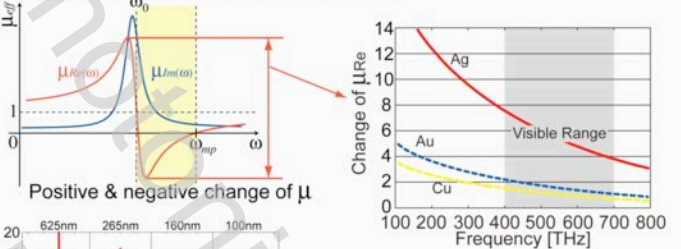
$$\mu_{eff} = \mu_{Re} + i\mu_{Im} = 1 - \frac{F\omega^2}{\omega^2 - \frac{1}{CL} + i\frac{Z(\omega)\omega}{L}}$$



Frequency dependence of metal impedance

- In visible light freq. region.
- R_s saturates at the inherent frequency.
- $\rightarrow R_s$ is Not dominant
- X_s moves away from zero drastically.
- \rightarrow A large phase-delayed current

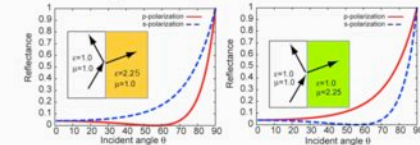
Frequency dependence of μ_{Re} & μ_{Im}



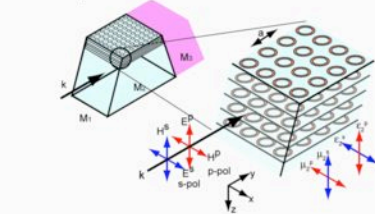
Two factors toward $\mu = 1$
~ 100THz: due to the increase of R_s
100THz ~: due to the decrease of L

An application of metamaterials to novel photon control device

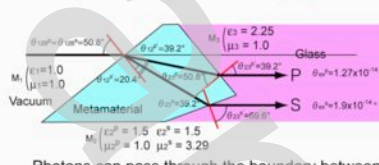
Brewster in p- and s-polarization



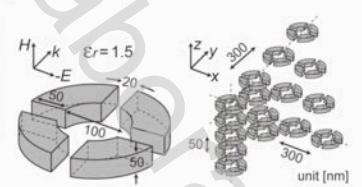
Anisotropic metamaterial



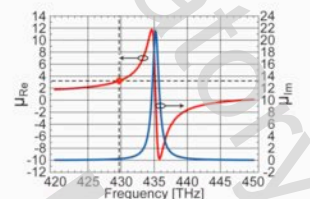
T. Tanaka, A. Ishikawa, and S. Kawata, Phys. Rev. B 73, 125423 (2006).



Photons can pass through the boundary between vacuum and glass without any reflection.



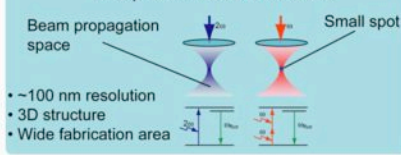
Reflection lossless optical fiber



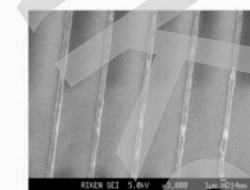
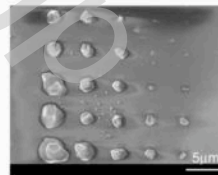
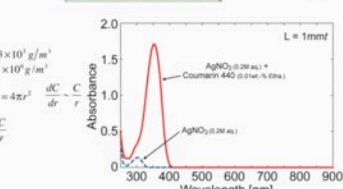
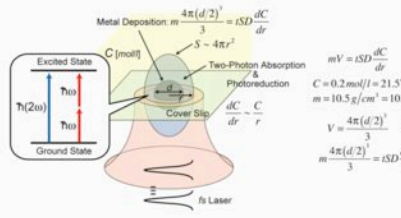
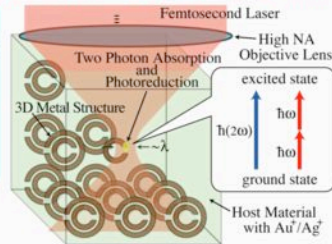
Fabrication technique of 3D metal structure

T. Tanaka, A. Ishikawa, and S. Kawata, Appl. Phys. Lett. 88, 81107 (2006).
A. Ishikawa, T. Tanaka, and S. Kawata, Appl. Phys. Lett. 88, 81107 (2006).

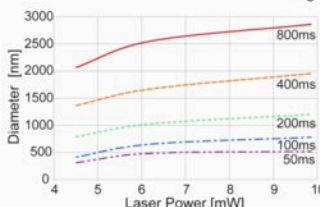
Two-photon micro fabrication



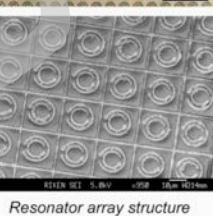
- ~100 nm resolution
- 3D structure
- Wide fabrication area



Resistivity was just only 3.3 times larger than that of bulk silver.



Self-standing metal structure



Resonator array structure