SAND2017-8258C

High-Contrast, All-Optical Switching of Infrared Light using a Cadmium Oxide Perfect Absorber

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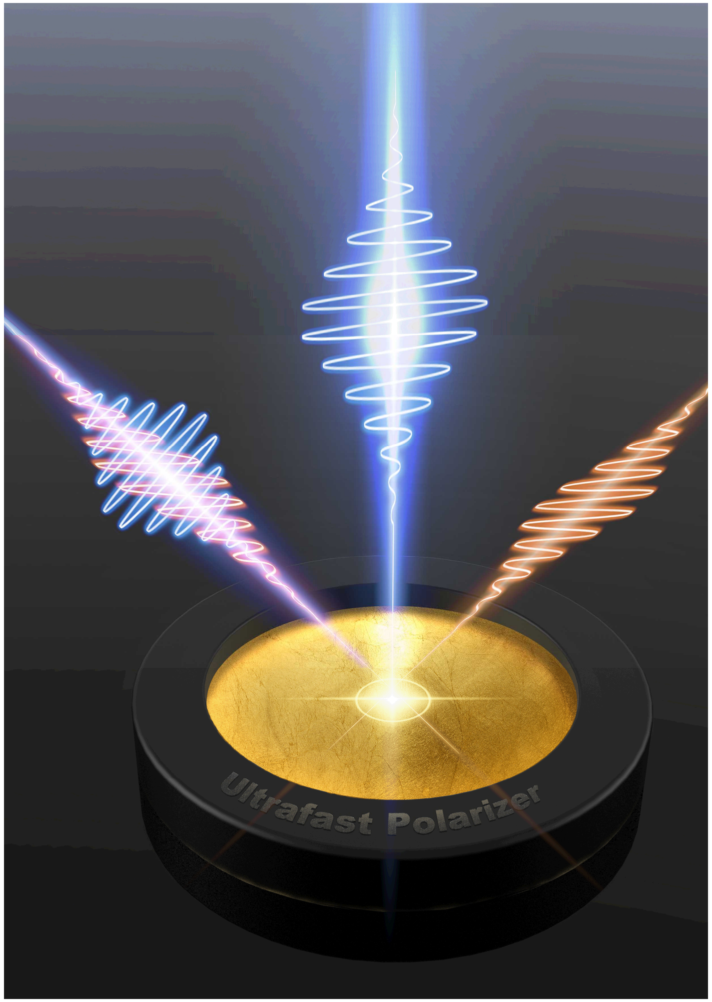

CLEO, San Jose, CA

May 15th, 2017

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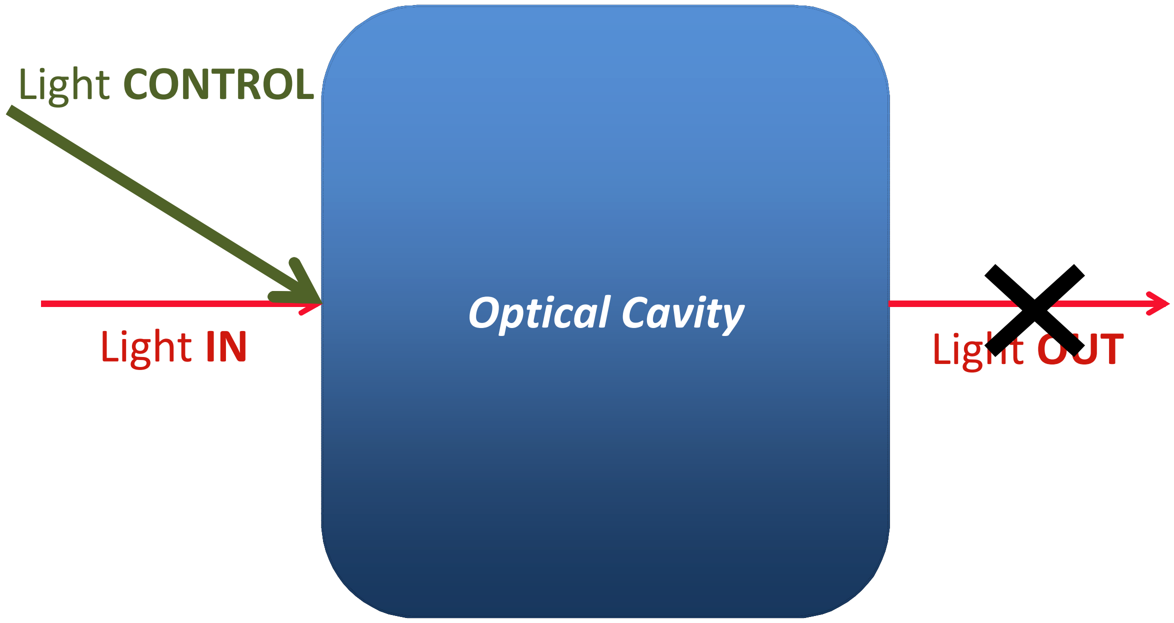
SAND2017-5100C

All-optical switching

All-optical switching:

- **Photon** as the ***control***.
- **Photon** as the ***signal***.

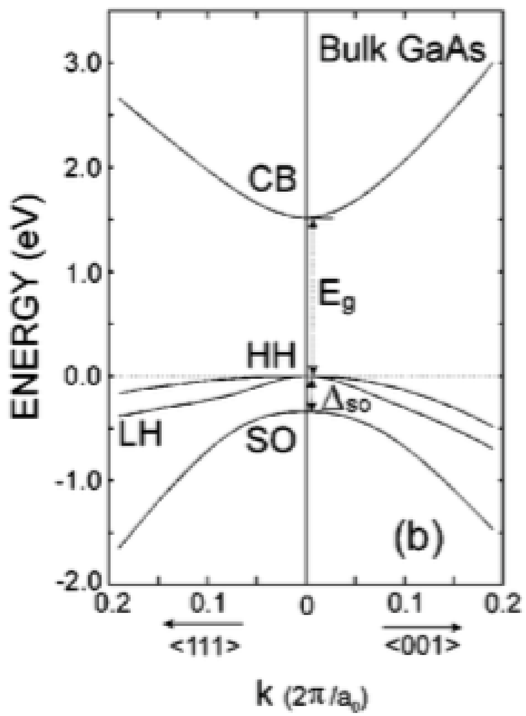


Metrics:

- Fast Switching Speed
- Large Switching Contrast
- Small Form Factor
- Low Power Consumption

Switching Mechanisms

Photon-”create” electrons:



Vurgaftmana JAPN (2001)

Pump

Plasma frequency:

$$\omega_p = \sqrt{ne^2 / \varepsilon_0 m^*}$$

Speed limitations:

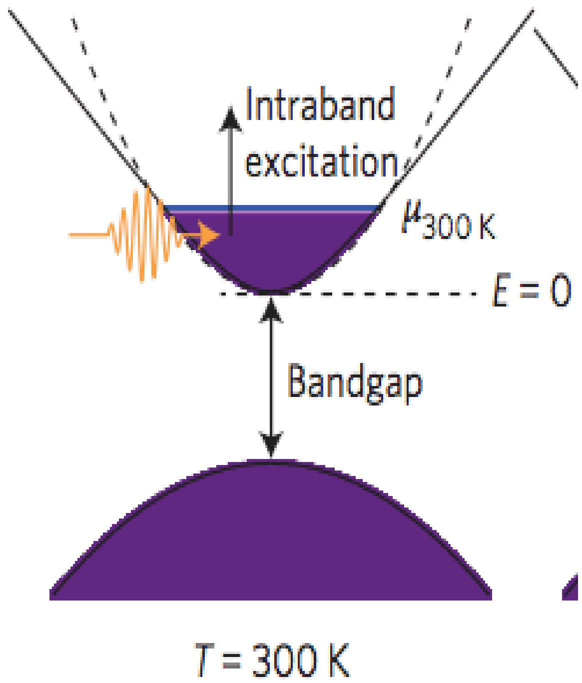
- Carrier lifetime

Switching Mechanisms

Photon-”perturb” electrons:

$$m^* = \frac{\hbar^2 \int f(E,T)\, dk}{\int f(E,T)\left(d^2E/dk^2\right) dk}$$

Pump



Plasma frequency:

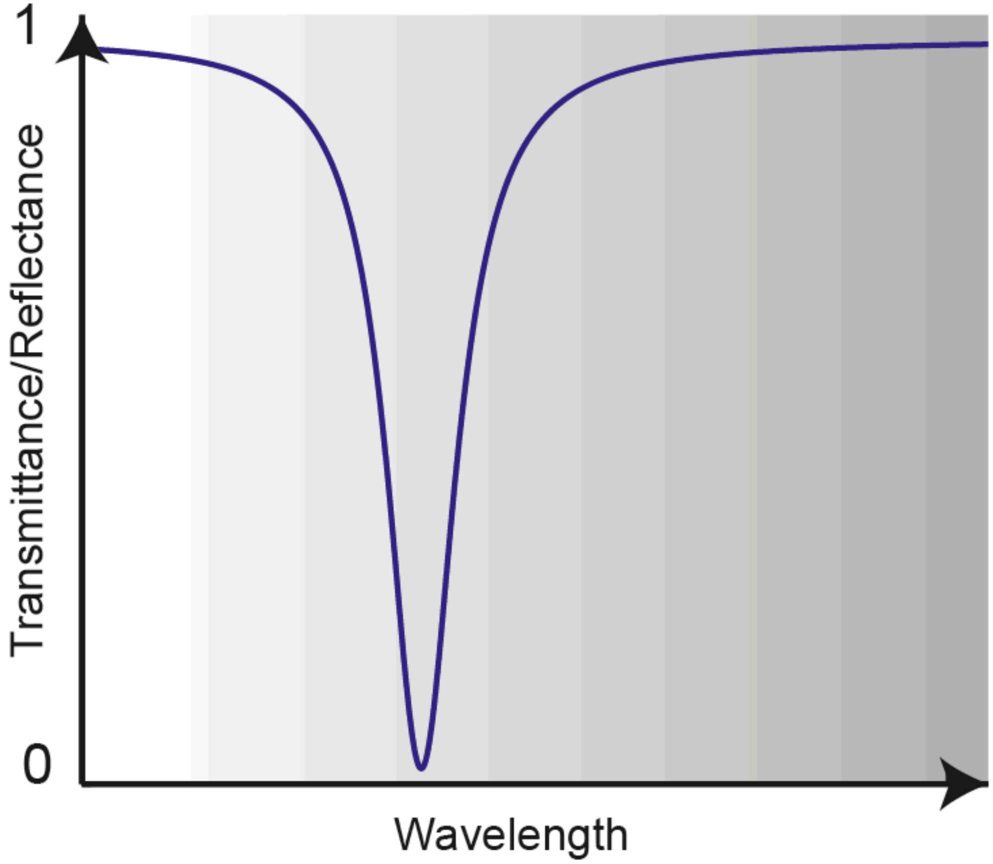
$$\omega_p = \sqrt{ne^2/\varepsilon_0 m^*}$$

Speed limitations:

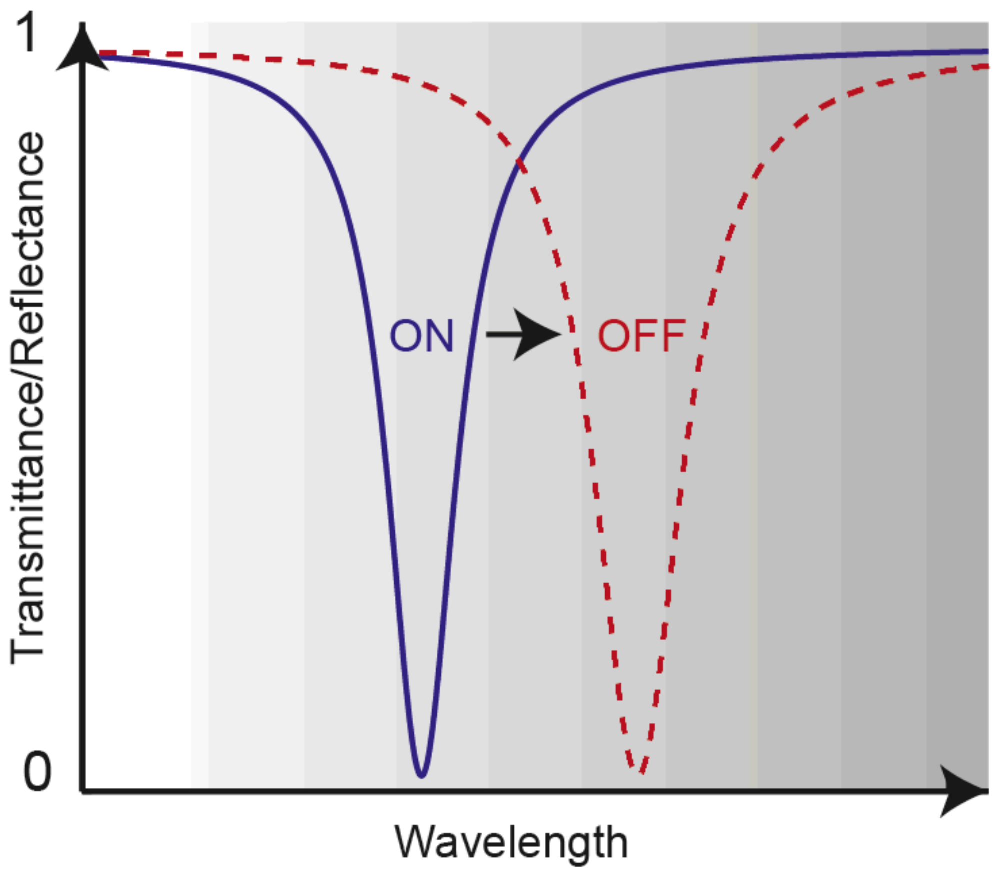
- Hot carrier lifetime

Guo et. al., Nat. Photon, (2016)

Cavity



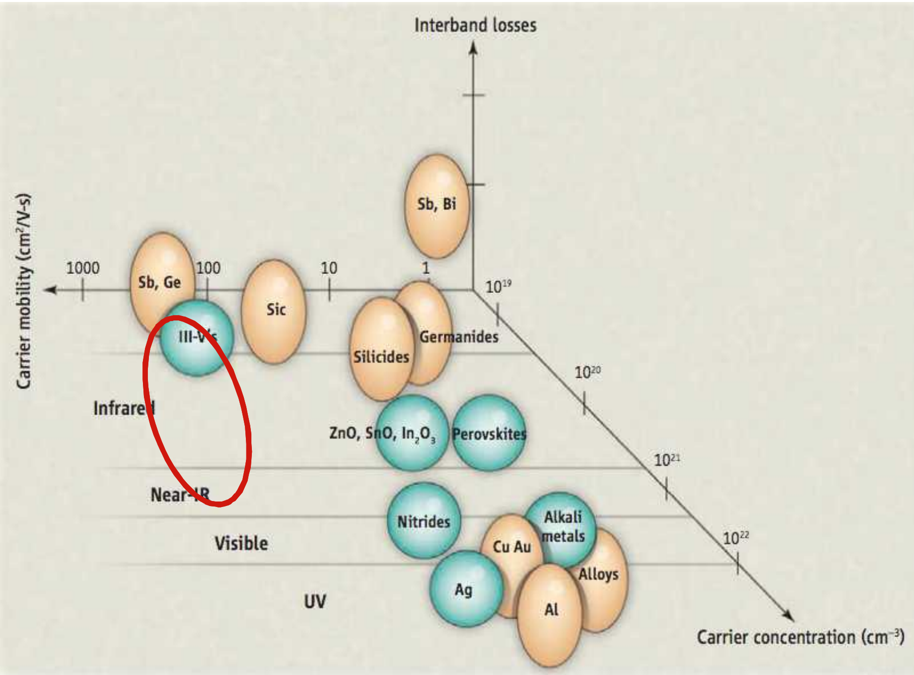
Cavity



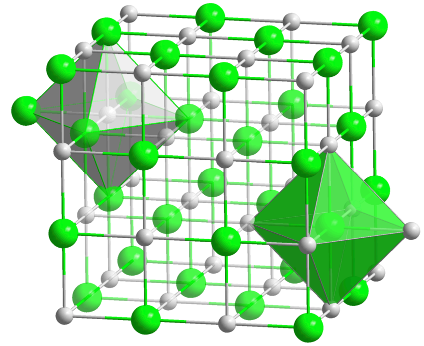
Requirements

- High quality factor resonance
  - Low loss plasmonic material
- Small reflectance minimum
  - Proper cavity design

Plasmonic materials: Doped CdO



Boltasseva & Atwater, Science 331, 290 (2011)



http://chemistry.stackexchange.com/questions/23673/rock-salt-structure

- Cubic rocksalt lattice (similar to NaCl)
- n-doping (In populates the Cd sublattice with a 3^+ charge)

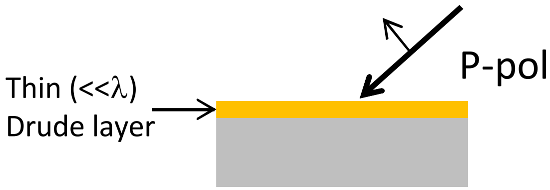
- Doping density can reach > 10^{20}cm^{-3}.
- Plasma frequency tunable from near to mid IR.
- Mobilities in the 100's via accurate defect equilibrium engineering.

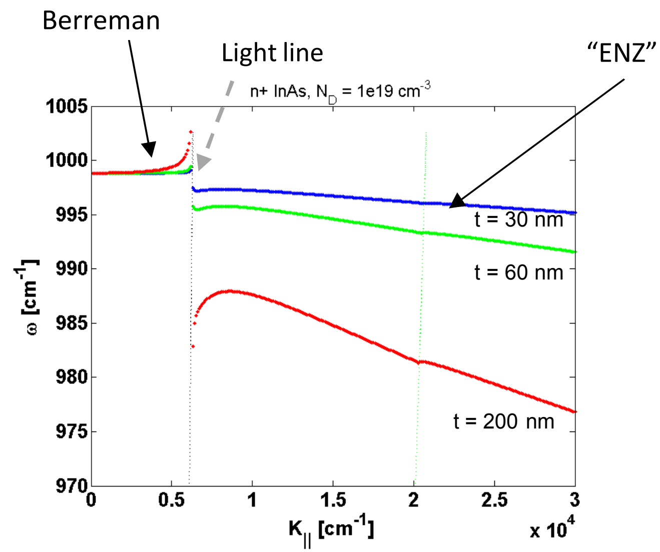
Material	Carriers [cm^{-3}]	Mobility [cm^2/V·s]	ε_1=0 [cm^{-1}]	ε_2 at ε_1=0	ε_2 at ε_1=-2
CdO:Dy	9.94x10^{19}	474	2770	0.19	0.30
CdO:Dy	3.70x10^{20}	359	5350	0.13	0.20
AZO (2 wt%)[4]	7.2x10^{20}	48	6970	0.21	0.39
ITO (10 wt%)[4]	7.7x10^{20}	36	7122	0.69	1.29

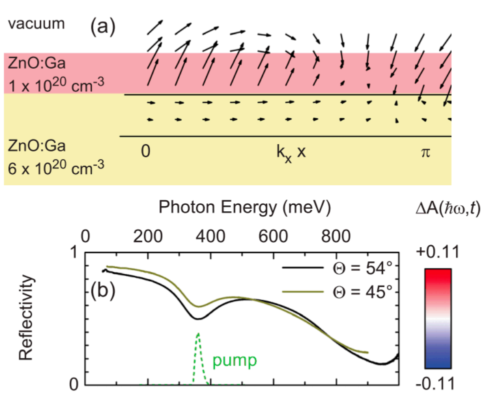
Sachet et. al., Nat. Mat (2015)

J-P Maria, NC State

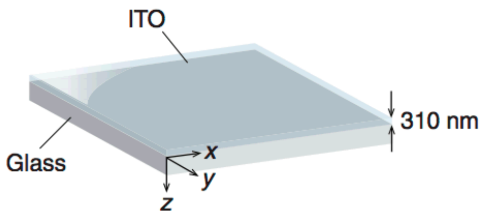
Plasmonic Cavity: Berreman/ENZ mode



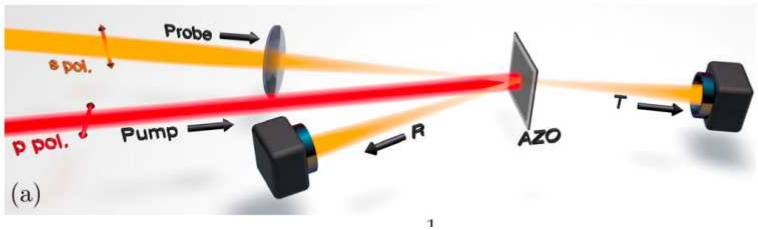




Tyborski et. al., PRL (2015)

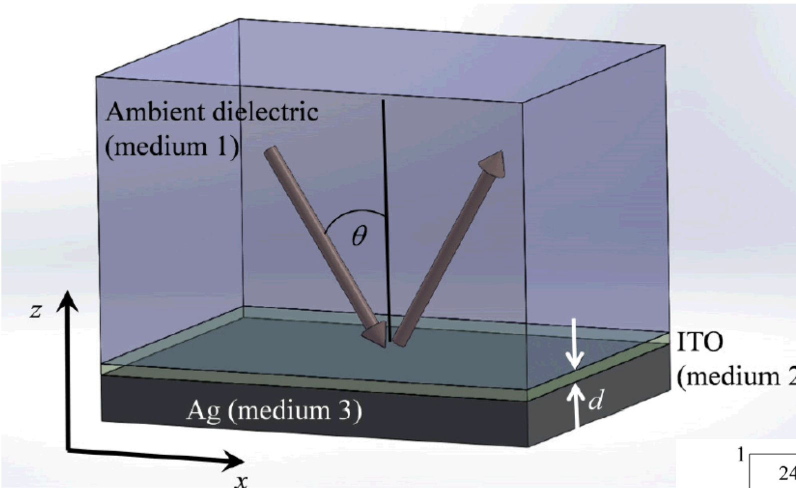


Alam et. al., Science (2016)



Caspani et. al., PRL (2016)

Berreman-mode Perfect Absorber



PHYSICAL REVIEW B **90**, 085411 (2014)

Directional perfect absorption using deep subwavelength low-permittivity films

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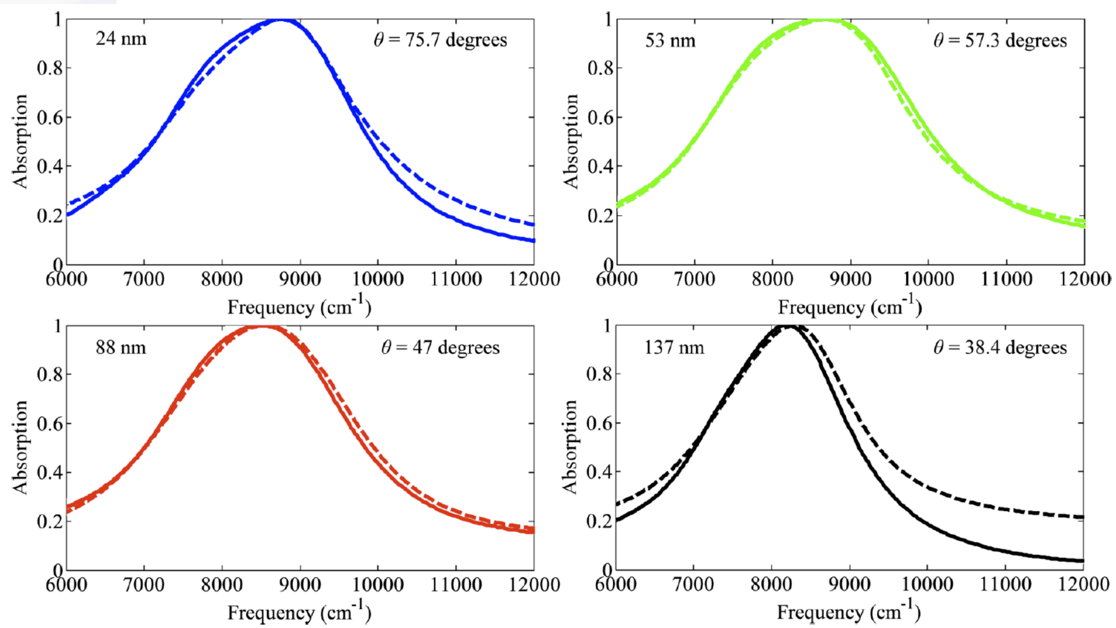
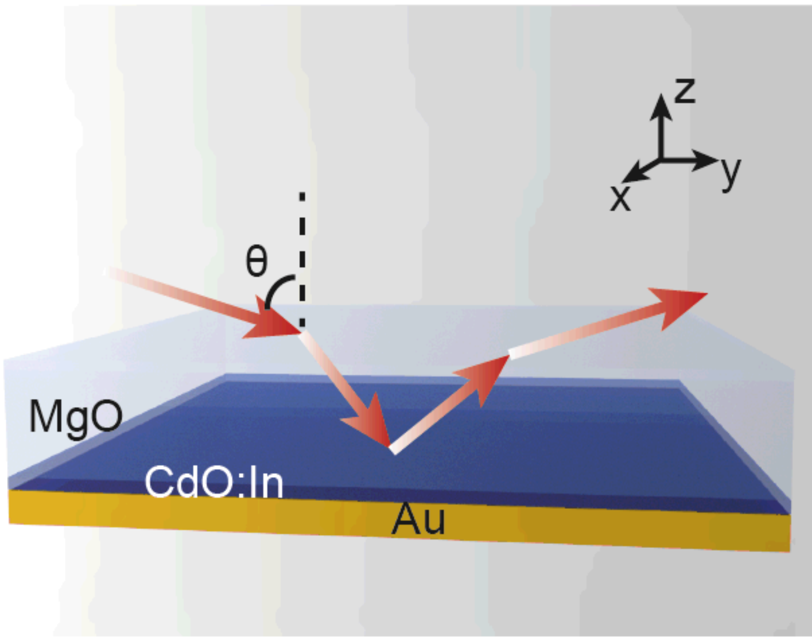
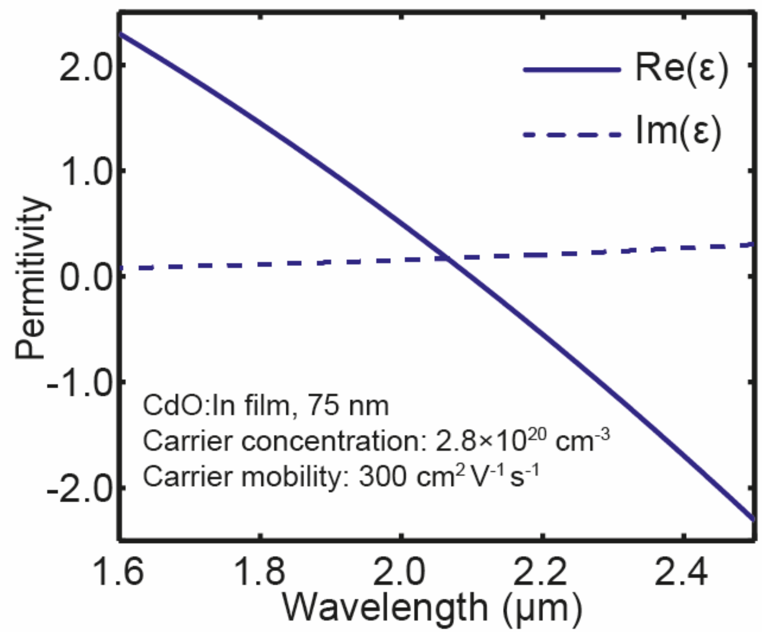


Perfect absorber:
- Small reflectance minimum

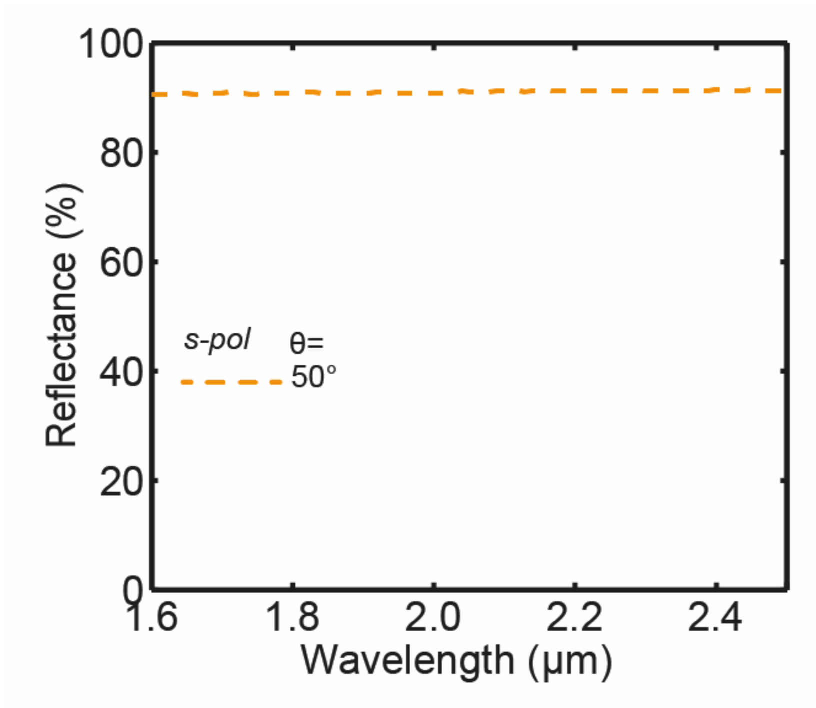
CdO-based Berreman-mode Perfect Absorber





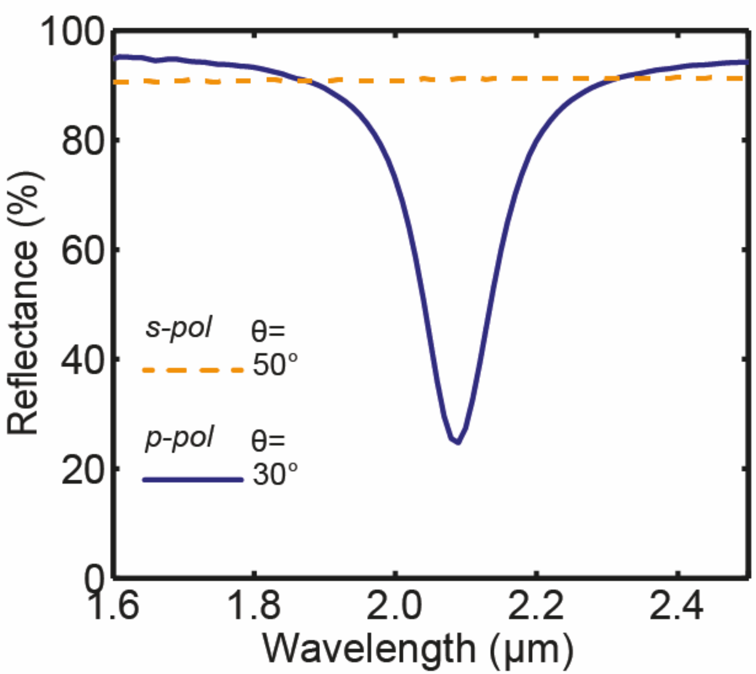
Yang et. al., Nature Photonics, Advanced Online Publication

CdO-based Berreman-mode Perfect Absorber



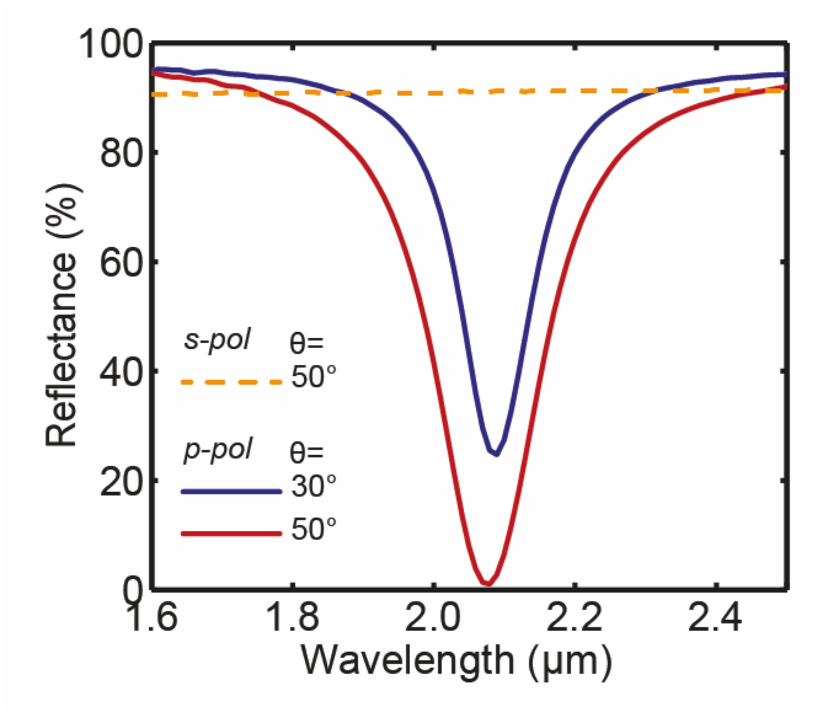
Yang et. al., Nature Photonics, Advanced Online Publication

CdO-based Berreman-mode Perfect Absorber



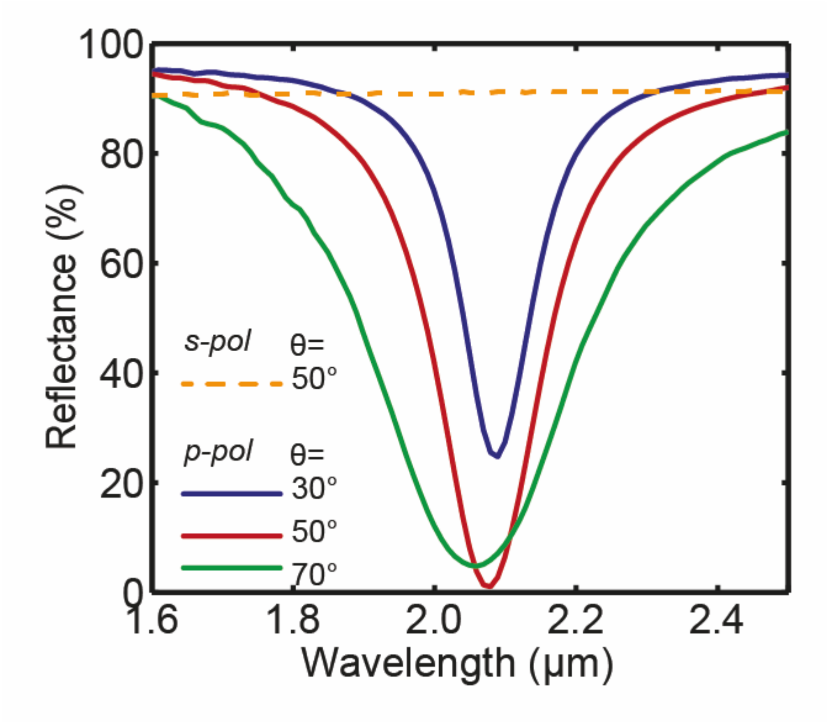
Yang et. al., Nature Photonics, Advanced Online Publication

CdO-based Berreman-mode Perfect Absorber



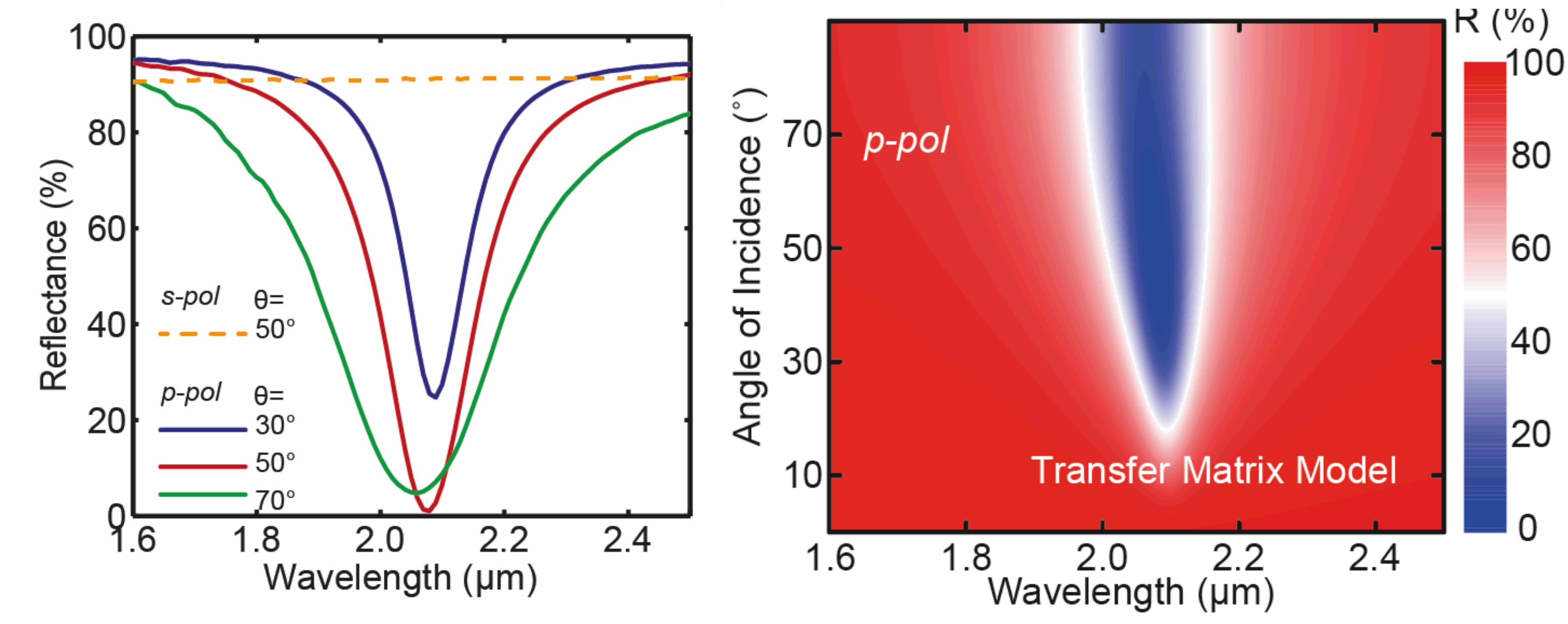
Yang et. al., Nature Photonics, Advanced Online Publication

CdO-based Berreman-mode Perfect Absorber



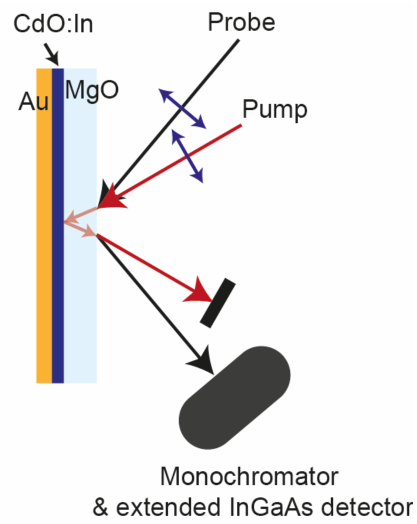
Yang et. al., Nature Photonics, Advanced Online Publication

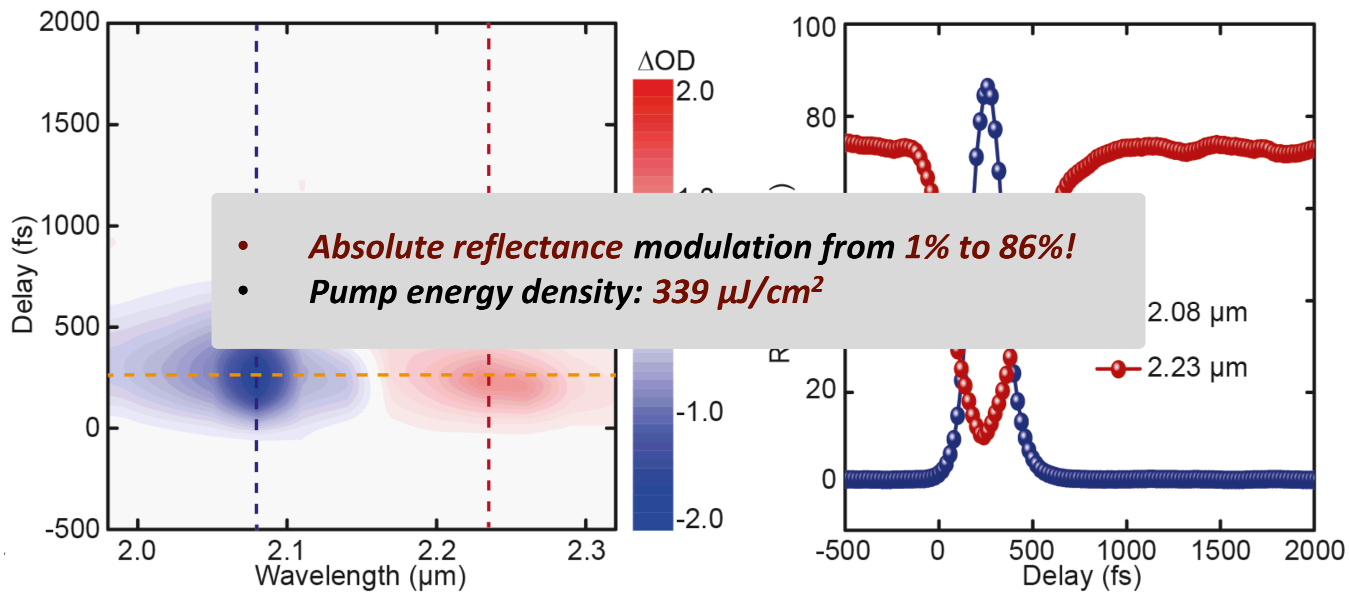
CdO-based Berreman-mode Perfect Absorber



Yang et. al., Nature Photonics, Advanced Online Publication

Ultrafast AMPLITUDE SWITCHING of the Perfect Absorber

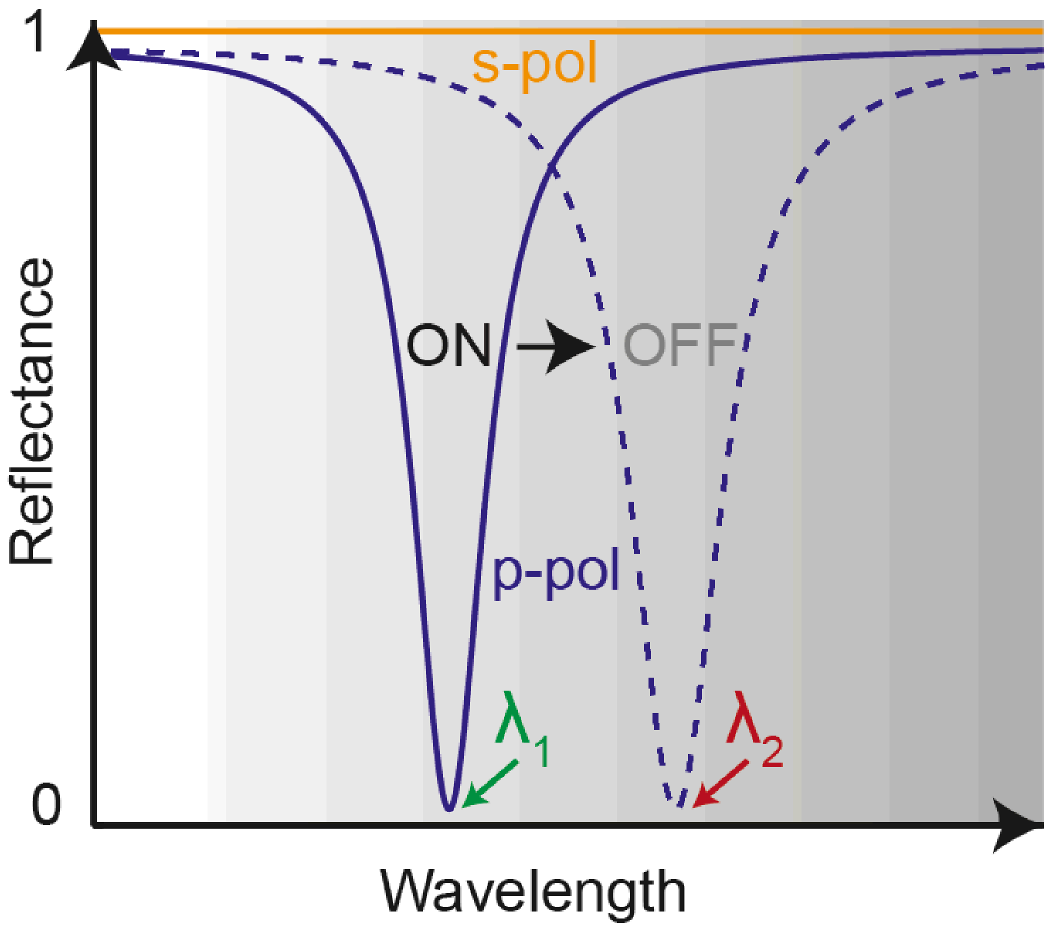




- ***Absolute reflectance* modulation from *1% to 86%!***
- ***Pump energy density: 339 μJ/cm²***

Yang et. al., Nature Photonics, Advanced Online Publication

Ultrafast POLARIZATION SWITCHING



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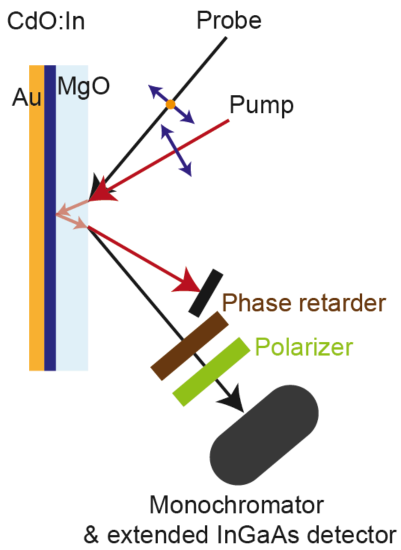
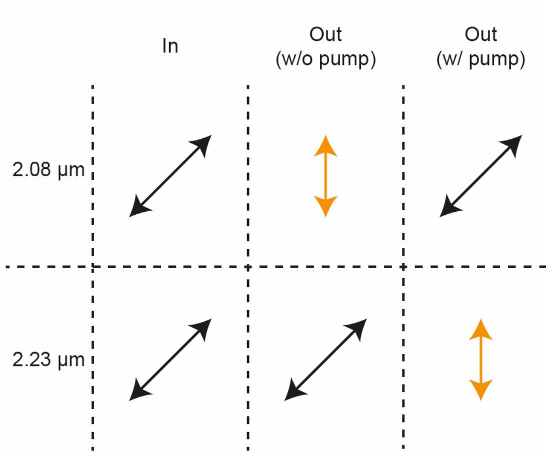
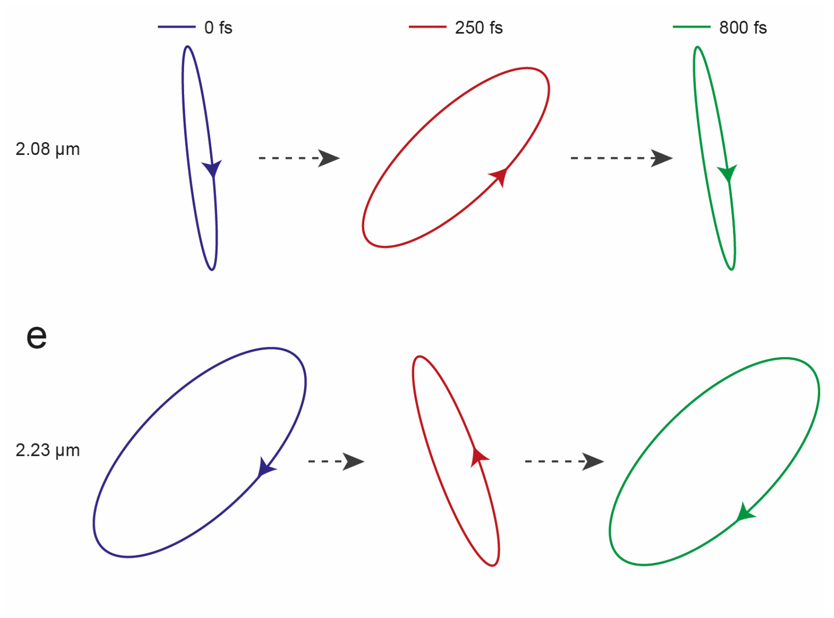
Ultrafast POLARIZATION SWITCHING



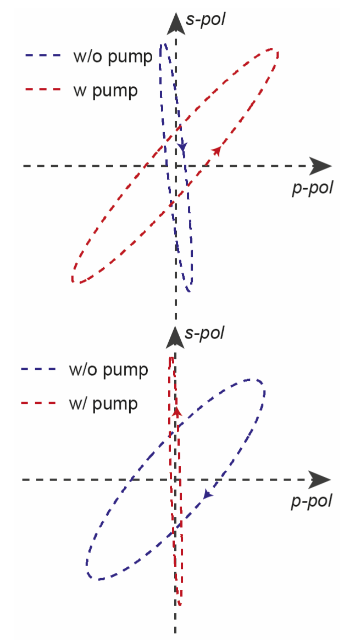
Predicted polarization input/output:



Experiments



Simulations



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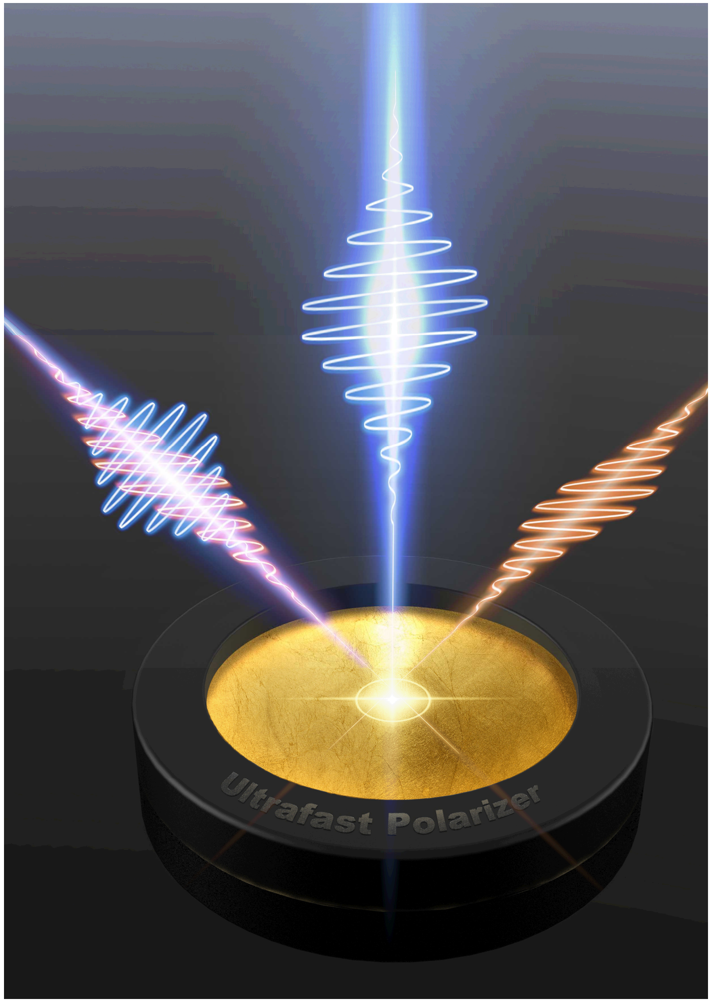
Conclusions

- Ultrafast switches using doped CdO
  - High electron mobility oxide/perfect absorber
  - High contrast amplitude switch
  - Femtosecond polarization switch



Acknowledgement

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  - I. Brener, M.B. Sinclair, S. Campione, S. Liu, T.S. Luk, P.Q. Liu
- North Carolina State
  - J-P. Maria, K. Kelley, E. Sachet

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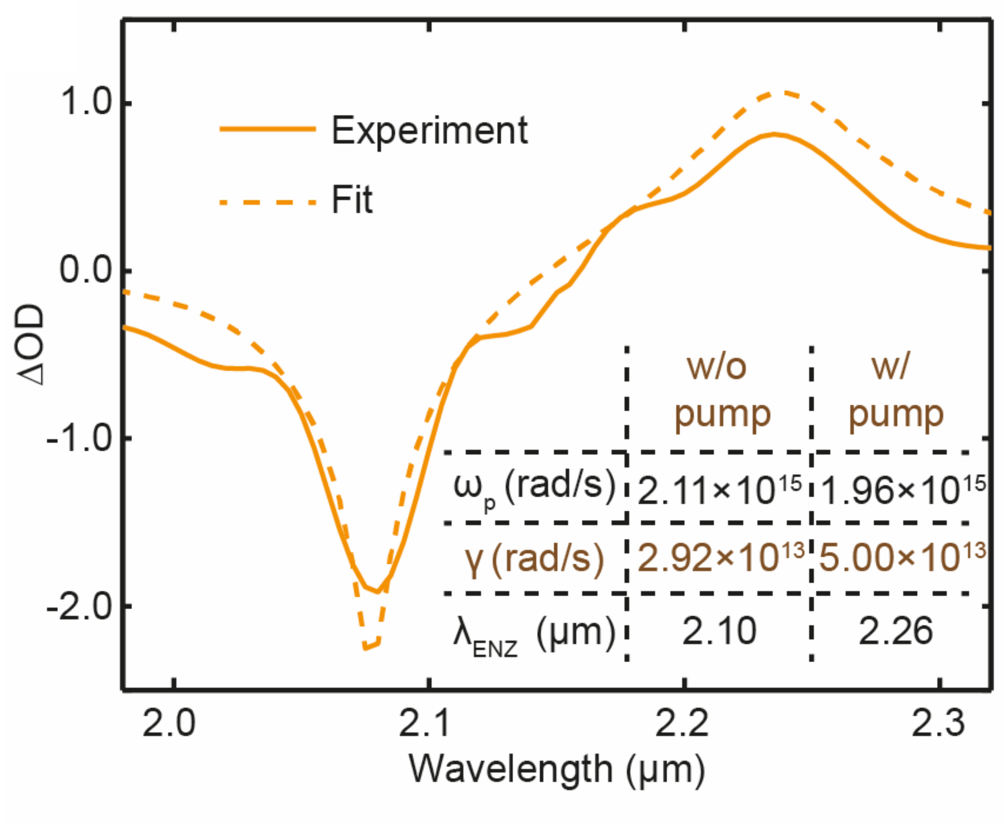

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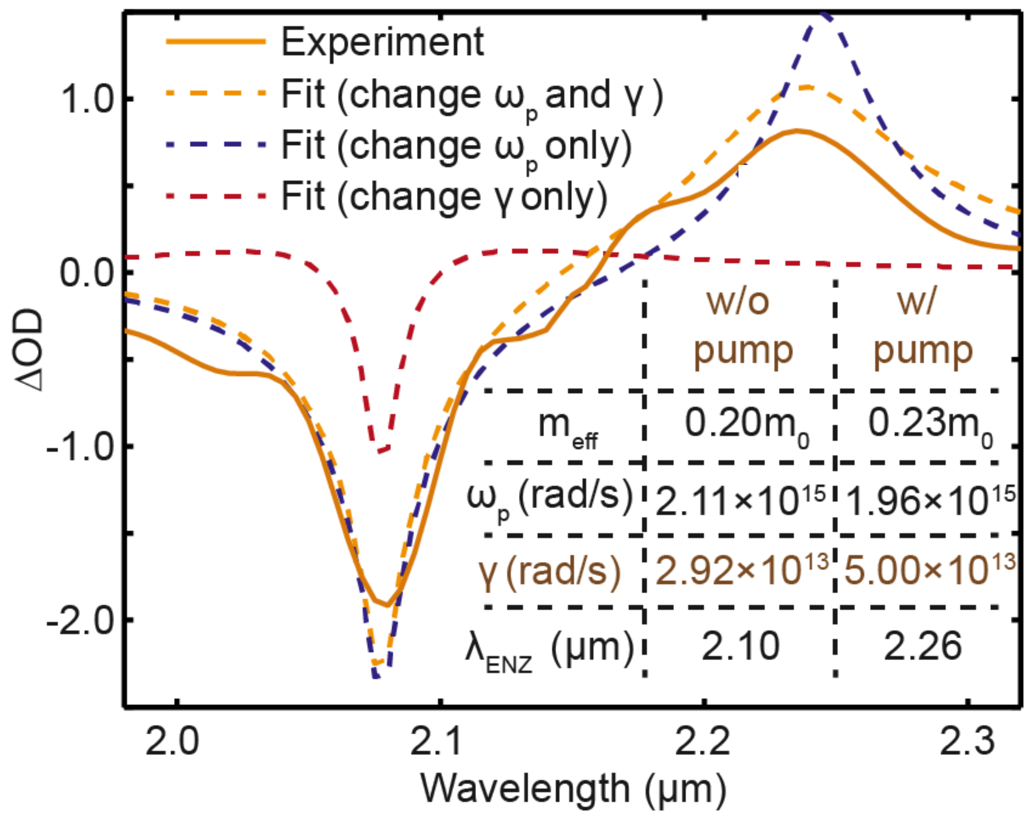

- **Change in plasma frequency plays the dominant role.**
- **Change in plasma damping observed.**

Yang et. al., Nature Photonics, Advanced Online Publication