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Photoconductive Metasurfaces:
Principles and Applications

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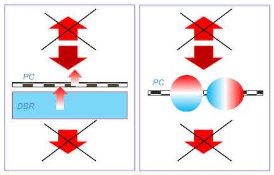
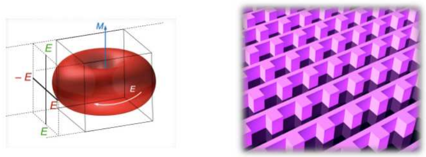
U.S. DEPARTMENT OF ENERGY
Office of Science

Perfect Optical Absorption via Nanoengineering

Perfect optical absorption in an ultrathin layer is achieved using two architectures:
1. Nanostructured surface supporting a resonance, with a back reflector;
2. Nanostructured surface supporting two degenerate resonances, which display odd and even symmetry.

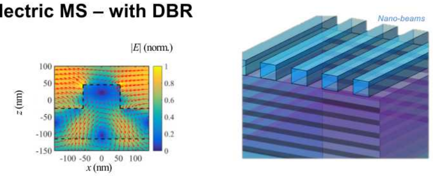


All-dielectric MS – network of Mie resonators



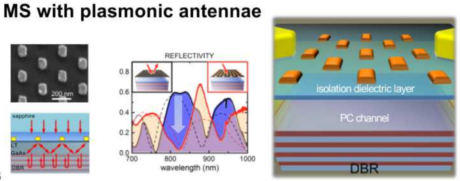
Ref 1

All-dielectric MS – with DBR



Ref 2

PC MS with plasmonic antennae

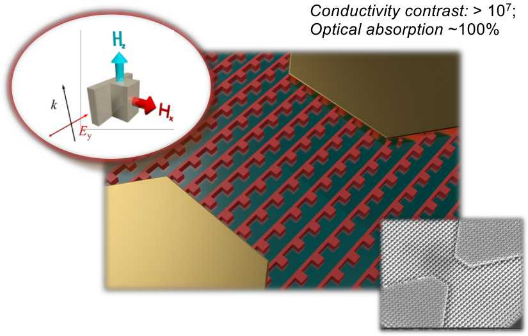


Ref 3

Photoconductive Metasurface – Concept

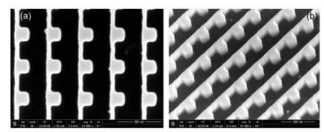
Photoconductive (PC) Metasurface (MS) - optically thin layer that efficiently absorbs light at specific wavelength and switches electrical conductivity from highly resistive to highly conductive state.

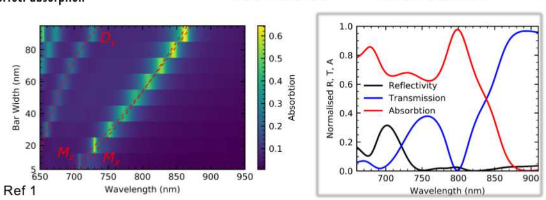
Switching time: < 1 ps;
Conductivity contrast: > 10^7;
Optical absorption ~100%



Perfect absorption is achieved by nanostructuring, using:
Mie modes in dielectric resonators or
plasmonics resonances in nano-antennae

LT GaAs-based PC Metasurface.
(a,b) SEM of dielectric resonator network;
(c) Dependence of ED and MD modes on resonator geometry;
(d) Two degenerate resonators can lead to perfect absorption



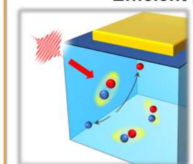


Ref 1

Applications and Impact

This metasurface is an optically thin layer of precisely nanostructured material, it is practically invisible when it is placed onto glass, while providing perfect absorption of light within a design wavelength range.
Integration of PC metasurfaces into practical devices, such as THz PC detectors, allowed us to improve their efficiency, and to make the active region of THz wave detectors significantly thinner in comparison to conventional detectors.[1-3]
This, in its turn, enables new applications, such as THz near-field imaging.[3-5]

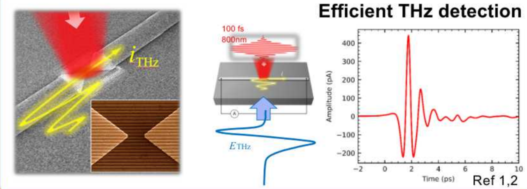
Efficient photon conversion to charge carriers for ultrafast switches



Photoexcited Charge Carriers in LT GaAs:
- lifetime: 0.1-1 ps
- absorption length (1 μm)
- drift length (<< 1 μm)

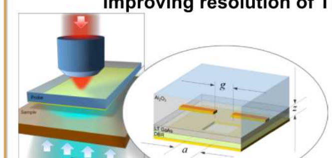
Optically thin PC MS enables:
Efficient photo-excitation
High conductivity contrast

Efficient THz detection



Ref 1,2

Improving resolution of THz near-field imaging



Integration of THz detectors into near-field scanning probes improves their sensitivity and leads to better spatial resolution

Ref 4,5

References

[1]. T. Siday et al., Nano Letters (2019)

[2]. O. Mitrofanov et al., APL Photonics (2018)

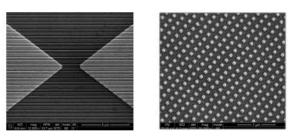
[3]. O. Mitrofanov et al., ACS Photonics (2015)

[4]. O. Mitrofanov et al., IEEE THz Sci and Tech. (2016)

[5]. O. Mitrofanov et al., Optics Express (2018)

Key CINT Capabilities

Integration Lab - Nanofabrication



PC Metasurfaces fabricated in the IL
(a) GaAs nanobeams integrated into a THz detector;
(b) Array of Gold nanoantennae over PC channel

Nanophotonics and Optics Labs

Optical microscopy and spectroscopy

Ultrafast lasers

In-depth knowledge of nanophotonics and experience in design, modeling and fabrication of metasurfaces.

Molecular Beam Epitaxy

Low-temperature growth of ultrafast semiconductors (GaAs) and AlGaAs/GaAs heterostructures for Distributed Bragg Reflectors with atomic monolayer precision.

Acknowledgement

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