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# Terahertz Photoconductive Metasurface Detector with Enhanced Two-Step Photon Absorption at 1550 nm

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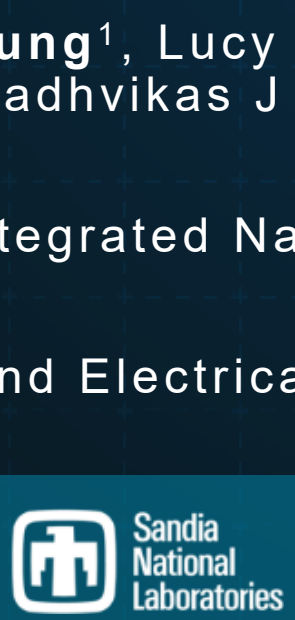
CLEO 2023





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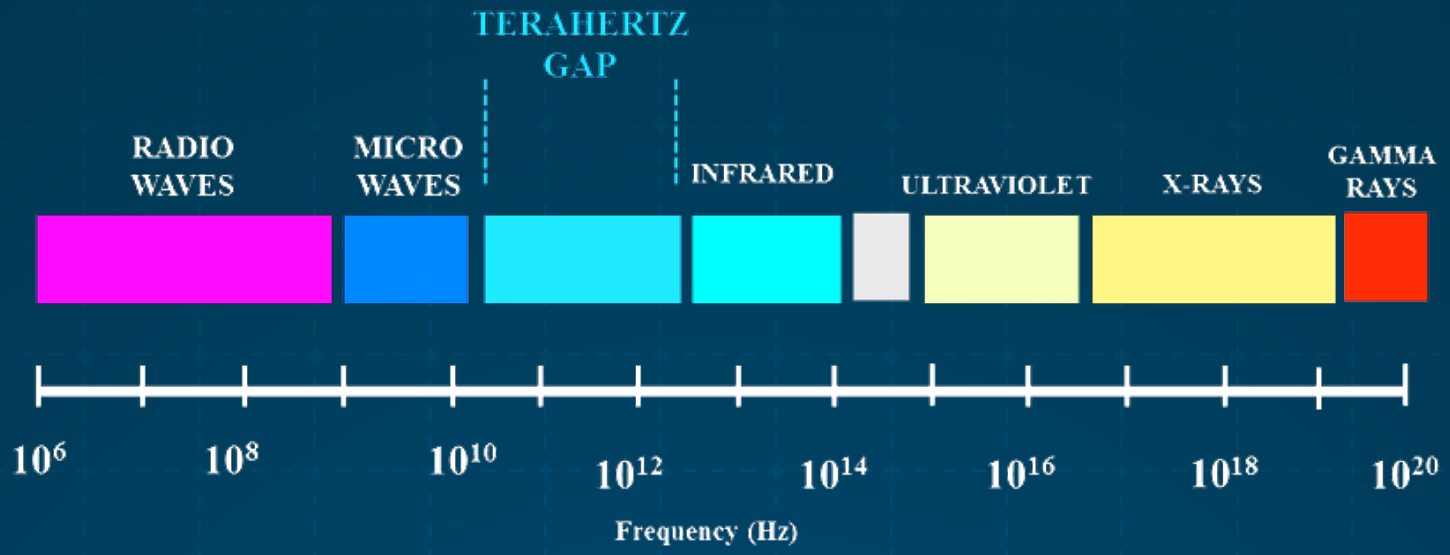
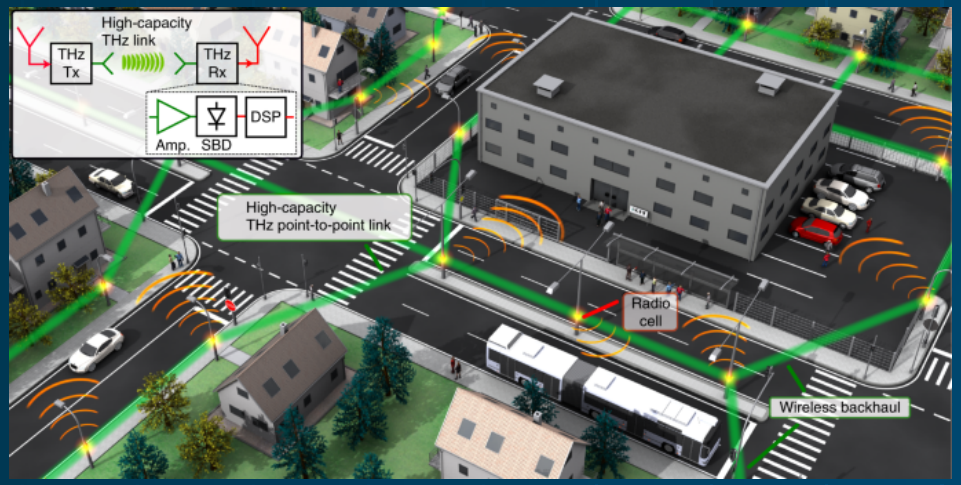
# Terahertz technologies

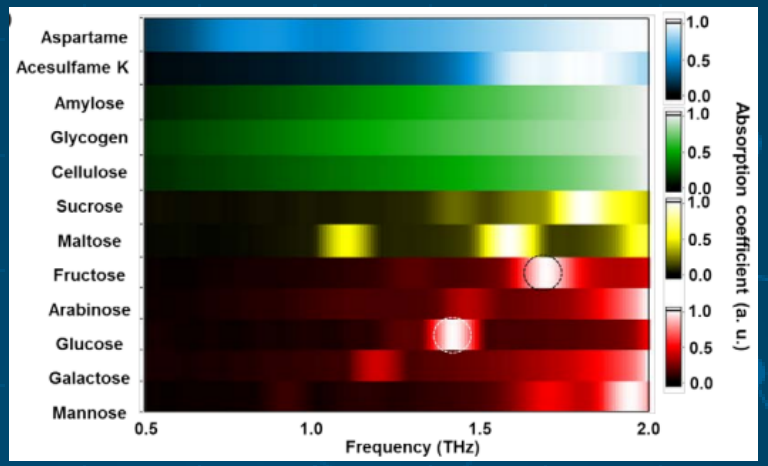



## Telecommunication



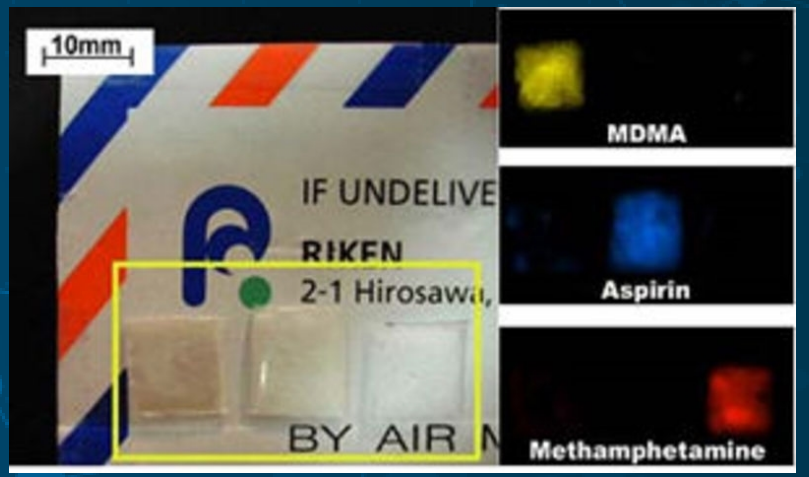

Nat. photon. 14, 601–606 (2020)

## Sensing




Sci. Rep. 5, 15459 (2015)

## Imaging

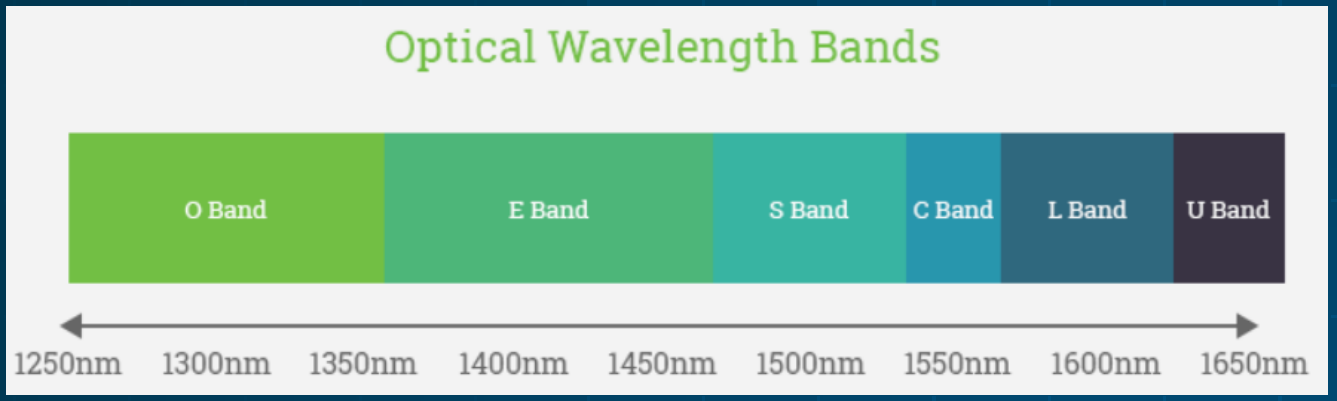


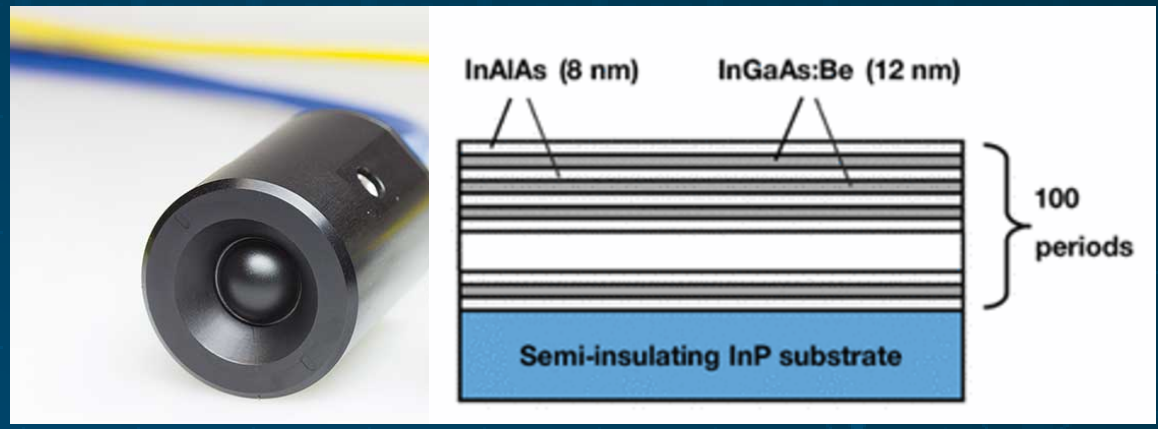

Opt. Express, 11, 2549 (2003)

# Terahertz technologies using telecom band

Fiber-based lasers at telecom wavelengths are particularly attractive for gating photoconductive devices due to their high stability, robustness, compact footprint and reduced cost in comparison to Ti:Sapphire lasers.

**Conventional band (C band)** ranges between 1530nm and 1565nm and is the most widely used band in optical communication.

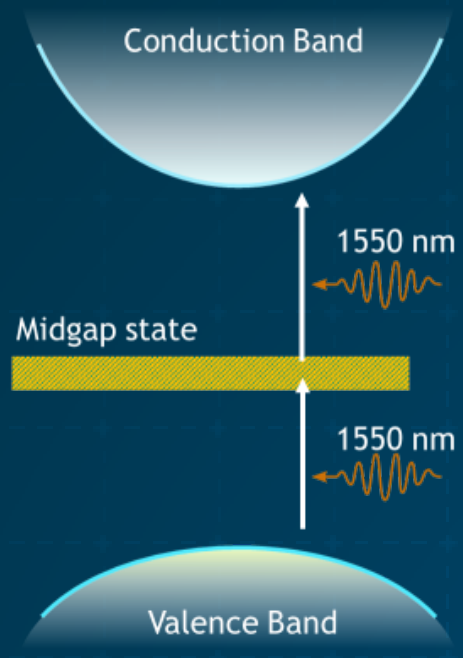


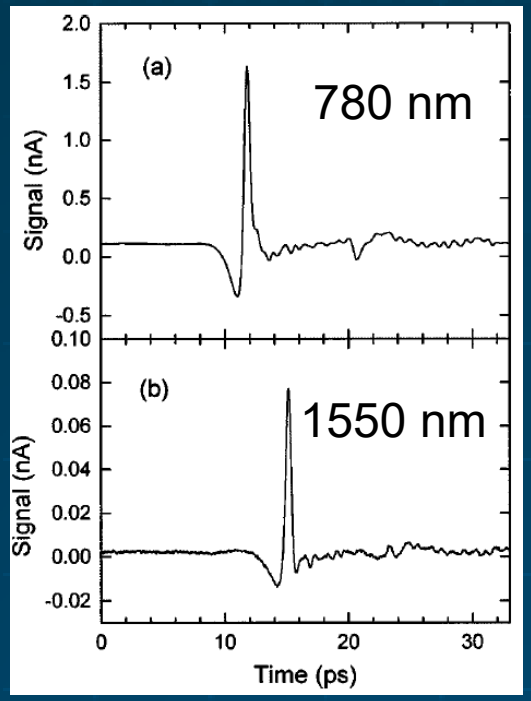




**But, this tends to exhibit:**

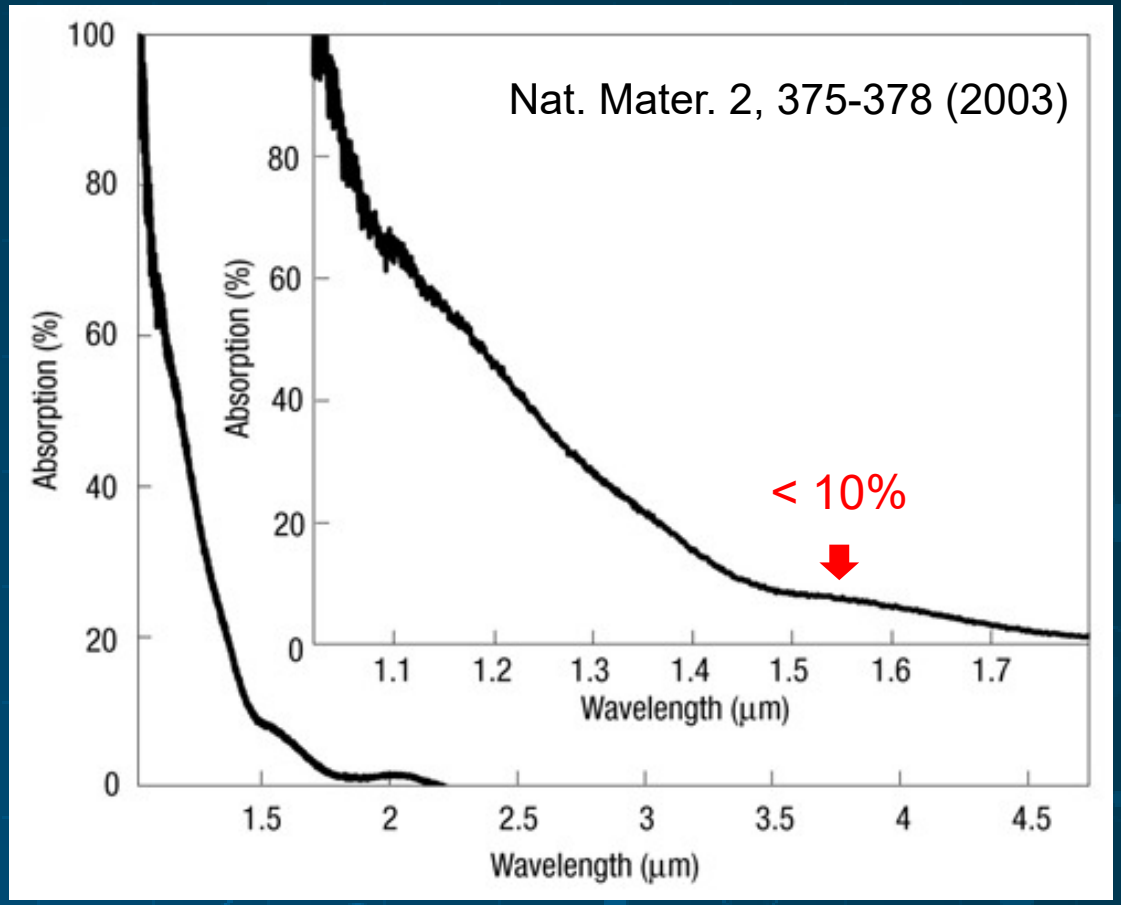
- Low resistivity (limit sensitivity)
- Long carrier lifetimes (limit THz bandwidth)
- Limits output power of THz source

# LT-GaAs as a photoconductive switch at 1550 nm




LT-GaAs absorption spectra




Low-temperature-grown GaAs (LT-GaAs) has been the most widely used material for PC emitter and detector because of **its unique properties**, such as

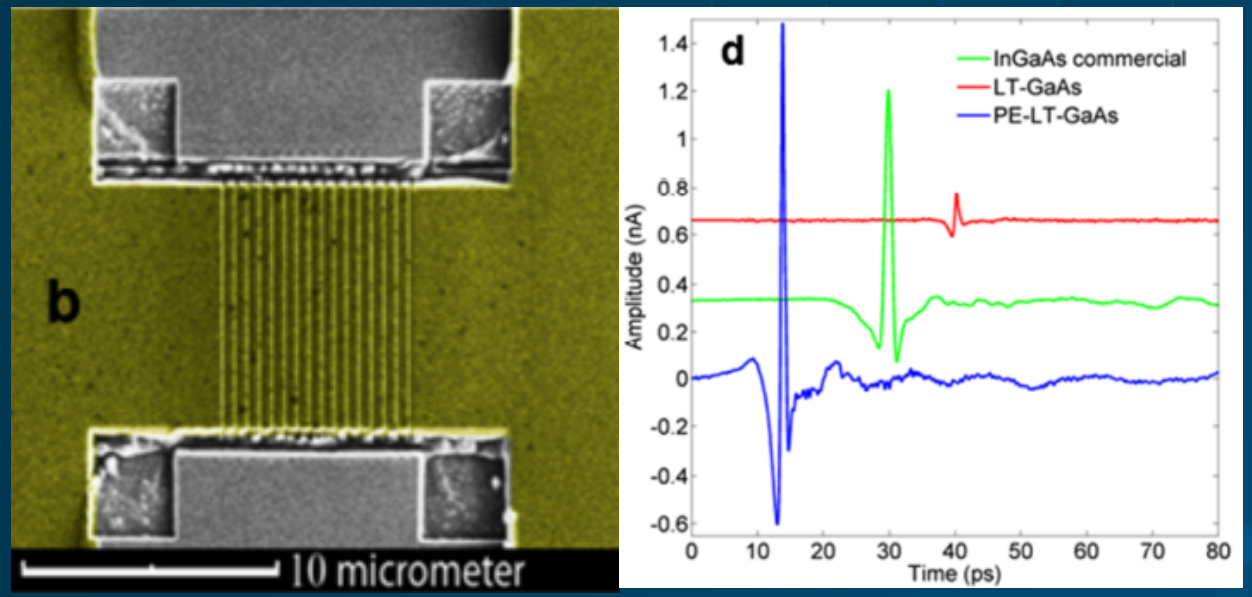
- Ultrashort carrier lifetime (<1 ps)
- Large resistivity (~$10^7$ V/cm)
- Relatively good carrier mobility (~200 $cm^2$/Vs)

But, **two-step photon absorption is very small**, so it is rarely used in practical devices

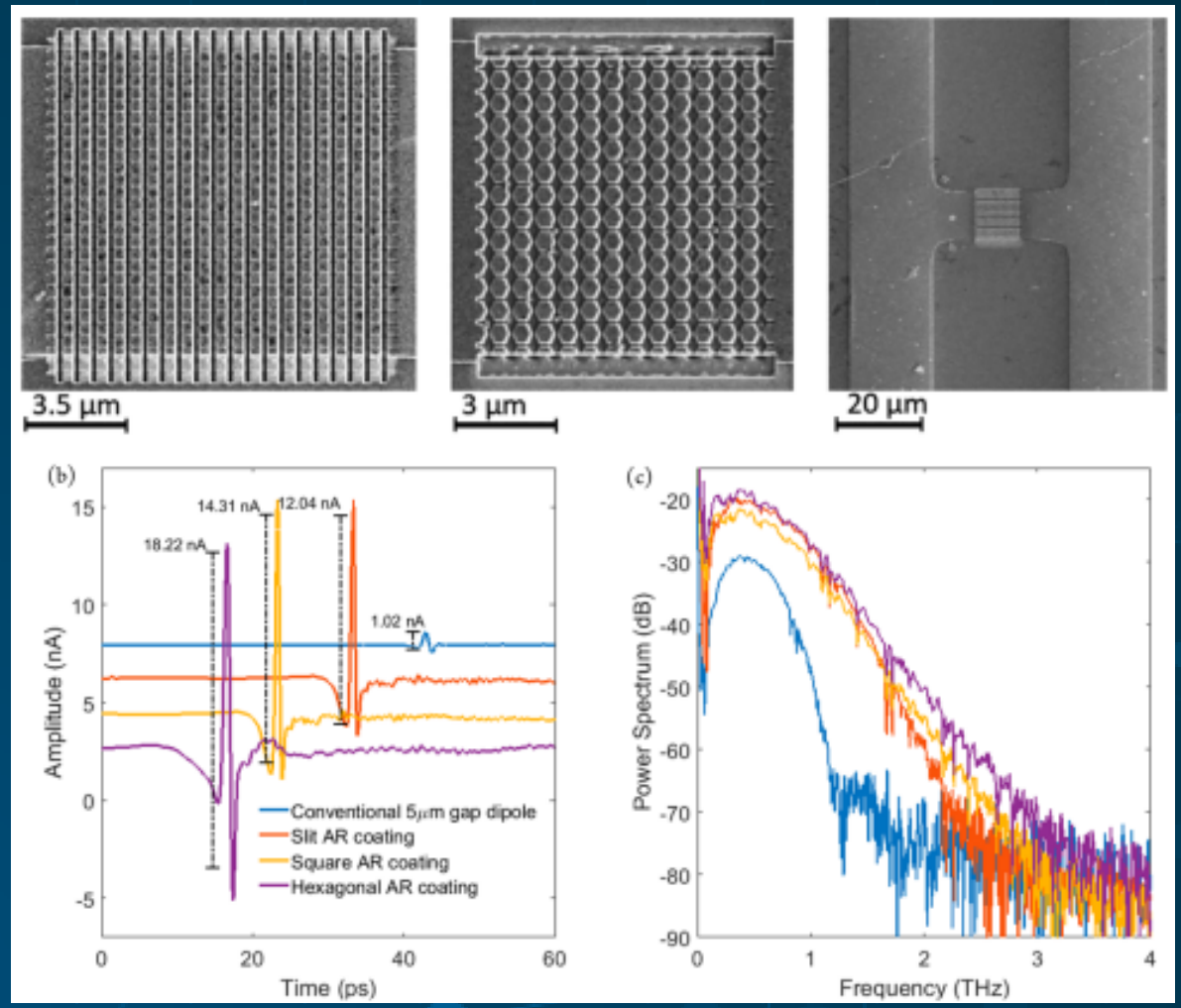
# Plasmonic enhanced LT-GaAs PC switches

**Advantage**
- Enhance generation and detection of THz signal

**Challenges**
- Additional plasmonic layer is needed
- Reduced dark resistance, low damage threshold



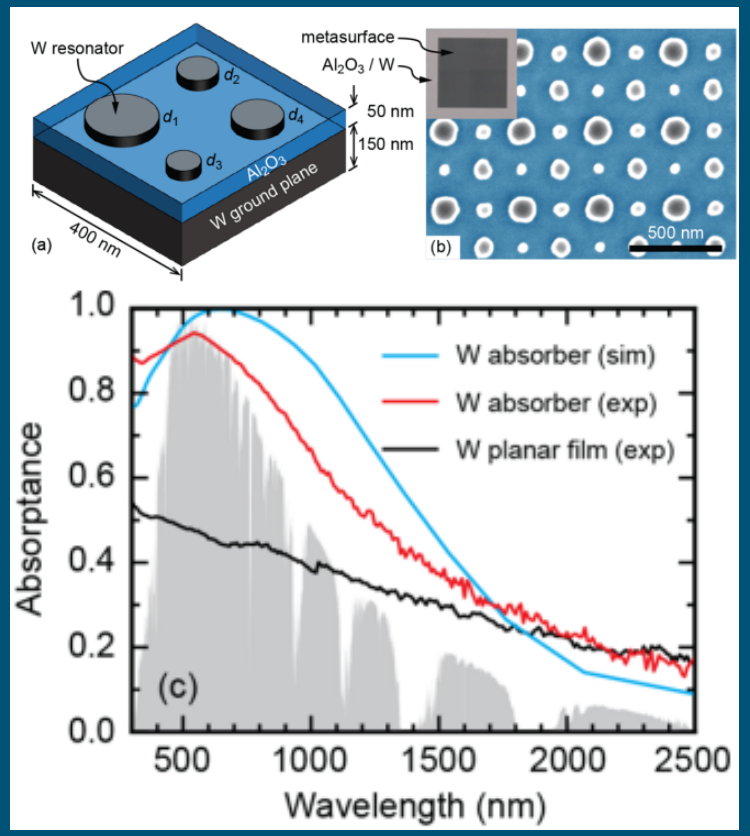

Nano Lett. 15, 8306-8310 (2015)



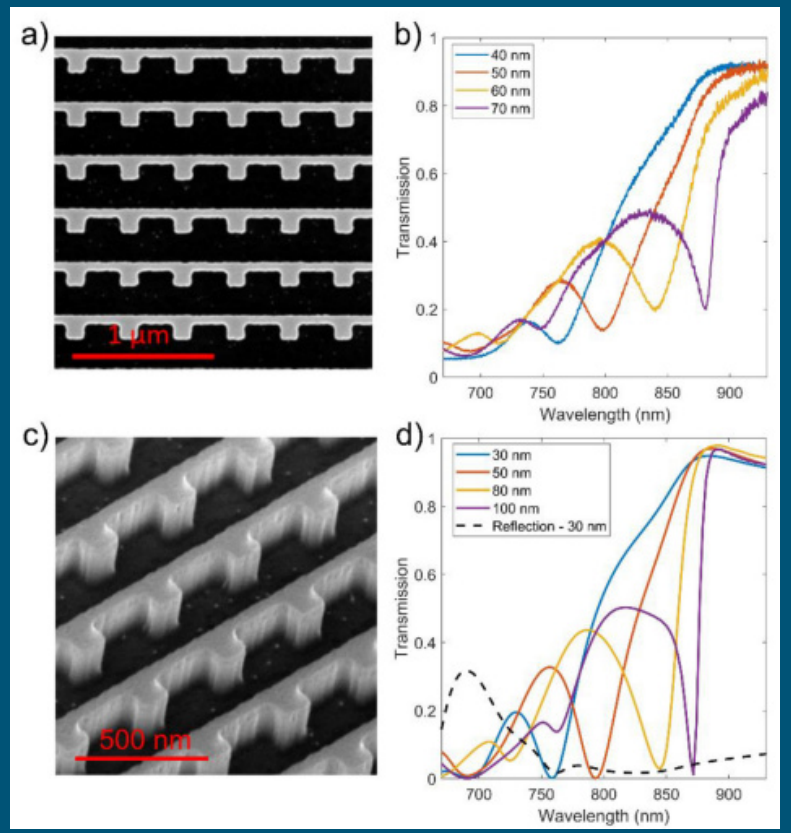

ACS Photon. 4, 1350-1354 (2017)

# Enhancing absorption using semiconductor metasurface

## Semiconductor metasurface enhanced absorption

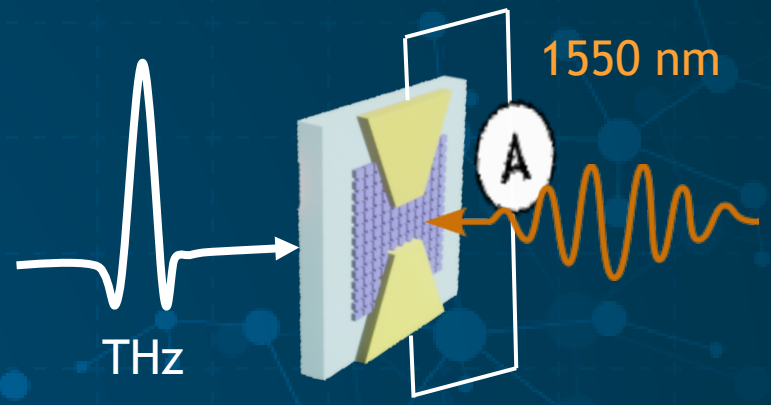



Nano Lett. 18, 7665-7673 (2018)



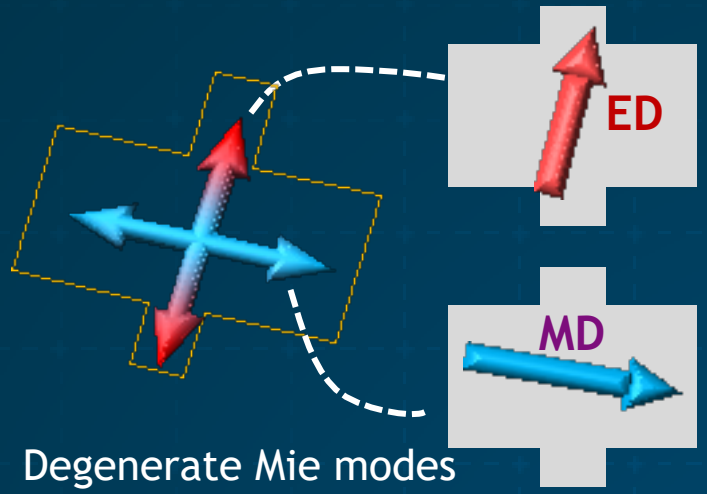

Opt. Express 28, 35284 (2020)

Metasurface enhanced photoconductive detector

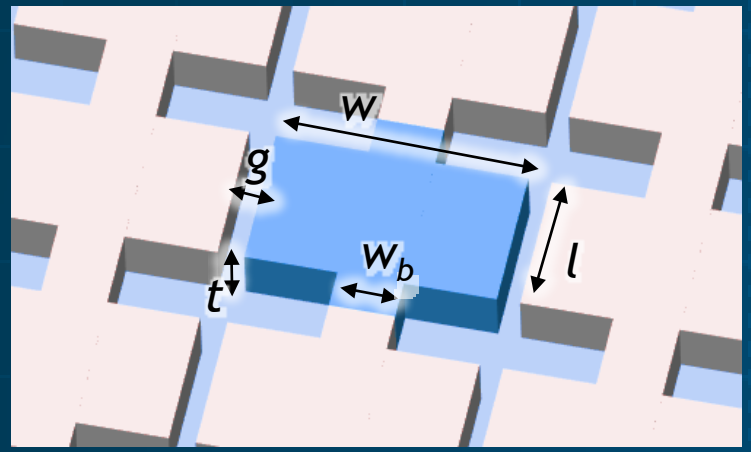


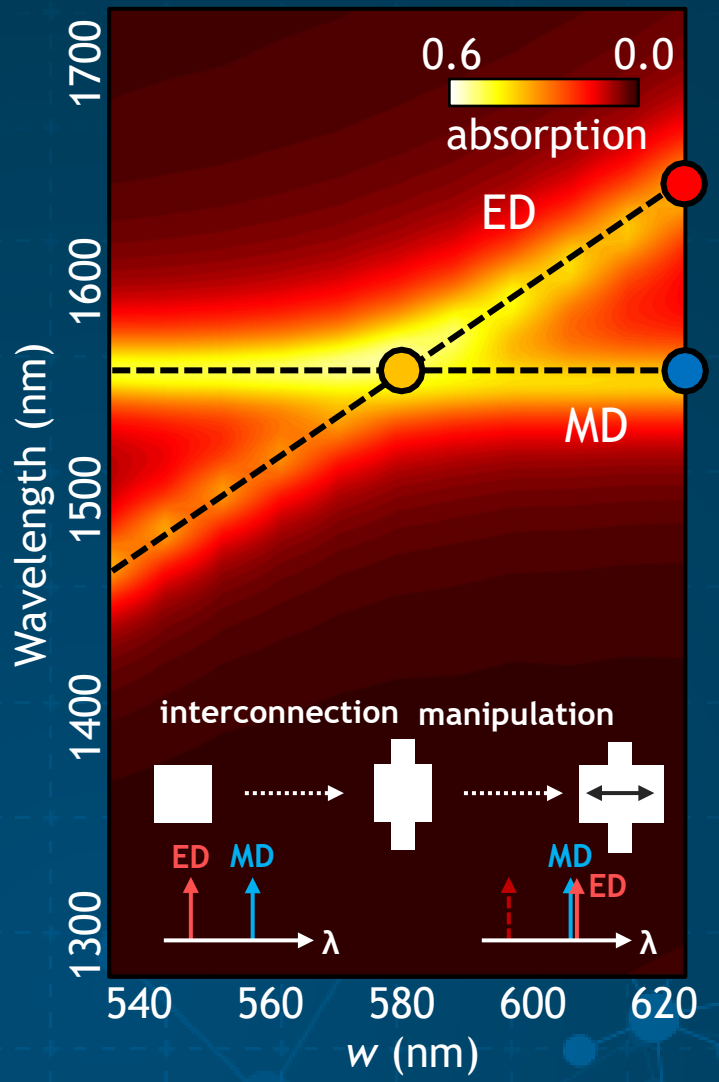
# Degenerate Mie modes for enhancing absorption

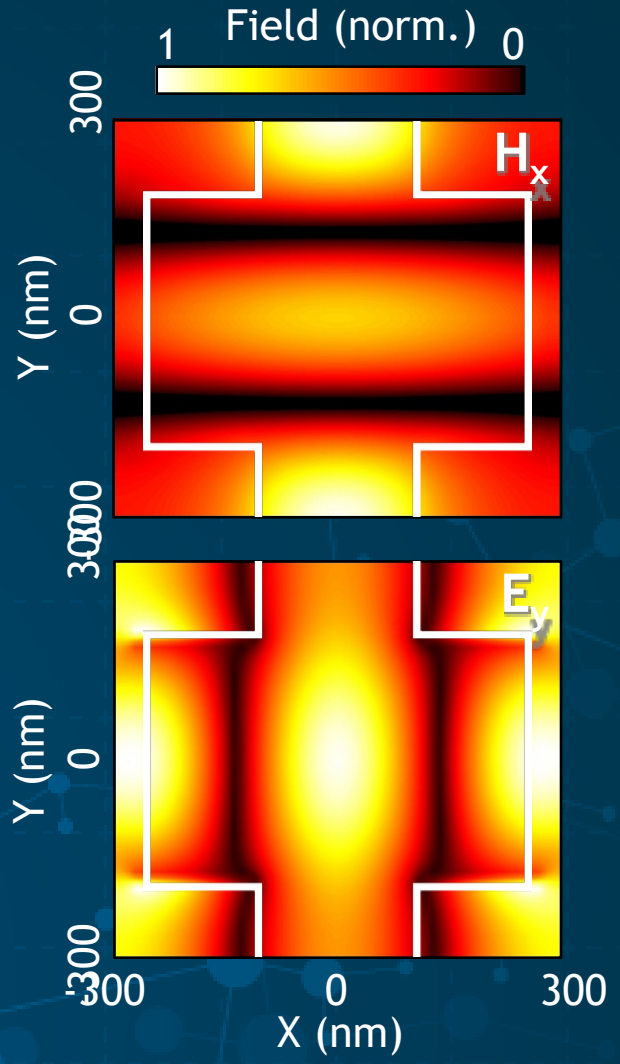
LT-GaAs metasurface design using degenerate Mie modes




Degenerate Mie modes

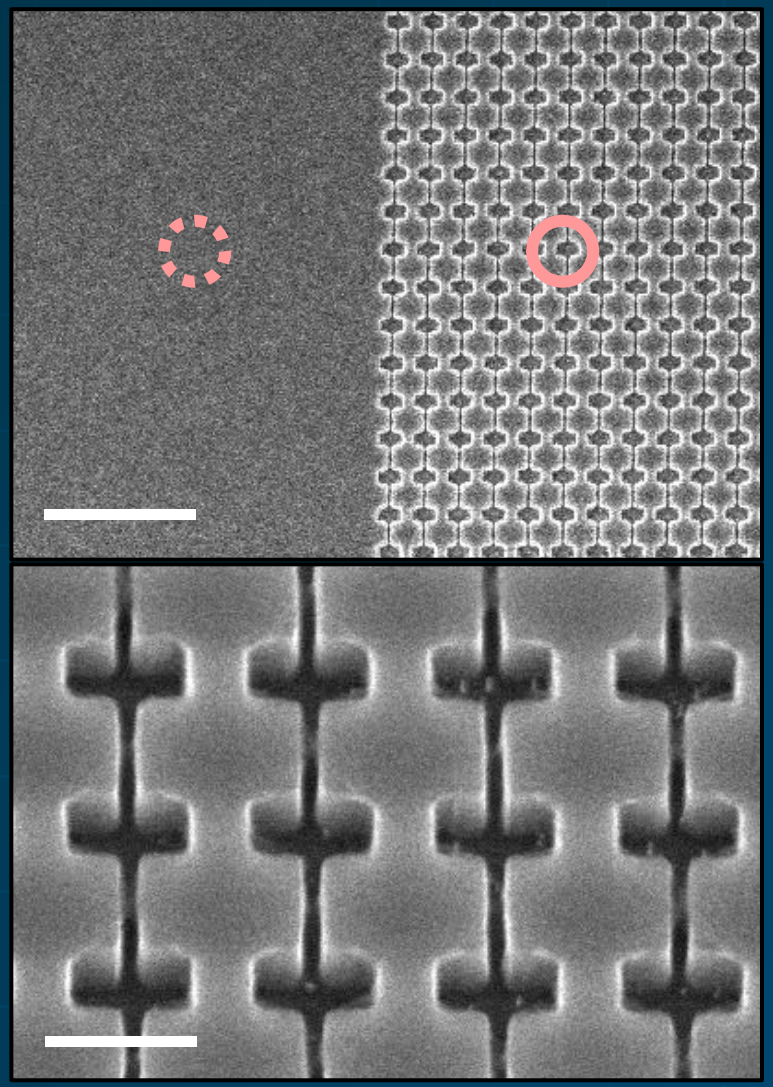


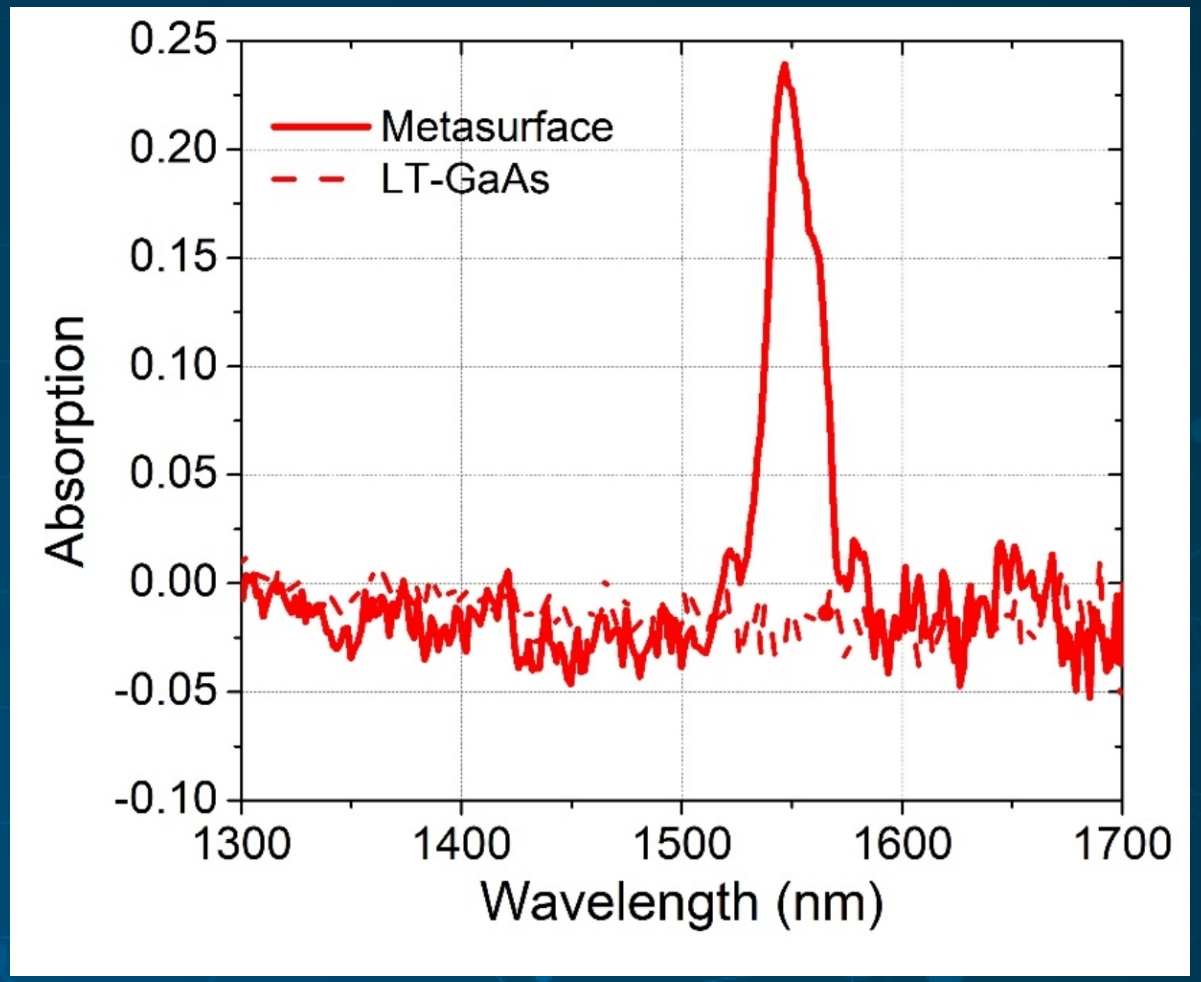




H. Jung et al. Adv. Opt. Mater. 11, 2201838 (2023)

# Comparison between LT-GaAs and metasurface



Enhanced absorption of LT-GaAs metasurface

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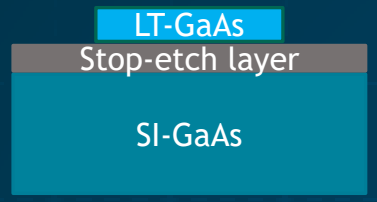
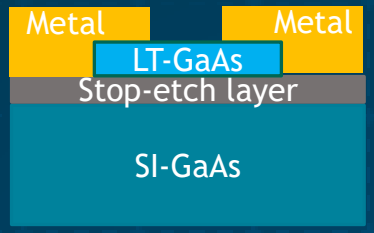
# Fabrication of metasurface photoconductive detector

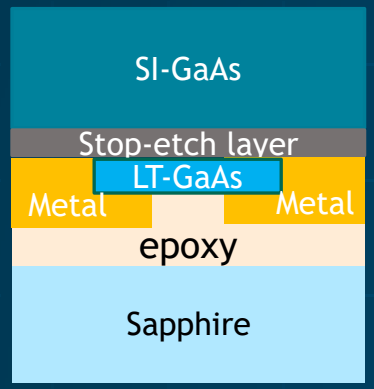
LT-GaAs metasurface photoconductive (PC) detector shows high sensitivity THz detection with a dynamic range of 60 dB and large bandwidth up to 4.5 THz.



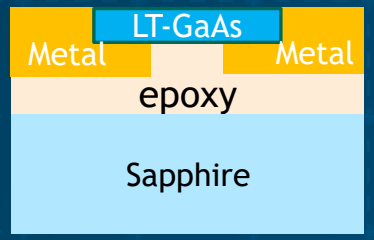

**ICP RIE** etching of LT-GaAs (Metasurface)



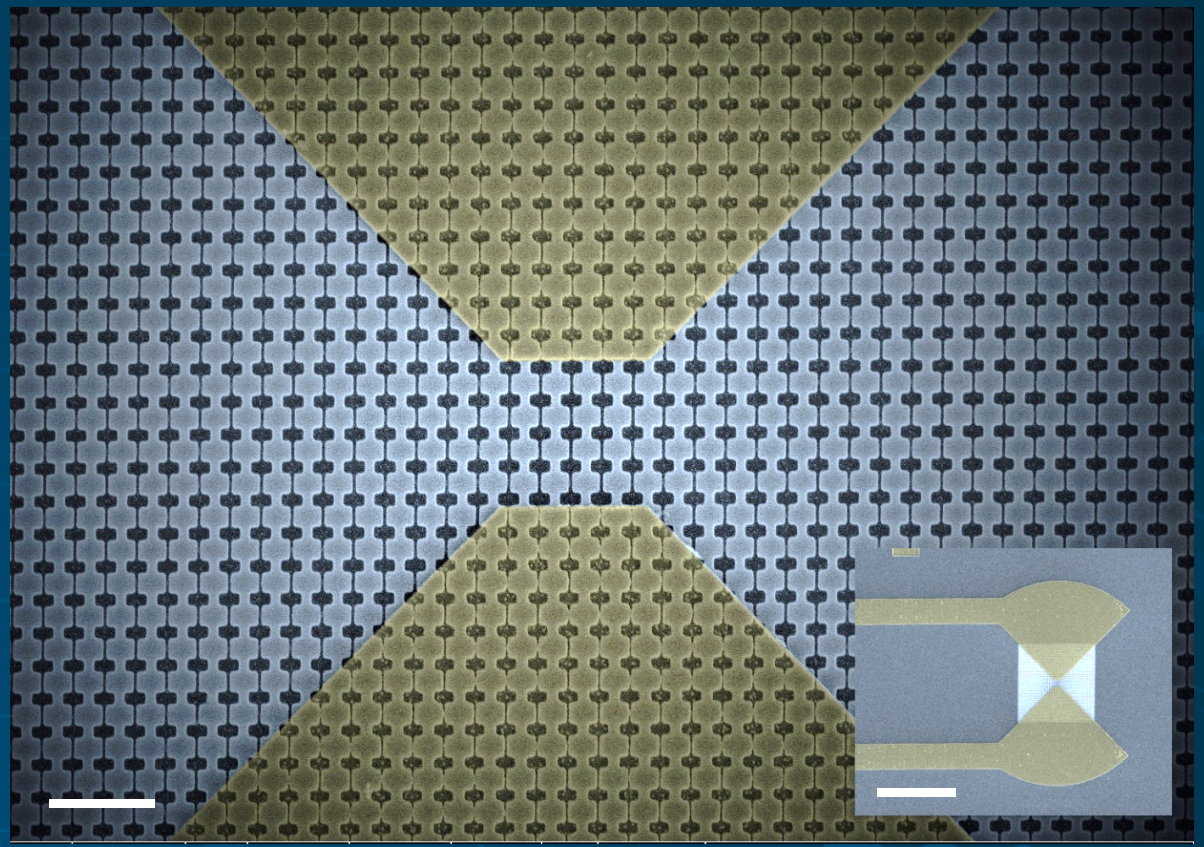

E-beam deposition of 300-nm thick metallic alloy (Ni/Ge/Au/Ni/Au)




**Bonding** to sapphire substrate




Mechanical lapping and wet etching of **SI-GaAs** (citric acid and $H_3PO_4$)



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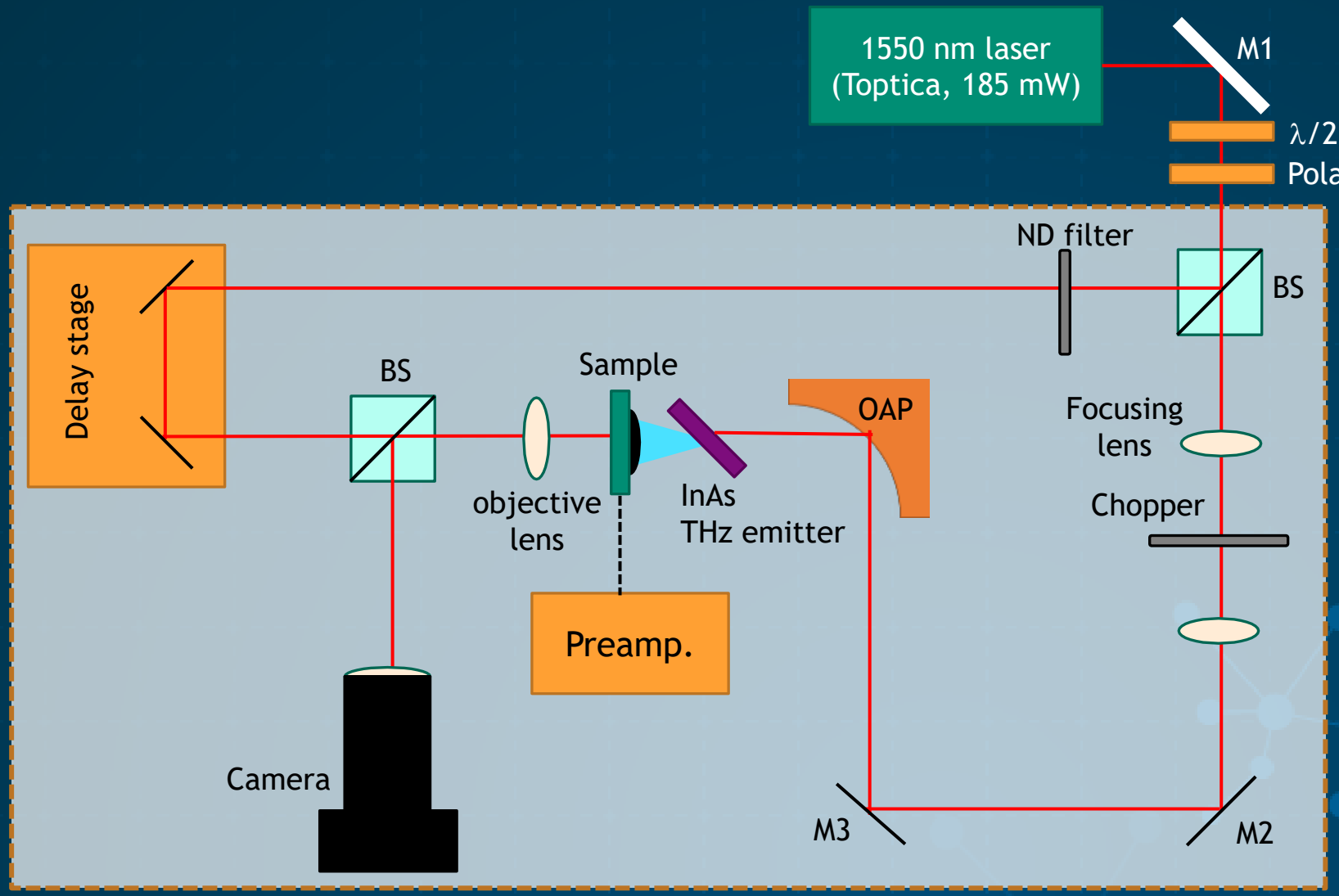
# Experimental setup

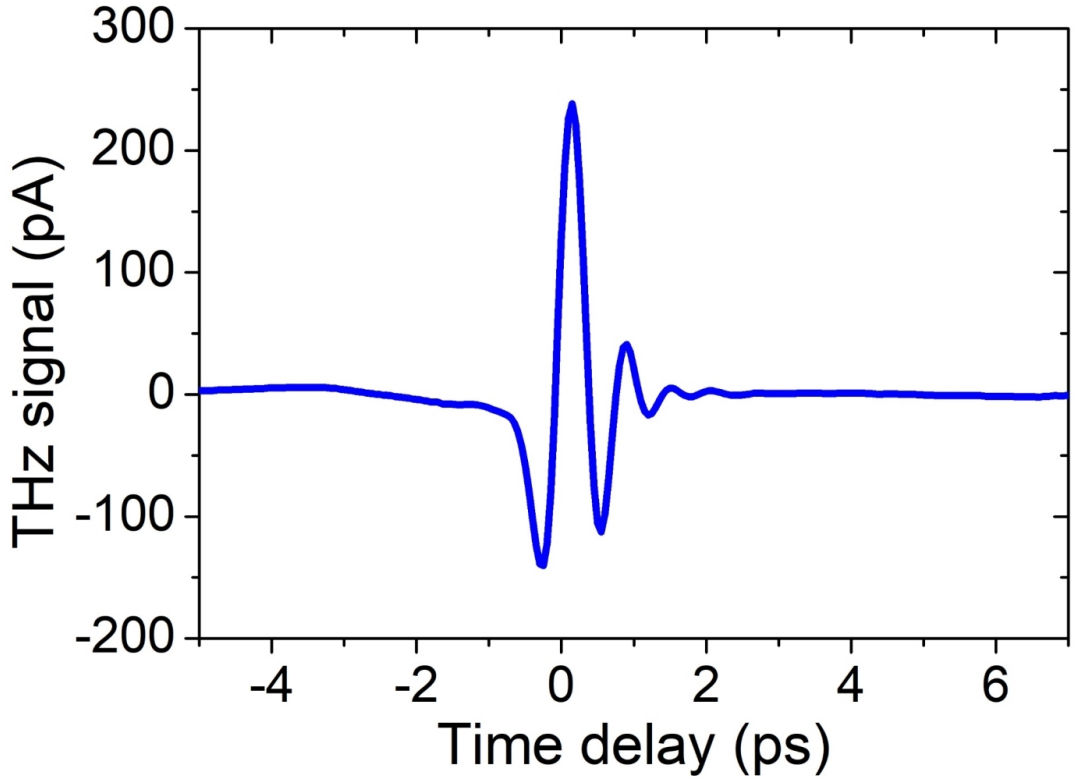


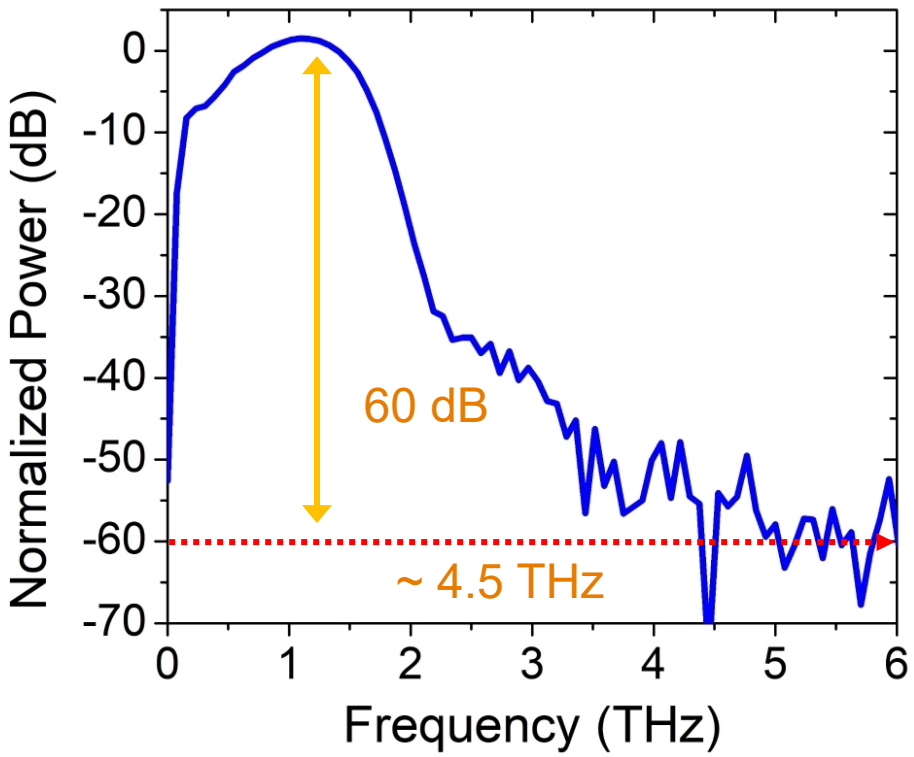

A 1550 nm fs-pulsed laser system (Toptica, 100 fs, 76 MHz) is used in the THz pulse detection experiment.

The gate beam power is 17 mW and the pump beam power is 80 mW.

# Experimental results

LT-GaAs metasurface photoconductive (PC) detector shows high sensitivity THz detection with a dynamic range of 60 dB and large bandwidth up to 4.5 THz.

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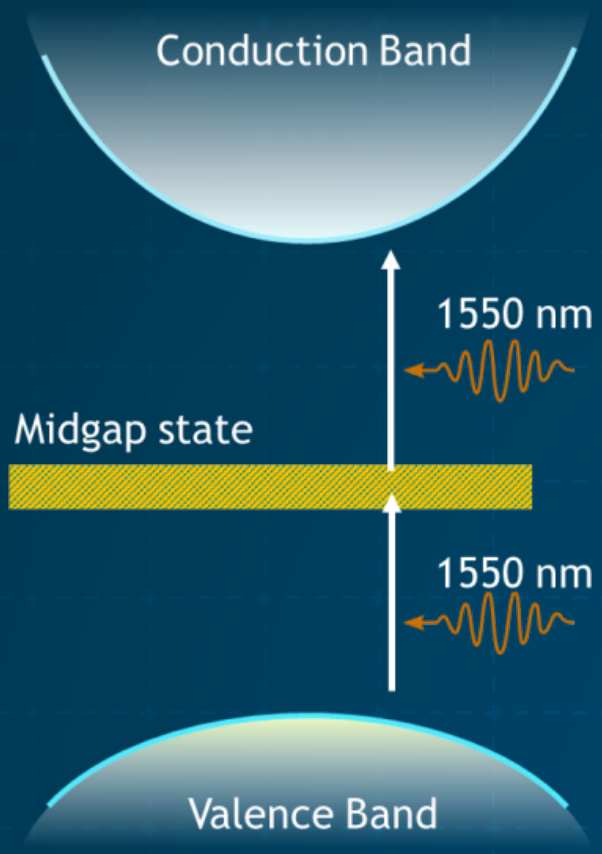
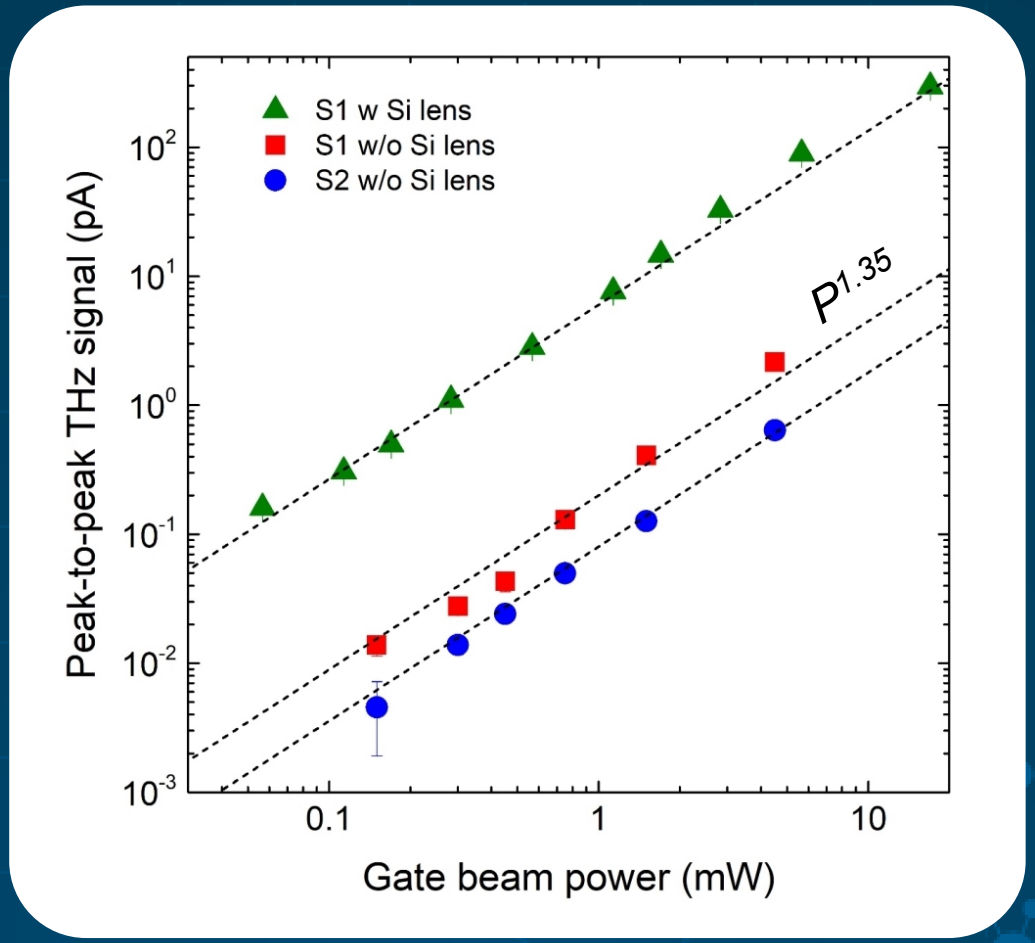
# THz dependence of LT-GaAs MS on gate power

To verify the **two-step absorption mechanism**, we investigate THz detection for a range of gate powers and different THz field strengths.




A super-linear power dependence on gating power can be seen in the logarithmic plot.

The peak THz amplitude follows a **$P^{1.35}$ power-law** for all samples (dashed lines).

M. Tani et al. Appl. Phys. Lett. 77, 1396 (2000)

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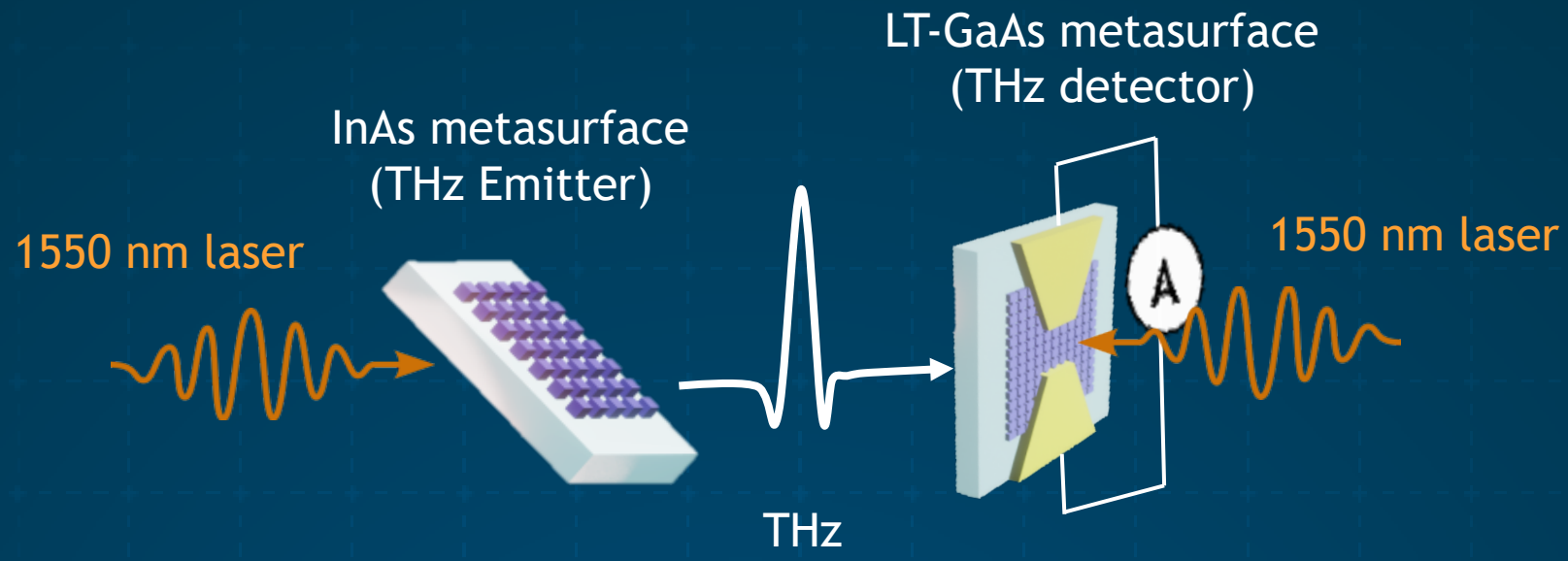
# Full THz system using semiconductor metasurfaces




High-performance

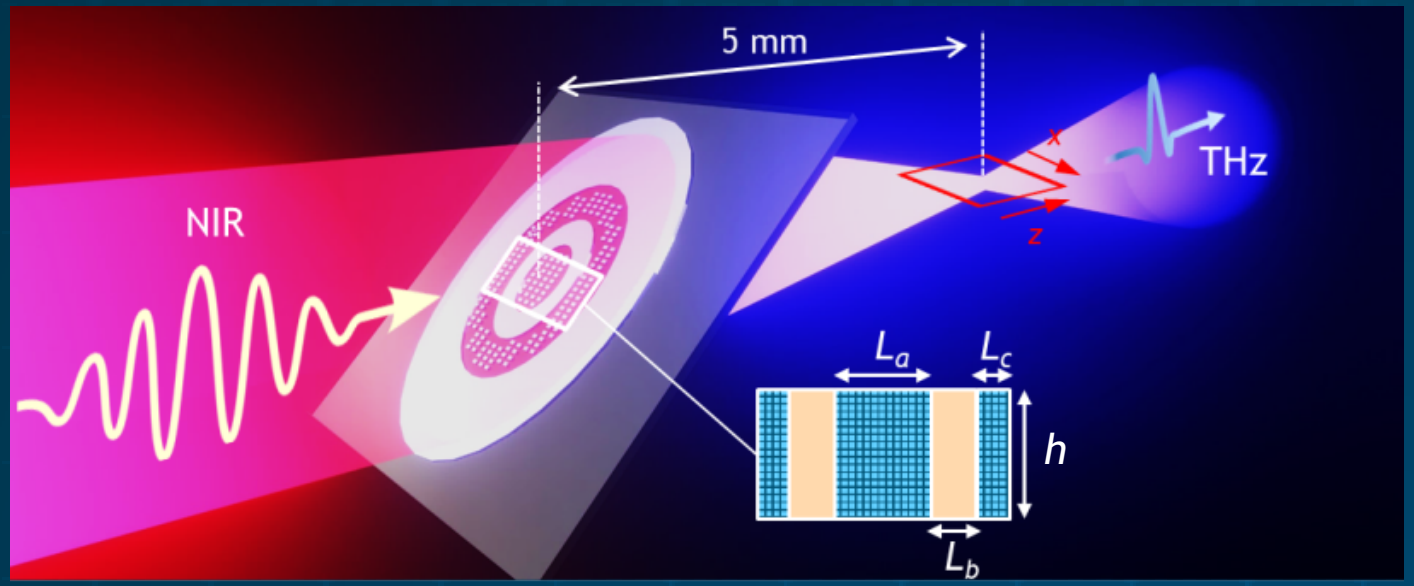
Compact

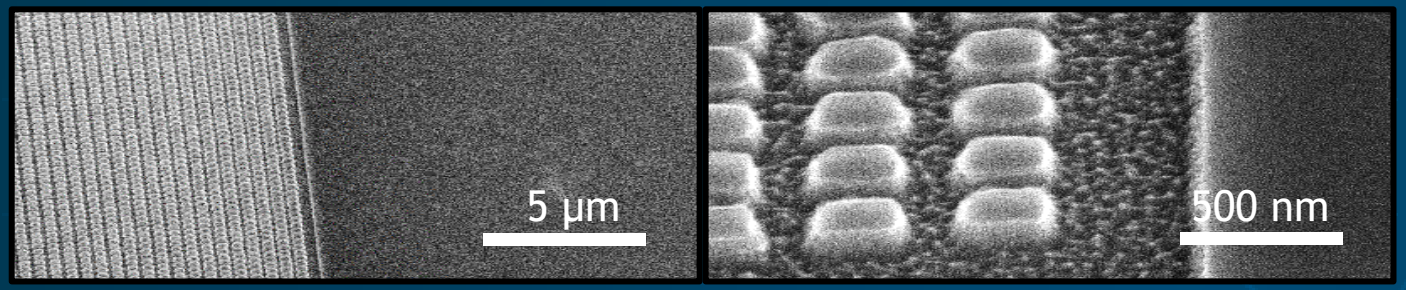
Cost-efficient

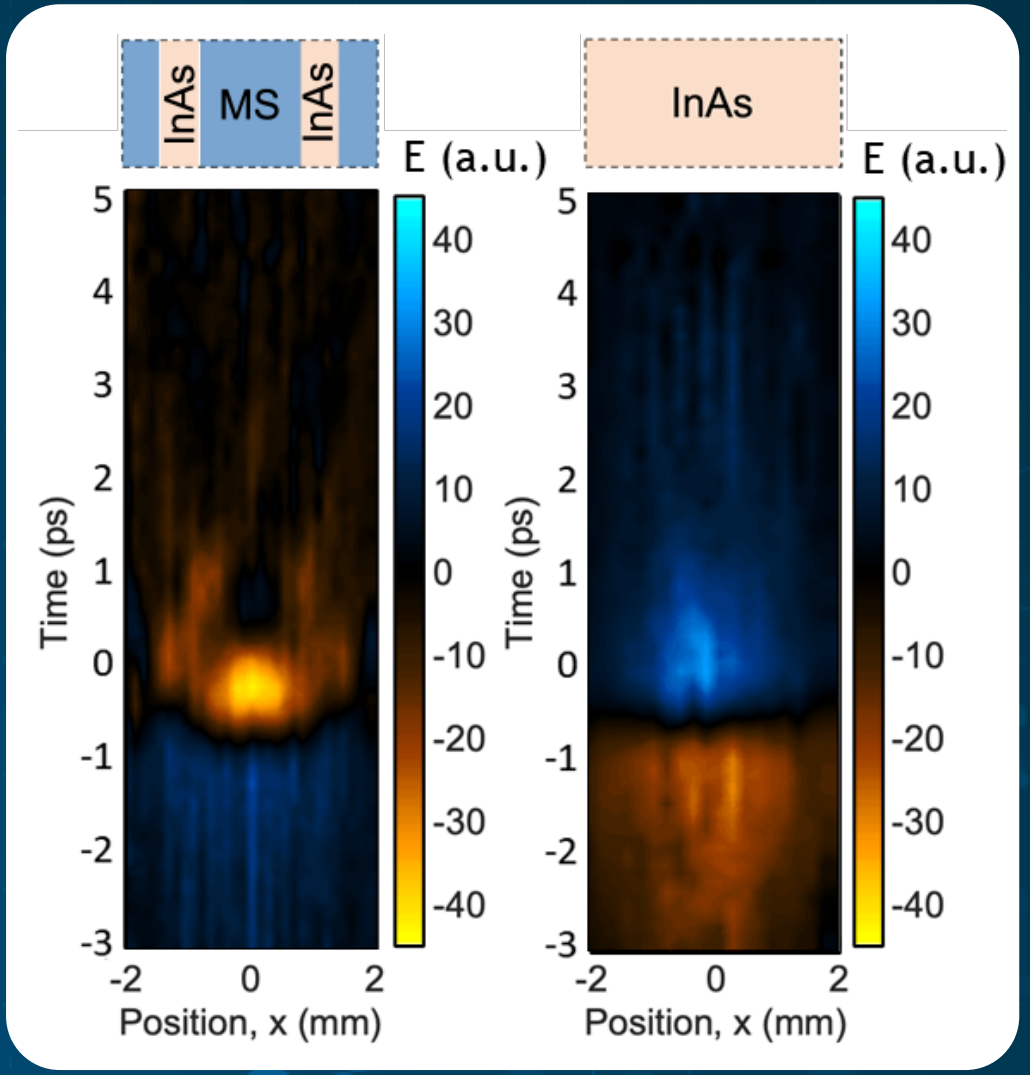
Multi-functional

# Focused THz beam generation of InAs metasurface

InAs metasurface design can offer a platform for realizing binary-phase THz generation (without THz modulators!)




H. Jung et al. Nano Lett. 22, 9077-9083 (2022)

# Acknowledgments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Lucy L Hale

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# New postdoctoral position!

## We are looking for self-motivated postdoctoral researchers!

- Igal Brener group

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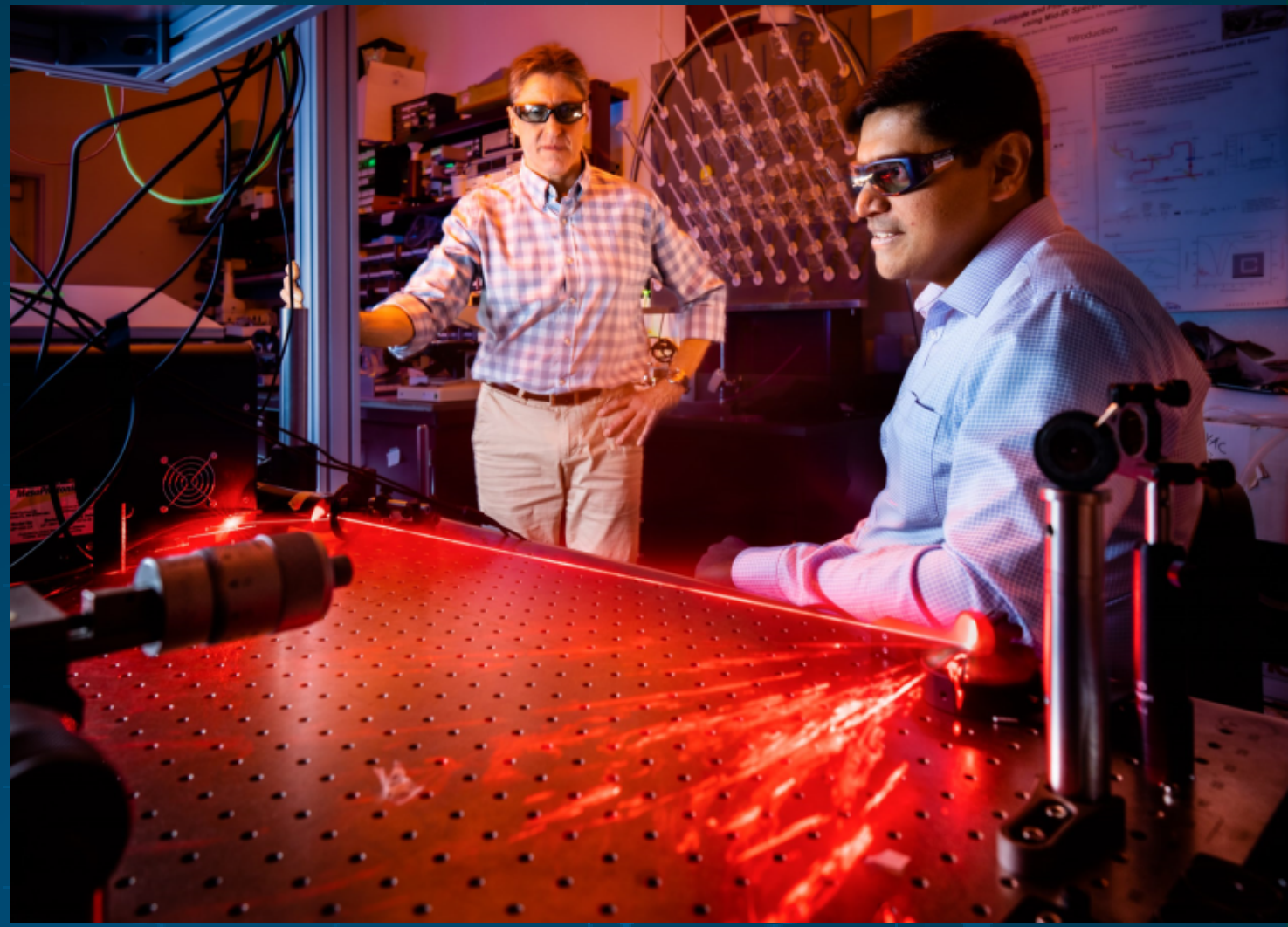

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