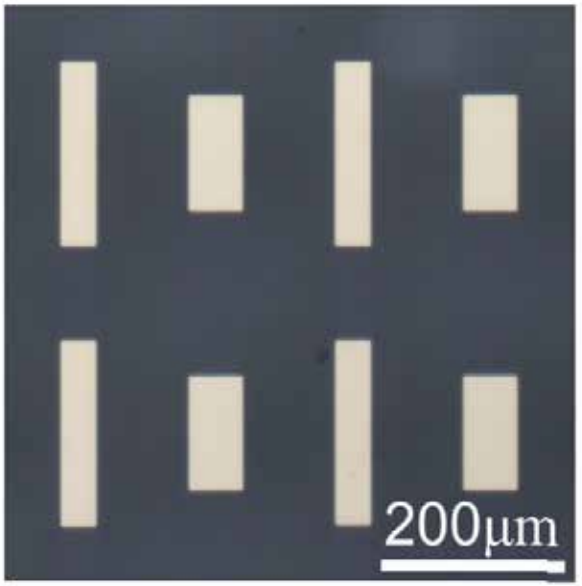
# THz Resonances with Infinity Lifetime

**Jaime Gómez Rivas**

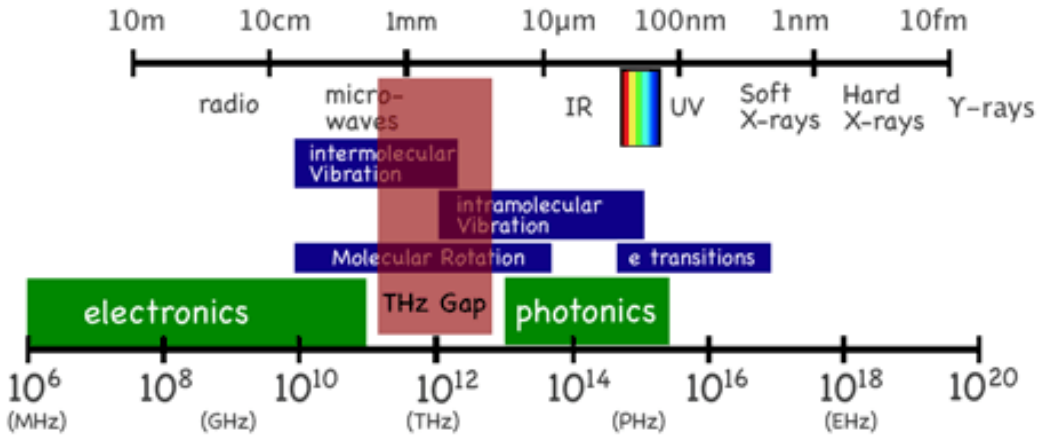
j.gomez.rivas@tue.nl




CWTe
Centre for Wireless Technology Eindhoven

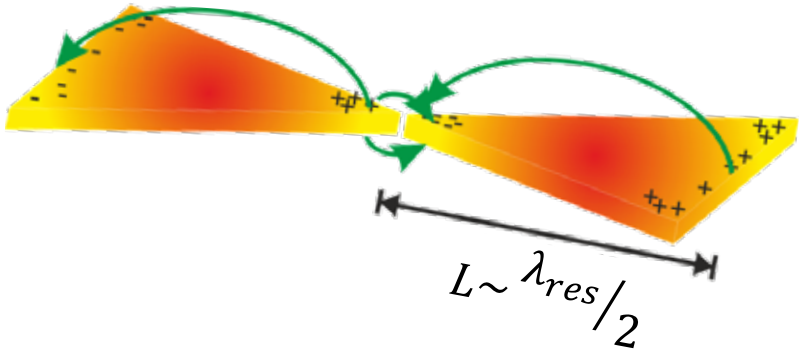
TU/e Technische Universiteit Eindhoven University of Technology

# Our motivation




n = 100 GHz … 10 THz
l = 3 mm … 30 µm

Semiconductors, nanostructures, (bio-)molecules, tissue…




- Resonant structures at THz frequencies Þ THz trapping and Large local field enhancements.
- Metals and Semiconductors Þ Active control of resonant response.

# Contents

- Introduction to optical THz time domain techniques
- THz plasmonics with semiconductors
- THz metasurfaces and near-field ( THz beaming, plasmon induced transparency and bound states in the continuum)

# Acknowledgements


TU/e

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NWO

FOM

erc

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- Diego Abujetas

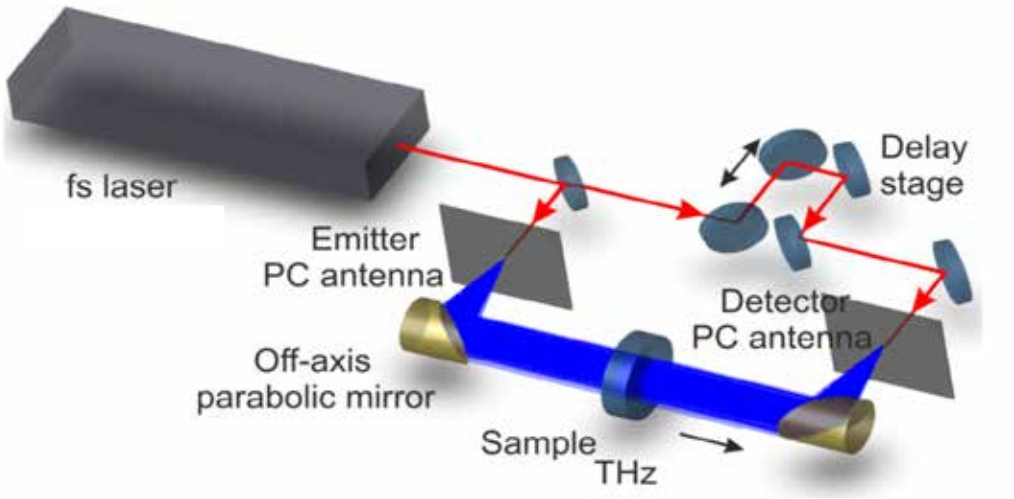
PHILIPS

- Lorenzo Tripodi
- Marion Matters

TeraNova

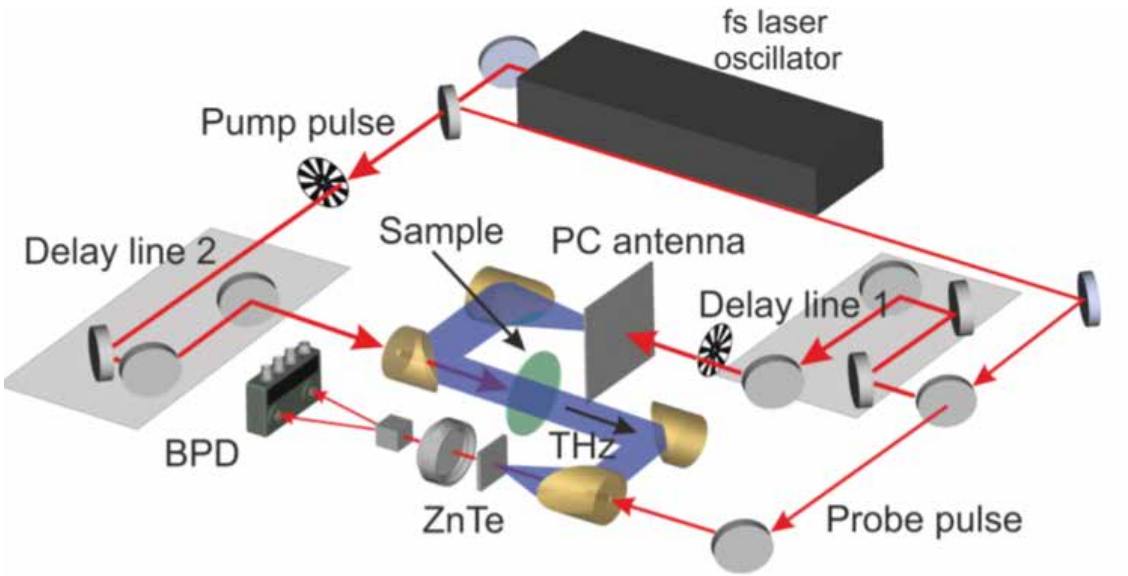
- Mohammad Ramezani

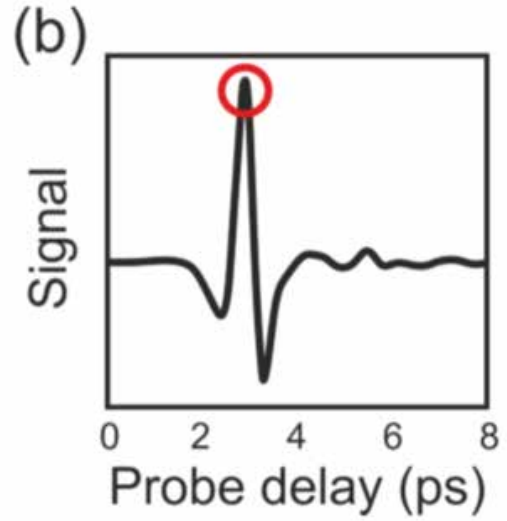
# THz time domain spectroscopy (THz-TDS)

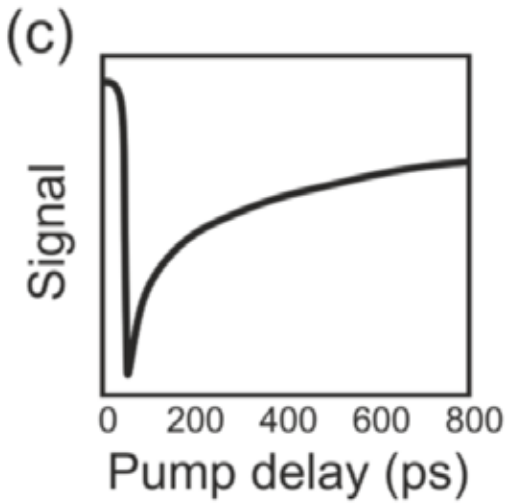



THz time domain spectroscopy is based on ultrashort optical pulses to generate and detect single (or few) cycle THz pulses

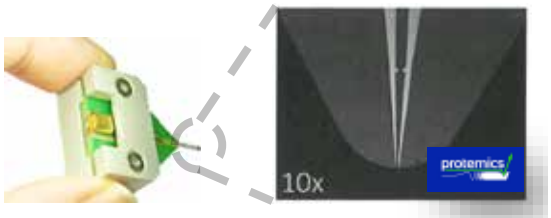
# Time-resolved THz-TDS (TR-THz-TDS)

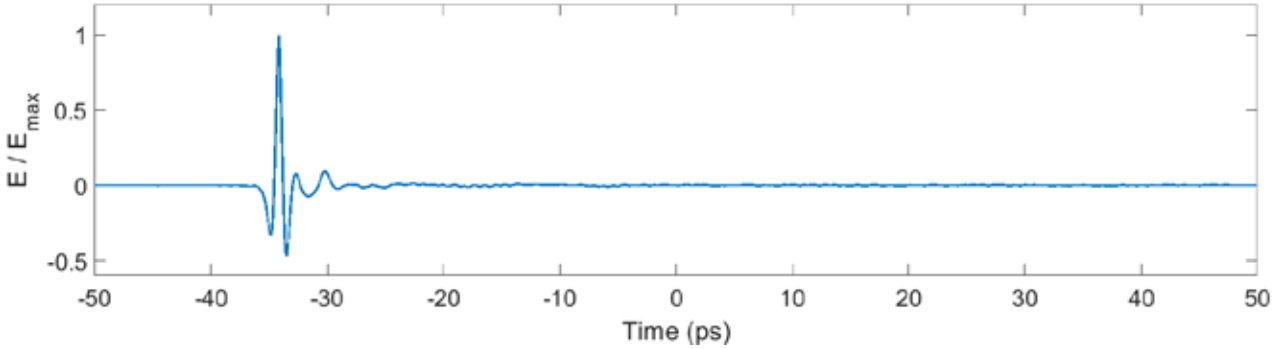


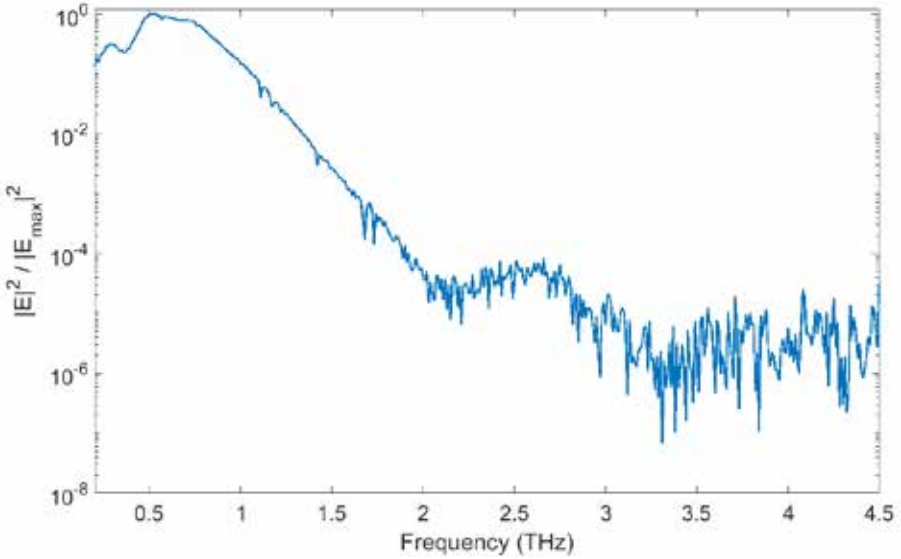



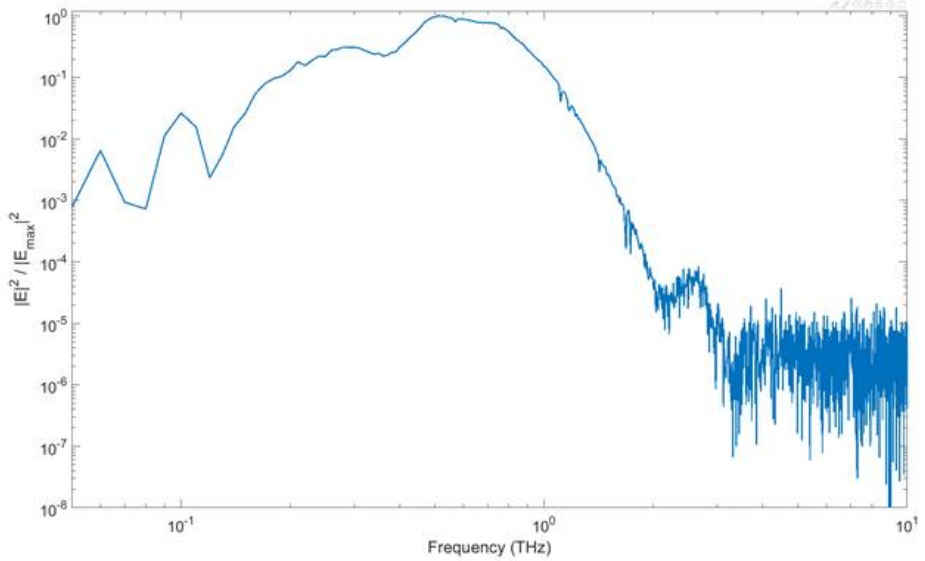



# TR-THz-TD near-field microscopy (TR-THz-TD-NFM)

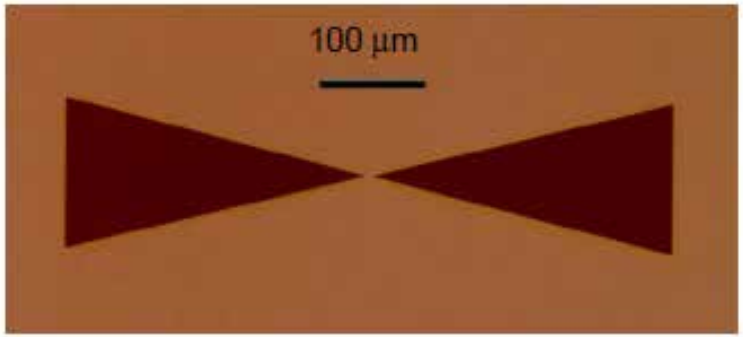


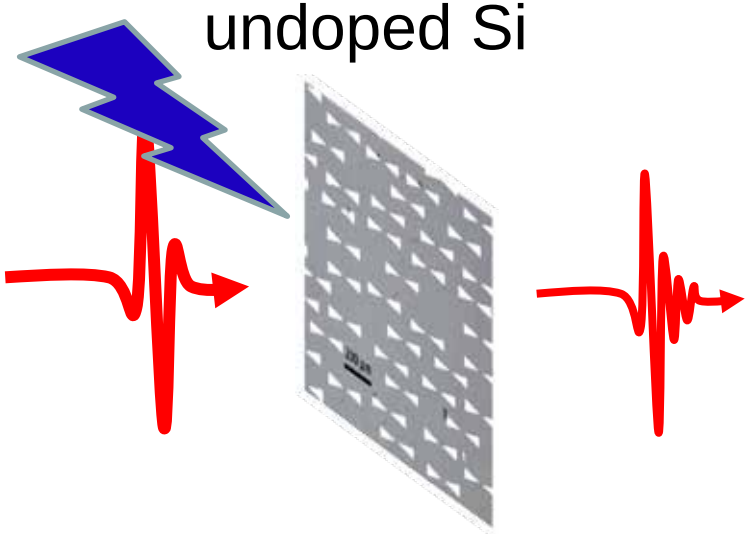



# Si bowtie resonators



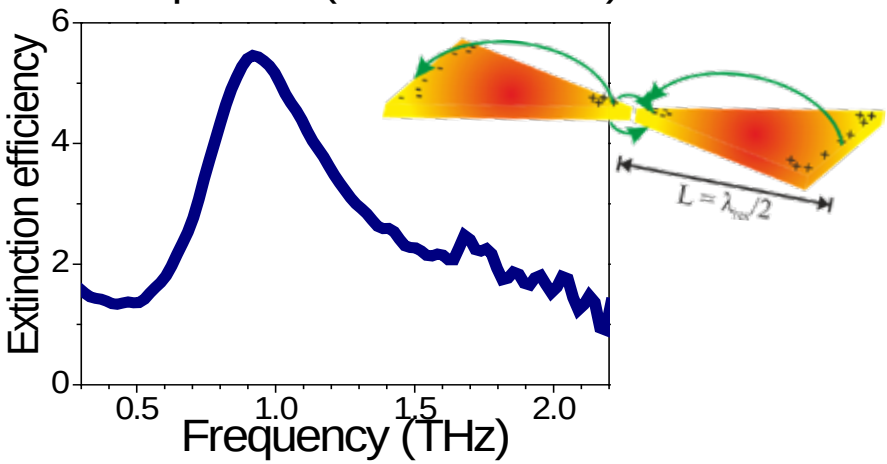

l = 400 nm

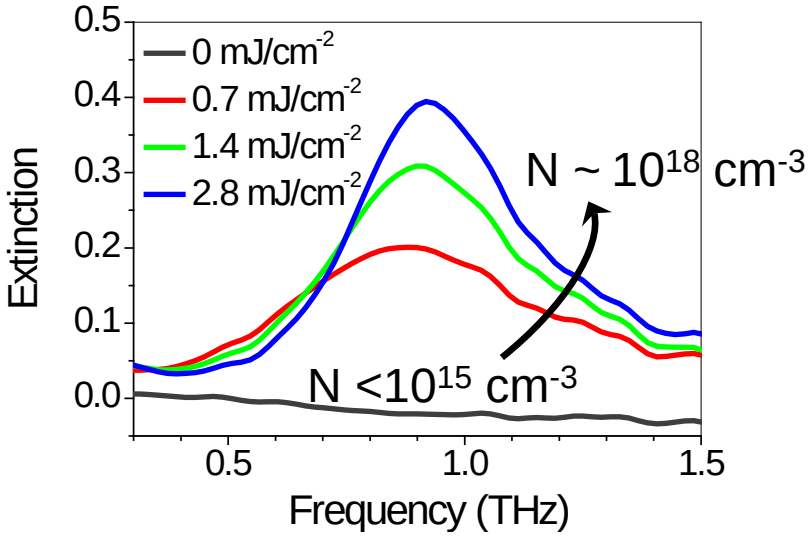
undoped Si



$t_{THz\text{-}probe} - t_{opt\text{-}pump} \sim 5$ ps

n-doped Si (N= $10^{19}$ $cm^3$)

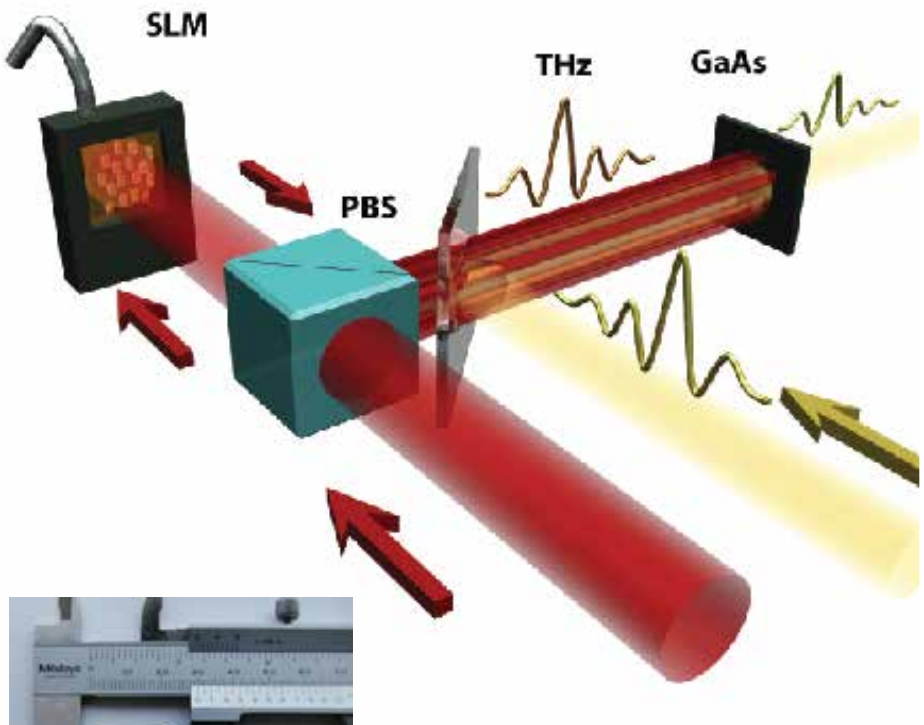



**A. Berrier ... JGR, Optics Express, 20(5), 5052 (2012)**
**A. Berrier ... JGR, Biomedical Optics Express, 3(11), 2937 (2012)**

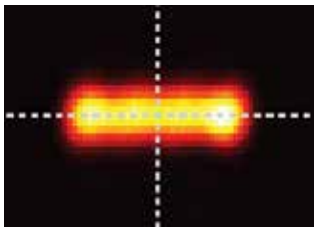
# Photo-generated THz antennas

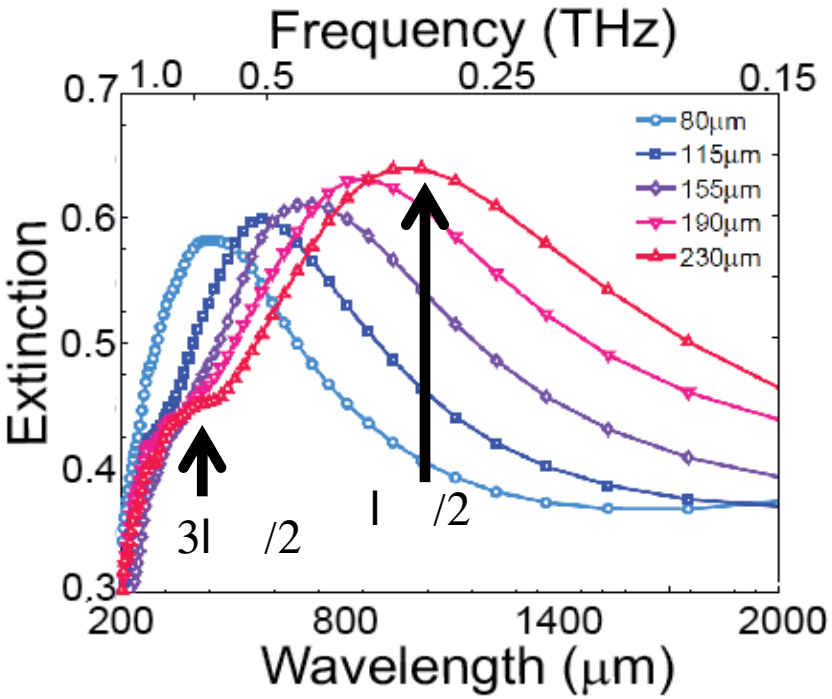
Sample: flat single crystal GaAs layer (1 mm) on quartz

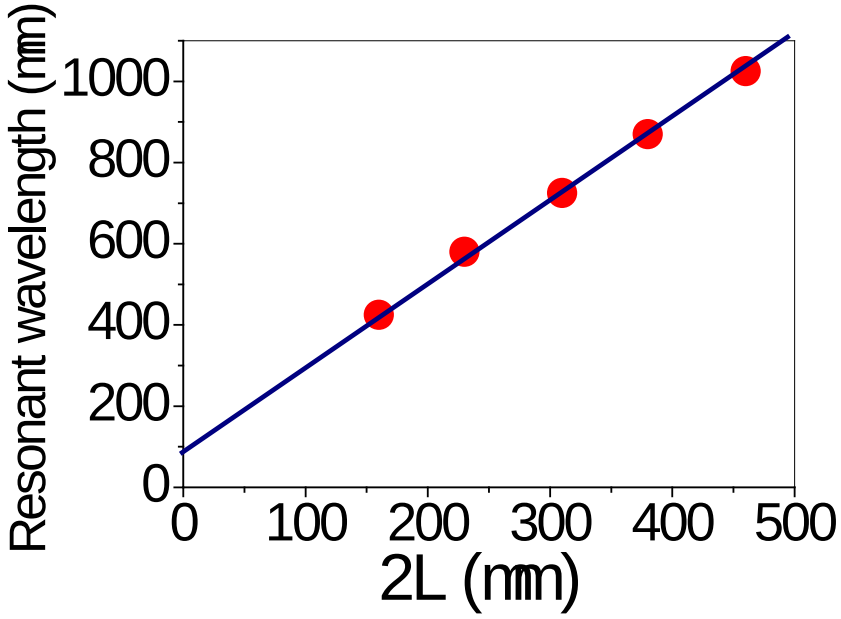



G. Georgiou … JGR , Scientific Reports 4, 3584 1-5 (2014)

# Photo-generated THz antennas

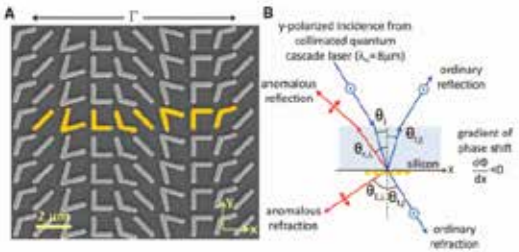





Active THz beam steering

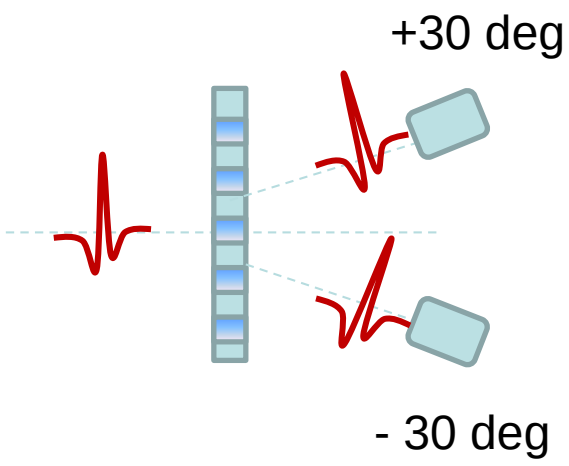
**Light Propagation with Phase Discontinuities: Generalized Laws of Reflection and Refraction**



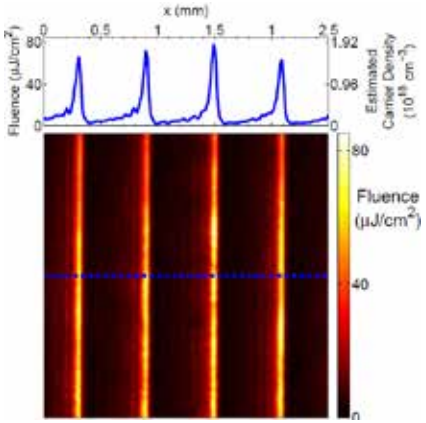

**T. Steinbusch ., Opt. Express 22, 26559 (2014).**

**G. Georgiou … JGR , Scientific Reports 4, 3584 1-5 (2014); Phys. Rev. B 91, 125443 (2015).**

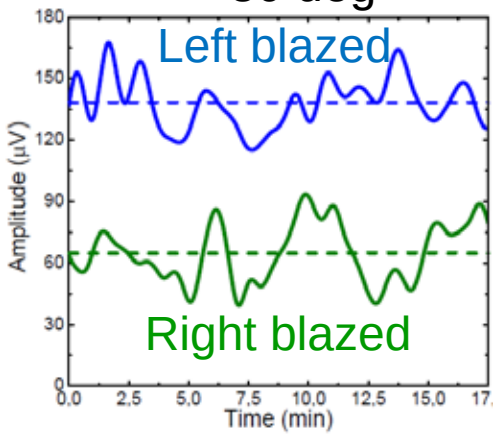
# Photo-generated metasurfaces




Left blazed

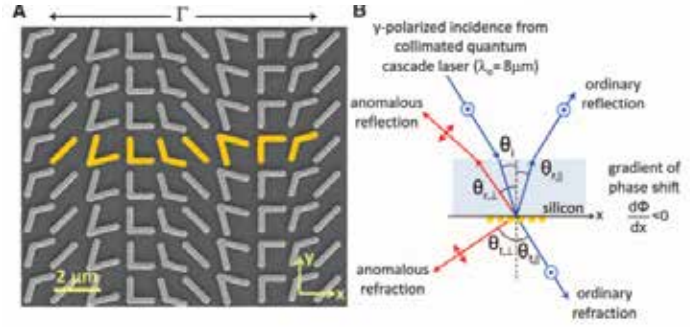



+30 deg

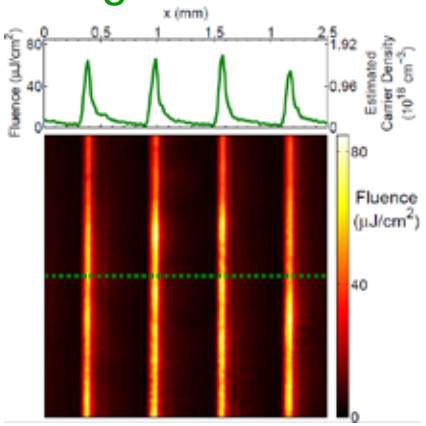



**Light Propagation with Phase Discontinuities: Generalized Laws of Reflection and Refraction**

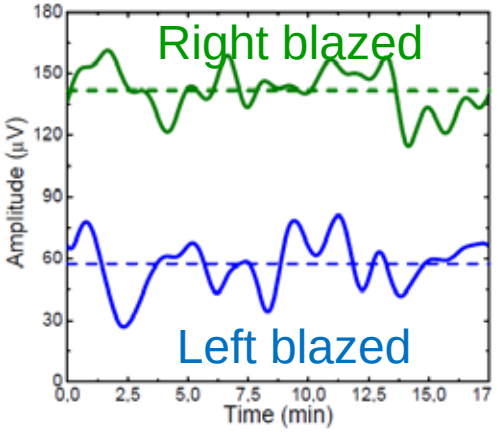
Nanfang Yu,[1] Patrice Genevet,[1,2] Mikhail A. Kats,[1] Francesco Aieta,[1,2] Jean-Philippe Tetienne,[1,3] Federico Capasso,[1]* Zeno Gaburro[1,3]*




Right blazed

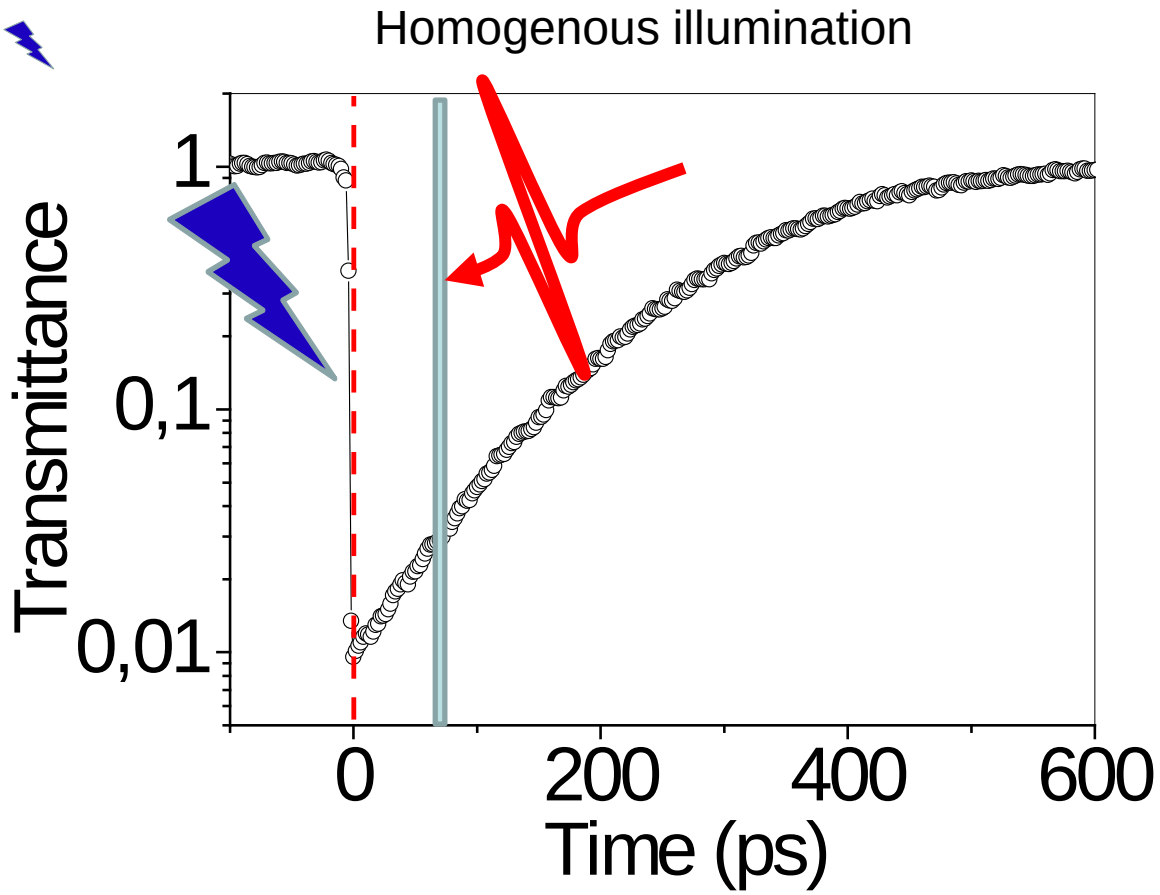



- 30 deg



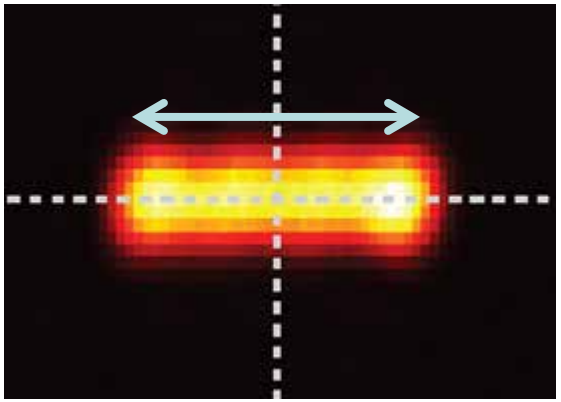

**T. Steinbusch ., Opt. Express 22, 26559 (2014).**

# Photo-generated carrier dynamics in GaAs

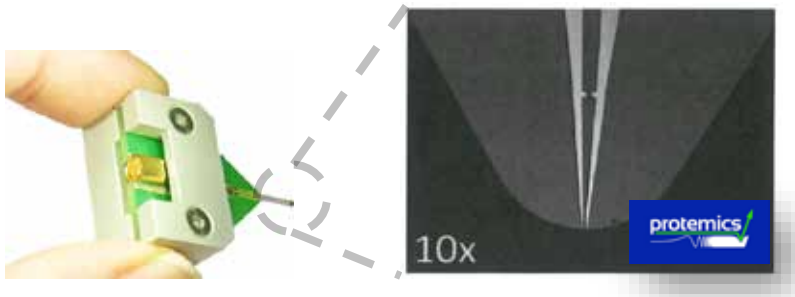


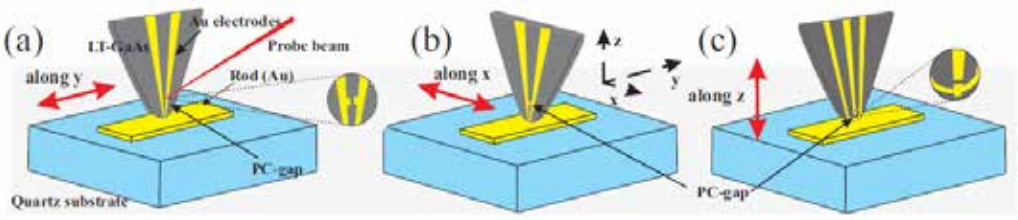

» 500 ps >> » 1 ps

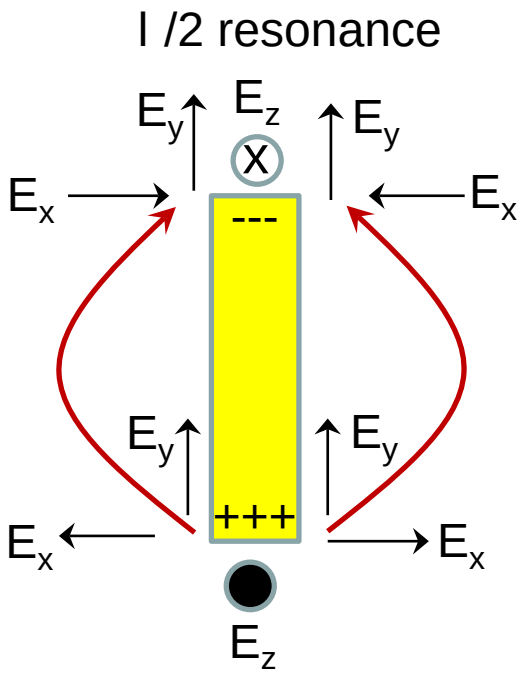
<< » 100 mm

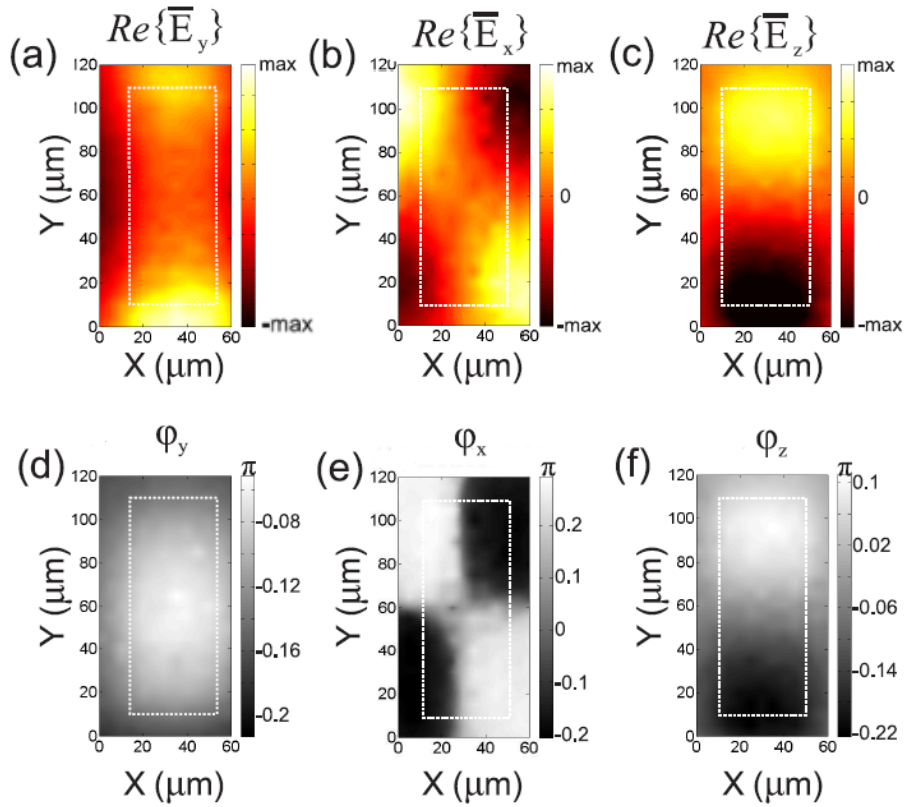


# Full vectorial mapping of resonant THz near-fields



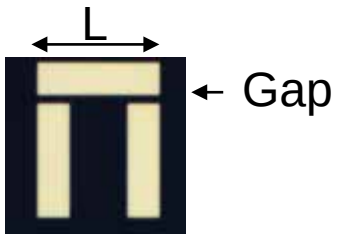



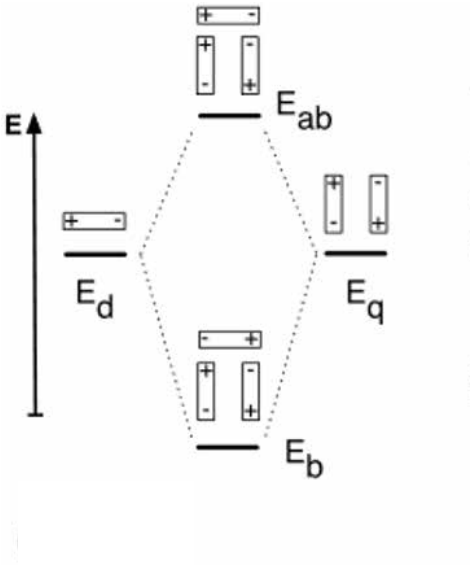

Batthacharya … JGR, APL Photonics (2016); Phys. Rev. B 93, 035438 (2016)

# Plasmon induced transparency

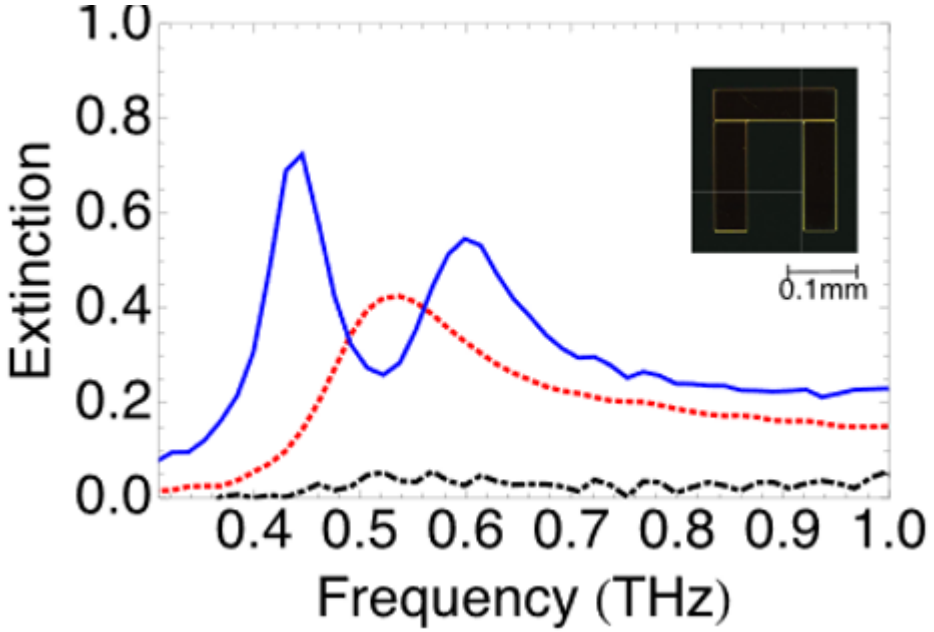



Dolmen resonators: plasmon induced transparency:
**Xiang Zhang et al., Phys. Rev. Lett. 101, 047401 (2008)**

Mode hybridization

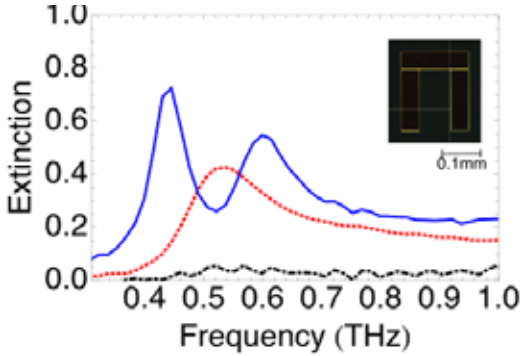


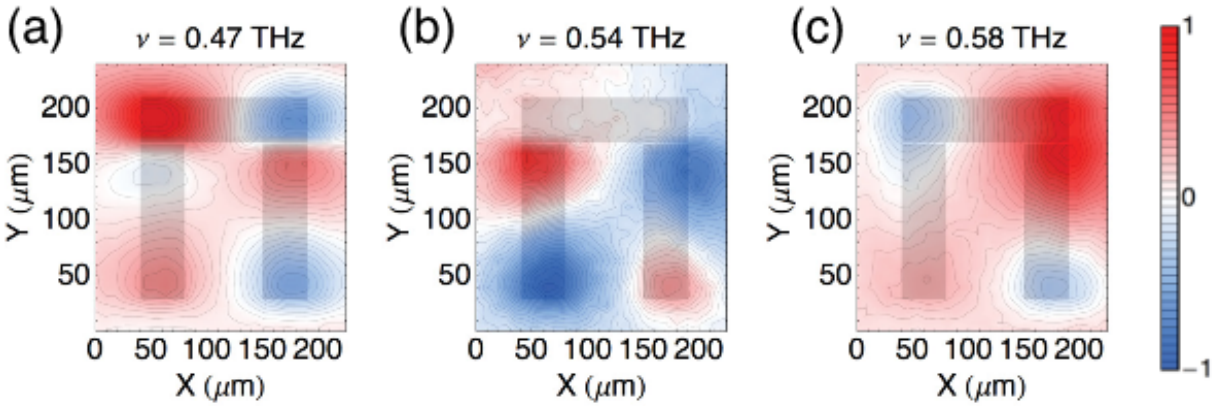

Extinction = 1-Transmission

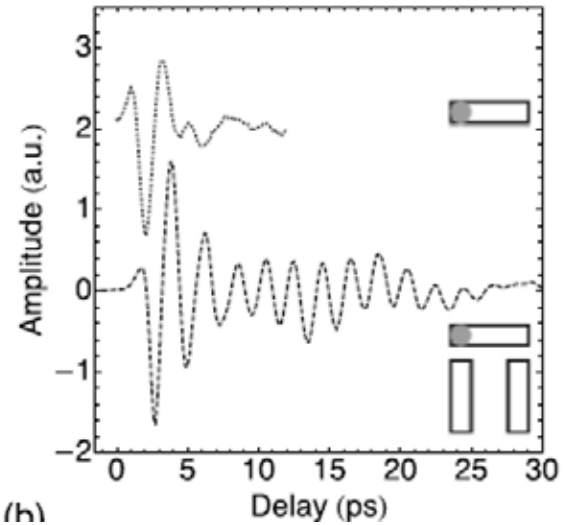


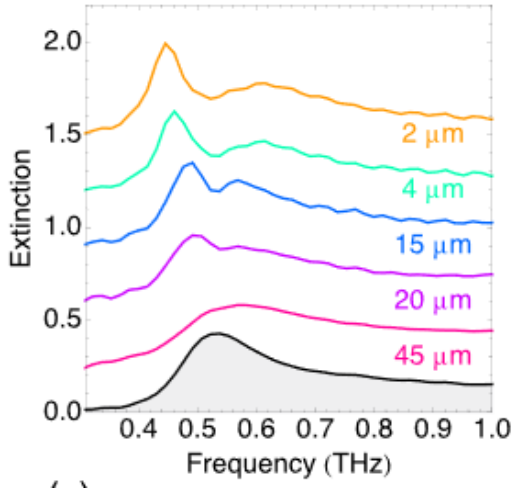

**A. Halpin ... JGR, Appl. Phys. Lett. 110, 101105 (2017)**

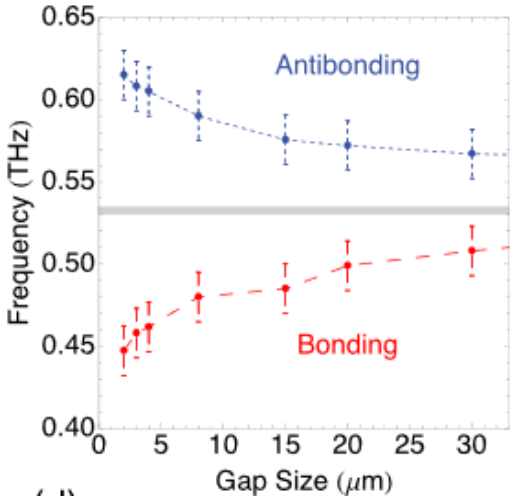
# Plasmon induced transparency



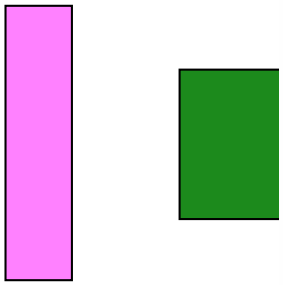



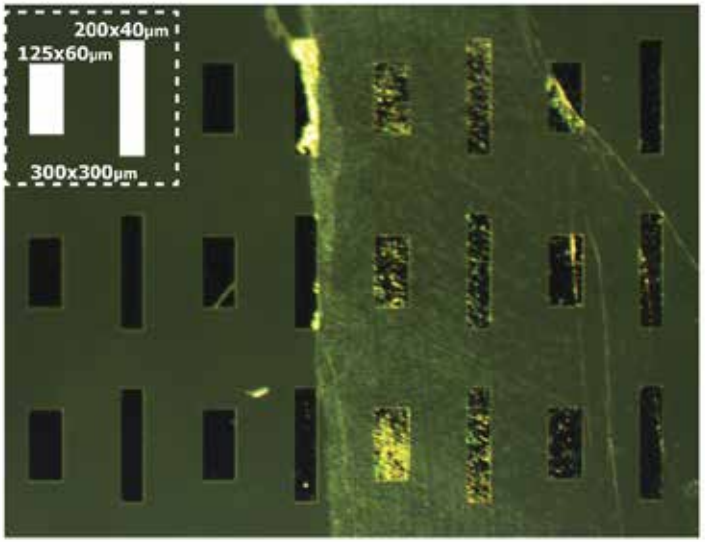

A. Halpin et al., Appl. Phys. Lett. 110, 101105 (2017); Phys. Rev. B 96, 085110 (2017)

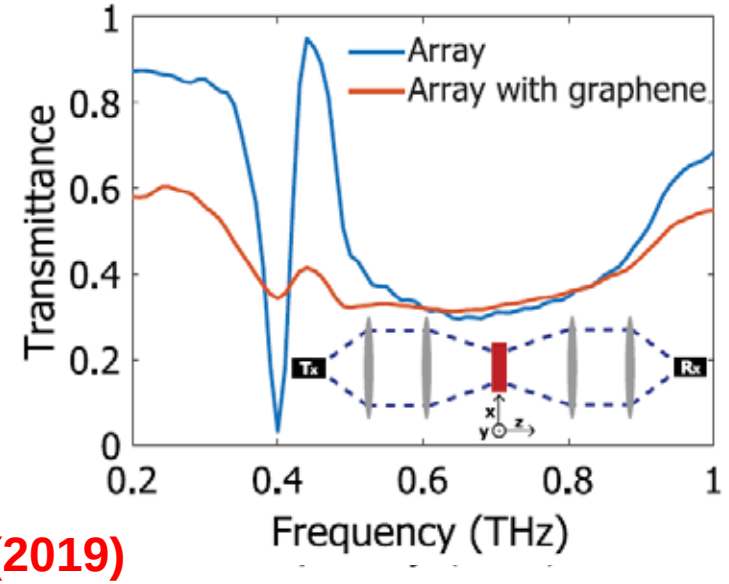
# Lattice of detuned resonators: Diffraction induced transparency



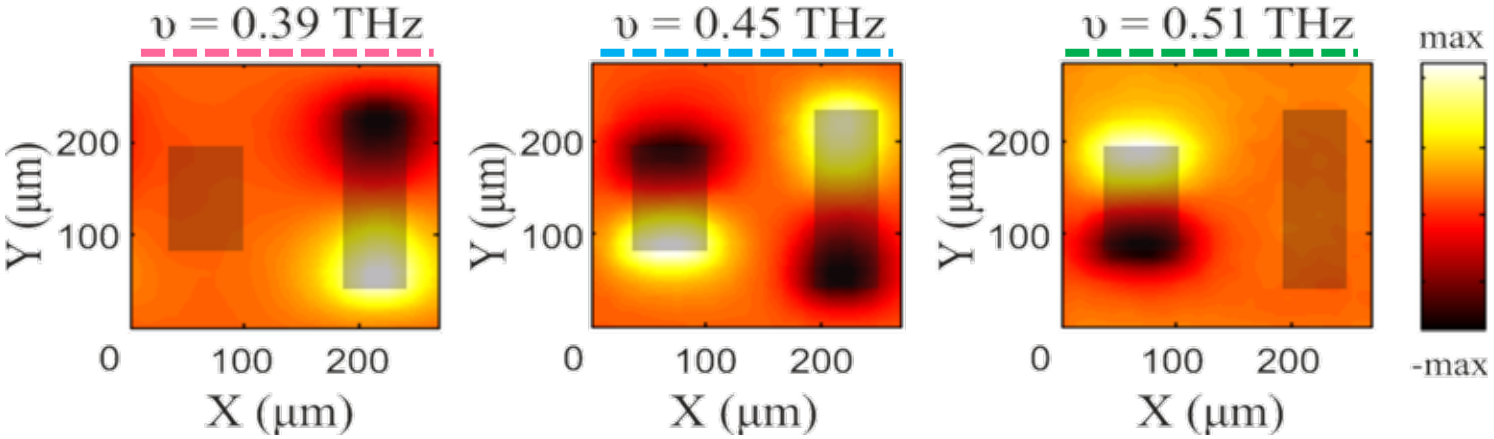


Gap = 150 mi



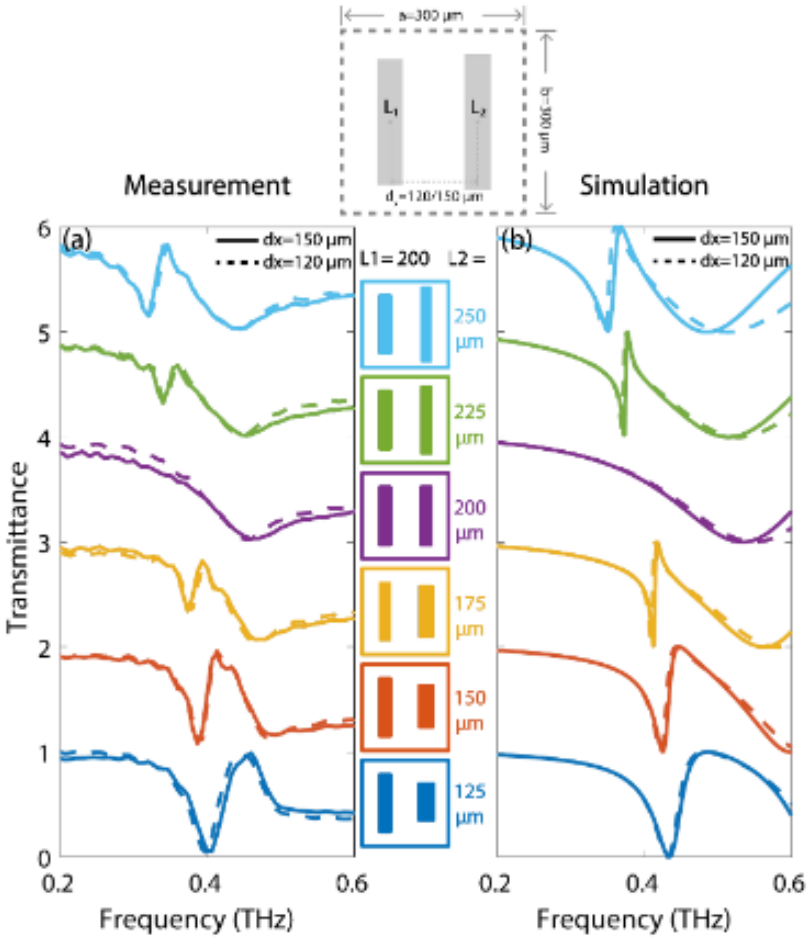



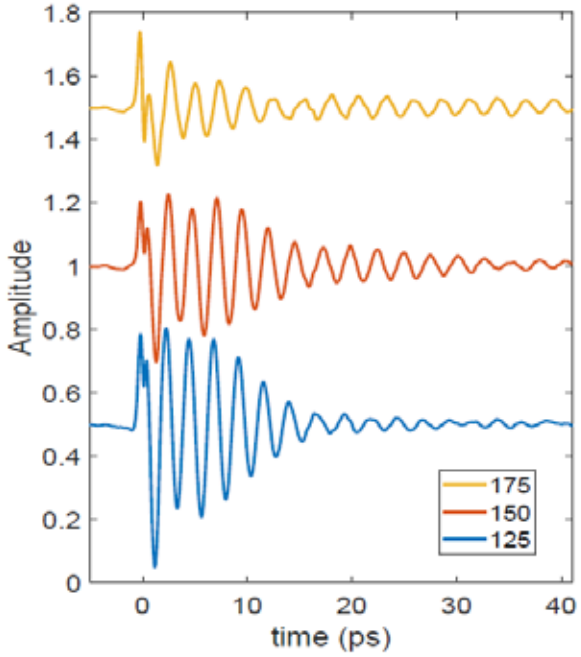

**N. Van Hoof … JGR, APL photonics (2019)**

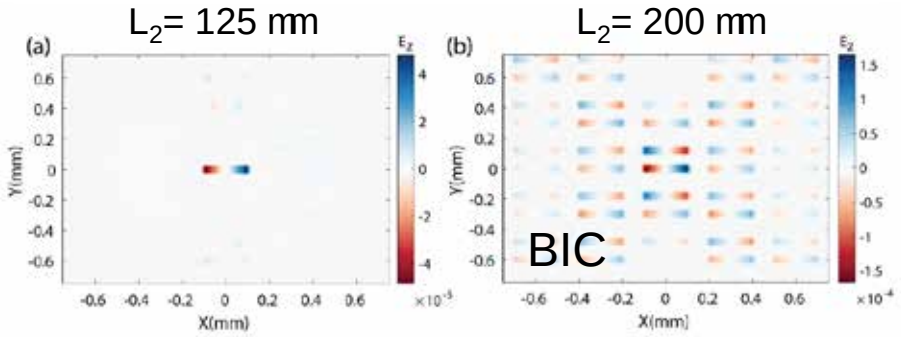



**M. Schaafsma … JGR, ACS photonics 3, 1596 (2016)**

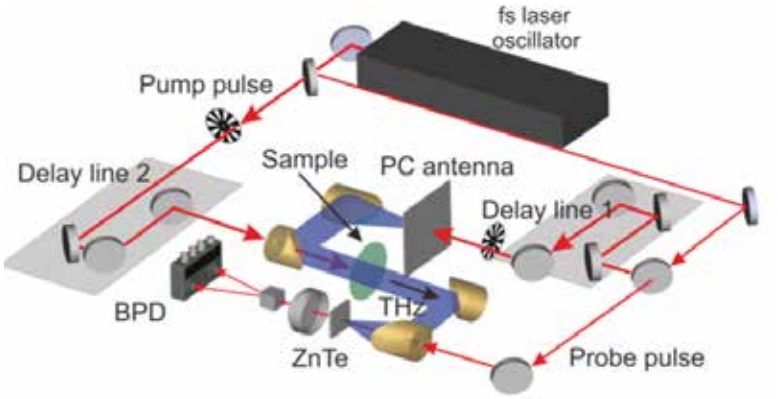
# Bound states in the continuum

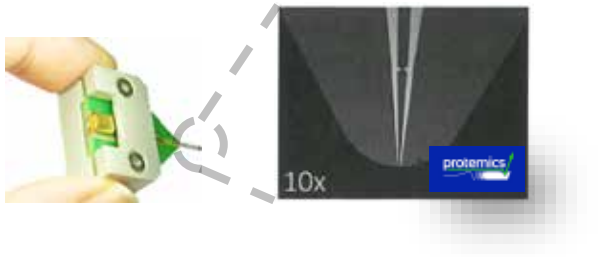


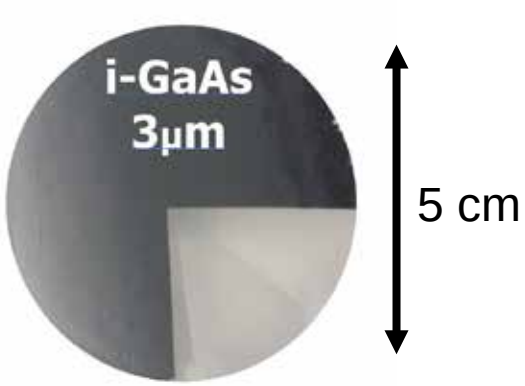



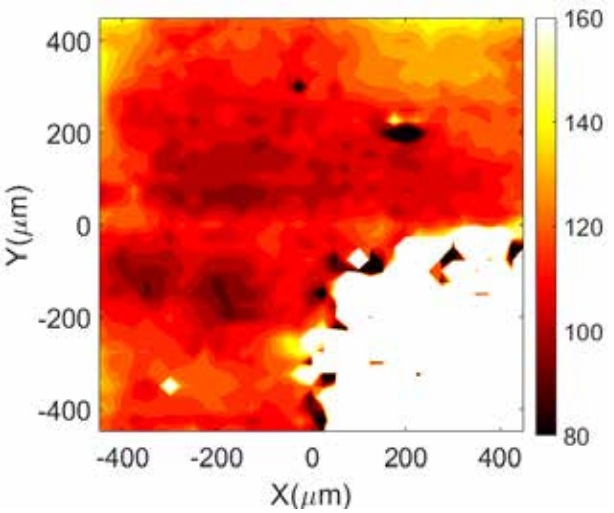



# TeraNova




Contact free and high resolution mapping of:

- Carrier mobility
- Carrier density (doping)
- (photo-)conductivity
- Carrier lifetimes