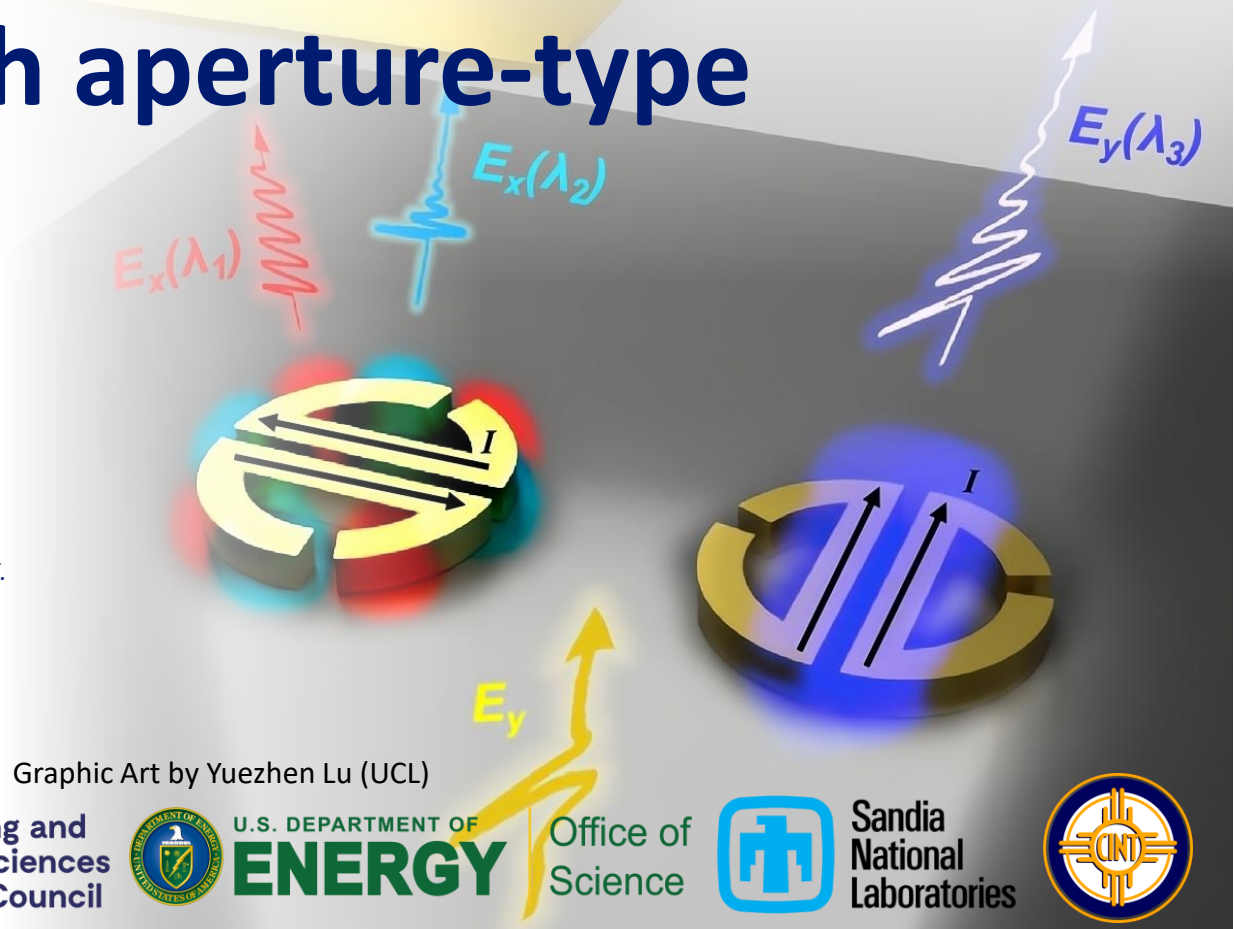
Rank Symposium on THz Applications of Liquid Crystals
November 2024

Non-contact terahertz surface current imaging in metallic resonators with aperture-type near-field microscopy

Sarah Norman,[1] James Seddon,[1] Yuezhen Lu,[1] Lucy Hale,[2] Abdullah Zaman,[3] Sadhvikas J. Addamane,[4,5] Igal Brener,[4,5] Riccardo Degl'Innocenti,[6] and Oleg Mitrofanov,[1,4]

[1]*University College London, Electronic and Electrical Engineering, London WC1E 7JE, UK*
[2]*ETH Zurich, Institute of Quantum Electronics, Auguste-Piccard-Hof 1, 8093 Zurich, Switzerland*
[3]*Lancaster University, School of Engineering, New Engineering Building, Gillow Ave, Bailrigg, Lancaster LA1 4YW, U.K.*
[4]*Center for Integrated Nanotechnologies, Sandia National Laboratories, Albuquerque, New Mexico 87123, USA*
[5]*Sandia National Laboratories, Albuquerque, New Mexico 87123, USA*
[6]*Queen Mary University of London, School of Electronic Engineering and Computer Science, London E1 4NS, UK*

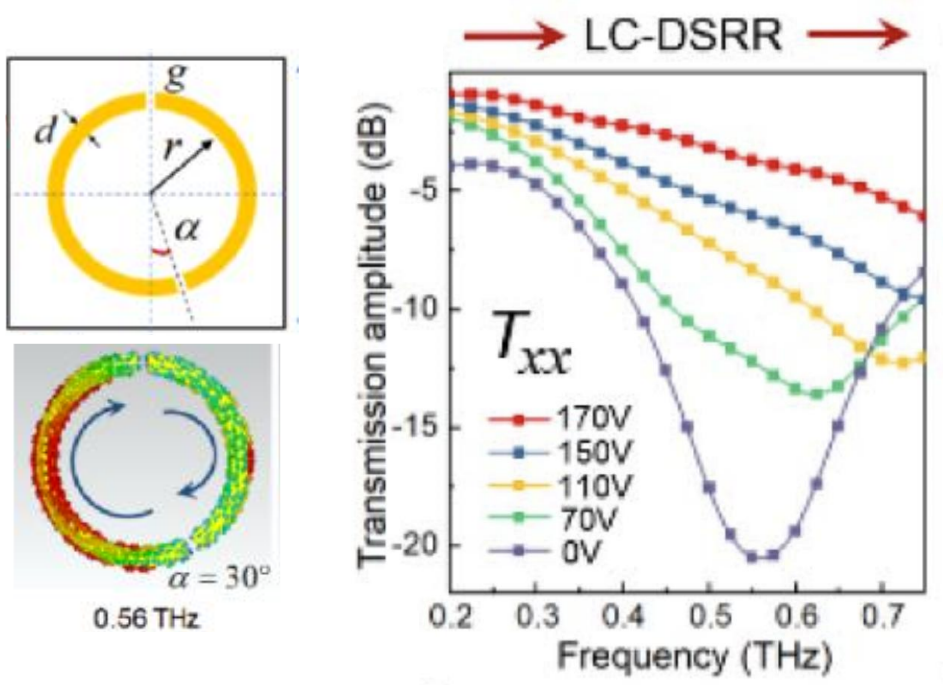
@UFPhotonicsUCL sarah.norman.21@ucl.ac.uk



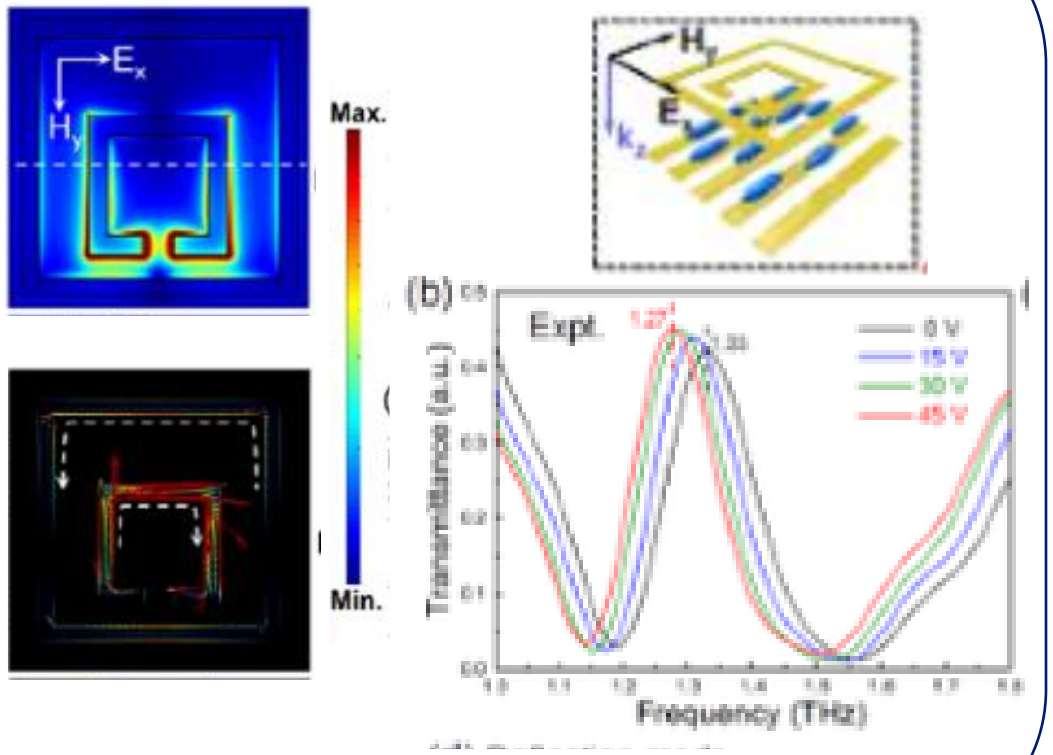
Graphic Art by Yuezhen Lu (UCL)

Queen Mary University of London
Lancaster University
UKRI Engineering and Physical Sciences Research Council
U.S. DEPARTMENT OF ENERGY Office of Science
Sandia National Laboratories
CINT

Background



Xu, S. at al. *Photon. Res.* **12**, 2207-2213 (2024)

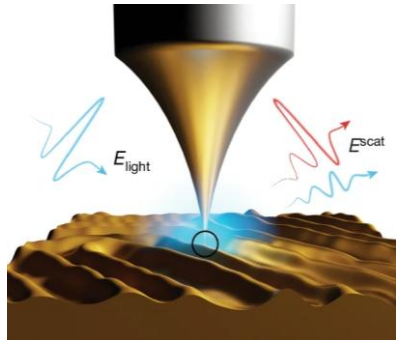


Shen, Z. et al. *Opt. Lett.* **43**, 4695-4698 (2018)

Terahertz Techniques

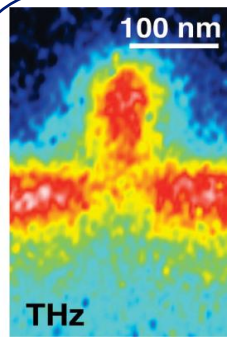
THz-STM / NOTE, $\sim$Å

(Cocker, T. et al. *Nat. Photonics* **15,** 558–569 (2021))

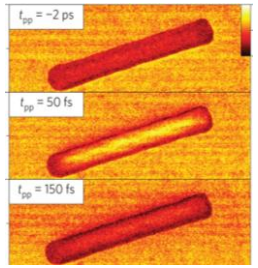


(Siday, T. et al. *Nature.* **629**, 329-334 (2024)

s-SNOM, $\sim nm$



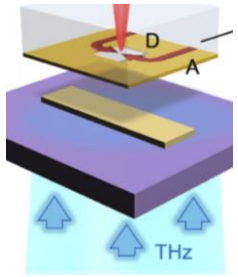
(Huber, A. J., *Nano Letters* **8,** 3766 (2008))

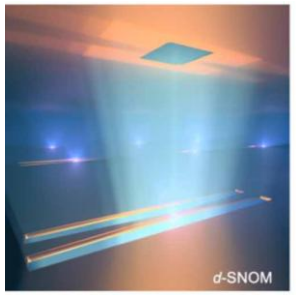


(Eisele et al., *Nature Photonics.* **8,** 841 (2014))

Aperture-type Microscopy, $\sim 2 - 10\ \mu m$

(Hale, L. L. *et al. Laser Photon. Rev.* **14**, 1900254 (2020))



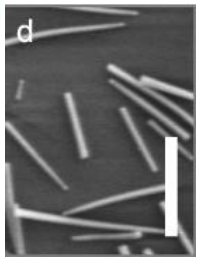


(Hale, L. L., Siday, T. & Mitrofanov, O. *Opt. Mater. Express* **13**, 3068 (2023))

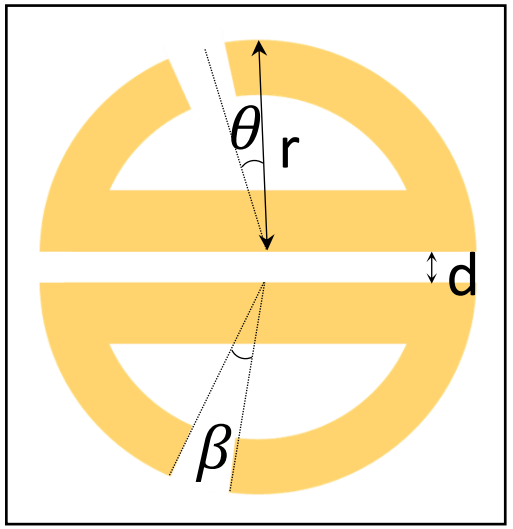
Far-Field, ~ 500 μm

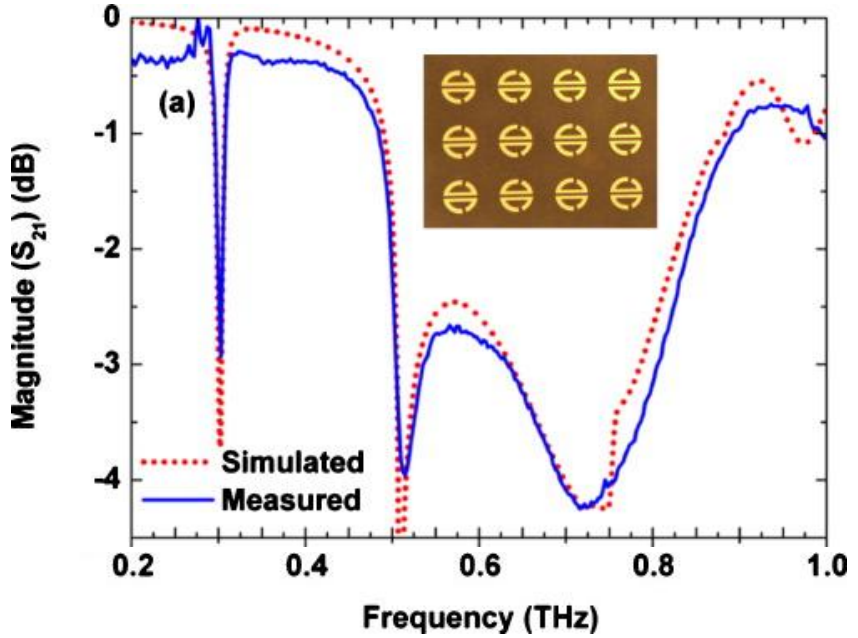
(Jansen, C. *et al. Appl. Phys. Lett.* **98**, 051109 (2011))

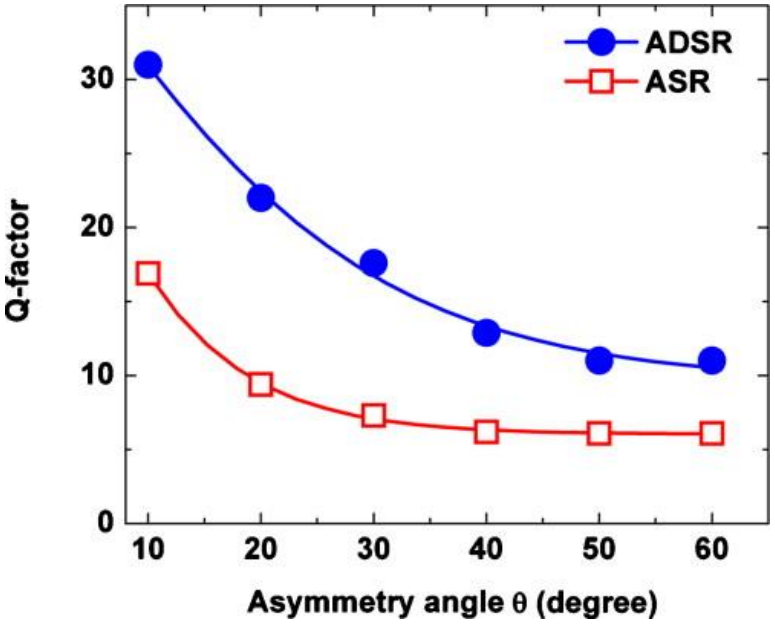
Joyce et al., *Nanotechnology.* **24**, 214006 (2013)



Asymmetric D-Split Ring Resonator (ADSR)

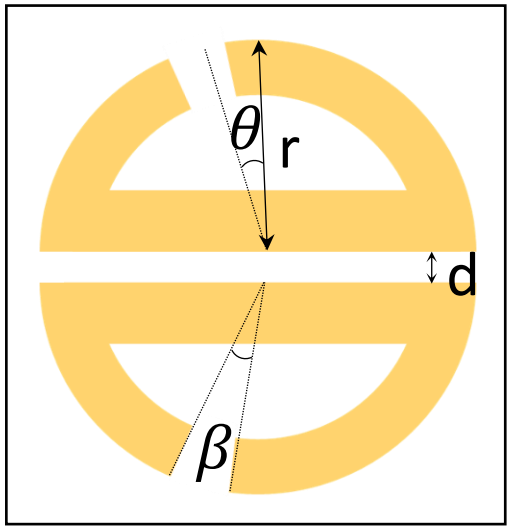




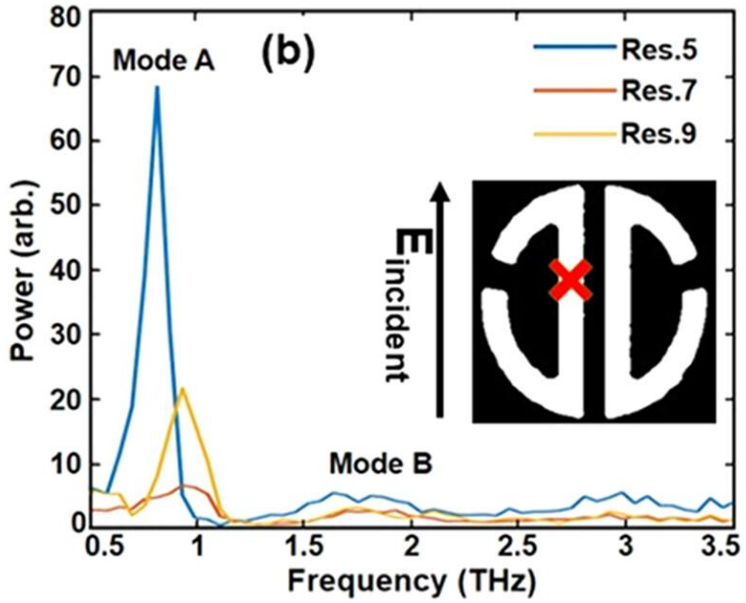


Jansen, C. *et al. Appl. Phys. Lett.* **98**, 051109 (2011)

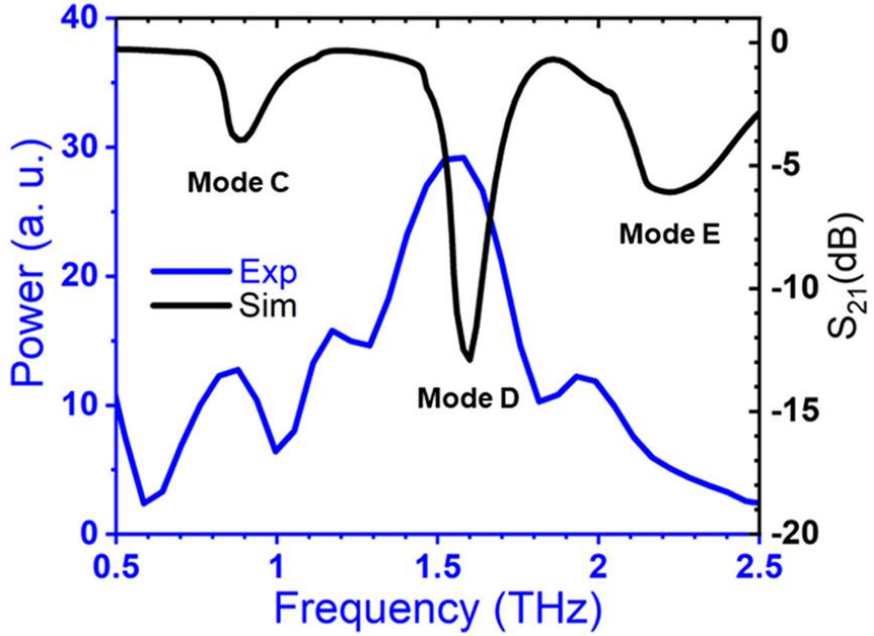
Individual ASDR Resonators



Co-polarised



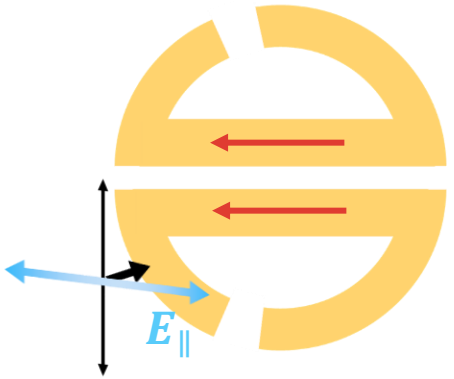
Cross-polarised



Lu, Y. *et al. ACS Photonics* **10**, 2832–2838 (2023)

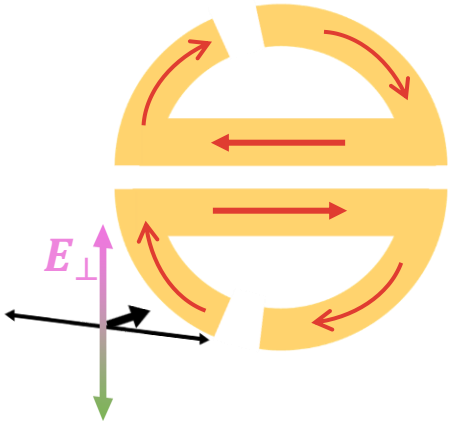
ADSR Modes - Surface Current Pattern

$f_{Res} = 0.76\ THz$

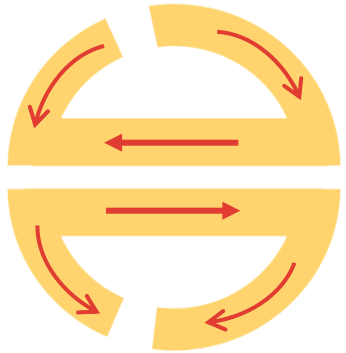


Co-polarised

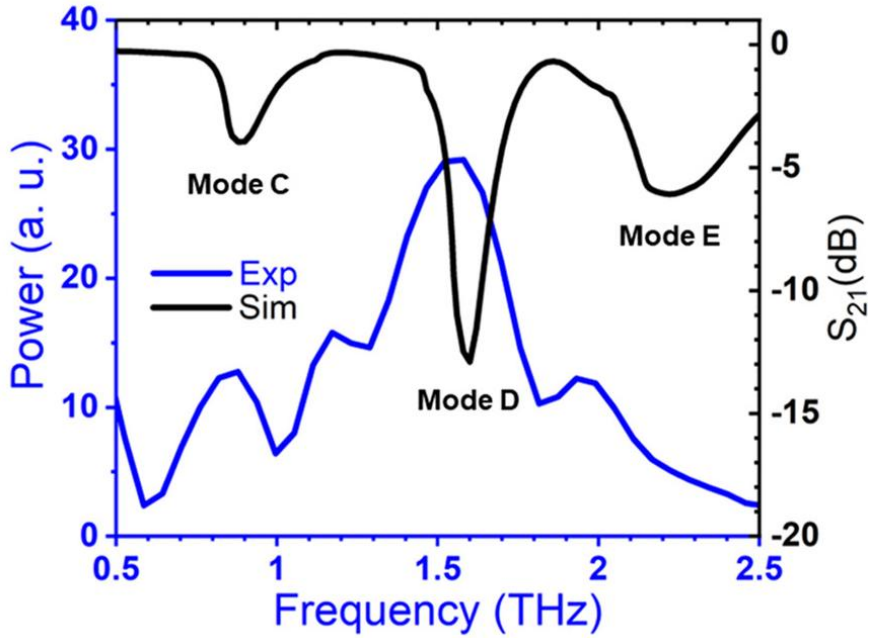
$f_{Res} = 0.84\ THz$



$f_{Res} = 1.50, 1.82\ THz$



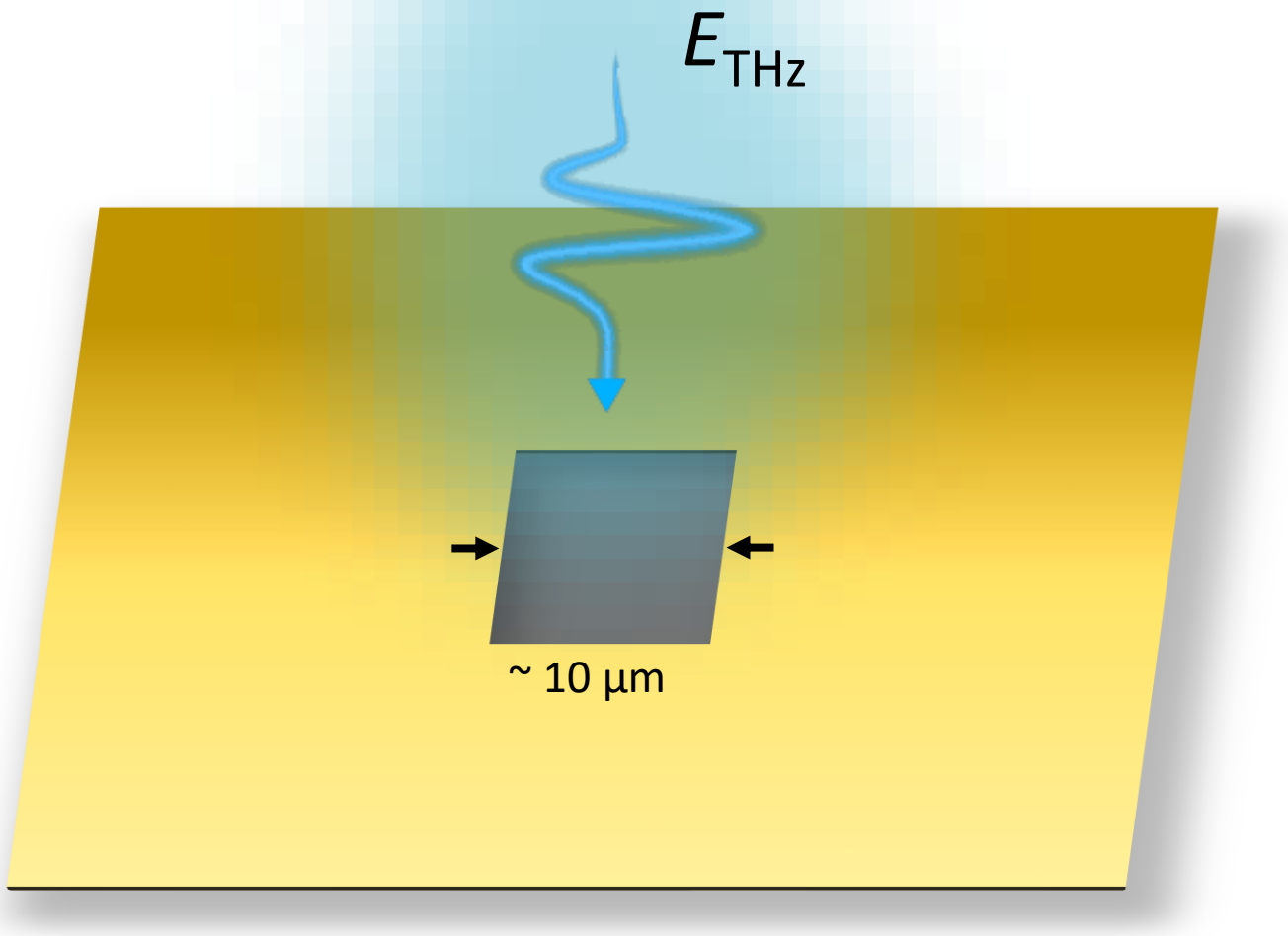
Cross-polarised

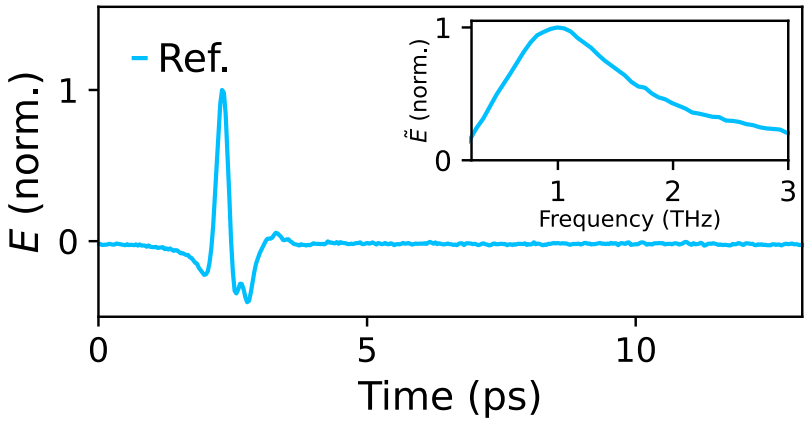


Jansen, C. *et al. Appl. Phys. Lett.* **98**, 051109 (2011)

Lu, Y. *et al. ACS Photonics* **10**, 2832–2838 (2023)

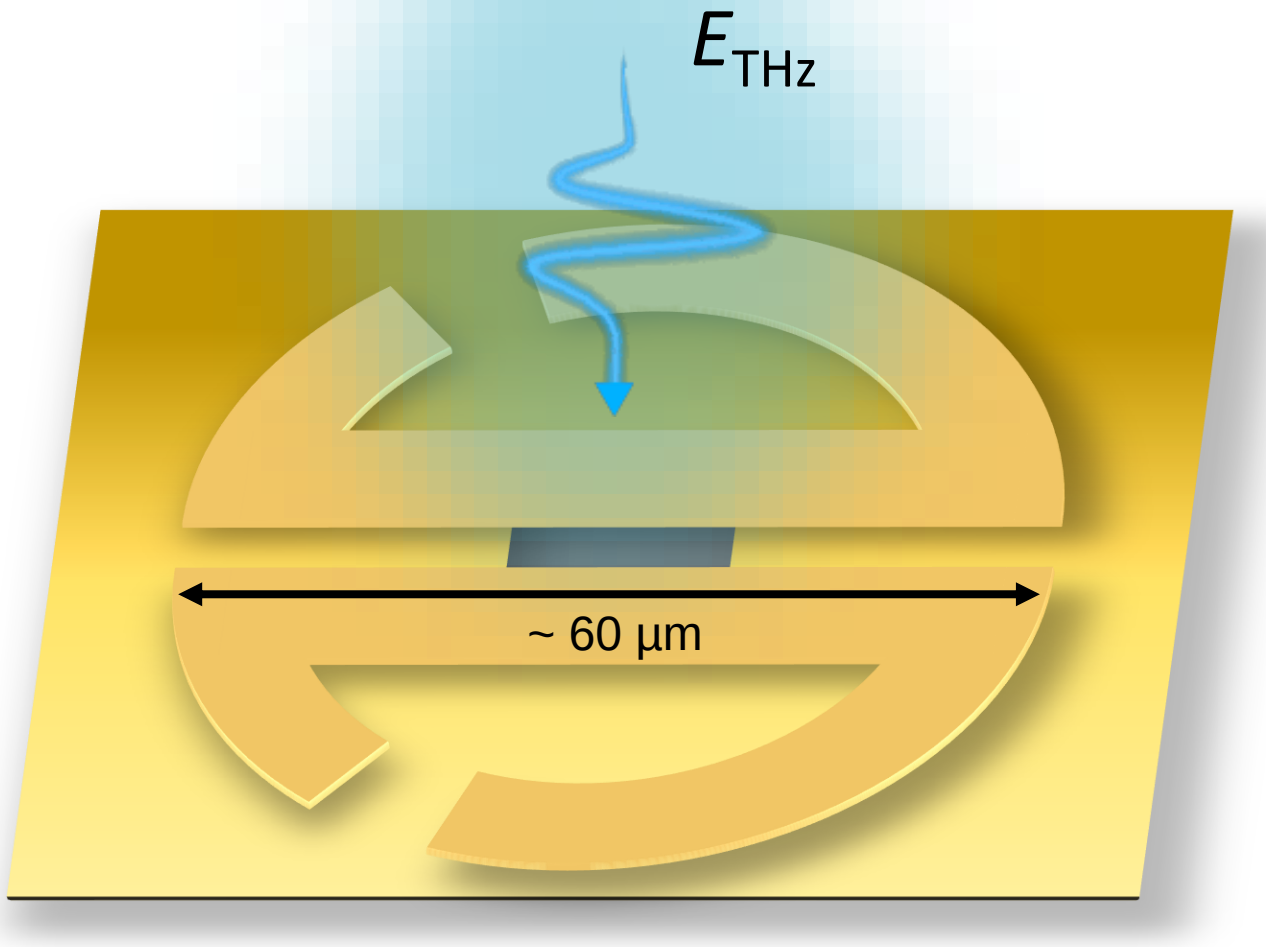
Aperture-type Near-Field THz Spectroscopy

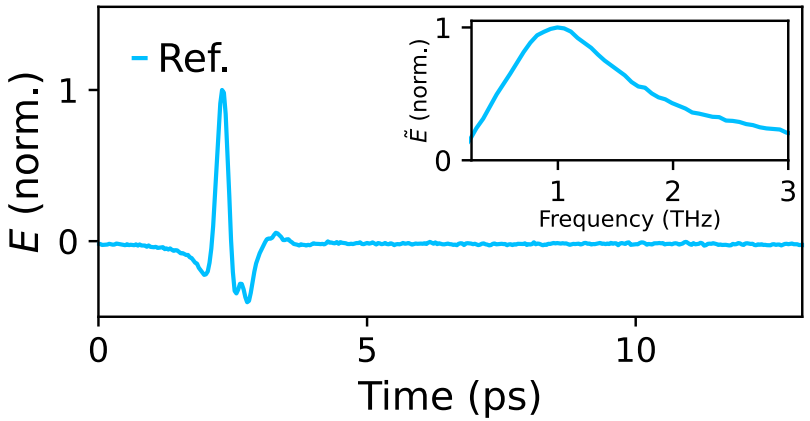




- Direct detection
- Microscale spatial resolution
- In-plane field sensitivity

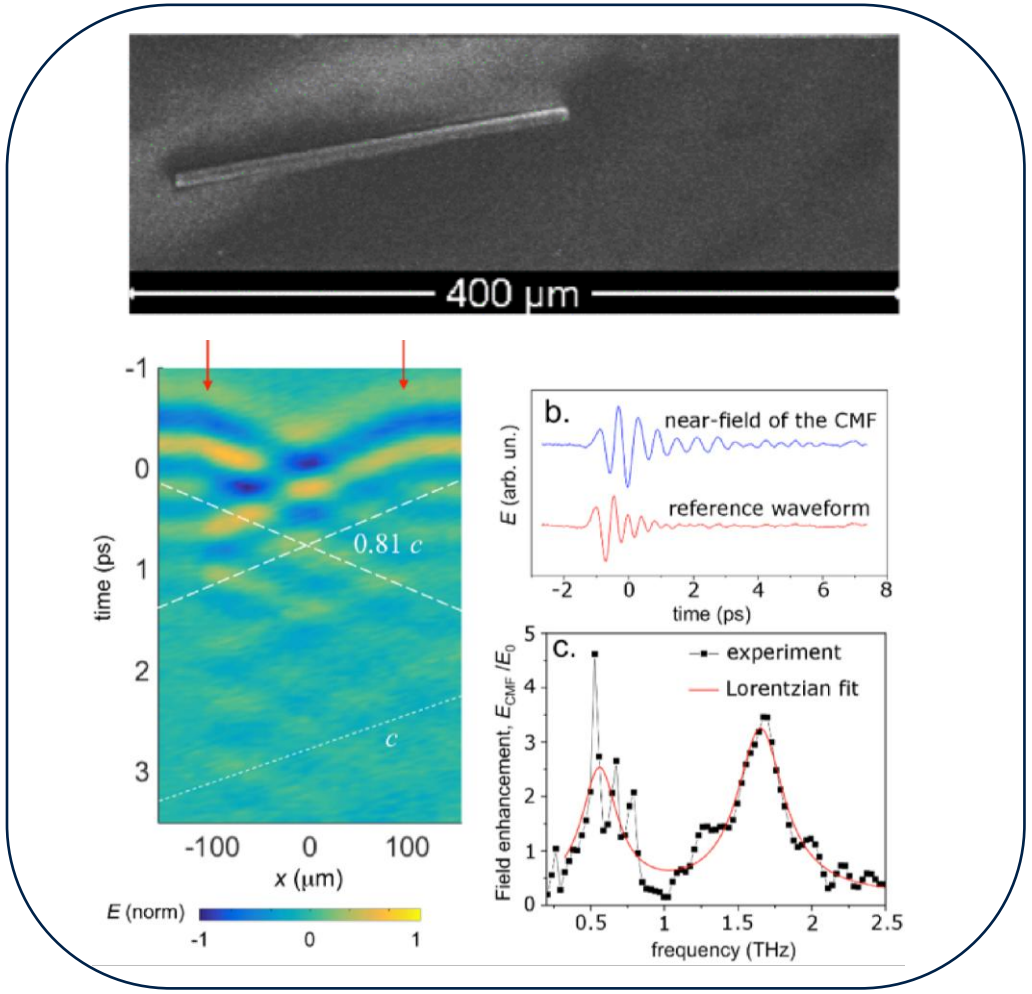
Aperture-type Near-Field THz Spectroscopy





- Direct detection
- Microscale spatial resolution
- In-plane field sensitivity

Near-Field Terahertz Spectroscopy

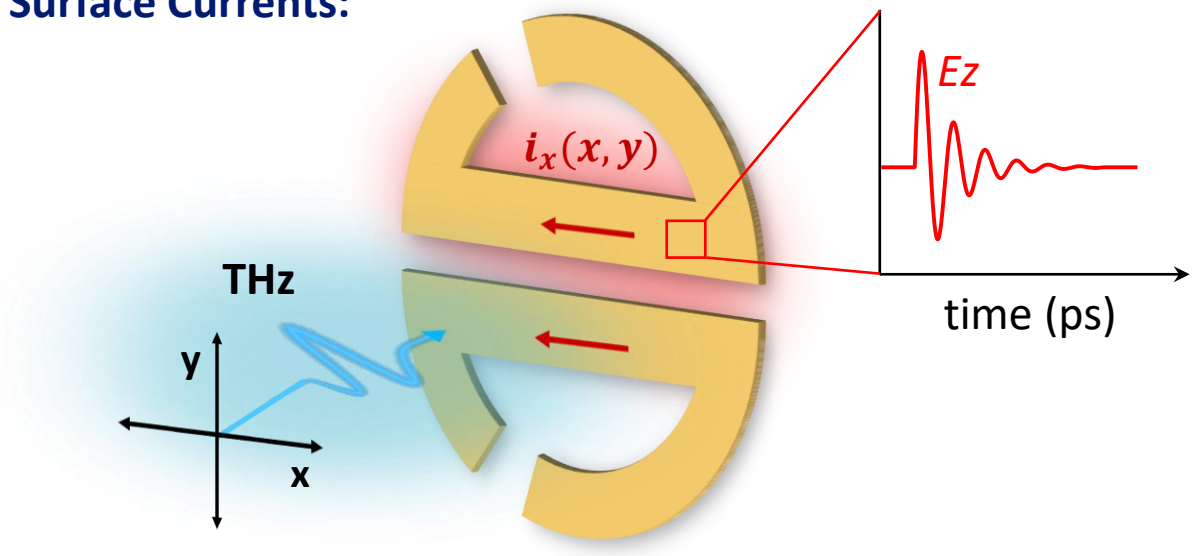


(Khromova et al., 2015; Hale et al., 2023)

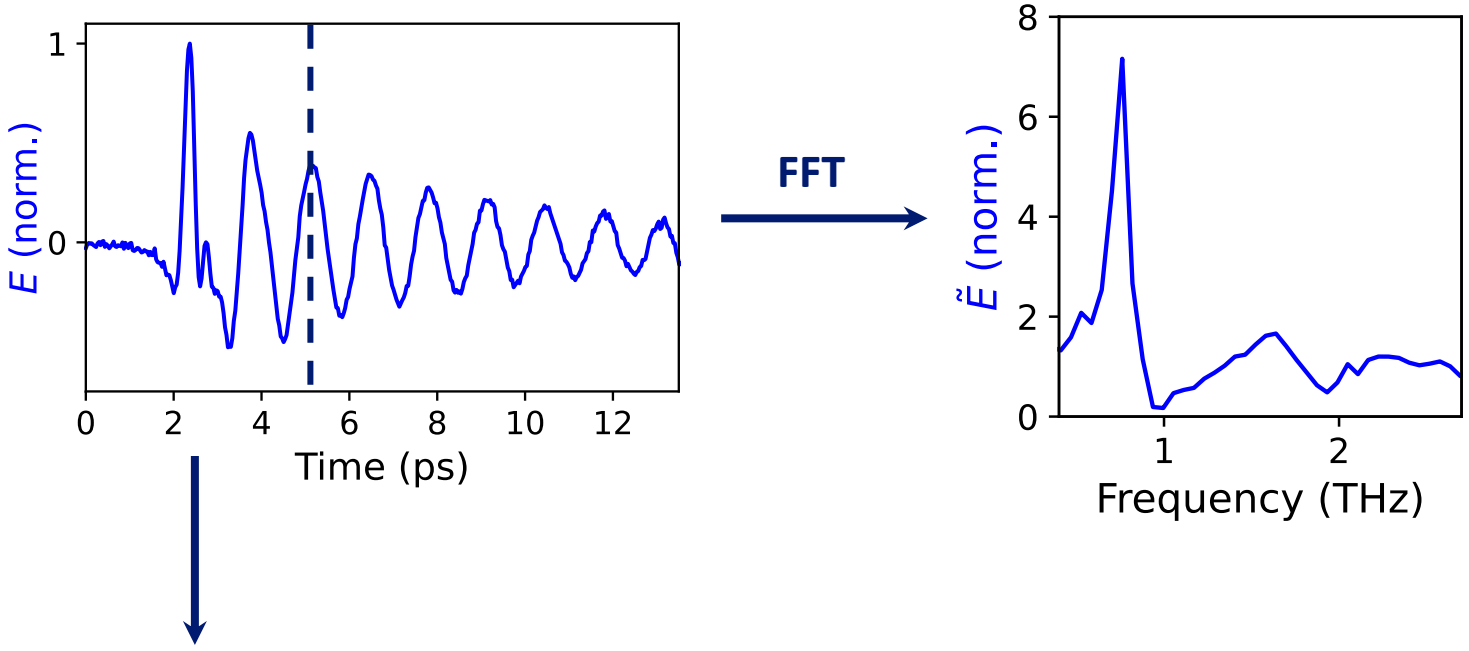
Aperture-Probe and Surface Plasmons:

$$\frac{dE_z}{dx} \qquad \frac{dE_x}{dt}$$

Surface Currents:

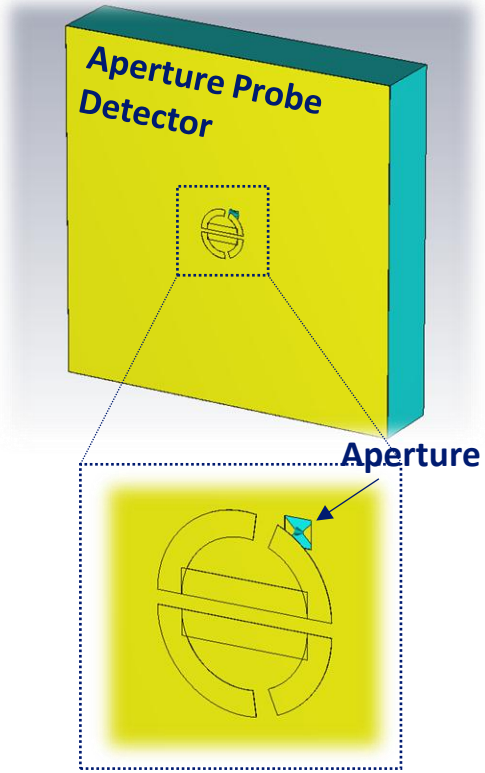


Dipolar Mode - Co-Polarised Excitation

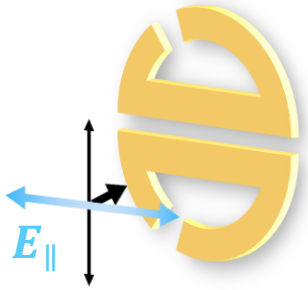


Numerical Modelling

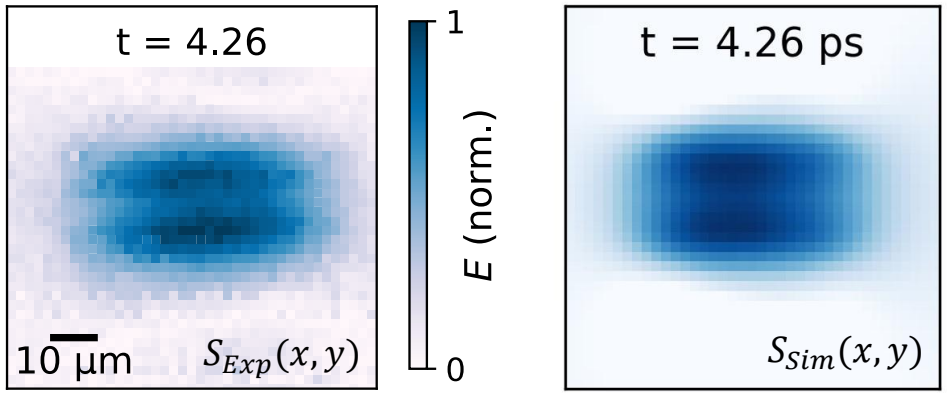
CST Microwave Solver



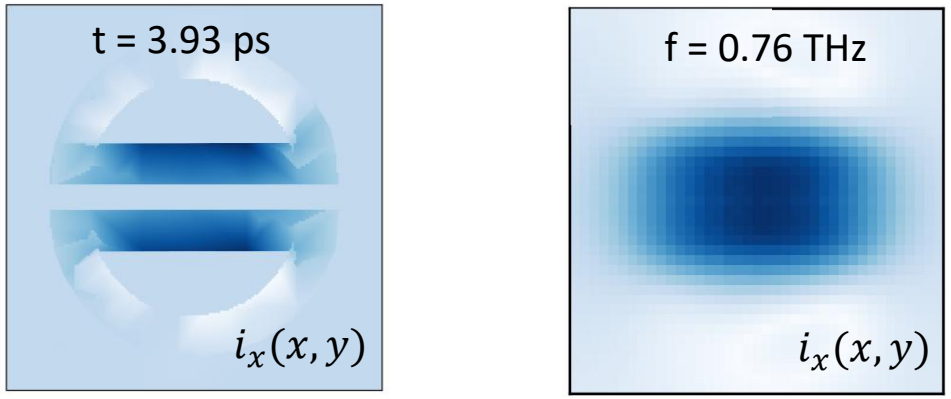
Dipolar Mode - Co-Polarised Excitation



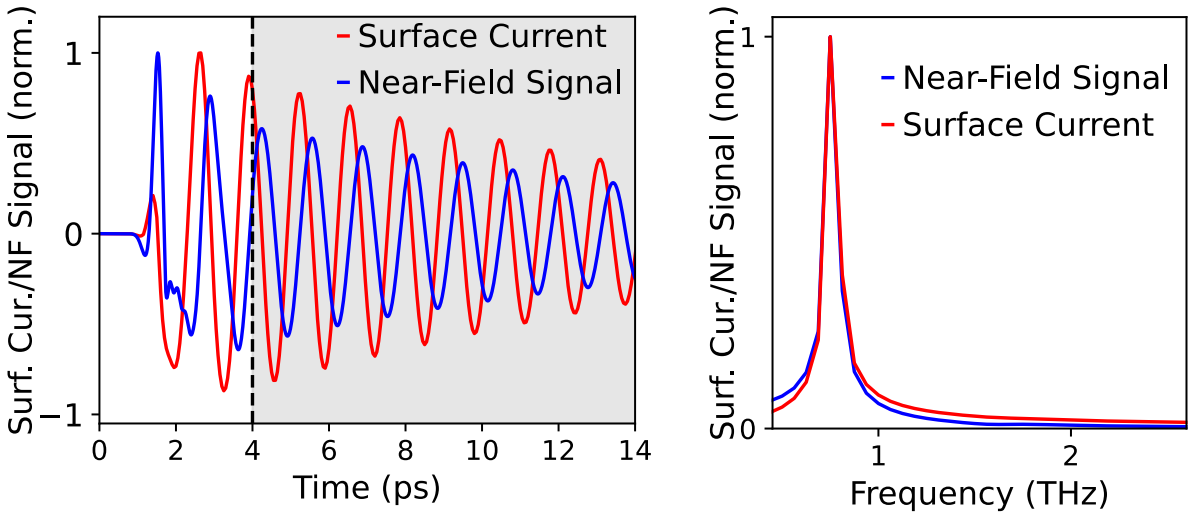
Spatial Maps:



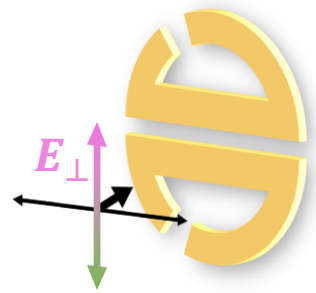
Surface Current:



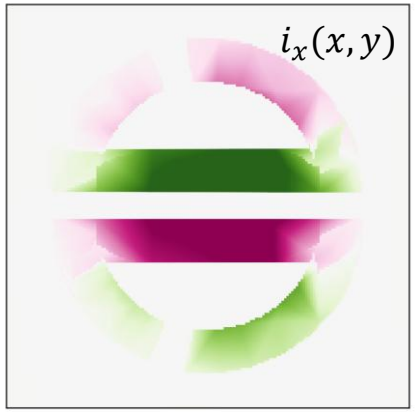
Local Spectroscopy:



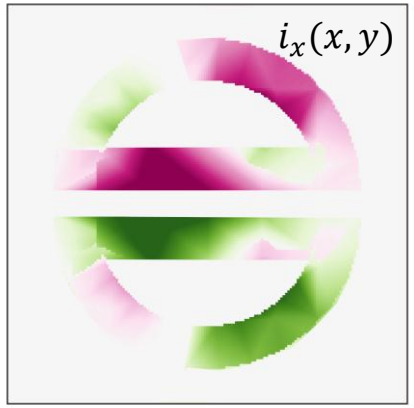
Cross-Polarised Excitation



f = 0.84 THz

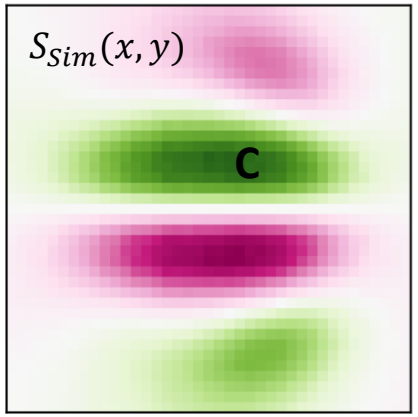


f = 1.50 THz

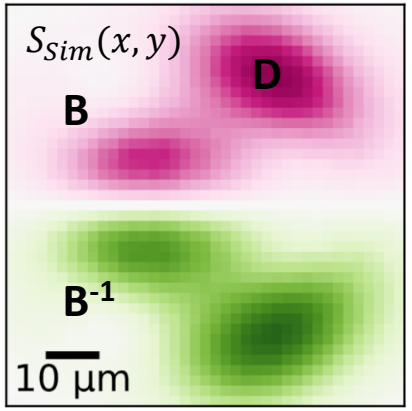


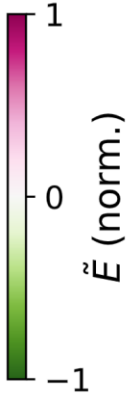
NF Maps at selected frequencies:

f = 0.84 THz

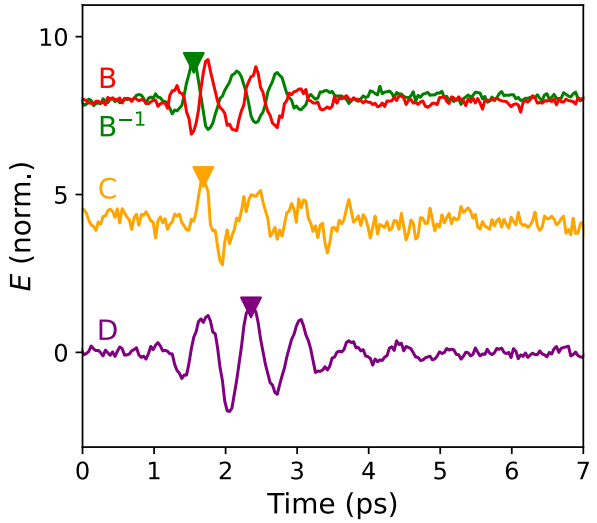


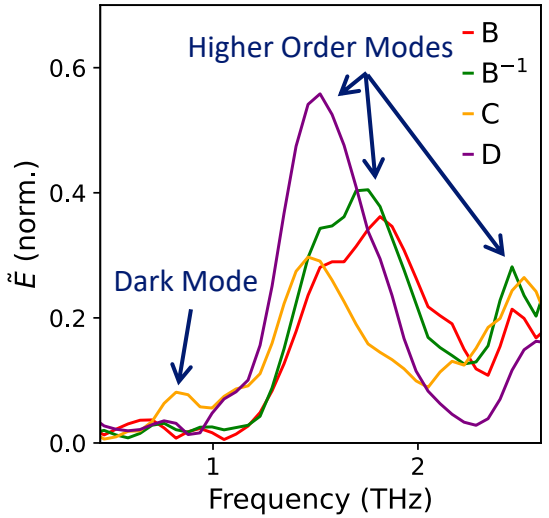
f = 1.50 THz



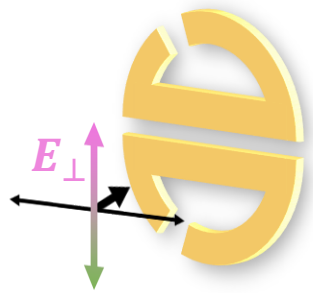


Local Spectroscopy:

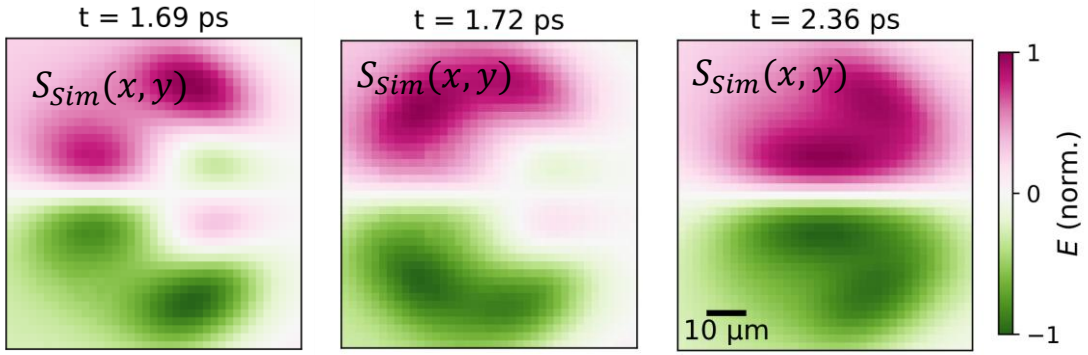




Cross-Polarised Excitation



NF Maps at selected moments:



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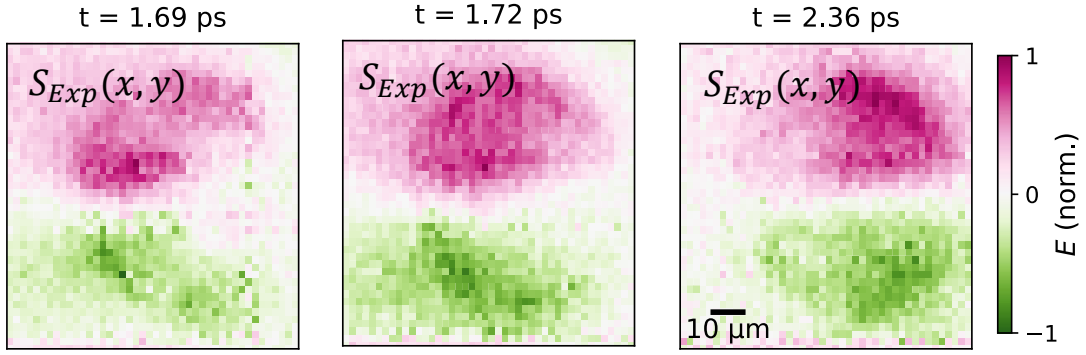
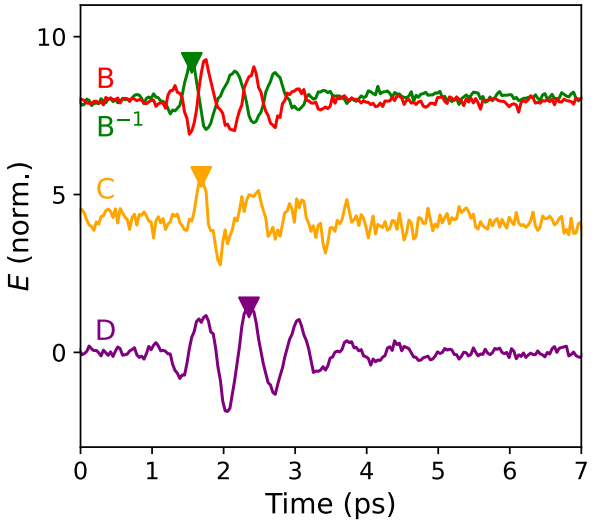
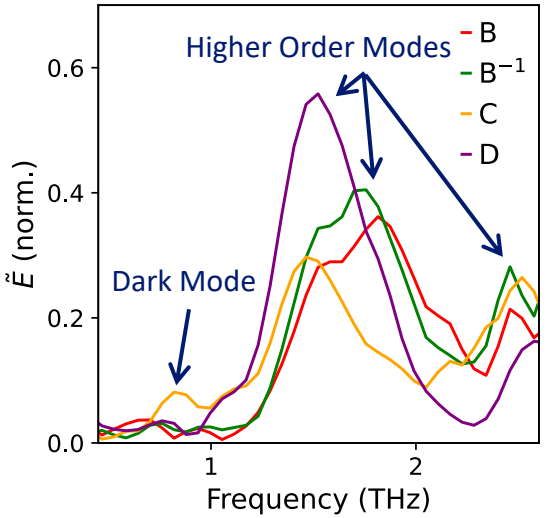


Local Spectroscopy:





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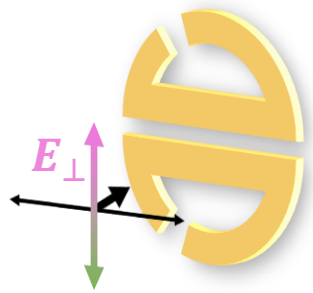

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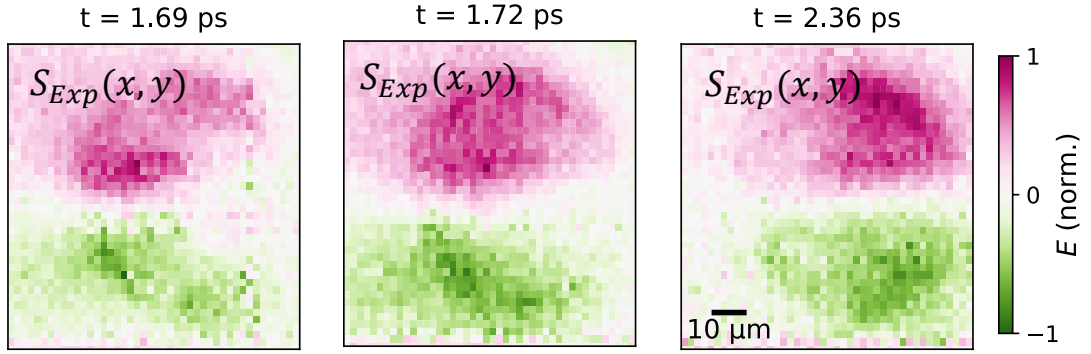
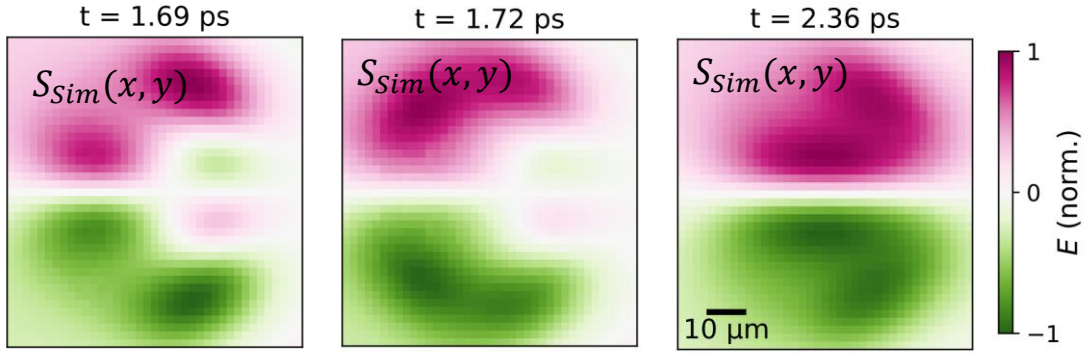
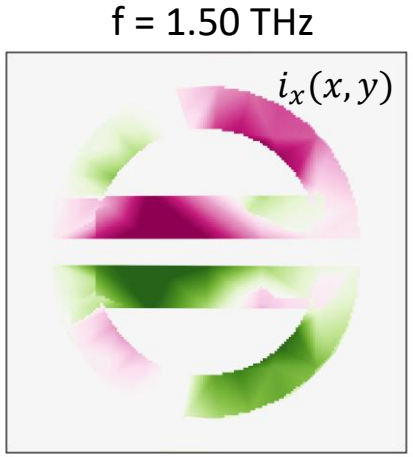
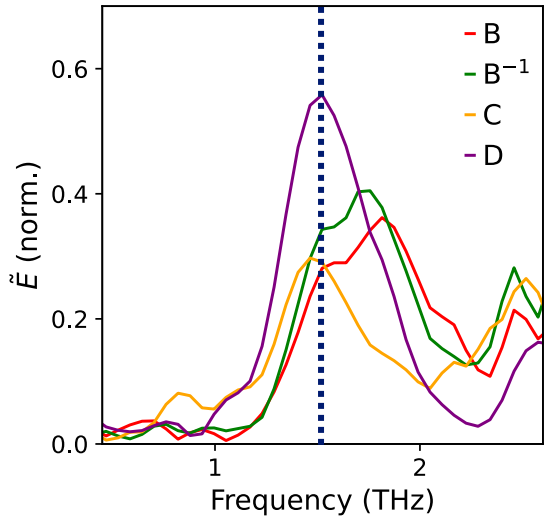


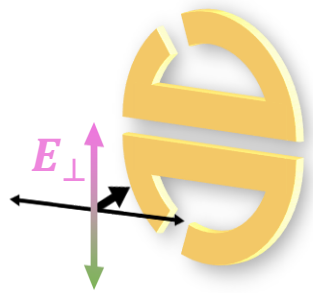
Simulation:

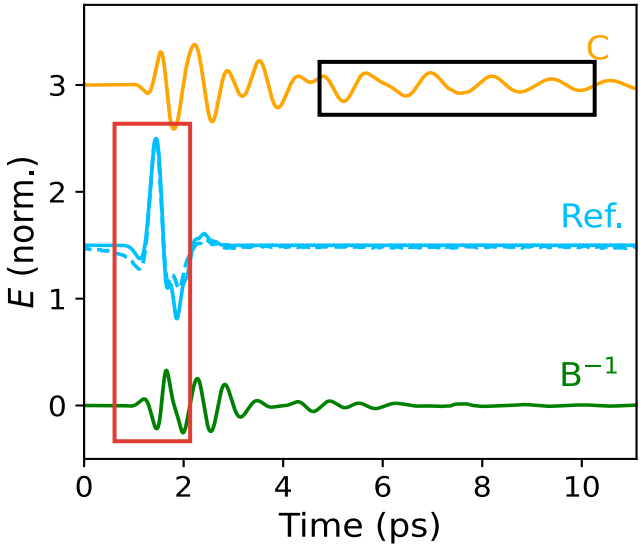


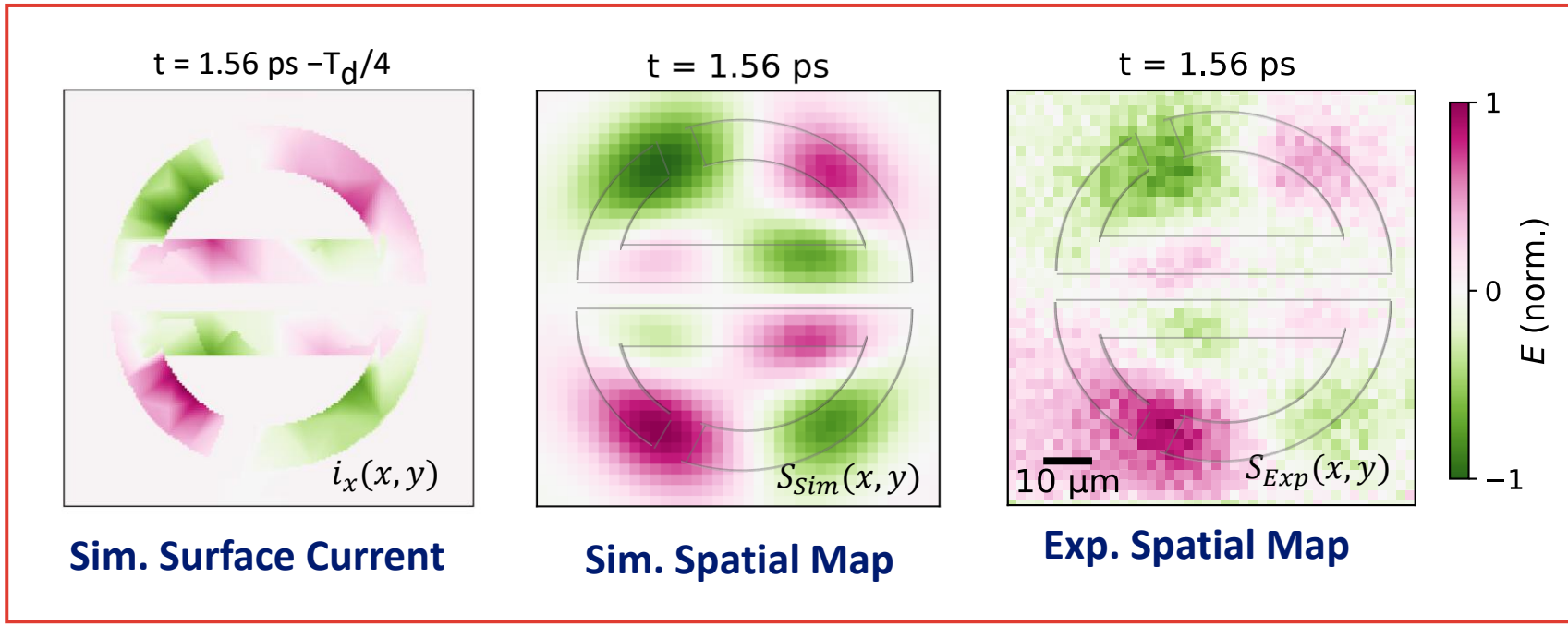




Cross-Polarised Excitation







Sim. Surface Current **Sim. Spatial Map** **Exp. Spatial Map**

Summary and Outlook

- Aperture-type near-field microscopy enables imaging of THz surface currents for both single and multimode excitation.

- Potential for characterisation in the design and develop of novel plasmonic THz metamaterials and metasurfaces.