CONTROLLABLE GENERATION OF AZIMUTHAL AND RADIAL TERAHERTZ BEAMS USING MULTI-PIXEL PHOTOCONDUCTIVE EMITTERS

Justas Deveikis, James Lloyd-Hughes

20th June, 2022

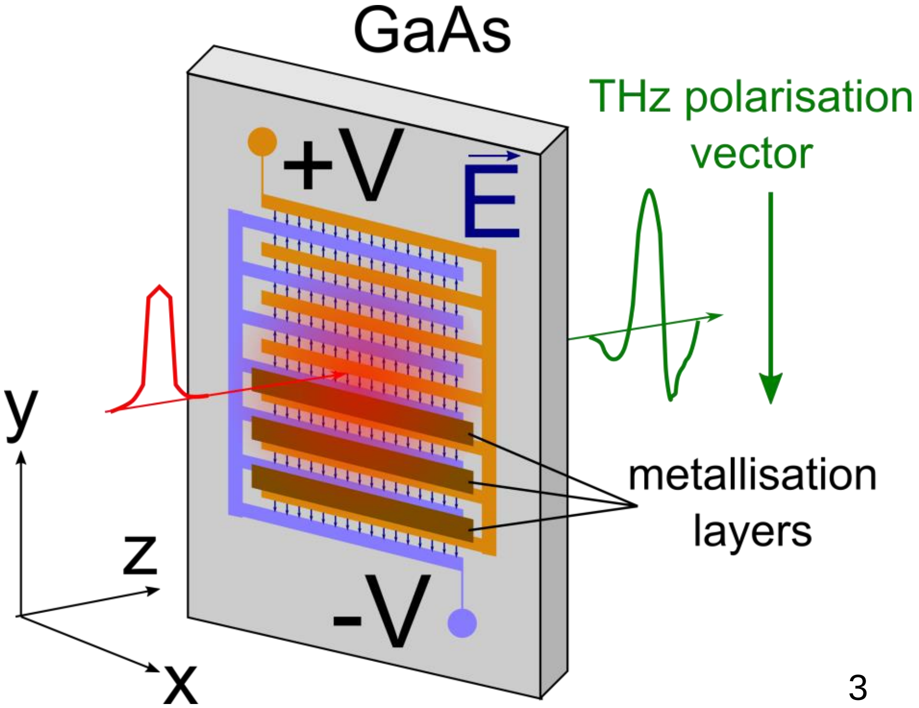
OTST conference, Budapest, Hungary

Outline

- Interdigitated photoconductive THz emitters
- Methods to control THz polarisation state using emitters
- Azimuthal and radial THz beams and their differences from linear/elliptical beams
- Multi-pixel emitter for generation of azimuthal and radial THz beams
- Characterisation of azimuthal and radial THz beams
- Conclusions and further work

Interdigitated Photoconductive Emitter (PCE)

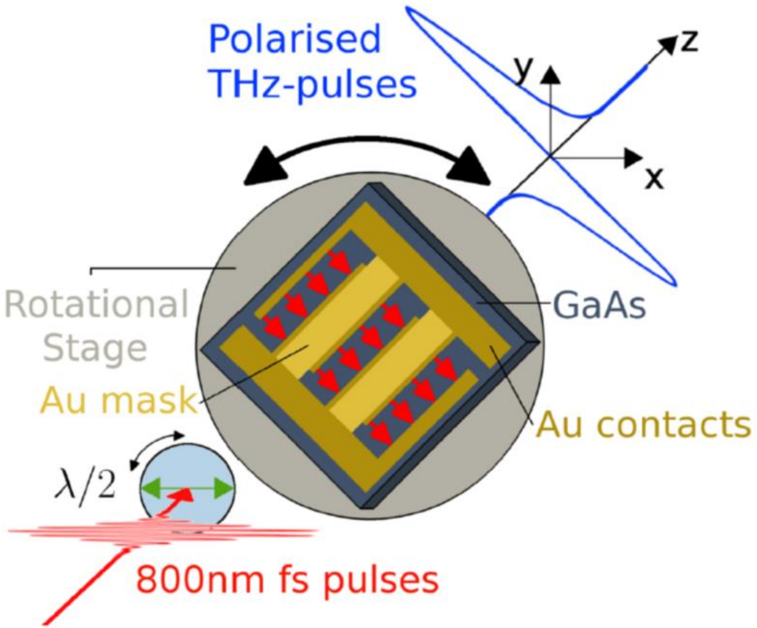
- Advantages: improved radiation pattern, higher THz emission power, higher polarisation purity.
- Metallisation layers (shadow mask) prevent THz from interfering destructively in the far-field (Dreyhaupt, A., et al. Appl. Phys. Lett. **86**, 121114 (2005)).
- THz polarisation plane is parallel to the direction of biased E-field.



Control of THz Polarisation State (1)

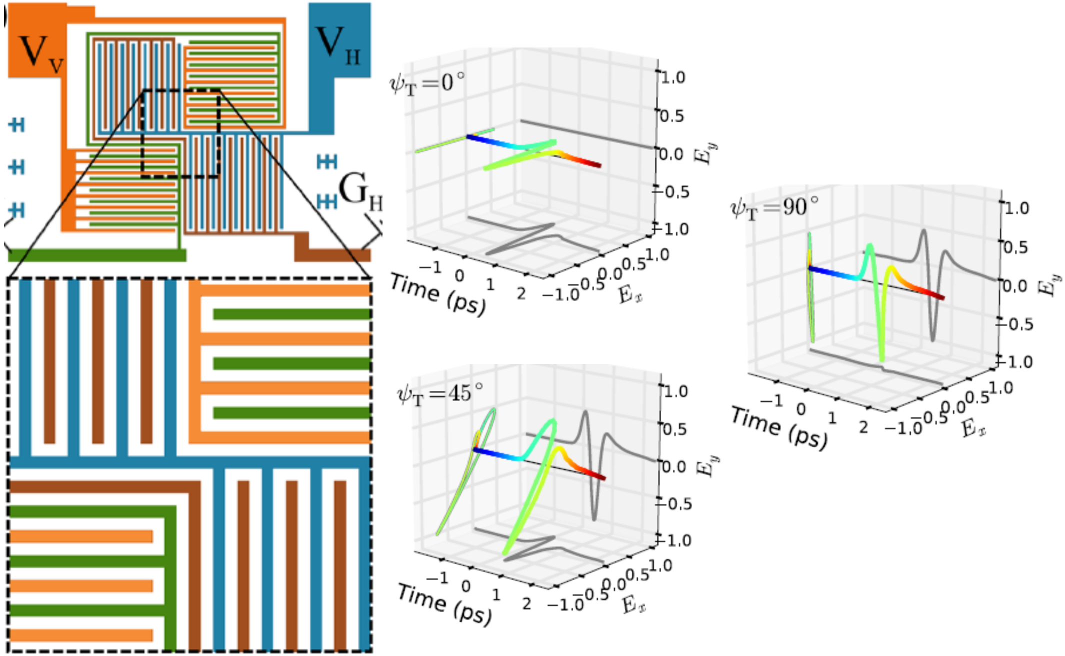
WARWICK
THE UNIVERSITY OF WARWICK

Mechanical rotation of THz emitter



Mosley, C.D.W., *et al. Sci Rep* **7,** 12337 (2017).

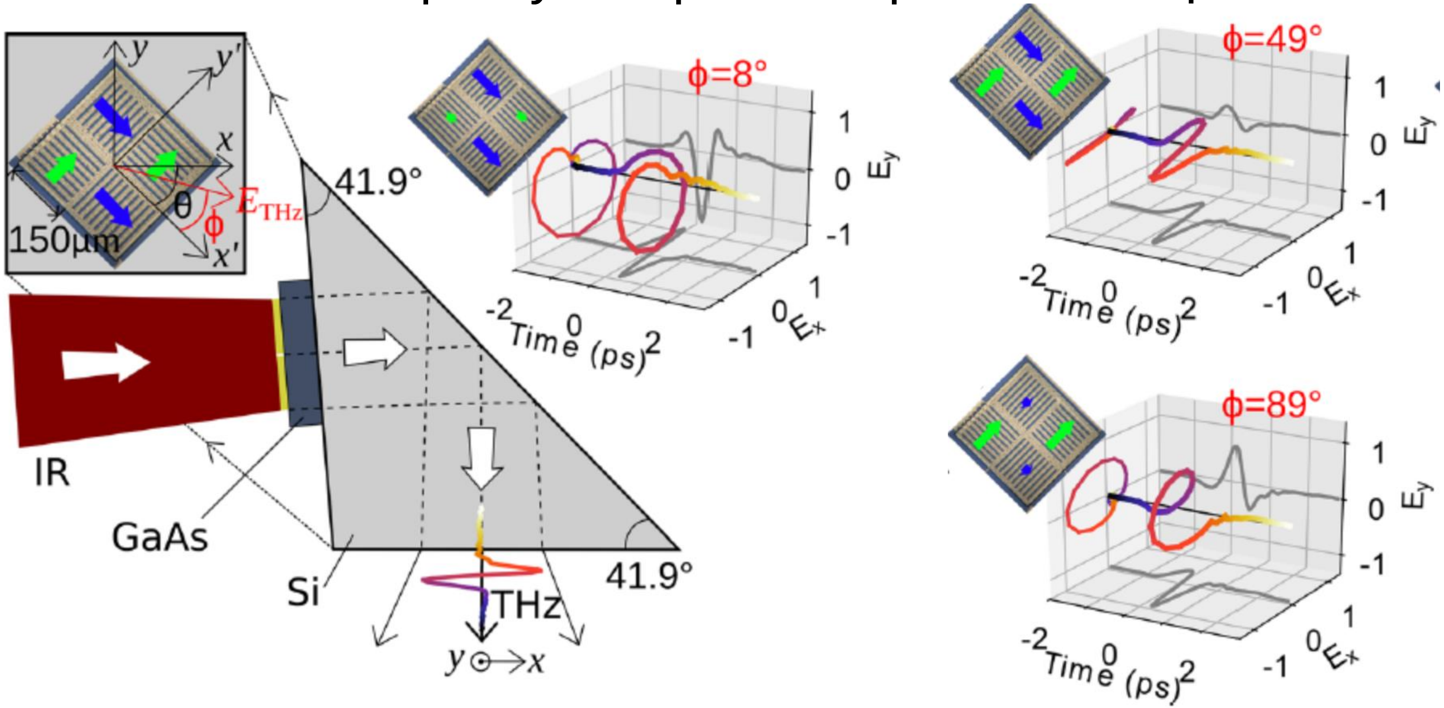
Electrical control using 4-pixels



Mosley, C.D.W., *et al.* AIP Advances **9**, 045323 (2019).

Control of THz Polarisation State (2)

Controllable ellipticity setup with Si prism and 4-pixels



Mosley, C.D.W., Deveikis, J., Lloyd-Hughes, J.,. Appl. Phys. Lett. 119, 121105 (2021).

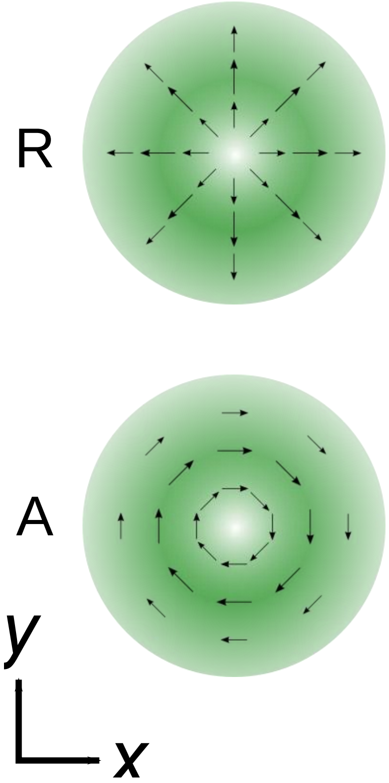
Azimuthal (A) and Radial (R) Beams

Properties:

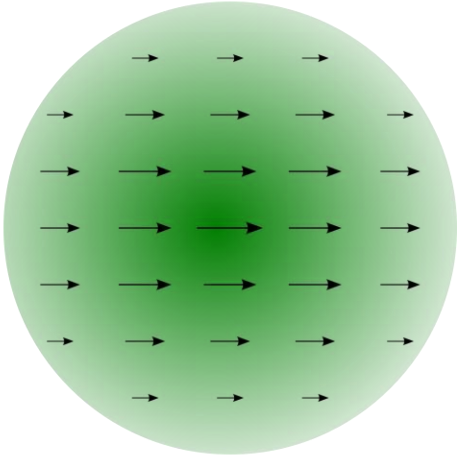
- Non-gaussian beamprofile;
- Inhomogeneous polarisation.

Applications:

- Tighter beam spot at the focus position;
- Enhancement of longitudinal E-field component under focusing (R beam only).



Linearly polarised beam profile (comparison).

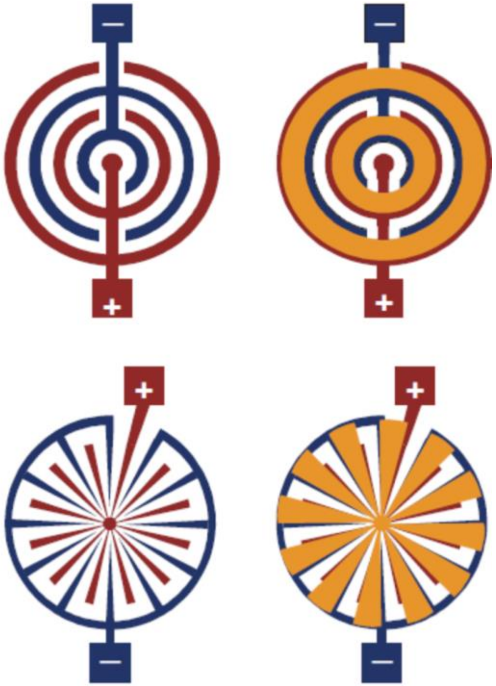


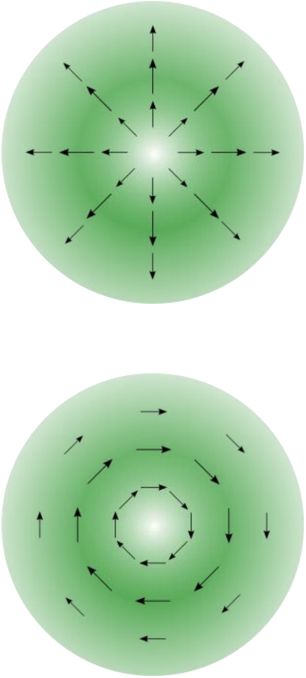
Azimuthal and Radial THz Beams Generation

Without shadow mask | With shadow mask | Beam profiles

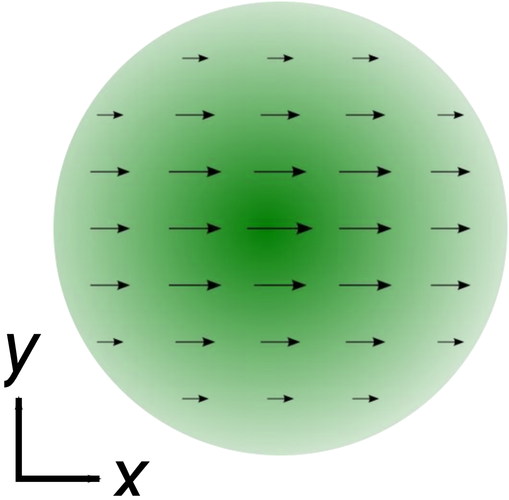
Radial

Azimuthal





Linearly polarised beam profile (comparison).

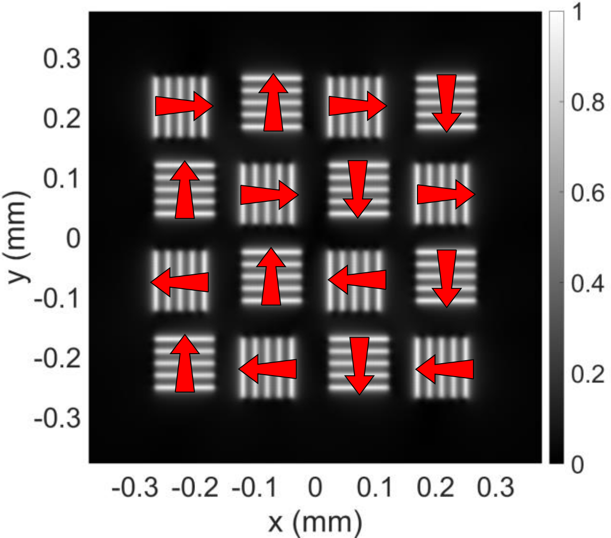


S. Winnerl, *et al.* Opt. Express 17, 1571-1576 (2009).

Modelling of Azimuthal (A) THz Beam

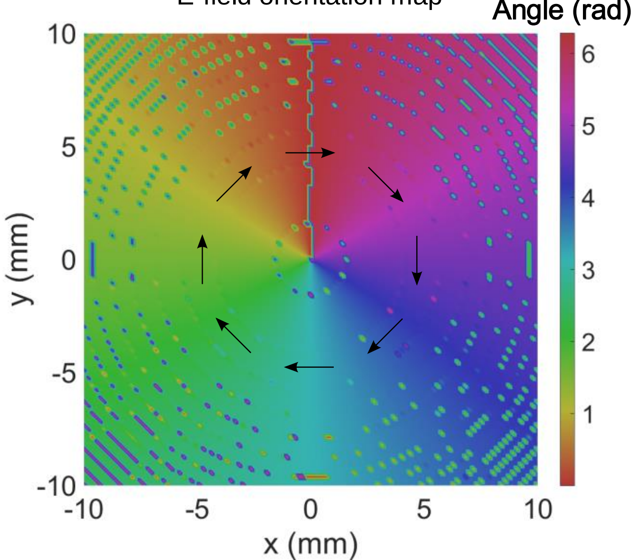
- Dipole array modelling has been employed at 1 THz.
- Red arrows – direction of biased electric field.

Near-field (5um)

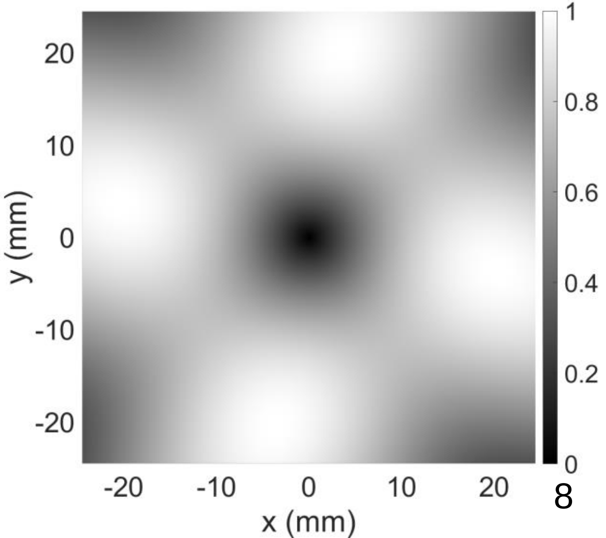


Far-field (50mm)

E-field orientation map



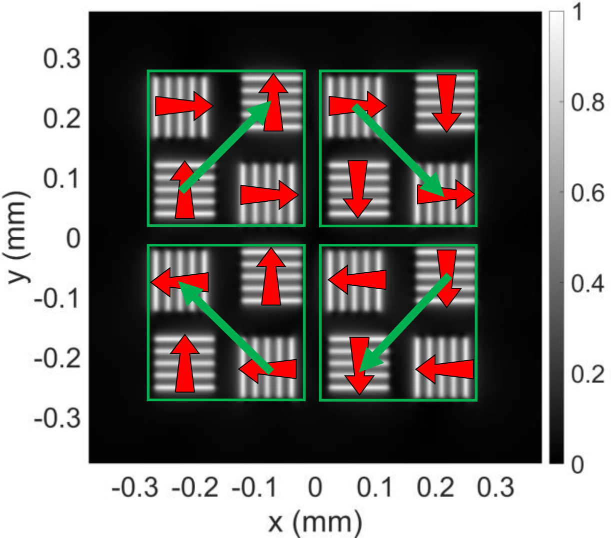
Intensity map



Modelling of Azimuthal (A) THz Beam

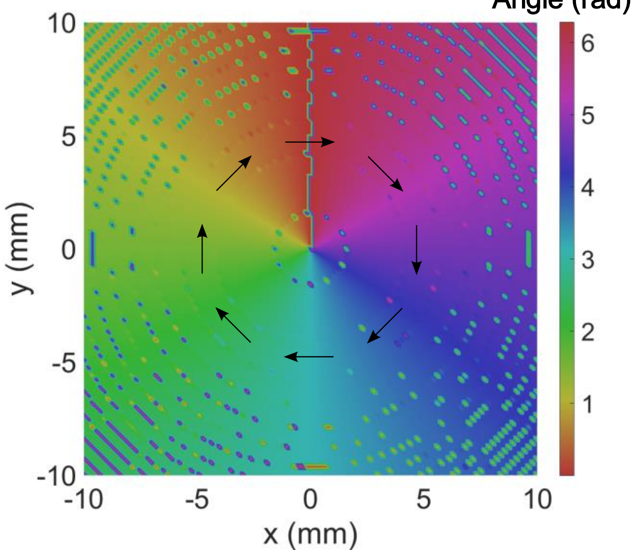
- Dipole array modelling has been employed at 1 THz.
- Red arrows – direction of biased electric field.

Near-field (5um)

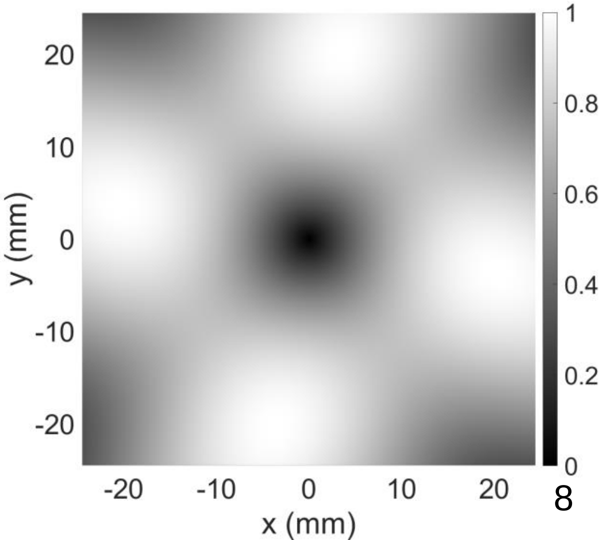


Far-field (50mm)

E-field orientation map



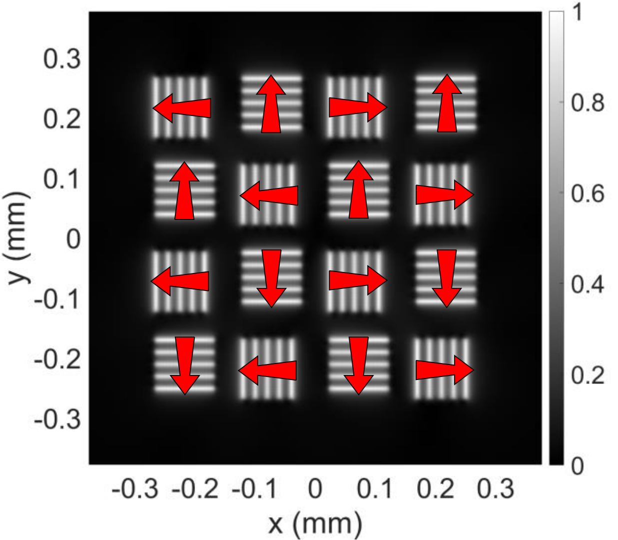
Intensity map



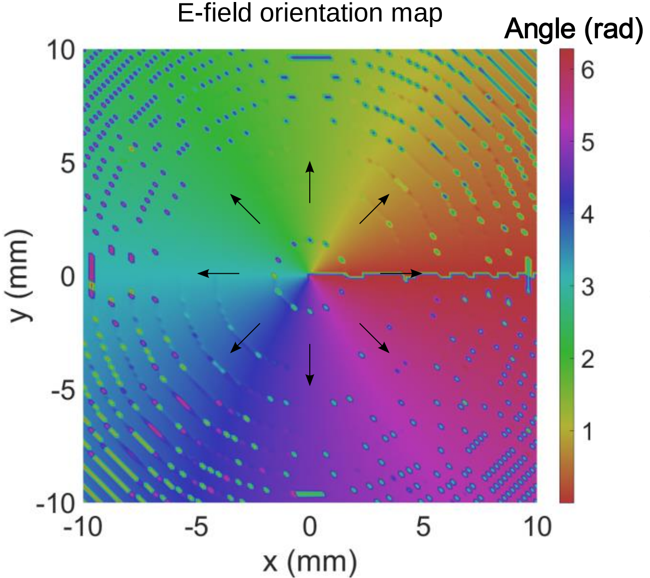
Modelling of Radial (R) THz Beam

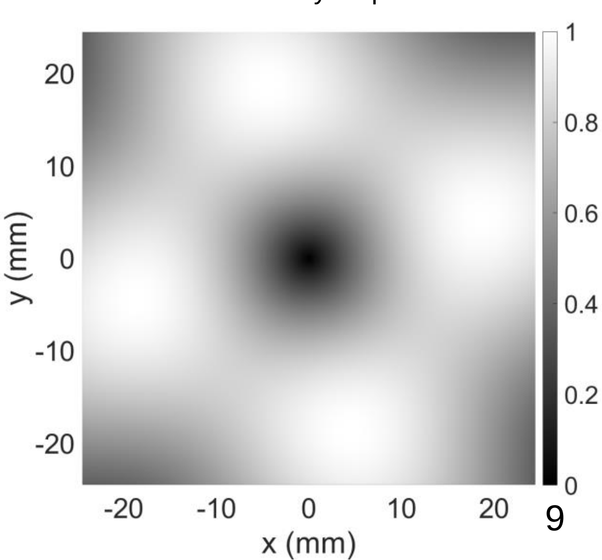
- Dipole array modelling has been employed at 1 THz.
- Red arrows – direction of biased electric field.

Near-field (5um)



Far-field (50mm)



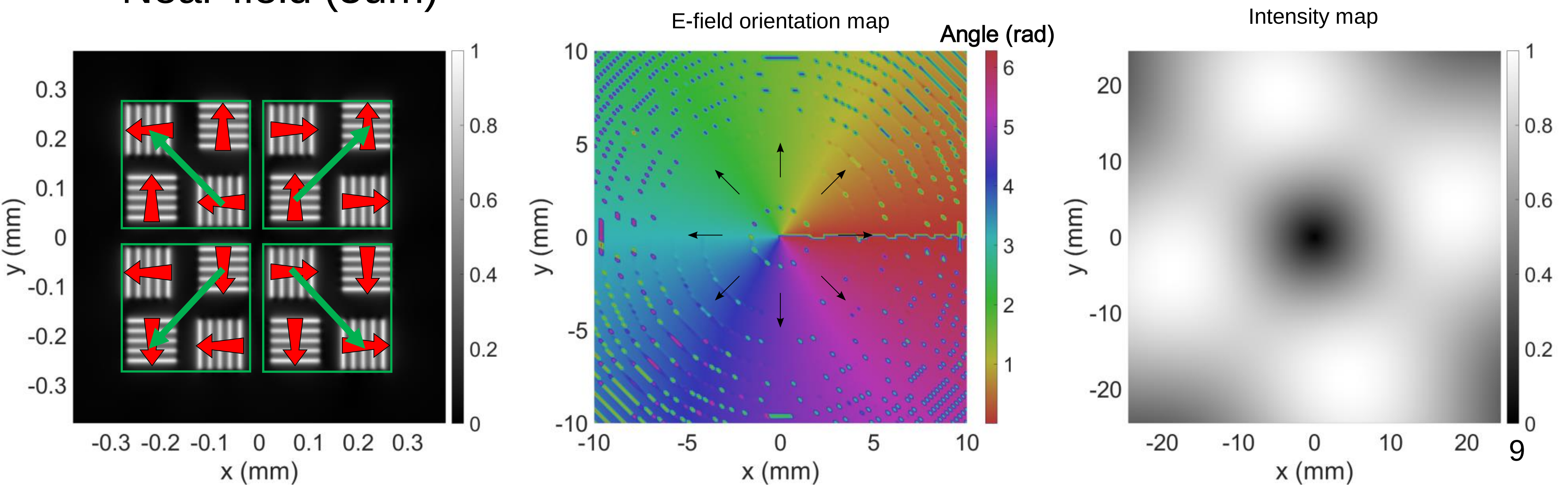


Modelling of Radial (R) THz Beam

- Dipole array modelling has been employed at 1 THz.
- Red arrows – direction of biased electric field.

Near-field (5um)

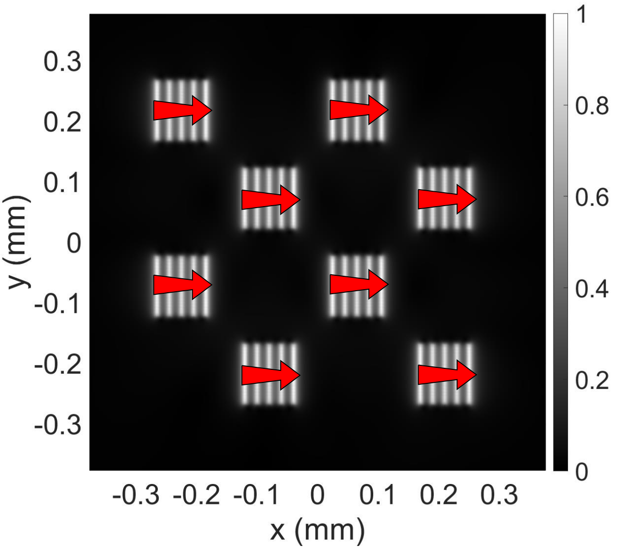
Far-field (50mm)



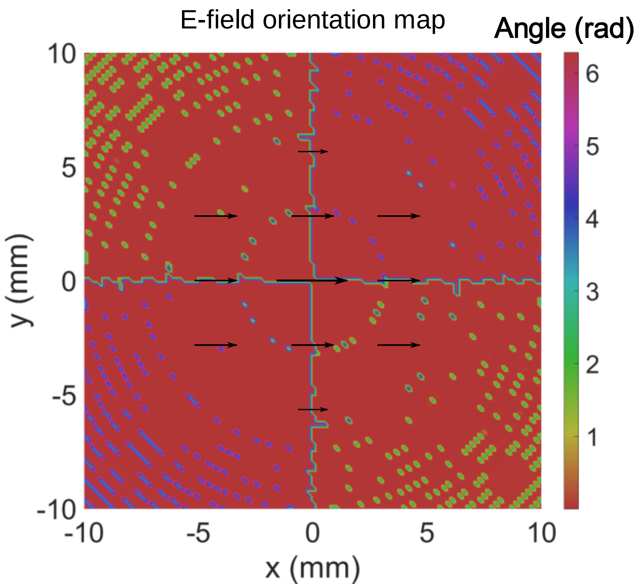
Modelling of Linear (L) THz Beam

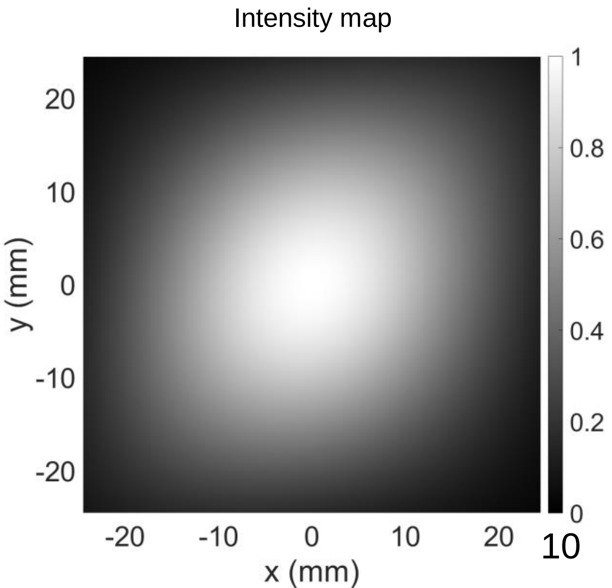
- Dipole array modelling has been employed at 1 THz.
- Red arrows – direction of biased electric field.

Near-field (5um)



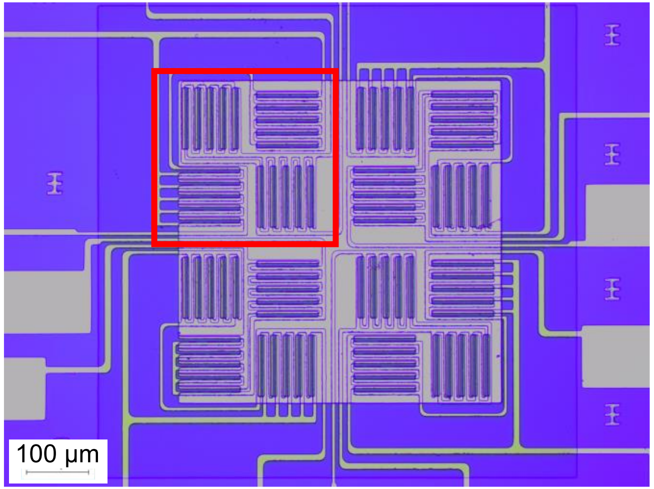
Far-field (50mm)





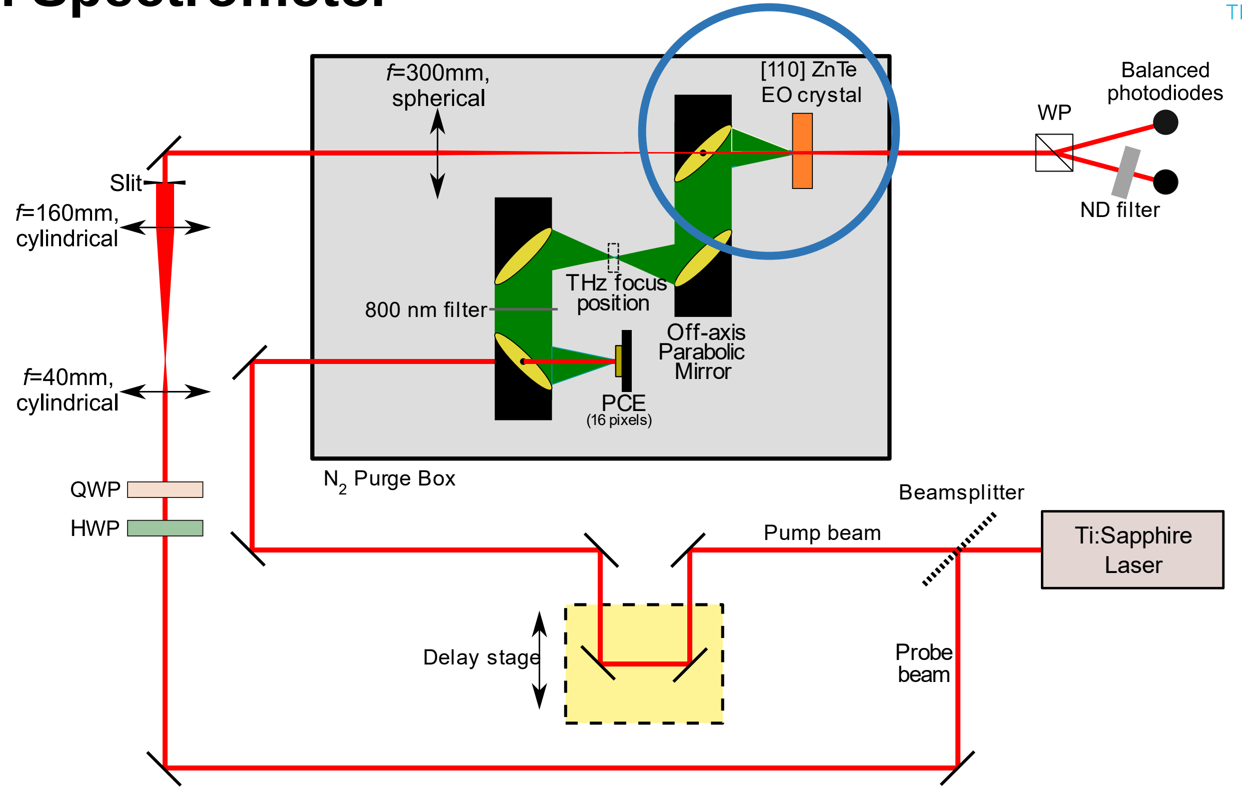
16-pixel Photoconductive Emitter

- To employ electrical modulation for azimuthal, radial and linear beams, it is necessary to use at least 16 pixels.
- The 4-pixel emitter electrode geometry (highlighted by red rectangle) has been repeated 4 times.
- Conventional lithography process and metal magnetron sputterer for material deposition has been used in this work.



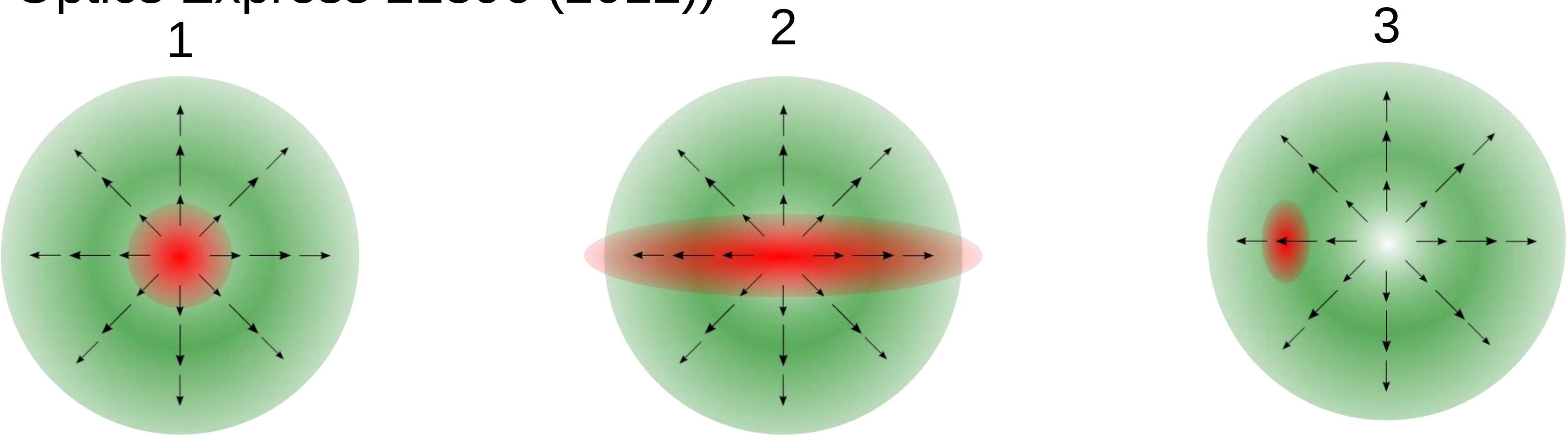
Optical microscope images of emitter's interdigitated area (x50 magnification).

16-pixel Emitter Implementation in THz Time-Domain Spectrometer



Spatially-Resolved Electro-Optic Sampling (1)

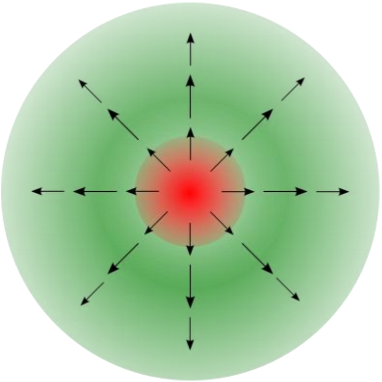
- Standard EOS detection does not work for beams with doughnut-like profile (1).
- To measure a beam profile, the gate beam was expanded in a line (2). A slit was used to scan the gate beam along the axis of a beam (3). (Imai, R. et al. Optics Express 21896 (2012))



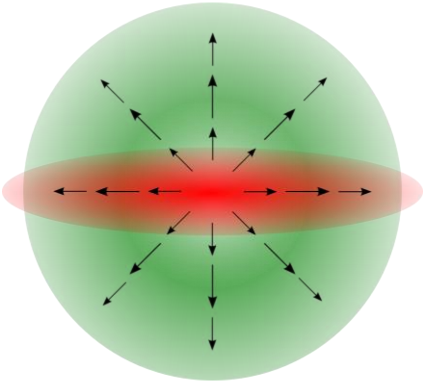
Spatially-Resolved Electro-Optic Sampling (1)

- Standard EOS detection does not work for beams with doughnut-like profile (1).
- To measure a beam profile, the gate beam was expanded in a line (2). A slit was used to scan the gate beam along the axis of a beam (3). (Imai, R. et al. Optics Express 21896 (2012))

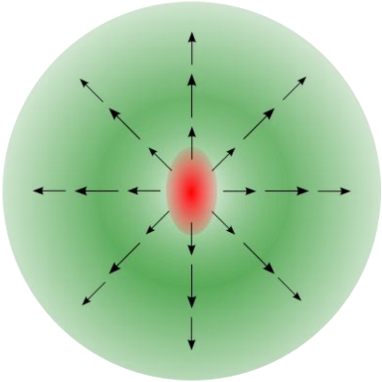
1



2



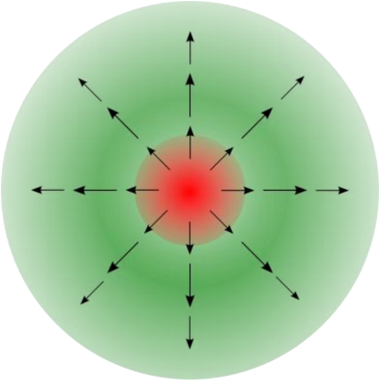
3



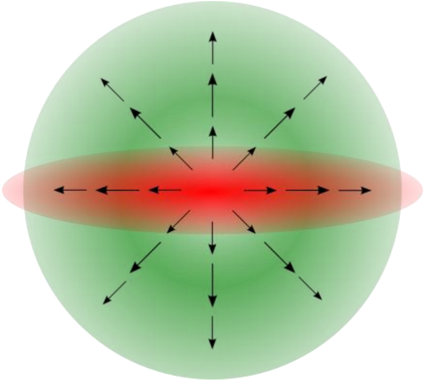
Spatially-Resolved Electro-Optic Sampling (1)

- Standard EOS detection does not work for beams with doughnut-like profile (1).
- To measure a beam profile, the gate beam was expanded in a line (2). A slit was used to scan the gate beam along the axis of a beam (3). (Imai, R. et al. Optics Express 21896 (2012))

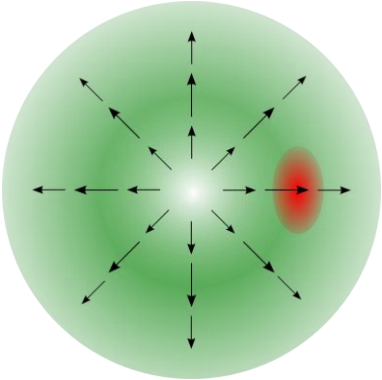
1



2

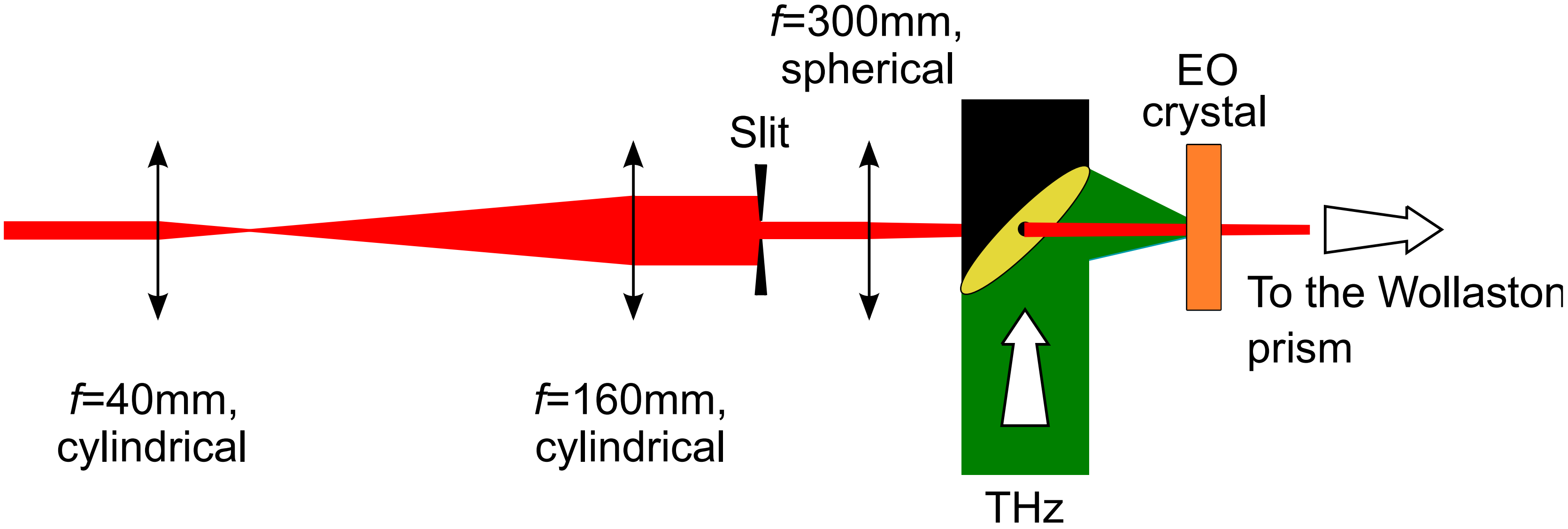


3



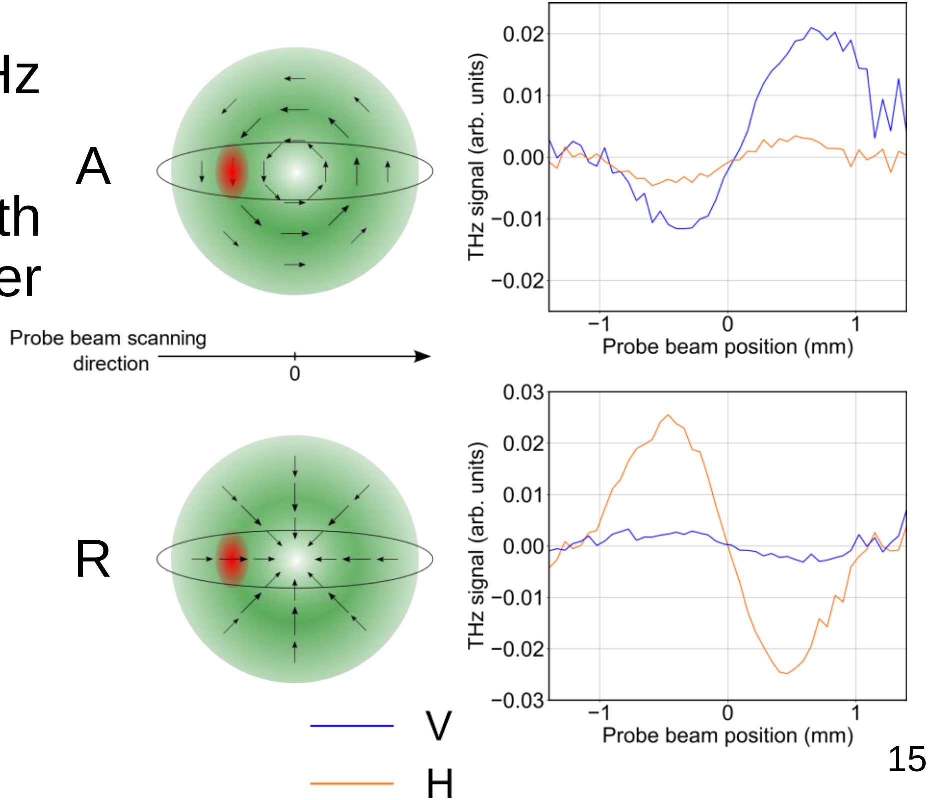
Spatially-Resolved Electro-Optic Sampling (2)

- Experimental implementation of spatially-resolved (SREOS) method for transversal THz field detection:



Beamprofile of A and R beams

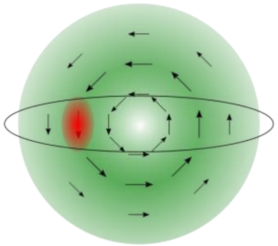
- Both horizontal and vertical THz components were detected.
- THz field was corrected with respect to the probe beam power at position.



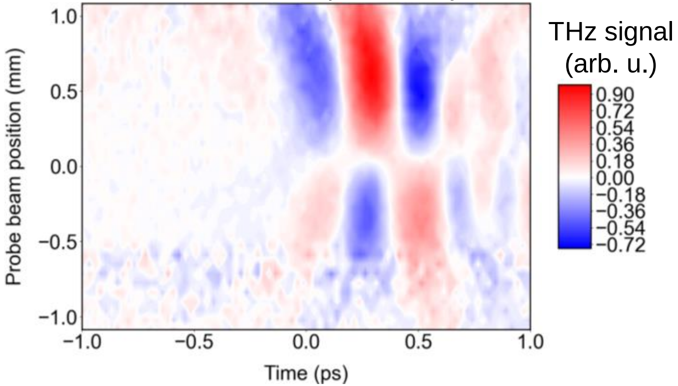
Deveikis, J., Lloyd-Hughes, J. (in preparation), 2022

Spatially- and Time-Resolved Data of A and R beams

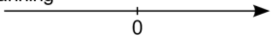
A



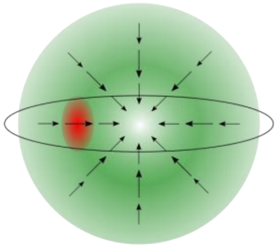
Vertical component only



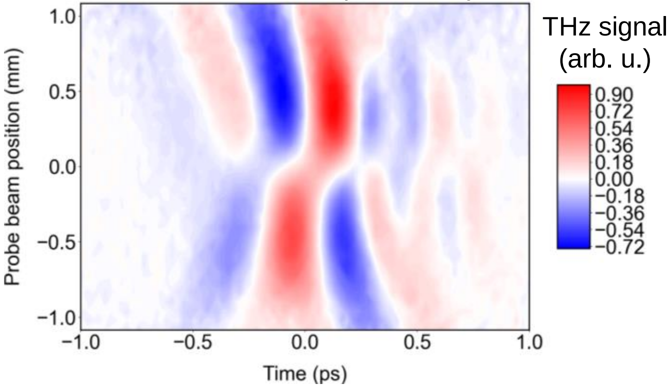
Probe beam scanning direction



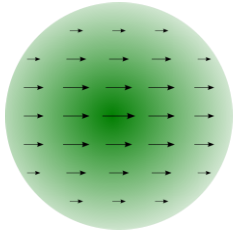
R



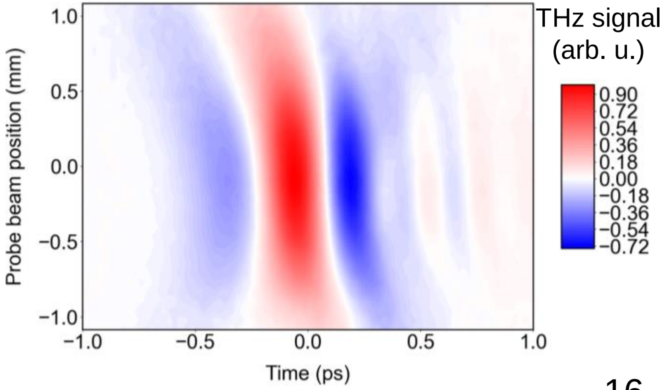
Horizontal component only



L (horizontal polarisation)



Horizontal component only



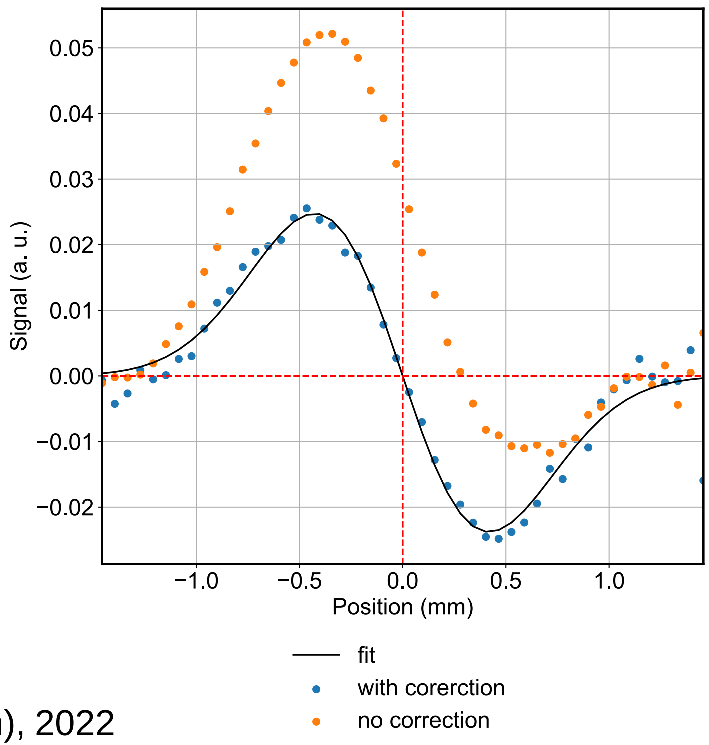
Deveikis, J., Lloyd-Hughes, J. (in preparation), 2022

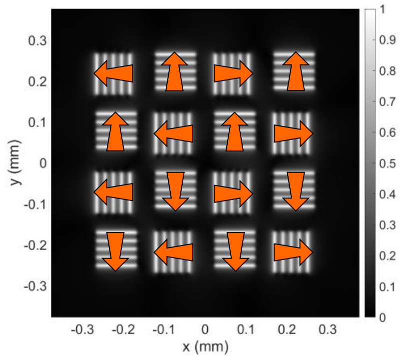
Electrical Beamprofile Control

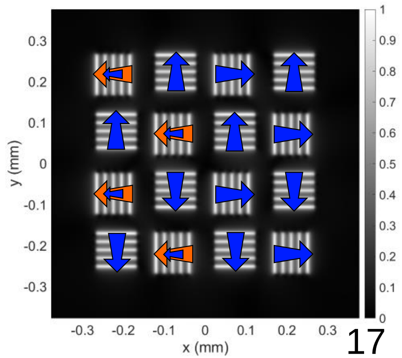
- Changing pixel bias configuration alters the beamshape.
- Useful to correct the beamprofile when pixels are not excited uniformly.
- Fitting function:

$$E_x = AJ_1(x)e^{-\frac{(x-x_0)^2}{2\sigma^2}}$$

R beam





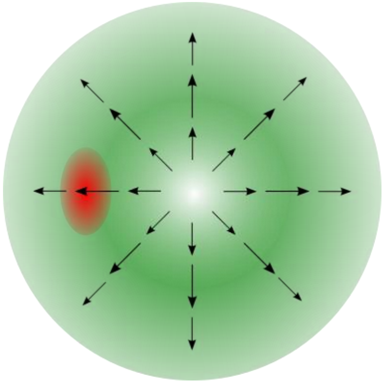


Deveikis, J., Lloyd-Hughes, J. (in preparation), 2022

Conclusions and further work

- Azimuthally, radially and linearly polarised beams were generated using the same 16-pixel emitter.
- Further studies to investigate polarization state in x-y plane.
- Scaling the number of pixels and their size for studying impact on quality of the beam.

1 THz



Acknowledgements

Supervisor

Dr James Lloyd-Hughes

Dr Gerard Colston

(Cleanroom)

David Greenshields

(Electronics Workshop)

CONTROLLABLE GENERATION OF AZIMUTHAL AND RADIAL TERAHERTZ BEAMS USING MULTI-PIXEL PHOTOCONDUCTIVE EMITTERS

Justas Deveikis, James Lloyd-Hughes

20th June, 2022

OTST conference, Budapest, Hungary

Dipole Array Modelling

Electric field equations by a Hertzian dipole in a spherical coordinate system:

$$E_r = Z_0 \frac{I_0 l \cos\theta}{2\pi r^2}\left(1 + \frac{1}{ikr}\right) e^{-ikr};$$

$$E_\theta = iZ_0 \frac{kI_0 l \sin\theta}{4\pi r}\left(1 + \frac{1}{ikr} - \frac{1}{(kr)^2}\right) e^{-ikr};$$

$$E_\varphi = 0;$$

where r, θ, φ are radial distance, polar and azimuthal angle respectively; l is the length of a dipole; Z_0 is the impedance of free space; I_0 is photocurrent; k is wavenumber; i is the imaginary unit.

Dipole Array Modelling Implementation

Red arrow shows individual dipole of length $l = 5\ \mu m$ matching the gap between electrodes.

Dipoles were distributed along the gap with spacing between adjacent dipoles equal to $d = 5\ \mu m$.