Smart devices for terahertz wavefront manipulation

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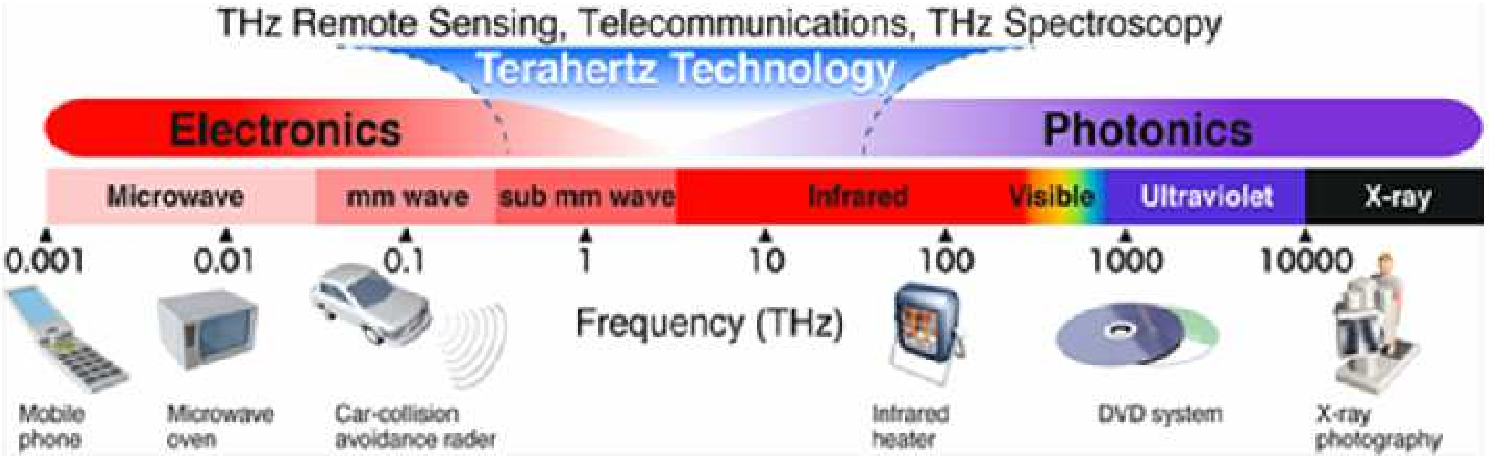
2013.09.14

Outline

- Introduction of THz
- Metasurface based devices for THz wavefront control
- Active control of THz wavefront
    - Optical control of THz wavefront via metasurface
    - Optical control of THz wavefront via optically generated hologram
- Conclusions

Introduction of Terahertz

1 THz~1 ps~300 μm~33 cm^{-1}~4.1 meV



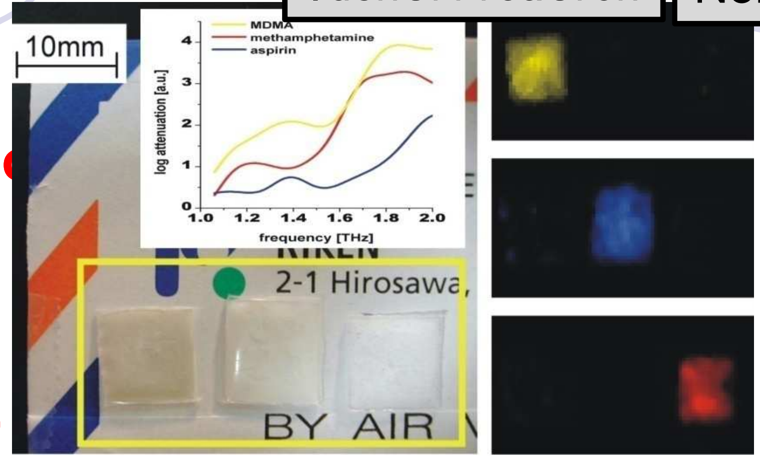
- **Terahertz (THz, 1 THz=10^{12} Hz), sandwiched between the microwave and infrared**

Introduction of Terahertz

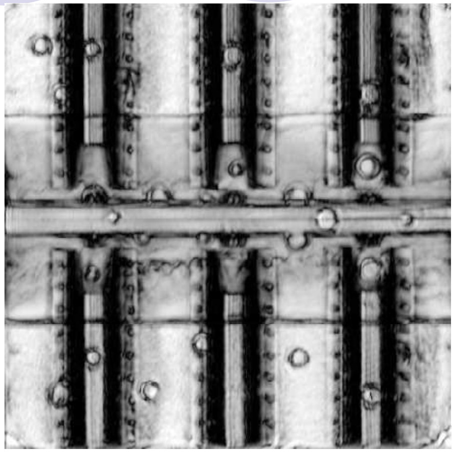
Unique nature

- Coherent detecti
- Transparent
- Low photon energ
- Fi

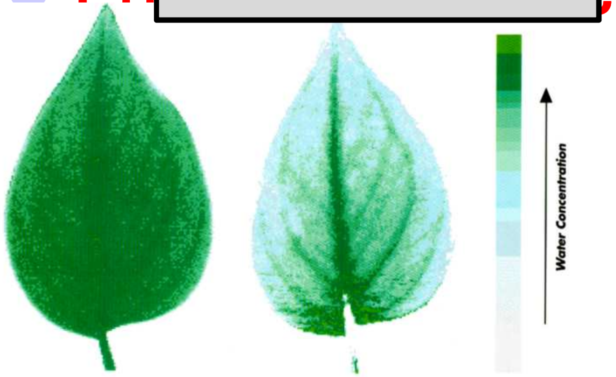
Identification



Nondestructive Inspection



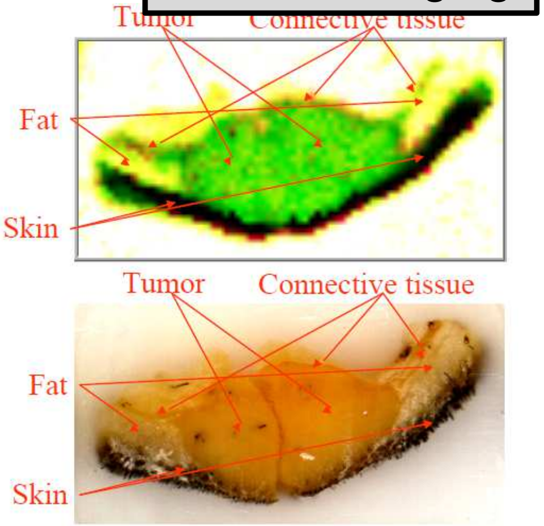
Moisture Detection



Safety Inspection

Spot the knife? Millimeter waves, close to terahertz, show their ability to see through clothes and paper.

Medical Imaging



Applications of Terahertz

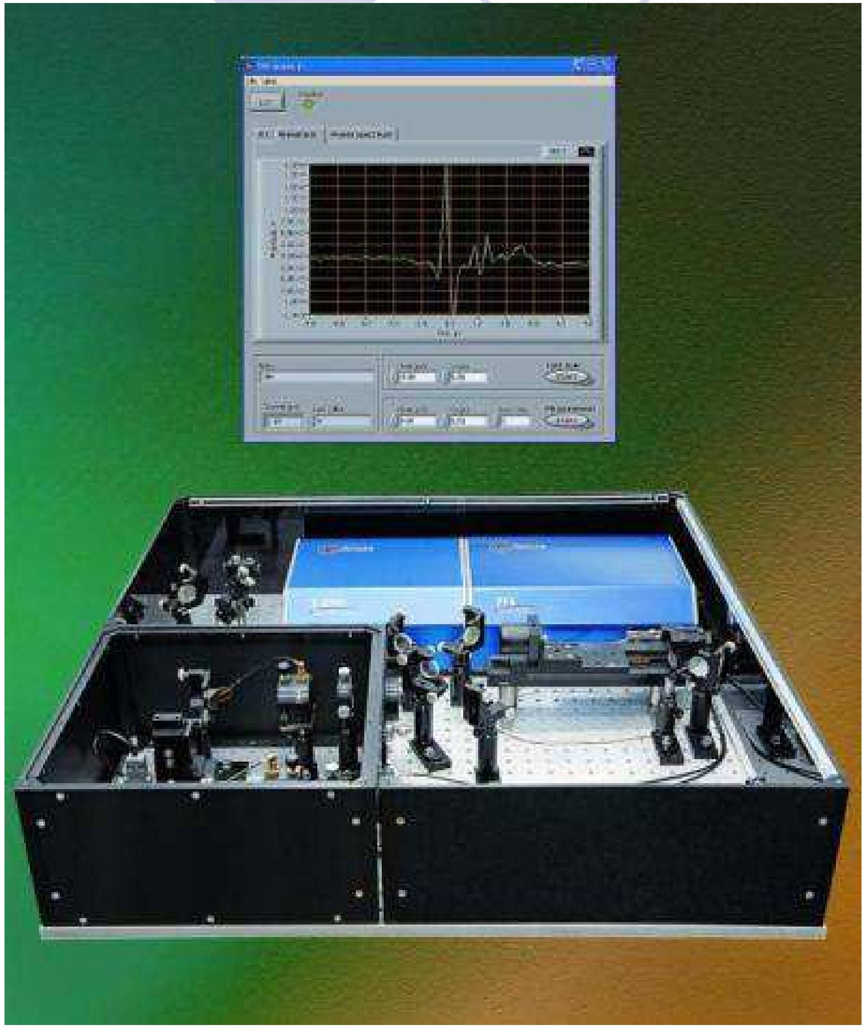
Defense: homeland security, chemical and biological agents detection, explosives detection, see-through-the-wall, imaging in space using satellites.

Commercial: biomedical, such as skin imaging for cancer detection, forgery, mail inspection, luggage inspection, gas spectroscopy, non-contact and non-destructive method.

Research: physics, plasma fusion diagnostics, electron bunch diagnostics, THz wave microscope, zero resistivity under THz radiation, Left Hand Materials (LHM) at THz range, THz spintronics.

……..

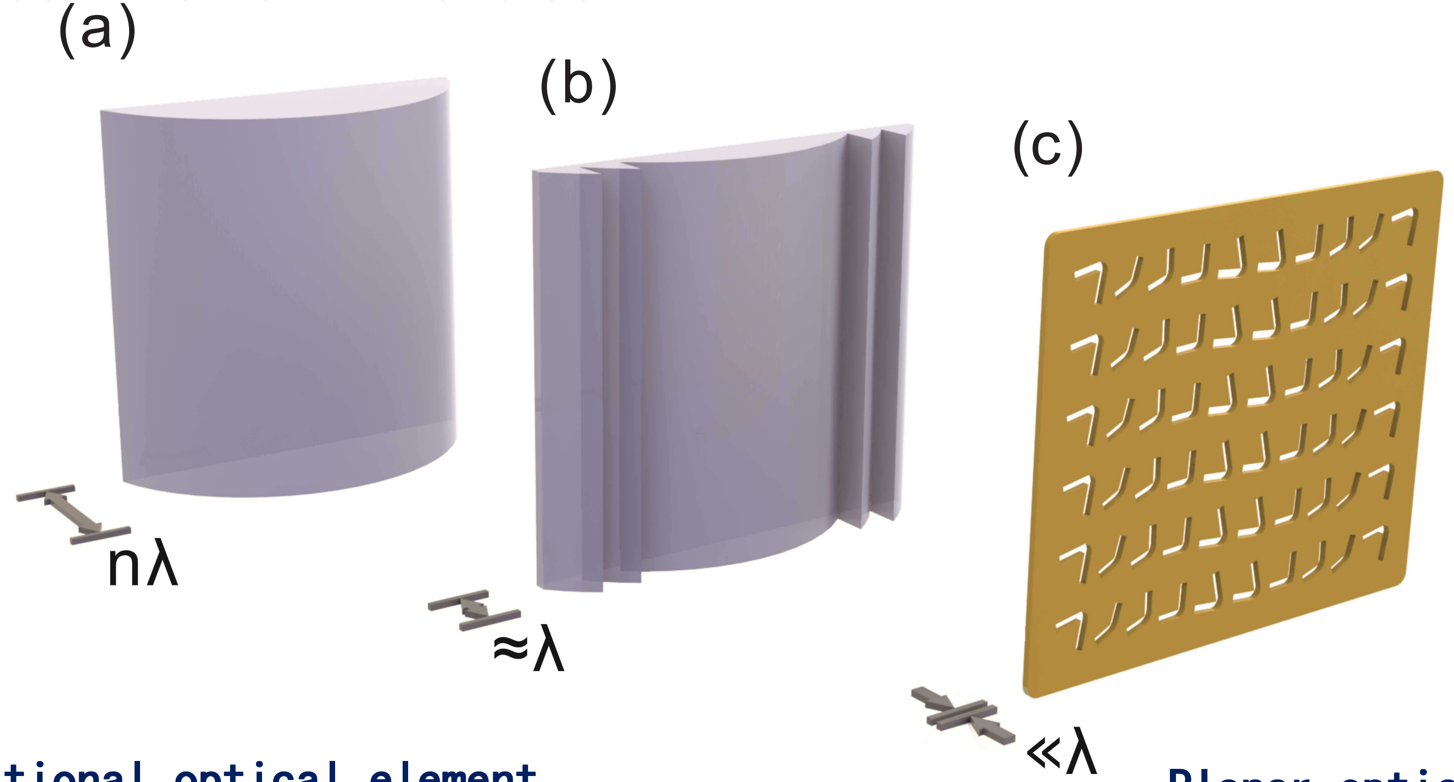
Introduction of Terahertz



THz system is too huge for real applications.

More flexible method for wavefront control

How thick can a lens be?

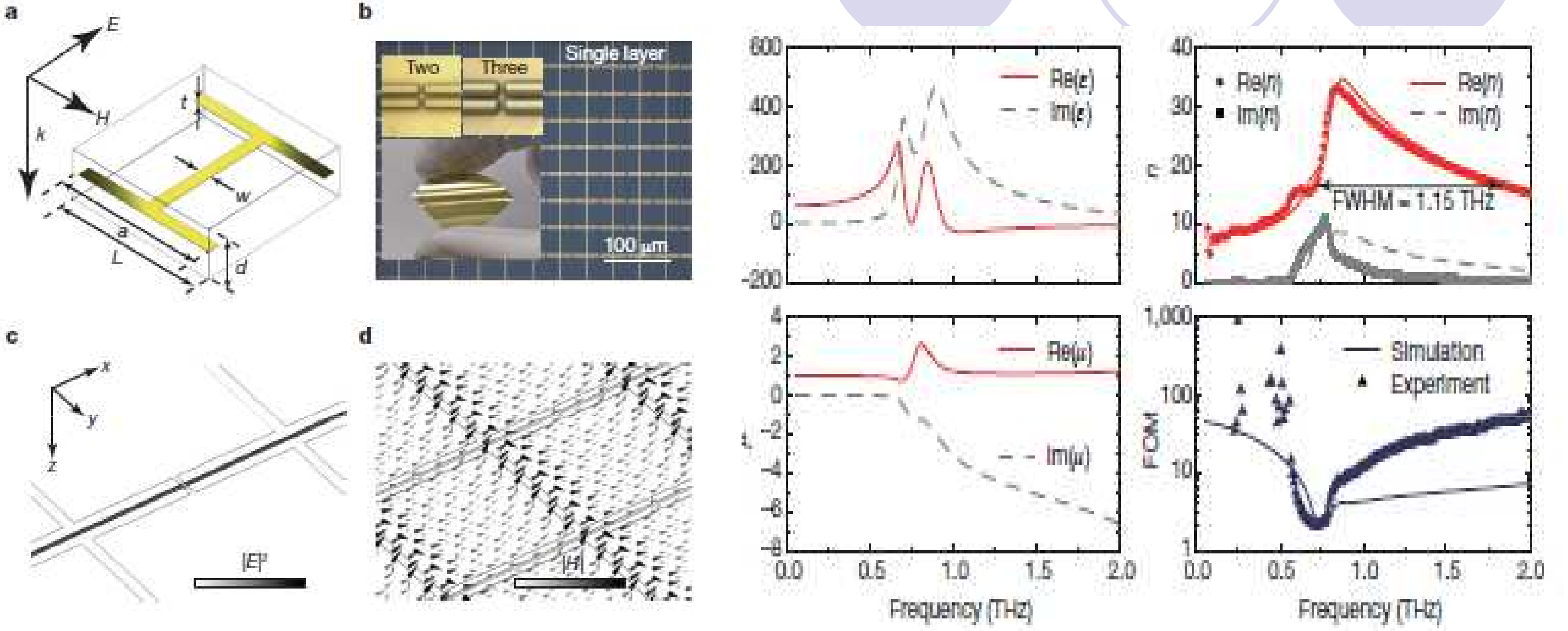


Traditional optical element

Planar optical element

Diffractive optical element

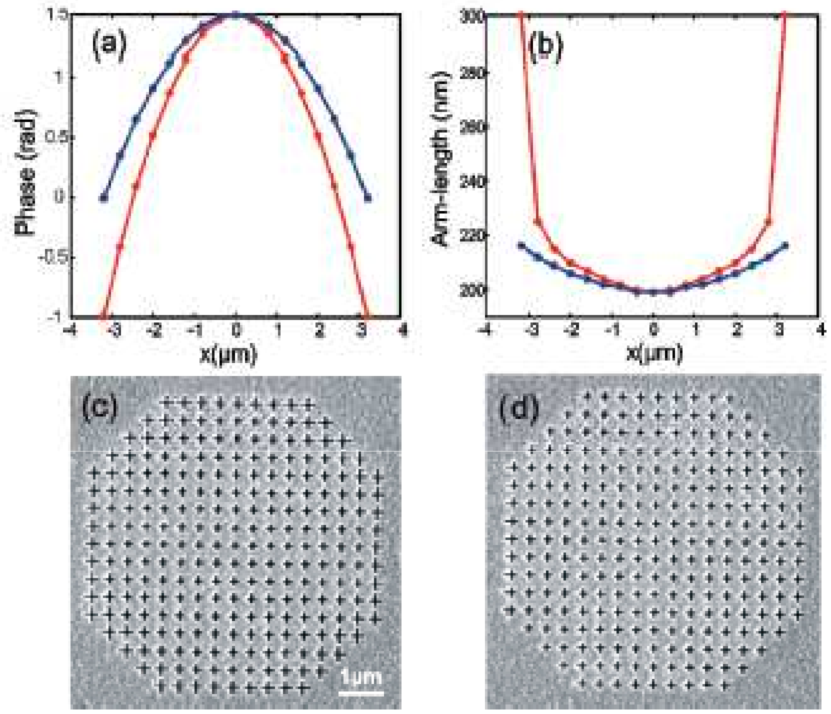
Metasurface based devices

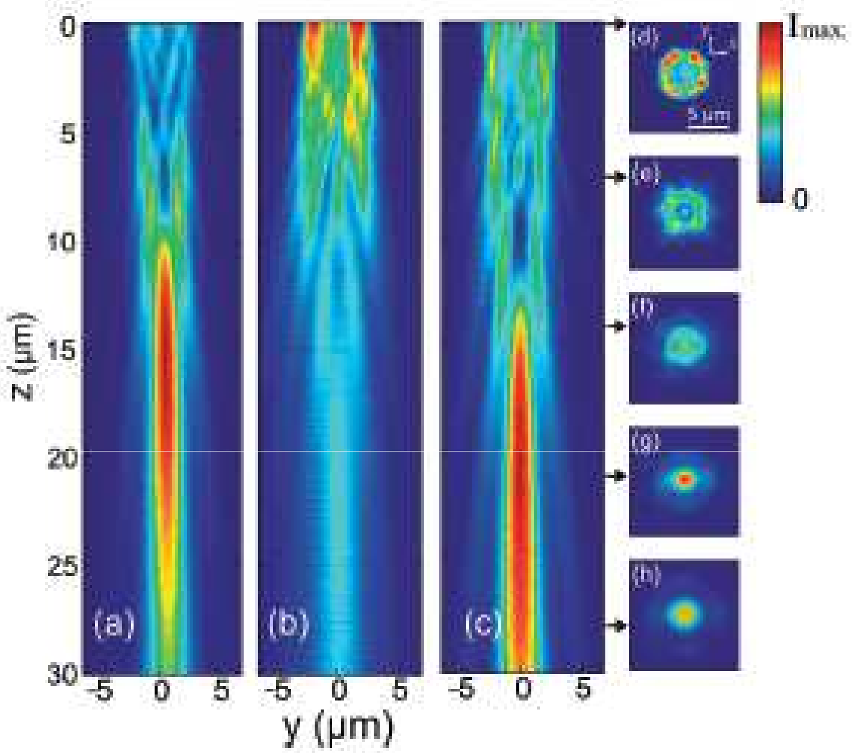


A terahertz metamaterial with unnaturally high refractive index

Nature. ***2011, 470, 369–373***

Metasurface based devices

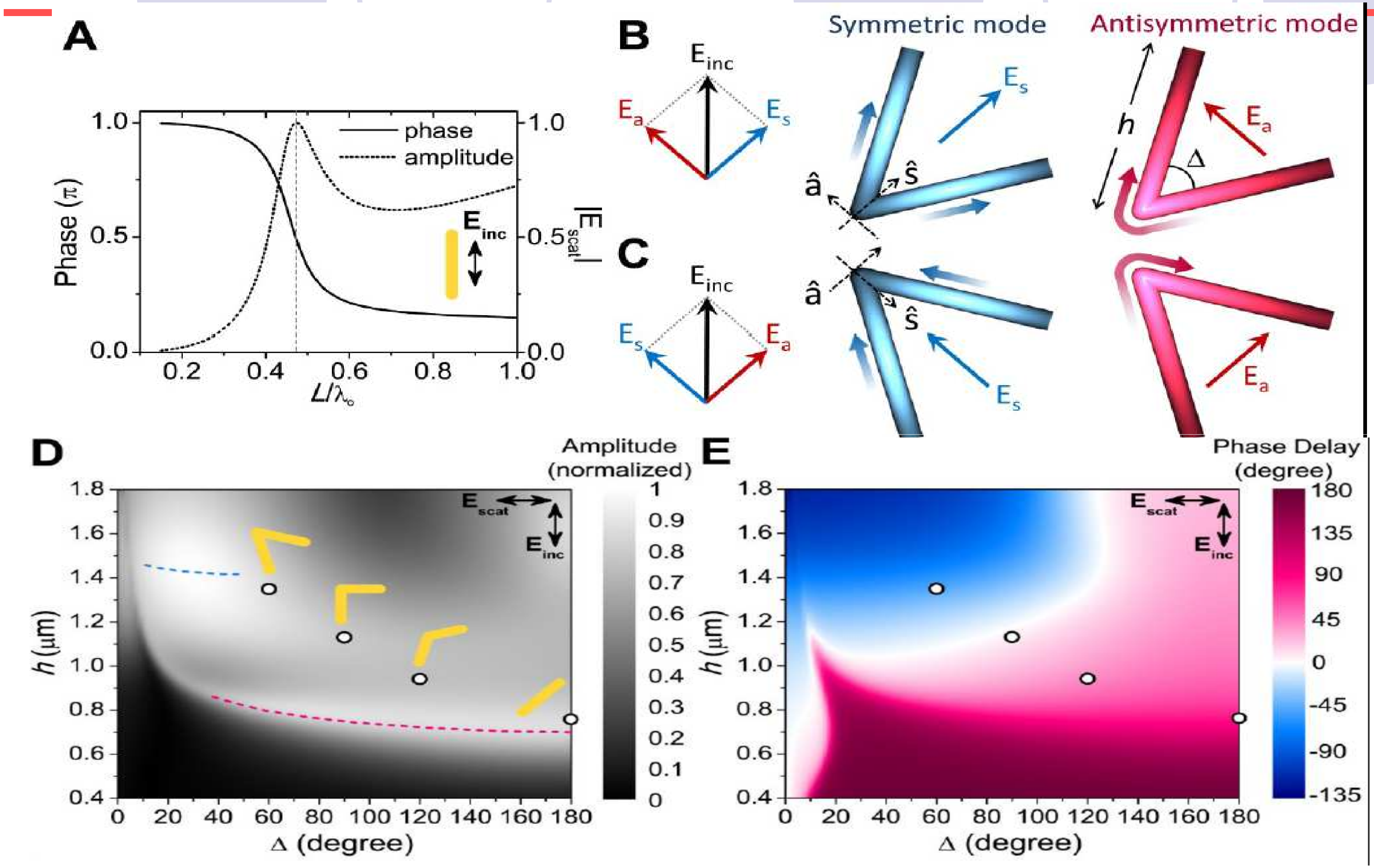




Plasmonic Lenses Formed by Two-Dimensional Nanometric Cross-Shaped Aperture Arrays

Nano Lett. ***2010, 10, 1936—1940***

Metasurface based devices

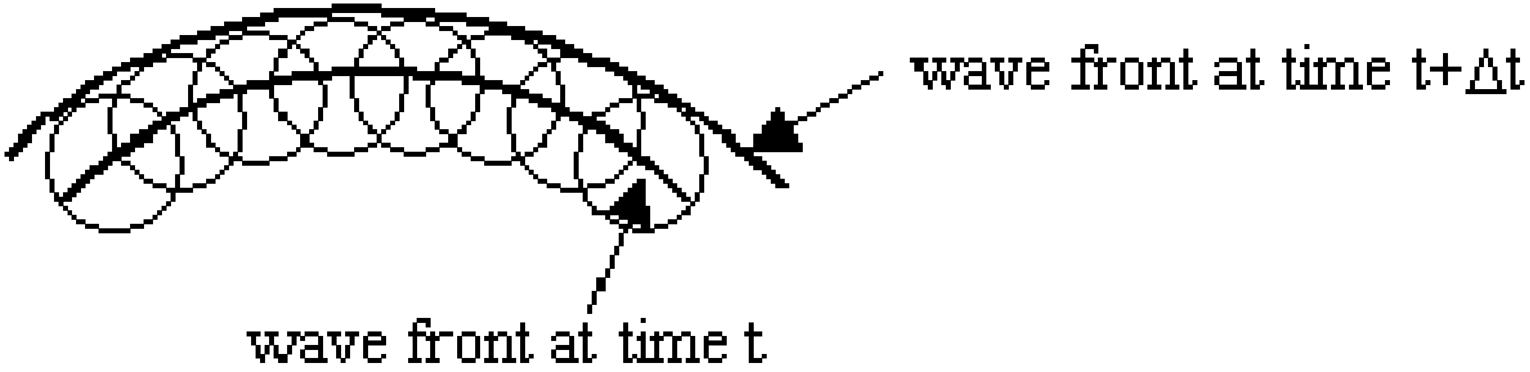


Phase modulation based on antenna resonance

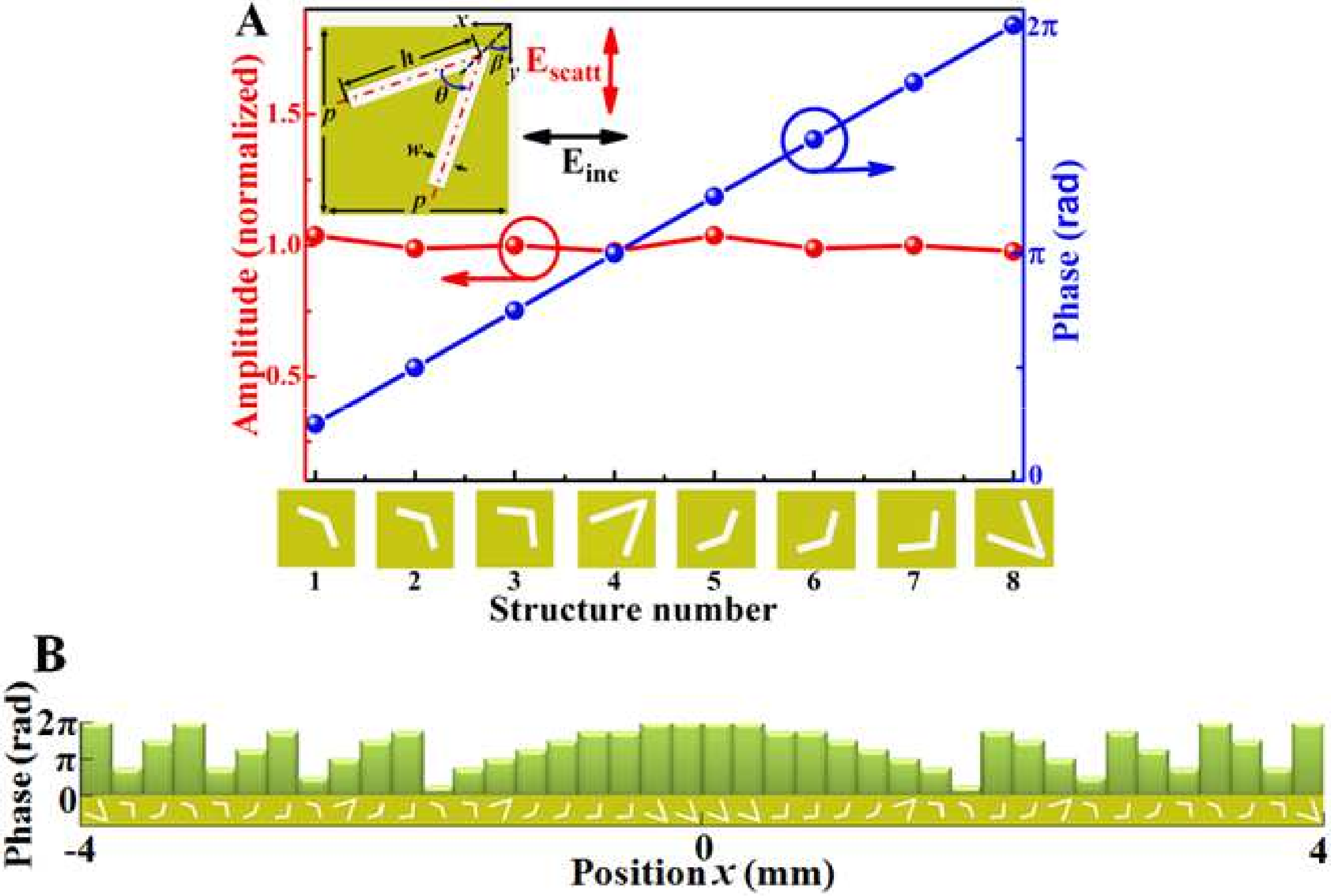
Science ***2011, 334, 333***

Huygens' Principle

The wavefront of a propagating wave of light at any instant conforms to the envelope of spherical wavelets emanating from every point on the wavefront at the prior instant.

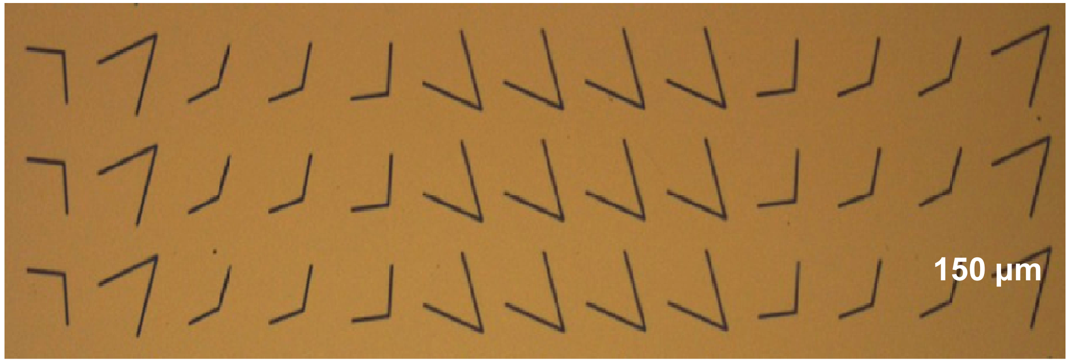


Metasurface based devices



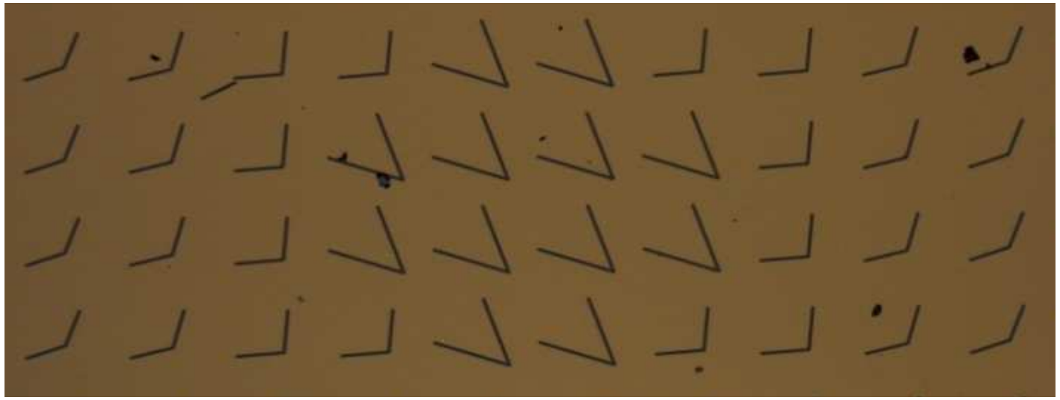
Metasurface based devices

Part of cylindrical lens



Focal length:
4mm@400μm

Part of spherical lens

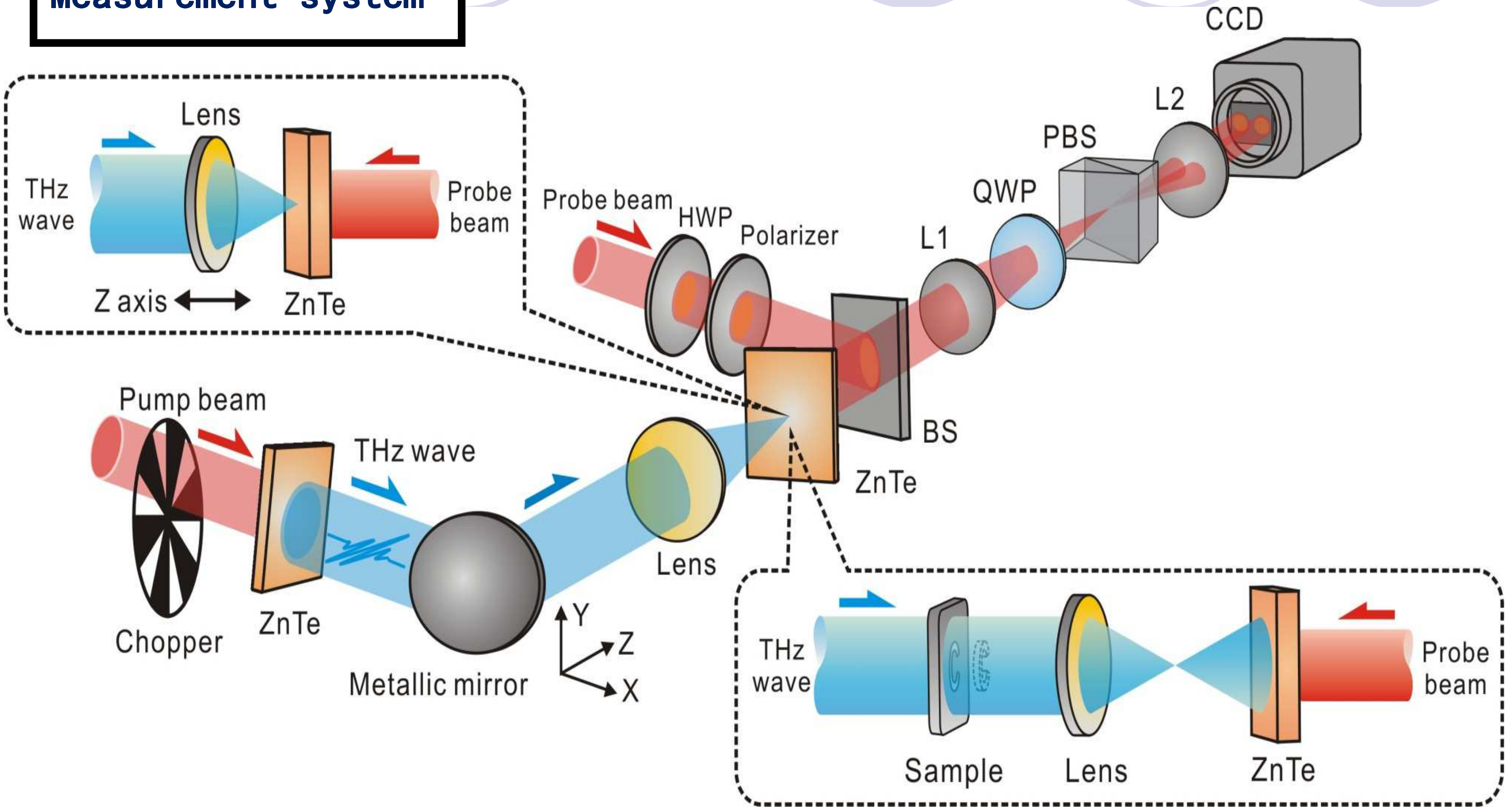


Focal length:
4mm@400μm

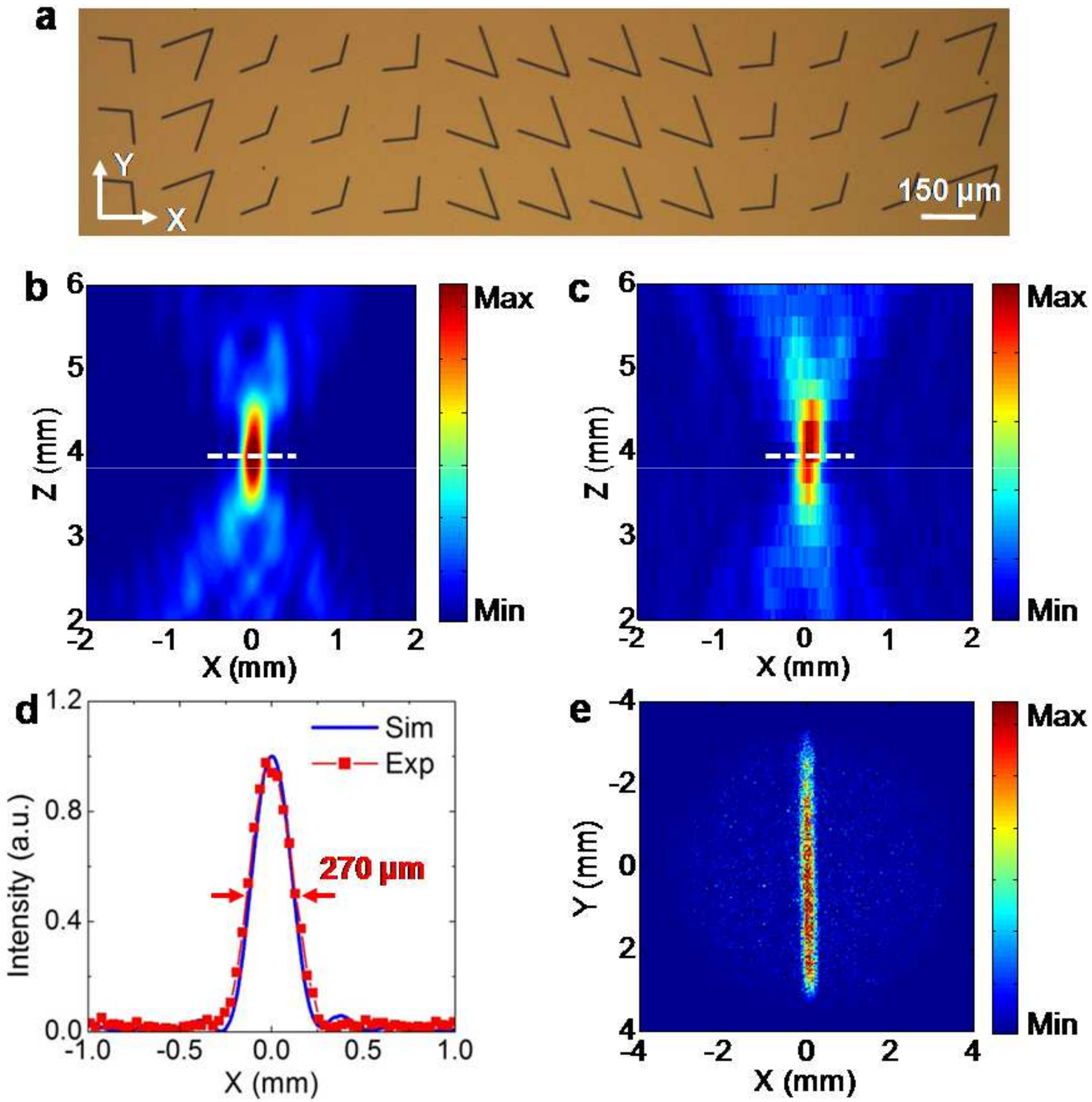
100nm gold on 500um silicon

Metasurface based devices

Measurement system



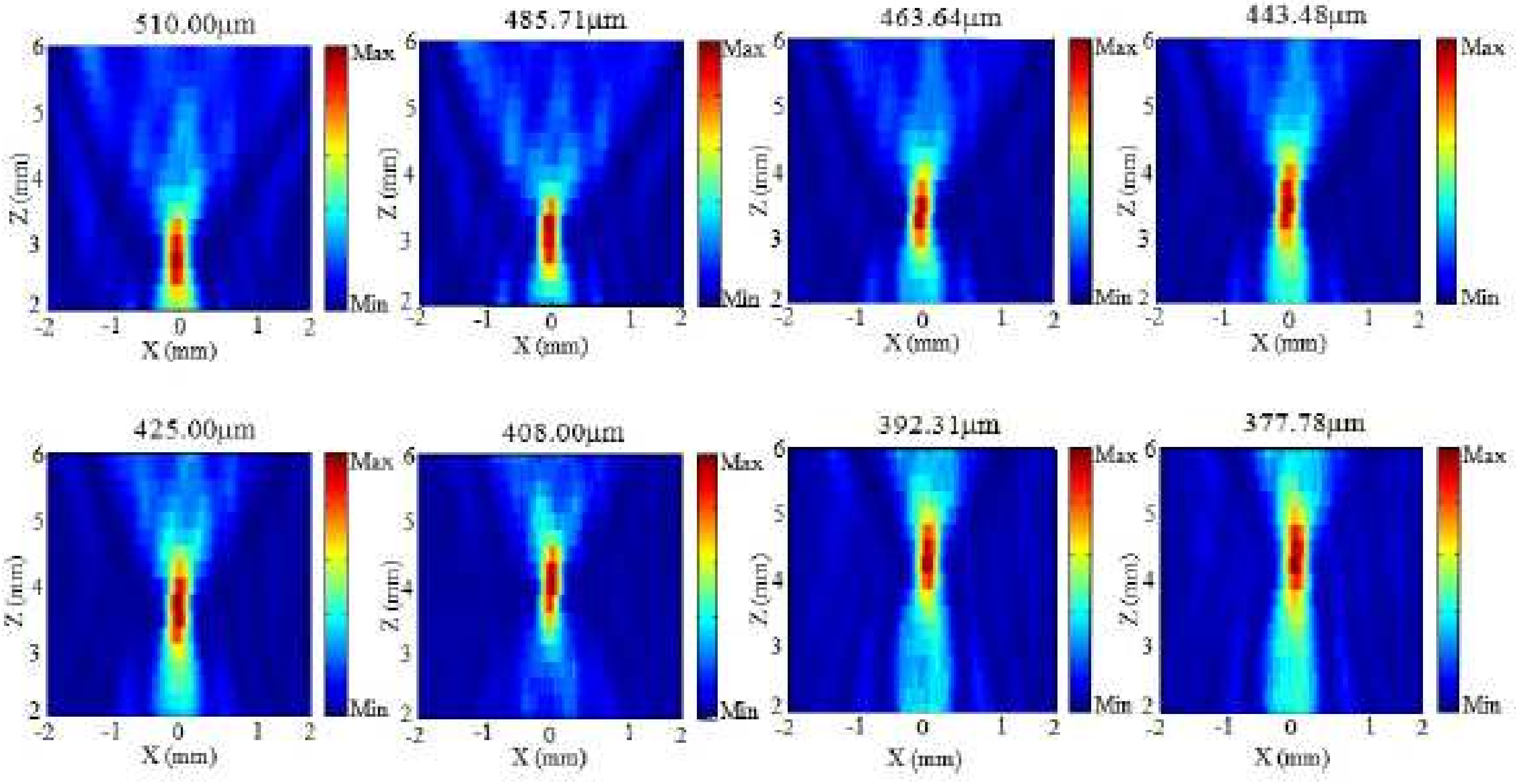
Metasurface based devices



(a) Photograph of a part of the fabricated cylindrical lens. **(b)** Intensity distribution of the cross polarized light for the designed cylindrical lens. **(c)** Experimental measurement of the intensity distribution. **(d)** Intensity distributions along the white dashed lines shown in (b) and (c). **(e)** The line focus of the cylindrical lens on the preset focal plane in experiments.

Adv. Opt. Mater., Vol. 1 186-193 (2013)

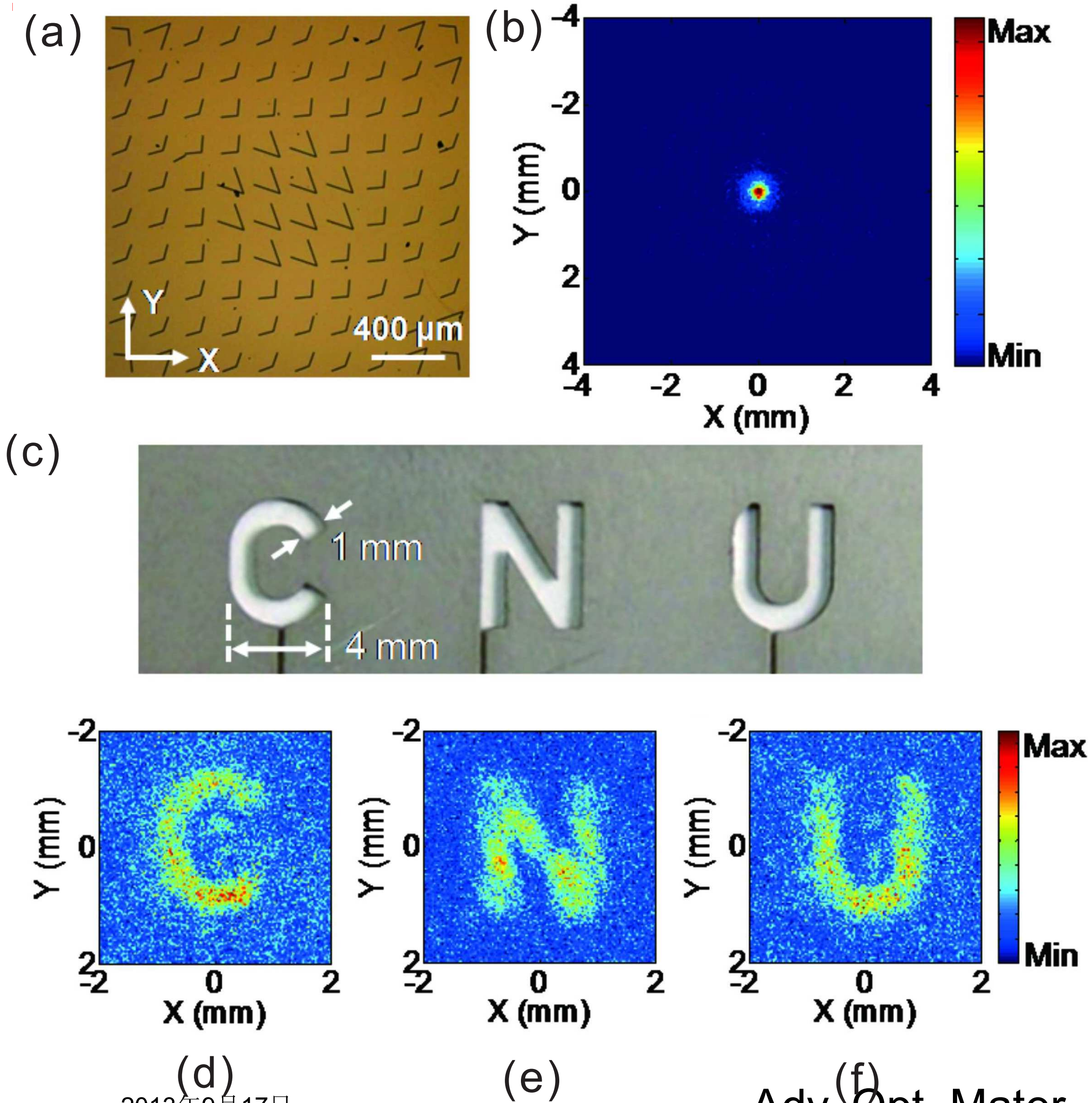
Metasurface based devices



Dispersion of the cylindrical lens

Metasurface based devices

Spherical lens imaging



The thickness of the lens is only 1/4000 of the wavelength!

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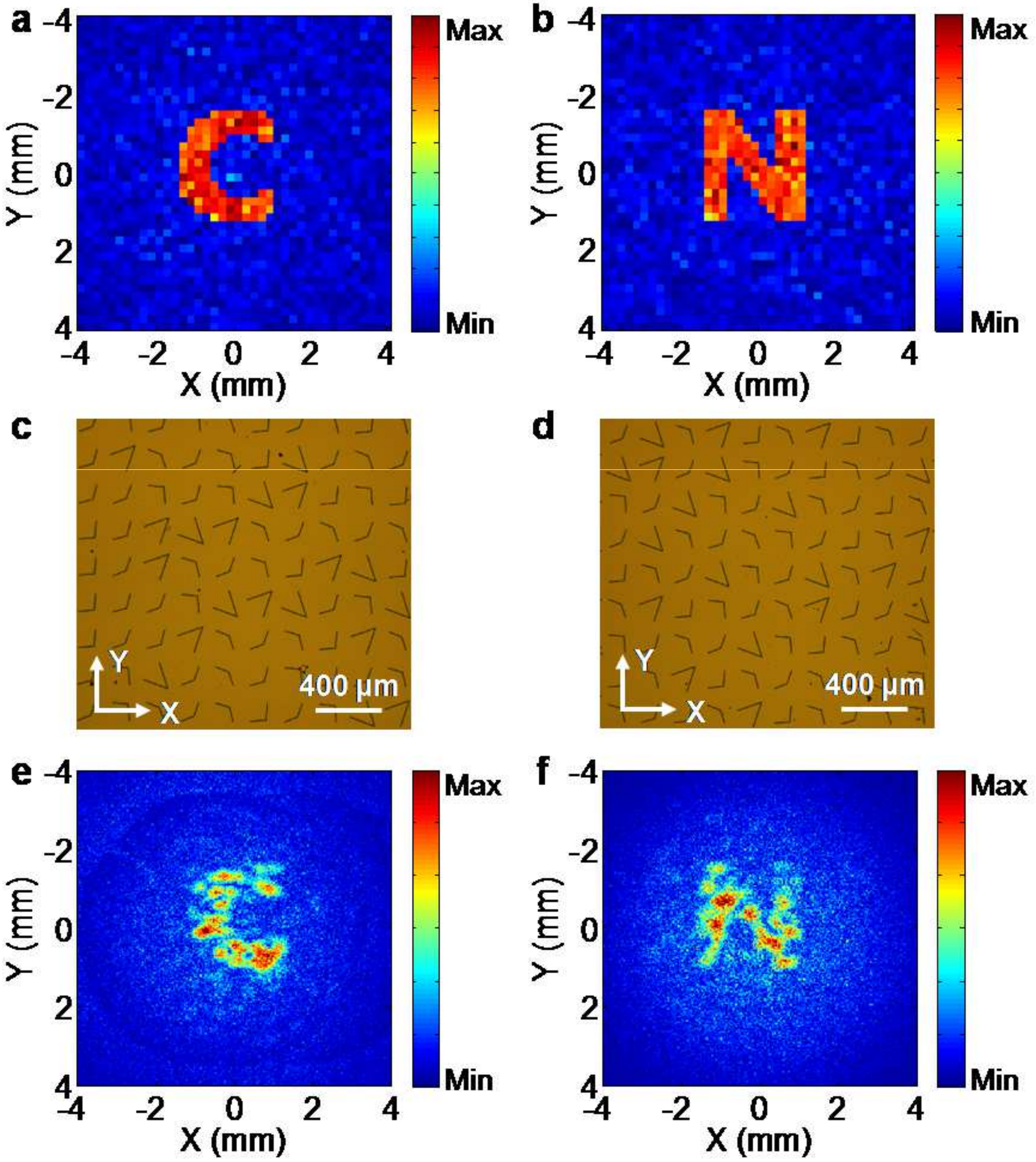
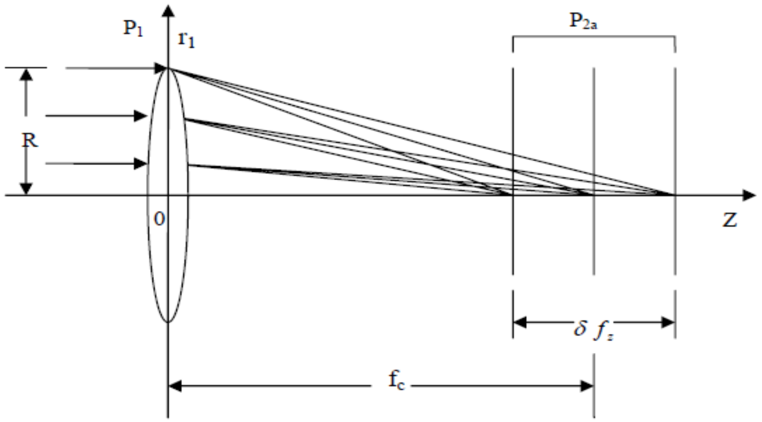
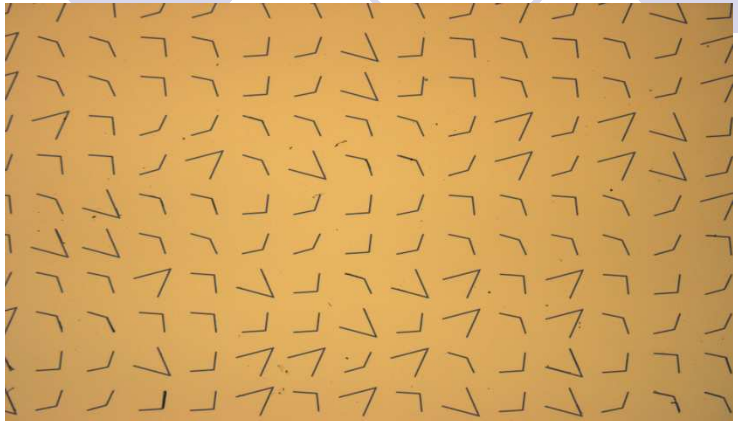
Metasurface based devices

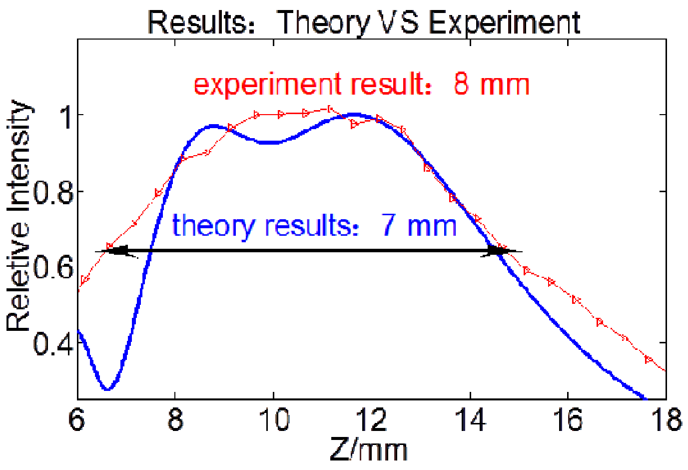


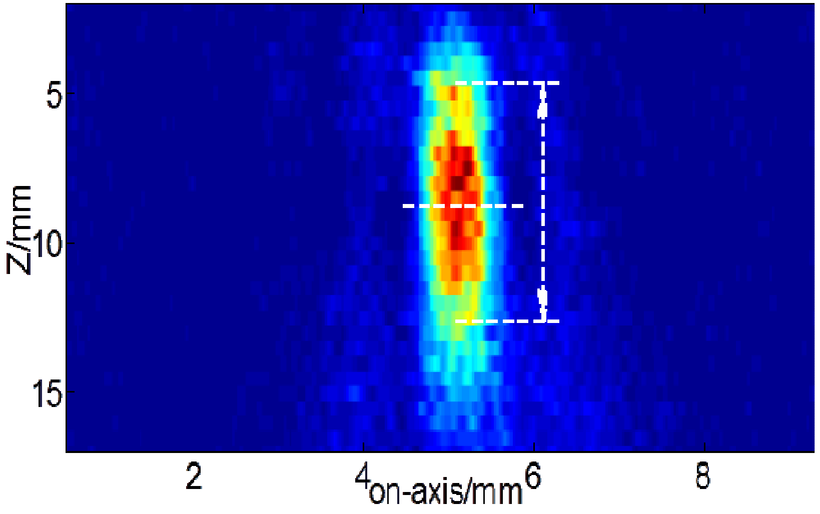
Ultrathin phase holograms for special optical field generation. **(a)** and **(b)** Desired images to be appeared on the plane which is 4mm away from the holograms. **(c)** and **(d)** Optical pictures of part of the ultrathin phase holograms for generating the desired images shown in (a) and (b), respectively. **(e)** and **(f)** Images generated by the holograms.

Metasurface based devices



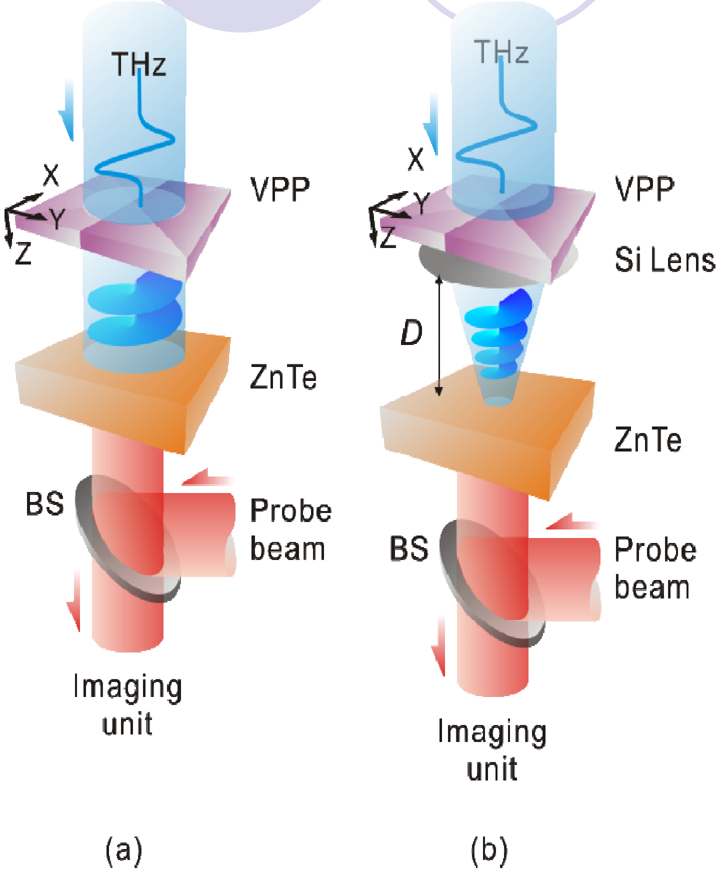




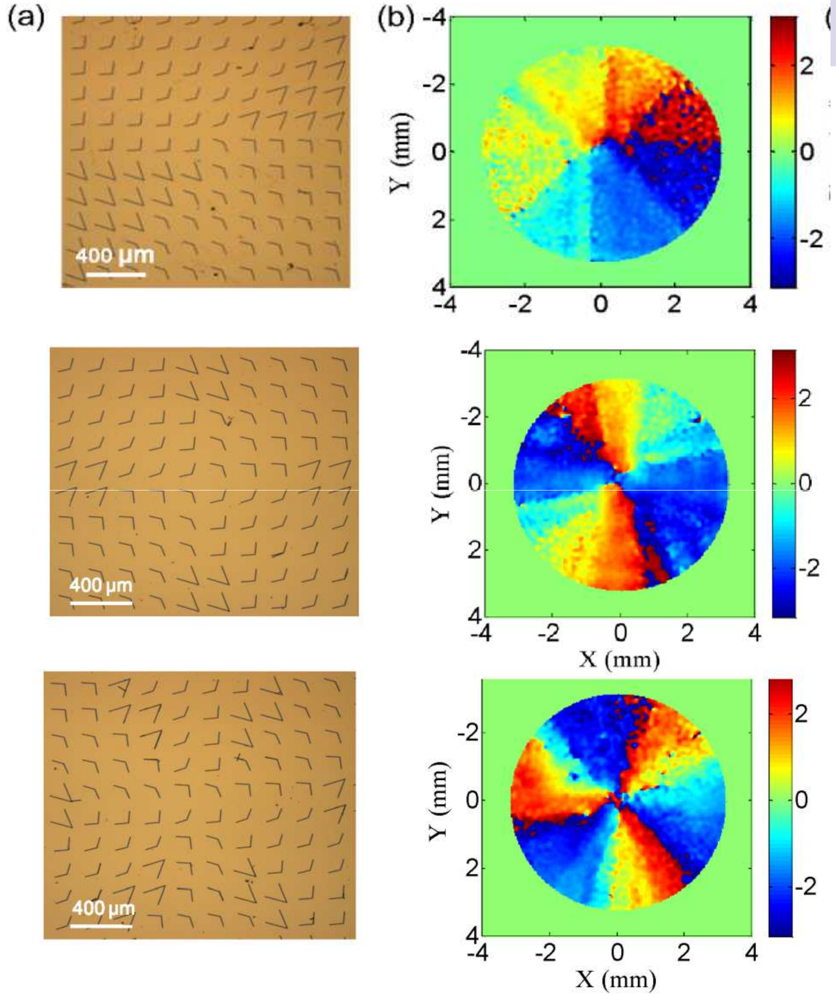


Ultrathin phase element for generating long focal length

Metasurface based devices

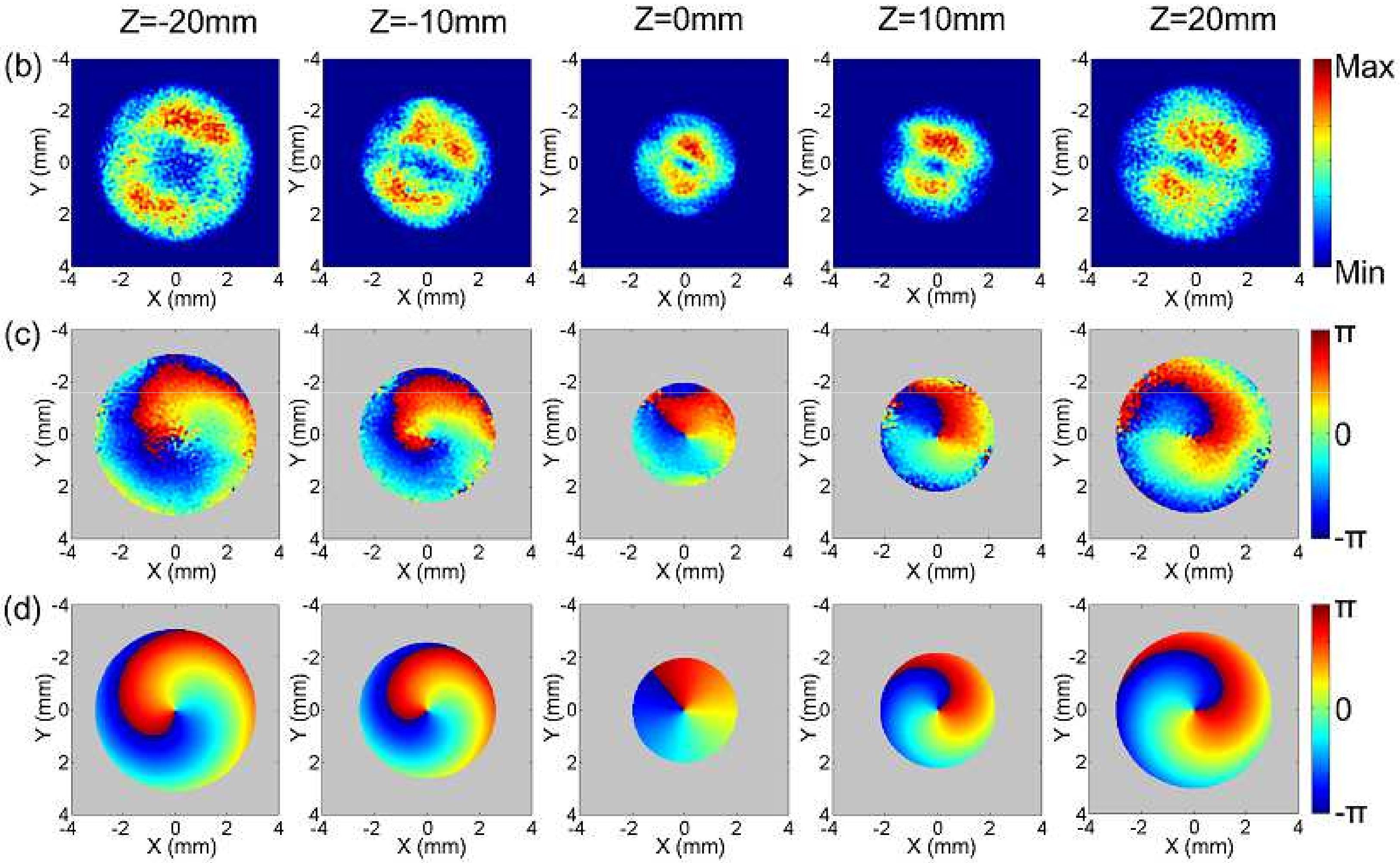


Experimental setup



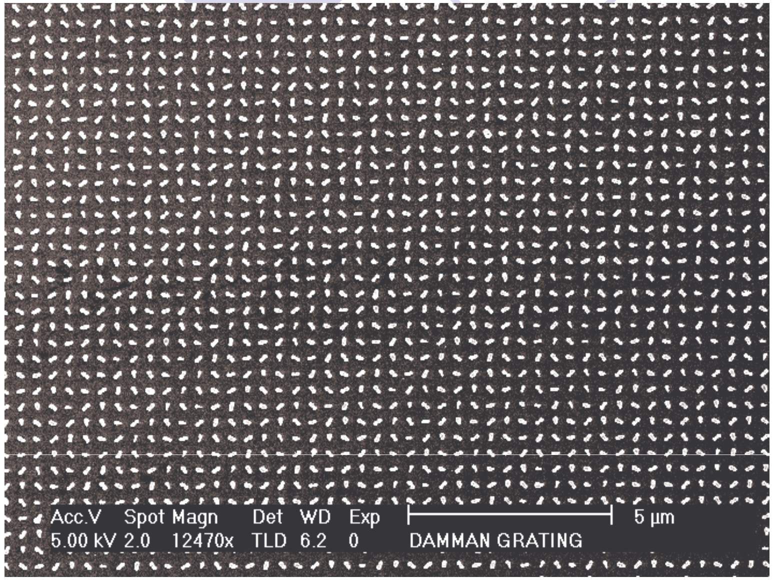
The central region of the designed devices for *l*=1,2, and 3, and (b) corresponding optical vortex phase

Metasurface based devices



Variation of phase and intensity with propagation

Active control of THz wavefront



Damman grating

Working wavelength: 750nm

Wavelength range: 650-1000nm

Size of device： 180 µm

Size of cell: 400nm

Focal length: 150 µm

Typical size: 40nm

Active control of THz wavefront

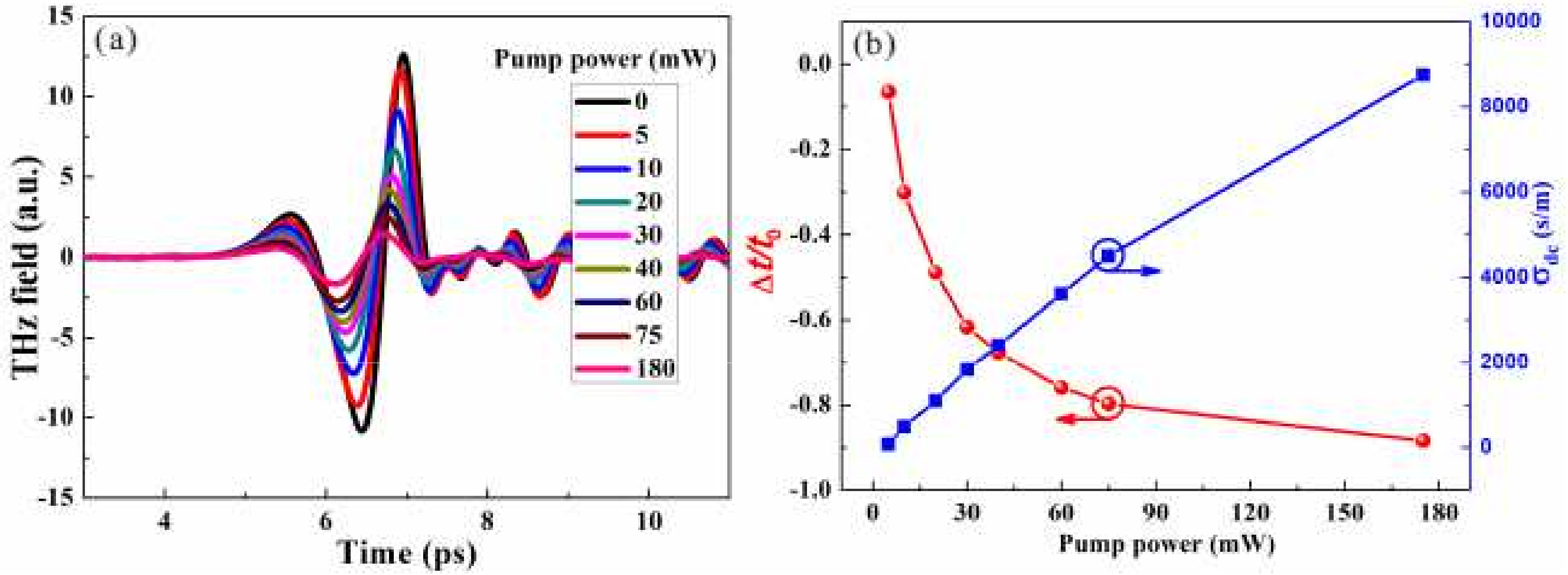
Ultrathin planar elements

- 🙂 thin, aberration free,……
- 🙁 low efficiency, function fixed

Active control of THz wavefront

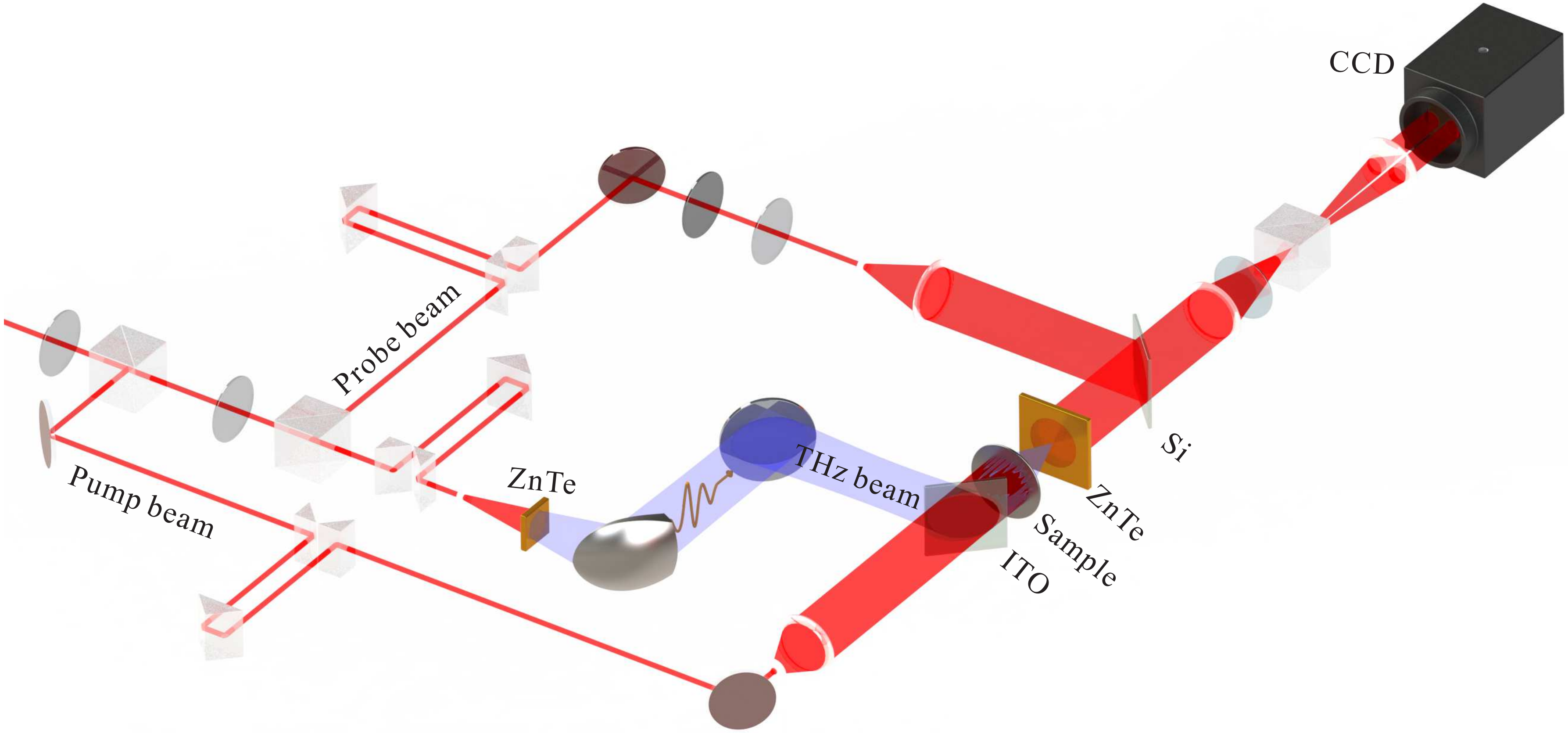
Capital Normal University

Active control of THz wavefront



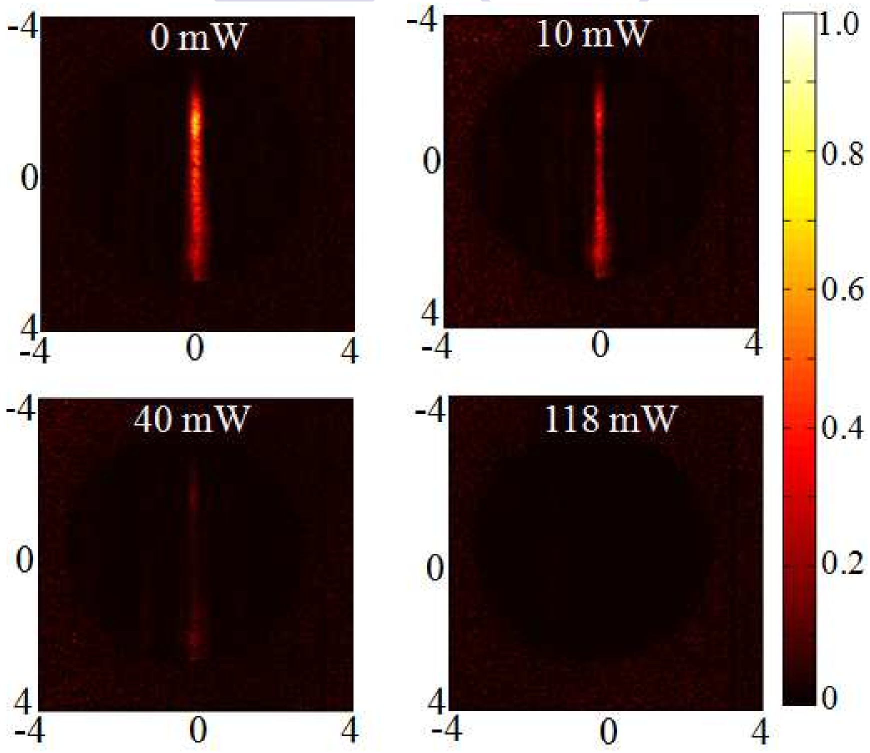
Variation of transmission and DC conductivity of Si under pump with different power.

Active control of THz wavefront

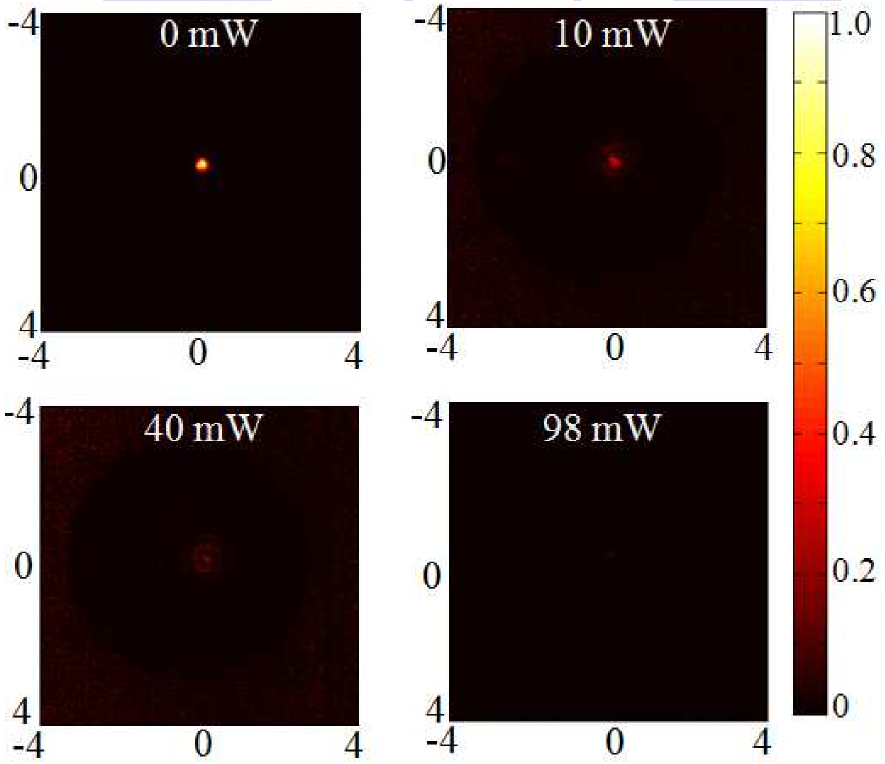


THz pump probe imaging system

Active control of THz wavefront

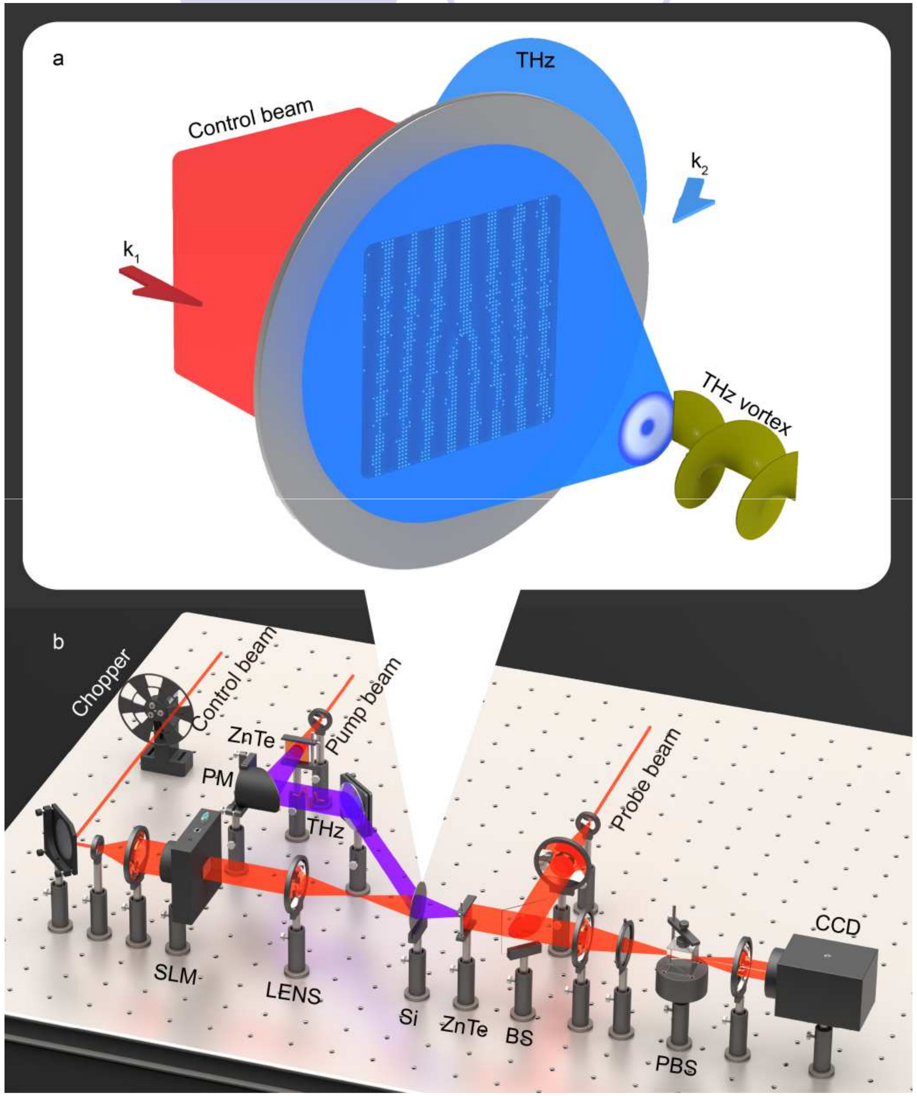


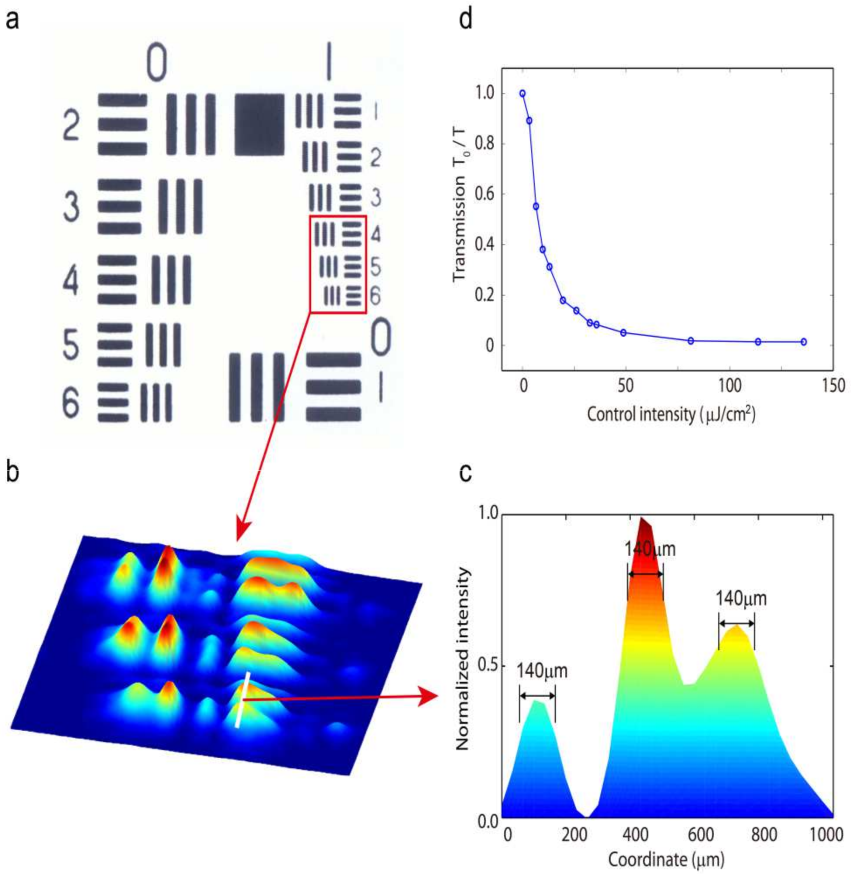
Cylindrical lens,
Modulation depth 98.3%



Spherical lens
Modulation depth 90%

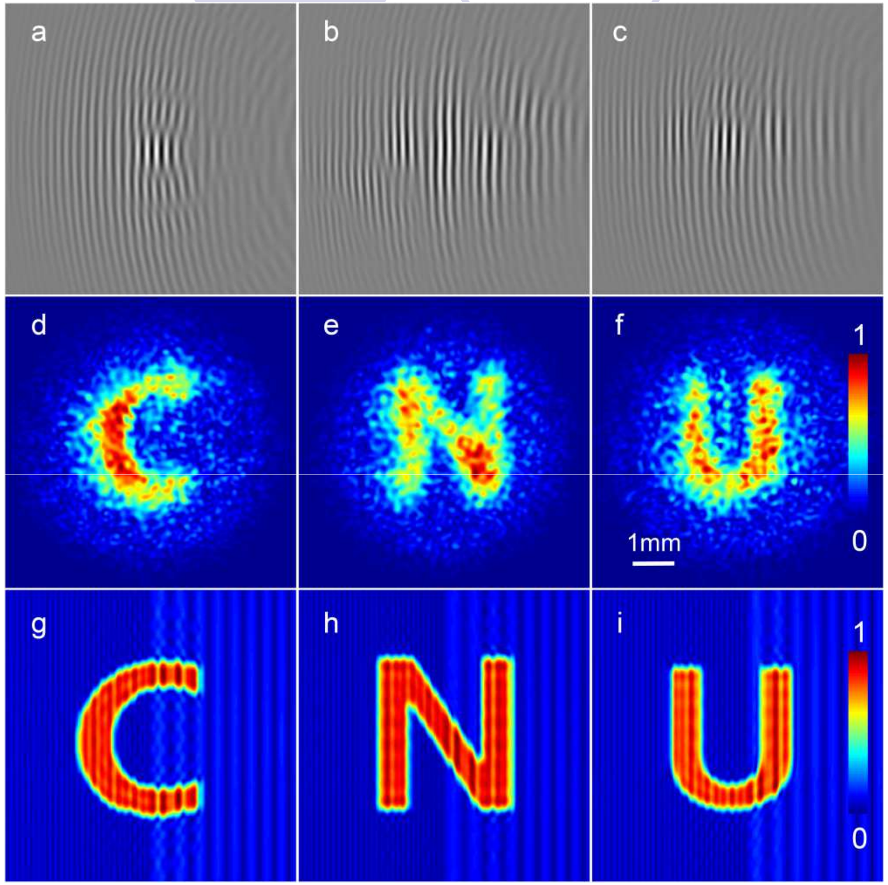
Active control of THz wavefront



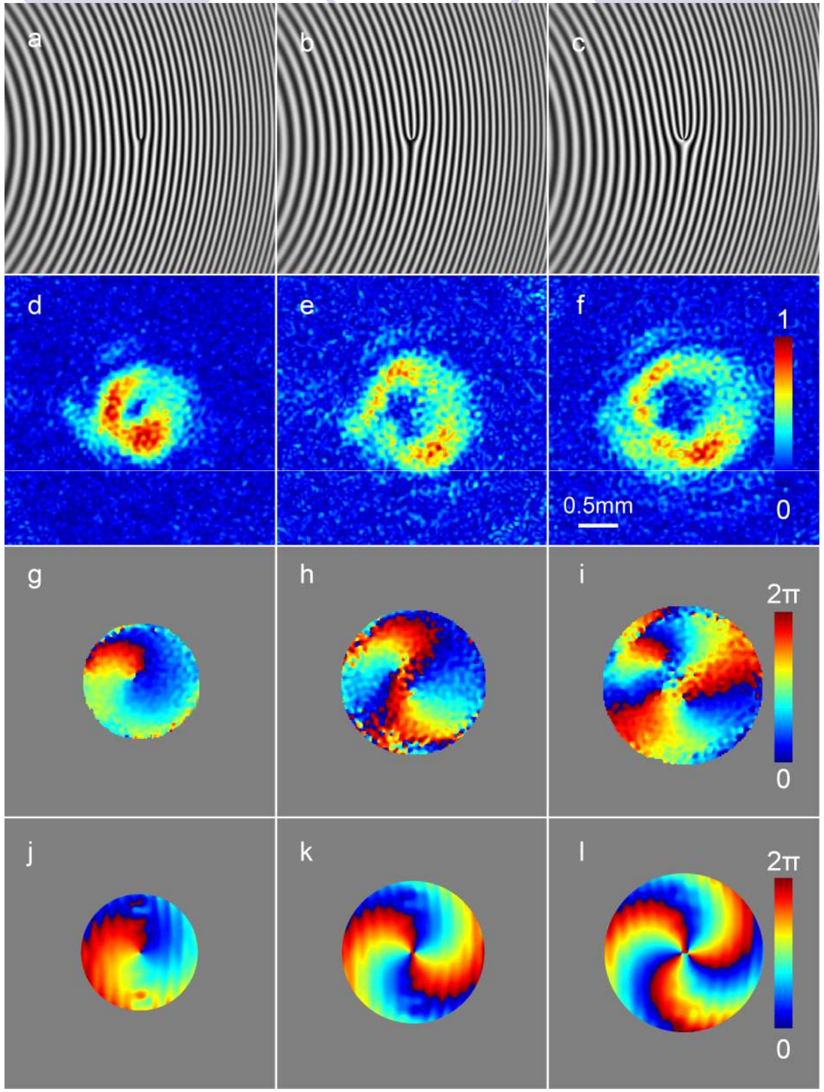


Active optical controled spatial THz modulator (STM)

Active control of THz wavefront



THz offline holograph for desired pattern generation.



Conclusions

Conclusion：

- ◆Ultrathin planar elements

  Lens, holograms, diffractive phase elements…

- ◆ Characterization of ultrathin planar elements

  Intensity, phase, polarization, wavelength…

- ◆ Active control of THz wavefront

Acknowledgements

Collaborated with

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from Capital Normal University, China

Dr. Qiang Kan, from Institute of Semiconductors, China

Prof. Peter J. Klar, from Justus-Liebig University, Germany

Acknowledgements

Thank you for
your attention!

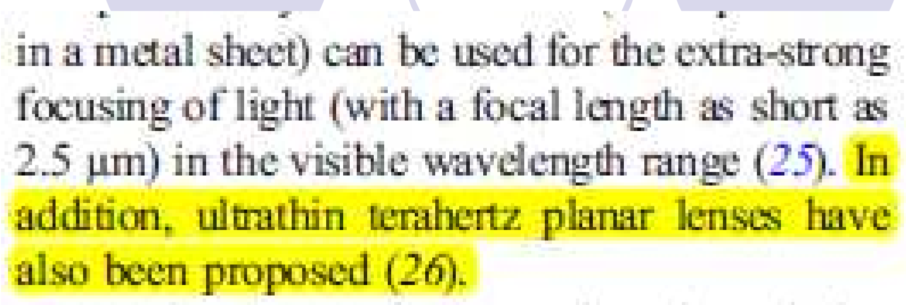
Metasurface based devices

REVIEW

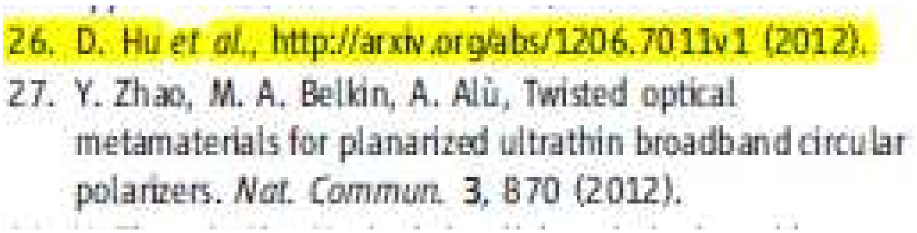
Planar Photonics with Metasurfaces

Alexander V. Kildishev, Alexandra Boltasseva, Vladimir M. Shalaev*

www.sciencemag.org SCIENCE VOL 339 15 MARCH 2013 1232009-1



in a metal sheet) can be used for the extra-strong focusing of light (with a focal length as short as 2.5 μm) in the visible wavelength range (*25*). In addition, ultrathin terahertz planar lenses have also been proposed (*26*).



26. D. Hu *et al.*, http://arxiv.org/abs/1206.7011v1 (2012).
27. Y. Zhao, M. A. Belkin, A. Alù, Twisted optical metamaterials for planarized ultrathin broadband circular polarizers. *Nat. Commun.* 3, 870 (2012).