

Smart devices for terahertz wavefront manipulation

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首都师范大学物理系

张 岩

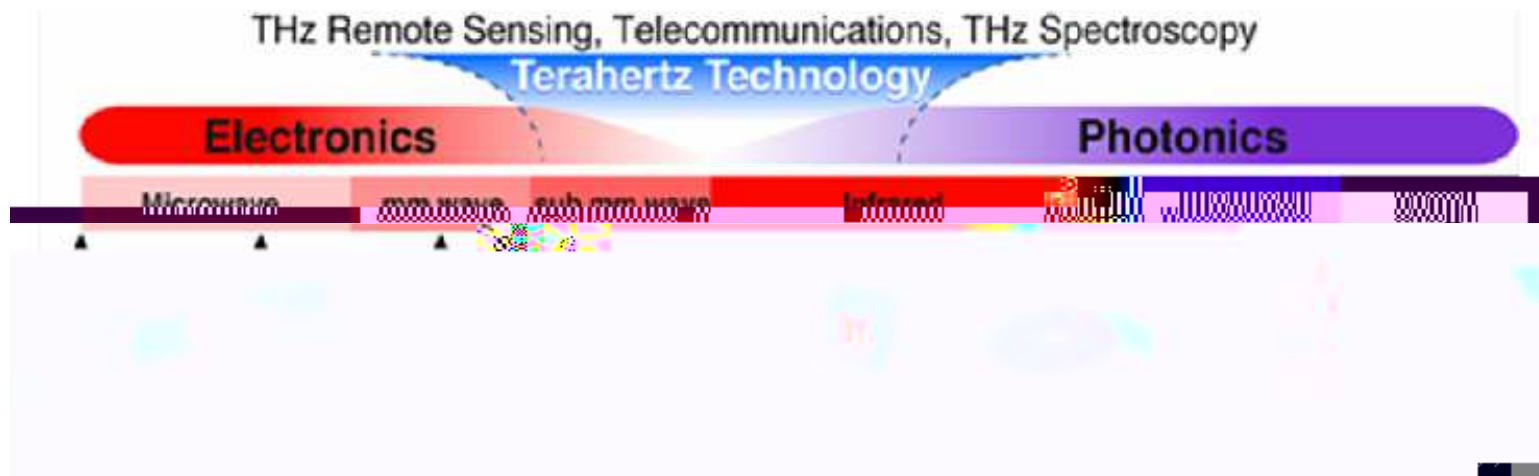
Yan Zhang

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

1 THz~1 ps~300 μm ~33 cm^{-1} ~4.1 meV



- Terahertz (THz) is sandwiched between the microwave and infrared

Identification

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Unique nature

- Coherent detection
- Transparent
- Low photon energy

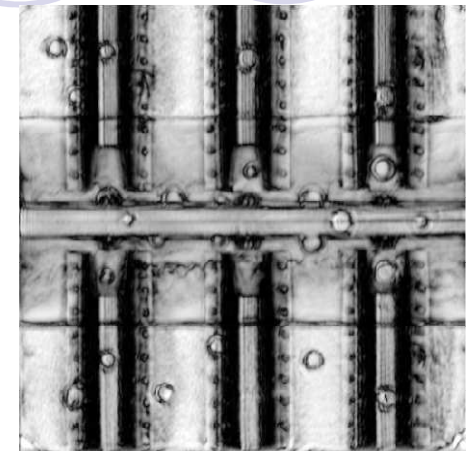
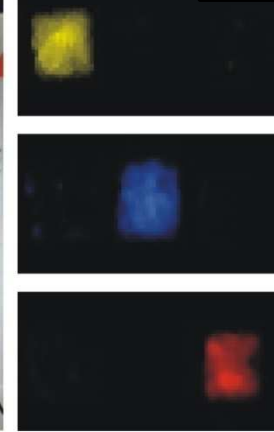
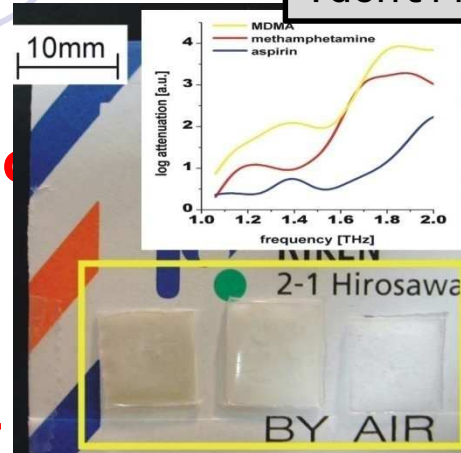
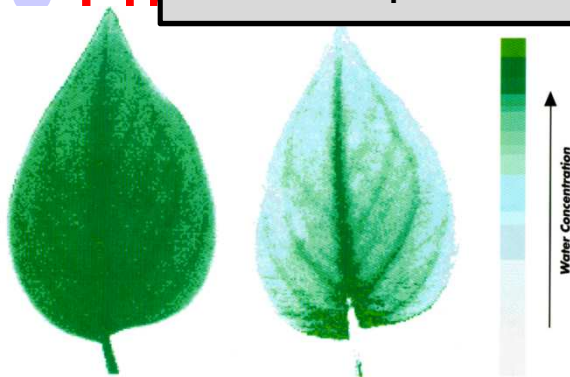
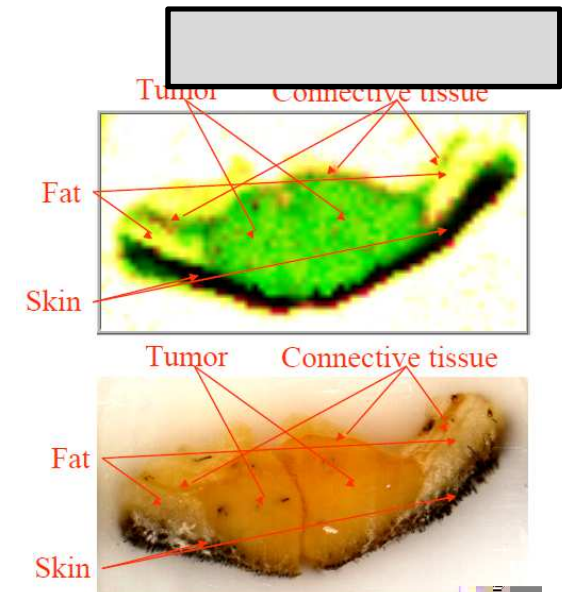


Figure 1



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



Applications of Terahertz

Defense:

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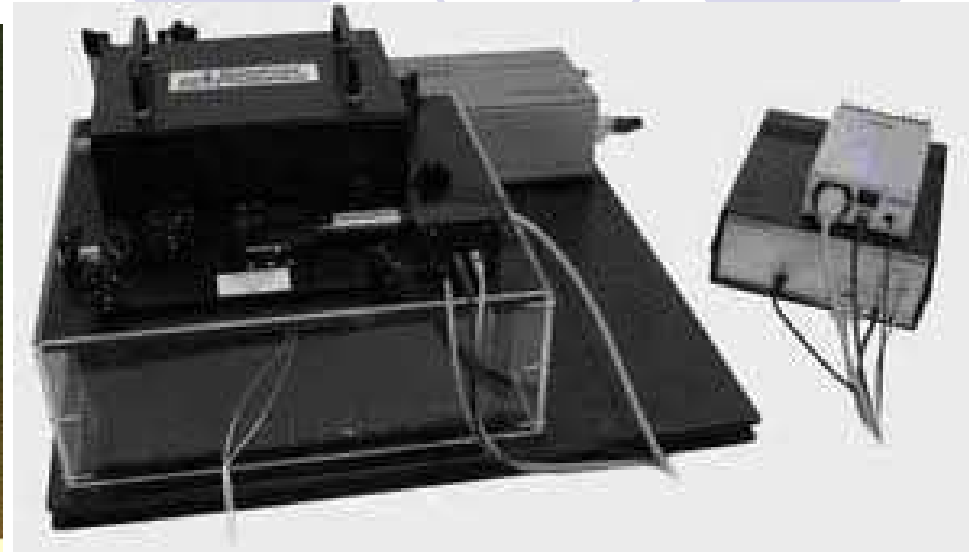
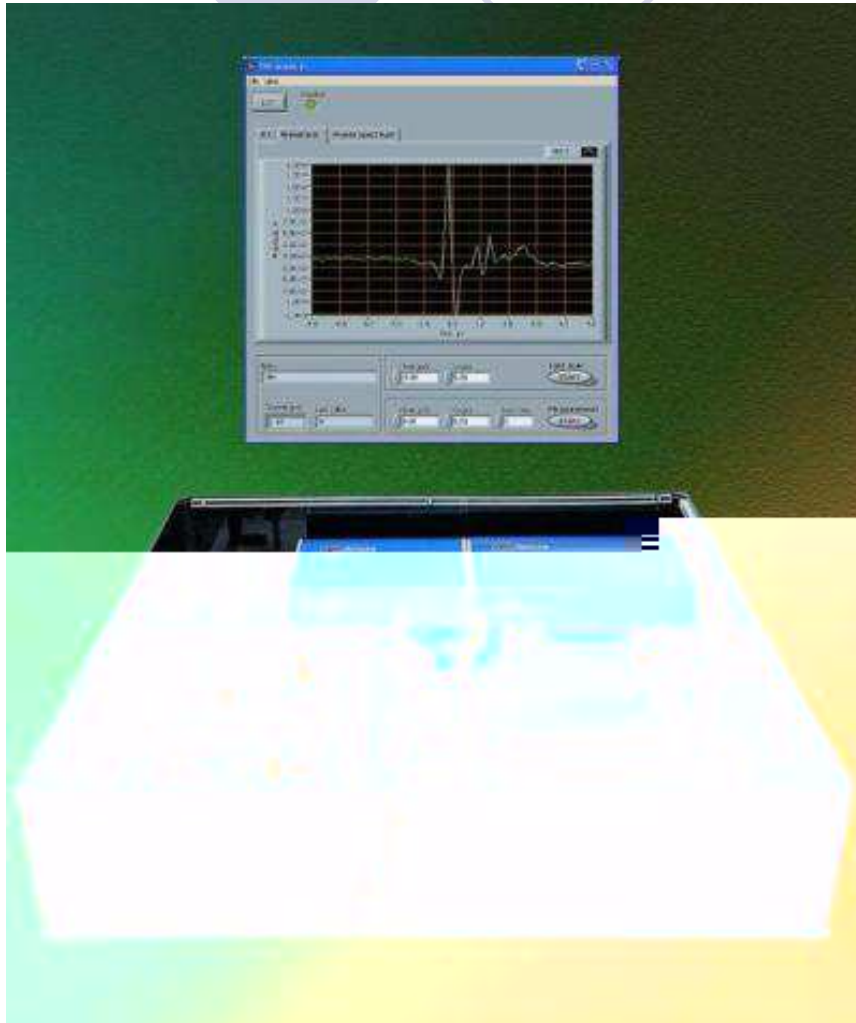
Commercial²

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Research:

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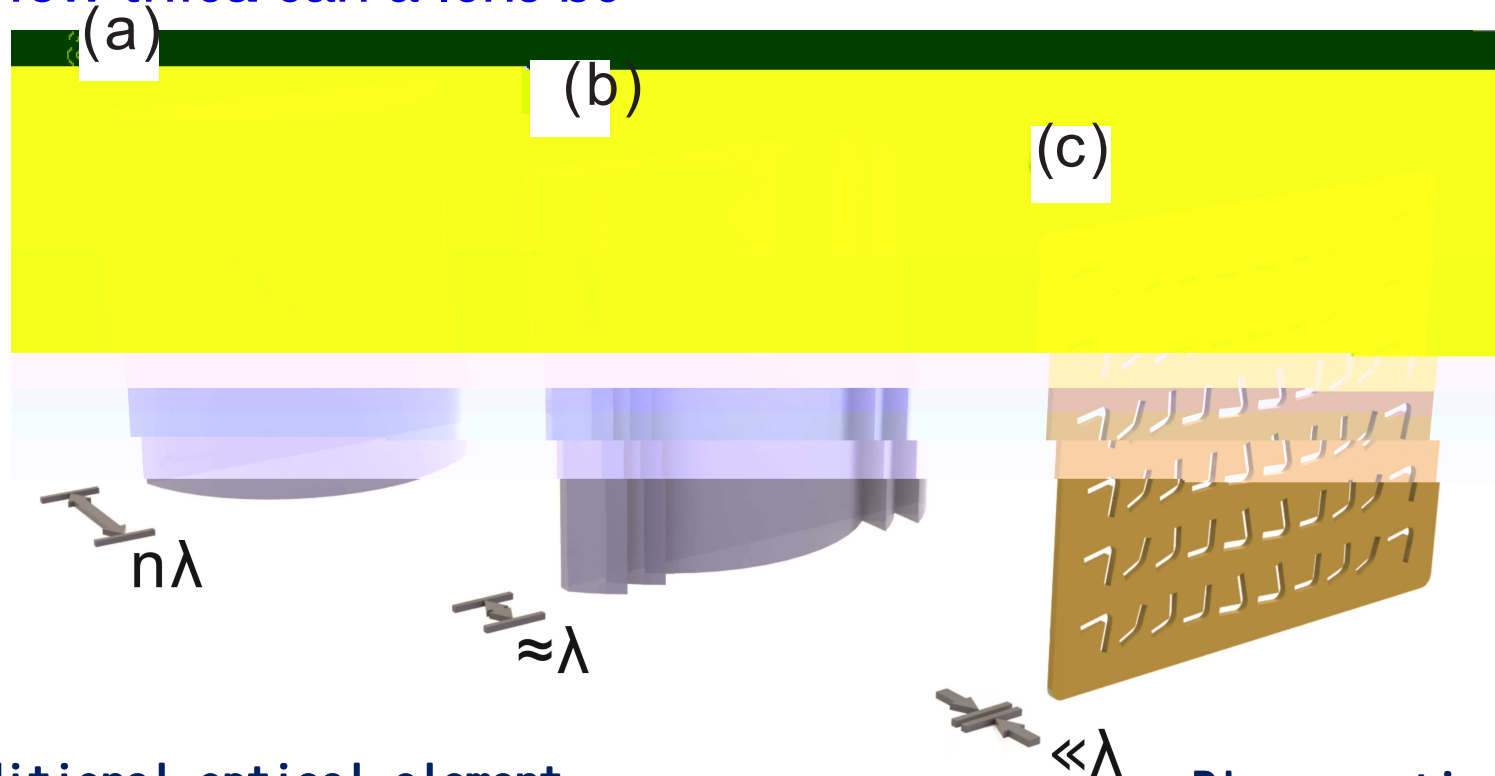
Introduction of Terahertz



**THz system is too huge for
real applications.**

**More flexible method for
wavefront control**

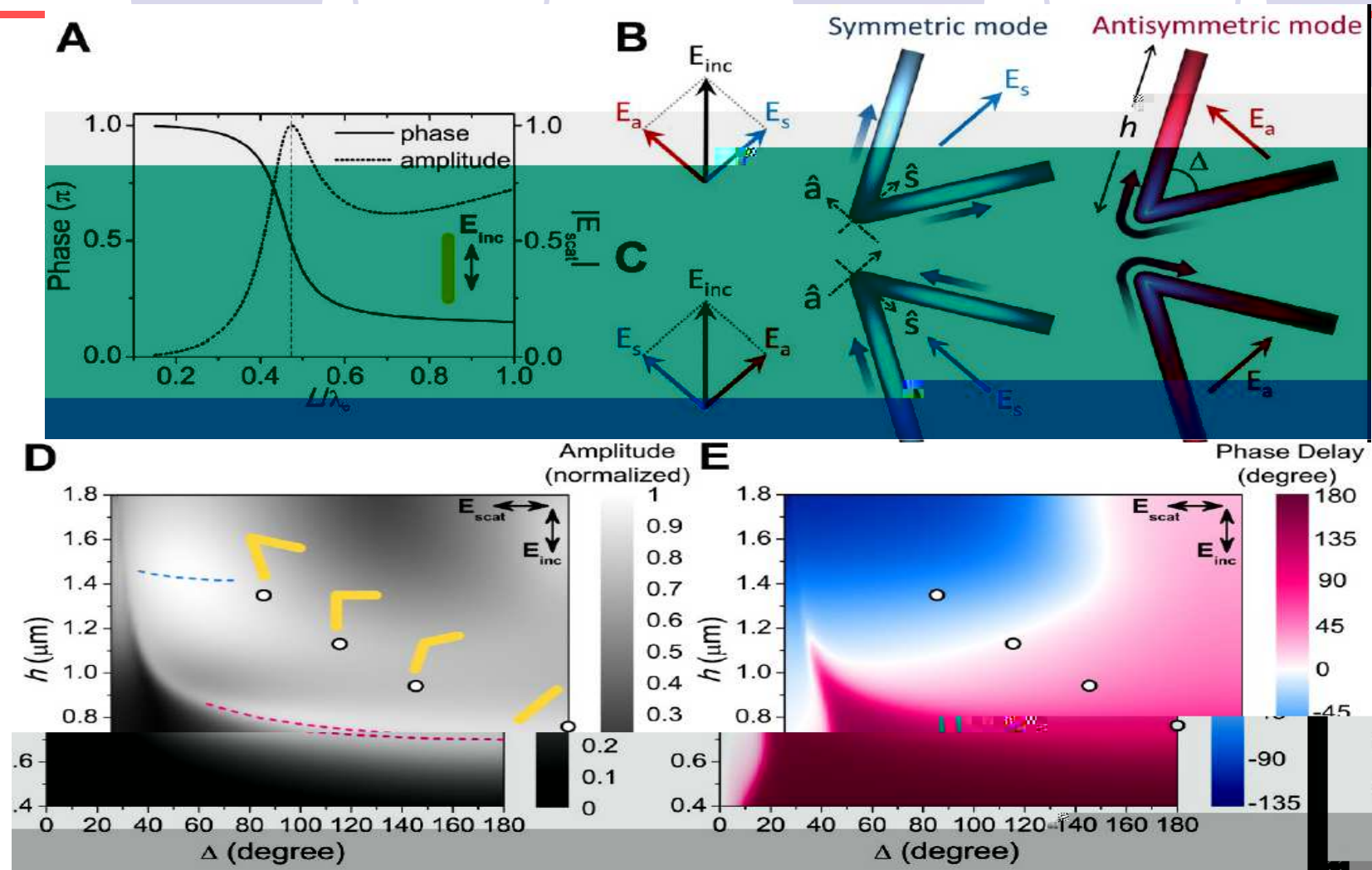
How thick can a lens be?



Traditional optical element

Planar optical element

Diffractive optical element



(hase modulation based on antenna resonance

Huygens' Principle

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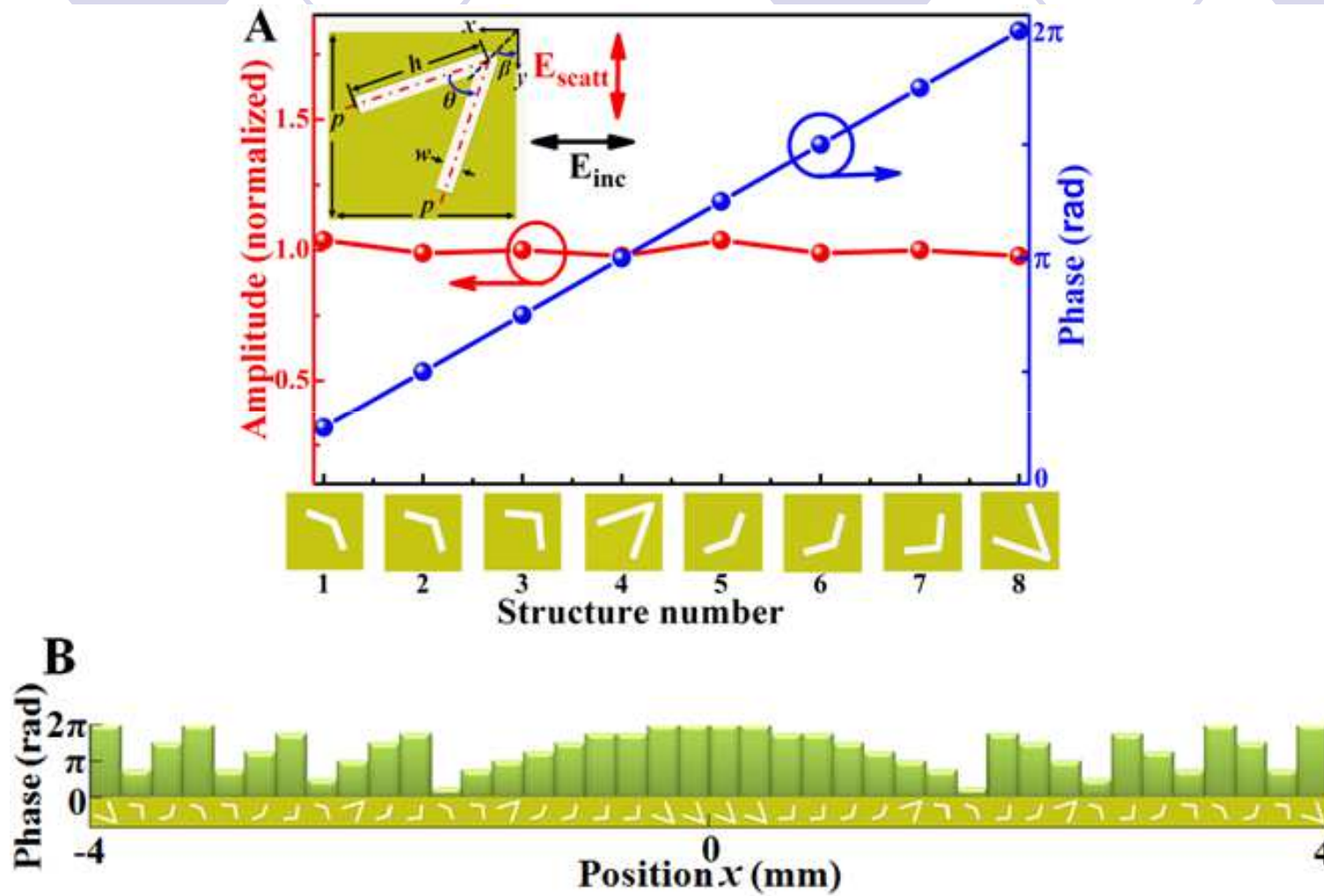
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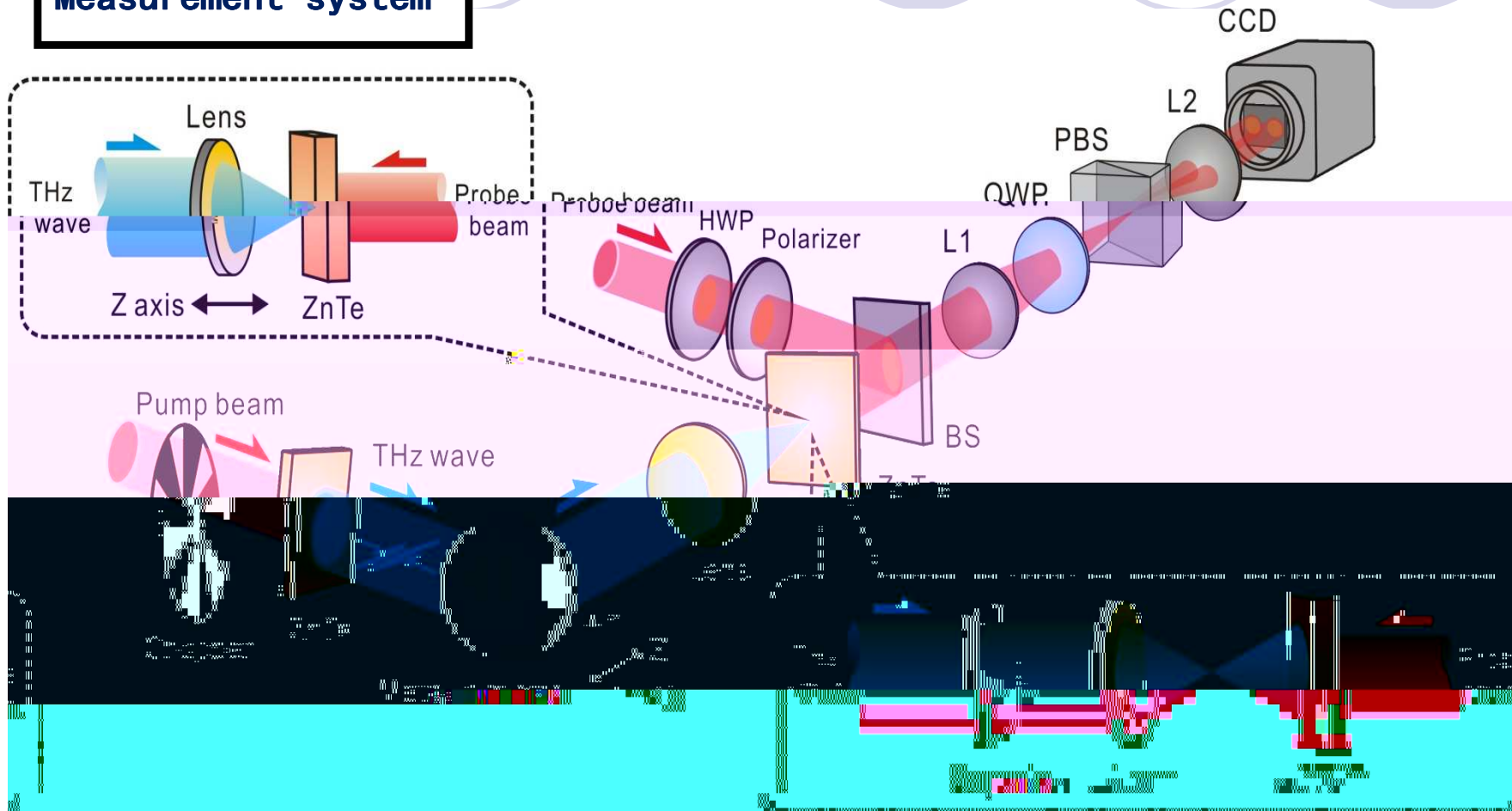


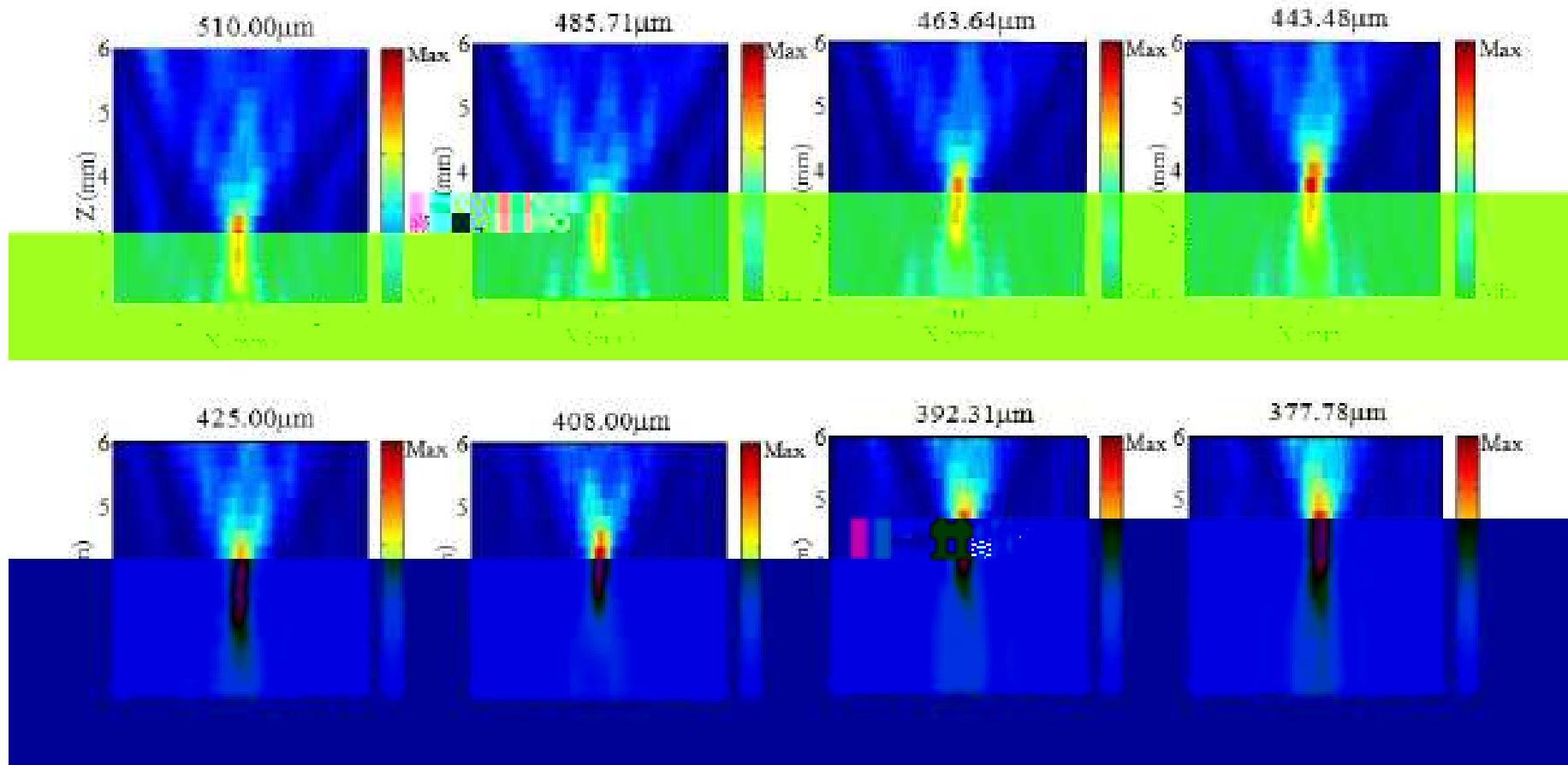


Part of cylindrical lens

Focal length:
4mm@400 μ m

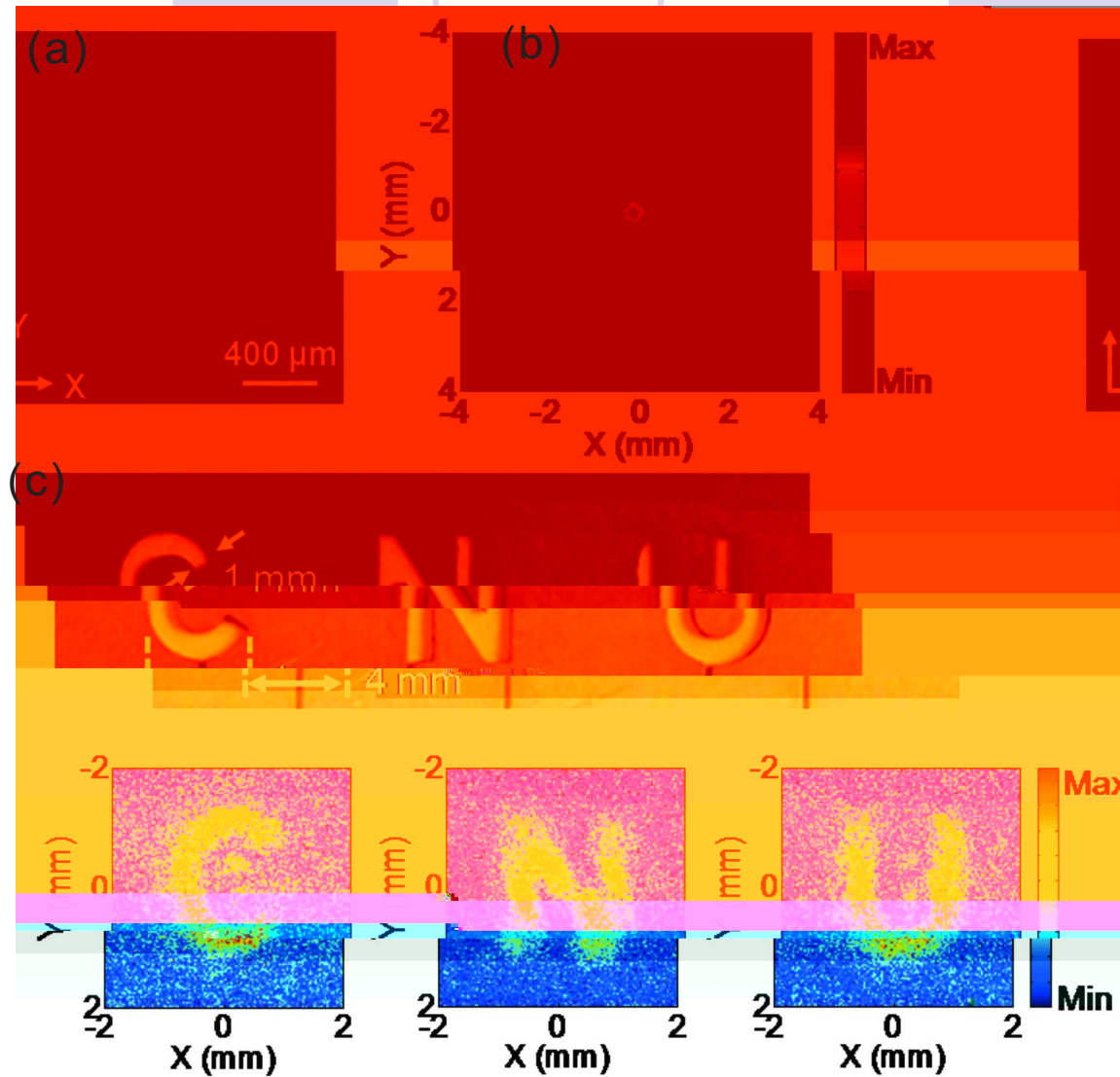
Measurement system





Dispersion of the cylindrical lens

Metasurface based devices



The thickness of the lens
 is only $\lambda/10$ of the
 wavelength

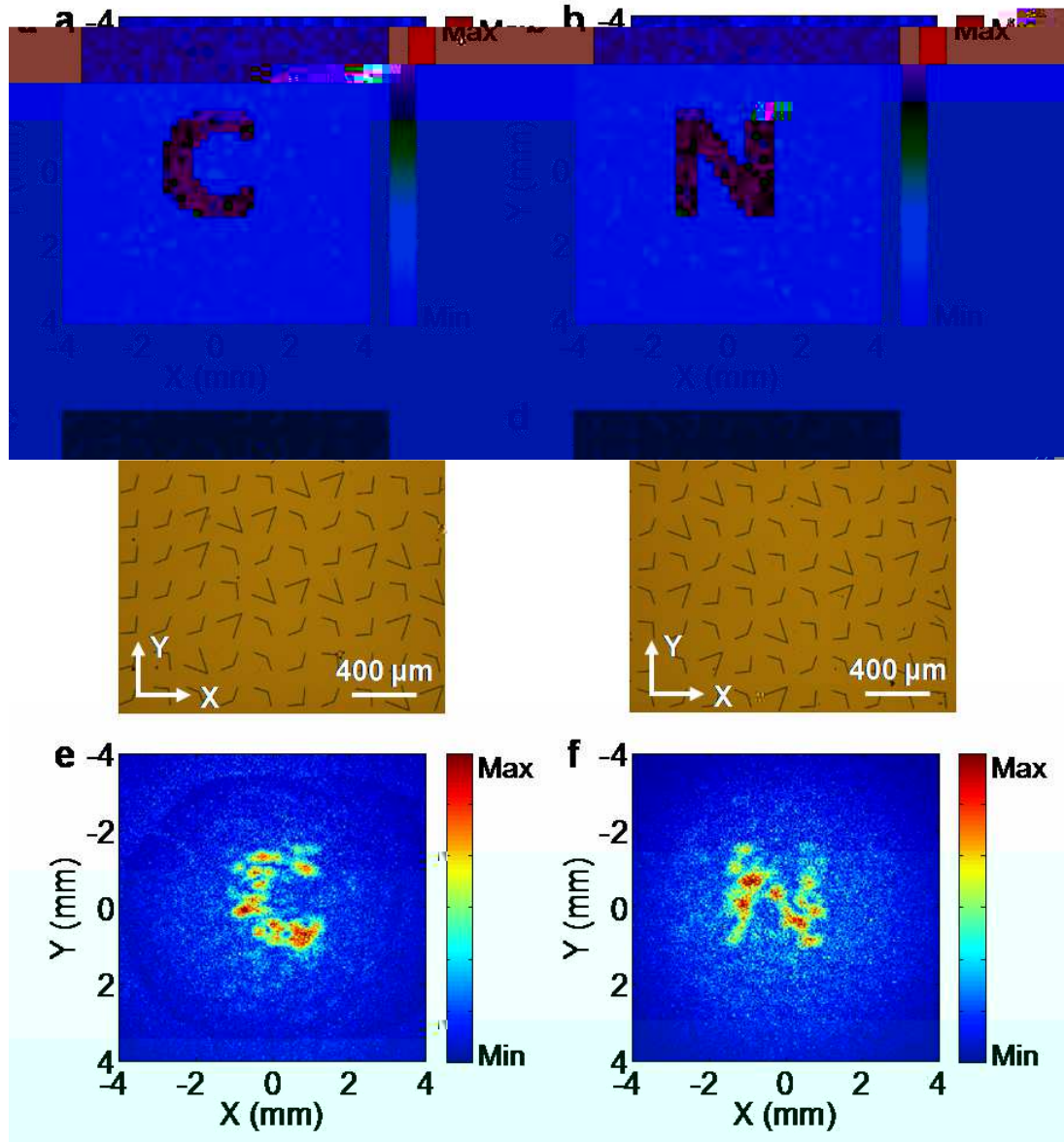
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Metasurface based devices



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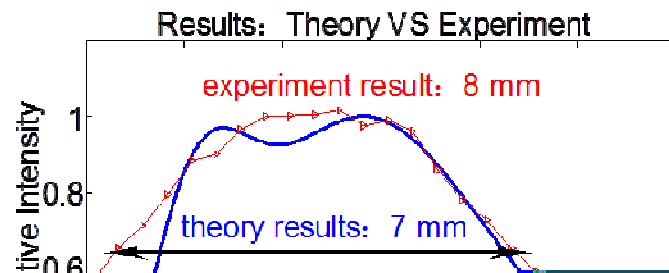
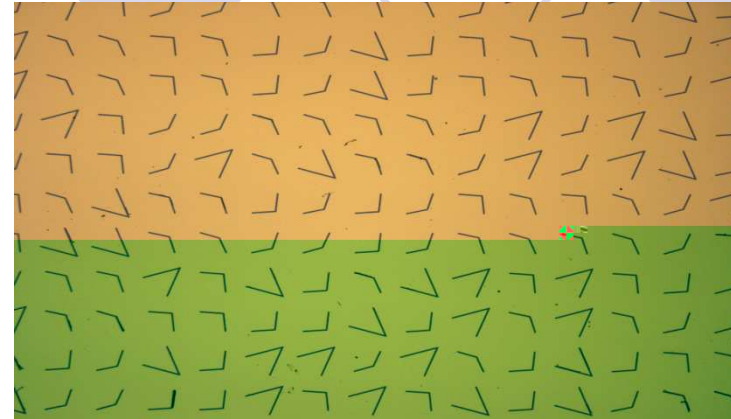
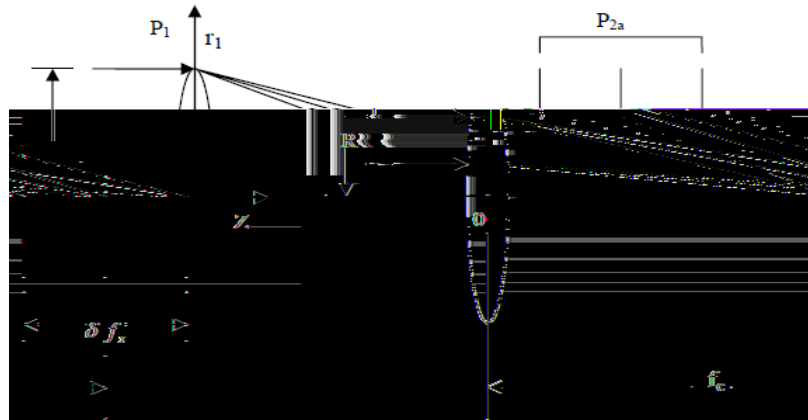
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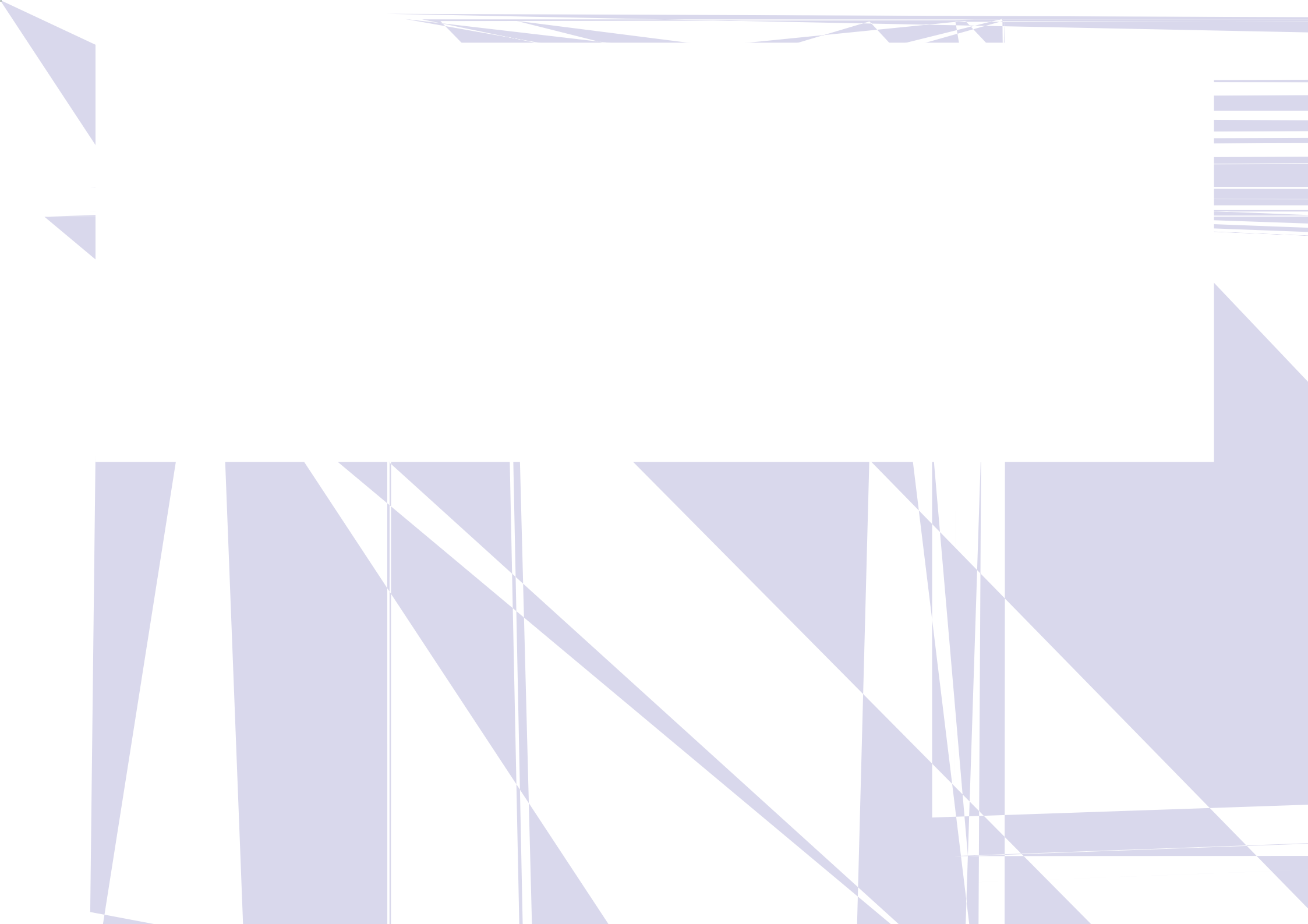
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Metasurface based devices





Active control of THz wavefront

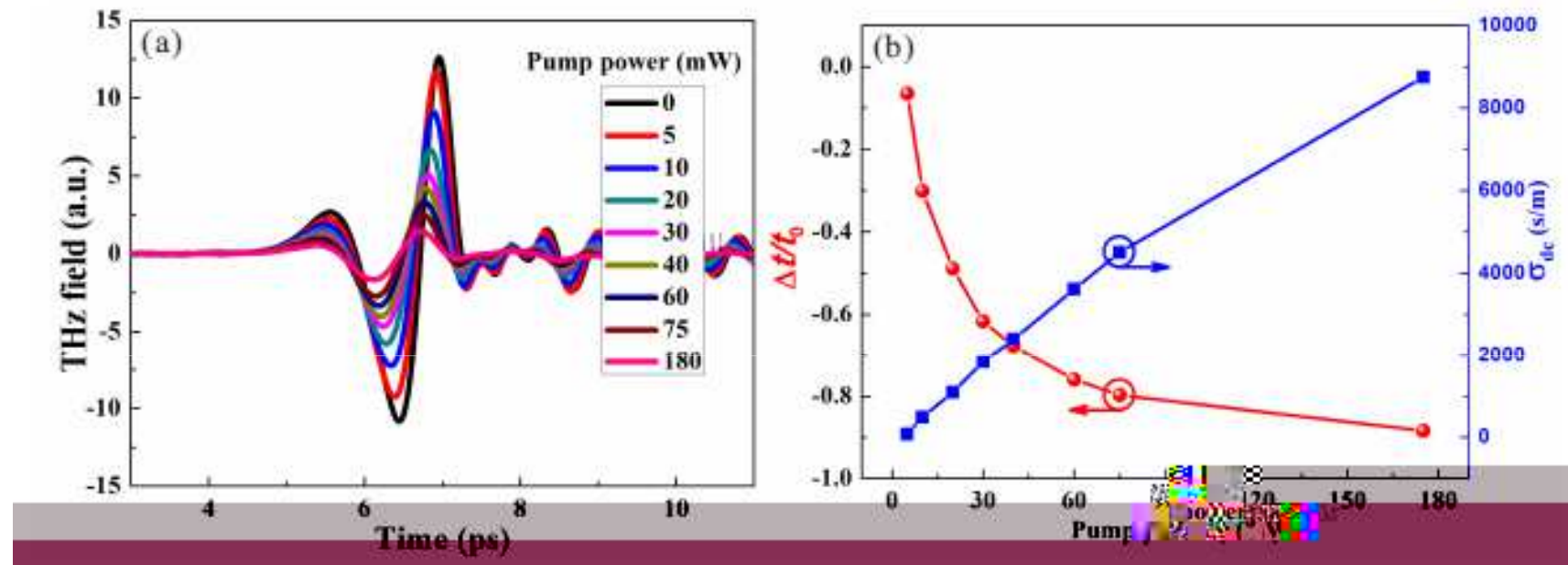
7 Ultrathin planar elements

😊 thin aberration free 8 8

😞 low efficiency function fixed

Active control of THz wavefront

Active control of THz wavefront



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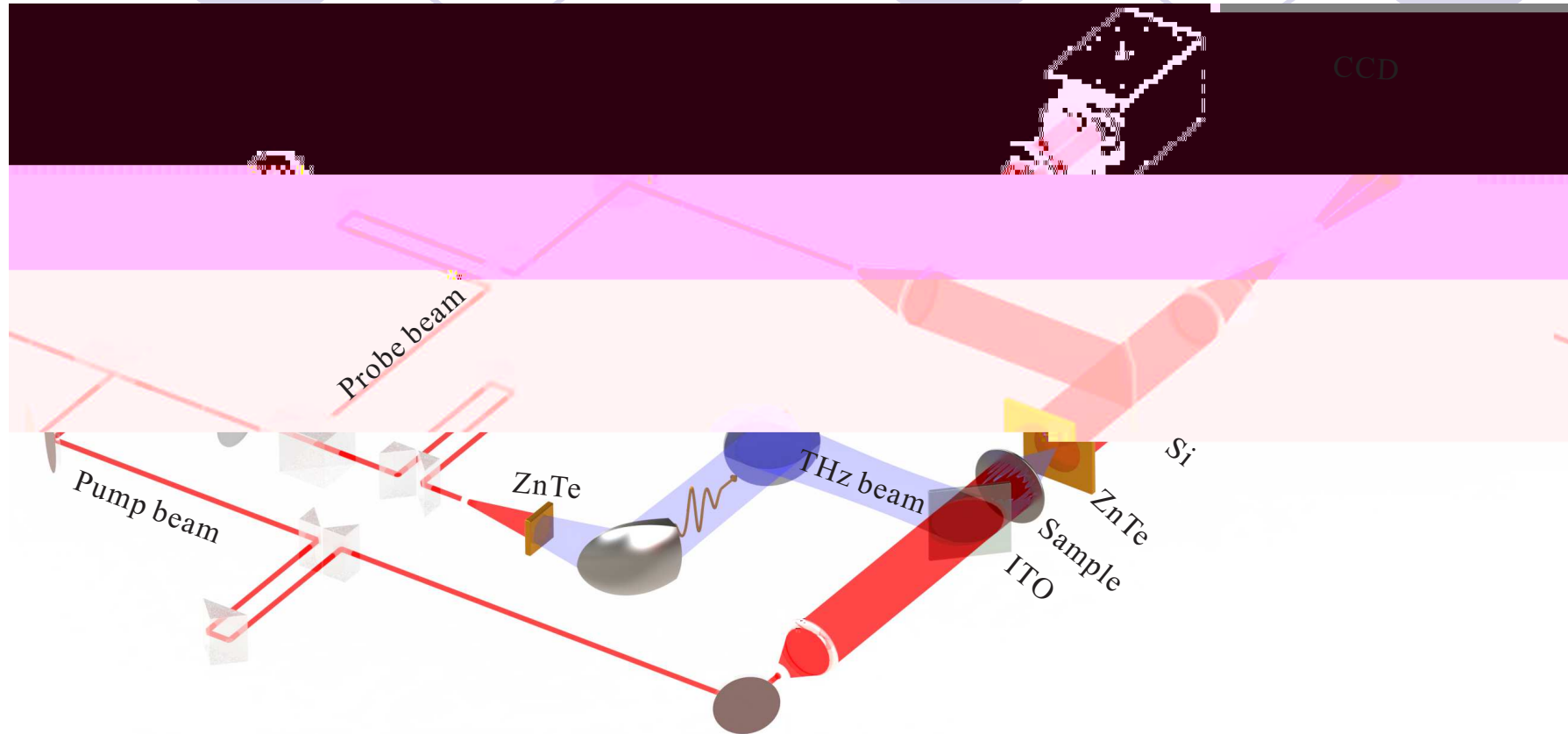
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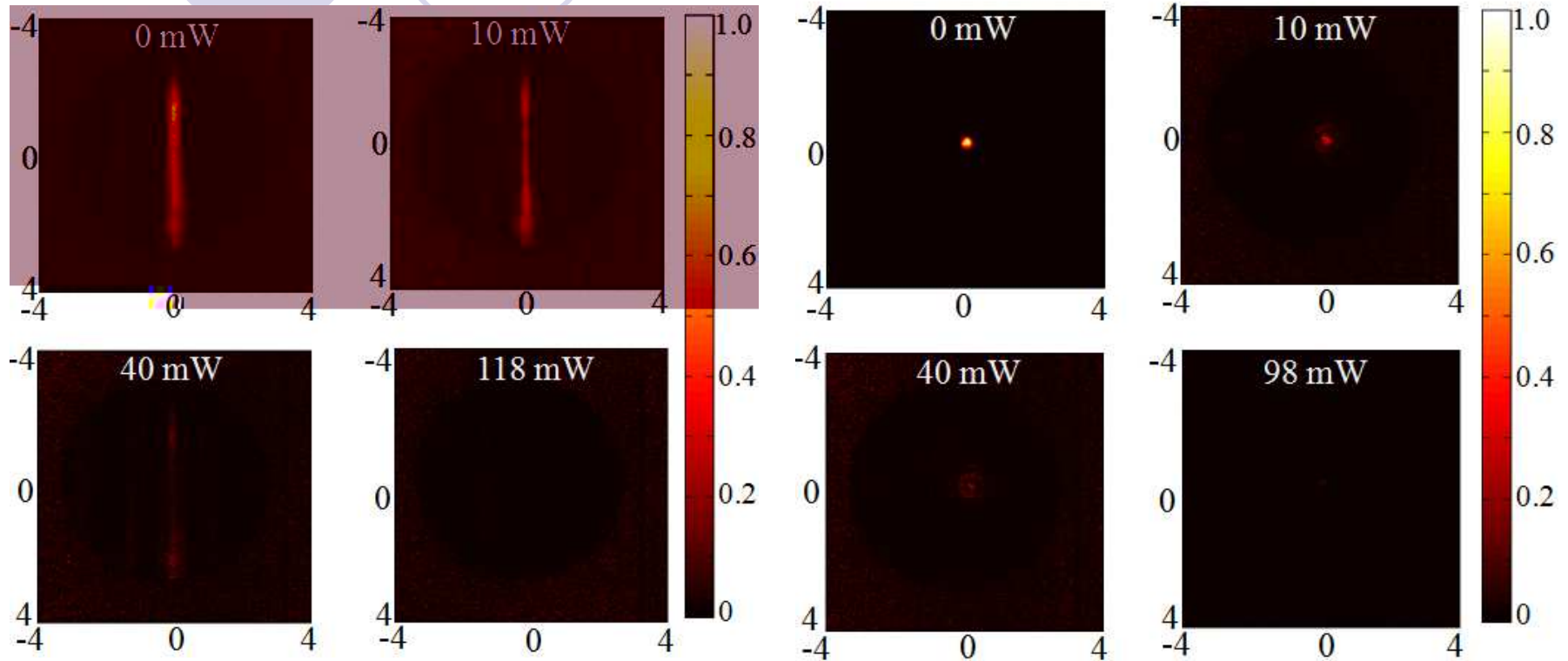
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Active control of THz wavefront

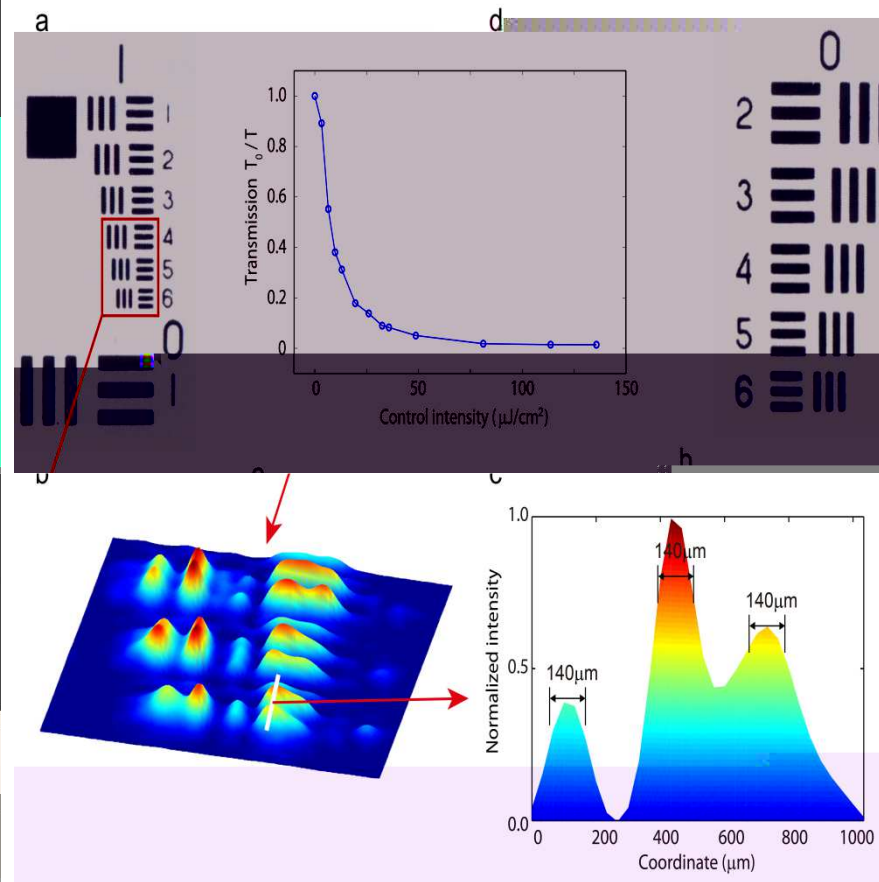
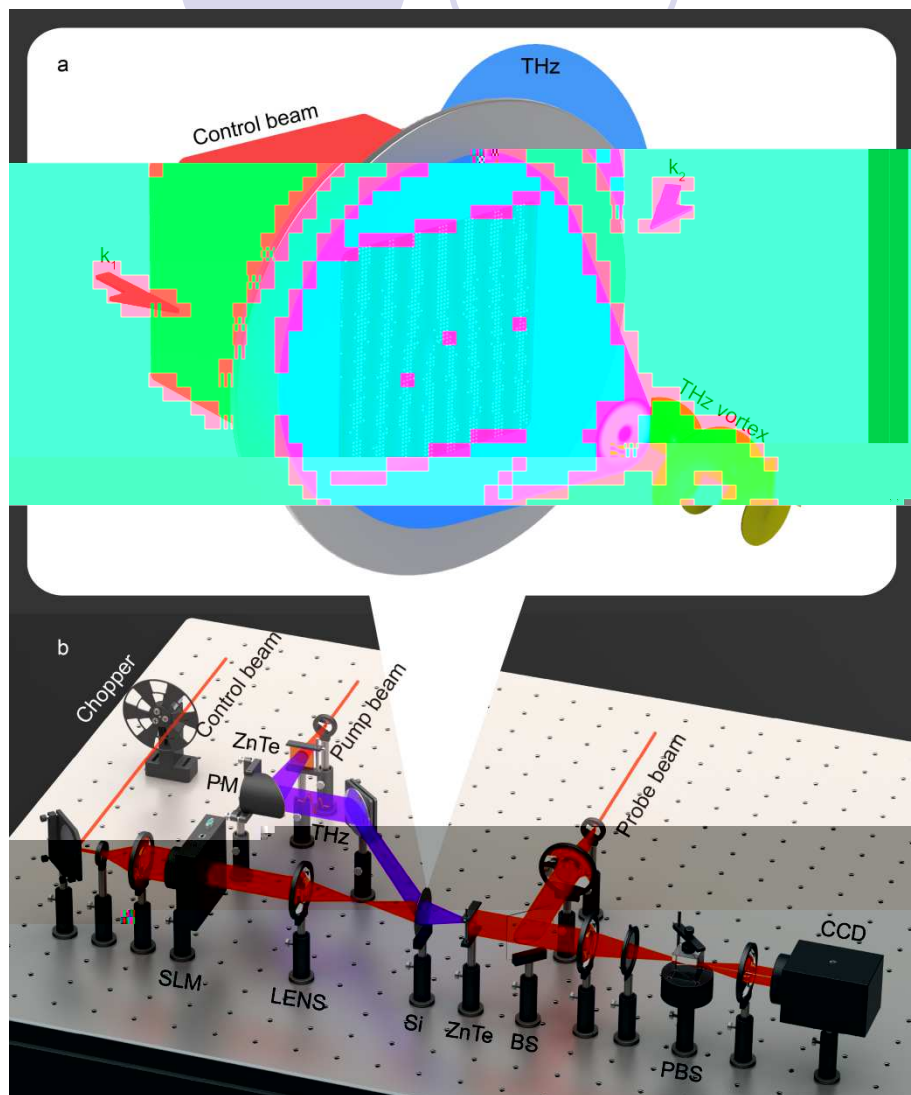


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Active control of THz wavefront



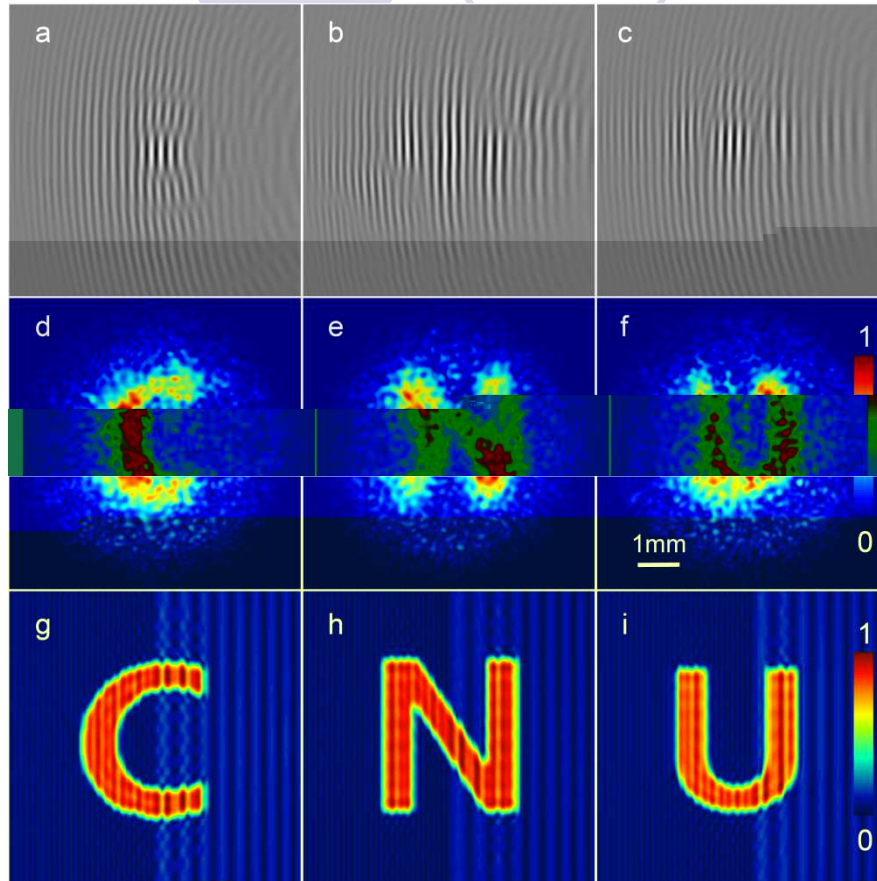
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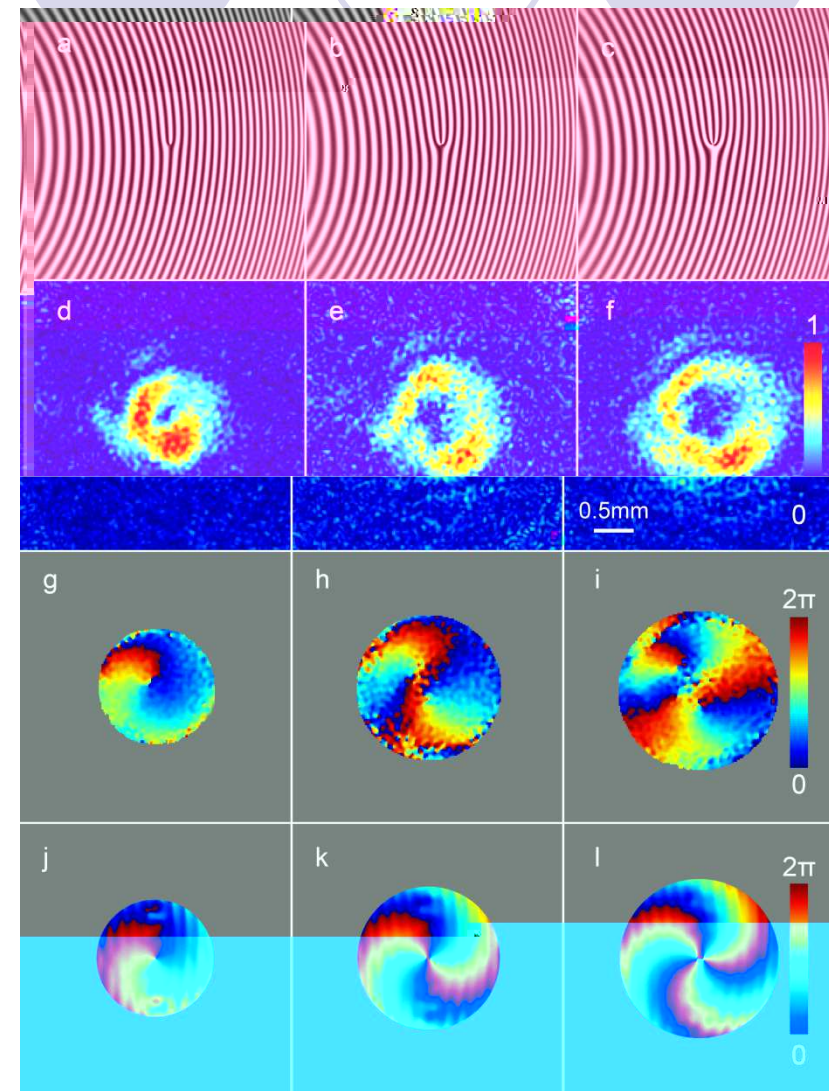
Active control of THz wavefront



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Conclusion:

◆ Ultrathin planar elements

transmission holograms diffractive phase elements 8

◆ Characterization of ultrathin planar elements

Intensity phase polarization wavelength 8

◆ Active control of THz wavefront

Thank you for
your attention!

REVIEW

Planar Photonics with Metasurfaces

Alexander V. Kildishev, Alexandra Boltasseva, Vladimir M. Shalaginov

Metamaterials, or engineered materials with rationally designed, subwavelength-scale building blocks, allow us to control the behavior of physical fields in optical, microwave, radio, acoustic, heat transfer, and other applications with flexibility and performance that are unavailable with naturally available materials. In turn, metasurfaces—planar, ultrathin metamaterials—enhance these capabilities even further. Optical metasurfaces offer the fascinating possibility of controlling light with surface-confined, flat components. In the planar photonics concept, it is the reduced dimensionality of the optical metasurface that enables new physical phenomena and, thus, new functionalities and applications that are distinctly different from those of bulk materials.

Metasurfaces, introduced recently, are a new type of subwavelength-scale structures that have emerged over the past few years with an eye toward the promising future directions in the field.

With the recent advances in silicon and nanofabrication methods, we can now control the flow of light in a way that was not possible before. Metamaterials (MMs) are engineered materials with rationally designed, subwavelength building blocks ("meta-atoms"). MMs allow us to build devices with responses in light, acoustic waves, and heat flows that are unavailable with naturally available materials.

planar photonic devices and, thus, to realize "planar photonics." Metasurfaces enable new physical phenomena that are distinctly different from those observed in their 3D counterparts. Moreover, they are compatible with on-chip waveguide devices, which is of critical importance for their applications in optoelectronics, ultrafast information technologies, microscopy, imaging, and sensing.

(1–3). In the artificial patterns of metasurfaces, the propagation of electromagnetic energy can be defined by the spatial and spectral dispersions of the effective dielectric and magnetic properties.

A metasurface structured on the subwavelength scale in the lateral directions can be deterministic (i.e., periodic and aperiodic) or random. In practice, such a metasurface is represented by a pattern of meta-atoms.

These synthetic structures offer the distinct potential to guide and control the flow of electromagnetic energy in an engineered optical space (2) and serve the drive to a number of applications.

Metasurfaces are a very thin compared with the wavelength of the incident light and is typically deposited on a supporting substrate. The functionality

of metasurfaces is determined with the dimensions of resonant elements and array periods of a magnitude comparable in size to the incident or transmitted free-space wavelength (15).

The importance and power of planar photonics was demonstrated earlier for the specially designed case of planar chiral elements (16–19). The recently discovered generalized Snell's law suggests a way toward ultimate control of light propagation (5). As demonstrated by Ye et al. (6), special metamaterials—metasurfaces—enable phase discrimination for light propagating

parallel to the surface. In this case, the phase of reflected and refracted light, in addition to the incident angle, is also determined by the subwavelength periodicity of the metasurface. This phenomenon has been demonstrated in the near-IR wavelength range (20), where it was also shown that the effect is robust and broadband. With these new approaches, metasurfaces could be used to fully control light propagation, including frequency, phase, polarization, wavevector, and angular momentum (20–22). Metasurface-based optical waveguides (23) enhance the light-matter interaction as well as subwavelength waveguides (24) have recently been demonstrated. In a related experiment, the extremely thin (20 nm) and very small (2 μm in radius) metasurfaces based on Fabry-Pérot complementary nanocavities (V-shaped slots in a dielectric disk) with a periodicity of 25 nm (25) in the visible wavelength range (26) 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).

Metasurface based devices

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).