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Flat Ultrathin Metasurface Parabolic Reflector for THz Applications

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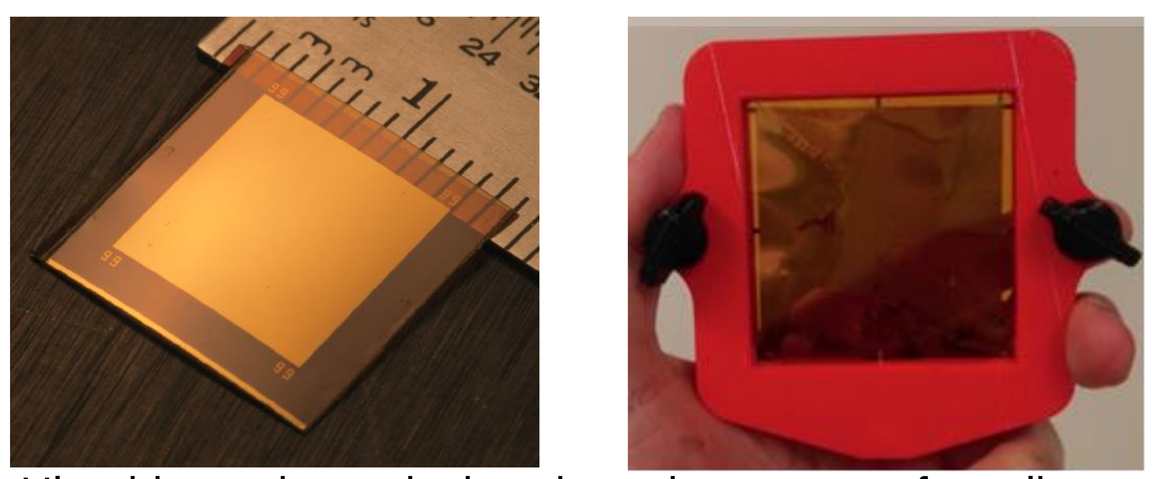
Background and Motivation

The efficient use of terahertz (THz) radiation promises to foster many practical applications including nondestructive spectroscopy, imaging, high-speed communication, biological and chemical sensing. In contrast to the neighboring bands, THz technology is relatively underdeveloped due to the lack of efficient and compact components/devices in this frequency regime. Natural materials has only limited responses at terahertz frequencies, therefore, artificial materials such as metamaterials have been explored for realizing terahertz devices. Metasurfaces are two-dimensional analogue of metamaterials, which enable unconventional control of scattering phase at the material interface by tuning the size and shape of subwavelength resonators. A full 2π phase shift from these artificial materials makes it possible to shape the wavefront of the outgoing light to realize anomalous reflection/refraction, flat lens, quarter wave plate, and other applications.



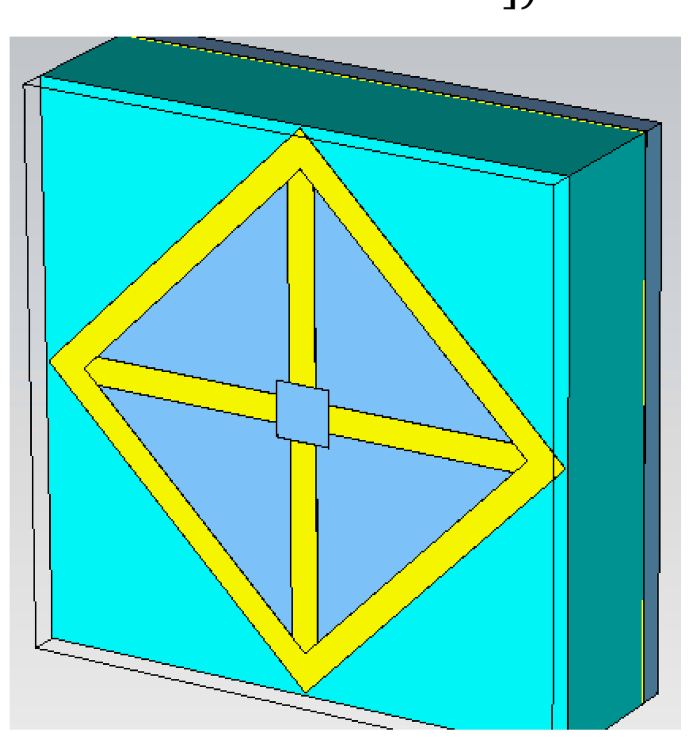
Ultrathin terahertz devices based on metasurface: linear phase conversion (left [1]) and terahertz flat lens (right [2])

Introduction

The goal of this project is to achieve a flat, ultrathin, ultralight, and flexible metasurface-based off-axis parabolic reflector for the terahertz regime.
The phase distribution for a parabolic reflector lying along xy-plane can be written as,

$$\varphi(x,y) = \frac{2\pi}{\lambda}\left\{\sqrt{(x-x_f)^2 + (y-y_f)^2 + {z_f}^2} - z_f\right\}$$

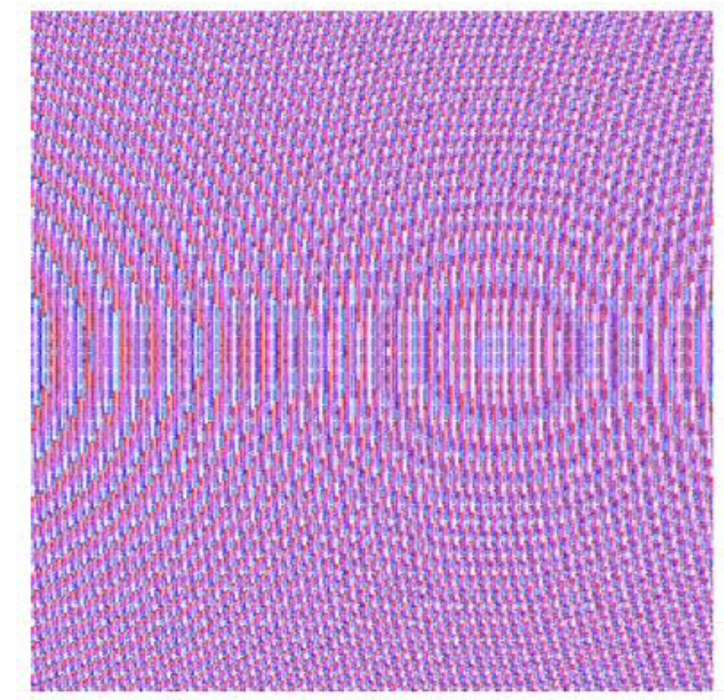
Our metasurface reflector was designed to operate at 0.7 THz, normal incidence with an off-axis angle (θ) of 45° and a focal length (f) of 12.7 cm (5 inch).



The designed unit cell (polarization independent)

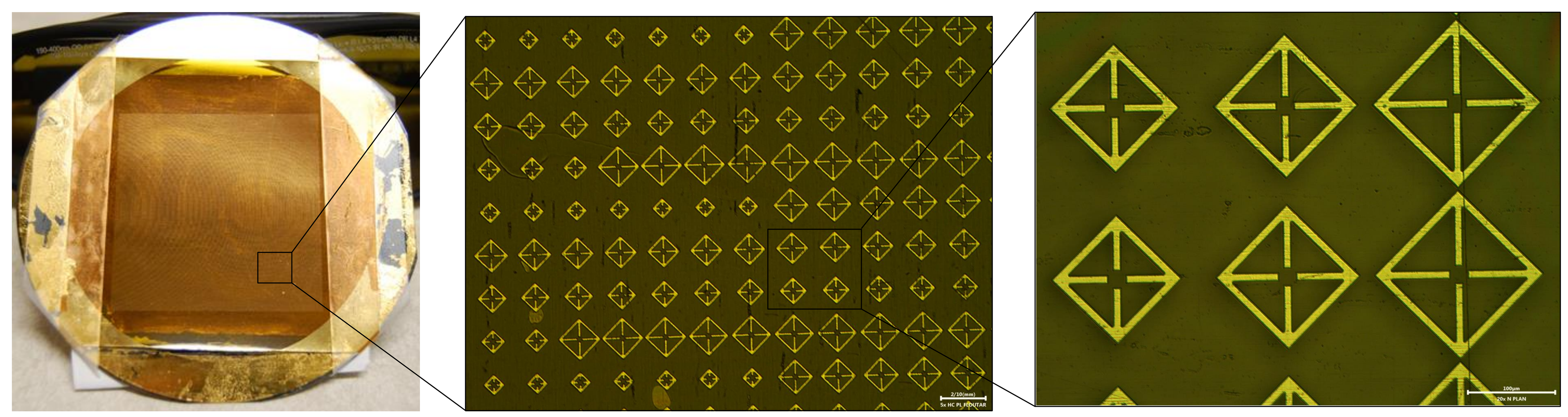
Methods and Results

Using the phase distribution formula, we calculated the phase map for a 2 × 2 inch^2 parabolic with zones having phase increments of 22.5° (as shown below)



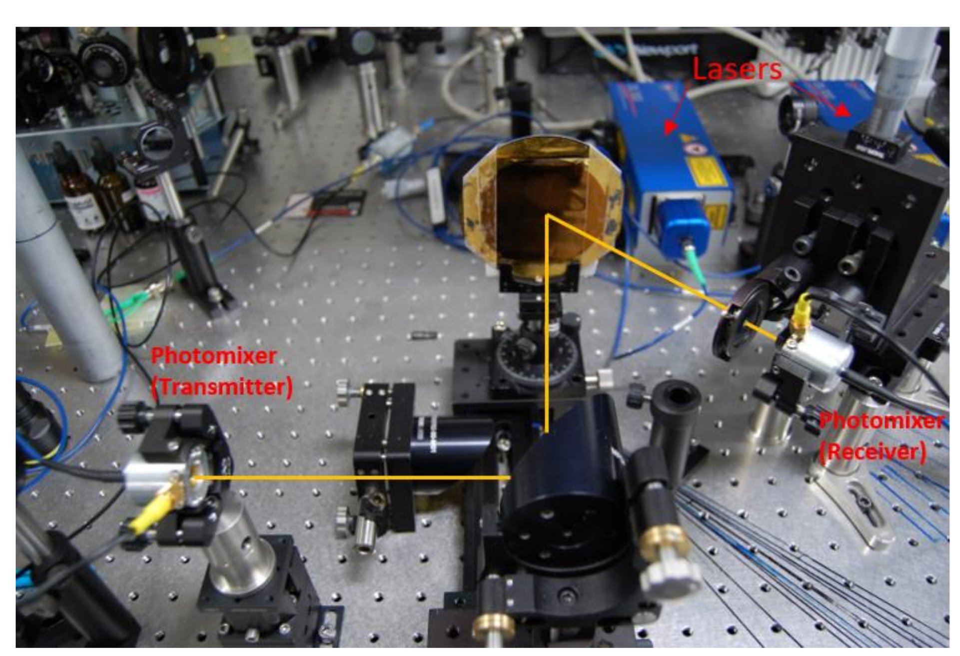
A photolithography mask of this design was designed and fabricated. The metasurface was fabricated on commercially available Kapton film of 50 um thickness. During fabrication the substrate Kapton film was cleaned. We deposited 200 nm gold on top of the substrate using e-beam metal deposition. Standard photo lithography using AZ5214E (positive-tone) was applied to create a protected pattern followed by a chemical etching of gold to create gold resonators.

Another 200nm gold film was deposited on the back side of the substrate to create the metallic ground plane. Finally, the photoresist protection layer was removed using acetone.

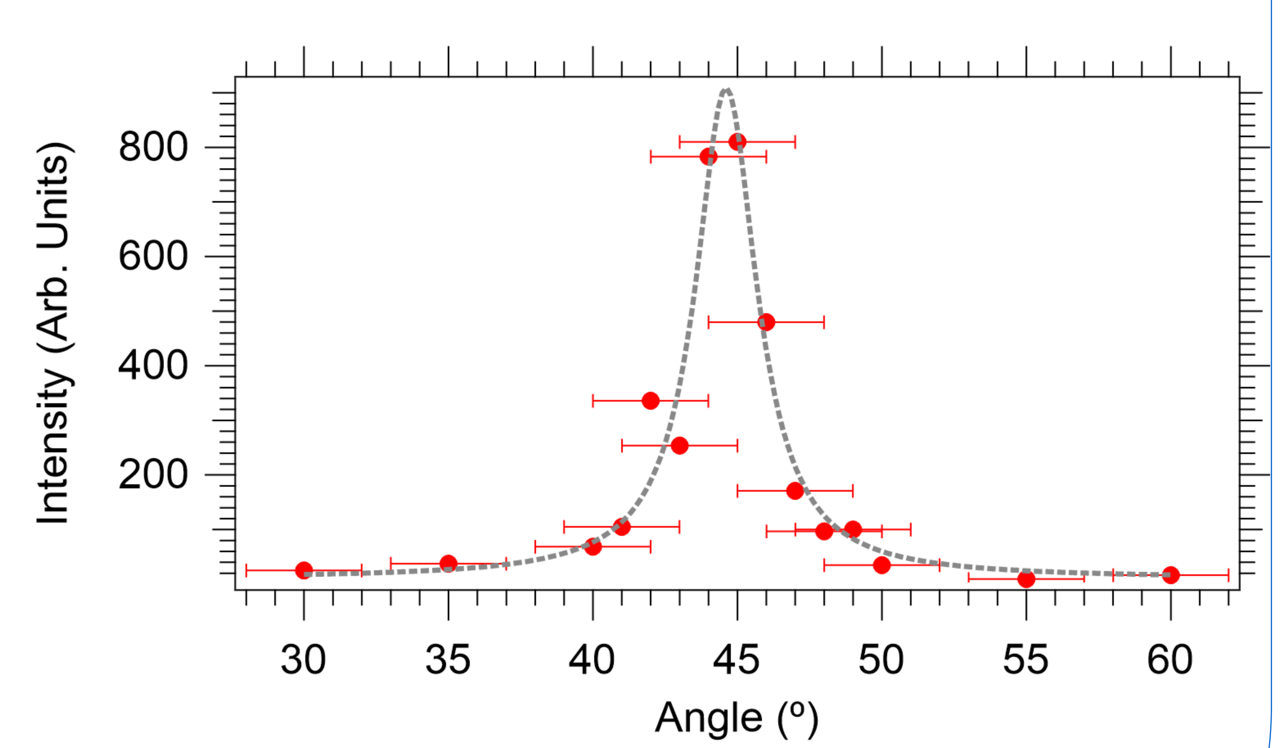


Optical image of the entire reflector mounted on a silicon wafer(left), expanded views of the fabricated gold resonators (middle and right).

The sample was characterized using a continuous wave (CW) terahertz system purchased from Toptica Photonics. The THz output from the photoconductive antenna transmitter is collimated by a traditional off-axis parabolic mirror. The metasurface off-axis parabolic reflector is used to reflect the and focus the THz beam to the terahertz receiver. The reflected power spectrum was measured for angles ranging from 30º to 60º, and frequency ranging from 450-750 GHz.



Experimental setup for sample characterization



Reflected THz beam from the sample at 0.59 THz

Between 40º to 50º, measurements were conducted in 1º increments. The detector position was varied along the off-axis direction and we noticed a sharp roll-off of the detected power beyond a separation of 11 cm between the metasurface and the detector.

Discussion

Using a simple fabrication process, we have demonstrated a flat, ultralight and flexible metasurface-based THz parabolic reflector.

The results show that the metasurface achieves directionality for 45º reflection at 0.590 THz. This is lower than the designed 0.7 THz frequency. This could be due to differences in the thickness and dielectric constant of the commercially available Kapton film, when compared to the design.

Varying the distance of the receiver from the metasurface showed that the peak intensity is achieved at a focal length of f ~ 10.5cm, which is lower than the designed 12.7 cm. However, since these measurements were conducted manually, it will be important to test them again with a more precise, automated system using a rotational stage and optical rail.

Future Work

- Building a precise, fully automated testing system with a rotational stage and optical arm.
- Fabrication and testing of samples at angles other than 45º.
- Measurement of dielectric constant of the commercial Kapton to understand results when compared to simulation.
- Simulation of the entire metasurface (using HFSS) to compare with experimental results.
- Investigation of an active version of this metasurface: Graphene-based electrically tunable metasurface for terahertz parabolic reflection.

References

1. N. Grady *et. al.* Science **340** , 1304 (2013)
2. C. Chang *et. al.* Optics Letters **42**, 1867 (2017)

Acknowledgements

Samples have been fabricated at the CINT Core facility at Sandia National Laboratory.