Dielectric hole lattice for terahertz diffractive optics with high transmission

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***Abstract*—A dielectric hole lattice is proposed for creating diffractive optics in the terahertz range. An array of sub-wavelength air-holes in a dielectric material gives rise to an artificial dielectric, with refractive index depending on hole radius. The design uses low-loss dielectric materials, and exploits a half-wavelength etalon effect to minimise reflection, leading to near-perfect transmission. A potential application is a zone plate to create high gain antennas for use in future terahertz communications links.**

I. Introduction

THE terahertz range has the potential to support high-bandwidth short-range wireless communications, but due to strong atmospheric attenuation, high gain radiators are required [1]. Terahertz radiator gain is commonly boosted using dielectric lenses, however these can have issues including size, weight, and reflection loss.

Planar optics using arrays of phased elements, typically metal resonators, have been demonstrated as an alternative to dielectric lenses for terahertz beam control. However, such structures typically have significant ohmic loss originating from metallic components. Examples include arrays of rectangular patches [2], polarization converters [3], and shaped holes in a metal sheet [4]. In this work, an all-dielectric hole lattice for planar terahertz optics is proposed. Since it is non-resonant, and low-loss dielectrics are used, it has higher bandwidth and lower loss than typical metal resonators. Dielectric hole lattices have previously been demonstrated in the optical [5], and microwave ranges [6], [7].

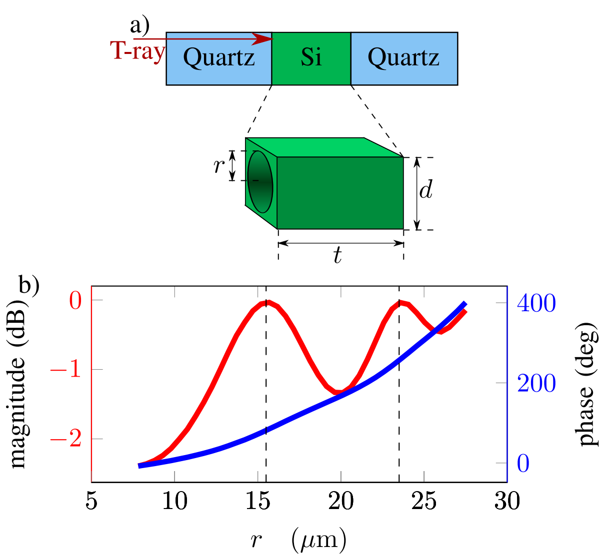

Fig. 1. a) Construction of array element, $d = 60$ μm, and $t = 250$ μm. **b)** Simulated response at 1 THz as a function of hole radius r. Dashed lines denote the Fabry-Pérot maxima, which correspond to an approximate 180° phase difference. The electromagnetics software package HFSS was used to generate these results.

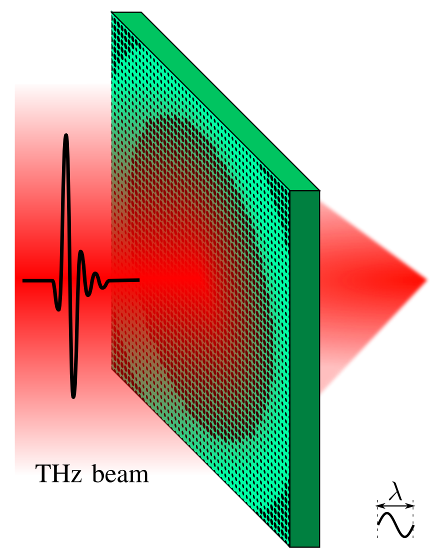

Fig. 2. Diagram of hole lattice zone plate, with air holes shown as black dots.

II. Hole Lattice Array Element

The array element, shown in Figure 1.a), is a block of high resistivity silicon with an air-hole in the centre, housed in quartz for structural integrity. At subwavelength scales, the air and silicon behave as an artificial dielectric, with effective refractive index depending on hole radius. Therefore, transmission phase response may be engineered with careful selection of hole radius, as shown in Figure 1.b). Additionally, since the parameter giving rise to the desired phase response is the optical length, one may increase the achievable phase range by simply increasing the thickness of the patterned layer.

In a manner not unlike in a Fabry-Pérot etalon [8], reflection loss is cancelled out when the silicon layer thickness is a multiple of a half-wavelength, giving near-perfect transmission. The in-medium wavelength can be changed by altering the effective refractive index through alteration of hole radius to satisfy this condition. Two cases of near-perfect transmission for different phase responses have been indicated in Figure 1.b). These Fabry-Pérot fringes are the key advantage of the hole lattice zone plate over simpler cut-groove zone plates.

III. Diffractive optics

If the thickness of the silicon layer is selected such that two Fabry-Pérot maxima are phased 180° apart, as in Figure 1, one may construct phased diffractive optics with near-perfect transmission. Terahertz zone plates may be constructed in this way, in order to boost terahertz antenna gain. Such zone plates have concentric zones of alternating large and small hole radii, as shown in Figure 2. The response of a hole lattice zone plate, with operating frequency of 1 THz and focal length 5 mm, was simulated using the commercially available electromagnetics software package CST, and results are given in Figure 3. These simulations suggest that, although the focal length changes with frequency, the zone plate successfully focuses a beam over a frequency range from 0.5 THz to at least 1.75 THz; a bandwidth of over 1.25 THz. Note that higher frequencies could not be simulated as computational resources were limited.

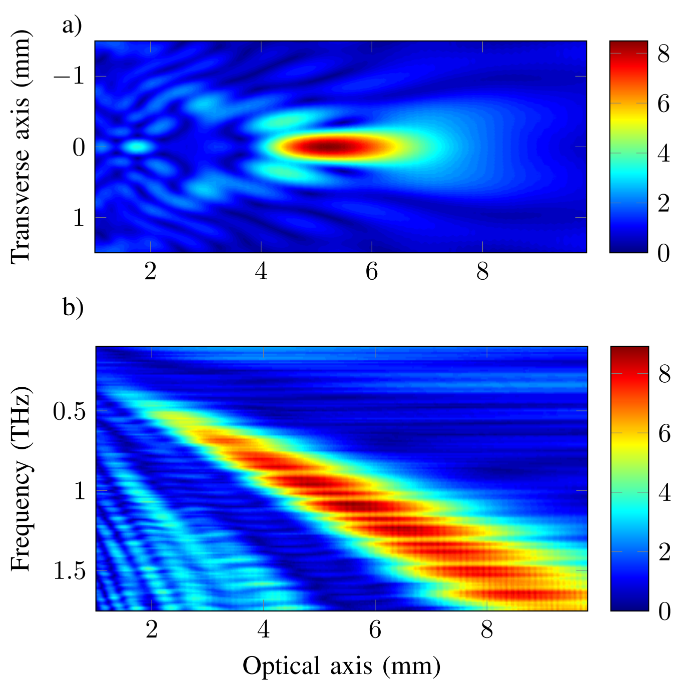

Fig. 3. a) Simulated near field response of hole lattice zone plate. **b)** Broadband performance of hole lattice zone plate, showing electric field magnitude distribution along the optical axis. Electric field magnitude is given in linear scale, normalised against the magnitude of the input plane wave.

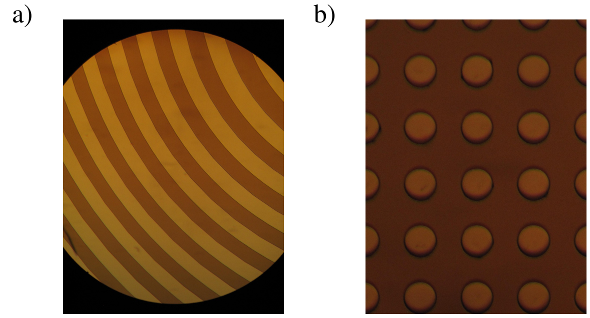

Fig. 4. a) Photographs of patterned silicon, showing a section of the concentric zone structure. **b)** Zoom in, showing individual holes

IV. Fabrication

One limitation in the fabrication of hole structures is the achievable depth-to-diameter aspect ratio of the holes. In order to effectively double the aspect ratio, the silicon layer is processed in two halves, with each having half the thickness of the overall layer. They are then bonded together face-to-face.

Fabrication of a hole lattice zone plate is in progress, and the process uses conventional micro-fabrication techniques involving photolithography and deep reactive ion etching (DRIE). Ultra-thin silicon wafers are diced into quadrants, bonded with SU8 photoresist to fused quartz, and laminated. Thereafter the wafers are patterned and etched. Fabrication progress photographs are given in Figure 4.

V. Conclusion

In this work we present the design and simulation of an all-dielectric diffractive zone plate for planar phase control using a dielectric hole lattice. By exploiting Fabry-Pérot fringes, a zone plate with near-perfect transmission has been designed, and fabrication of this zone plate is presently underway.

References

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