Direct Observation of Terahertz Wavefront Converted by a Metal Hole Array

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***Abstract*—Wavefront conversion by a metal hole array (MHA) has been experimentally observed via a visualization of the continuous-wave terahertz (THz) field. At the resonant frequency of the MHA, curved wavefront of the THz wave (125 GHz) emitted from a horn antenna has been converted to a plane wavefront. Near field visualization at the MHA surface (transmission side) revealed that the field re-emitted from the MHA oscillates in phase. We experimentally confirmed that the MHA acts as a planar THz wave collimator.**

I. Introduction

TERAHERTZ (THz) waves, which cover the frequency range from 100 GHz to 10 THz, have gained much attention in recent years for their application in the ultrafast wireless communications, spectroscopy, non-destructive imaging, etc. For practical applications, flat and thin optical components, such as lenses and antennas have been highly desired. It has been reported that a thin metal plate with a periodic subwavelength hole array which is called a metal hole array (MHA) exhibits extraordinary optical transmission (EOT) [1]. Cao et al. demonstrated that the MHA exhibits not only the EOT, but also a beam-collimating effect in the microwave region [2].

Recently, we proposed and demonstrated a visualization of the spatial-temporal evolution of continuous THz waves based on photonics technology [3]. In order to study physical dynamics and diagnose the devices, visualization of the field evolution of the continuous waves with high phase and spatial resolution is considered to be a powerful approach. In this paper, we demonstrate by the near-field visualization that the MHA acts as an wavefront converter in the THz region.

II. Experiments and Results

Figure 1 shows experimental setup [3]. Two free-running 1.55 μm laser diodes (LDs) were used as optical sources. The difference frequency of the LDs was set to be 125 GHz. An electrooptic (EO) frequency shifter (FS) was used to shift the frequency of the LD1 by 500 kHz for self-heterodyne detection [4]. A uni-travelling-carrier photodiode (UTC-PD) was used as an optical-to-electrical (O/E) converter. We used an F-band horn-antenna (radius=13 mm) as the THz wave radiator. The radiated power was 650 μW. For detection, a ZnTe EO crystal (1 mm$\times$1 mm$\times$1 mm) mounted on a polarization maintaining fiber (PMF) was used as an EO sensor. The diameter of the collimated probe beam in the EO crystal was 0.2 mm, which limits the ultimate spatial resolution. The THz field (RF signal)

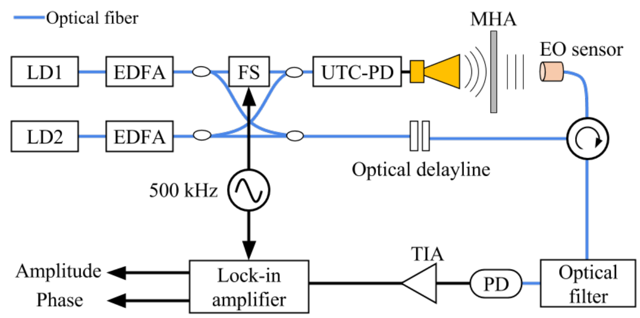

Fig. 1. Experimental setup. LD: laser diode, EDFA: erbium doped fiber amplifier, FS: frequency shifter, UTC-PD: uni-traveling-carrier photodiode, MHA: metal hole array, PD: photodiode, TIA: transimpedance amplifier.

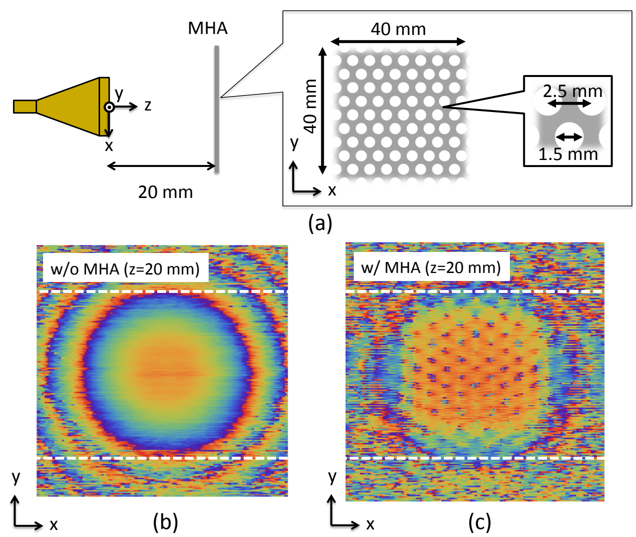

Fig. 2. (a) Schematic of a MHA placed at the distance of 20 mm from the horn antenna. Measured phase distribution in the xy plane (b) without and (c) with the MHA.

interacted with the optical LO (probe beam) in the EO crystal. The probe beam was reflected by the high-reflective-coated surface of the EO crystal. The reflected probe beam that passed through the optical filter was detected with the photodiode (PD). The amplitude and phase of the IF signal were measured with a lock-in amplifier.

Figure 2(a) shows a triangular MHA fabricated on an aluminum plate with a thickness of 1 mm. The diameter of holes is 1.5 mm. The lattice constant of the array is 2.5 mm.

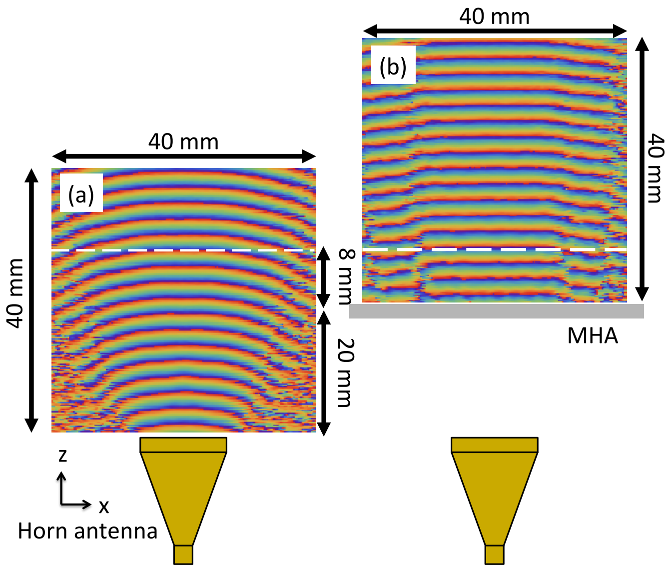

Fig. 3. Phase distribution in xz plane (a) before and (b) after placing the MHA at z=20 mm.

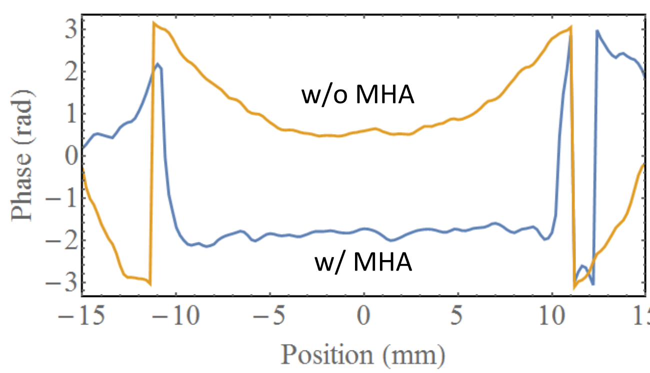

Fig. 4. One-dimensional phase distribution of the THz wave in the x direction at z=28 mm.

This MHA shows extraordinary transmission at the frequency of about 125 GHz, which is confirmed by FDTD simulation. The MHA was placed at the distance of 20 mm (z= 20 mm) from the surface of the horn antenna. Figures 2(b) and (c) show the spatial phase distribution in the xy plane at z=20 mm before and after placing the MHA, respectively. The phase of the field re-emmited from the MHA oscillates in phase, whereas there is a spatially varying phase delay in Fig. 2(b) because of the spherical phase front.

Figures 3 (a) and (b) show the measured spatial phase distribution in the xz plane before and after placing the MHA, respectively. The THz wave emitted from the horn antenna has a curved wavefront as shown in Fig. 3 (a). The in-phase oscillation at the surface of the MHA shown in Fig. 2(c) makes the wavefront planar as shown in Fig. 3(b). Figure 4 shows one-dimensional phase distribution in the x direction at z=28 mm. It is clearly shown that the spherical wavefront of the THz wave emitted from the horn antenna is converted to planer wavefront by the MHA.

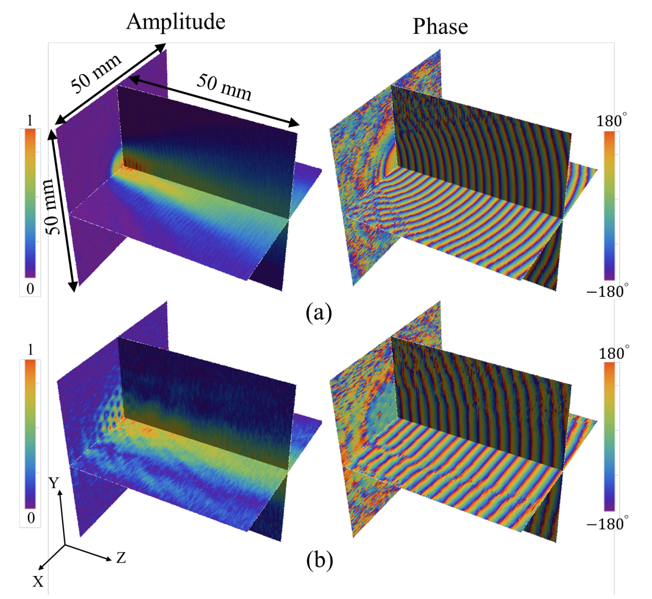

Fig. 5. Three-dimensional field distribution of the THz wave. (a) Emitted from the horn antenna and (b) re-emitted from the MHA.

Figures 5 (a) and (b) show three-dimensional field distribution of the THz wave emitted from the horn antenna and re-emitted from the MHA, respectively. The amplitude data were normalized to their maximum values in each plane. The MHA makes the wave front planar, thus it acts as a THz wave collimator as shown in the amplitude distribution.

III. Conclusion

We demonstrated direct observation of the wavefront conversion made by a MHA. The MHA can be used as a planar THz wave collimator at its resonant frequency.

Acknowledgment

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References

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