Coherent Absorption of Terahertz Pulses by a Checkerboard Metasurface

Y. Urade*, Y. Nakata†, T. Nakanishi*, and M. Kitano*
*Department of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Japan
Email: urade@giga.kuee.kyoto-u.ac.jp
†Center for Energy and Environmental Science, Shinshu University, 4-17-1 Wakasato, Nagano 380-8553, Japan

***Abstract*—We experimentally demonstrate coherent perfect absorption of terahertz pulses by a self-complementary checkerboard-like metasurface. Under symmetrical illumination of terahertz pulses, the metasurface absorbs most of the incident energy below its diffraction frequency.**

I. Introduction

When two counter-propagating waves coherently illuminate a medium with a specific amount of dissipation, the incident radiation can be perfectly absorbed in the medium due to destructive wave interference (see Fig. 1). This system is called coherent perfect absorber (CPA) and initially introduced as the time-reversed process of laser [1]. It has also been shown that CPA can be achieved by a lossy thin film and that such a CPA operates in a broad bandwidth [2]. Although experimental demonstrations of CPAs have been reported in optical regime [3] and microwave [4], there is no report in terahertz frequencies.

Recently, we have theoretically shown that self-complementary checkerboard-like metasurfaces (artificially structured surfaces) serve as CPAs [5]. Self-complementary metasurfaces are invariant under an interchange of their metallic parts and non-metallic parts. The CPAs based on self-complementary metasurfaces can operate in a broad bandwidth, and therefore they can absorb single-cycle pulses, which are often used in terahertz time-domain spectroscopy. In addition, the size of their absorptive area can be made much smaller than the wavelength of the incident electromagnetic waves. In this paper, we experimentally demonstrate a CPA using self-complementary metasurfaces in the terahertz regime.

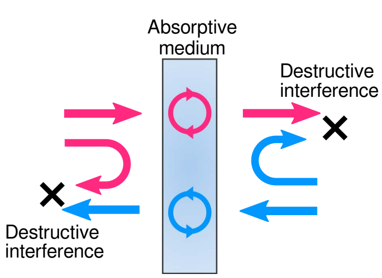

Fig. 1. A schematic picture of CPAs.

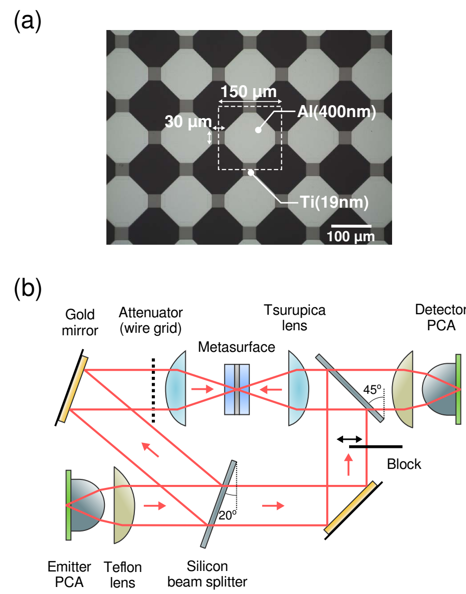

Fig. 2. (a) A photomicrograph of the self-complementary metasurface. (b) A schematic of the experimental setup.

II. Theory

Here, we consider a single-layer metasurface illuminated by two counter-propagating waves being in phase. We assume that polarization conversion and diffraction do not occur. In this case, the condition for CPA is written by

$$\tilde{t} = -\tilde{r} = \frac{1}{2}, \tag{1}$$

where $\tilde{t}$ and $\tilde{r}$ are, respectively, the amplitude transmission and reflection coefficients of the metasurface. This condition is frequency-independently satisfied for self-complementary metasurfaces [5]. Therefore, the energy of the incident waves can be perfectly absorbed by the self-complementary checkerboard-like metasurface below its diffraction frequency.

III. Experiment and Result

A. *Experimental setup*

A self-complementary metasurface with a checkerboard-like geometry was fabricated on a c-cut sapphire substrate by the standard photolithography and lift-off technique, as shown in Fig. 2(a). The gaps between the square aluminum (Al) patches are bridged by resistive titanium (Ti) pads with the appropriate thickness to satisfy self-complementarity. These Ti patches absorb the incident radiation, and, in principle, their size can be made much smaller. The details of the fabrication process are shown in Ref. [6].

Figure 2(b) shows a schematic picture of the experimental setup. Linearly polarized terahertz pulses emitted from the photoconductive antenna (PCA) were divided into two paths by the high-resistivity silicon beamsplitter. A wire-grid polarizer was used in order to attenuate the intensity of one of the two paths and equalize it to that of the other path. Then, the two beams were focused on the metasurface in opposite directions. The optical path lengths of the two paths were adjusted so that the two pulses reach the metasurface at the same time. We performed measurements for two cases: the metasurface is illuminated from (i) the single side (one of the two paths is blocked by aluminum foils) and from (ii) the both sides symmetrically. During the measurements, the metasurface layer was sandwiched between its substrate and another c-cut sapphire plate, which is necessary for symmetrical illumination and self-complementarity [6].

B. Result and discussion

Figure 3 shows the electric fields measured at the detector PCA in the two cases. We can confirm that the transmitted signal is clearly small in the case of the symmetrical illumination due to destructive wave interference.

We estimate the absorption A by the following equation:

$$A = 1 - \frac{\int_{\nu_1}^{\nu_2} |\tilde{E}_{\rm (ii)}(\nu)|^2 {\rm d}\nu}{\int_{\nu_1}^{\nu_2} |\tilde{E}_{\rm (i)}(\nu)|^2 / |\tilde{t}(\nu)|^2 {\rm d}\nu}, \tag{2}$$

where $\nu_1 = 0.1\,\mathrm{THz}$, $\nu_2 = 0.65\,\mathrm{THz}$, and $\tilde{E}(\nu)$ represents the Fourier transforms of the electric fields in each case. The upper bound ν_2 is set to the lowest diffraction frequency of the metasurface. For simplicity, we assume the transmission coefficient $\tilde{t}(\nu) = 1/2$. From the experimental result, we have $A = 0.991$.

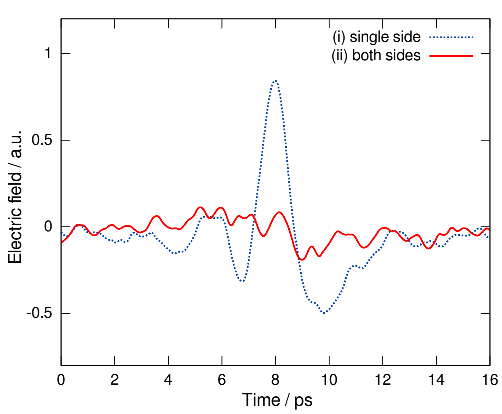

Fig. 3. The measured temporal waveforms of the terahertz electric fields.

IV. Conclusion

We observed that the self-complementary checkerboard-like metasurface works as a nearly perfect absorber when illuminated by two counter-propagating terahertz pulses simultaneously.

Acknowledgment

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