Spectral and Polarization Characteristics of Terahertz Radiation from Metaatom-loaded Photoconductive Antennas

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Photoconductive antennas (PCAs), which are excited by lasers, are important devices for emission and detection of terahertz radiation. Various types of PCAs such as dipole, bowtie, spiral etc. have been developed for controlling spectrum and enhancing efficiency. It has been demonstrated by O'Hara *et al*. [1] that loading split-ring resonators (SRRs) to the PCAs is effective to enhance the efficiency at specific frequencies. We have investigated the terahertz radiation characteristics from dipole-type PCA loaded with metaatoms. In this report, the SRRs are located with various configurations and the spectrum and polarization characteristics of radiation are investigated precisely.

The PCAs were fabricated by super-fine ink-jet (SIJ) printing technology on semi-insulating GaAs substrates [2,3]. The SIJ printer has the ability to draw metallic lines with 2 μm width. We used silver nanopaste (Harima Chemicals, Inc.) for printing. The simple dipole-type PCA and SRR and closed-ring resonator (CRR) loaded dipole PCA were fabricated as shown in Fig. 1. We fabricated two types of the SRR-loaded PCAs: the PCA with the SRR located so as to keep the mirror symmetry of the PCA (D-SRR1) and that which breaks the mirror symmetry (D-SRR2). Their radiation characteristics including polarization ones were measured by the terahertz time-domain spectroscopy (THz-TDS).

Figures 2 and 3(a) shows the time-domain waveforms and emission spectra of the terahertz radiation from the samples, respectively. The emission spectrum of the D-SRR1 shows the resonant peak at 0.4 THz, which is the resonant frequency of the SRR. The spectra of the D-SRR2 and PCA loaded with the CRR (D-CRR) do not show such a peak and are rather similar to the spectrum of the simple dipole-type PCA. Figures 3(b) and (c) indicate the ellipticity and polarization angle of the radiation, respectively. The polarization becomes elliptic at around 0.4 THz for the D-SRR1 although those for the D-SRR2, D-CRR, and

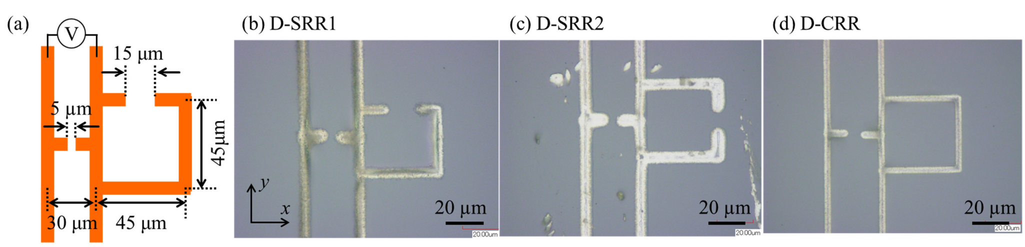

Fig. 1 (a) Schematic of the dipole antenna with the SRR and (b) - (d) microscopic photographs of the samples: Line width and the thickness of the substrates are 2 μm and 350 μm, respectively. The antenna patterns were formed with silver nanopaste (Harima Chemicals, Inc.) on semi-insulating gallium arsenide substrates.

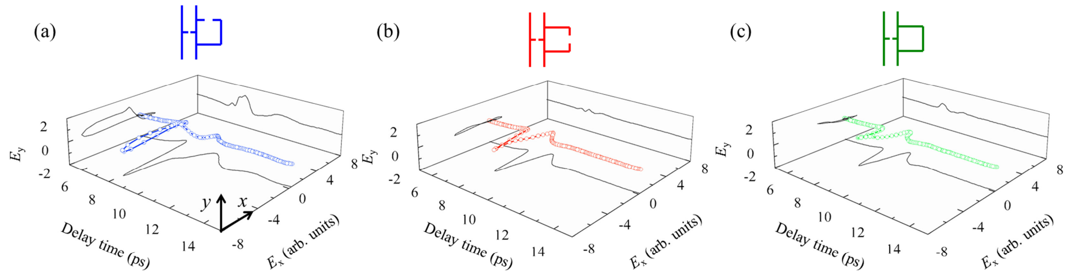

Fig. 2 Time evolution of the polarization of the electric fields radiated from the samples.

simple dipole antenna are linear at all frequencies as shown in Figs. 3 (b) and (c) (The spectrum of the simple dipole-type PCA is not displayed here). The strong modification of the emission spectrum and polarization of the D-SRR1 from that of the simple dipole-type PCA is explained by the resonant excitation of the *LC* resonance mode of the SRR. In the D-SRR1, the electric field generated by exciting the gap of the dipole antenna with femtosecond laser pulses excites the *LC* resonance mode of the SRR. The *LC* resonance can be excited in the D-SRR1 but cannot in the D-SRR2 because of the difference of the symmetry [3]. This mechanism explains the large difference of the emission spectra and polarization for the D-SRR1 and D-SRR2. The present result demonstrates that the spectrum and polarization of the radiation can be controlled by loading the metaatoms to the PCAs.

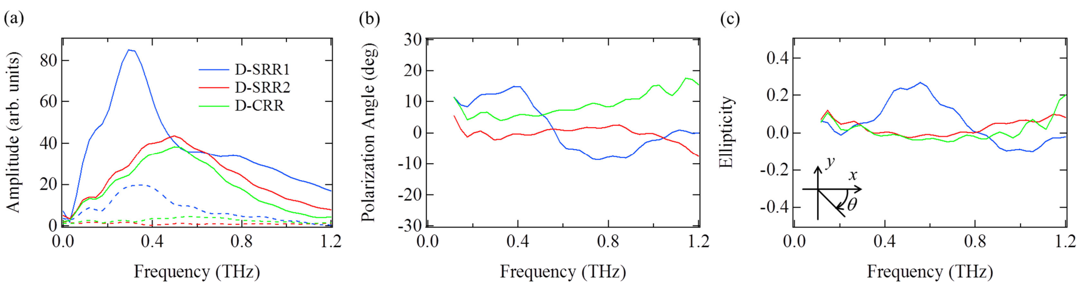

Fig. 3 (a) Amplitude, (b) ellipticity, and (c) polarization angle spectra of the terahertz radiation. The solid and dash lines in (a) indicate the polarization components parallel to the *x*- and *y*-axes, respectively.

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