Fabrication and Characterization of Terahertz Metamaterials

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Terahertz technology has developed greatly in recent years. In the THz region, structured metals such as wire grids and frequency selective surfaces (FSS) have been used traditionally as optical devices. Since the optical devices have not been developed well in the THz region compared to other electromagnetic frequency regions, it is of great importance to develop optical devices with various functions using structured materials such as metamaterials.

At the end of the last century, the extraordinary optical transmission (EOT) was found for metal hole arrays (MHA) by T. W. Ebbesen et al. [1]. We are interested in this phenomenon in the THz region and investigated various types of MHAs and found several new phenomena. We found that the linearly polarized incident THz waves become elliptic after transmitting through the trigonal array of metallic holes when the incident angle is slightly tilted from the normal [2]. This phenomenon is called the geometrical birefringence [3] and mediated by the spoof surface plasmon polariton (spoof SPP). The double layer MHA system shows unusual transmission which depends on the relative position of the two MHAs [4]. This is explained also by the coupling of the spoof SPP on the surfaces of the two MHAs. When the holes have screw structures, it shows the optical activity at specific resonant frequencies [5]. Recently, we investigated the transmission property of the MHA with the “kagome” lattice structure to clarify the properties of the spoof SPP and its role in the EOT phenomenon [6].

Usually, planar THz metamaterials are fabricated by photolithography. Recently, we proposed to use super-fine ink-jet printing (SIJ) technology [7] to fabricate planar THz metamaterials [8]. This technology has several advantages compared to the photolithography for fabricating various test structures in the early stage of developing metamaterials. The spatial resolution of the SIJ technology is comparable to that of the photolithography. It does not need photomasks and metal deposition in vacuum, but needs just writing with nanopaste ink and annealing at about 220 ℃. Thick metallic structures can be made by repeated writing. Further, three dimensional structures can be made. Figure 1(a) shows the

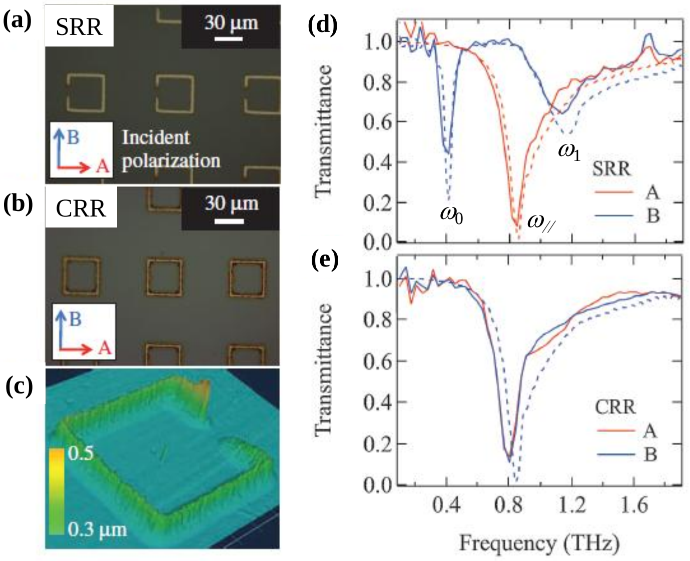

Fig. 1. (a) and (b) show the photographs of the SRR and CRR arrays, respectively. (c) shows the topographic image of the SRR. (d) and (e) show the transmission spectra of the SRR and CRR arrays, respectively. The solid and broken lines indicate experimental and simulation results, respectively.

photograph of a sprit-ring resonator (SRR) array. The sample is consisted of 2500 SRR elements and have an area of 5×5 mm^2. A closed ring resonator (CRR) array was also fabricated for comparison. Figure 1(d) shows the THz transmission spectra for two polarizations of incident THz waves. When the polarization is perpendicular to the gap of the SRR (Pol. B), the sharp LC resonance dip appears at 0.4 THz (ω_0) [9]. This dip does not appear when the polarization is parallel to the gap (Pol. A). The LC resonance dip disappears completely for the CRR arrays. The experimental result agrees well with the FDTD simulations (denoted by broken lines), indicating the accuracy of the sample structures. By using this technology, we have fabricated the standing U-shape arrays.

In most cases, metamaterials are fabricated using metals. However, the negative permeability can be obtained utilizing Mie resonances in high permittivity dielectric spheres or cubes [10]. TiO_2 has very high relative permittivity more than 100 and relatively low loss tangent in the THz region. We have fabricated a two-dimensional array of TiO_2 cubes on an alumina substrate by the ceramic process [11]. Figure 2(a) shows the schematic structure of the sample. From the amplitude and phase shift spectra for transmission and reflection measured by the THz-TDS, we deduce the effective permeability and permittivity as shown in Fig. 2(b). The negative permeability is obtained at around 0.28 THz corresponding to the lowest Mie resonance.

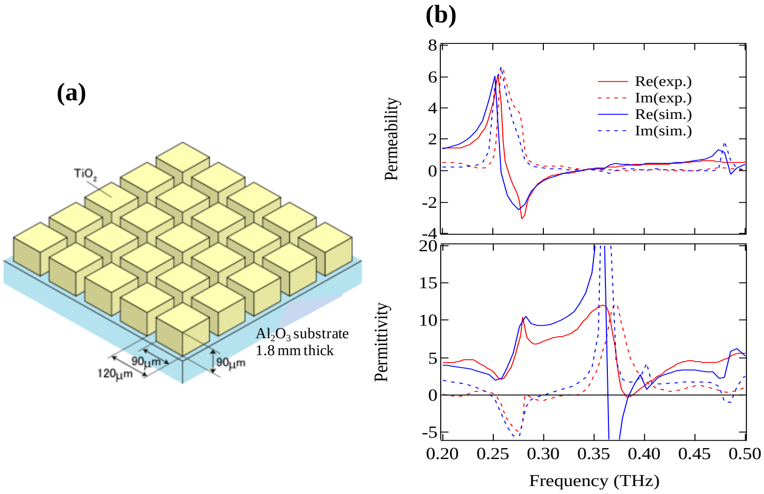

Fig. 2. (a) Schematic structure of the TiO_2 cube array. (b) Experimental and simulated effective permeability and permittivity.

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