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Terahertz Component Platforms Inspired by Metamaterials

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Abstract: *Terahertz metamaterials make unprecedented refractive indices possible and open up the potential of terahertz components with on-demand electromagnetic properties. We demonstrate a wide range of refractive indices from 11.3 to −5.1 in the terahertz waveband, including a refractive index near zero. We have also produced extreme-sensitivity terahertz polarizers and a terahertz quarter-wave plate. These metamaterials can provide a variety of path-breaking applications and develop terahertz component platforms for terahertz science and technology.*

1. Introduction

The recent rapid advances in terahertz science and technology puts stress on demands for high-performance and convenient optical elements with properties exceeding those of conventionally possible naturally available compounds. However, naturally occurring materials are extremely limited in the terahertz waveband when considering the performance losses they give rise to, and it is not straightforward to simply produce materials with arbitrary refractive indices. Here, inspired by the possibilities of metamaterials, we demonstrate unprecedented refractive indices in the terahertz waveband and the first steps in the development of terahertz component platforms for a wide range of potential applications, such as imaging and wireless communication.

2. Terahertz Metamaterials

Figures 1 and 2 [1] show terahertz metamaterials with extremely high refractive indices and low reflections by paired cut metal wires on the front and back surfaces in a symmetric alignment. These properties can be achieved by simultaneous control of permittivity and permeability. Figures 3 [2], 4 [3], 5, and 6 [4] show artificial dielectric terahertz lenses with the control of only permittivity which have been utilized in the microwave band instead of bulk dielectric lenses. Figure 6 shows a terahertz epsilon-near-zero (ENZ) structure controlled by holes on the metal slits, here the dimensions of the holes can arbitrarily generate designs of an effective refractive index between 0 and 1. Figure 7 shows a structure with a refractive index near zero and with nearly perfect transmission achieved by the simultaneous control of permittivity and permeability. Figures 8 [5] and 9 show terahertz metamaterials with negative refractive indices, and Fig. 9 achieves a negative refractive index above 1.0 THz.

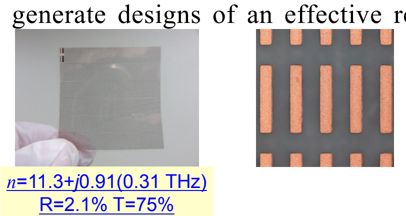

Fig. 1. Extremely high refractive index and low reflection by symmetrically aligned paired cut metal wires.

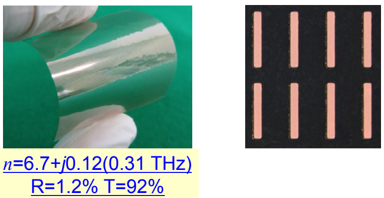

Fig. 2. High refractive index and low reflection by symmetrically aligned paired cut metal wires.

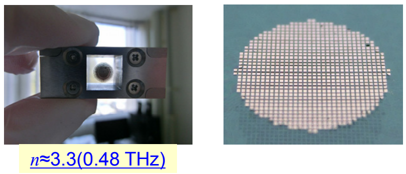

Fig. 3. Artificial dielectric multilayer terahertz lens with rectangular metal chips.

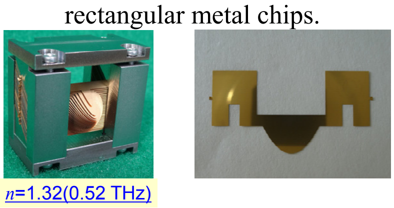

Fig. 4. Terahertz path-length lens consisting of an oblique metal slit array

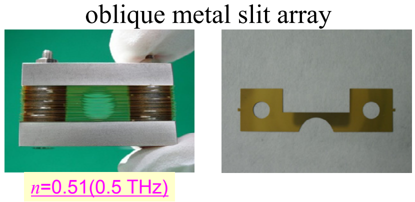

Fig. 5. Terahertz ENZ array antenna with concave cut-through metal slits.

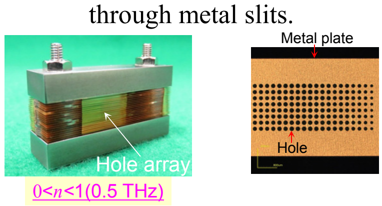

Fig. 6. Terahertz ENZ array antenna with holes.

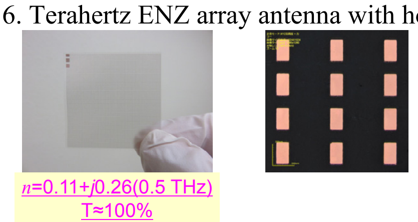

Fig. 7. Refractive index near zero and nearly perfect transmission by symmetrically aligned paired cut metal wires.

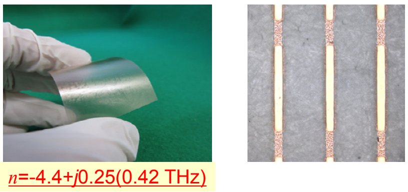

Fig. 8. Negative refractive index by asymmetrically aligned paired cut metal wires.

Fig. 9. Negative refractive index above 1.0 THz by symmetrically aligned paired cut metal wires.

3. Terahertz components

Figures 10 [6] and 11 [7] show terahertz polarizers GoIS® consisting of laminated dielectric films with copper layers and a hollow cut-through metal slit array with gold layers. The terahertz polarizers consisting of the robust structures compared with fragile conventional polarizers can achieve both high extinction ratios below approximately −50 dB and transmission power with approximately 80%. Figure 12 shows a terahertz quarter-wave plate with symmetrically aligned paired cut metal wires which has been utilized in a microwave band device. This structure can simply convert a linearly-polarized wave generated from various CW terahertz sources to circular one.

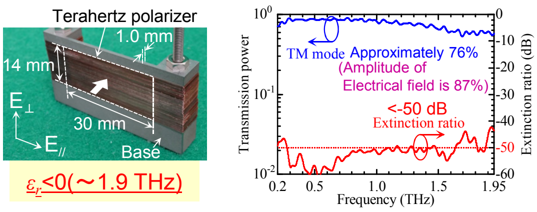

Fig. 10. Terahertz polarizer with a dielectric structure.

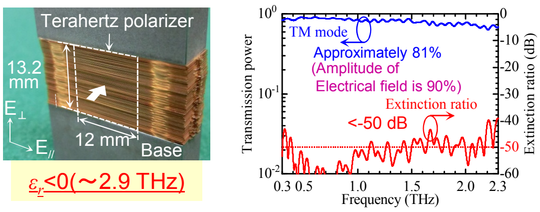

Fig. 11. Terahertz polarizer with a hollow structure.

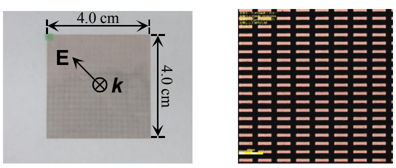

Fig. 12. Terahertz quarter-wave plate with symmetrically aligned paired cut metal wires.

4. Conclusions and future potential

We have demonstrated various terahertz metamaterials with refractive indices from extremely high to negative refractive indices including a refractive index near zero and have produced terahertz components utilizing the concept of metamaterials, such as extreme-sensitivity polarizers and a quarter-wave plate. Metamaterials over a range from 11.3 to −5.1 can offer numerous practical and industrial applications, such as the extremely thin terahertz components in Fig. 13 (a) instead of conventional bulk components as in Fig. 13 (b). Further, a metamaterial with an extremely high refractive index as well as a negative index offers the potential to achieve terahertz imaging with resolutions better than one wavelength.

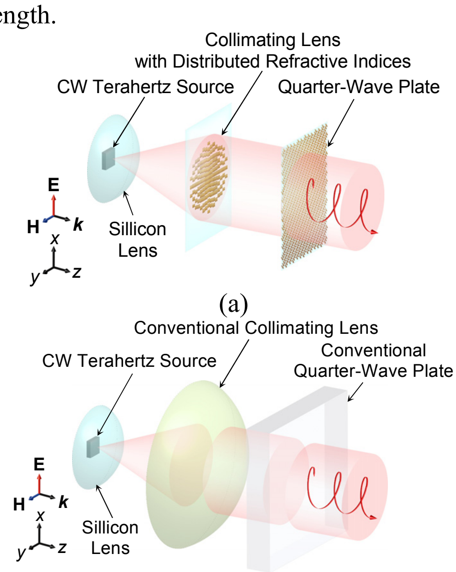

Fig. 13. Terahertz CW application consisting of (a) terahertz components inspired by metamaterials and (b) conventional terahertz components.

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