THz Transmission Properties of Metallic Slit Array

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Abstract: Terahertz (THz) transmission spectrum of metallic slit array is studied by means of terahertz time-domain spectroscopy. Frequency-selective THz transmission of metallic slit array is shown experimentally and analyzed by numerical simulation. The results illustrate that the obvious transmission enhancement occur with the narrowing of slits. The terahertz transmission peak has a blue shift until the peak disappear when the slit width becomes larger. The transmission enhancement of metallic slit array strongly depends on the polarization of terahertz radiation. For the metallic fractal structures of slit array, the multiband including the pass band and stop band exists and their frequencies of transmission peaks are determined by the length of first-level of fractal line. The electric field distribution on the metallic fractal array of square hole shows that THz field is localized on the boundary of metallic hole. It implied that THz transmission properties of metallic mesh structure are domain by the interaction between the photon and boundary plasma of metallic slits.

Keywords: THz, function materials, devices, metallic slit, array

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1. Introduction

The extraordinary transmission of light through the subwavelength metallic apertures has been investigated by theoretically and experimentally [1-2]. The modulation of metallic structure to electromagnetic wave shows a potential application [3]. The investigation on effect of metallic structures on THz wave is significant to the development of THz photonic devices.

In the recent years, the study on the transmission properties of subwavelength apertures has become a very active area of research in electromagnetism. The mechanism of these phenomena becomes a topic of considerable fascination in recent years. Ebbesen et al [1-2, 4-5] showed that EM wave transmission through a silver film with a periodic array of sub-wavelength holes can be significantly higher than the conventional predictions due to the excitation of surface plasma (SP). Subsequently, Porto et al [6-9] identified another waveguide mode resonance inside metallic slits due to the Fabry-Perot （FP） interferences. In both cases the length scales relevant to the transmission mechanism must be comparable to the wavelength: in the SP case the periodicity must be comparable to the wavelength; the FP resonance requires at least one dimension of the cross section of slit be comparable to the relevant wavelength, so that a fundamental TEM propagating mode [10] may exist. Recently, more and more works focus on the optical transmission of subwavelength metallic structures [11-15]. Our research on THz transmission of metallic fractal structures also verified that the frequency-selectivity of metallic slits [16].

In this paper, Terahertz transmission spectrum of metallic slit array is studied by means of terahertz time-domain spectroscopy (THz-TDS). Two kinds of metallic slit array is fabricated by the laser cutting to the copper foil and investigated by the THz-TDS. We focus on the dependence of THz transmission through the slit array on the shape and the size of slits. The effect of THz polarization on the transmission is studied in detail. Frequency-selective transmission of metallic slit array is shown at terahertz frequencies experimentally and analyzed by numerical simulation.

2. Experimental samples and methods

To investigate THz transmission properties of metallic slit arrays, two kinds of metallic slits structures are fabricated by the laser cutting on the copper foil with the thickness of 50 micro. Firstly, we studied the rectangular slits with the different length and width of slits. The transmission of single rectangular slit is so week that is difficult to detect the signal after the sample. We fabricated the slit array with the length of slit as a and the width as b and the period of T, shown as Fig.1. By checking the different length-to-width ratio a/b, while keeping the area of slit as a constant so that the occupation ratio of slits is unchanged, we can investigate the dependence of THz transmission of metallic slits on its shape and size.

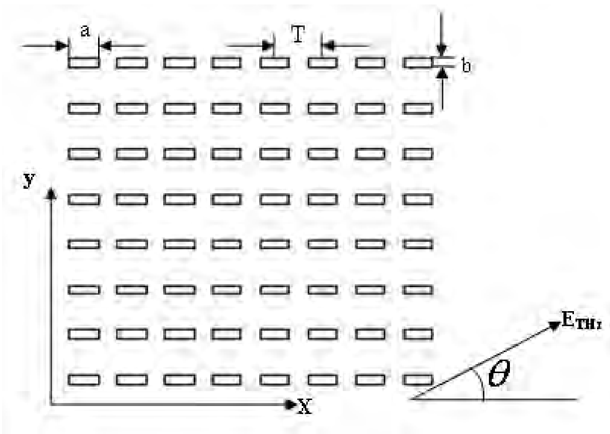

Fig. 1 Schematic diagram of the metallic slit array.

Secondly, the H-shaped fractal structure as Ref. [11] is formed from a slit of W = 40 μm of width and a1 = 1.4 *mm* of length, defined as the first level of fractal structure. The slits have been fabricated by the YAG laser cutting to the copper foil. The second level of slit with a1 = 1.4 *mm* of length is oriented along the direction perpendicular to the first level and connected at the midpoint of the first level slit, forming an H-shape. The third and fourth levels are constructed similarly except the line length is scaled down by a factor of 2, that is, a3 = a4 = 0.7 *mm*. By continuing this procedure, a self-similar H-fractal structure is realized [16], shown as Fig. 2. Here the 7-level of fractal slit structures are repeated into a 3×3 array with the period of 2.8 *mm*.

THz transmission of these samples is measured by a standard terahertz time-domain spectroscopic system. The polarization dependence of THz transmission spectra of metallic slit arrays is investigated by rotating the samples relative to the edge of slits.

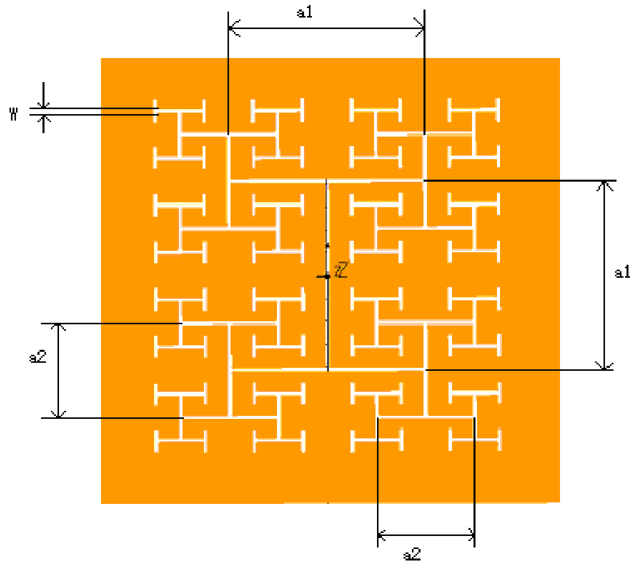

Fig. 2 Schematic diagram of the metallic fractal slit array.

3. Results and discussions

Fig. 3 shows THz transmission spectrum of metallic slit array as Fig.1 with the different length-to-width ratio a/b of slit where a/b=1:1 corresponds to the square hole.

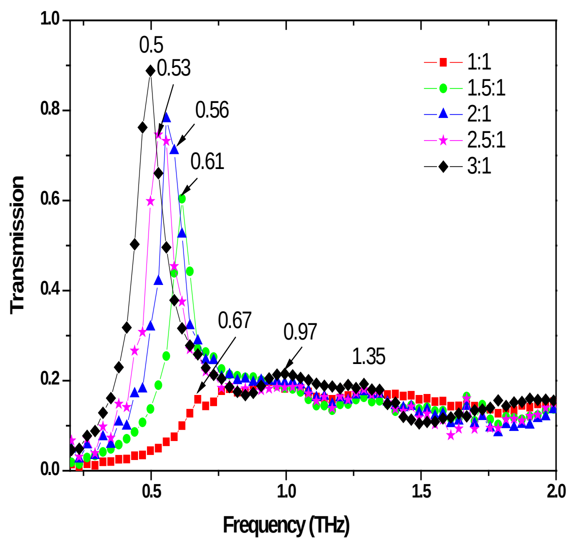

Fig. 3 THz transmission spectra of the rectangular metallic slit array for different length-to-width ratio of slits.

From Fig. 3, it is clear that THz transmission enhancement occur when the slits become narrow. The square holes array with a/b = 1:1 has little transmission enhancement, but has an obvious cut-off frequency. On the other hands, the frequency of transmission peak depends linearly on the length-to-width ratio of slit, and there is a blue shift with increasing of a/b. It is significant to design the suitable THz transmission filter from our research result. Finally, it is worth to mention that THz transmission of metallic slit array is strongly polarization-dependent.

In the following, we have investigated THz transmission of metallic fractal slit array as Fig. 2 by THz-TDS measurement. Fig. 4 shows THz transmission spectra of fractal slit array with the different direction of THz polarization, where the long side of first-level of slit along with the polarization of THz radiation defined as θ = 0 degree.

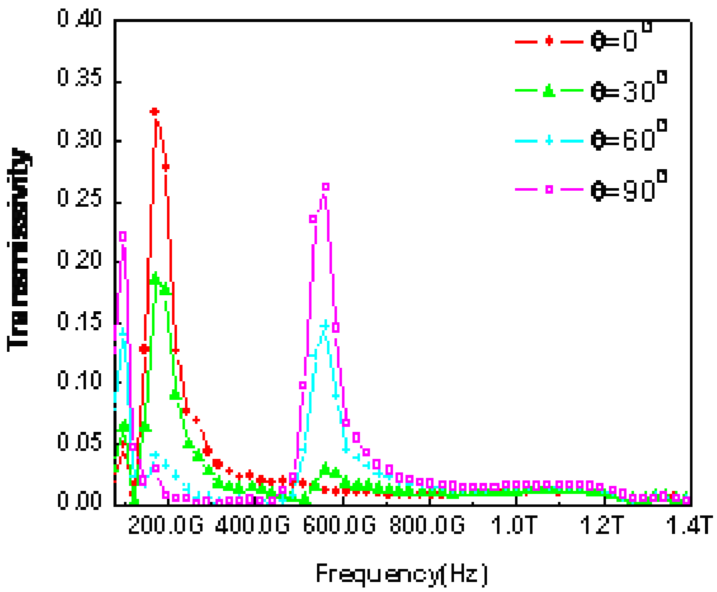

Fig.4 THz transmission spectra of the 7-level fractal slit array

It is clear that there are multiple pass bands separated by the stop band which is strongly dependent to the polarization of THz radiation and the length scale of metallic fractal slits. By rotating the sample so that changing the angle of the first-level of slit line relevant to THz polarization, one can decrease THz transmission of metallic fractal slit array at one frequency of pass band, while increase THz transmission at another pass band. This kind of THz transmission behavior may be an important basis of THz photonic functional devices.

Finally, to understand the physical origin of this kind of THz transmission property of metallic mesh structures, THz transmission of metallic fractal holes array, so called Sierpinski Fractal Structure, is analyzed numerically by using the commercial software CONCERTO which is based on the FDTD method.

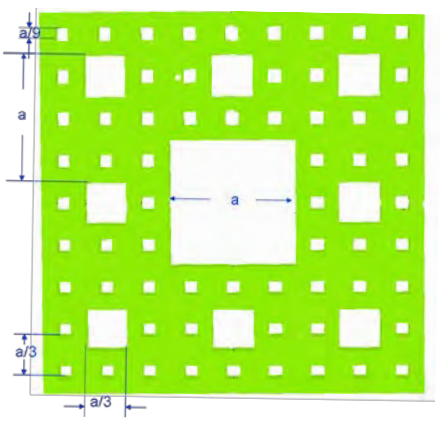

Fig. 5 Schematic diagram of Sierpinski Fractal Structure.

Fig. 5 is the schematic diagram of Sierpinski Fractal Structure. One third of side length of last-level fractal square hole is designed as the side length of next-level hole, so as on. We simulate THz transmission and reflection spectra of a three-level fractal holes array with the side length of first-level square hole as 450 μm, shown as Fig. 6. The multi-band characteristic is shown at both of transmission and reflection spectrum. The same physics is from the localized resonance of different fractal levels as that of H-Shape fractal slit array [16]. It is clear that there are the stronger frequency-selective reflections than that of transmission for the Sierpinski Fractal Structure.

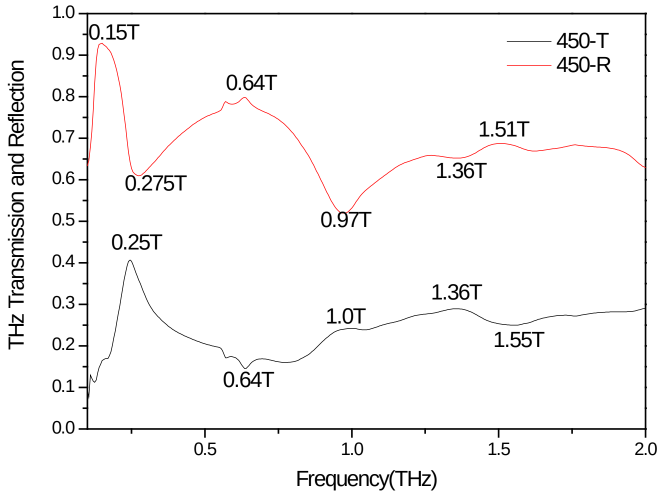

Fig. 6 THz transmission and reflection spectra of Sierpinski Fractal Structure.

The numerical simulation results of THz electric field distribution on the fractal holes array are shown in Fig. 6 for the different moment. It illustrate that the transmission enhancement of narrow slits come from the localized resonance of THz electric field.

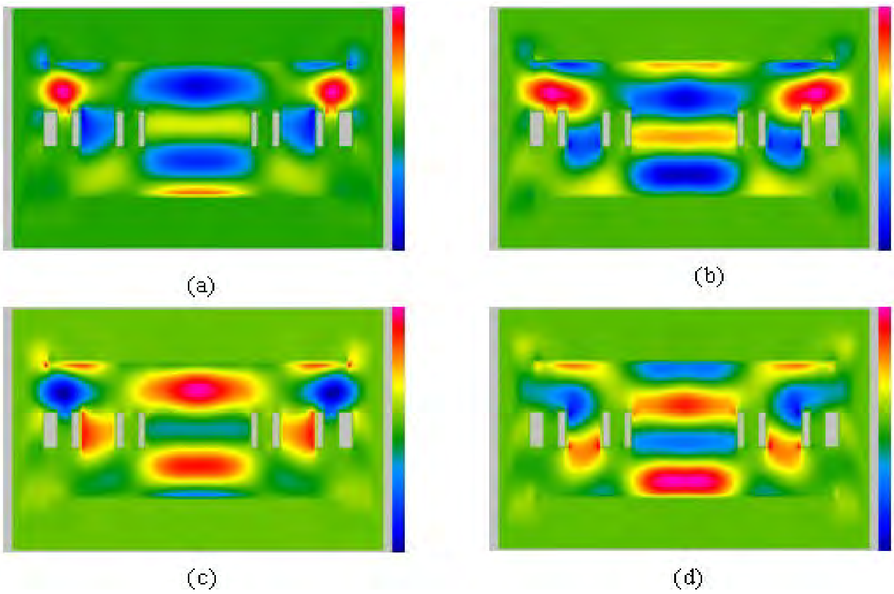

Fig. 7 The distribution of THz electric field of Sierpinski Fractal Structure.

Fig. 7 shows that THz electric field is localized at the boundary of metallic holes. Especially, the localized electric field oscillates back and forth which go with the surface plasma oscillation of metallic fractal structure. It shows that the THz electric field accompanies the surface plasma oscillation so that causes the frequency-selective transmission and reflection behavior.

4. Conclusions

In summary, we have presented the transmission properties of several metallic slit arrays at the terahertz frequencies. The results show that the metallic slit array has the good frequency-selective THz transmission which is domain by the shape and size of slits, and is strongly polarization-dependent. The numerical simulation shows that THz electric field is modified strongly by the boundary plasma polariton of metallic slits. The local field of metallic slit boundary is related to the THz transmission enhancement. The research on THz transmission properties of metallic slit array makes a strong basis for the THz functional materials and devices.

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