테라파에서의 플라즈모닉 필터
Plasmonic Filters in Terahertz Region

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Ⅰ. Introduction

Recently the concept of surface plasmons have been extended to include perfect metals [1-5], thereby encompassing any phenomena involving strong surface electric field in microwave and terahertz frequency range. Strong surface field and scattering of this field into the far field can resultin nearly perfect transmission, as has been predicted by many theoretical groups [6-9]. In this paper, we demonstrate perfect transmission through various plasmonic metamaterials with diverse hole shapes where we can easily tune the transparent frequencies through hole shapes [10], incident angle [11], and polarization direction [12]. Perfectly transmitting plasmonic metamaterials would find immediate applications as highly efficient spectral filters in terahertz range where achieving the same performance would be extremely difficult through dielectric coating, because of the large number of layers involved and the thickness of each layer.

Ⅱ. Experiment

A laser machining system used to fabricate the plamonic meta-materials with periodic structures perforated with various shapes (Figure 1 a). This system is realized by irradiation of an amplified Ti:Sapphire laser pulses onthe sample surface, delivering pulses with energy of up to 1 mJ at 800 nm and a repetition rate of 1 KHz. A galvanometer scanner and a fast optical shutter with a rising time less than 0.5 ms are employed to control a laser exposure. The samples fabricated by this system have slit structures of various widths and sample thicknesses and free standing which make possible to remove complex mixing of air-metal and dielectric-metal modes.

We used a standard THz time-domain spectroscopy system (Figure 1 b) with a spectral range of 0.1 to 2.5 THz generated by a semi-insulating GaAs emitter biased with a 50 KHz and 300 V square voltages. Electro-optic sampling method is used to detect the transmitted THz waves which induce a polarization change by a synchronized probe pulse (Figure 1 c).

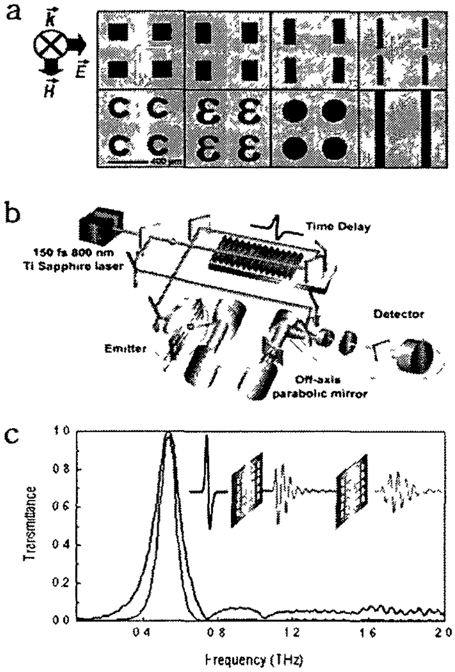

Figure 1 Samples and THz time domain system

Ⅲ. Result

Figure 2a shows that the peak position shifts to smaller frequency as b increases, while maintaining transmittance of near unity Interesting case is seen at the slit sample (b = infinity), where the transmittance keeps increasing with decreasing frequency, until the low frequency limit of our detection method (50 GHz) shows over 90% transmittance Our results suggest that the cut-off frequency of the first *eigenmode*(the half wavelength mode) is where the transmittance of unity occurs Plotting spectral peaks versus the half wavelength mode frequency $c/2b$ results in a straight line of slope 1 (Fig 2b), supporting our picture The problem of transmittance through an infinite array of rectangular slits can be analytically solved by boundary-matching inside-cavity modes and Rayleigh expansion outside the holes The shift of peak positions with b (Fig 2c) is in good agreement with experimental results We now discuss angular dependencies of transmission spectra, both by rotating the sample while maintaining the normal incidence, and by changing the incidence angle

Dielectric coated reflection and transmission filters in the optical range often changes its wavelength upon changing the angle of incidence While this small *tunability* might be desirable for some applications, it makes constant-wavelength alignment tricky Here we show that our plasmonic meta materials possess both the constant-frequency *and* slight-tunability characteristics, depending upon the hole shape Shown in Figure 2d is the contour plot of the incident angle (q) dependent transmission for the square hole sample With increasing deviation from the normal incidence, the transmission becomes weaker as the peak frequency becomes smaller, and the peak position occurs at slightly smaller frequency than the first Rayleigh minimum $f_R(\theta) = \frac{c}{d(1+\sin\theta)}$, making this filter slightly tunable

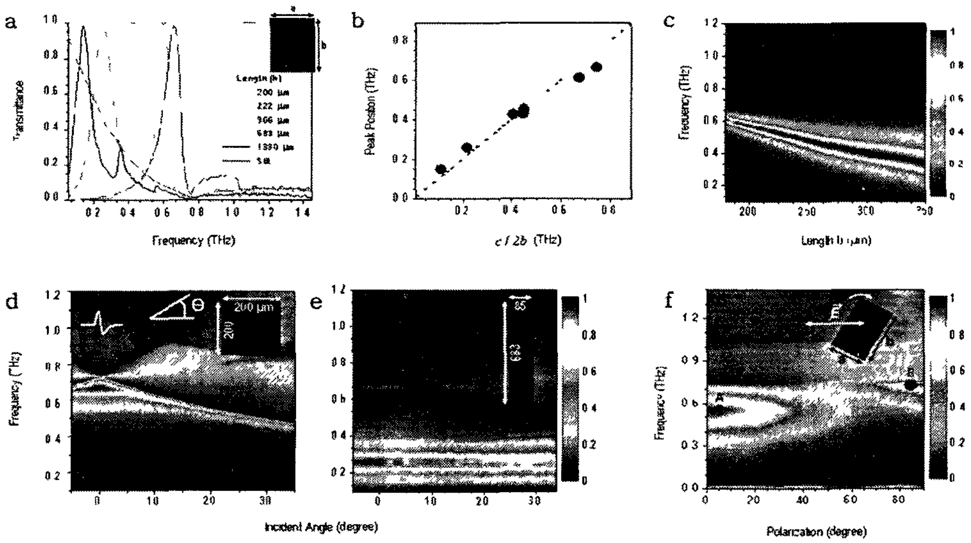

Figure 2 Transmission spectra for samples

In stark contrast to the square hole sample, a strongly rectangular hole array supports angle-independent perfect transmission, as shown in Figure 2e in this strongly rectangular shape with width to length ratio of 1 to 8, the peak position is predominantly determined by the length only, making this filter a constant-frequency one In a sample with width to length ratio of 2 to 3, we can switch the transparent frequency simply by rotating the sample by 90 degrees relative to the polarization, as shown in Figure 2f we now have a switchable frequency filter which changes transparency frequency with sample rotation The origin of this frequency switch can be thought of as follows the cut-off frequency for the fundamental mode is given by $c/2b$, and as we rotate the sample we switch a and b

Ⅳ. Conclusion

We have demonstrated the existence of the perfect transmission for periodic structures with various shapes in the terahertz region Single-resonance is achieved by the structures with simple shapes and by rotating of sample Spectral peak positions are controlled by changing the polarization and angle of the incident light Of course, the perforated shapes designed with wide variety can offer specific resonance type and can select the spectral peak positions We believe that this work can provide the possibility of the perfect filter with narrow spectral width, various resonance types which can realize color filters, perfectly transmitted resonance peaks and tunability

V. Reference

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