Abstract— An extraordinary transmission effect for terahertz (THz) waves in a complementary metallic disk and hole array was experimentally and numerically demonstrated. Moreover, this result was also theoretically confirmed that the enhanced transmission peak in this structure was contributed both by the SPPs excited on the metallic structures and also the resonance in the dielectric rod between the metallic disk and hole. This novel plasmonic structure shows great promising applications in THz sensing and filtering.

I. INTRODUCTION

The extraordinary transmission of light through the array of metallic subwavelength holes discovered by Ebbesen et al. [1] has inspired great interest to explore the underlying physics and the possible applications of surface plasmon polaritons (SPPs). The resonance of SPPs excited on periodically structured metal by the incident light tunnel through the subwavelength holes, which is the origin of the enhanced transmission. At terahertz (THz) frequencies, the extraordinary transmission through the subwavelength metallic arrays has been reported [2-5]. Their results showed that the geometry shape of the metallic array structure had a significant effect on the THz transmission magnitude, whereas in the optical region hole shape was not a crucial parameter for the transmission coefficient.

In this work, we fabricated a special metal-dielectric plasmonic structure composed by a metallic disk, dielectric rod and a complementary metallic hole array, and measured its normally incident transmission spectrum by the THz time-domain spectroscopy (THz-TDS) system. A strong THz extraordinary transmission effect in this structure was experimentally and numerically demonstrated, which shows great promising applications in THz sensing and filtering.

II. RESULTS

This complementary metallic disk and hole array (CMA) was fabricated by the MEMS technique: firstly, a Si rod array was fabricated by the lithography and inductively coupled plasma etching on a 400μm thick 6kΩ·cm Si wafer for about 40 minutes. We obtained the Si rod array with a cylinder diameter of d=100μm, an array period of a=250μm and the rod height h =125μm [6, 7]. Then, 100nm Cu film was deposited on the top of Si rod and the Si substrate by magnetron sputtering. Cu film was not deposited on the sidewall of Si rod. Finally, a special metal-dielectric plasmonic array structure was formed. In one unite cell, a metallic disk is on the top, a complementary metallic hole is on the substrate, and a Si rod is located between the disk and hole as shown in Fig.1.

Experiments were performed on a standard four parabolic mirror THz-TDS system [8]. THz wave was normally incident through such closed metallic structure with normal incidence. As the definition of classical diffraction theory, the transmission coefficient $T = \frac{4264}{27\pi^2} kr^2$, where $r$ is the hole radius and $k=2\pi/\lambda_0$ [9]. However, as shown in Fig. 2, the experiment transmission spectrum of this structure show a transmission peaks at 0.706 THz with a 70% transmittance. Thus, the transmission coefficient $T$ of this structure is far more than 1 of the classic diffraction theory. We also used the finite-difference time-domain (FDTD) method to simulate the CMA model shown in Fig.1(b). The simulation result also fits well with the experiment data as shown in Fig. 2. In the following, we’ll explain the high transmission peak at 0.706 THz in this structure.

Fig. 1 (a) SEM photo of the CMA. (b) Schematic diagram that THz waves normally transmit through this structure.

For normal incidence, the resonant wavelengths for the excitation of SPPs of a rectangular lattice structure are approximately given by [2, 3]

$$\lambda_{sp} = \frac{n_{sp} a}{\sqrt{m^2 + n^2}}$$

where $a$ is lattice period; $m$ and $n$ are the integer order indices of SPP modes. $n_{sp}$ is the function of the dielectric constant of the dielectric material and the geometry of the rod. Fig. 3 shows the
field distribution of our CMA structure at 0.706THz simulated by the FDTD method. The resonance pattern can be clearly seen in the silicon rod of the CMA, and the effective refractive index of $n_{\text{pp}}=1.70$ for this SPP mode can be obtained. By Eq.1, we can calculate that the extraordinary transmission originated from SPP resonances occur at 0.706THz for $m=1$ and $n=0$ in our CMA structure when the polarization direction of THz wave is along $y$ axis, which agrees well with both the experiment and simulation results.

![Image](image.png)

**Fig. 3** $H_y$ field distribution of CMA structure in the cross plane of one periodic unit cell at 0.706THz.

We also simulated different $h$ of dielectric rod in the CMA structure, and the results were shown in Fig. 4 and Fig. 5. We notice that the rod height does not affect the frequency of the extraordinary transmission peak but strongly affects the transmittance of the peak. Only when

$$h > \frac{\lambda_{\text{pp}}}{\sqrt{\varepsilon_d}}$$  \hspace{1cm} (2)

the resonance can be existed in the dielectric rod, and thus enhanced transmission peak can be formed through the metallic holes below. According to Eq. 1, $h$ should be larger than 120\,$\mu$m in this CMA structure, so as shown in Fig. 4, $h=60$ and 90\,$\mu$m has no transmission peak, while $h=120$ and 150\,$\mu$m has a transmission peak both at 0.706THz, indicating that $h$ has no relation with the $n_{\text{pp}}$.

### III. SUMMARY

In conclusion, the enhanced transmission peak in this CMA structure was contributed both by the SPPs excited on the metallic structures and also the resonance in the dielectric rod between the metallic disk and hole. This enhanced THz extraordinary transmission effect in this CMA structure shows great promising applications in THz sensing and filtering.

### ACKNOWLEDGEMENT

This work was supported by the National Basic Research Program of China (Grant 2014CB339800), the National High Technology Research and Development Program of China (Grant 2011AA010205), the National Natural Science Foundation of China (Grant 61171027; Grant 61378005), and the Science and Technology Program of Tianjin (Grant 13RCGFGX01127).

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