THz Bandpass Filter Based On Sub-wavelength Holes in Free-Standing Metal Thin-Films

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***Abstract*—The design of a free-standing (substrate-less) metallic hole array is proposed for Terahertz frequencies. The band-pass filtering effect through free standing perforted Aluminium (Al) films is demonstrated using a square array of circular holes on Al films having thickness of $\sim$ 11 μm. The effect of variation of periodicity and hole diameter on the transmittance due to excitation of surface plasmons and coupling between resonant and non-resonant modes is studied.**

I. Introduction and Background

TERAHERTZ (THz) filters have generated a lot of interest in recent years due to their numerous potential applications in Terahertz Imaging, Biomedical applications, communication systems. Previous works using plasmonic transmission mainly use a substrate for the design and operation at optical frequencies [1], [2]. Mark W. Knight et al reported that aluminum has plasmonics properties that enable strong plasmon resonances spanning much of the visible region of the spectrum and into the ultraviolet region [3].

In this paper, a substrate-less bandpass filter in the THz regime is proposed which makes use of perforated arrays. The resultant transmission is characterized by two processes, resonant excitations of surface plasmons and non resonant transmission [4]. The effect of periodicity and hole diameter on the transmission response has been studied [5].

II. Results

In order to observe the effect of parametric variation on the response from the free-standing filter, we carried out simulations by varying the periodicity as well as the radius.The simulations were performed using Microwave CST Studio. The design was simulated as a periodic structure. Drude model was used to represent the Al films in simulations with plasma frequency (ω_p)= 119,000 cm^{-1} and collision frequency (ω_s)=660 cm^{-1} [6]. Fig. 1 shows the results for varying periodicity with constant hole radius. The resonant bandwidth becomes narrower with increasing periodicity as the relative metal filling factor increases with respect to the surface area covered by the hole.

The variation of the radius with constant periodicity is shown in Fig. 2. In this case, as the radius increases the response is seen to have a larger bandwidth. This is caused

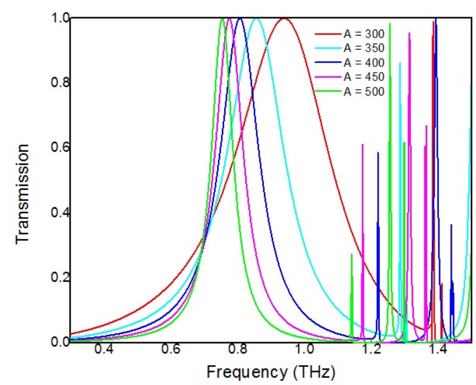

Fig. 1. Simulation results for varying periodicity from 300 μm to 500 μm with hole radius constant at R = 100 μm

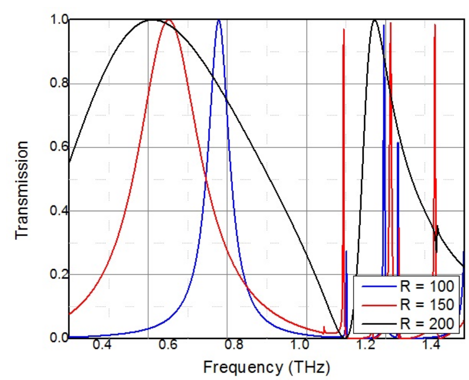

Fig. 2. Simulation results for varying radius from 100 μm to 200 μm with periodicity constant at A = 500 μm

because of the increase in the direct transmission due to the increasing hole surface area.

Fig 3. shows experimental and simulated results for a free-standing Al film in the frequency range from 0.3 to 1.5 THz. The samples were fabricated using Al foils with 11 μm thickness and tested using Terahertz Time Domain Spectroscopy (THz-TDS). There are two types of transmission phenomena mainly observed in the fabricated array, namely, radiative transfer to free space (reflection) and radiative trans-

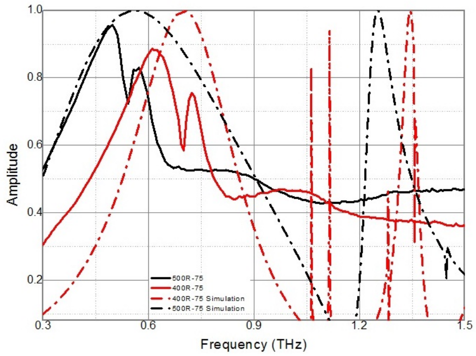

Fig. 3. Experimental and Simulated Transmittance. The solid lines are for experimental results and the dotted lines are the simulated results; Black Line: A = 500 μm , R = 195 μm , Red Line: A = 400 μm, R = 143 μm

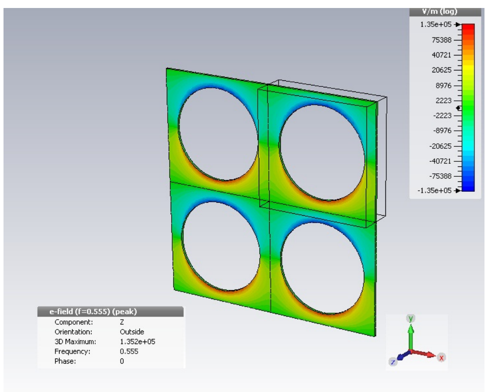

Fig. 4. E_z at resonating frequency for array having periodicity of 500 μm and radius 200 μm

fer through the subwavelength holes (transmission). Maximum transmission is observed at the resonant frequency which is determined by the array geometry.

The experimental results show a secondary peak which is caused due to the aperiodic nature of the fabricated array. The array was fabricated using laser micro-machining. A fiber laser with a power rating of 20W, frequency of 20kHz and wavelength of 1064nm was used for the fabrication process. The microscopic images in Fig 5, show that there is a slight aperiodicity observed in the fabricated samples due to imperfect machining. From the images it can be seen that there is metal deposition around the hole circumference (burr) which causes scattering. At the same time, the surface finish is rough, which can be seen in Fig. 5 that show the microscopic images for the fabricated subwavelength array. This is the cause for mismatch between the experimental and simulated results. The measured resonant frequencies are 0.7 THz,0.56 THz for holes with radii 143 μm and 195 μm respectively.

One possible solution to this fabrication error is to try laser ablation in order to reduce the burring and surface roughness. Optical micromachining [7] can also be used in order to obtain accurate array dimensions.

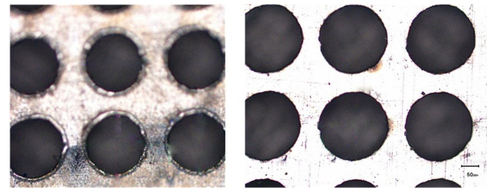

Fig. 5. Left: Microscopic image for fabricated array with Radius = 143 μm and periodicty 400 μm; Right: Microscopy image for array with radius = 195 μm and periodicity 500 μm

III. Conclusion

It was experimentally demonstrated that subwavelength holes on a free-standing substrateless metal foil can be used to design a THz bandpass filter. The fabricated filters have resonant frequencies of 0.7 and 0.56 THz for varying geometric dimensions. The filtering can be made selectively for a band by varying the hole diameter as well as the hole array periodicity. The free standing design has advantages of low cost,compact size, easy fabrication which makes it suitable for low cost Terahertz communication systems.

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