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A Broadband FSS Bandstop Filter in Terahertz Region

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Abstract

A wideband bandstop filter using frequency selective surface (FSS) operating in the terahertz (THz) frequency range has been reported. The simulation results show that it has a 3-dB bandwidth of 22.9 THz over the resonating frequency of 24.1 THz. The transmission stopband lesser than 30dB has been achieved along with a fractional bandwidth of 95%. The structure has been analyzed under the variations of several geometrical parameters. The structure is found to behave as wideband stopband filter till 40º incident angle. The structure offers wide stopband till 15º polarization angle. Being ultra-thin (~λ/12) and simple in nature, the filter can be very easy to realize in practice. The structure finds its application in spectroscopy, imaging etc.

1. Introduction

Terahertz (THz) technology has rapidly become an attractive research area due to its potential for applications related to imaging and sensing, space science, security applications etc [1-3]. Blocking of signals over a particular frequency range is extremely important for these applications [4]. Frequency selective surfaces (FSSs) have been extensively used in filter designs due to the design of the surface by using repetitive design over substrate to transmit or reflect electromagnetic waves at a particular frequency range over the last few years [5]. Realization of filters using FSS is particularly advantageous as it does not require any physical electrical connections and is significantly useful in the field of wireless communication [5]. The frequency response of such a filter depends upon the geometry of the design, shape, size and dimension. The design geometry of an FSS can be of many types like solid interior or plate type, center connected elements, loop type structures, and the combination of the above three together [6]. FSS based filters can be applied in radomes, dichoric subreflectors, lenses, RFID, modification in radar cross section of a device, GSM, GPS, ISM, selective shielding of frequencies in military and airport communication, isolation of unwanted and harmful radiation in hospitals, schools and domestic environment [7]. Recently, stopband FSS filters have been realized in terahertz domain, although they suffer from the narrow bandwidth responses [8-9].

In this manuscript, we present a wideband bandstop frequency selective surface (FSS) filter of bandwidth 22.9 THz over the resonating bandwidth of 24.1 THz to realize a fractional bandwidth close to 95%. This is probably the maximum bandwidth ever achieved at a resonating frequency of 24.1 THz with a transmission minima lower than 30 dB. The structure is made of periodic metallic patch made of gold imprinted over silicon dioxide. The structure has been studied under the variations of several geometrical parameters and the optimized geometrical dimensions are considered. The structure has been studied under oblique incidences, where the wide stopband is realized upto 40º incident angles. The structure is also studied under polarization angle variations and the structure offers wide stopband response till 15º polarization angle owing to its two-fold symmetry.

2. Design of FSS unit cell

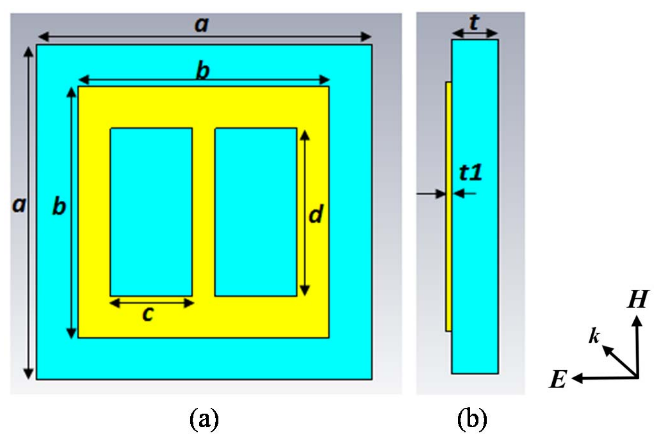


Figure 1. (a) Top view and (b) side view of the unit cell of the broadband bandstop FSS filter.

The resonant frequency in the unit cell is controlled by the inductance derived by the metallic strips while the two symmetrical slots give rise to the equivalent capacitive effect. Hence the geometrical dimensional variations of the slots and metallic patches will lead to different sets of capacitances and inductances [10]. The bandwidth of the

FSS depends upon the electrical properties and the geometry of the structure [5, 11].

The unit cell is a two-layered structure. The schematics for the top view and side view of the FSS unit cell are shown in Figure 1(a) and Figure 1(b) respectively. The metal patch used here are made of gold with thickness of 0.1 µm on top of a 1 µm thick silicon dioxide substrate of relative permittivity of 3.9 at the frequency of operation. The geometrical dimensions of the unit cell of the FSS are optimized and listed in Table 1. The directions of the electric field, magnetic field and the direction of wave propagation are also shown in Figure 1.

Table 1: Geometrical Dimensions of the Unit Cell of The Proposed FSS Filter

Parameters	Dimensions (µm)
Period of the unit cell *(a)*	8
Length of the metal patch *(b)*	6
Width of the slot *(c)*	1.95
Height of the slot *(d)*	4
Thickness of the dielectric *(t)*	1
Thickness of the metal patch *(t1)*	0.1

3. Simulated results

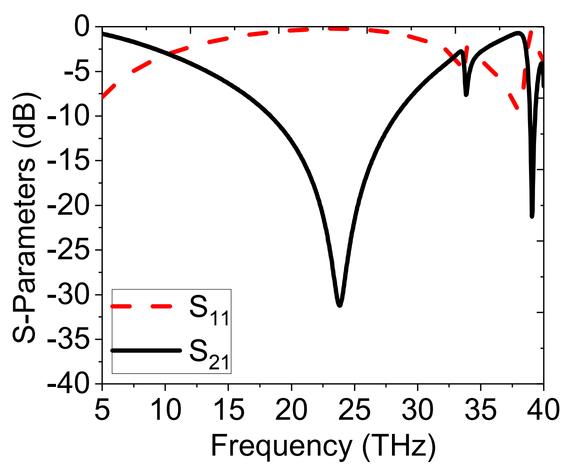


Figure 2. Reflection and transmission characteristics of the proposed FSS filter structure whose unit cell is shown in Figure 2.

The unit cell shown in Figure 1 has been simulated using CST Microwave Studio Suite under periodic boundary conditions [12]. The resultant return loss (S_{11}) and transmission loss (S_{21}) are shown in Figure 2. It is observed that transmission minimum occurs at 24.1 THz with S_{21} of -30.8 dB. Also, the 3-dB transmission stopband lies between 10.1 THz and 33 THz, thus providing a bandwidth of 22.9 THz. Thus, the fractional bandwidth has been computed as 95% with respect to the frequency of transmission minima.

The effects of the bandwidth and transmission attenuation of the FSS filter with respect to the geometrical dimensions of the unit cell. Initially, the thickness of the substrate has been (*t*) has been varied from 1 µm to 4 µm. It is seen from Figure 3 that the attenuation of the transmission minima gets enhances as due to increase of substrate thickness, more energy gets trapped resulting in decrease of bandwidth [13]. Next, the thickness of the metal layer (*t1*) has been varied and the identical response has been observed in Figure 4 where increase of *t1* leads to the decrease of the stopband bandwidth.

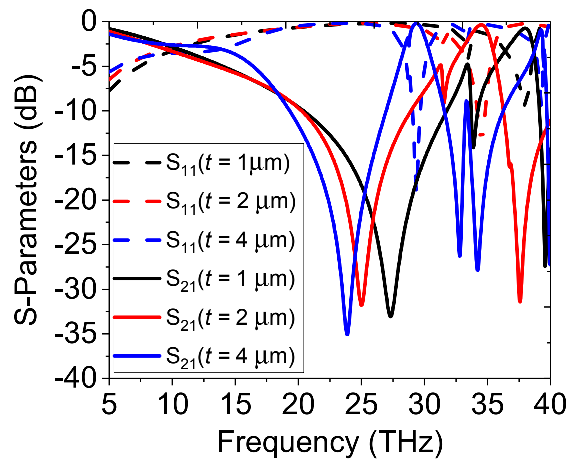


Figure 3. Variation of S-parameters with respect to varying thickness of the substrate (*t*) of the reported FSS unit cell.

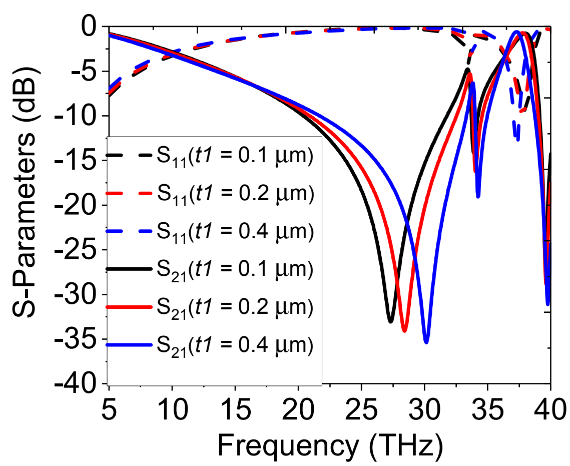


Figure 4. Variation of S-parameters with respect to variation of the thickness of the metal FSS patch (*t1*).

Figure 5 shows the variation of S_{11} and S_{21} with respect to the varying slot width (*c*). It is seen that as the slot width increases, the width of the metal patch decreases, which further results in decrease of the resonating frequency.

The variation of S-parameters is shown with respect to the variation of the angle of incidence (θ) of the electromagnetic wave in Figure 6. It is evident that the structure behaves as a wideband stopband FSS filter upto 40^{o} incident angle. The structure has been also studied under the different angles of polarization (ϕ) and it is shown in Figure 7. It is concluded that the structure offers wideband stopband response till 15^{o} polarization angle. Due to the two-fold symmetry of the structure, polarization insensitivity has not been achieved.

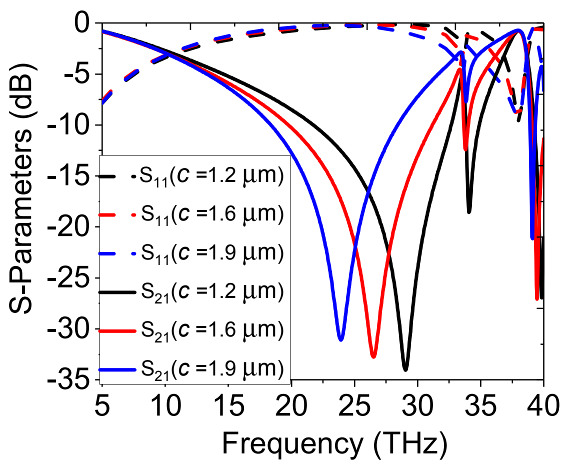


Figure 5. Variation of transmission and reflection coefficients with varying slot width (c) of the FSS unit cell.

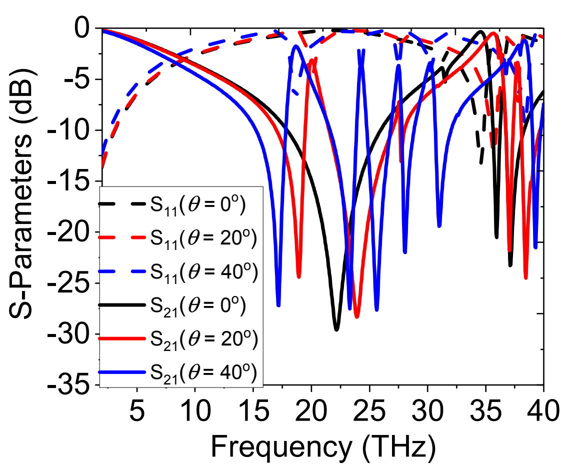


Figure 6. Variation of transmission and reflection coefficients with under different angles of incidence (θ) of the electromagnetic wave.

To get better understanding of the response of the structure, the electric field distribution has been studied as provided in Figure 8 (a). This shows the electric field distribution of the surface when illuminated by the electromagnetic radiation falling from +z direction at 24.1 THz frequency. It is found that a dipole has been formed at 24.1 THz between the adjacent metallic patches as the field concentration is high. The surface current distribution at 24.1 THz reveals that the density of surface current is very high at the same frequency along the metallic patch which gives rise to strong reflection from the surface, thereby reducing the transmission at this frequency. At 24.1 THz, the combined effect of electric field and surface current on the horizontal and the vertical patches results in such a huge attenuation of transmission as well as very high reflection.

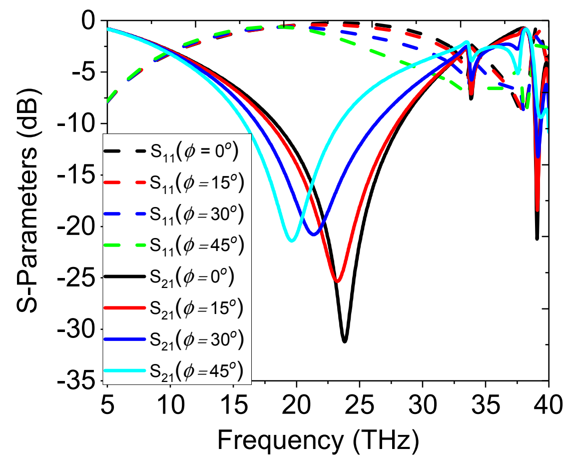
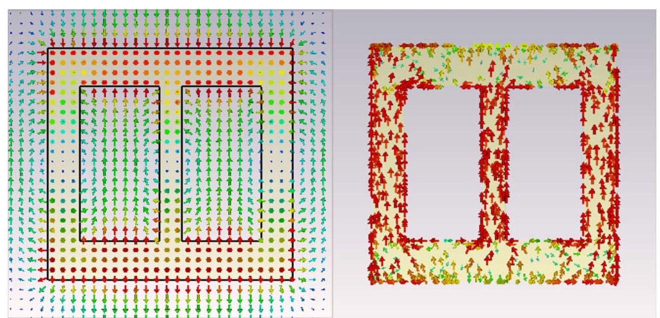


Figure 7. Variation of S_{11} and S_{21}under different angles of polarization (ϕ) of the incident electromagnetic wave.



(a) (b)

Figure 8. Distributions of (a) electric field (b) surface current on the top surface of the FSS unit cell.

Table 2: Comparison of the Performance of the Proposed Stopband FSS Filter with Reported Stopband FSS Filters

Terahertz Stopband Filter	3-dB Bandwidth (THz)	Fractional Bandwidth	Thickness (μm)
Hussein *et al.* [8]	0.075	40%	λ/6
Ebrahimi *et al.* [9]	0.42	45%	λ/6
Proposed structure	22.9	95%	λ/12

The proposed wideband bandstop filter has been compared with the existing FSS filters as shown in Table 2. It is observed that the structure offers significant enhancement of fractional bandwidth compared to the existing ones by maintaining very thin nature. This is the highest stopband reported till date to the best of our knowledge.

4. Conclusion

In this paper, an FSS based broadband bandstop filter has been proposed. This proposed structure offers a bandwidth of 22.9 THz ranging from 10.1 THz to 33 THz, exhibiting a maximum attenuation of -30.8 dB at 24.1 THz. Thus, it offers a fractional bandwidth of 95%. The structure is exhibiting broadband bandstop filter response till 40^{o} incident angle and 15^{o} polarization angle. This filter can be used for future applications like in IR spectroscopy and IR photography.

5. Acknowledgements

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