A Broadband Bandpass FSS Filter in Terahertz Region

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Abstract

A terahertz (THz) bandpass filter has been presented in this manuscript based on frequency selective surfaces (FSS). The presented structure is very simple and of compact design with various rectangular metallic patches, showing a bandpass characteristics in THz region lying between 6.4 THz and 23.9 THz. The structural design along with the evolution of the geometrical shape of the unit cell has been discussed. The center frequency of the filter is around 15.15 THz with 3-dB bandwidth of 17.5 THz. The structure provides ultra-thin nature and can be used for spectroscopy and imaging applications in infrared domain.

1. Introduction

Due to wide available bandwidth, researches on terahertz (THz) domain have generated keen interest globally [1]. Terahertz wave filters have been used as crucial manipulating device towards terahertz sensing, communication, imagining system etc. [2]. Frequency selective surfaces (FSS) have been proposed for various transmission and reflection characteristics to the electromagnetic waves (EM) over different frequency domain [3]. Till date, various THz FSS filters have been proposed including a high pass filter working in the THz region consisting of wire arrays of the order of micron and an innovative two-dimensional silicon photonic crystal based bandpass filter [3, 4]. Tunable THz filters have also been proposed employing liquid crystal [5-6]. THz bandpass filters have also been made using metallic mesh; however, the operating wavelength of the filter is not adjustable [2].

In this literature, a terahertz bandpass filter based on frequency selective surfaces consisting of a dielectric substrate sandwiched between two metal plates is presented. Top surface of the substrate consists of two vertical rectangular-shaped metallic patches while the back side of the substrate contains two horizontal rectangular-shaped metallic patches. The dimensions of the metallic patches and the square metallic border in the unit cell of the back-side plate are exactly identical as that of the front side plate having different alignments of the patches. The structural evolution has been presented to show the optimized geometry of the proposed unit cell. The parametric studies of several geometrical dimensions have also been carried out to obtain the best possible transmission characteristics in the passband. Finally, the optimized FSS filter possesses a huge 3-dB bandwidth of 17.5 THz with the center frequency at 15.15 THz in the lower THz range which can be very much efficient for the futuristic terahertz applications. The structure provides better option in comparison with other structure for its comparatively flexible design and its simplicity.

2. Design of the Unit Cell of the Bandpass Filter Structure

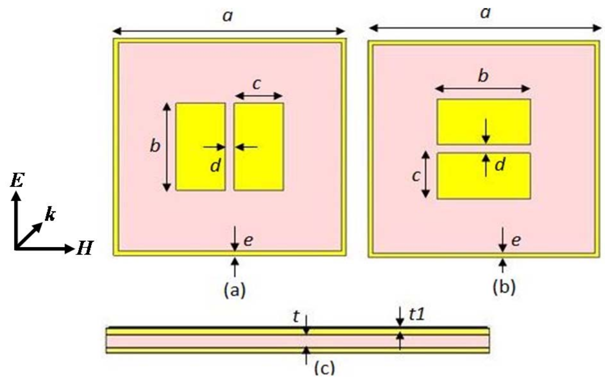
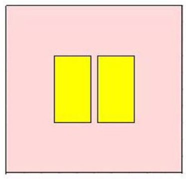
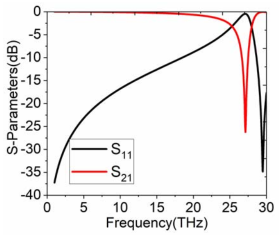
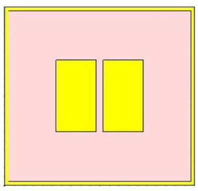
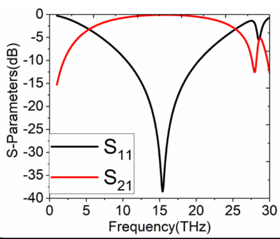
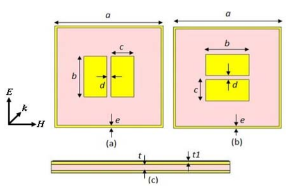
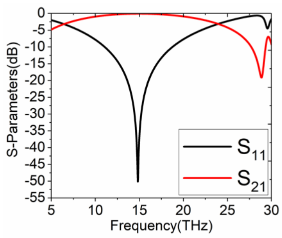


Figure 1. (a) Top view, (b) bottom view and (c) side view of the unit cell of the proposed FSS along with direction of wave propagation (Period of the unit cell (*a*) =10 μm, Length of the metal patch (*b*) = 4 μm, Width of the metal patch (*c*) = 2.12 μm, Distance between two metal patches (*d*) = 0.4 μm, Width of the metal border (*e*) = 0.2 μm, Thickness of the dielectric (*t*) = 0.2 μm, Thickness of the metal patch (*t1*) = 0.1 μm).

The top view, bottom view and side view of the unit cell of the proposed bandpass filter is shown in Figure 1(a)-(c) respectively. The optimized geometrical dimensions of the parameters are mentioned in Figure 1 for wide passband in THz region. The top surface of the unit cell structure consists of the vertical rectangular-shaped metallic patches made of gold, characterized using Drude model. A square shaped metallic border made of gold has also been used as shown in Figure 1(a). The bottom side of the unit cell comprises horizontally placed rectangular-shaped gold patches nested in square ring made of gold. These gold patches have been made on amorphous SiO_2 substrate (relative permittivity of 3.9 and loss tangent 0.0006 at the frequency of interest).

Table 1: Evolution of the Geometry along with Responses

Evolution of geometry	**Responses**
 (a)	
 (a)	
	

The evolution of the finally optimized geometry has been carried out using a number of steps shown in Table 1. At first the design of the FSS bandpass filter is initiated with a very basic design consisting of two vertical metallic patches on both top and bottom sides of the dielectric. This structure while interacting with incident EM wave of frequency near 26.3 THz shows low transmission coefficient (S_{21}) as shown. Next a square-shaped metallic border is incorporated in the structure as shown in Table 1. Now, due to the combined effect of the metallic border and the vertically placed rectangular-shaped metallic patches, reflection minima at frequency near to 15 THz is observed as its response. Finally, the bottom rectangular-shaped metallic patches are placed horizontally in the bottom surface which provides enhanced passband between 6.4 THz and 23.9 THz. Simultaneously, the reflection coefficient is minimized to -50.1 dB at 15.15 THz. Thus, 3-dB bandwidth of 17.5 THz has been achieved with respect to the center frequency of 15.15 THz, thus yielding a fractional bandwidth of 115.51 %.

3. Simulated Results

The reflection and transmission coefficients of the proposed band pass filter is shown in Figure 2 with identical patterning and orthogonally oriented patterning of the top and bottom metallic patches. Different reflection and transmission spectra have been observed for the FSS geometry under two different (TE and TM) modes of operation as shown in Figure 2(a). Hence, to achieve 4-fold symmetry in the structure the metal patches of the backside of dielectric are rotated orthogonally by 90^0. This leads to nearly identical responses of the reflection and transmission spectra for TE and TM modes as illustrated in Figure 2 (b).

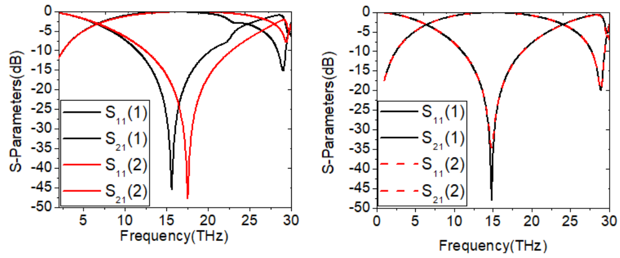


Figure 2. (a) S-parameter response of the FSS having same design on both the sides of the dielectric. (b) S-parameter response of the final FSS.

The response has been studied under variations of different geometrical dimensions. Initially, the variation of transmission coefficient (S_{21}) and the reflection coefficient (S_{11}) of the proposed filter has been studied with respect to the variation of metal border width (*e*) while all the other parameters are kept constant as shown in Figure 3(a). As the value of *e* increases, the net inductance gets enhanced which decrease the frequency of operation of the higher cut-off frequency of the proposed bandpass filter. The bandwidth is found to be maximum for $e = 0.2$ µm.

The responses of transmission and reflection characteristics with the variation of metal patch length (*b*) has also been performed and shown in Figure 3(b). Here, S_{11} drops down to -65 dB at $b = 4$ µm though for other values of *b*, it is in between -30 to -40 dB. Hence, the optimum value of *b* is chosen as 4 µm shown in Figure 3(b).

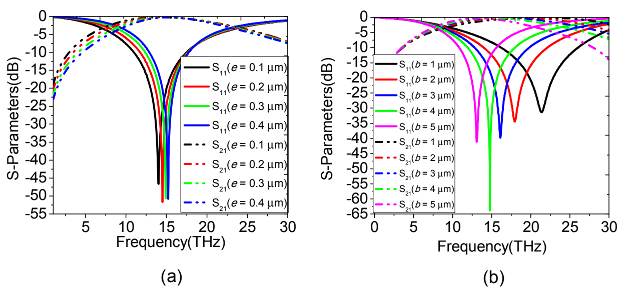


Figure 3: Variation of S-parameters with respect to variation in the width of the metal border (*e*) and patch length (*b*).

An interesting behavior of the transmission and reflection spectra has been experienced by performing the variation of the patch width (*c*). As the value of *c* increases, the resonant frequency decreases, so it may happen that this geometrical parameter controls the cut-off frequency towards the lower sideband. The best result is achieved at $c = 2.12$ µm. The increase in c increases the total equivalent capacitance of the FSS and hence the resonating frequency is shifted towards the left which can be determined from Figure 4(a).

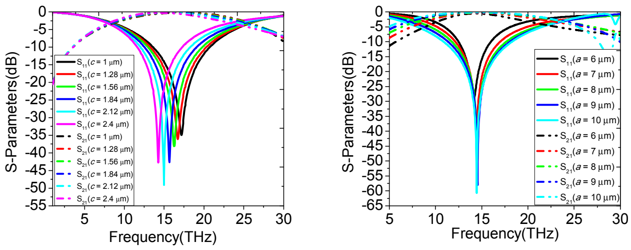


Figure 4: Variation of S-parameters with respect to the variation of patch width (c) and periodicity of the unit cell (a).

While increasing the periodicity of the unit cell dimension **(*a*)** keeping the other parameters constant, the slots present in the surface increases in size compared to the metal. Hence, less energy gets trapped which results in increase of bandwidth and the attenuation of S_{11}. At a =10 µm the best result is achieved and is taken as the optimum value for a and it is in the order of λ/2 with respect to the centre frequency pertinent to the obtained frequency range. This is illustrated in Figure 4(b).

Since the structure possesses 4-fold symmetry for both TE and TM modes of operation, the structure offers polarization insensitivity in its S_{11} and S_{21} responses as evident from Figure 5(a). The structure has also been studied under oblique incidences where the wideband bandpass characteristics has been observed till 30□ incident angles as observed in Figure 5(b).

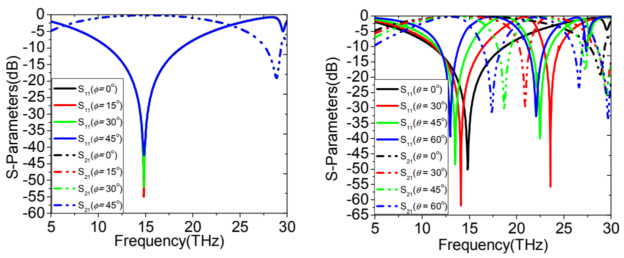


Figure 5: Variation of S_{11} and S_{21} under different angles of polarization *(ϕ)* and different angles of incidence (θ) of the electromagnetic wave.

The performance of the proposed structure is compared with respect to the existing literatures of THz bandpass filters as provided in Table 2. It is found that the proposed structure offers superior performance in comparison with the state of the art literatures.

Table 2: Performance of proposed bandpass filter with respect to existing bandpass filters

Terahertz Passband Filter	3-dB Bandwidth (THz)	Fractional Bandwidth	Thickness (µm)
Feng Lan *et al.*[8]	0.027	8.7%	λ/7
Amir Ebrahimi *et al.* [9]	0.1	25%	λ/5.53
Shruti Nirantar et al. [10]	0.189	45%	λ/5
M. Hussein et al. [11]	0.075	40%	λ/6.4
De Song Wang et al. [12]	0.021	3.1%	λ/19.1
Amir Ebrahimi *et al.* [13]	0.18	45%	λ/6
De Song Wang *et al.* [14]	0.044	5.17%	λ/15
Proposed structure	17.5	115.51%	λ/66

4. Conclusion

A FSS broadband bandpass filter has been proposed in this manuscript offering a bandwidth of 17.5 THz, exhibiting a maximum attenuation of -50.1 dB at 15.15 THz. The evolution of the finally optimized design of the unit cell of the bandpass filter has been carried out. Thus, it offers a fractional bandwidth of 115.5%. The structure is exhibiting broadband bandpass filter response till 30^0 incident angle and provides polarization insensitivity. The structure is ultrathin in nature having thickness of approximately λ/66. This filter can be used for future applications like in IR spectroscopy and IR photography.

Acknowledgement

Authors like to acknowledge Dr. Abhijit Banerjee and Mr. Anirban Saha for their continuous support. Dr. Bhattacharyya likes to acknowledge SERB, Govt. of India for funding of the research grant.

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