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Microstrip microwave band gap structures

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Abstract. Microwave band gap structures exhibit certain stop band characteristics based on the periodicity, impedance contrast and effective refractive index contrast. These structures though formed in one-, two- and three-dimensional periodicity, are huge in size. In this paper, microstrip-based microwave band gap structures are formed by removing the substrate material in a periodic manner. This paper also demonstrates that these structures can serve as a non-destructive characterization tool for materials, a duplexor and frequency selective coupler. The paper presents both experimental results and theoretical simulation based on a commercially available finite element methodology for comparison.

Keywords. Microwave band gap; microstrip; gap width; frequency selective switch.

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1. Introduction

The conventional free standing microwave band gap structures (MBG) are huge in size and therefore do not permit the use for practical applications. Therefore, efforts are on to reduce the size of the structure either by increasing the dielectric contrast or by choosing other kinds of transmission lines. Use of high dielectric constant materials results in high reflectivity or scattering from the surface and therefore the spacing between the materials alone controls the stop band characteristics. Hence one cannot achieve small structures as expected. Though waveguide-based microwave band gap structures can be used as a one-dimensional MBG structure, the length of the structure will be large.

To effectively decrease the size of the MBG structure, stripline methodology can be employed. The microstrip transmission line offers one-dimensional propagation of microwave radiation. Though one can expect a loss by radiation, a shorter propagation distance makes the loss within the acceptable limit. It is known that microstrip devices such as filters, resonators, couplers and antennas are made by modifying the geometry of the strip. The behaviour of these systems is easily explained by the equivalent lumped electrical circuit parameters and does not come under the category of band gap structure due to the absence of periodicity. Radisic *et al* [1] developed a microstripline by creating two-dimensional honey-comb lattice with circular holes around the microstripline. The other method is by patterning the metallic top of the printed circuit board and connect the top metal and ground plane through the substrate [2]. Recently, Fei Zhang *et al* [3] have reported planar band gap structures that are formed by etching square slots or cross slots on the ground plane. Similar such work was also reported by Naoyuki Shino and Zoya Popovic in 2002 [4]. Sang Soon Oh *et al* [5] developed duplexer by removing the substrate material selectively in the plane.

In this paper, MBG is constructed by periodically removing the substrate material in the microstripline. This creates a one-dimensional periodicity in the impedance. The substrate material used in this paper is a lossless polytetraflouroethylene. In this one-dimensional MBG structure, it is possible to create various defects such as removing the material from a lattice site (acceptor defect), changing the size of the substrate at a given lattice site and replacing the material with a different material at a given lattice site. This defect creates a defect mode within the band gap region. Apart from being small in size, these structures also help in the non-destructive evaluation of materials. This paper reports the formation of the defect mode due to the defect and also uses this defect mode to characterize the photoconductive nature of a semiconductor. By extending the structure in a two-dimensional plane, a duplexer and a frequency selective coupler are fabricated.

2. Experimental arrangement

The MBG structure was formed by taking a polytetraflouroethylene (PTFE) as the substrate material. The substrate with a thickness of 1 mm and width 10 mm was fixed on the copper ground plane. The substrate was then selectively removed from the ground plane such that the gap between two substrate pieces (each having a length of 5 mm) is 5 mm. A copper strip of width 4 mm and thickness 0.1 mm is used as the top conductor of the microstripline. The schematic of the MBG structure is shown in figure 1a. The periodic lattice of PTFE–air combination has the dielectric contrast (defined as the ratio between the dielectric constant of the substrate to that of the background, air) of 2.08. At both ends of the microstrip MBG, two sub-miniature adapter (SMA) coaxial connectors were placed.

The measurements as well as theoretical analysis were also performed by creating an acceptor defect by removing the centerpiece of the substrate (figure 1b). A parallel-type duplexor and a plus-type frequency selective coupler were designed and their performances were checked numerically.

The measurement of transmission and reflection coefficients in the frequency range 10 to 30 GHz was performed using Agilent N5230A microwave vector network analyzer. The numerical simulations are performed using FEMLAB package.

3. Results and discussion

The numerical simulation performed in the frequency range 5 to 20 GHz region indicates that the microwave band gap appears between 10.83 and 14.3 GHz for the structure without any defect. Creation of acceptor defect introduces a defect

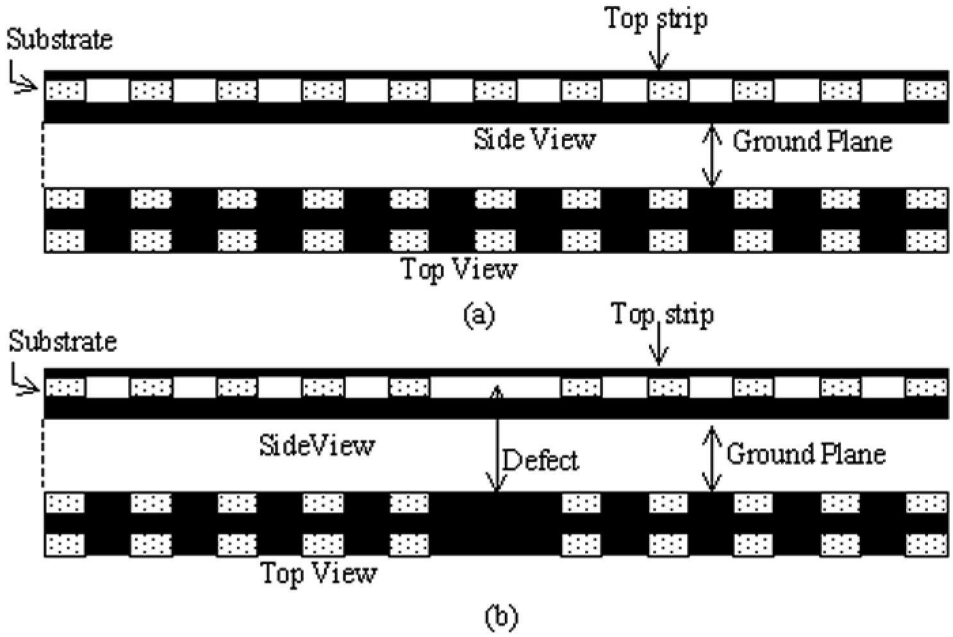

Figure 1. The microstrip microwave band gap structure, (**a**) without a defect and (**b**) with an acceptor defect.

at around 11.51 GHz. The width of the defect mode is around 0.35 GHz (figure 2). Figure 3 presents the measured transmitted power for both pure and defect structures. The defect mode appears around 11.6 GHz and the width is 0.38 GHz giving a very good agreement between the experiment and theory. It may be noted that the attenuation in the simulation is around 20 dB whereas in the measurement it decreases to around 12 dB. This may be attributed to the effect of the SMA connectors, exact alignment of the PTFE pieces and proper alignment of the top copper strip. Moreover, the striplines are bound to generate higher-order modes as the frequency increases beyond 15 GHz. By increasing the number of elements, the attenuation in the band gap region can be increased. Simulation having 21-element lattice structure indicates that the attenuation increases by around 20 dB. Also, it reduces the width of the defect to around 0.15 GHz. This shows that as one increases the number of elements, the stop band becomes narrow and deep. It is suggested that one has to compromise with the length of the structure and the value of the attenuation or the width of the band gap. Simulation also suggests that if the 8th element in the 11-layered structure are from the input port, there is a shift of defect mode to 11.35 GHz. This dependency of the defect mode to the position of the defect is the consequence of the finiteness of the structure along the propagation direction [6]. It may be noted that even for a smaller value of dielectric contrast (2.08), one gets a good stop band characteristics. Nagesh *et al* have also reported a considerable stop band characteristics for the two-dimensional band gap structures formed using PTFE [7].

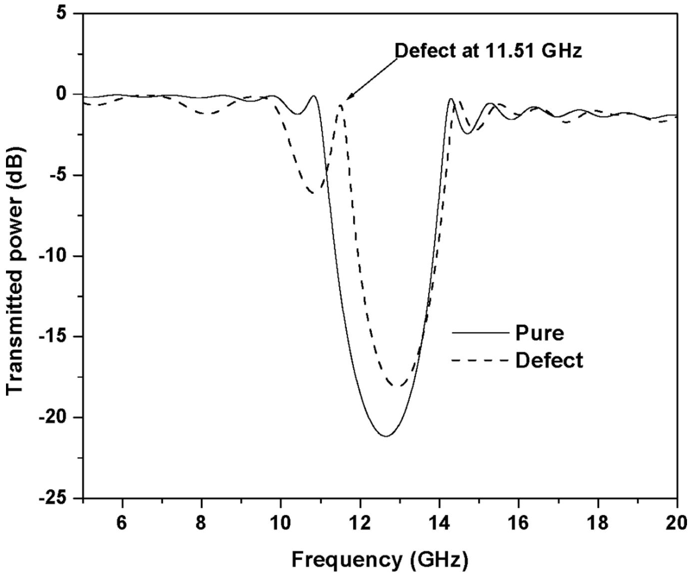

Figure 2. Theoretical simulation of the transmission spectra for the pure and defect structures.

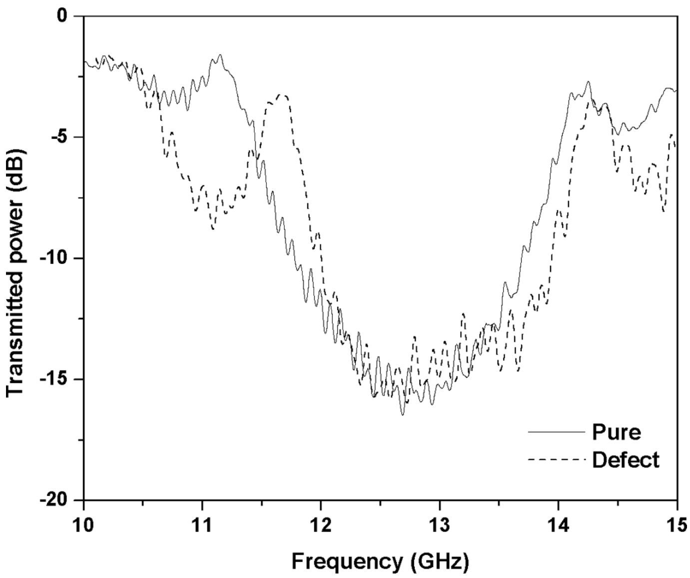

Figure 3. Experimental result obtained for the pure and defect structures.

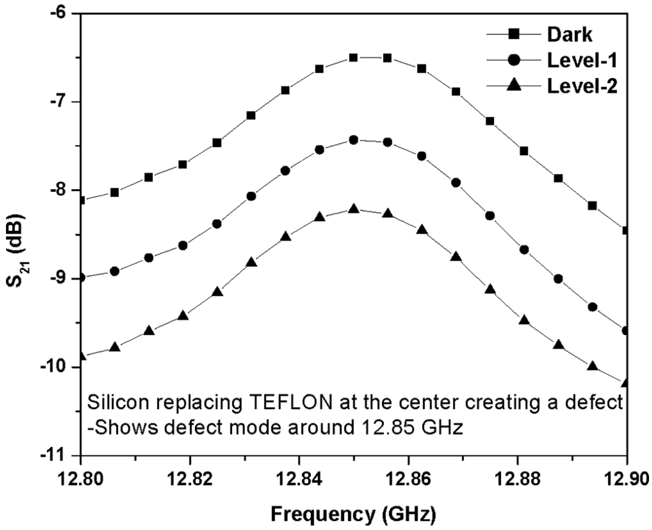

Figure 4. The formation of defect mode due to replacement of a PTFE substrate piece with an intrinsic silicon and the variation of transmitted power under photo-excitation.

To study the nature of hetero-defects, an intrinsic silicon sample replaced the 6th element of the PTFE. A defect mode is induced at around 12.5 GHz. This mode can be used for the non-destructive evaluation of conductivity. Figure 4 shows the decrease in the defect mode power level with increase in the conductivity of the sample due to photo-excitation. This is due to the increase in the absorption of the microwave with increase in the conductivity.

Another important application is the use of these structures as a duplexer. This structure is constructed using two independent microstrip MBG structures sharing the same ground plane and situated parallel to each other with a gap of 10 mm (figure 5a). It may be noted that the spacing between the two substrate pieces is 8 mm for the structure with Port 3 whereas the structure with Port 2 has a spacing of 10 mm. Figure 5b shows a plus-type frequency selective coupler. This structure has two MBG structures with acceptor defect located at the center. While the structure with Port 2 has a spacing of 10 mm between the two substrate pieces, the structure with Port 3 has a spacing of 8 mm. The transmitted spectra for S_{21} and S_{31} for the structure in figure 5a are presented in figure 6. This indicates that at frequencies 13.8 and 24.1 GHz, the transmitted power at both ports suffer an isolation greater than 20 dB and greater than 30 dB respectively. From figure 7, one can observe that when the power is fed to Port 1, the transmission suffers 12 dB more attenuation at Port 3 compared to Port 2 at 12.2 GHz whereas Port 3 transmits more by 12 dB at 15.1 GHz and equally at 14 GHz compared to Port 2. One can use similar such structures to generate a three-dimensional microstrip frequency selective transmission at different ports.

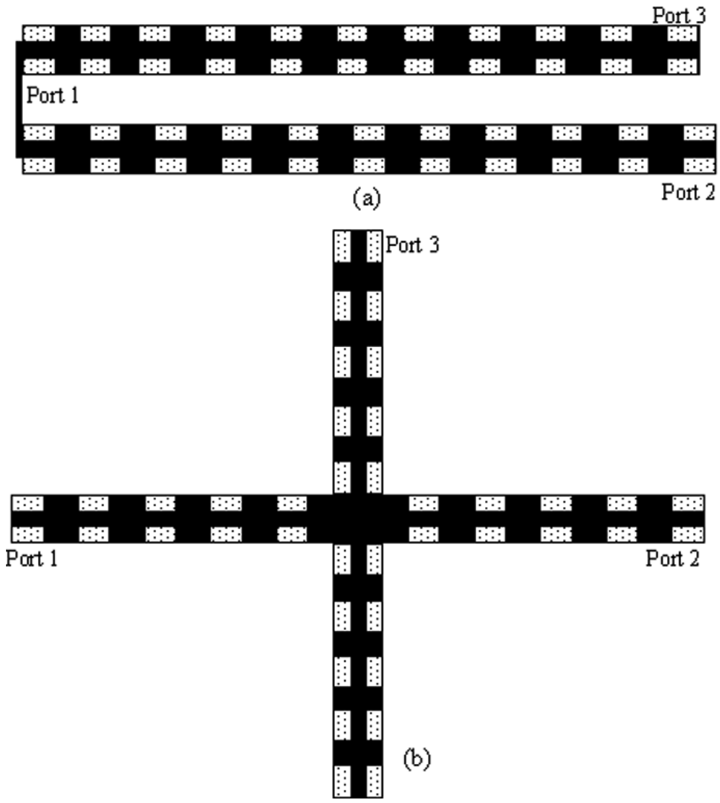

Figure 5. (**a**) The top view of a parallel duplexor. The input power is fed at Port 1 and transmission is observed in Port 2 and Port 3. (**b**) The top view of the plus-type frequency selective coupler based on defect-induced MBG structure.

4. Conclusion

Microwave band gap structures had been fabricated on the microstrip transmission line by selectively removing the substrate to create a periodic one-dimensional lattice. The finite-sized structure was of length 100 mm with the substrate material made of lossless polytetrafluoroethylene (dielectric constant 2.08) of width 10 mm and length 5 mm. The air gap between the substrate pieces was 5 mm. The structure exhibited band gap between 10.83 and 14.3 GHz, which was also confirmed with the experiment. The creation of acceptor defect by removing the centerpiece of the substrate resulted in the creation of defect mode at 11.51 GHz and of width around 0.35 GHz which was also confirmed by the experimental result showing defect mode around 11.6 GHz and a gap of around 0.38 GHz. Theoretically it is observed that by increasing the number of elements, the attenuation at the band gaps increased and the sharpness of the defect mode increased. This indicates that even with lesser dielectric contrast, it is possible to get good stop

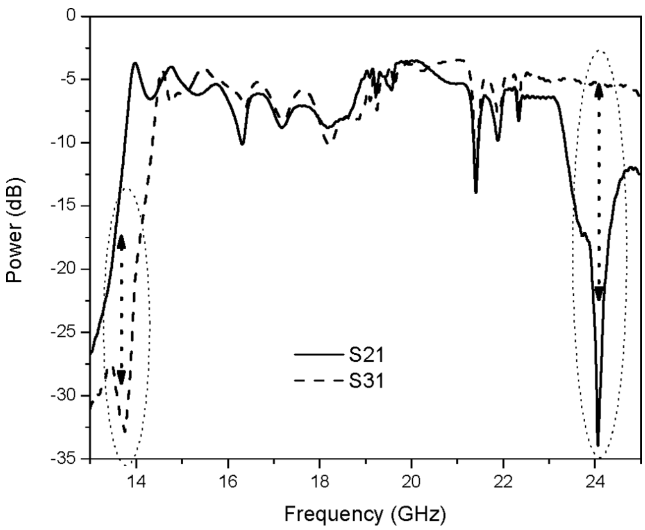

Figure 6. Transmission spectra of the parallel duplexor. Lesser transmitted power at Port 3 compared to Port 2 at 13.8 GHz and lesser transmitted power at Port 2 compared to Port 3 at around 24.1 GHz.

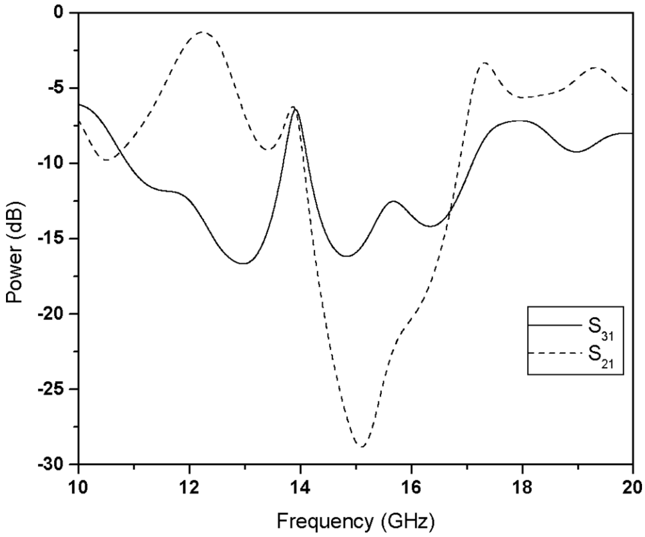

Figure 7. The transmission spectra between Ports 1 and 2 and between 1 and 3 for the structure given in figure 5b.

band characteristics. The controlling of the electromagnetic radiation was possible by employing two frequency selective switches. Use of such MBG structures for the non-destructive evaluation of material properties was demonstrated by replacing the substrate with silicon.

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