Tunable Millimeter-Wave Band-Stop Filter Using Electromagnetic Crystal (EMXT) Surfaces

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1 Introduction

Electromagnetic crystals (EMXT), also known as photonic bandgap crystals when used in optical applications, are periodic electromagnetic structures that may consist of both dielectric and conductors. The term 'bandgap' has its origin in the 'band-stop' characteristic of transmission through the bulk of the structure or along the surface of the structure. EMXTs exhibit this rejection band at a 'resonant frequency'. The type of EMXT surfaces discussed here provides a high impedance surface at the resonant frequency [1]. In recent years, because of their unique EM properties, EMXT surfaces have received growing interest and been used in many microwave and millimeter wave applications, such as antenna ground plane [2], TEM waveguide [3], and bandpass filter [4]. While combined with actively tunable devices or materials, an EMXT surface with a dynamically controllable bandgap can be realized. This may have great potentials in many modern and future systems requiring frequency and phase agility, multi-band, and multi-function capabilities. A novel millimeter wave phase shifter has been demonstrated using tunable EMXT surfaces [5].

This paper presents the results of band-stop filters using the high surface impedance EMXT surfaces as the top and bottom walls of a rectangular waveguide. Fixed-tuned waveguide band-stop filters using passive EMXT surfaces with different resonant frequencies were made and demonstrated. Tunable EMXT surfaces based on InP heterostructure barrier varactors (HBV) were fabricated and used to demonstrate a proof-of-concept band-stop filter with its rejection band tuned from 31 to 36.3 GHz with a dc bias voltage from 0 to 10 Volts.

2 EMXT Surfaces

The EMXT surfaces used in this paper are composed of a thin dielectric substrate that has a solid ground plane on the backside and periodic stripes of conductor separated by narrow gaps on the front side (Fig.1). Through substrate vias are used to suppress undesired substrate modes. For an incoming EM wave with the E-field polarization perpendicular to the conducting strips long dimension, this EMXT exhibits high surface impedance at certain resonant frequency (center of the bandgap). The resonant frequency of an EMXT surface depends on its geometry and material properties, for example, the substrate thickness, the conducting strip width, the gap between adjacent strips, and the permittivity and permeability of the substrate. EMXT surfaces with tunable resonant frequency can be achieved by loading adjacent strips with varactors, as shown in Fig. 2.

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In this work, both passive and active EMXT surfaces were designed and fabricated. Because of their periodicity, a unit-cell design approach is usually accurate enough. Rogers Duroid RO3006 of relative dielectric constant 6.15 and loss tangent 0.013 at 35 GHz was used as the substrate of the passive EMXTs. By varying the conducting strip width and the gap width between adjacent strips, EMXT surfaces with resonant frequency from 35 to 39 GHz were made. Varactor (InP HBV) based tunable EMXT surface was also fabricated monolithically on 3" InP substrate wafers. With a dc bias voltage from 0 to 10V, the resonant frequency of the InP EMXT surface was tuned from 31 GHz to beyond 40 GHz [5].

3 EMXT Band-Stop Filter Results

Figure 3 shows a picture of an EMXT waveguide band-stop filter. The top and bottom walls of a section of regular WR28 waveguides are replaced by the striped-EMXT surfaces, with the strips oriented perpendicular to the wave vector in the guide to inhibit longitudinal surface currents. Since no longitudinal fcurrent is allowed to flow along the EMXT surface within its bandgap, the dominant TE and TM modes are inhibited and an effective band-stop filter can be realized in this configuration.

For the fix-tuned waveguide, 20-mm long passive EMXT surfaces with different resonant frequencies were used as the top and bottom walls of a WR28 waveguide. Figure 4 shows the transmission results of the fix-tuned waveguide with EMXT bandgap at 35 and 39 GHz. The direct correspondence between the bandgap and the stop band of the waveguide is illustrated in Figure 5. The reflection phase of the 35 GHz EMXT is plotted to the right y-axis and the waveguide transmission response is plotted to the left y-axis. It is clear that the EMXT bandgap (31 – 40 GHz across which the reflection phase of an incoming EM wave varies from –90 to 90 degrees) coincides very well with the stop band of the waveguide filter. 70 dB (20mm EMXT) of isolation was achieved for the stop band. Finite-element simulations have confirmed the measured waveguide responses.

The InP HBV based tunable EMXT discussed in the previous section was also used to demonstrate a proof-of-concept tunable band-stop filter. In this case, due to limited samples, only 3-mm long InP EMXT surfaces was used as the top and bottom walls of a WR28 waveguide. As shown in fig. 6, the stop-band center of the waveguide was tuned from 31 to 36.3 GHz with a dc bias voltage of 0 to 10 Volts. Because of the short length of the EMXT walls, only 5 – 6 dB of isolation was achieved for this tunable band-stop filter. It was worth noting that in contrast of the EMXT waveguide phase shifter described in reference [5], the loss associated with the series resistance of the tuning devices of the EMXT surface near its resonant frequency would not impact the performance of the band-stop filter. Instead, the resonant loss would enhance the band rejection of the filter and lower the reflected power.

4 Conclusions

Fix-tuned and actively tunable waveguide band-stop filters at millimeter wave frequencies were demonstrated. The rejection band is a direct reflection of the EMXT bandgap so that the EMXT design determines the center frequency and the bandwidth of the filter. The fix-tuned waveguide was measured to have up to 70 dB of isolation for the rejection band and less than 2 dB of insertion loss for the pass band. The center of the stop band for the waveguide using InP HBV EMXT surfaces was tuned from 31 to 36.3 GHz with 0 to 10 Volts of dc bias. The results indicate that with optimized design, high performance tunable millimeter-wave filters with adjustable center frequency and bandwidth can be realized.

Acknowledgement

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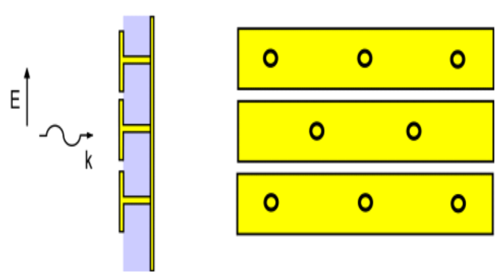

Figure 1. Side view (left) and top view (left) of a passive striped-electromagnetic crystal (EMXT).

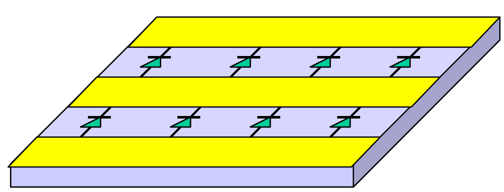

Figure 2. Schematic drawing of a tunable EMXT surface with varactors loaded between adjacent conducting strips.

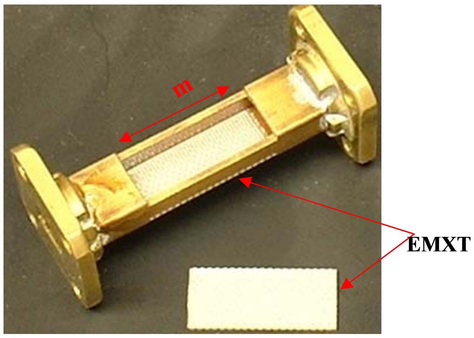

Figure 3. A picture of the waveguide band-stop filter with its top and bottom walls replaced by passive striped-EMXT surfaces.

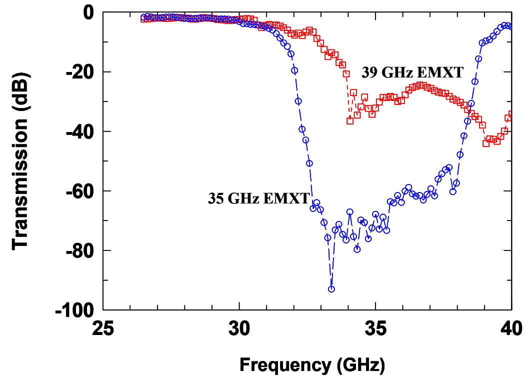

Figure 4. Measured transmission response of the fix-tuned waveguide with 20-mm long EMXT surfaces (bandgap centered at 35 GHz and 39 GHz) as the top and bottom walls.

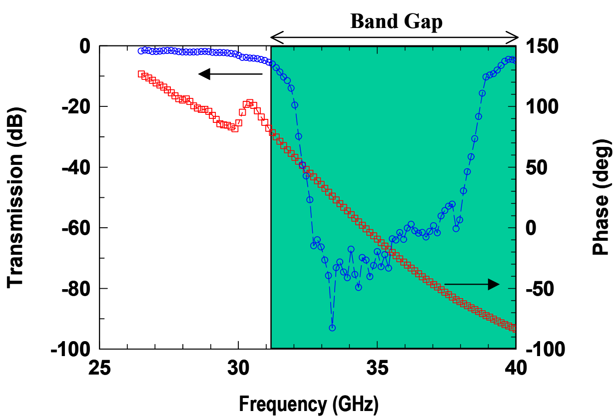

Figure 5. Measured transmission response of an EMXT waveguide (left y-axis) and reflection phase of the EMXT surface used as the top and bottom walls of the waveguide (right y-axis).

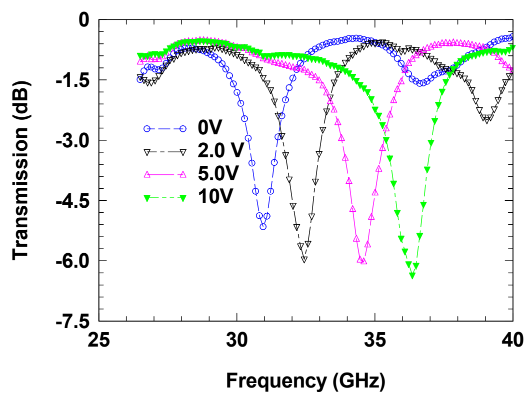

Figure 6. Measured transmission response of the tunable waveguide with 3-mm long InP HBV tuned EMXT surfaces as the top and bottom walls.