Switchable directional filter based on defect-control by plasma discharge within a metallic EBG structure

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Abstract

Using plasma discharges to control partial propagation mode of an Electromagnetic Band Gap (EBG) structure presents interesting advantages: plasma discharge parameters (i.e. electronic density and collision frequency) are easily tunable to match the need in terms of microwave propagation. In this paper, our aim is to investigate the use of localized plasma discharges within a metallic EBG structure. We showed that plasma discharges may be used to compensate defects within an EBG, and thus, to design a switchable directional filter based on metallic EBG.

1. Introduction

Electromagnetic Band Gap (EBG) materials are periodical structures allowing the control of electromagnetic wave propagation by creating diffraction characteristics such as frequency stop-bands, pass-bands and band-gaps. Since Yablonovitch et al. realized a 3D EBG structure in the late 1980ǒs [1], periodic structures continue to fascinate the research community and many investigations have been carried out to analyze their exotic properties (anisotropy, forbidden band-gap and negative refraction index [2]). EBG materials in the microwave range have been studied during the past few years in the context of antenna, filter, frequency selective surface, and resonator design [3]. Plasma discharges, on the other hand, may be seen as a medium potentially interesting to change or to control the properties of an EBG structure. The plasma electronic density, hence the plasma dielectric constant is tunable simply by modifying the discharge parameters. Recent studies by Hojo et al. and Sakai et al.[4,5], proposing plasma photonic crystal showed one possibility of the use of plasma discharges in an EBG structure: plasmas are used as basic array element of an EBG structure. The plasma arrays generation in an EBG structure may however be complex and cause energy losses. Therefore, focusing on single or localized plasma discharges to control EBG properties is another alternative as shown by our previous work [6], where defects within an EBG structure are exploited.

Generally, defects are inserted within an EBG structure in order to create an allowed band within the frequency band gap. Our main focus here is however to use defects to control the already existing partial propagation band [6, 7]. Compared to our previous work [6] where plasma discharges were used as added defect elements to control the EBG mode, this paperǒs purpose is to present experimental results where plasma discharges may also be used to compensate and nullify the presence of defects.

3. Experimental setup

The schematic of our experimental setup is as shown in Fig.1(c) where a square lattice metallic EBG structure is investigated with a step size, a = 10 mm. Metallic rods with diameter d = 2 mm are distributed in a triangular form in order to reduce parasitic reflections. Previous papers [6, 7] showed that this arrangement is an EBG system allowing diagonal wave propagating mode around 45° in Fig.

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1(c) for frequencies in the 18 GHz range, the 0x propagation direction being forbidden. A 50 mm width pyramidal wave source antenna has been specifically designed and positioned to form an unstable cavity with the EBG. This instability allows easy modification on the coupling between the incident wave and the EBG; by introducing localized defects at the interface of the EBG, the diagonal propagation modes may be turned on or off. The EBG structure operates then as a directional filtering device.

Two metallic rods positioned at *(x,y) = (0, ± a)* have been removed and replaced with plasma discharges as seen in experimental setup shown in Fig.1(a)-(b). The plasma discharges are generated in a 3 mm internal diameter discharge tubes, illustrated in Fig. 1(d). A thermionic cathode is placed at the high end part of the tube in order to easier initiate the discharge. A DC voltage source is connected to the other end while up to 3 kV pulse is used to ignite the discharge in Neon at 40 Torr gas pressure. Plasma discharge currents values are made to vary from 0 mA to 120 mA, resulting to electronic density estimation up to 2.10^{13}cm^{-3}. With the plasma complex permittivity defined with the classical expression:

$$\varepsilon_r(\omega) = 1 - \left(\frac{\omega_p}{\omega}\right)\left(1 - j\frac{\nu_m}{\omega}\right)^{-1}$$

where ω_p is the plasma angular frequency, ω is the angular frequency of the incident wave and ν_m is the electron-neutral collision frequency, the real part, Re(ε) is then definitely negative.

Scattering parameters measurements have been carried out with an Anritsu vector network analyzer. A receiver antenna is then placed at the radius of 50 cm from the reference point *(x,y) = (0,0)*, for angular direction varying from 0° to 90° in Fig.1(c).

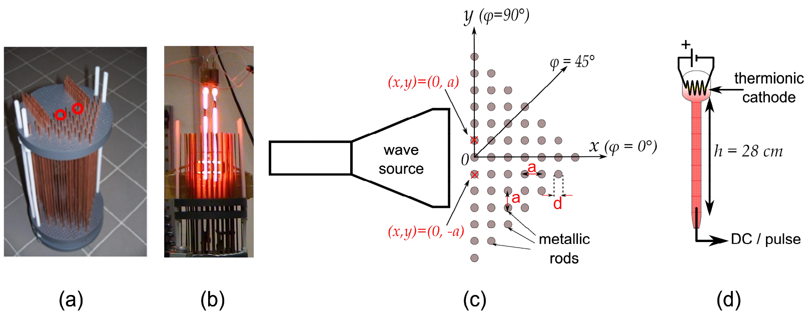

Fig. 1: (a) experimental EBG structure, discharge plasmas positioned at red circles (b) experimental EBG structure with plasma discharge tubes, (c) schematic of EBG structure with d = 2 mm diameter metallic rods distributed in a square lattice with a = 10 mm step size, (d) schematic of 3 mm internal diameter discharge tube used to replace metallic rods positioned at *(x,y)=(0,± a).*

4. Results and discussion

Fig. 2 (a)-(c) show the scattering parameters measured for different discharge currents where two metallic rods positioned at *(x,y) = (0, ± a)* have been removed and replaced by plasma tubes described earlier. In Fig. 2(c), if we observe the frequencies ranging from 17.75 GHz to 18.75GHz, a decrease up to 20 dB is registered in the reflected wave when two of the designated metallic rods are replaced by discharge tubes. In Fig. 2(b), the reflected waves decreasing, in parallel with the transmitted waves increasing, show us that the EBG structure is quite adapted for transmitting microwave energy towards the diagonal direction. Once the plasma is switched on, the transmitted waves in the diagonal direction is reduced, reflecting more the waves back to the source. In Fig. 2(b) and (c), the higher the current, the closer the behaviour with the ñperfectò EBG configuration is observed. In Fig. 2(a), an increase in the transmitted waves is observed in the 0x direction. Explanation comes from the fact that the number of rows in the 0x direction is reduced; hence the band gap effect is also reduced. We did do not seek to ameliorate the band gap effect in this direction as the transmitted level is still low compared to the one in the 45° direction in all cases.

All observations made previously may be explained by the fact that the defects introduced on the EBG interface play a major role in source-EBG interface coupling. Since plasma discharges wear a variable complex permittivity value, controllable with the varying discharge parameters (n_e and ν_m), the coupling can be modified up to a certain extent by replacing the defects with plasma discharges. The plasma discharges used may not necessarily be identical in size with the metallic rods replaced or provide conductivity as high as metallic rods. A certain plasma diameter - electronic density - collision frequency combination may be achieved in order to nullify the source-EBG coupling which excite diagonal propagation direction.

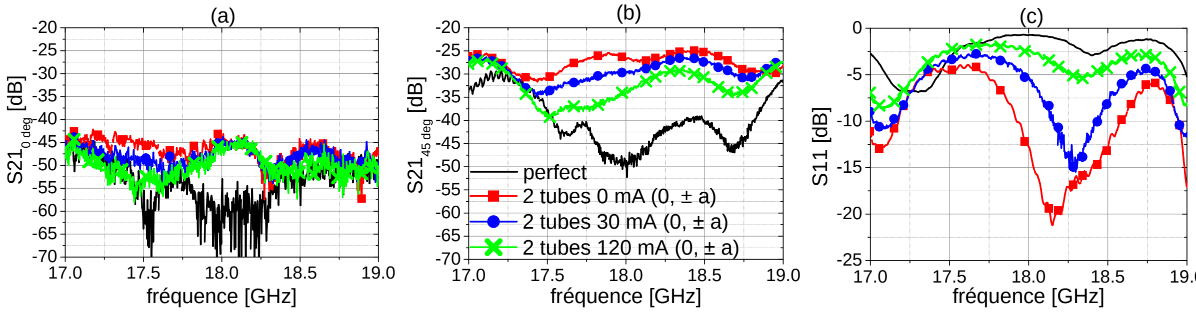

Fig. 2: Scattering parameters in function of signal frequencies for different current discharges, illustrating the transmitted waves in 0x direction (a), the transmitted waves in the diagonal direction at 45° (b), and the reflected waves (c). The ñperfectò configuration corresponds to the case when all the initial metallic rods are present, the ñ2 tubesò configuration to the case when the discharge tubes are positioned at (0, ±a) replacing the metallic rods. Plasma discharges are switched on for different current once the discharge tubes are placed. The transmitted waves for different angular direction, S21, are measured at the radius of 50 cm from the reference point *(0,0)*.

5. Conclusion

Experimentally, we have shown another possibility to use plasma discharges in order to control an EBG directional filter device in frequencies varying from 17.75 GHz to 18.75 GHz. The plasma is used to compensate the defect created at the interface of an EBG, modifying the source-EBG coupling. Anisotropic propagation mode of an EBG is therefore controlled.

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