2D electromagnetic band gap structure controlled by plasma

L.V. Simonchik, M.S. Usachonak

B.I. Stepanov Institute of Physics NASB, Minsk, Belarus

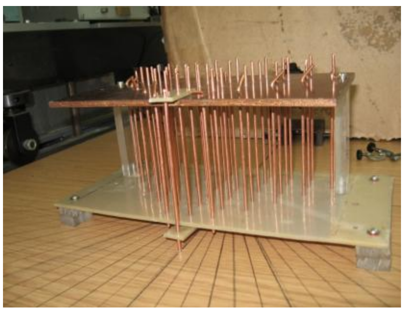
Introduction

Most of the modern devices, which utilize the electromagnetic band gap (EBG) effect, are built using metallic (or dielectric) elements. As a result, they have fixed parameters and do not allow fast reconfiguration and adjustment. At the same time, glow discharge plasma has a great potential for application as a control element in microwave devices [1]. The 1D EBG structure formed solely by plasma column in the waveguide was reported in [2]. The possibility to control microwave propagation by plasma columns through triangle 2D EBG structure was experimentally demonstrated in [3]. In this report, plasma control of microwave propagation through a triangle 2D EBG at high power is addressed.

Experimental situation

Triangle 2D EBG structure is formed by lengthy copper rods of 140 mm in length and 5 mm in diameter located in parallel to each other in square lattice points (fig. 1, *a*). The lattice spacing is 22 mm. This arrangement allows a diagonal propagating mode of wave (around ±45°) for the frequency of 9.15 GHz while it is forbidden for the principal propagating mode (0° direction). In order to excite the diagonal mode it is needed to introduce the defects in the front rod row of the EBG structure by removing two rods (fig. 1, *b*, *II*) or by adding a rod (or plasma column) (fig. 1, *b*, *III*).

a



b

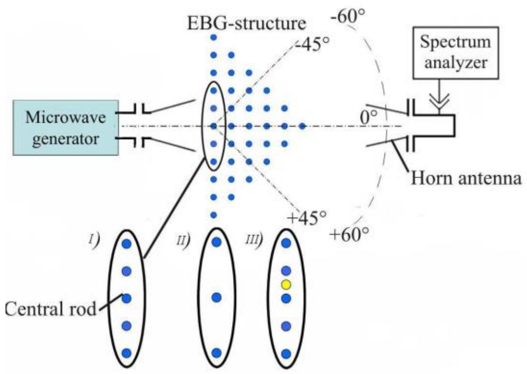


Fig. 1. *(a)* The triangle 2D EBG structure photo and *(b)* schematic of the experimental setup (*I* - perfect EBG structure, *II* – structure with tow vacations, *III* – structure with additional defect).

Structure is irradiated by continuous microwave radiation at frequencies in the range of 8.5 – 10.0 GHz using a horn antenna with the aperture of 110 × 50 mm^2 (directive gain 55 dB). The power of the generator G3-14A, which is used, is about 5 mW. Microwave radiation transmitted through the 2D EBG structure is received by horn antenna with the aperture of 23 × 24 mm^2 (directive gain 5.5 dB) and is registered using a spectrum analyzer C4-27. Receiving antenna with a waveguide-to-radio adapter is moved along a circular arc of 0.5 m in radius, centered in the middle of the base of the triangular periodic structure. This movement is realized within an angle range of ± 60° relative to the axis of the radiating horn antenna (fig. 1, *b*).

Plasma as a control element of the EBG structure

Let's consider the case of a defect of the first type (fig. 1, *b*, *I*). Directional diagram is registered at frequency 9.15 GHz (λ = 3.3 cm). This wavelength corresponds to a square lattice diagonal and to a wavelength of the radiation mode propagating in the direction of ± 45°.

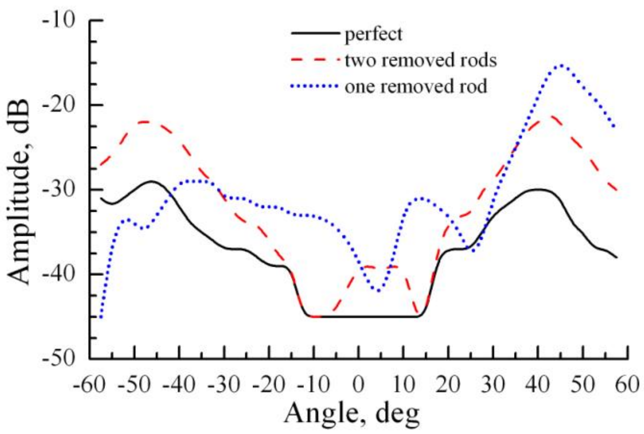


Fig. 2. Directional patterns of the 2D EBG structure.

When the structure has no defects (fig. 1, *b*, *I*), only weak microwave radiation reaches the receiving antenna, where the signal level is 1000 times lower (fig. 2, solid curve) than the microwave radiation signal from the radiating horn antenna without 2D EBG structure. If two rods neighbouring to the central rod in the first row are removed (fig. 1, *b, II*), then microwave radiation begins to propagate in directions ± 45° and signal level grows up on7 dB (dashed curve). If only one rod is removed, then a microwave signal increases on 15 dB (dotted) at the side of removed rod.

Let's place the plasma columns in the places of removed rods, i.e. plasma will be used as the defect compensators. For this purpose we use the discharge lamps GSh-5, filled with neon at a pressure of 70 Torr. The inner diameter is 3 mm, outer - 4 mm, length 200 mm. The operating current of each lamp is 70 mA at the interelectrode voltage of about 200 V. According to the estimations made by means of the reduced electric field strength in the lamps, the electron concentration in positive column is 0.7×10^{13} - 3.5×10^{13} cm^{-3} at the discharge currents in the range of 30 – 120 mA. These concentrations are one order of magnitude higher than the critical electron concentration for frequency of 9.15 GHz, which equals 1.1×10^{12} cm^{-3}. Dependence of the transmitted microwave radiation signal in the direction of ± 45° on the plasma density of the GSh-5 lamp is shown in fig. 3. It is seen that the increase in discharge

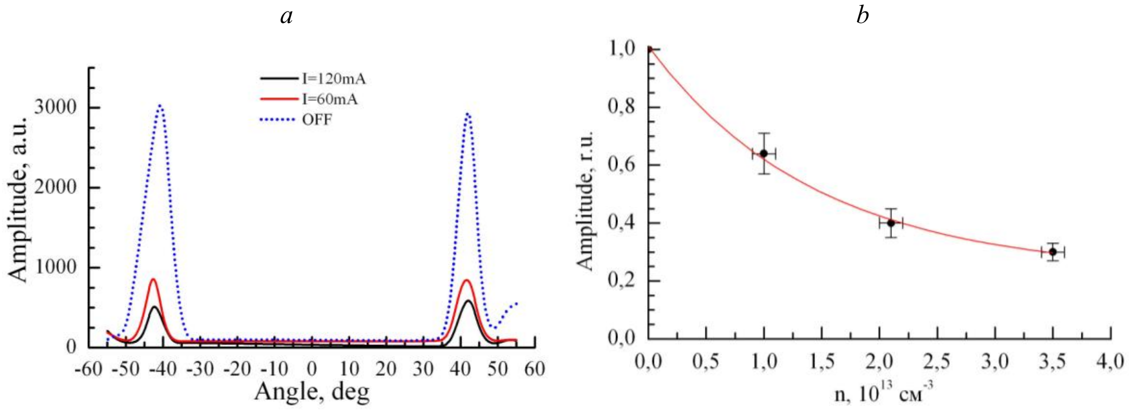


Fig. 3. *(a)* Directional pattern of the 2D EBG with plasma and *(b)* dependence of the transmitted microwave radiation signal in the direction of ± 45° versus the electron density magnitude in the lamp GSh-5 plasma.

current up to 120 mA leads to about four times decrease in the transmitted microwave signal, i.e. the regularity of triangle 2D EBG structure becomes restored (fig. 3).

The 2D EBG structure at high microwave power

The 2D EBG structure is irradiated by powerful (about 50 kW) microwave radiation at frequency 9.15 GHz with pulse duration of about 150 ns. Due to the high power it is possible to visualize microwave transmission through the structure. The signal neon lamps MTX-90 are used for this purpose (fig. 4, *a*). Let's place the metallic rod in the place of additional defect (fig. 1, *a*, *III*). When the powerful generator is turned on, the MTX-90 lamps located close to the direction of 45^{o} start to glow.

Let an additional defect be formed by the plasma positive column of a GSh-2 lamp. Unlike the GSh-5 lamp, this lamp is longer and its internal diameter is 6 mm. Under the influence of the incident powerful microwave the breakdown of neon occurs in the tube and microwave radiation begin to propagate in the direction of 45^{o}. As a result, the MTX-90 lamps located close to the direction of 45^{o} light up (fig. 4, *b*).

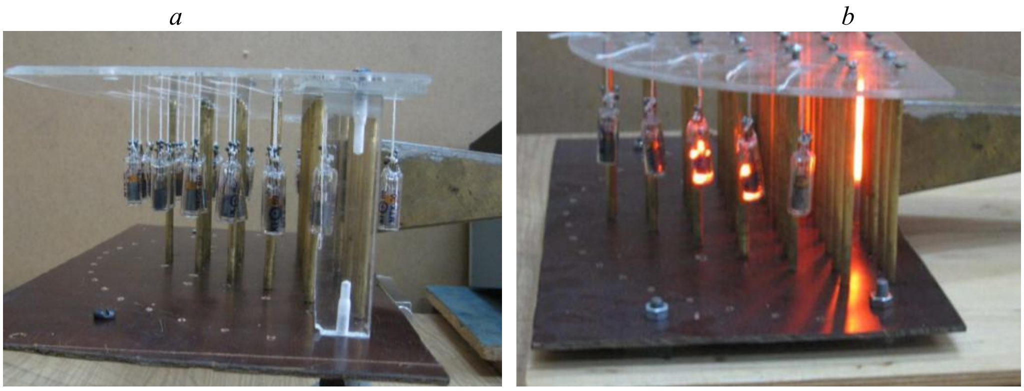


Fig. 4. Photos of the 2D EBG structure with signal lamps: powerful microwave is turn off (*a*) and turn on (*b*).

The waveforms of pulses transmitted through the 2D EBG structure with additional defect are shown in fig. 5, *a*. When the structure is perfect, then the weak microwave signal is registered in the direction of 45° (solid curve in fig. 5, *a*). The dotted curve in fig. 5 represents a microwave pulse waveform when a metallic rod (diameter 5 mm) is used as a defect. It is seen that these curves are similar and differ only by the signal amplitudes. For the case of plasma defect (GSh-2 lamp), pulse waveform is slightly changed (dashed curve). The main changes occur on the leading edge of the pulse. We observe the delay of about 30-40 ns. This time probably corresponds to the time of electron density growth.

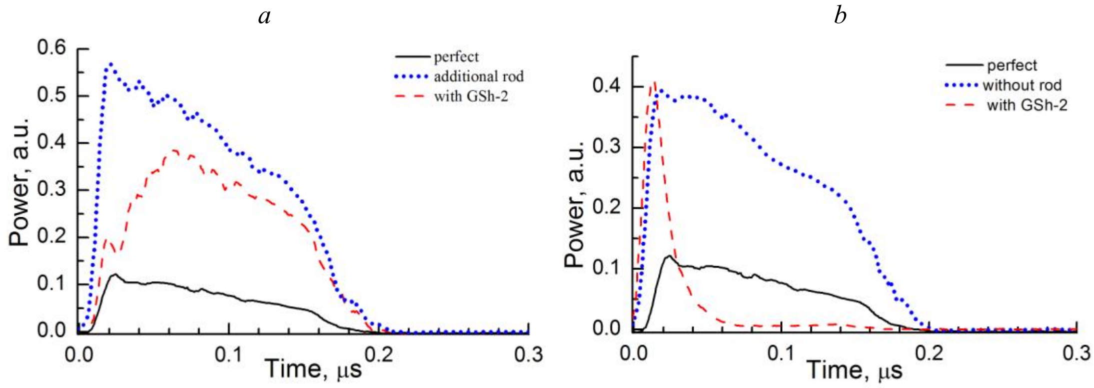


Fig. 5. The waveforms of the microwave pulses transmitted through the 2D EBG structure in case plasma is an additional defect (*a*) and a defect compensator (*b*).

Let now the GSh-2 lamp be used as a defect compensator. The corresponding waveforms of the pulses transmitted through the 2D EBG structure are shown in fig. 5, *b*. Again, the waveforms of pulses for the cases of the perfect structure (solid curve) and the structure with removed rod (dotted) differ only by the magnitudes. Transmitted pulse is quite different when the GSh-2 lamp is used as a defect compensator. The transmission in this case takes place during a short period, which is less than 20 ns. This time is defined by the time of electron concentration rise as a result of a microwave breakdown.

Conclusions

The feasibility of using a switchable plasma channel to control the anisotropic behavior of an 2D EBG structure has been demonstrated. It is shown that plasma control of periodical EBG structures can be possible at high microwave power (more than tens of kiloWatts).

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References

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