Study on transmission characteristics of two-dimensional defective plasma photonic crystals

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Abstract. Several defective plasma photonic crystals were designed based on crystal edge dislocations, and their transmission characteristics were studied using CST software. The transmission characteristics of PPC with different defects in TM mode are mainly discussed. Compare defective PPCs to non-defective PPCs and other defective PPCs. Defective plasma photonic crystals with the largest changes in PPC electromagnetic characteristics were obtained. This type of defective photonic crystals can create a band gap in a certain frequency band and control its movement through defect parameters.

1. Introduction
The concept of photonic crystal was introduced by E. Yablonovitch and S. John in 1987. [1-2], it refers to materials that are periodically distributed in space by different media. According to the medium distribution form, photonic crystals can be divided into three types: one-dimensional, two-dimensional and three-dimensional. Due to the Bragg scattering effect, photonic crystals can limit the propagation of electromagnetic waves at certain frequencies, forming a band structure---photonic band gap [3-4]. Another feature of photonic crystals is the localization of photons, that is, when the periodic distribution of the medium changes, photons can tunnel in the photonic band gap to form a defect mode. [5]. the above two characteristics of photonic crystals can be used to make practical devices such as filters, optical waveguides, and optical transistors.

After the preparation of conventional photonic crystals, their electromagnetic properties are determined accordingly. In order to make the photonic crystals more controllable, Hojo and Mase introduced plasma into photonic crystals in 2004 and proposed the concept of plasma photonic crystals [6]. Plasma photonic crystal is a material in which the plasma and other media are periodically arranged. The plasma can be adjusted by external adjustments such as plasma density, temperature and other parameters, as well as the spatial distribution of the plasma [7], to achieve the purpose of adjusting the electromagnetic characteristics of the photonic crystal. After more than ten years of development, plasma photonic crystals have become a hot research topic in the electromagnetic field due to their important basic research value and huge application potential. The current research work of PPC is based on theory, simulation and experiment. PPC products are still far from practical applications.

In this paper, some two-dimensional defect plasma photonic crystal models based on edge dislocations are designed, and the CST software is used to simulate the model of different defect PPCs.
The transmission characteristics of photonic crystals with different angles in TM mode and the defect PPC are obtained. The transmission characteristics have been investigated to some extent.

2. Calculation method and model of plasma photonic crystal

2.1. Calculation method

At present, there are several calculation methods for solving photonic crystals. The Transfer Matrix Method (TMM) is an analytical method. Based on the Maxwell equations, iterative equations of the electric and magnetic fields are derived based on the continuity boundary conditions of the magnetic and electric fields to obtain plasma photons. Crystal reflection, transmission characteristics, and dispersion relationship [8].

The FDTD method is a commonly used method for calculating the dispersion relationship of plasma photonic crystals. This algorithm uses a basic Yee cell to mesh the computing area space, and the E and H field components at the nodes are alternately arranged in space and time. Convert Maxwell’s rotation equation with time variables into difference equations, and gradually advance the solution of electromagnetic fields in space on the time axis [9].

2.2. Calculation method

In this paper, a square lattice photonic crystal is used, and a 4 * 6 plasma column array is used as a medium, and the air in the middle of the plasma column is another medium. As shown in Figure 1:

![Figure 1. (a) Stereogram of Defect free plasma photonic crystal (b) plane graph](image)

The diameter b of the plasma columns in the model is 26mm, and the column spacing a is 13mm. Plasma. The plasma in the model is described by the drude model, considering the specific plasma frequency wp the correspondent relative permittivity is given as:

\[ \varepsilon(\omega) = \varepsilon_{\infty} - \frac{\omega_p^2}{\omega(\omega - i\nu_c)} \]

In the formula, the plasma density \( \omega_p \) is \( 4.7 \times 10^{10} \) rad / s, and the plasma collision frequency \( \nu_c \) is \( 1.45 \times 10^{10} \). The electromagnetic wave is incident from the right red waveguide along the positive direction of the z-axis. The boundary in the x-axis direction of the model is set as a periodic boundary to simulate the electromagnetic effect of an infinite-length plasma column. The boundaries in the y and z-axis directions are all absorption boundaries. The polarization direction of the electromagnetic wave is the X-axis direction.

Figure 2 shows the plane graph of defective PPC. Figure 2(a) is the defect if edge dislocation in PPC. It comes from lattice defects in materials science. And it evolved into the other defective PPC in Figure
2. Figure. 2(d), Figure. 2(b) and Figure. 2(c) can be grouped together. Duplicate the middle two rows of plasma columns and open them at an angle, remove any other plasma columns they encounter. They’re like special edge dislocations. Another group of defective PPC, Figure. 2(d), Figure. 2(e) and Figure. 2(f), made by the same process but there are no duplicate steps. In the edge dislocation PPC the values of c and d are 44mm and 16mm. The angles $\beta$ in Figure. 2(d), Figure. 2(e) and Figure. 2(f) are 7.5°, 15° and 22.5°. The other group has the same angle $\beta$.

![Diagram](image)

**Figure 2.** Plane graph of defective plasma photonic crystal. The curve (a) is the defect of dislocation. (d) (b) (c) and (d) (e) (f) are two groups of defects.

3. Result and discussion
Figure 3 is the overall picture of all model S21 parameters, in the figure, the trend of all curves from high frequency to low frequency is consistent, the transmittance is low in the low-frequency region, and as the frequency increases, the transmittance gradually increases. This is because when the frequency of the electromagnetic wave is lower than the plasmon resonance frequency, the plasma appears metallic. At this time, the plasma has a strong reflection effect and weak transmission; and when the frequency of the electromagnetic wave is higher than the plasmon resonance frequency, the plasma metal attenuation is reduced, and the transmission effect is enhanced. At the same time, we can see that in the frequency band higher than 10GHz, the s21 curves become stable and the gap is small, so we will look at the range of 2~10GHz.
From Figure 4. (a), we can see that the simple edge dislocation has a very limited effect on the transmission characteristics of the plasma photonic crystal. Between 4-8GHz, the reflection effect of edge dislocation defect crystals is slightly larger than that of non-defective crystals due to the addition of two plasma columns, so the transmission of defective crystals is smaller than that of non-defective crystals in this frequency range. In Figure 4 (b) we can get similar conclusions. However, as the opening angle in the right group is larger, the plasma columns are smaller, so it can be seen that as the angle increases, the transmittance of PPC is higher in the low frequency range.
In groups b, c, and d, things are something different. As shown in Figure 5, in the range of 2 to 4 GHz, it can be clearly seen that there is a band gap on the PPC transmission curve of the 30° defect and the 45° defect, and the band gap moves with the change of the defect angle. In addition, according to the experience of the first two groups of controls, the plasma columns of the 2 (b) and 2 (c) groups are less than the non-defective PPC, and their transmittance should be greater than that of the non-defective plasma. The transmittance in the 4GHz range is significantly smaller than that of non-defective PPC. This shows that the defects introduced in this group have caused a large change in the transmission characteristics of PPC in the 2 ~ 4GHz.

4. Conclusion
In summary, I designed several PPC based on edge dislocation 2D defects and simulated their transmission characteristics using CST software. One of these defective PPCs greatly changes the transmission characteristics of the original PPC in a certain frequency band, so that the PPC can obtain the band gap in a certain frequency band, and the band gap can be moved by adjusting the defect parameters. At the same time, I learned that when building photonic crystals, it is necessary to use materials with large differences in dielectric constants as much as possible, and it is easier to obtain more significant experimental results. It has accumulated valuable experience for subsequent experiments. It also provides a theoretical reference for the design of photonic crystal defect mode devices.

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