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Calculation and Fabrication of Photonic Crystal with Diamond Structure*

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Abstract: The plane wave propagation method was used to calculate the band gap width of photonic crystals (PCs) with diamond structure. When the lattice constant of the crystal is 8.5mm, the PC has a maximal band gap width of about 3.5GHz. In this case, the frequency of the band gap ranges from 15.3 to 18.7GHz. A computer solid model of a photonic crystal with diamond structure was designed. The epoxy PC was fabricated by stereolithography. The fabricated epoxy PC is 7.40mm × 36.54mm × 54.32mm in size, and the periodic numbers of the crystal in the x, y, and z directions are 2, 4, and 6, respectively. The transmission of microwaves from 10 to 20GHz was measured along the ⟨100⟩ direction by an HP network analyzer. A band gap is formed in the range of 14.7～18.5GHz. The magnitude of the maximum attenuation is as large as −30dB at 17.3GHz, indicating that the fabricated structure works well as a photonic crystal.

Key words: photonic crystal; band gap; stereolithography
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1 Introduction

Since the pioneering work of Yablonovitch and John in 1987[1,2], periodic dielectric structures exhibiting a complete photonic band gap (PBG) have attracted considerable attention. There have been numerous attempts to design and fabricate three-dimensional (3D) PBG structures because of their wide potential applications in optics, especially in the visible and near-infrared region[3,4]. These applications may include telecommunications[5,6], zero-threshold microlasers[7], light-emitting diodes[8], all-optical chips [9], optical switches[10], and the control of thermal emission[11].

PCs with diamond structure[12] exhibit a larger PBG than PCs with other structures constructed with the same material system. However, it is still difficult to fabricate a diamond structure due to its complexity by using usual methods such as drilling holes and the self-assembly of microballs.

SLA was developed in 1986. It was invented to build three-dimensional structures, especially in millimeter or sub-millimeter scale. SLA can fabricate 3D structures no matter how complicated they are. In SLA, the structures are fabricated point by point and layer by layer by scanning liquid photopolymer resin with a UV laser. The minimum fabrication size of SLA can reach a few hundreds of micrometers, and the production accuracy can be controlled to around 50μm. Since the lattice size of microwave-PCs is on the order of millimeters, SLA is a possible choice for the fabrication of PCs with diamond photonic structure.

In this work, the plane wave propagation method was used to calculate the characteristics of the band gap. The computer model of the optimized PC was designed. The epoxy PC was fabricated by SLA. Furthermore, the transmission of microwaves was measured by an HP network ana-

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lyzer.

2 Theoretical calculation

The unit cell of a PC with diamond structure is shown in Fig. 1. R and L are the radius and length of the dielectric rods, respectively, and a is the lattice constant for the ⟨100⟩ direction. The plane wave propagation method was utilized to calculate the characteristics of the band structures to determine the parameters R, L, and a. The parameter RA is defined as $\sqrt{2}R/a$, which affects the shape of the structure. The dielectric contrast was fixed at 9 during the calculations.

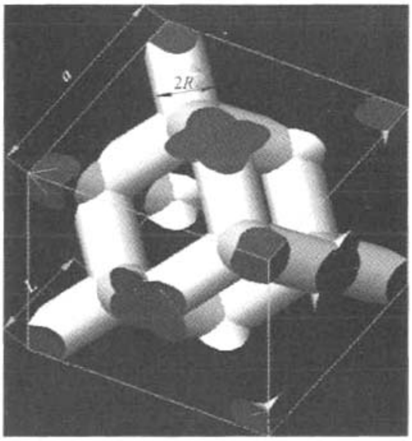

Fig. 1 Unit cell of photonic crystal with diamond structure

The relationship between PBG and RA is shown in Fig. 2. PBG increases with the increase of RA. After reaching the maximum value, it drops to zero. It can be seen in Fig. 2 that the structure with RA = 0.16 has the largest PBG located at a frequency region between the eighth and ninth bands, which is shown in Fig. 3. The horizontal axis represents wave vector. The coordinates of points Γ, X, and L are $[000]$, $\frac{2\pi}{a}[100]$, and $\frac{2\pi}{a}\left[\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}\right]$[13]; and as shown in Fig. 4, Γ-L, Γ-X, and Γ-K indicate the ⟨111⟩, ⟨100⟩, and ⟨110⟩ directions, respectively. Thus, the lattice size was optimized as 8.5mm, and then R and L were 0.47 and 2.99mm subsequently.

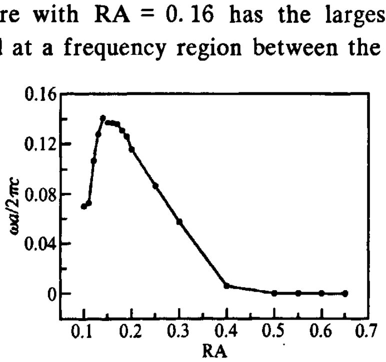

Fig. 2 Relationship between PBG and RA

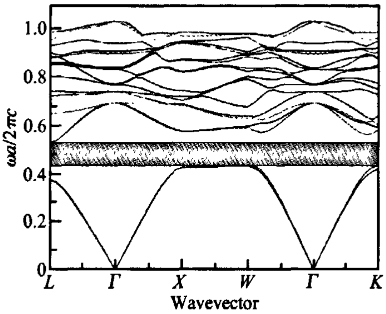

Fig. 3 Theoretic band structure of photonic crystal with RA = 0.16

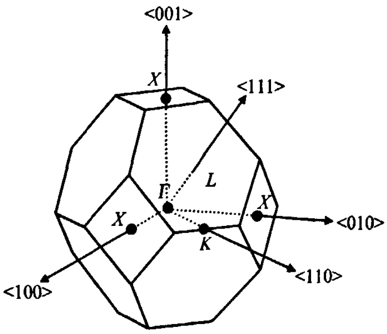

Fig. 4 First Brillouin zone of photonic crystal

Figure 5 is the computer model of the structure. The periodic numbers of the structure in the x, y, and z direction are 2, 4, and 6, respectively.

The photonic band gap structure was fabricated by SLA based on the CAD model. Figure 6 shows a photograph of the fabricated structure, which is 7.40mm × 36.54mm × 54.32mm in size. There is slight deformation compared with that of the model.

The attenuation of the microwave transmission amplitude through the samples was measured by using an HP network analyzer and microwave cavities. The transmission of microwaves from 10 to 20GHz was measured in the ⟨100⟩ direction,

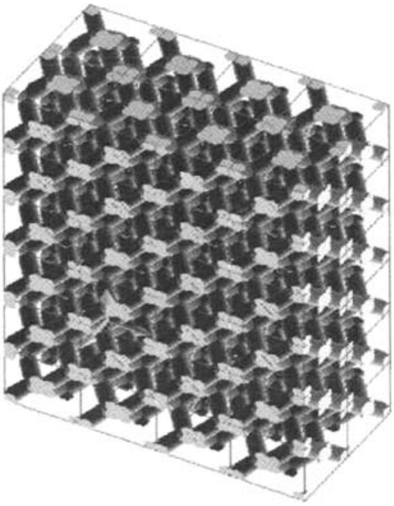

Fig. 5 Computer model of photonic crystal

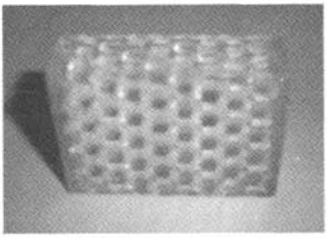

Fig. 6 Photograph of the obtained photonic crystal sample

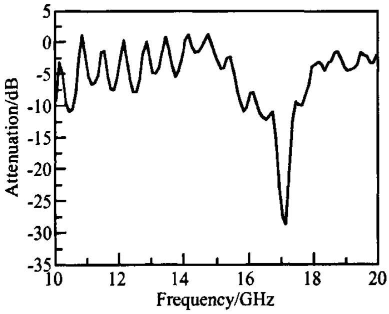

Fig. 7 Attenuations of transmission amplitude of microwaves as a function of frequency in ⟨100⟩ direction

and the result is shown in Fig. 7.

The result shows that the photonic crystal band gap opens in the frequency range from 14.7 to 18.5GHz, which corresponds well with the theoretical results, and the maximum attenuation was about −30dB at 17.3GHz.

3 Conclusion

A three-dimensional photonic crystal with diamond structure has been optimized. Epoxy PC has been fabricated successfully by stereolithography. The transmission of microwaves from 10 to 20GHz was measured in the ⟨100⟩ direction by an HP network analyzer. A band gap is formed in the range of 14.7～18.5GHz. The magnitude of the maximum attenuation is as large as −30dB at 17.3GHz, which indicates that the fabricated structure works well as a photonic crystal.

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金刚石结构光子晶体的计算与制备*

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摘要: 通过平面波法计算金刚石结构光子晶体的禁带特征,得出:当 RA = 0.16 时,禁带宽度最大;当晶格常数 a = 8.5mm 时,对应的最大禁带宽度为 3.5GHz,对应的禁带范围为 15.3~18.7GHz.利用 CAD 软件设计了在 x,y,z 三个方向上的周期数分别为 2,4,6 的金刚石结构的光子晶体模型,并采用立体印刷技术制备出了 17.40mm×36.54mm×54.32mm 的三维微波金刚石光子晶体.最终通过 HP 网络测试仪对样品的禁带特征进行测试,结果表明:在晶体的〈100〉方向上存在频率为 14.7~18.5GHz 的光子禁带,这与理论值相一致.当电磁波频率为 17GHz 时,对应的衰减率为 −30dB.

关键词: 光子晶体; 光子禁带; 立体光刻
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