Control of Microwave Emission from Photonic Crystals by Lattice Modification†

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Abstract

Three-dimensional photonic crystals with periodic variations of the dielectric constant were fabricated by using a rapid prototyping method called stereolithography. Millimeter-order epoxy lattices with a diamond structure were designed to reflect electromagnetic waves by forming an photonic bandgap in the GHz range. Titania based ceramic particles were dispersed into the lattice to control the dielectric constant. The diamond lattice structures formed the perfect bandgap reflecting electromagnetic waves for all directions. Diamond structures with stretched lattice spacing were successfully fabricated as well, resulting in the directional transmission of microwaves. A microwave antenna head composed of the normal and stretched diamond structure was fabricated and achieved unidirectional transmission.

KEY WORDS: (Photonic Crystal) (Micro Joining) (Stereolithography) (Microwave) (Dielectric Material)

1. Introduction

Photonic crystals composed of dielectric lattices form a bandgap for electromagnetic waves [1-3]. These artificial crystals can totally reflect light or microwaves at a wavelength comparable to the lattice spacings. The bandgap can be controlled by varying structures, filling ratio, and dielectric constant of the lattice. Structural modifications, by introducing defects or varying the lattice spacing, can control the transmission of light or microwaves as well [4,5].

In our previous study, millimeter order epoxy lattices with diamond structures were fabricated by using a rapid prototyping method of stereolithography [6-8]. Titania-based particles with high dielectric constant were dispersed into the epoxy lattice. These photonic crystals formed a perfect bandgap in the frequency range of about 16-19 GHz, which prohibited the microwave propagation in all directions. Recently, we fabricated modified diamond structures with stretched lattice spacings in one direction. The bandgap shifted toward a lower frequency range depending on the stretching ratio of the lattice spacing.

In this study, the microwave transmission through the directional diamond structure was measured for various crystal directions. A model structure of a microwave antenna head composed of the normal and stretched diamond structure was fabricated.

2. Experimental Procedure

Three-dimensional diamond lattices were designed by using a CAD technique. A unit cell image of the diamond structure is shown in **Fig. 1-(a)**. The crystal sample of 50×50×50 mm in size was composed of dielectric rods of ϕ2.88×4.33 mm in dimension. The lattice spacing for the Γ-X <100> direction was 10 mm in length. **Figure 1-(b)** shows the modified diamond structure with the stretched lattice spacing for the Γ-K <110> direction and a stretching ratio of 150 %. A microwave antenna unit is shown in **Fig. 1-(c)**. The normal and stretched diamond lattices were joined together to achieve the directional transmission of microwaves.

The crystal samples were fabricated by using a stereolithography machine (D-MEC Ltd. SCS-300P). The titania-based particles of about 10 μm in average diameter were dispersed into the photosensitive liquid resin at 10 vol%. An UV laser of 100 nm in diameter was scanned on the liquid surface to draw the cross section of the diamond structure. Dielectric layers as thin as 150 μm in thickness were solidified, layer by layer, with a dimensional accuracy of 0.15 %.

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The band diagram of the diamond structure along symmetry lines in the Brillouin zone was calculated by means of the plane wave propagation method. The plane waves of 127 in number were propagated for the periodic structure composed of the dielectric lattice. The dielectric constant of the lattice material was measured by using a dielectric prove test kit (HP-8570B).
The microwave transmissions through the crystal samples was measured by using two mono-pole antennas and a network analyzer (HP-8720D). A mono-pole antenna for microwave emission was inserted into the center position of a crystal sample. Another mono-pole antenna was placed at an interval of 150 mm away from the center to receive the microwave. The transmission amplitude was measured for Γ-L <111>, Γ-X <100> and Γ-K <100> directions.

3. Results and Discussion

Figure 2-(a) shows (110) planes of a normal diamond structures fabricated using stereolithography. Titania based ceramic particles were dispersed uniformly without pores in the epoxy matrix. The measured dielectric constant of the lattice material was about 10. This crystal sample exhibited a perfect bandgap opening for all directions in the frequency range of 13.5-16.5 GHz. The measured bandgap agreed with the calculated one. The lattice structures were stretched along the Γ-K <110> direction for 125 and 150 % as shown in **Fig. 2-(b)** and **(c)**, respectively. The three-dimensional structures were processed exactly according to the CAD data. The reflection of waves shifted toward the lower frequency range with an increase in stretching ratio.

A microwave antenna head composed of the normal and stretched diamond lattice structures was fabricated to achieve the directional transmission as shown in **Fig. 1-(c)**. In the stretched part, the stretching ratio of the lattice spacing was 150 %. A mono-pole antenna for microwave emission was inserted into "Hole A" in **Fig. 1-(c)**. This position is at the interface between the normal and stretched lattice regions. The electromagnetic wave propagation from the directional antenna fabricated for the air space was observed by using a receiver mono-pole antenna. The microwave attenuations were measured for Γ-L <111>, Γ-X <100> and Γ-K <100> directions as shown in **Fig. 1-(c)**. The forbidden gap is formed in the frequency range of 11.5-14.5 GHz for the <110> direction. The bandgap shifted to a higher frequency

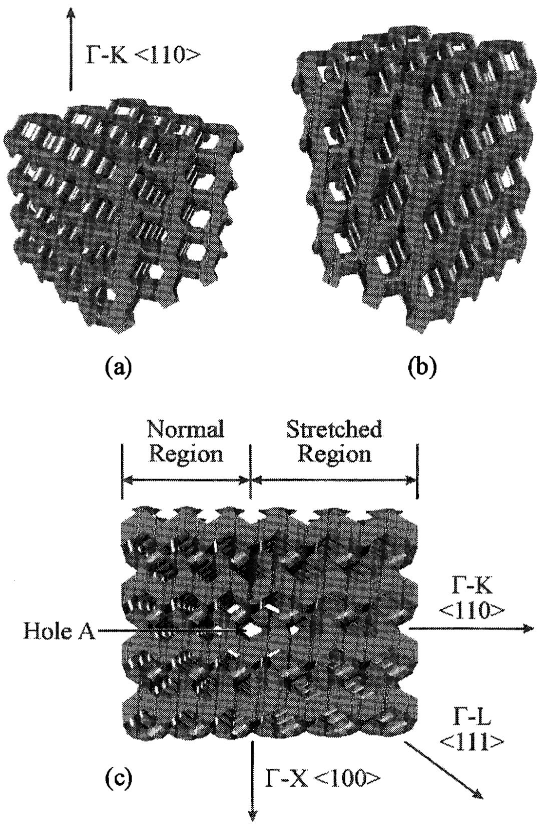

Fig. 1 Three-dimensional CAD models of photonic crystals with diamond lattice structures. (a) normal structure, (b) modified structure with stretched lattice spacing, (c) a directional antenna head composed of normal and stretched diamond structures.

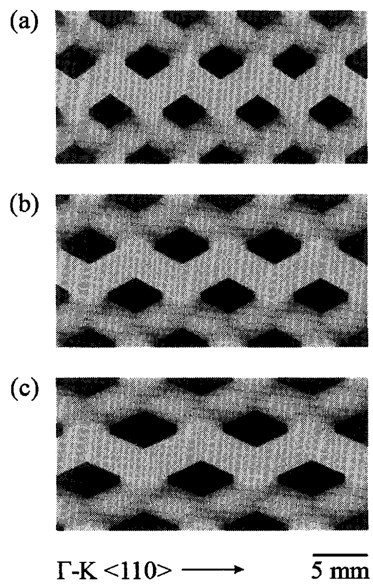

Fig. 2 The modified photonic crystals with the diamond lattice structures. (a) normal lattice, (b) and (c) stretched lattices for the Γ-K <110> direction at 125 and 150%, respectively.

range corresponding to the change of direction from <110> to <111>. For the <100> direction, the bandgap is formed in the similar frequency range of 13.5-17.0 GHz. When the microwave of ~15 GHz is emitted from the source antenna at Hole A, the wave can transmit for the <110> direction as shown in **Fig. 3**. The transmission amplitude was about +20 dB, meaning that the amplification of wave power occurs at two orders magnitude higher. The transmission amplitude through air was calibrated as 0 dB. In this case, the microwave transmission is considered to be collected successfully in the specific direction. **Figure 4** shows the emission profile for a microwave of 15 GHz from the directional antenna head to the air space. The transmission efficiency of microwaves was amplified for the limited direction in the range of 0-30 degree. This result means that the power and direction of microwave emission can be controlled by the structural modification of the diamond lattice.

4. Conclusion

The lattice modification of electromagnetic crystals having a diamond structure was investigated to control the microwave emission. The lattice structure was designed using CAD and the real lattice structures of titania-based ceramic particles dispersed epoxy were fabricated by using stereolithography. The normal diamond structure formed a perfect photonic bandgap in the frequency range of 13.5-16.5 GHz. Modified diamond structures having a stretched lattice spacing in the Γ-K <110> direction shifted the bandgap toward lower frequencies. A microwave antenna head combining the normal and stretched lattice structures exhibited amplified emission in the stretched direction.

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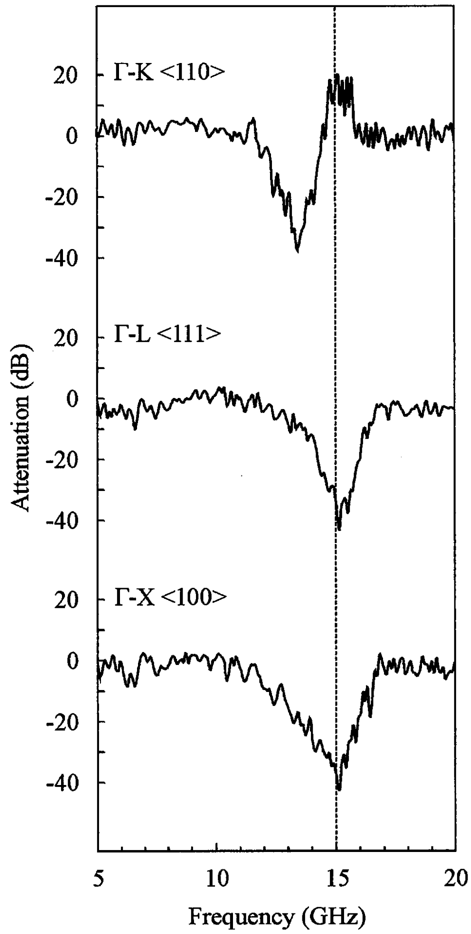

Fig. 3 Microwave attenuations of transmission amplitude through modified diamond structures with stretched lattice spacing for the Γ-K <110> direction.

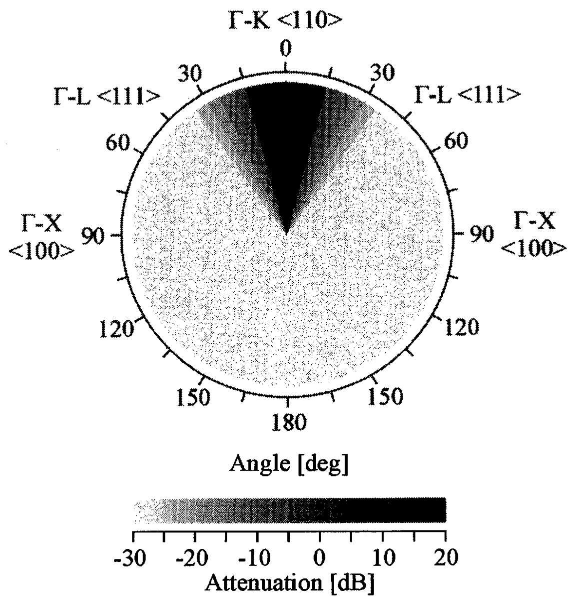

Fig. 4 A microwave emission profile through the crystal composed of the normal and stretched diamond structures.