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Terahertz Wave Properties of Magnetophotonic Crystals Fabriacated by Micro Stereolithography†

KIRIHARA Soshu*, NAKANO Maasa**

Abstract

Magnetophotonic crystals with periodically arranged magnetic materials can reflect the terahertz waves through Bragg diffraction. The micrometer order magnetophotonic crystals were fabricated by stereolithographic methods. In this process, the photo sensitive acrylic resin paste mixed with micrometer sized metallic glass and oxide glass particles was spread on a glass substrate in a 10 μm layer thickness by using a mechanical knife edge, and two dimensional images of UV ray were exposed with 2 μm in part accuracy. Through the layer by layer stacking, micrometer order three dimensional structures were formed. The metallic glass and oxide glass composite structures could be obtained through the dewaxing and sintering process with the lower temperature under the transition point of metallic glass. The amorphous structure formation after the heat treatment was verified by a X-ray diffraction analysis. A transmission spectrum of electromagnetic wave in terahertz frequency ranges for the formed magnetophotonic crystals with a diamond lattice structure was measured by using terahertz time domain spectroscopy.

KEY WORDS: (Photonic crystal), (Metallic glass), (Oxide glass), (Stereolithography)

1. Introduction

Periodically arranged structures of magnetic materials are called magnetophotonic crystals. These artificial materials can form photonic band gaps to totally reflect electromagnetic waves with wavelengths comparable to the lattice constant though Bragg diffraction [1,2]. Electromagnetic waves in terahertz frequency ranges have lately attracted considerable attentions as novel analytical light sources. Because the terahertz wave at terahertz frequency can be synchronized with collective vibration modes of various harmful substances, the spectroscopic technologies are expected to be applied to novel imaging sensors for real time detection of toxic materials in aqueous phase environments [3,4]. However, the terahertz waves are difficult to transmit into the water solvents due to electromagnetic absorptions [5]. In our investigation group, micrometer order alumina or zirconia lattices with diamond structures were fabricated successfully by using a micro stereolithography system to resonate the terahertz waves [6]. In this study, the micrometer order magnetophotonic crystals with the diamond structure composed of the metallic glass dispersed oxide glass were fabricated by the micro stereolithography and to be applied to the terahertz wave sensor devices. These sensors are composed of the magnetophotonic crystals with through holes and micro tubes as schematic illustrated in **Fig. 1**. The artificial crystal having a cylindrical structural defect can resonate the specific terahertz wave with wavelength comparable to the diameter of cylinder, and a localized mode of a transmission peak appears in the band gap. For the water solvents flowing into the micro tube, and the terahertz wave spectra will be measured. If the resonated terahertz wave can harmonize with the collective vibration mode of the introduced water solvents, the transmission peak will disappear through the electromagnetic wave absorptions. The magnetophotonic crystal sensors will be applied to various scientific and engineering fields by utilizing the terahertz wave spectroscopic database.

2. Experimental

The magnetophotonic crystal was fabricated by using the micro stereolithography. **Figure 2** shows a schematic illustration of the method. A three dimensional model was designed by using a computer graphic software (Materialise Japan Co. Ltd., Japan, Magics Ver. 14). Thedesigned model was sliced into a series of two dimensional cross sectional data of 10 μm in layer thickness. These data were transferred into the micro stereolithography equipment (D-MEC Co. Ltd., Japan,

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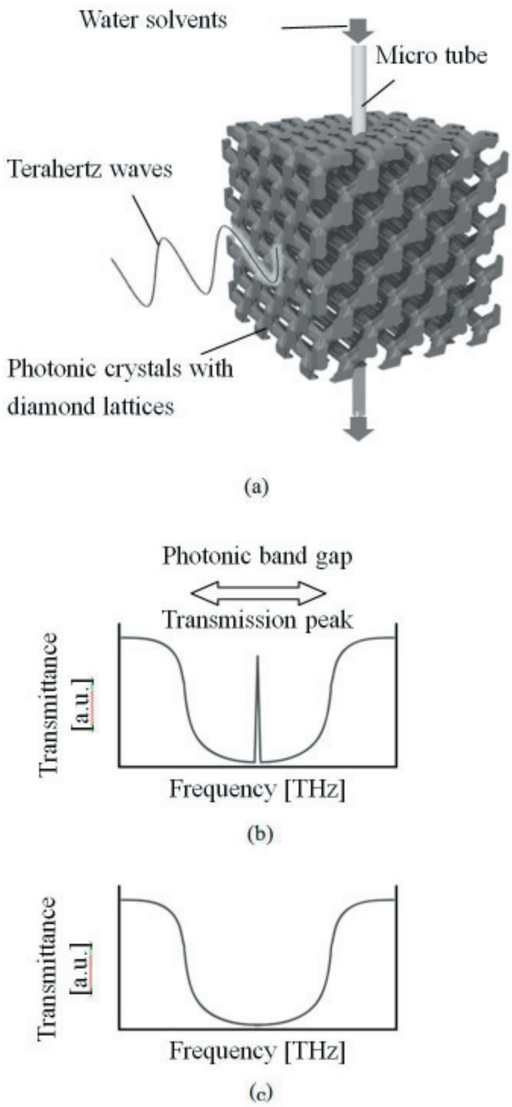

Fig. 1 A schematic illustration of a magnetophotonic crystal sensor device (a). Transmission spectra of terahertz waves for the device including water solvents without (b) or with (c) harmful substances.

SI-C 1000). In this machine, photo sensitive acrylic resins dispersed with metallic glass (Fe72B14.4Si9.6Nb4) and oxide glass (B2O3•Bi2O3) particles of 2.6 µm and 1.0 µm diameter was supplied on a substrate and spread uniformly by a mechanical knife edge. The thickness of each layer was controlled to 10 µm. The two dimensional pattern was formed clearly by illuminating ultra violet laser of 405 nm in wavelength on the slurry surface. The high resolution was achieved by using a digital micro-mirror device (DMD) and an objective lens. The DMD is composed of micro mirrors of 14 µm in edge length with 1024×768 in numbers. The each tiny micro mirror can be tilted independently according to the two dimensional cross sectional data by a computer operation. The three dimensional structures were built by layer stacking. Using process parameters of the micro stereo-lithography were optimized to fabricate these magneto-

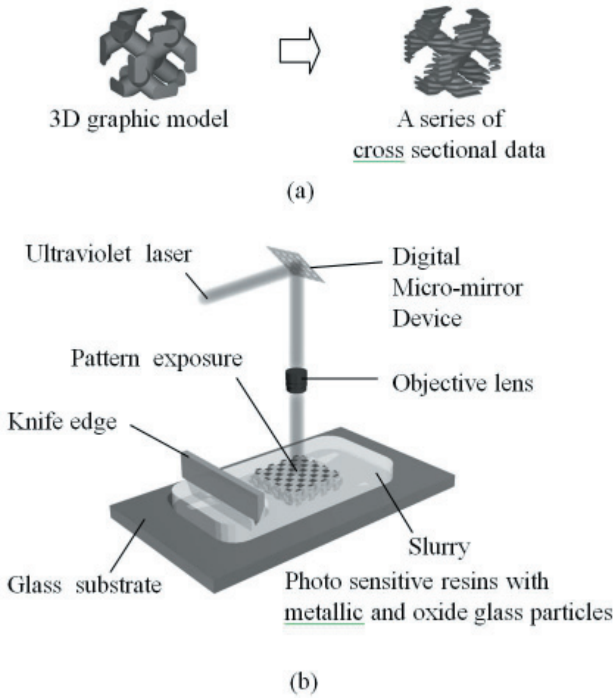

Fig. 2 A schematic illustrations of a stereolithography method. A three dimensional model is sliced into two dimensional cross sections (a). The two dimensional layers are stacked up to create the three dimensional object in micrometer order (b).

photonic crystals exactly. Three kinds of slurry were mixed to create the three dimensional objects. The metallic glass and oxide glass particles were dispersed acrylic resin at 40 vol. % in total, and these two kinds of particles were mixed each other at 16:24, 17:23 and 18:22 in volume ratios. The model shown in **Fig. 3** was fabricated to measure the thickness of one layer and the size tolerance by laser scattering. The process parameters to expose and stack the layers were optimized and input into the stereolithographic system. The magnetophotonic crystals with diamond lattice structures were fabricated along the optimized condition. The rod diameter and length were 144 and 217 µm, and the lattice constant of the diamond structure was 500 µm, respectively. The whole structure was 5×5×0.5 mm in size consisting of 10×10×1 unit cells. Under the glass transition temperature at 552 ºC of the selected metallic glass, the formed precursor was dewaxed at 420 ºC for 8.0 hs with the heating rate of 1.0 ºC /min, and sintered at 460 ºC for 0.5 hs with the heating rate of 2.0 ºC /min in an Ar atmousphere7. The diamond lattice model was corrected and re-designed according to the liner shrinkage ratios. Microstructures of the lattices were observed by an optical microscope (OEM) and a scanning electron microscopy (SEM), and microstructural stabilities of the amorphous phase alloy were analyzed by using a X-ray diffraction (XRD). The transmittance of the terahertz waves were analyzed by using a terahertz time domain spectroscopy (Aispec Co. Ltd., Japan, J-spec spc/ou).

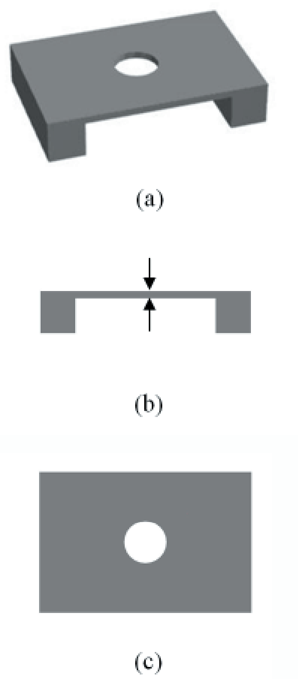

Fig. 3 A graphic model of solid specimen (a) to measure layer thicknesses (b) and scale tolerances (c) at ultra violet lay exposing for the photo sensitive resin with fine particles in the micro stereolithographic process.

3. Results and Discussion

The Influences of the laser power for the layer thickness and size tolerances of the solid objects were compared and investigated. The compositions of metallic glass and oxide glass were varied systematically. The thickness of one layer was required over 14.5 μm to stack layers every 10 μm successfully. The optimized slurry compositions of the acrylic resin, metallic glass and oxide glass were 60 %, 17 % and 23 % in volume ratios, respectively. And the laser power was optimized at 700 mJ/cm2 to create the fine cross sectional micro patterns. **Figure 4 (a)** shows the magnetophotonic crystals with the diamond lattices fabricated by the micro stereo-lithography. Tolerance between the designed model and formed sample was converged within ± 3μm. The sintered diamond lattice structure with 500 μm in lattice constant is shown in **Fig. 4 (b)**. The micrometer order three dimensional structure was formed successfully. The liner shrinkage ratios of horizontal and vertical axis were 10.2 % and 12.5 %, respectively. **Figure 4 (c)** shows the microstructure of the sintered metallic glass and oxide glass composite lattice. The metallic glass particles dispersed into the oxide glass matrix. The XRD patterns of metallic glass particles before and after heat treatments were analyzed as shown in **Fig. 5**. The metallic glass wasnot crystallized through the dewaxing and sintering heat treatment. **Figure 6** shows the measured terahertz wave transmission spectrum for the fabricated magneto-photonic crystal with the diamond structure. The electro-magnetic band gap can be formed at the frequency range from 0.19 to 1.02 THz.

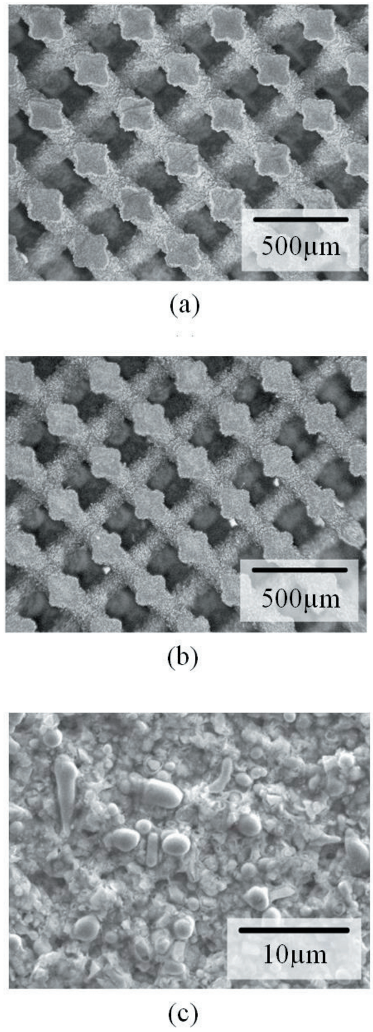

Fig. 4 Magnetophotonic crystals with diamond lattices composed of metallic glass and oxide glass particles dispersed acrylic resin fabricated by using the micro stereolithography (a) and the sintered metallic glass and oxide glass composite lattices (b). An SEM image of the oxide glass lattice with metallic glass dispersion (c).

4. Conclusion

Through careful optimizations of process parameters regarding a stereolithography method, three dimensional micrometer order diamond lattices composed of acrylic resin including metallic glass and oxide glass particles at 17 % and 23 % in volume ratios could be fabricated using the micro stereolithography. The metallic glass and oxide glass composite crystals were obtained through dewaxing and sintering process. The metallic glass was not crystallized through the heat treatment. The sintered magnetophotonic crystals formed an electromagnetic band gap in a terahertz frequency range from 0.19 to 1.02 THz. The artificial crystals with micro through holes are expected to resonate the terahertz waves in wavelengths comparable to the hole diameters, and to be applied to real time sensing of harmful substances in aqueous phase environments.

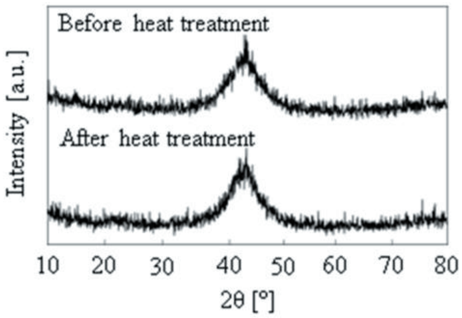

Fig. 5 XRD patterns of the metallic glass particle before and after the dewaxing and sintering heat treatments.

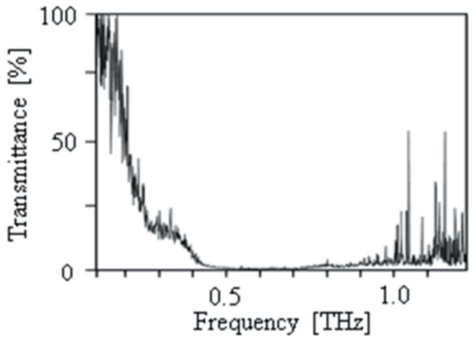

Fig. 6 A transmission spectrum of terahertz waves through the fabricated magnetophotonic crystal with the micro diamond structure.

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