MEMS TUNABLE OPTICAL FILTER USING AUTO-CLONED PHOTONIC CRYSTAL

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ABSTRACT

This paper proposes a novel MEMS tunable optical filter (TOF) using an auto-cloned photonic crystal (PhC). The auto-cloning method has great gains to fabricate multi-dimensional PhCs in productivity, flexibility and robustness. A two-dimensional PhC was fabricated by stacking Nb_2O_5 and SiO_2 layers alternately keeping nano-scale periodic corrugations (190nm in pitch) formed on a substrate. This PhC was designed for splitting an incident light into the TM and TE modes at 500nm. Photonic band-gaps were changed by rotating the PhC and the transmittance of the TE mode was changed drastically at 420nm. The PhC was attached on the MEMS device (Eco Scan: Japan Signal) to control its angle of incidence. A resonance frequency of the MEMS structure was 183Hz and that rotation angle reached up to 40 degree. Switching characteristics of our MEMS-TOF were confirmed and its availability was demonstrated.

1. INTRODUCTION

Photonic crystals (PhCs) are attaching much attention as a key technology for manipulating photons by utilizing their photonic band-gaps. Since PhCs have not only the designable photonic band-gaps but also high dispersion and anisotropy, PhCs are expected to be used in various useful applications. Optical characteristics of a PhC can be controlled by adjusting its structural parameter. Convenient optical properties are achieved using this flexibility of PhCs. Realization of these useful properties is quite difficult by using conventional optical materials.

The photonic properties of PhCs are convenient; however, these are static properties. Studies on the photonic crystal controlled by MEMS systems were reported [1-3]. Although almost of these studies employed the PhC slab waveguide, an auto-cloned PhC was chosen in this study. The auto-cloned method has great productivity, flexibility and robustness against perturbation.

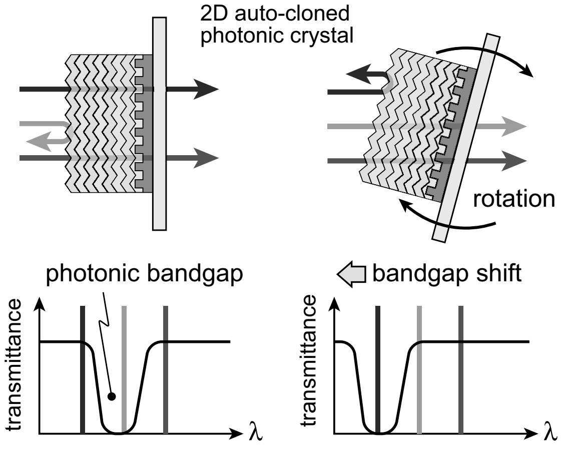

Fig. 1. Schematic diagram of our active and simultaneous measurement method using a glass micro injector. Injection, pickup, potential recording and stimulus functions are integrated.

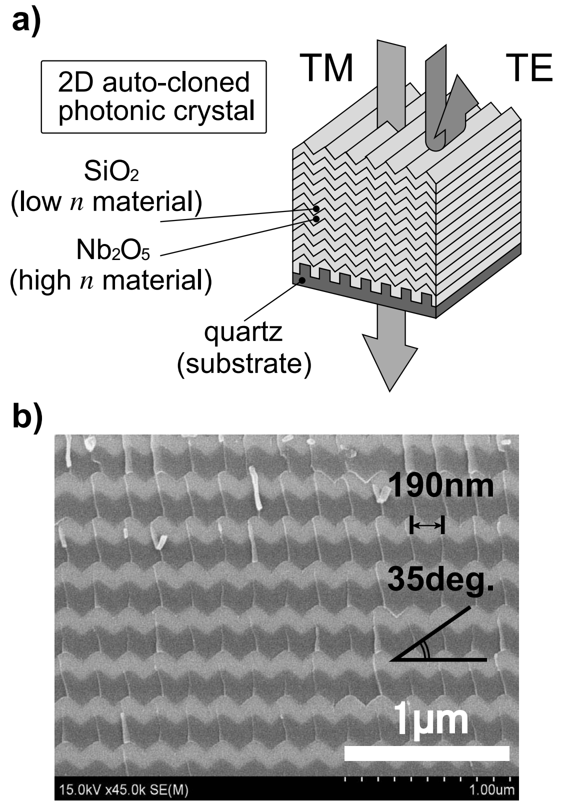

Fig. 2. 2D auto-cloned PhC [4]. a) Schematic figure of 2D Nb2O5/ SiO2 structure. This PhC was designed that TM polarized light is transmitted and TE is stopped at 500 nm. b) A cross-sectional SEM image of the fabricated PhC. A nano-scale periodic layers were formed by the auto-cloning method.

Figure 1 illustrates a schematic diagram of our MEMS-TOF using a 2D auto-cloned PhC. A photonic band structure of the PhC is designable. Since positions of photonic band-gaps are controlled by rotating the PhC, the PhC attached on MEMS devices can utilize useful photonic characteristics dynamically.

2. Auto-cloned Photonic Crystal

Auto-cloned method

Recently, many kinds of the PhC fabrication methods were proposed. This auto-cloned method has been developed at Tohoku University and is suitable for 2-D or 3-D PhC fabrication. First, nano-size periodic corrugation patterns are formed on a substrate using electron beam lithography. Then higher and lower refractive index materials are stacked alternately on that corrugation pattern. A combination of sputtering deposition and sputter etching under appropriate conditions keeps the nano-size corrugation pattern on the each stacking layer. Since the auto-clone method is similar to conventional optical multi-coating process, this method can be adopted to existing production line.

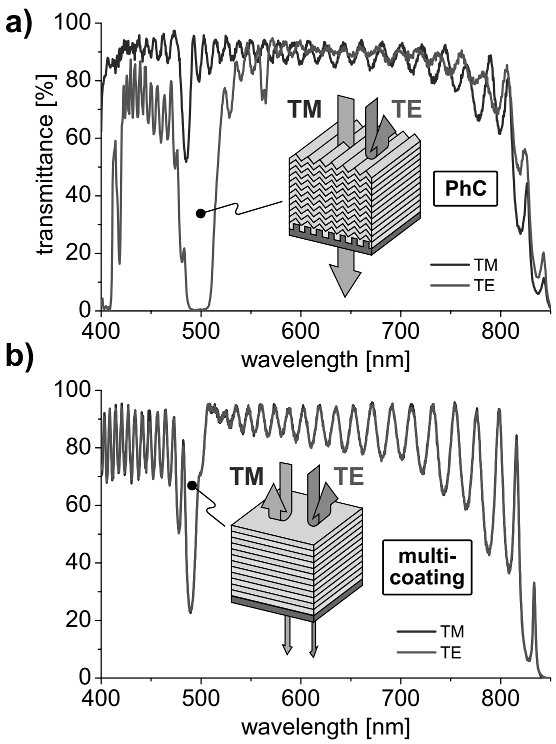

Fig. 3. Photonic band structure. a) Designed 2D auto-cloned PhC. TM polarized light was transmitted and TE was reflected near 500 nm. b) Multi-coated filter as a reference component. A bandgap was narrow and jitters were shown in pass-band area.

Figure 2a) shows the PhC structure fabricated by the auto-clone method [4]. Periodic corrugations were formed in 190nm pitch on a quartz substrate by electron beam lithography. A higher refractive index layer (Nb_2O_5) and a lower one (SiO_2) were stacked on the substrate alternately. Figure 3b) depicts a cross-sectional SEM image of the PhC. This PhC was consisted of two PhCs, named PhC-A and PhC-B. In the PhC-A (PhC-B), thicknesses of the Nb_2O_5 and SiO_2 were 108 (106) nm and 161 (158) nm, respectively and its period was 12 (10), total 24 (20) layers.

PhC photonic band structure

Figure 3 shows Photonic band structure. Figure 3a) indicates superiorities of our PhC to a multi-coating filter (Nb_2O_5/ SiO_2). The PhC was theoretically designed in order to split an incident light into the TM and TE modes at 500nm. The photonic band structure of the PhC in the TE mode had a deep and wide photonic band-gap near 500nm. Contrastively, the multi-coating filter's one had a halfway and narrow bandgap and jitters in the pass-band area.

The photonic band structure is changed by tilting the PhC against the incident light. Figure 4 illustrates an experimental setup for measuring the photonic band structures changing an angle of incidence manually. A W-Halogen balanced light source was employed in order to obtain a continuous spectrum from 400nm to 900nm. The incident light was collimated and a pinhole made the incident beam 2mm in diameter. The PhC was rotated in an axis paralleled with the corrugation pattern of the PhC. the TM and TE polarized lights were selected by changing a direction of a polarizer.

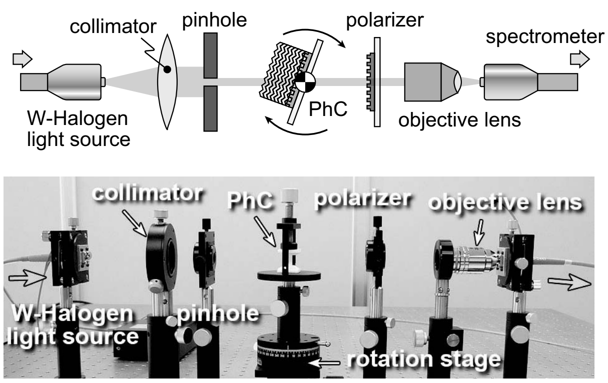

Fig. 4. Experimental setup for measuring the photonic band structures of the PhC changing an angle of incidence. The PhC was rotated in an axis that was parallel with the periodic corrugations of the PhC. The TM palarized light and TE were selected by changing a direction of a polarizer.

Figures 5a) shows the results of the experiment in the TE mode. Band-gap positions shifted increasing the angle of incidence. Figure5b) illustrates changes of the transmittance at 420nm. Since the transmittance changes drastically around 0 degree, the PhC works as a TOF with a slight tilt at this wave length.

3. MEMS TUNABLE OPTICAL FILTER

MEMS-TOF prototype

Our MEMS-TOF prototype is shown in Figure 6. A commercial MEMS device (Eco Scan ESS115B: The Nippon Signal Co., Ltd.) was chosen for rotating the PhC. The PhC was glued on the MEMS structure perpendicularly in order to measure transmittance characteristics. The rotation angle was controlled by frequency and amplitude of the driving current supplied to the driving coil. In normal operation, this MEMS device was driven by approximately 20mA and amplitude was 35 degree at that drive current. The original resonance frequency was about 530 Hz. The frequency characteristic of the rotation angle after the PhC was glued is shown in Figure 7. Its resonance frequency was 183Hz and that rotation angle was up to 40 degree.

Switching characteristics

Figure 8 shows switching characteristics of our MEMS-TOF. The PhC was swigging at 1Hz - 5Hz; each response of transmittance at 420nm was recorded. The transmittance was changed approximately from 40% to 60% synchronized with the driving signals. Figure 8f) depicts results of FFT analyses of each response. This result indicates availability of our MEMS-TOF.

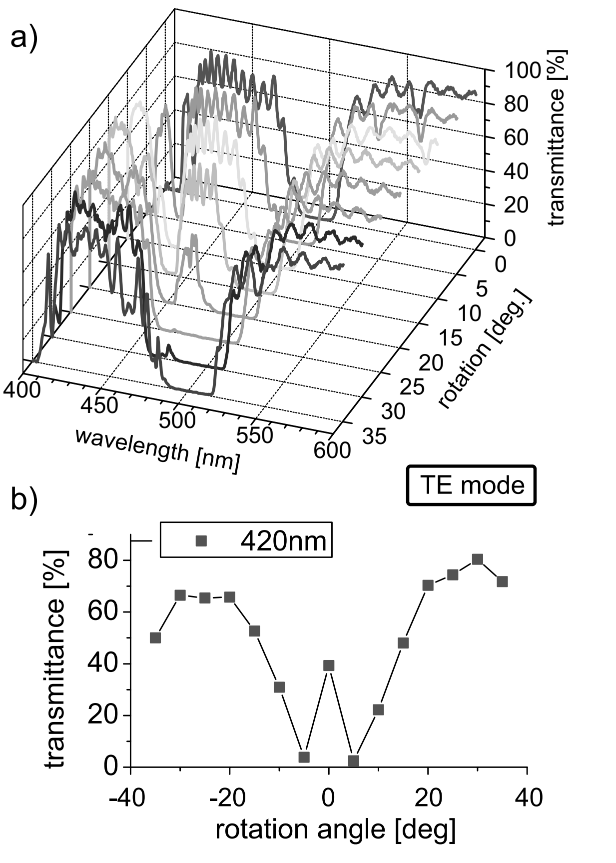

Fig. 5. a) shows changes of the photonic band structure rotating the PhC. b) illustrates changes of the transmittance at 420 nm. The transmittance changes drastically around 0 degree.

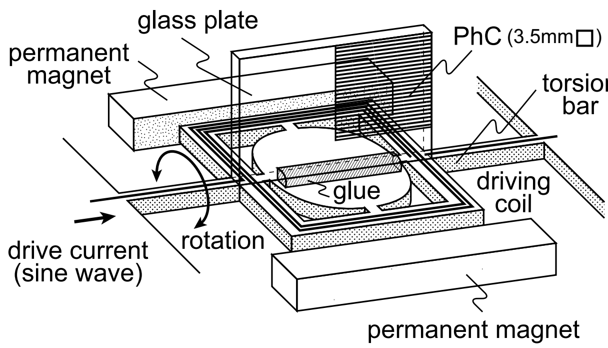

Fig. 6. MEMS-TOF. A PhC was glued on a MEMS structure (Eco Scan: Nippon Signal) perpendicularly. The rotation was controlled by frequency and amplitude of the drive current.

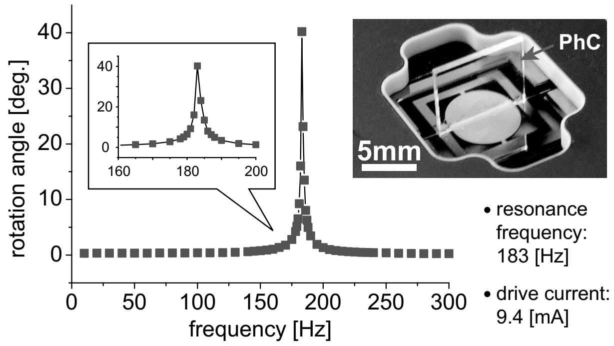

Fig. 7. A frequency characteristic of the rotation angle. It has a steep peak at a resonance frequency 183 Hz. The rotation angle reached up to 40 degree at the resonance point.

4. Conclusions

A novel MEMS tunable optical filter (TOF) using an auto-cloned photonic crystal (PhC) was proposed. A two-dimensional PhC was fabricated by the auto-cloned fabrication method. Nb_2O_5 (higher refractive index) and SiO_2 (lower refractive index) layers were stacked alternately keeping nano-scale periodic corrugations (190nm in pitch) formed on a substrate. The PhC has a deep and wide photonic band-gap near 500nm. It was confirmed that the photonic band structure of our PhC was changed when tilting the incident angle manually. The PhC was attached on the MEMS device to control its angle of incidence. A resonance frequency of the MEMS structure was 183Hz and that rotation angle reached up to 40 degree. Switching characteristics of our MEMS-TOF were confirmed and its availability was demonstrated.

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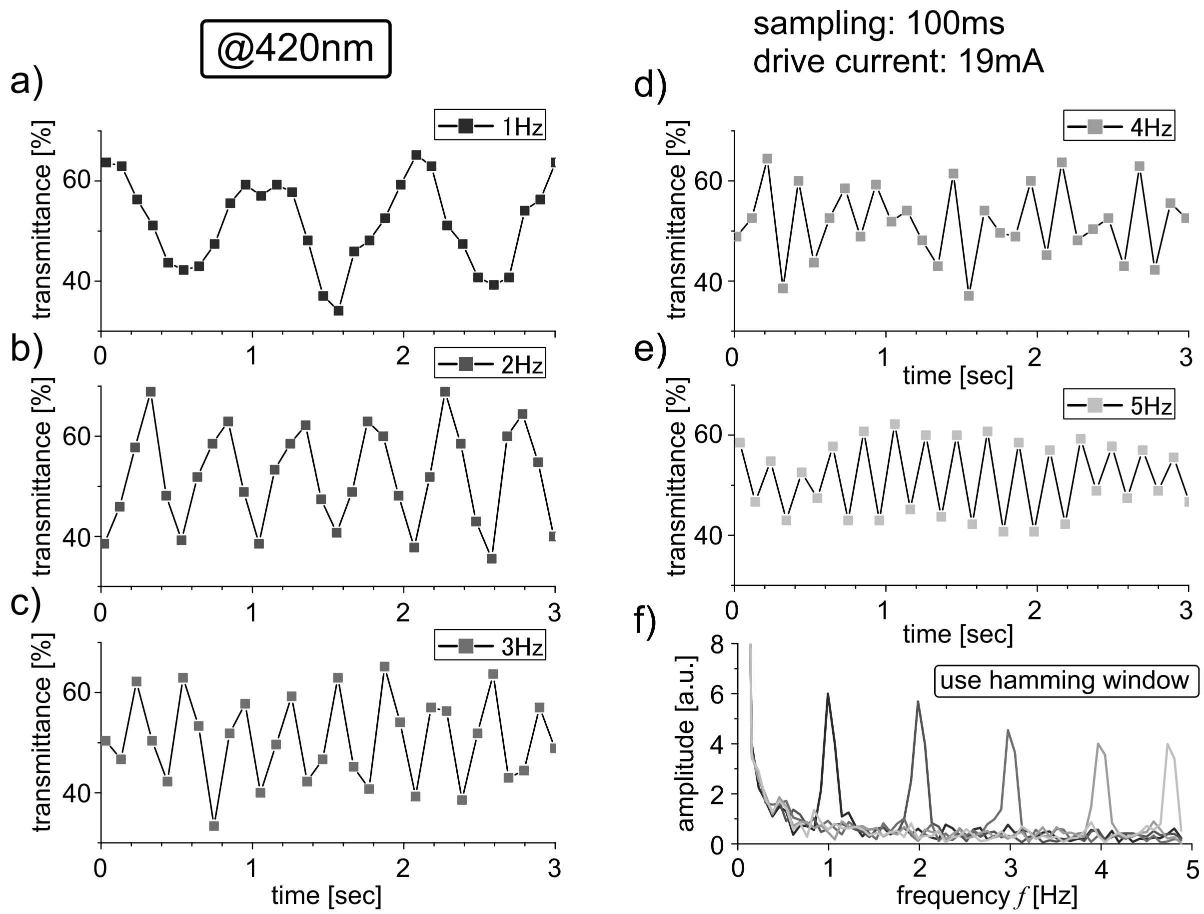

Fig. 8. Switching characteristics of our MEMS-TOF at 420 nm. a), b), c), d) and e) show responses of the transmittance when the PhC was driven by the current in 1, 2, 3, 4 and 5 Hz, respectively. f) shows results of FFT analyses of each response.