Glass molding of nano grating structure using vitreous carbon nanostamp for photonic crystal optical filter

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Abstract

A method to fabricate vitreous carbon (VC) stamp was proposed for glass molding of micro/nano-scale components. A VC nanostamp having a nanograting cavity with a pitch of ~380 nm and a height of ~150 nm was fabricated by carbonization of nano replicated furan precursor having a nanograting structure with a pitch of 500 nm and height of 230 nm. A glass nanograting structure with a pitch of ~380 nm was fabricated by glass molding with the VC stamp. To examine the feasibility of the proposed method, the thermal stability of photonic crystal optical filters composed of glass moulded nanograting and physical vapor deposited TiO_2 layer was evaluated.

1 Introduction

As the demands of nano optical components operating in severe environment are increased in the fields of high power laser, solar cell, automobile, outdoor lighting, and projection display, a suitable process for fabricating glass micro/nano optical components has become a priority, due to the excellent properties of glass material such as high chemical and heat resistance, low optical absorption and large optical transmission range. Among the various methods for patterning a glass material, the glass molding is regarded as the most promising method for fabricating glass micro/nanostructures with a high-throughput and low-cost. To fabricate glass micro/nanostructure by glass molding, a stamp which is durable at high temperature is first required, because the molding temperature of glass is much higher than the thermoplastic, and the conventional stamp materials, which used for polymer imprinting, cannot provide sufficient hardness and durability at that temperature. A vitreous carbon (VC), which is an amorphous carbon, can be a candidate for stamp material of glass imprinting. Takahashi *et al.* successively fabricated quartz and Pyrex micro/nano structures by glass molding process using a focused ion beam machined and a reactive ion etched VC micro/nano stamps, respectively[1]. However, the previous patterning methods for VC stamp are expensive and time consuming when a large area micro/nano VC stamp is required. In this study, a low cost and large area fabrication method for VC nanostamp was proposed. To examine the feasibility of the proposed method, we fabricated a glass photonic crystal (PC) optical filter by deposition of TiO_2 thin layer on a glass moulded nanograting with the fabricated VC stamp, and the thermal stabilities of the glass PC optical filter was examined.

2 Fabrication of glass molded nanograting using vitreous carbon nanostamp

Fig. 1 shows the procedures of the proposed fabrication method for VC nanostamp and the glass molding using VC stamp. A silicon master pattern with a pitch of 500 nm, a height of 230 nm and a duty cycle of 50 % was fabricated by reactive ion etching (RIE) using KrF laser photo-lithographed barrier pattern. A polymer mold was replicated from the silicon master pattern by UV imprinting process (1st replication) and a mixture of 89.8 wt% furan resin, 0.2 wt% p-Toluenesulfonic acid and 10 wt% ethanol was poured on the polymer mold. After the curing process in the temperature and vacuum level controllable chamber, the backside of cured furan precursor was polished. To obtain VC stamp, a carbonization of the replicated furan precursor was carried out in a N_2 purged furnace with a maximum carbonization temperature of 1000 °C. To minimize the defects in VC stamp, including micro/nano air bubbles, warpage, and sublimation deposited nanostructures, the effects of various processing parameters including material compositions, vacuum and temperature history in curing process, and temperature history and N_2 purging speed in carbonization process, were analysed and an optimized processing sequence and parameters were developed.

A glass molding process using K-PG375 glass (Sumita Optical Glass, Inc., Japan) was performed, in which the molding temperature and pressure were 380 °C and 8 MPa, and the holding time was 10 min. Fig. 2 shows the SEM images of nanogratings on the fabricated polymer master, furan precursor, VC stamp and moulded glass nanograting. To quantitatively examine the change of geometrical properties during each fabrication process, the surface profile of nanograting in each sample was measured by AFM. Although the shape changes in the replication of furan precursor from polymer master and the molding of glass nanograting from VC stamp were negligible, a significant shrinkage was observed in carbonization process. Fig.3 shows the comparisons of surface profiles between furan precursor and VC stamp obtained from AFM measurements. From the SEM and AFM measurements, the shrinkage of geometrical properties during carbonization process was revealed ~ 23% in pitch and ~ 35% in groove height due to the thermal decomposition of material. The different of shrinkage ratio between pitch, and groove height and width may be explained by the presence of internal void in the substrate generated during the carbonization process, because the escape of thermal decomposed material is easy in the surface area of VC stamp.

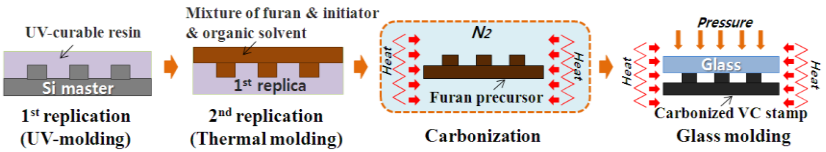


Figure 1: Fabrication process for glass molded nanograting with VC stamp

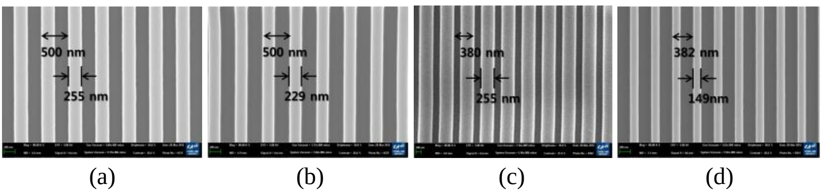


Figure 2: SEM images of nanogratings on (a) polymer master, (b) replicated furan precursor, (c) carbonized VC stamp and (d) molded glass substrate.

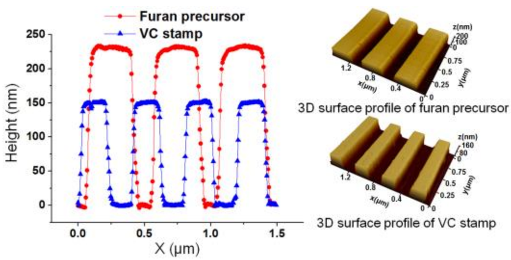
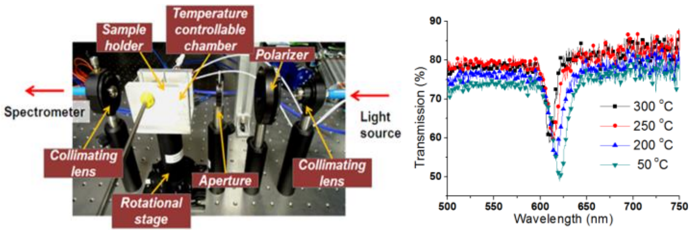


Figure 3: Comparison of surface profiles of nanogratings between furan precursor and VC stamp.

3 Fabrication of PC optical filter using glass molded nanograting

To fabricate PC optical filter, a TiO_2 layer was deposited on the glass imprinted nanograting. A measurement setup for the transmission spectra at different environment temperatures was designed and constructed to examine the performance of glass moulded PC optical filter. Figure 4 shows (a) the transmission spectra measurement setup with temperature controllable chamber and the measured transmission spectra of glass imprinted PC optical filter with various temperature environments for the s-polarized light source. The temperature was increased with a speed of 10 °C/min and maintained for 10 min at every 50 °C increment. Also the transmission spectrum was measured at every 50 °C increment. The fabricated glass imprinted PC shows a transmission minimum at wavelength of ~ 620 nm and the transmission minimum was observed up to the temperature of 300°C.



(a) (b)

Figure 4: (a) Image of transmission spectra measurement setup and (b) measured transmission spectra of glass PC structure with varying environmental temperature.

4 Conclusion

A method to fabricate VC nanostamp for glass imprinted nanostructure was proposed. It was clearly noted that the PC structure fabricated by glass imprinted nanograting can be a high temperature stable optical filter. The application of the proposed method to other nano optical components is the subject of our on-going research.

5 Acknowledgement

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[1] Takahashi, M., Sugimoto, K., and Maeda, R., 2005, "Nanoimprint of Glass Materials with Glassy Carbon Molds Fabricated by Focused-Ion-Beam Etching", Jpn. J. Appl. Phys., Vol. 44, pp. 5600~5605.