An improved micro injection molding technique for grating devices

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ABSTRACT

In this research, we propose a mass production method of gratings integrated with micro channels (GIMC) by means of an improved micro injection molding technique. The GIMC can be used together with a waveguide layer as a biochip in bio-medical assays. In the improved micro injection molding technique of this work, we fabricate an injection mold of gratings through the use of a nanoimprint and photolithography processes. The injection mold of gratings is composed of a hybrid inorganic/organic sol-gel material and stainless steel substrate. The grating pattern of a commercial epoxy grating (EG) is first transferred to a PDMS mold of grating (PMG) via a casting process, and then the PMG is used to imprint the sol-gel material. After exposure, the sol-gel material will solidify and is used as a part of the injection mold. COC (Cyclic olefin copolymer), because of its high luminous transmission and melt flow index, is used to inject the 1800 line/mm period and 100nm depth grating integrated with a 30μm height micro channel at 110℃ mold temperature. From the measured results, it is noted the structure of the sol-gel mold of grating remains intact after 1000 times of injection. The diffraction-efficiency uniformity among the grating array elements of COC 3 x 3 grating arrays is better than 97%.

Keywords：micro injection molding, grating, sol-gel, COC

1 INTRODUCTION

In recent years, diffraction optics has been developed for use in bio-detection. For example, the grating devices can be used in bio-chips by combining micro channels [1]. In general, the mechanical ruled, electron beam lithography and holography are the most used methods for the grating device fabrication, but they are time-consuming and expensive. Nanoimprint technique is a good alternative to transfer grating pattern with a faster speed and less cost.

In 2000, Edwards et al. [2] used a photoresist material which was patterned on the silicon substrate as an injection mold. However, the photoresist material is unsuitable for high temperature and can’t be cleaned by organic solvents. Therefore, Pranov et al. [3] used electron beam lithography to write the pattern on the silicon substrate which was covered with a photoresist layer. Electroforming was then proceeded to transfer the pattern on a nickel mold. The nickel mold is good for injection molding, but it is time-consuming and the plating solution creates heavy metal pollution. In this work, we present a fast method for injection-mold fabrication by means of nanoimprint technique and sol-gel material. Through injection molding, the plastic grating devices can be produced easily. Because of the thermal and chemical stability, the sol-gel mold of grating (SMG) can be cleaned with organic solvents and is suitable for injection molding.

2 EXPERIMENTAL

In this research, we transfer the grating pattern from a commercial EG (Newport, 10HG1800-500-1) which is 555 nm in period to a PMG. The PDMS (Dow Corning, sylgard 184), which has good hydrophobicity and transparency for the demolding and transfer processes [4], is poured onto the commercial EG, cured at 70°C for 2 hr and then gently released when the PDMS is cool. The sol-gel material is synthesized by the hydrolytic condensation reaction of two precursors, titanium (IV) n-butoxide and methacryl-oxypropyltrimethoxysilane. Methacrylic acid is added to complex the titanium precursor and Irgacure 1800 (Ciba, Switzerland) is used as the photoinitiator for the radical polymerization [5]. Because of the high chemical stability and fine texture, we can transfer the single-grating pattern from the PMG to the sol-gel film, and after curing, the grating structure of the sol-gel film is complete with excellent repeatability.

By using the photolithography process, which provided both high stability and adaptability, we could then fabricate different patterns of grating mold from the SMG in a short time at low cost. The fabrication process is shown in Fig. 1. The first step is to spin the sol-gel material onto a stainless steel substrate at 3000 rpm, followed by putting the PMG on the sol-gel film. Second, bake the substrate with the sol-gel film and PMG at 70°C on a hot plate for 30 minutes and expose it to UV light for 10 minutes. Then we peel off the PMG and put the substrate with the sol-gel film into an oven for the hard-bake process at 110°C for 12 hr. After cooling, we obtain an SMG, which has the same grating profile as the commercial EG. In steps (d) – (f), we spin a JSR THB151N photoresist layer on the SMG and then use photolithography to process the single-grating pattern on the SMG to a GIMC pattern and form a temporary mold of the GIMC. This procedure can create a GIMC pattern according to our design. This temporary mold of the GIMC is only suitable for using a few times because the strength and the chemical stability of the photoresist are not good enough for long-term use. To make a durable mold, we fabricate the sol-gel mold of the GIMC by the steps (g) – (j) and the parameters are similar to steps (a) – (c).

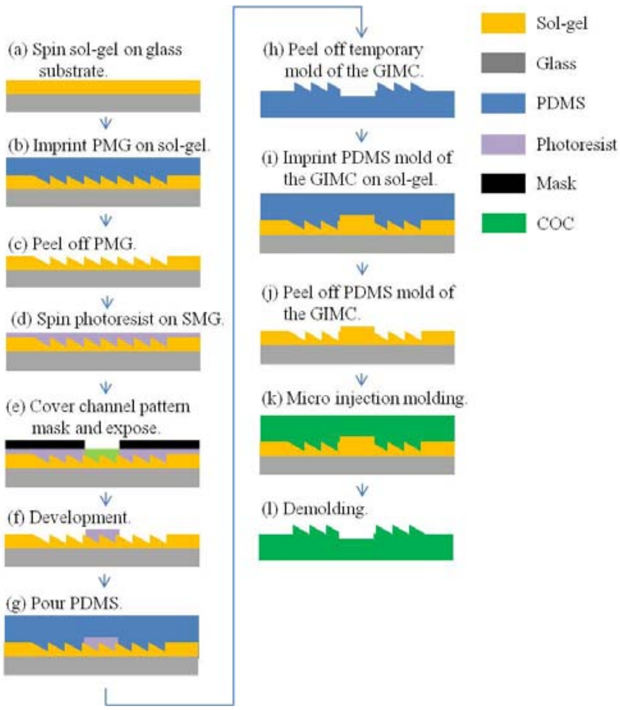

Fig. 1 Schematic diagram showing the fabrication process of a GIMC.

In our research, COC is used as the injection material because of its high luminous transmission, good chemical stability and high melt flow index [6]. The COC gratings are injected with a 30-ton injection machine (FANUC 2000i-30B). In order to determine the quality of the injected COC gratings, we measure the diffraction efficiency of 3 x 3 grating arrays and calculate the diffraction-efficiency uniformity. The diffraction-efficiency uniformity is defined as

$$U = 1 - \frac{P_{max} - P_{min}}{P_{max} + P_{min}} \text{ x } 100\% \quad (1)$$

where P_{max} and P_{min} represent the 1^{st} order diffraction efficiency of the brightest and the faintest elements of a 3 x 3 grating array, respectively [7].

3 RESULTS

There two types of COC gratings, GIMC and grating array, are fabricated in this work. Figures 2(a) and (b) show the PDMS soft mold of the GIMC and grating array, respectively. Figures 3(a) and (b) show the photos of the sol-gel mold of the GIMC and the injected COC GIMC, respectively. The micro channel is 30μm in depth. In order to examine the quality of the grating, we measure the diffractive efficiency of a 3 x 3 grating array and calculate the uniformity of diffractive-efficiency. Table 1 shows that the uniformity of the mold is 97.8% and the injected COC grating array is about 97%, indicating the excellent injection quality. Figures 4(a) and (b) show the photos of the sol-gel mold of a 3 x 3 grating array and the injected COC 3 x 3 grating array, respectively. To check the repeatability of the injection molding, we inject 1000 pieces and measure the average diffractive efficiencies of 1000 pieces of the injected COC 3 x 3 grating arrays. From the measured results, the relative standard deviation (RSD) of the average diffractive efficiency is 1.9%. This shows the grating array mold is durable and good for mass production.

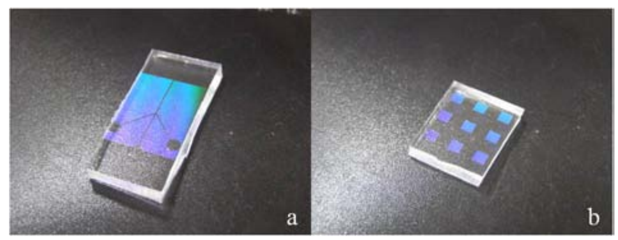

Fig. 2 Photos of PDMS soft molds of (a) the GIMC and (b) grating array.

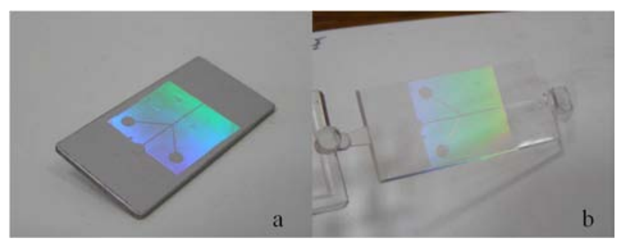

Fig. 3 Photos of (a) the sol-gel mold of the GIMC and (b) injected COC GIMC.

Table 1. The average diffraction efficiency ($P_{average}$) and the diffraction-efficiency uniformity ($U_{average}$) of grating array.

	Mold of grating array	1^{st} copy	500^{th} copy	1000^{th} copy
$P_{average}$(%)	2.8	4.1	4.2	4.2
$U_{average}$(%)	97.8	96.9	96.6	97.2

N=3

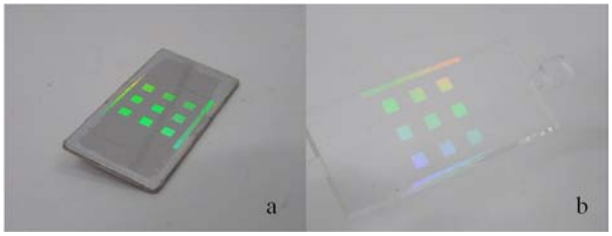

Fig. 4 Photos of (a) the sol-gel mold of a 3 x 3 grating array and (b) the injected COC grating array.

4 CONCLUSION

In this research, we propose a mass production method of GIMC by means of an improved micro injection molding technique. We fabricate an injection mold of gratings composed of a sol-gel material and stainless steel substrate through the use of a nanoimprint and photolithography processes. Through the injection molding process, we can replicate the plastic grating devices for mass production. From the measured diffractive efficiency of grating arrays, it is noted that the uniformity is 97% and the repeatability (1 - RSD) is 98.1%. Due to its low cost and ease of use, this method is suitable for both laboratory research and mass production without the need for expensive equipment like EBL or RIE and can be a potential technique for plastic grating devices fabrication.

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