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Processing of polymer optical circuit by micromachining Silicon mold

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1. Introduction

With the rapid progress of optical communication, low cost optical components consisting of optical circuits are required for access network use. Polymer material is one of the potential candidate for such devices. In order to realize the polymer based optical circuits cost-effective production technique is necessary. In this study we fabricated the polymer optical circuit elements by using the mold method. We form a channel waveguide, a 45° mirror and a fiber guide with hot-embossing or imprinting technology using Si mold. The mold technique is advantageous over other techniques reported so far; (a) a lot of replica can be produced. (b) nanometer-sized pattern can be easily fabricated. (c) the device pattern can be formed in air without using large equipments. Therefore, this technique is sufficient for low-cost high resolution optical devices. Using wet etching technique [1] [2] of the Si dependent on the crystal orientation the etched plane is much smoother than that fabricated by dry etching such as RIE. We also mention the advantage of the processing of excellent controllability of the size and the shape of optical circuit elements. Furthermore, it is possible to form large optical elements with a size of mm, since the etching rate is rapid. In the experiment, Si {110} was used for fabricating the optical waveguide, and Si {100} for fiber guide, and off cut silicon for 45° mirror. The result of the mold manufacture and the polymer replica is reported.

2. Manufacture of Si mold and master

Si mold

Using the KOH aqueous solution the Si wafer is wet-etched and formed the mold pattern. The SiO_2 patterned thin layer by the thermal oxidation acts as the mask for etching. The etching was carried out with the following condition; The KOH concentration was 25.5wt%, the temperature was 70°C, and the etching time 60 min. During etching the solvent was stirred to avoid the additional bubble attached on the surface.

Master Fabrication

In the next step we have fabricated the masters of the elements. Fig.1 shows the schematics of the master fabrication. We used a polymer material with high heat-resistance and high mechanical strength such as polyimide or UV-cured resin as a master material. The master polymer material was filled or dipped on the Si mold, and then, after setting the glass substrate onto the polymer, the polymer was hardened by curing with heat treatment or UV exposure. Lastly, the master was removed from the mold. In order to avoid the adhesion of the polymer to the mold, we inserted the SiO_2 film for a removing layer produced by the oxidation of the Si mold. [3]

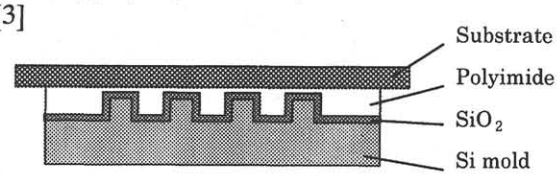

Fig.1 Schematics of the master fabrication.

3. Results

The master was set on conventional PMMA and high Tg polyarylate (PAR) films (U100:Tg=193°C) as optical polymers. Fig.2, Fig.3 and Fig.4 show the SEM photographs of the fiber guide silicon mold with a depth of 70μm and width of 140μm, its master consisting of UV resin, and the replica of the fiber guide made in the PAR film by hot-emboss technique. From these figures, it is proved that the fiber guide pattern can be successfully copied through the hot-emboss process. [4] Moreover, the UV-cured resin acted as the master material sufficient for hot embossing. Fig.5 and Fig.6 show the SEM photographs of the waveguide mold with a depth of 100μm and the width of 100μm and the replicated pattern on PAR film produced by coating the mold with PAR material. It is possible to fabricate the waveguide by filling the appropriate core material in the groove, and by putting the overclad. Fig.7 shows a Si mold of the 45° mirror. Since the Si was turned by 9.7° from the {100} plane and sliced, the mirror plane of 45° appeared through the wet etching process. By filling the master polymer material in the groove and by the replication through hot-emboss or coating, the replica of the 45° mirror can be realized.

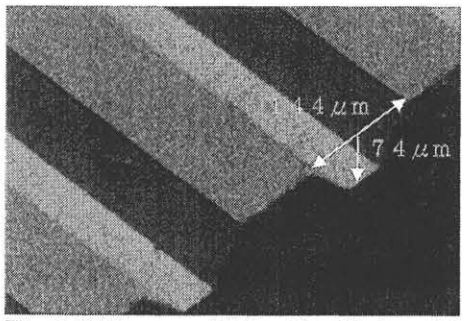

Fig.2 Silicon mold for the fiber guide

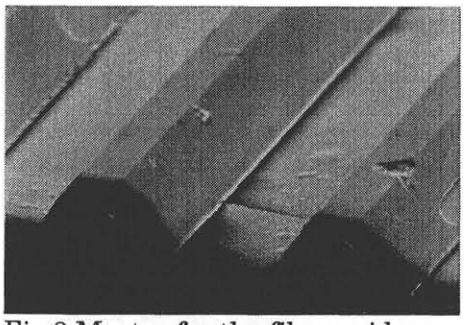
Fig.3 Master for the fiber guide.

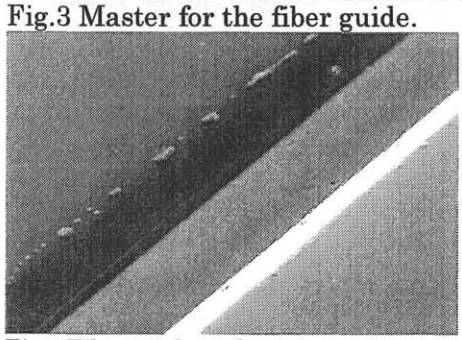
Fig.4 Fiber guide replica

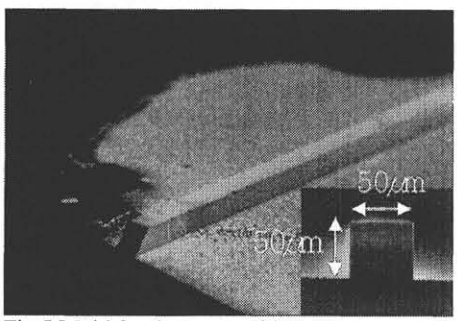

Fig.5 Mold for the waveguide

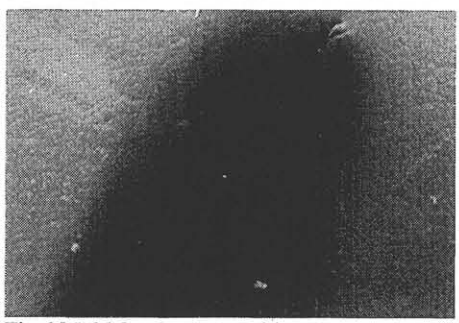
Fig.6 Mold for the waveguide

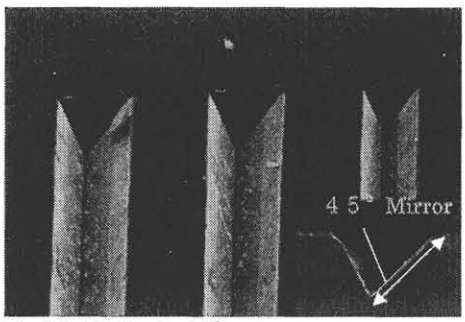

Fig.7 Mold for the 45° mirror

4. Discussion

Using the wet etching of Si, we have fabricated the molds of waveguide elements such as the channel waveguide, 45° mirror, and fiber guide. The mold pattern was smooth enough for low-loss polymer optical waveguide devices. Using the mold pattern we have fabricated the fiber guide, waveguide groove replicas in PAR polymers by hot-embossing and imprint techniques. It was confirmed that the both techniques are useful for the mass production of the replicas with low cost.

References

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