Fabrication of metallic hard mold for polymeric waveguides with embedded micro-mirrors

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Abstract—In this paper, we presented fabrication of nickel metal mold with 45º tilted surfaces on both waveguide ends through electroplating process. To obtain 45º angle, SU-8 was exposed under D.I. water, with repeatable 0.5º error.

I. INTRODUCTION

In the past many years, optical interconnects were extensively investigated to provide high-density and high speed data transmission [1-6]. Traditional electrical circuits have the disadvantage of bandwidth limitations, electromagnetic interference, and skin effect. Polymer based fully embedded board level optical interconnect attracts more and more attention because of its low transmission loss, compatibility with printed circuits board (PCB) and high speed data transmission [1]. In the board level optical interconnect, 45º total internal reflection (TIR) micro-mirrors play a significant role in vertical-horizontal optical coupling [2-6]. Many techniques can be used to fabricate the 45º micro-mirrors, such as polishing and soft molding [2-3], sawing [4], tilted exposure [5], and ultra-precision machining (UPM) method [6]. In this letter, we presented a method with combination of tilted exposure and metal electroplating process, to achieve the optical waveguide metallic hard mold and 45º total internal reflection (TIR) micro-mirror surfaces simultaneously.

In the process of optical waveguide metal mold fabrication, the waveguide pre-mold(50um×50um cross section) with reverse 45º surfaces on both ends was firstly prepared using SU-8 (from MicroChem) through tilted exposure under D.I. water. After achieving the waveguide pre-mold, metal Ni was electroplated into SU-8 defined waveguide trenches. After the electroplating process, SU-8 was removed completely. Hence the metallic mold with 45º surfaces was successfully fabricated. The advantage of this method is fabricating waveguide metal mold and the 45º surfaces simultaneously, which can save the polishing [2-3] or cutting process to obtain the 45º surfaces separately. After achieving the metal mold, polymeric optical waveguide array with fully embedded 45º total internal reflection micro-mirrors was fabricated by UV imprinting technique.

II. SU-8 PRE-MOLD FABRICATION

In order to fabricate Ni metal mold through electroplating method, we firstly prepared the pre-mold for the waveguide, which defines the shape and structure of the waveguide metal mold. We used negative photoresist SU-8 2025 for the pre-mold, which can be spin-coated with a thickness around 50um. The refractive index of SU-8 is around 1.62 at 365nm. If directly exposed in air, the largest refraction angle in SU-8 is only 34.2º. This process is simply governed by Snell's law: $n_{medium}\sin(\theta_i) = n_{SU8}\sin(\theta_r)$, θ_i and θ_r are the incident and refractive angles in the medium and SU-8, respectively. To solve this problem, de-ionized (D.I.) water (refractive index of 1.34 at 365nm) is chosen as the input media. The tilted exposure setup is shown in Fig. 1(a). When the UV light (mercury lamp) is vertically shined onto the D.I. water, the tilted angle for the substrate in water is 58.7 to make 45º refraction angle within SU-8. In the paper of Wang *et al* [5], they also used the similar method to achieve 45º angle structures in the LightLink™ photopolymer. They directly fabricated the waveguide devices. Here we use tilted exposure to create the 45º surfaces in SU-8 pre-mold for the electroplating instead of waveguide device. Once achieving the metal hard mold with 45º surfaces by electroplating, it can be repeatedly used to imprint the optical waveguide array.

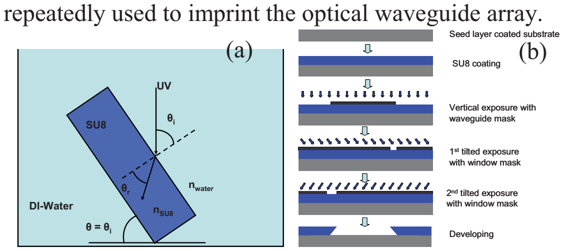

Fig. 1 (a) Schematic process of tilted exposure under D.I. water (b) SU-8 pre-mold preparation with 45º surfaces.

There are a few steps in SU-8 pre-mold preparation process, as shown in Fig. 1(b): (1)evaporate-coating 10nm/100nm of Ti/Au seed layer on the substrate using e-beam evaporator to for the electroplating. (2) Spin-coating a thin layer of Omnicoat and around 50um thick of SU-8 2025, prebake on a hotplate at 65ºC for 2-3min then ramp to 95ºC, stay at 95ºC for 6min, then cooling down to room temperature. (3)Using the waveguide mask (50um in width, 250um in period, 65mm in length) do the vertical exposure. Exposure dosage is around 200-300mW/cm^2. A UV filter was used to cut off the light below 350nm. (4) Using a small window mask, to do the 1st and 2nd tilted exposure under D.I. water. A metal stage with 58.7º angle was used to hold the sample and the photomask. The two exposures were identical except that the small window was moved from one end of the waveguide patterns to another. After PEB, SU-8 pre-mold was developed.

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Fig. 2(a) shows the top view optical image of SU-8 pre-mold waveguide trenches. The black squares at the end of waveguide array are corresponding to the 45º surfaces. They are shown black because the light was not reflected back into the microscope but to waveguide trench direction. In order to inspect the quality of the waveguide trenches and the 45º surfaces at the end of the waveguide, the fabricated SU-8 pre-mold samples were cleaved in the perpendicular and parallel direction of the waveguide trench, respectively. The cleaved samples were sputtered with metal and viewed under Scanning Electron Microscope (SEM). Fig. 2 (b), (c) and (d) show the typical SEM pictures of SU-8 pre-mold. (b) shows the cross section view in perpendicular direction of the waveguide trench. (c) shows the cross section view in parallel direction of the waveguide trench. The cleaving line must be exactly in the middle of the trench in order to view the 45º surfaces directly. The 45º surface angle was measured under SEM (Fig.2(d)) which is 45.5º, only 1% deviating from the designed value. This result can be highly repeated. It also confirms our theoretical calculation on the tilted exposure under D.I. water.

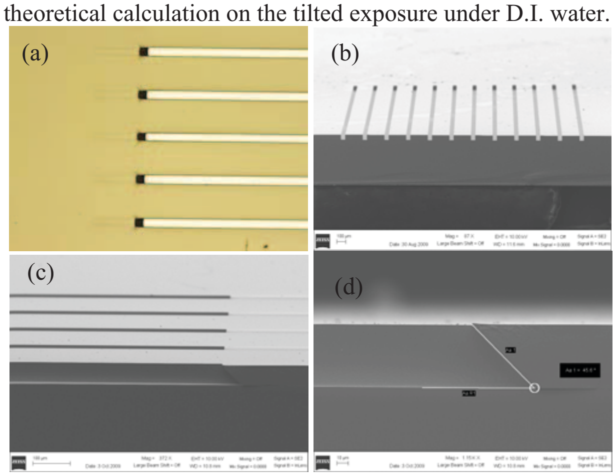

Fig. 2. (a) Top view of SU-8 pre-mold and SEM pictures of SU-8 pre-mold cross section with 45º surfaces at the end of the waveguide in the direction (b) perpendicular and (c) parallel to the waveguide trench (d) 45º angle measurement.

III. Electroplating Ni metal hard mold

After successfully achieving SU-8 pre-mold with 45º surfaces on both ends, metal Ni was electroplated into SU-8 pre-mold waveguide trenches. Fig. 3 shows SEM pictures of plated waveguide metal Ni mold on Si substrate. (a) gives a top view of the Ni hard mold, 12-channel waveguide array mold are shown. The width of the waveguide mold was measured to be 49.1um. To view 45º surfaces at the mold waveguide ends, the sample was cleaved between two mold waveguide lines. Fig. 3(b) gives a view of side cross section parallel to waveguide mold array. We measured actual slant angle of 45º surfaces to be 44.5º, which is highly consistent with SU-8 pre-mold inverse angle measurement. The height at the end of waveguide is a little greater than that in the middle because in the electroplating process the electric field is stronger at the end than that in the middle. More Ni ions are attracted and Ni grows faster at the ends region.

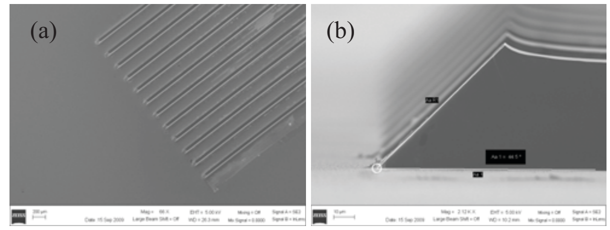

Fig. 3. (a) Top view SEM pictures of the Ni hard mold on Si substrate in large magnification. (b)Side view SEM pictures of Ni hard mold on Si substrate. The angle shown in (b) is 44.5º.

UV curable polymers to fabricate the optical waveguide array are WIR30 series (from ChemOptics), WIR30-450(n=1.45 at 850nm) for bottom and top cladding, WIR30-470(n=1.47 at 850nm) for the waveguide core. TEONEX thin film (from Dupont Teijin Films Inc.) with thickness of 200um was used as the TOPAS substrate. Au mirror was coated at 45º surfaces before core filling and top cladding coating. Hence the polymeric waveguide array with fully embedded 45º total internal reflection (TIR) micro-mirrors was successfully fabricated (Fig.4).

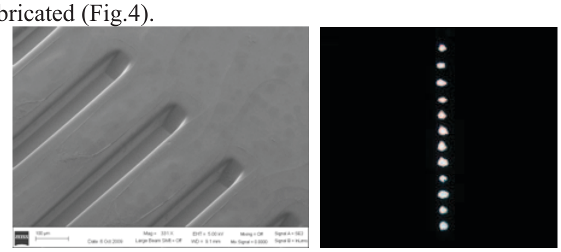
Fig. 4 (a) SEM image of the imprinted device (b) Output image from screen

In summary, we have successfully fabricated SU-8 pre-mold for the waveguide with reverse 45º surfaces on both ends through tilted exposure under D.I. water. Metallic hard mold with 45º surfaces was electroplated into SU-8 defined waveguide trenches. After obtaining the metal hard mold, 12 channel polymeric waveguide array based on UV curable photopolymers was formed by UV imprint technique. This work is supported by National Science Foundation.

IV. References

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