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NOVEL POLYMER MICRO-WAVEGUIDE USING ELECTROPLATING MOLD TECHNOLOGY

WEN-CHUNG CHANG [a,*] , KAO-FENG YARN [b] and WEI-CHING CHUANG [c]
[a]*Department of Electronic Engineering, Southern Taiwan University of Technology, Taiwan 710, ROC*
[b]*Department of Electronic Engineering, Far East University, Hsin-Shih, Tainan, Taiwan 744, ROC*
[c]*Department of Electro-Optics Engineering, National Formosa University, Huwei, Yulin, Taiwan, ROC*

A novel polymer micro-waveguide had been successfully developed by a new method, which was incorporated with a LIGA-Like and micro-molding process. The refractive index of the UV polymer used in this experiment could be changed by an extremely low electric field. The near field measurement with end-fire coupling had shown that the light had been totally restricted inside the core layer of the waveguide and the polarization dependent loss is very low. This process is easy, simply and suitable for mass production of any shape of polymer waveguides.

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1. Introduction

Recently, there are several widespread advanced techniques for nanofabrication research in physics, chemistry, biology and materials science. Well established nanolithographic methods, e.g. electron-beam lithography, deep ultraviolet photolithography, etc., require elaborate, expensive systems that can only be patterned in a narrow range of specialized materials over small areas on ultraflat surfaces of rigid inorganic substrates. These severe limitations have created substantial potential in another alternative techniques based on the forms of contact printing, molding, embossing, and writing. [1-2] Polymer optical waveguides have attracted much attention due to their low cost, and high process ability. Their possible applications include optical components in optical interconnects and optical communication systems. There are a number of simple methods to fabricate polymer waveguides, which include photocrosslinking, photobleaching, reactive ion etching, photolocking, and laser/electron beam writing. There are other many replication processes which are simple and easy fabrication and can be used for mass productivity, such as hot-embossing , UV-embossing , and micro-transfer molding method. Use of a LIGA-Like process to fabricate micro-optical components shows great mass production potential. [3] Following a molding process, optical component mass production can be achieved .

In this paper, the LIGA-Like process was used to fabricate polymer optical waveguides. In order to reduce the residual stress in the waveguide, which was induced by different materials of the core and cladding of the waveguide, the waveguide was fabricated in terms of the same material in this paper. The polymer used in the waveguide was UV epoxy (OG146), which was provided by the EPOXY TECK Company. The refractive index of the UV epoxy is between 1.52~1.54, which is close to the refractive index of the optical fiber, therefore the UV epoxy waveguide can effectively reduce the Fresnel reflection. The electric field was used to induce the change of the refractive index of the UV epoxy. It usually needed a very high electric field (V/μm)

[*]Corresponding author: wcchang_710@yahoo.com.tw

to change the refractive index of the waveguide materials, but the UV epoxy in liquid form only needs a low electric field (V/µm) to change the refractive index dramatically.

2. Experimental and results

The process for changing the refractive index of the UV epoxy was described as follows. Since it was found that the UV epoxy was not easy to be uniformly spun on the glass or Si substrate, another way was used to spread the epoxy on the substrate. First, Si wafers cut to 3cm x 2mm were clean, a spacer with thickness with 400µm was put between ITO and Si wafer substrate, and a pressure was used to clad the ITO Glass and Si wafer. After injecting the precure UV polymer**,** which has a relatively low viscosity (82 CPS), into the opening between the ITO Glass and Si wafer using a fine tip syringe, the liquid solution automatically spread and filled up the space due to capillary effects. The UV light with wavelength 300~400 nm was used to solidity the polymer at the intensity of 100 mw/cm^2 for 1~2 minutes by through the ITO glass, and a electric field was also applied to change the refractive index of the polymer during the curing process simultaneously (Fig. 1(a-b)).

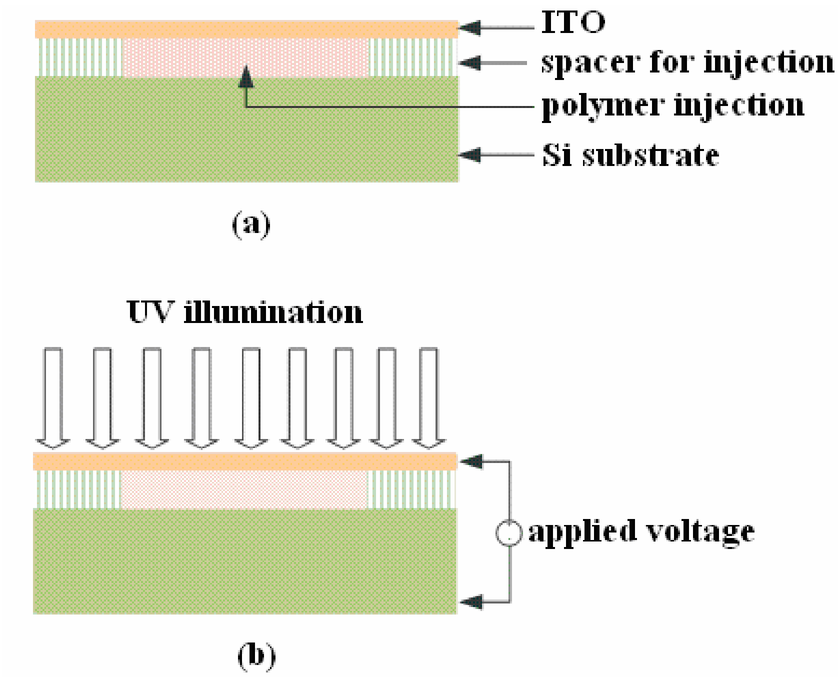

Fig.1. Schematic illustration of electric field induced change in refractive index.

After removing the ITO Glass, the uniform thin layer polymer on the Si substrate was formed which was confirmed by the AFM measurement. The thickness of the thin layer polymer was 400µm. The changes in refractive indexes, n^{TE} and n^{TM} induced by electronic field were measured with a prism coupler at a wavelength of 633nm. Fig. 2 shows the change in refractive indexes during UV irradiation at the electric field from 0 to 70 V. The n^{TE} and n^{TM} firstly decreased dramatically at 10 V, and then decreased slightly till 70 V for n^{TM}. The decrease in n^{TE} was accelerated in terms of increasing the applied voltage from 50V to 70V. The change in the refractive index may be due to the electric field that induced the change of the polymer molecular orientation. [4] When the electric potential was beyond 70V, the UV epoxy became un-curable.

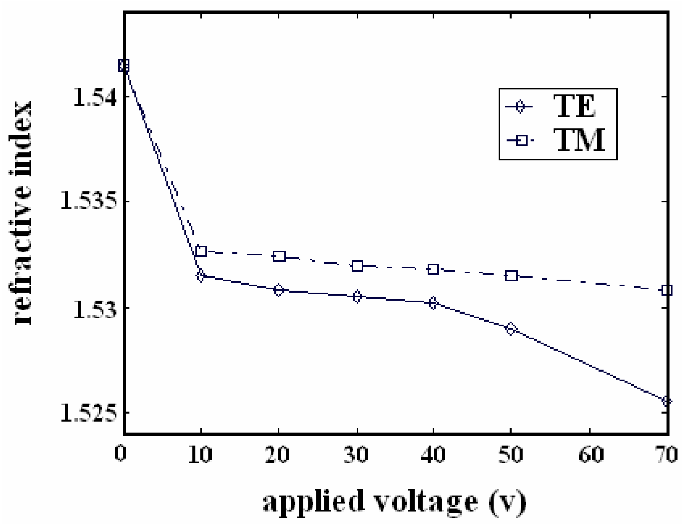

Fig.2. The refractive index change during UV irradiation under the external electric voltage from 0 to 70 V.

In order to fabricate the channel waveguide in terms of polymer, a metal mold was made by a LIGA-Like process. Wafers with a 10µm thick photoresist (FL4104) were exposed through the PET (Polyethylene Terephthalate)-based masks using a UV mask aligner (EVG620) for 90 seconds. After dipping in the developer for 30 seconds, the waveguide patterns in the opaque regions of the mask were obtained. The ICP/RIE with the gas Ar was used for continuing etching the sample to obtain the deep and vertical channel of the waveguide. After removing the photoresist by immersing the sample into the acetone for 10 minutes, the pattern on the mask was transformed into the wafers. The rectangular groove of the waveguide pattern formed on wafer measured by AFM was 1.5µm x 5µm, and the depth was 5µm.Next, the metal Ni-Co electroplating technique was applied to transfer the pattern into Ni-Co mold. After etching out the Si substrate, a ridged waveguide metal mold was obtained. The SEM micrograph of the electroplating metal mold shown in Fig.3 had indicated that the waveguide pattern was remained well and sharped in the boundary, and the thickness of the Ni-Co mold was about 0.5mm after 4 days electroplating process.

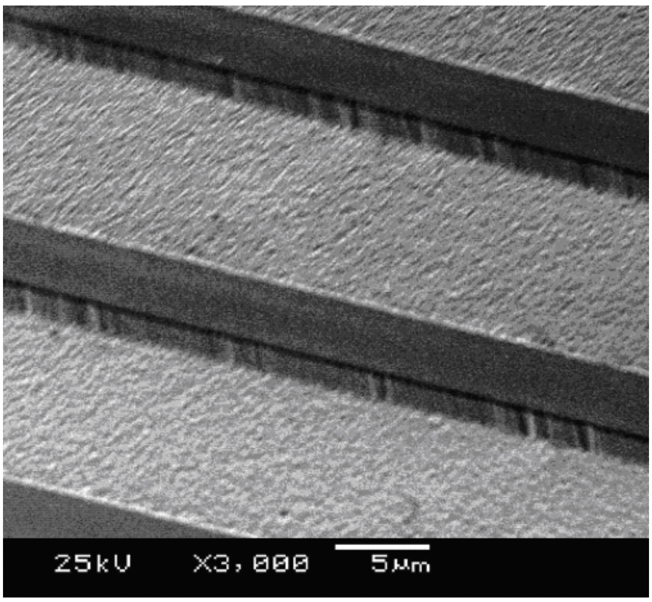

Fig.3. SEM micrograph of the fabricated metal mold.

Polymer waveguides were fabricated on a 4cm x 2cm ITO glass. The similar process as described in the front was adopted to form the cladding layer of the waveguide except the Si wafer was replaced by the ridge metal mold. A spacer of 400μm was put between the ITO Glass and the mother mold, and a pressure was used to clad the ITO Glass and the mold (Fig.4 (a)). After the UV epoxy was injected into the tunnel, the sample was simultaneously exposed to UV light with wavelength 300-400nm and electric voltage with 50 V (Fig.4 (b)). After separating with the Ni-Co metal mold, the solidified polymer could become the cladding layer of polymer waveguide (Fig.4(c)).

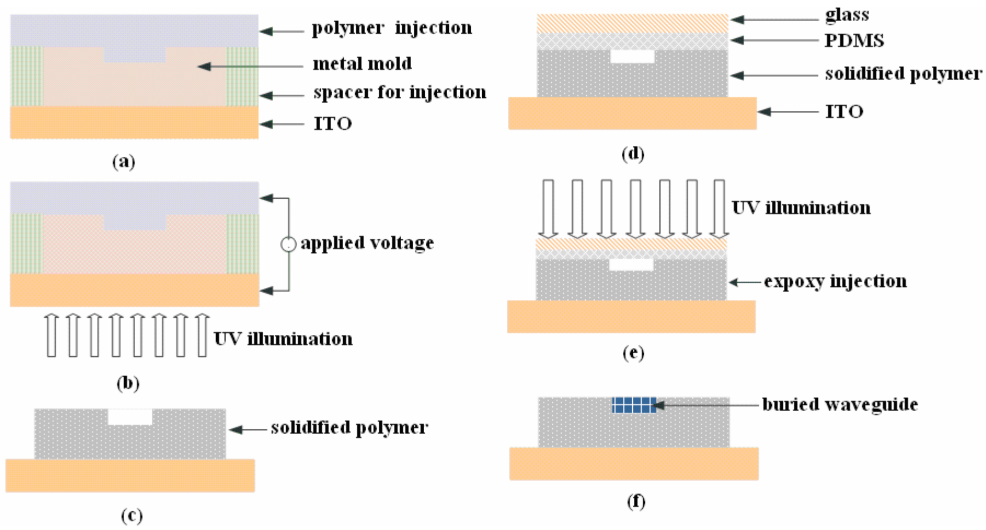

Fig.4. Schematic manufacturing process diagrams of the polymer waveguide.

The next step is to inject the UV epoxy into the groove to form the waveguide core. Instead of spin coating technique, which could cause the thick unguided layer outside the core region that would induce a large loss while the waveguide was bended, another means was proposed to fill the liquid epoxy into the groove with only thin layer outside the core. The process was shown in Fig.4 (d)-5(f). A thin layer of a polydimethylsiloxane (PDMS) polymer was made to cover on the polymer groove, both of the groove and the PDMS layer were supported by a piece of glass separately, and a pressure was used to clad both materials. Therefore, a rectangular tunnel was formed by the groove and PDMS layer, and the gap between the flat substrate (outside the groove) and PDMS was very small and could be neglected, which was observed by the optical microscopy. Then, one droplet of the UV epoxy was dropped at one end of the tunnel. After exposing the UV light, the tunnel at one end was sealed to form a closed tube.

Next, the above sample with the unclosed end in front was inserted into the non-cured liquid UV epoxy that was put into the vacuum chamber. When the pressure in the chamber was reached to ten mTorr, the Ar gas was vented to the chamber to push the liquid epoxy injecting into the tunnel. The epoxy in the tunnel was cured by exposing the UV light for 1-2 minutes, the upper glass was removed, and the PDMS layer was peeled off from the sample.To prevent the optical loss due to the air absorption on the core surface, the upper cladding layer of the waveguide was formed using the fabricating procedure as described in the front, the material used was the same UV epoxy, and the final product of the polymer waveguide was obtained.

The near-field pattern of the polymer waveguide mode was measured in terms of end-fired coupling technique. [5] The propagation experiment was performed at a 633 nm wavelength using a He-Ne as a light source. The light launched from the other edge of the waveguide was focused on the screen through the convex lens. The results showed that the all red light almost focused on the core layer of the waveguide to propagate; therefore the energy loss of the light propagating through the waveguide was very small.

3. Conclusions

The adjustable refractive index of the UV polymer could be changed by a low external electric field (about maximum electric field 70V/400μm) for optical waveguide applications. The UV polymer waveguide was fabricated by the LIGA-Like process, which possessed easy and simple fabrication process which had the potential to fabricate any shape of polymer waveguides. The experiment of the near-field measurement with end-fire coupling had shown that the polarization dependent loss is very small.

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