Fabrication of Zero Bending Loss Flexible Film Optical Waveguide by UV Moulding of Sol-Gel Hybrid Materials

Byeong-Soo Bae and Woo-Soo Kim

Laboratory of Optical Materials and Coating (LOMC), Department of Materials Science and Engineering, Korea Advanced Institute of Science and Technology (KAIST), 373-1 Guseong-dong, Yuseong-gu, Daejeon, Korea

bsbae@kaist.ac.kr

Keun Byung Yoon

Optical Interconnection Team, Electronics and Telecommunications Research Institute (ETRI),161 Gajung-dong, Yuseong-gu, Daejon, Korea

Abstract: A flexible multi-mode channel waveguide with high Δn is fabricated by UV moulding method with organic-inorganic sol-gel hybrid materials for optical interconnects. Flexiblely bent film waveguide shows no bending loss until 2 mm bending radius.

OCIS Codes: (160.6060) Solgel; (230.7380) Waveguides, channeled

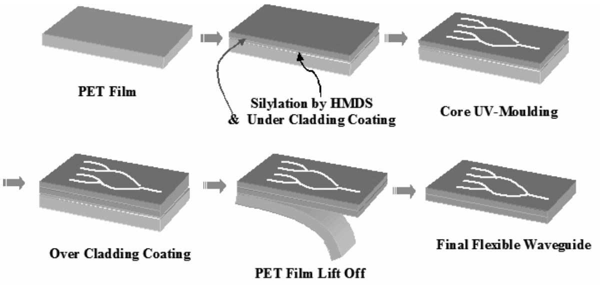
1. Introduction

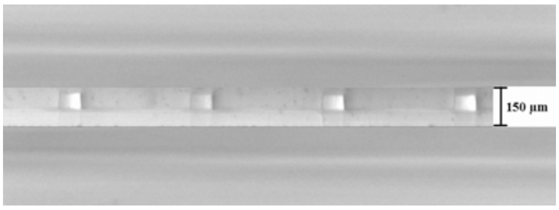
In order to represent high speed telecommunication and computer system, faster optical interconnection system is required. The flexible optical waveguide interconnects are an important component for optical interconnection technology. It will be used as an optically connected mediation systems, e.g. a board-to-board or chip-to-chip interconnections[1].

To be bent for a flexible interconnects, the used material must be soft. The applications of polymer film optical waveguide as short distance interconnects has been reported using deutrated-PMMA polymer and conventional photo-lithography method[2]. The organic-inorganic hybrid materials prepared by sol-gel process of organoalkoxy silanes, which will be called HYBRIMER, may be used in the room temperature for the fabrication of flexible optical waveguide, instead of polymers. UV-based soft lithography methods have been investigated for mass production of polymeric optical waveguides[3]. We have published a preliminary report on the fabrication and characterization of UV moulded multi-mode optical waveguide using the HYBRIMERs on the silicon substrate[4]. In this report, the free-standing flexible multi-mode optical waveguide, fabricated by UV embossing technique with the HYBRIMERs is reported. Because of easy refractive index tunability of the HYBRIMERs, the refractive index difference between the core and cladding can be made so large for low bending loss of flexible waveguide.

2. Fabrication and characterization of flexible waveguide

We fabricated flexible multi-mode optical waveguides with $60 \times 90\ \mu m^2$ thick core by the following process which is also shown in Fig. 1(a). The fabrication step is straightforward. First, the surface of PET substrate was modified with HMDS (1,1,1,3,3,3,-hexamethyl-disilazane), before spin-coating of under-cladding HYBRIMER material on a PET flexible substrate. This sylilation step by HMDS makes poor adhesion between PET and under-cladding layer for easy lift-off of flexible waveguide from PET film in the final step. Then, core structures were formed by UV moulding technique using PDMS mold with core HYBRIMER material as described in previous report[4]. Then, the over-cladding layer was spin-coated on the embossed core patterns of waveguide. By single spin-coating of over-cladding HYBRIMER, the whole core structure was covered well. The polished cleaved image of flexible multi-mode optical waveguide is shown in Fig.1 (b).

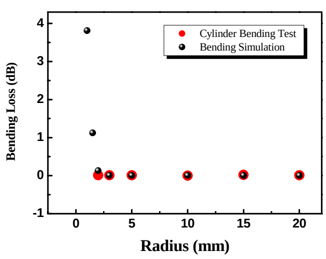




(a) (b)

Fig. 1. Fabricating procedure of flexible optical waveguide (a), and the cleaved edge image of HYBRIMER flexible waveguide (b).

The thickness of flexible optical waveguide is totally about 150 μm. The manufactured waveguide is 10 cm long enough to measure cutback loss measurement. The core HYBRIMER is the methacrylic HYBRIMER[5], which is simply UV-curable and thermally stable (> 300 °C) after curing and has very low birefringence (< 1×10^{-4}). The cladding HYBRIMER is the fluorinated methacrylic HYBRIMER[6], which contains methacrylic organic unit for curing and fluorine contents for lowering refractive index. Refractive index of this HYBRIMER can be controlled by varying fluorine composition easily. These two HYBRIMERs are synthesized by non-hydrolytic sol-gel process that can control the structure of nano hybrid material as a bottom-up approach. The non-hydrolytic sol-gel HYBRIMER can be condensed well from the resin preparation stage, so there can be little further inorganic condensation reaction during curing steps. Thus, the shrinkage of cured sample is so low enough to apply to a micro-moulding process, during UV and thermal curing steps (about 2.5 % volume contraction measured by Archimedes method).



(a) (b)

Fig. 2. Bent image of the pigtailed HYBRIMER flexible waveguide (a), and the result of cylinder bending test with bending simulation (b).

The refractive index difference between core and cladding materials is 2.27% (core HYBRIMER n= 1.536

& cladding HYBRIMER n= 1.501), which is designed for working as a multi-mode optical waveguide as well as a low bending loss waveguide. The propagation loss of flexible waveguide is measured by cutback method (about 0.24dB/cm at 850 nm wavelength). Finally fabricated flexible waveguide is pigtailed to multi-mode fiber for cylinder bending test[2]. The flexible waveguides are then bent around a cylinder of radius R and the bending loss measured as show in Fig. 2(a) and Fig. 2(b).

3. Discussion and Conclusion

The flexible multi-mode waveguide devices may be fabricated by UV moulding of the HYBRIMERs developed here. One of the major questions concerning flexible device is how much it can be bent without affecting its performance. In order to reduce bending loss when this waveguide would be interconnected flexibly between board arrays, the cladding HYBRIMER's refractive index is controlled for fitting the difference over 2 %. Fig. 2(a) shows the bent flexible waveguide for cylinder bending test. Manufactured flexible waveguide is flexible enough to bend 180° until 2mm bending radius. Simultaneously, the bending simulation is checked by conformal mapping of 2D effective index method. By varying bending radius from 1 mm to 20 mm, the change of light propagation is simulated. The bending loss can be seen slightly from 2mm and significanlty from 1 mm bending radius during bending. However, there's no bending loss in real HYBRIMER flexible waveguide until 2 mm bending point [Fig. 2(b)]. High refractive index difference of core and cladding (2.27 %) and clear surface of fabricated core structure (rms roughness < 1nm) cause little effect during bending until 2 mm bending radius. After repeated bending of the waveguides, no cracks were seen and no change of bending loss was checked.

In a conclusion, We demonstrated a flexible multi-mode optical channel waveguide of organic-inorganic hybrid materials fabricated by simple UV moulding methods. At a condition of low temperature and pressure, we can get thermally stable (over 300°C) waveguide patterns with clear surface. The manufactured flexible waveguide shows little bending loss until 2 mm bending radius, because of large difference of refractive index between core and cladding. The fabricated flexible multi-mode waveguide can be used for the board-to-board interconnects and the simple aligning optical interconnects.

4. Refereces

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