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Low-birefringent slab waveguide fabricated with hot-embossing for sol-gel derived phenyl-methyl silsesquioxane films

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1. Introduction

Organic polymer materials have been attracted as considerable attention particular for cost-effective waveguide device, because of its ease of processing, controllability in refractive index, and flexibility [1]. However, its durability against thermal or humidity exposure as well as birefringence still has concern compared with inorganic silica materials which have been widely used for telecommunication. Organically modified silica (ormosil) is well studied for combining the both advantages of organic and inorganic materials, and UV imprinted channel waveguide with the ormosil have been reported[2,3]. We have demonstrated a thermally stable grating made of the ormosil with hot-embossing [4]. In this report, optical properties of planar waveguide made of the ormosil are presented.

2. Experiments and results

Planarization of sol-gel derived film with hot-embossing

Sol-gel derived films were deposited with spinning mixture solution composed of phenyltriethoxysilane (PhTES), methyltriethoxysilane (MTES), ethanol, and catalytic hydrochloric acid solution, where the molar ratio was [organosilane] : [EtOH] : [H_2O] : [HCl] = 1 : 0~1, 2.8~4 : 0.0002. The film was plarnerized with hot-embossing using a planar silica mold. Since self-assembled monolayer of octadecyltriethoxysilane (OTE-SAM) has good anti-sticking property [5], the OTE-SAM was grafted on silica mold in accordance of [6] as an anti-sticking layer. Water contact angle of the OTE-SAM was measured to be 110° and excellent reproducible anti-sticking property was obtained.

Stability of silsesquioxane film

Table 1 shows comparative results of the refractive index by prolonged thermal or humidity exposure. No significant difference among them is seen, indicating good stability of the film.

Table 1 Measured refractive indices at 0.63μm wavelength.

	TE	TM
As prepared	1.489	1.489
200℃ 75hours	1.489	1.493
90℃ 90%RH 100hours	1.485	1.485

Phenyl-methyl silsesquioxane film for waveguide device

Figure 1 shows refractive index dependence on phenyl contents in the film at 0.63μm wavelength. The index almost linearly increases from 1.46 to 1.56 with the increase of the phenyl contents from 0 to 1. This wide range of the index tuning enables to adapt the both silica fiber and POF with low coupling loss. Proportional coefficient of the index is 1.05×10^{-3} $Ph\%^{-1}$ for the both TE and TM modes. Control in phenyl contents was ±0.5% from the target composition, thus attainable control in index is $\pm0.5\times10^{-3}$. When the index difference between core and cladding is designed to be 0.3%, index control can be attained with approximately 5% of compositional difference.

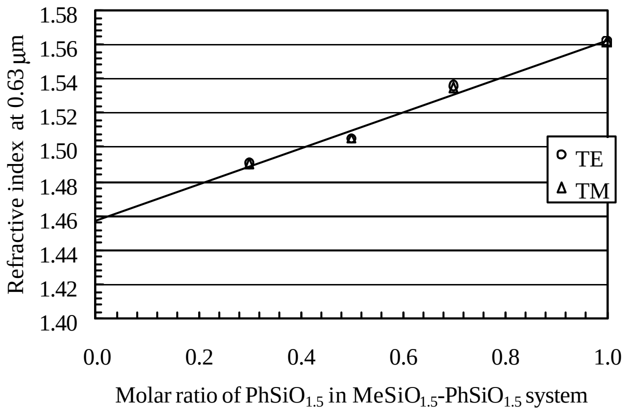

Fig. 1 Index dependence on phenyl contents in the film for TE and TM polarization at a wavelength of 0.63μm.

Figure 2 shows wavelength dispersion of the index for the 0.3Ph and 0.7Ph films at TE and TM modes. The index was measured from the three different positions on a sample with Metricon prism coupler. The difference at the position was less than 6×10^{-4}, indicating good index homogeneity. In addition, birefringence was less than 7×10^{-4}, which is comparative to the lowest birefringence for the thermally stable polymers [7, 8]. Coefficients of Sellmeier dispersion for 0.3Ph and 0.7Ph films were calculated to be 0.86 and 0.77, respectively.

Thickness control is important for waveguide design. Almeida [9] reported that spin-coated thickness of sol-gel derived silica gel linearly increased even at the rotational speed less than 1krpm. However, the thickness with such low speed was not uniform. Thereat, we have applied two-step spinning, where the rotational speed of the first step is less than 1krpm and the second one is faster. This spinning significantly improved the thickness uniformity. Consequently, uniform thickness as high as 7µm was coated with single spinning with the optimization of both spinning and sol-gel conditions.

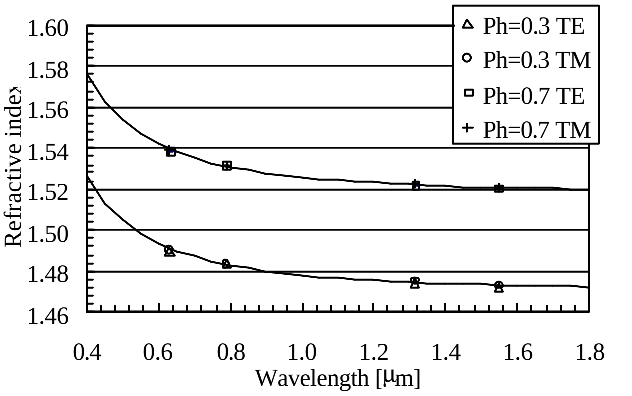

Fig. 2 Index of the phenyl-methyl silsesquioxane film for TE and TM modes as a function of wavelength.

Planarization of the slab waveguide and propagation loss

Radiative striation of the spin coated sol-gel film is concern for waveguide application, since such striation causes the increase in scattering loss. Nomarski micrograph and surface profile for as-spun waveguide (Fig. 3 (a)) show distinct striation. Propagation loss of these slab waveguides was measured to be 1 ~10dB/cm with scattering detection method using He-Ne laser. Du et al. [10] eliminated the striation using saturated solvent atmosphere in the spinning chamber. However, thickness of the resultant film was approximately a half of that without the method. Thus, this method is still concern, since undesirable multiple coating is requisite. We have applied hot-embossing to planarize the waveguide using planar mold. Nomarski image and surface profile of the planarized waveguide (Fig.3(b)) show smoother surface. Moreover, no streak pattern was observed, implying low scattering loss. This result also implies the possibility of channel waveguide with hot-embossing.

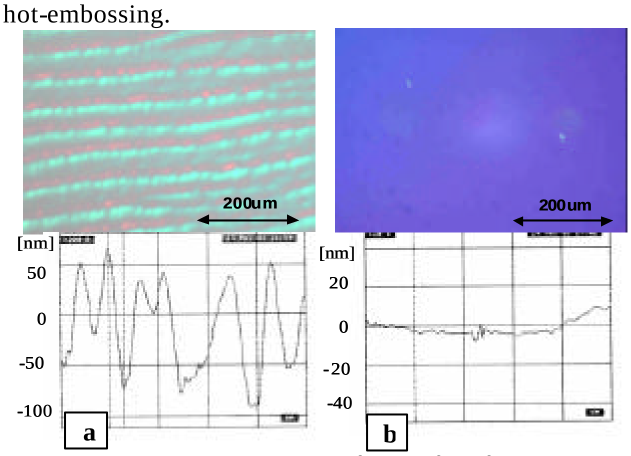

Fig. 3 Nomarski micrograph and surface profile of non-planarized (a) and planarized (b) waveguides. Profiling length was 500µm.

In addition to the extrinsic absorption, intrinsic absorption of the material needs to be considered. Absorption of the PhTES and MTES at the wavelengths of 0.65, 1.31 and 1.55µm was estimated to be 0.0, 0.3, and 0.4dB/cm for PhTES and 0.0, 0.2, and 0.8dB/cm for MTES, respectively. In addition, overtone absorption due to silanol which is the side-reactant of hydrolysis reaction locates at 1.38µm [11]. Propagation loss spectrum for the waveguide to be measured.

3. Conclusions

Phenyl-methyl silsesquioxane film was investigated as waveguide application. No difference in refractive index of the film before and after the 90°C 90%RH exposure for 100hours was observed. Even in good thermal stability, low birefringence less than 7×10^{-4} was obtained. This material showed excellent adjustability for refractive index and film thickness. Problematic radiative striation in spin-coated film was successfully eliminated with hot-embossment using planar mold. This result also implies the possibility of channel waveguide fabrication with hot-embossing.

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References

[1] L.Elanda, R.Blomquist, L.W.Shacklette, and M.J. MacFarland, Opt. Eng. **39**, 596 (2000).
[2] S.I.Najafi, T.Touam, R.Sara, M.P.Andrews, and M.A.Fardad, J. Lightwave Technol. **16**, 1641 (1998).
[3] R.Buestrich, F.Kahlenberg, M.Popall, P.Dannberg, R.Muller-Fiedler, and O.Rosch, J. Sol-Gel Sci. Technol. **20**, 181 (2001).
[4] K.Hasui, I.Takagaki, O.Sugihara, and N.Okamoto, Proc. SPIE **4991**-43 (2003).
[5] R.Maboudian and R.T.Howe, J. Vac. Sci. & Technol. B**15**, 1 (1997).
[6] J.Peanasky, H.M.Schneider, and S.Granick, Langmuir **11**, 953 (1995).
[7] T.Watanabe, N.Ooba, S.Hayashida, T.Kurihara, and S.Imamura, J. Lightwave Technol. **16**, 1049 (1998).
[8] S.H.Baek, J-W.Kang, X.D.Li, M-H.Lee, and J.J.Kim,. Proc. SPIE **4991**-45 (2003).
[9] R.M.Almeida, Int. J. Optoelectronics **9**, 135 (1994).
[10] X.M.Du, X.Orignac, and R.M.Almeida, J. Am. Ceram. Soc. **78**, 2254 (1995).
[11] G.R.Atkins, R.M.Krolikowska, and A.Samoc, J. Non-Cryst. Solids. **265**, 210 (2000).