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Humidity Tolerance for Athermal Si-Slot Wavelength Filters using Amorphous Fluoride Polymer and SiO_2 Protection Layer

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Abstract

We demonstrated an athermal Si slot wavelength filter with improved humidity tolerance by introducing amorphous fluoride polymer, CYTOP and SiO_2 protection layer on BCB cladding.

1. Introduction

Si photonics has been vigorously researched for chip-to-chip or on-chip optical interconnection for high-end electronic systems due to the potential of the higher-speed signal processing and lower power consumption [1]. However, heating caused by thermal diffusion from the LSI logic layer is a serious obstacle to Si-based photonic integrated circuits (PICs) on a CMOS logic layer, because of the positive temperature coefficient of the refractive index (dn/dT) of Si, i.e. 1.8×10^{-4} K^{-1} [2]. In order to solve this problem, we have demonstrated athermal wavelength filters using Si slot waveguides embedded with benzocyclobutene (BCB), which is polymer resin and has a negative dn/dT of -7×10^{-5} K^{-1} [3].

To realize the Si athermal wavelength filter with polymer cladding for practical use, a problem of hygroscopic tolerance should be solved. The moisture absorptivity of BCB was reported to be 0.2%, and the absorption results in the change of the refractive index of BCB and leads to red shift of the resonant wavelength. This time, we introduced an amorphous fluoride polymer and SiO_2 to the athermal Si slot ring resonator as a humidity protection layer and evaluated the humidity tolerance.

2. Experiment

A Si slot waveguide consists of two parallel Si waveguides with a nano-scale width gap, and the optical mode field especially in TE-mode is largely confined in the gap region filled with a cladding material in this structure, where an amorphous fluoride polymer, CYTOP (CTL-809A) of Asahi Glass Company (AGC) Inc., was used as a cladding or humidity protection material [4]. This material was developed for a plastic optical fiber [5] and has small moisture absorptivity of less than 0.01% as well as quite high transparency in the optical communication band. Furthermore, this also has a negative dn/dT of -7×10^{-5} K^{-1} with a low refractive index of 1.33 at 1.55-μm wavelength.

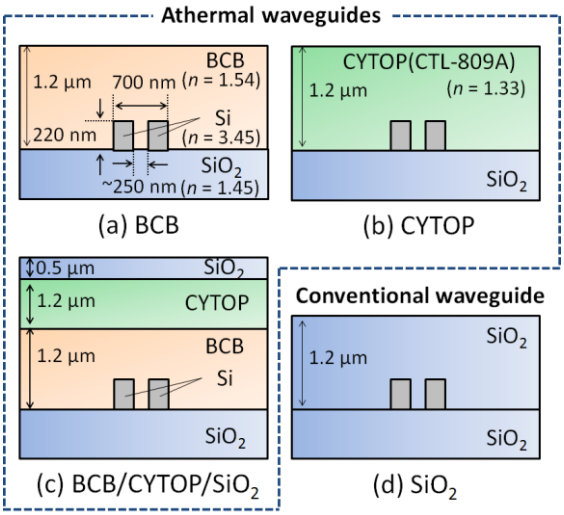

Fig.1 Cross-sectional structure of athermal Si slot waveguide with (a) BCB, (b) CYTOP, and (c) BCB overlaid with CYTOP and SiO_2 claddings, along with conventional waveguide with (d) SiO_2 cladding.

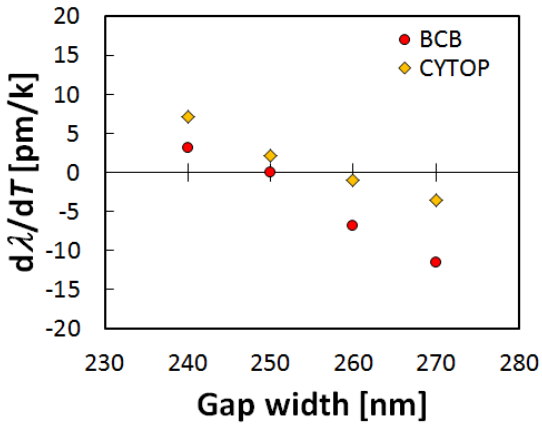

Fig. 2 Measured temperature coefficient of resonant wavelength as a function of gap-width for BCB and CYTOP claddings.

Figure 1 shows the cross-sectional schematics of athermal Si slot waveguides used for the experiment. The total core size of slot waveguides and the thickness of each cladding polymer were fixed to 700×220 nm^2 and about 1.2 μm, respectively. The waveguide in the Fig. 1(c) has multi-layered humidity protection films with CYTOP and SiO_2 onto BCB cladding. To enhance the interface adhesion,

Ar-plasma activation treatment was executed for the surface of BCB and CYTOP. Then SiO_2 was deposited using plasma-enhanced chemical vapor deposition (PECVD) with tetraethyl orthosilicate (TEOS) at low process temperature of 90°C for the reason of low glass transition temperature T_g for CYTOP, which was 108°C.

Figure 2 shows the measured temperature coefficient of resonant wavelength shift ($d\lambda/dT$) for various gap widths for 2 kinds of devices with BCB and CYTOP claddings. For the measurement of the filter characteristics, a thermo-electric controller (TEC) was used for temperature control and a vacuum chuck was used without glue. TE-polarized light in the 1.55-μm band from a tunable laser was put into device after it was focused through a single mode fiber (SMF) tipped with a lens. The light output from the through and the drop ports was detected by an optical power meter. By controlling the gap width to about 250 nm, $d\lambda/dT$ for both devices became closed to zero, i.e. athermalization could be achieved.

Next, a wavelength trimming using deep-ultra-violet (DUV) exposure to athermal wavelength filter with CYTOP cladding was investigated. Si photonics has a disadvantage of high structural sensitivity. Thus it is nearly impossible to obtain the designed resonant wavelength, due to structural fluctuations without wavelength trimming technology. So far, we have demonstrated a wavelength trimming for athermal Si slot wavelength filter embedded with BCB using DUV exposure [6]. In this experiment, the Xe lamp with a wavelength filter (λ = 254 nm) was used for DUV light source and light was exposed to the whole area of the device. Figure 3 shows the wavelength shift of Fig. 1(a) (BCB cladding) and (b) (CYTOP cladding) as a function of the dose amount of DUV exposure. The resonant wavelength for BCB cladding showed a red-shift in accordance with the increase in DUV dose, on the other hand, that for CYTOP cladding showed a negligible red-shift due to quite high transparency at the DUV wavelength. Therefore, CYTOP should not be used as a cladding layer but as a protection layer.

Then, these devices shown in Fig.1 were put into the thermo-hydrostat chamber under the condition with temperature of 30°C and the humidity of 80%. Figure 4 shows the measured process time dependence of the wavelength shift for Si slot ring resonator. The resonant wavelengths for BCB cladding and CYTOP cladding were red-shifted in accordance with the increase in process time and the wavelength shift saturated with the amount of 0.15 nm for CYTOP cladding. On the other hand, that for BCB overlaid with CYTOP and SiO_2 claddings was suppressed within 0.1 nm for more than 260 hours and temporary condition of 80°C and 80% for 27 hours. This indicates that humidity was blocked with CYTOP and SiO_2 protection layer.

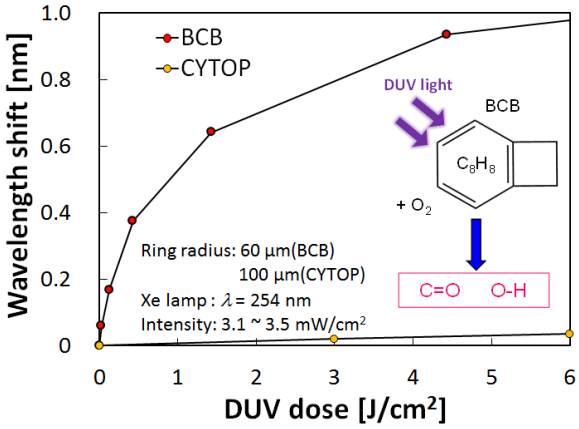

Fig. 3 Wavelength shift of Si slot ring resonator with BCB and CYTOP cladding after subsequent UV exposure. Inset shows mechanism of wavelength trimming for BCB.

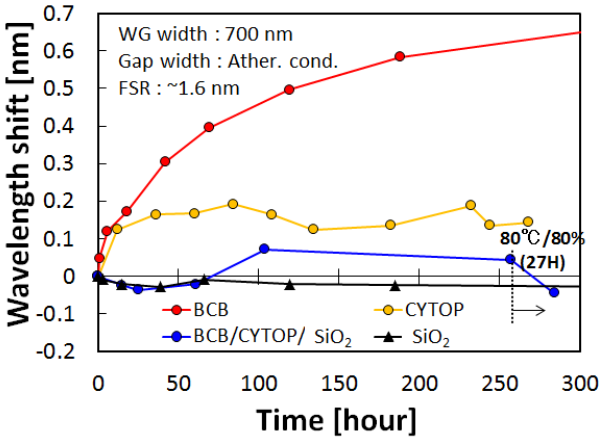

Fig.4 Measured wavelength shift for Si ring resonators at the condition of the temperature of 30°C and the humidity of 80% (partly 80°C for device with BCB/CYTOP/SiO_2 cladding).

3. Conclusion

We introduced an amorphous fluoride polymer and SiO_2 to the athermal Si slot ring resonator as a humidity protection layer. Wavelength shift was suppressed with the accelerated aging test at the condition of 30°C and 80% humidity.

Acknowledgments

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