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9. Perfluoropolymer Waveguide with Low Loss in Wide Wavelength Range

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A single-mode polymeric optical waveguide was fabricated using poly{perfluoro(3-butenyl vinyl ether)}. Its propagation loss was 0.10 dB/cm at 1.3 μm and 0.12 dB/cm at 1.55 μm. Its loss spectrum showed a flat feature in a wide wavelength range of 1.0 to 1.6 μm. We also fabricated a 4-channel wavelength-division multiplexer and a 1×8 splitter, and discuss their performance.

1. Introduction

The demands to manufacture low cost optical modules are increasing with the expansion of the optical communication network. Polymeric planar lightwave circuits are possible candidates for such modules, due to their good processability and flexibility.

However, optical transparency of polymers in the near-infrared range, especially at 1.55 μm, are not suitable in applications of optical communication, due to the absorption by C-H bonds. To solve this issue, the substitution of deuterium(1) or fluorine(2) for hydrogen has been developed. Recently, A.Yenity et al. reported several optical devices using perfluoropolymers with polymeric substrates for preventing the stresses caused by the difference of coefficients of thermal expansion(3).

We have been developing the perfluoropolymer poly{perfluoro(3-butenyl vinyl ether)} (PBVE) since 1988 as a material for optics and electronics(4). Its theoretical limit of propagation loss, when applied to optical fibers, is estimated to be less than 10 dB/km in the near-infrared range(5). The PBVE has inherently an amorphous structure. Therefore, it has no scattering center and shows isotropic optical properties for example polarization independence.

The PBVE is soluble in some organic fluorinated solvents. This property is quite unique among perfluoropolymers and it is advantageous for optical component fabrication.

In this paper, we report on the characterization of a PBVE optical waveguide on a silicon substrate, and its application to passive optical devices.

2. Materials

2.1 Cladding material

Typical PBVE was used as the cladding material. The structure of PBVE is shown in **Fig. 1**. The ring structure of the main chain inhibits crystallization. The transmittance of PBVE compared to that of PMMA is shown in **Fig. 2**. PBVE has high transparency at a wide wavelength range of the near UV to the near IR.

The refractive index of PBVE is 1.333 at the wavelength of 1.55 μm.

2.2 Core material

Modified PBVE with a small content of functional groups and dopants was used as the core material. The difference in refractive indices between core and cladding is 0.006. (Δ=0.45%)

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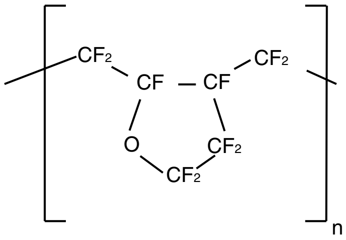

Fig. 1 Chemical structure of PBVE.

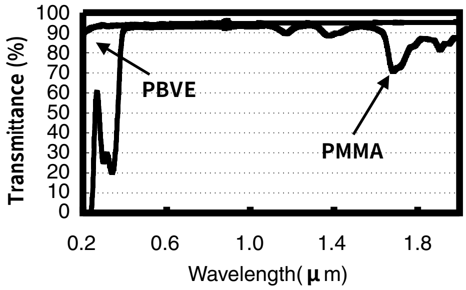

Fig. 2 Transmittance of PBVE.

2.3 Fabrication of optical waveguide

The fabrication process of PBVE optical waveguides is described in **Fig. 3**.

The under cladding layer and the core layer were formed on a silicon wafer by spin-coating. Afterwards, the core ridge was formed by photolithography and oxygen reactive ion etching. After the removal of the etching resist, the over cladding layer was formed over the core ridge by spin-coating.

A typical cross-sectional view of the PBVE optical waveguide is shown in **Fig. 4**. The bright square in the center is the core, which has a size of 7 μm×8 μm. Both the under and over cladding layers are 18 μm thick.

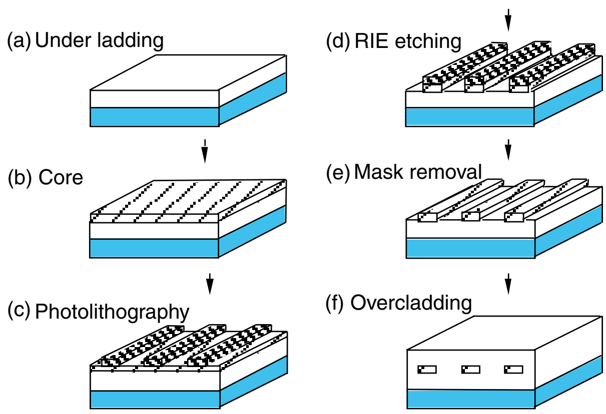

Fig. 3 Fabrication process of PBVE optical waveguides.

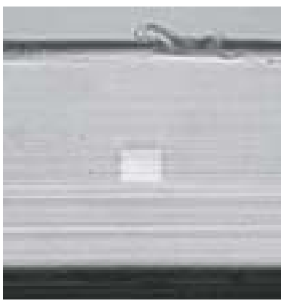

Fig. 4 Cross-sectional view of PBVE optical waveguide.

3. Characterization

3.1 Propagation loss measurement

Propagation loss was estimated using the cutback method with a 10 cm long PBVE optical waveguide. The light from a 1 mW distributed feedback laser diode (DFB-LD) was coupled with the PBVE optical waveguide via a single mode optical fiber. Propagated light was received by the optical fiber and then detected with a photo diode (PD). The results are shown in **Fig. 5**. The propagation losses, which were estimated from **Fig. 5**, were 0.10 dB/cm at 1.3 μm and 0.12 dB/cm at 1.55 μm.

3.2 100 cm long optical waveguide chip

The propagation loss of a 100 cm long PBVE optical waveguide chip (10 cm×8cm) was also measured. The chip layout of optical waveguides containing 14 right-angle bends, with a curvature

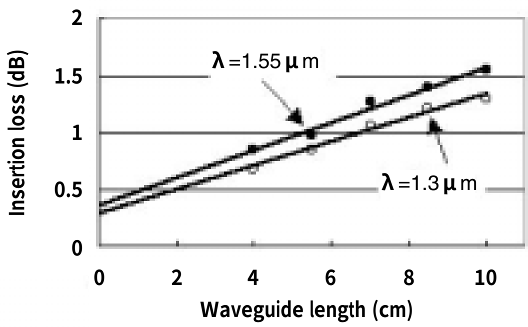

Fig. 5 Dependence of insertion loss on waveguide length.

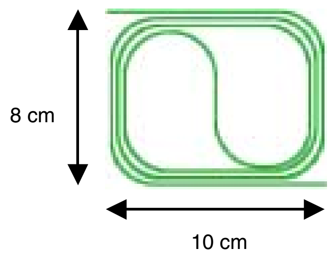

Fig. 6 Layout of 100 cm long optical waveguides.

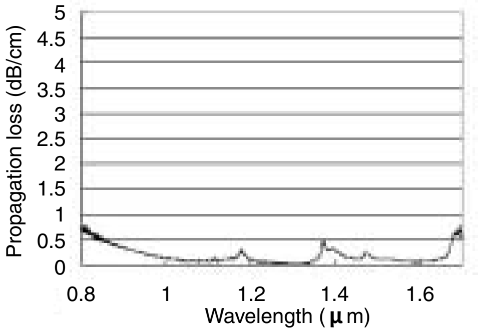

Fig. 7 Loss spectrum of PBVE optical waveguide.

radius of 20 mm, is shown in **Fig. 6**.

The insertion loss was 9.4 dB at a wavelength of 1.3 μm, which agree with the results estimated from the cutback data. These results indicate that the optical waveguide was uniformly fabricated throughout the relatively large area of the device, which is required for cost-effective mass production.

3.3 Loss spectrum measurement

The loss spectrum, which was measured from a 10 cm long straight PBVE optical waveguide, is shown in **Fig. 7**.

Despite several small peaks, the spectrum shows relatively flat features in a wide wavelength range of 1.0 to 1.6 μm. These peaks are caused by dopants and water present in the PBVE optical waveguide.

4. Applications

4.1 4-ch WDM Module

The results of characterization show that the PBVE optical waveguide is suitable for application with a wavelength-division multiplexer (WDM) module, which requires a flat loss spectrum. Thus, we applied this waveguide to 4-ch WDM module in an optical network unit.

The 4-ch WDM module operates as a multiplexer or a demultiplexer for four wavelengths of around 1.27, 1.33, 1.47 and 1.55 μm. The construction was a filter-embedded type[6], composed of a Y-branched PBVE optical waveguide and a multilayered dielectric filter as shown in **Fig. 8**.

After multiplexed light (composed of the four wavelengths mentioned above) enters the common port, one of the wavelengths is passed and the others are reflected by a filter. By use of appropriate filters, the multiplexed light is successively divided into separate wavelengths and emitted through each port (excluding the common port).

The fabricated 4-ch PBVE WDM module, with five single mode optical fibers, was successfully created and is shown in **Fig. 9**.

The spectral response of the 4-ch PBVE WDM module is shown in **Fig. 10**. The insertion losses were 4dB, 3dB, 4dB, 2.5dB at wavelengths of 1.27, 1.33, 1.47 and 1.55 μm, respectively. These losses are higher than expected for an optical waveguide. Most of these losses occur during the assembly process.

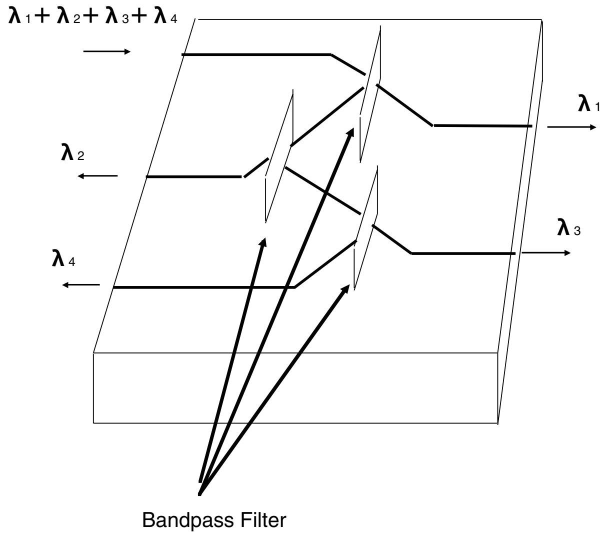

Fig. 8 Configuration of 4-ch PBVE WDM.

Fig. 9 Fabricated 4-ch PBVE WDM.

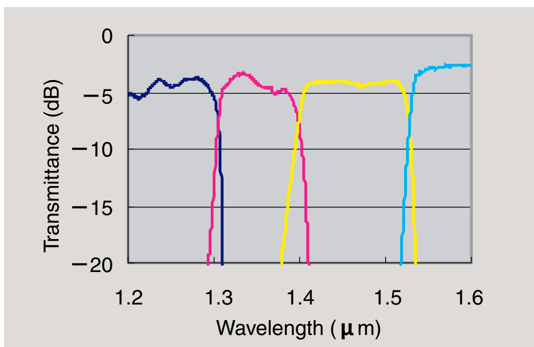

Fig. 10 Spectral response of 4-ch PBVE WDM module.

The transmittance of this module is indicated in **Fig. 10**. The transmittance of each port is relatively flat due to the characteristics of the PBVE optical waveguide.

Consequently, we deduce that the PBVE optical waveguide has the potential to be applied to WDM devices (especially wide-band WDM).

4.2 1×8 splitter

We fabricated a 20 mm long 1×8 splitter with 127 μm pitched ports. The insertion loss was less than 10 dB at each port at 1.55 μm. The uniformity of the light power at each output port was also less than 0.5 dB. Therefore, excess loss is very low.

These results prove that the PBVE optical waveguide can also be applied to various passive optical devices.

5. Conclusions

Optical waveguides were fabricated using PBVE. From propagation loss measurements and loss spectrum, the propagation loss was estimated to be 0.1dB/cm or less at wavelengths of 1.3 μm and 1.55 μm. The loss spectrum showed low and flat features. The 4-ch PBVE WDM and the 1×8 splitter were successfully fabricated. These show that the PBVE optical waveguide has the potential to be applied to passive optical devices.

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