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Novel Opto-Electro Printed Circuit Board with Polynorbornene Optical Waveguide

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1. Introduction

Recently, demands for high-speed and high-density data transmission have increased toward a ubiquitous network society. Although the processors and memories become fast, transmission speed of electrical interconnections cannot follow the operating speed of the processors. To overcome this problem, optical waveguide has been of great interest in data transfer speed instead of electrical interconnections [1]-[3]. Especially, polymer optical waveguide can provide a solution to the problem of long-distance interconnection between chips, boards, or both of them. In general, polymer optical waveguides have potential disadvantages in thermal property and transparency [4], [5]. Although fluorinated polyimides are well known as a high heat resistant polymer and candidate for a polymeric waveguide material, the waveguide formation using polyimides requires complicated process such as photolithography, reactive ion etching (RIE), and high-temperature curing. In addition, sidewall roughness caused by the RIE process increases scattering loss. Therefore, we newly prepare an optically transparent polymer called polynorbornene (PNB) that shows high heat resistance. In this paper, we propose a new opto-electro printed circuit board (O/E-PCB) using PNB optical waveguide, and describe the extremely simple formation process of the PNB optical waveguide and their excellent optical properties.

2. O/E-PCB with PNB optical waveguide

Our novel O/E-PCB with PNB optical waveguide can be expected for high-speed and high-density data transmission. And it can be also used for standard PCB processes such as photolithography, reflow soldering, and electroplating. Figure 1 shows the cross-sectional structure of the O/E-PCB. It is composed of glass epoxy multilayer materials, polyimide films, Cu circuits, PNB optical waveguides, vertical-cavity surface-emitting laser diodes (VCSELs), photo diodes (PDs), and mirrors. The chemical structure of PNB is shown in Fig. 2. The polycyclic backbone where norbornene rings link directly is so rigid that it can provide high heat resistance. And it can also provide high transparency because the polymer chain hardly crystallizes owing to the bulky ring of polycyclic backbone. Furthermore, additional desired properties can be obtained by introducing functional groups described as X in this figure. The waveguide formation process is shown in Fig. 3. In order to reduce process steps and decrease optical loss, we developed a new photo-induced patterning method. Our unique PNB can be patterned by an UV irradiation without RIE. Therefore, the sidewall of core area is so smooth that the optical loss is very low. Two kinds of PNB were developed such as PNB-A for the core and PNB-B for the cladding. The 50um-thick core layer film was exposed to UV light with a photo-mask. The resultant waveguide width was 50 um. Then, the film was fully cured in an oven. After that, the cladding layer films were laminated on the both sides of the core layer.

3. Experimental results and Discussions

A. Properties of the PNB optical waveguide

The properties of the PNB optical waveguide are listed in Table 1. Glass transition temperature (T_g) is high enough to endure high-temperature reflow soldering process. The waveguide propagation loss was measured with the conventional cutback method where 830-nm laser and multi-mode optical fibers were employed. Figure 4 shows the results of cutback measurement. Our optical waveguide has extremely low optical loss of 0.029dB/cm at 830nm, because the surface of core area is very smooth and the core area is uniform after curing. A near field pattern of output signal through the PNB optical waveguide is also shown in Fig. 4. There is no optical crosstalk between adjacent waveguides although the space was 25um. This is due to the large refractive index difference between the core and cladding area.

B. Highly Accelerated temperature and humidity Stress Test (HAST)

The insertion loss of a 2.5-cm-long PNB optical waveguide was measured under an 85℃ and 85% relative humidity atmosphere. The result is shown in Fig. 5. The initial loss value of 0.2dB keeps constant for more than 2500h. This is due to less moisture absorption of PNB optical waveguide.

C. Eye pattern measurement

A conventional setup for eye pattern measurement was employed. Input signals with data rates of 10Gbps and a pseudo random bit sequence (PRBS) of 2^{23}-1 were used. Output waveforms through a 5-cm-long PNB optical waveguide were detected from an oscilloscope. Wide-open eye pattern can be observed as shown in Fig. 6. This indicates that the data rate of 10Gbps or more can be transmitted.

D. Fabrication of O/E-PCB

Figure 7 shows our O/E-PCB with the PNB optical waveguide for a cellular phone application. The core layer film was formed in the same way as described above. After that, cladding layer films formed on resin-coated copper foils were laminated on the both sides of the core layer. Then, the circuit patterns were transferred onto the flexible PCBs by using a standard photolithographic process. Finally, it was put between other flexible PCBs that was already patterned by a press machine. In the O/E-PCB, the PNB optical waveguide is successfully formed and optically connects VCSELs with PDs.

4. Conclusion

We formed the excellent low loss PNB optical waveguide and developed extremely simple formation process of the PNB optical waveguide with the photo-induced patterning method. Furthermore, the novel O/E-PCB which has high process compatibility with standard PCB fabrication techniques was also successfully fabricated. In the future, the VCSELs and PDs will be integrated with the O/E-PCB, and it will promote the shift from electric interconnection to light.

References

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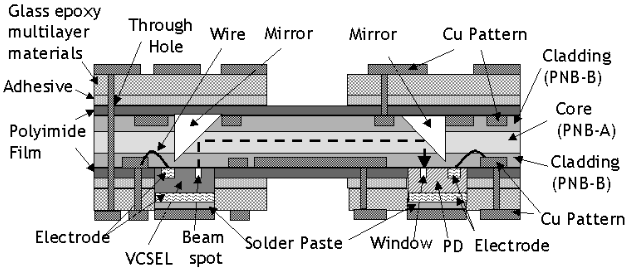

Fig. 1. Cross-sectional structure of O/E-PCB with PNB optical waveguide.

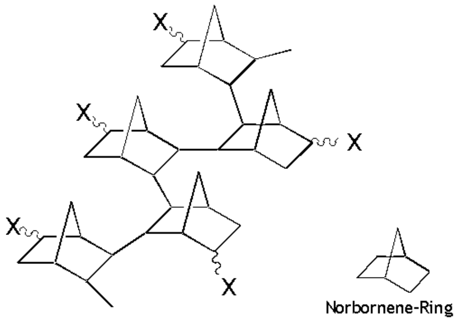

Fig. 2. Chemical structure of PNB. (X=functional group)

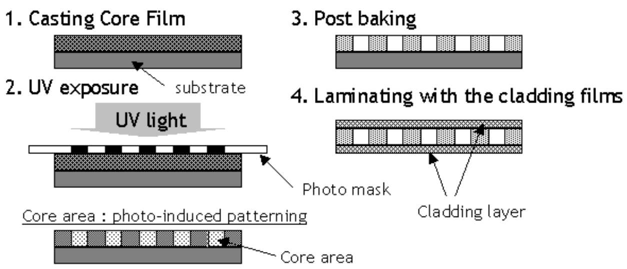

Fig. 3. Formation process of PNB optical waveguide by photo-induced patterning method.

Table 1. The PNB optical waveguide characteristics

Glass transition temp.	>250 ℃
Moisture absorption	< 0.1%
Mechanically robust	Elongation ~20%
Birefringence	$\Delta n(xy) \sim 10^{-5}$, $\Delta n(xz) \sim 10^{-3}$
Refractive index	Δn (core-clad) 0.01

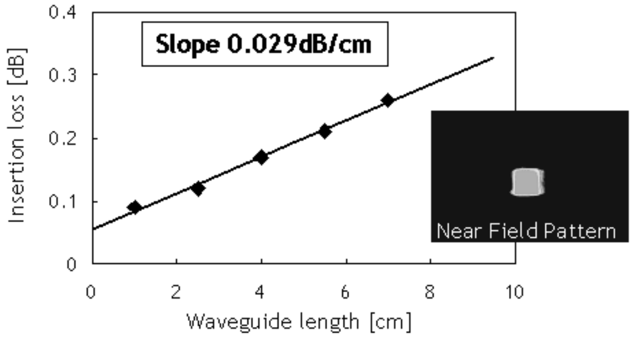

Fig. 4. Relationships between insertion loss at 830nm and waveguide length.

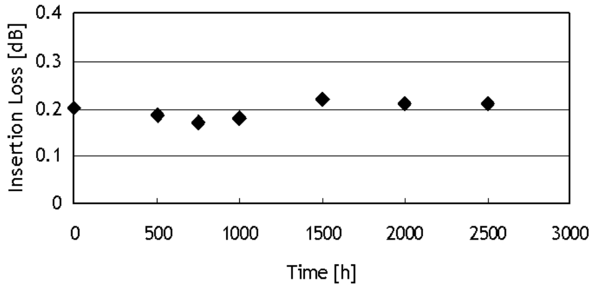

Fig. 5. Relationships between insertion loss and time under an 85℃ and 85% relative humidity atmosphere.

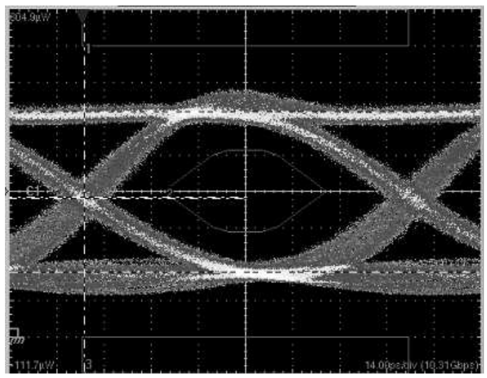

Fig. 6. Eye diagrams for 10Gbps and 2^{23}-1 PRBS.

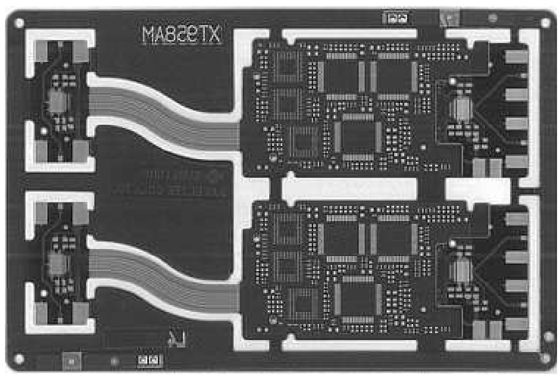

Fig. 7. Photomicrograph of top view of O/E-PCB with PNB optical waveguide for cellular phones.