Photosensitive Optical Waveguide Film for Optical Interconnection

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Abstract
Next generation high performance electronics demand wide bandwidth, high-density and low power consumption signal transmission. Optical interconnection is one of the most promising solutions and the optical waveguide technology is a key driver. This paper introduces photosensitive polymer film materials with high optical transparency and thermal properties. The materials are designed to fabricate high density multimode optical waveguides, which are suitable for optical interconnections, using lamination and exposure/development processes. The paper also reports on design of the materials, process, and properties of optical waveguides, as well as future aspects of applications.

Keywords: Photosensitive Film, Optical Waveguide, Optical Interconnection

1. Introduction

The technical advance of next-generation high-performance information processing devices and portable terminal devices has required high-speed and high-density intra-device interconnection. However, the current electric interconnections have faced many technical difficulties, such as the upper limitation of speed, the signal delay due to high density, reflection, as well as increasing electric power consumption[1]. Optical interconnection is one of the best solutions because of its low propagation loss and high data-transfer density, namely about ten times denser and faster, compared with conventional electrical interconnection. In addition, optical interconnection is expected to solve electromagnetic interference problem which becomes serious in various electronics applications[2].

There are two main methods for optical interconnection, using optical fibers and polymer optical waveguides[3]. For intra-device interconnection, polymer optical waveguides are thought to be better since they enable denser and multi-level interconnection structures readily[4-7].

We have recently developed photosensitive optical waveguide film materials for high-speed optical interconnection[8]. In this paper, we describe the current state of our development of materials enabling the fabrication of polymer optical waveguides by conventional processes which have low optical losses and high reliability for optical interconnection.

2. Materials

The development scheme of materials is as follows;

1) Optical characteristic: optical losses < 0.1 dB/cm (at a wavelength of 850 nm),
2) Reliability: little change of optical losses in a reflow test, thermal cycling test, and temperature-humidity test, and
3) Convenient fabrication process: the production of optical waveguides by film lamination, and photolithography.

Materials are designed to realize heat resisting properties by introducing aromatic molecules into molecular structures of the materials, and additionally to reduce their optical losses by breaking the conjugation between the aromatic molecules. In addition, to fabricate core pattern using exposure and development processes, reactive double bonds functional group are introduced into core materials to give them a photo-sensitive function so that they can be harden by UV exposure. Also materials are formed as a film shape so as not only to enable optical waveguide more conveniently but also to embed optical path into various substrates, such as printed circuit boards.

The optical and physical properties of the hardened optical waveguide films are summarized in Table1. Each film is cured under UV exposure, followed by post-baking process. The optical losses of the core film are measured by a prism coupler method and are less than 0.1 dB /cm at wavelength of 830 nm. The refractive index of the core and cladding materials are 1.583 and 1.548, respectively, giving a specific refractive index difference of 2.2%. The thermal-degradation temperatures of the core and clad films are 350°C, respectively.

Table 1 Properties of Optical Waveguide Film

Item	Unit	Experimental Results*		Conditions
		Core Film	Cladding Film	
Optical Loss	dB/cm	0.08	0.10	Prism Coupling, at 830 nm
Refractive Index	-	1.586	1.551	Prism Coupling, at 830 nm
Refractive Index Difference	-	2.2		
Thermal-decomposition Temperature	deg. C	350	350	5% weight loss, in air
Glass-transition Temperature	deg. C	130	150	-

*Curing condition: UV exposure (1000mJ/cm2 at 365nm) + 120 deg C / 1hour

Figure1 shows experimental results of optical transmission losses measurement of optical waveguides fabricated on a glass-epoxy substrate with a vertical cavity surface emitting laser (VCSEL) as a light source of a wavelength of 850 nm. The propagation losses measured are 0.05 dB/ cm. It is also confirmed that flexible optical waveguides also show similar transmission losses[8).

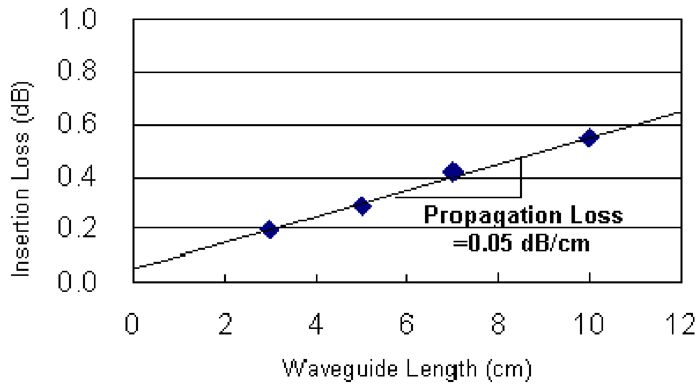


Figure 1 Propagation Loss

3. Process

Figure 2 illustrates the fabrication process of test vehicles with developed materials. The optical waveguides are produced by

(1) Lamination of a lower clad film on a substrate and hardening,
(2) Lamination of a core film,
(3) and (4) Core pattern formation by photolithography by UV light,
(5) Core pattern embedding by the lamination of an upper clad film, and hardening.

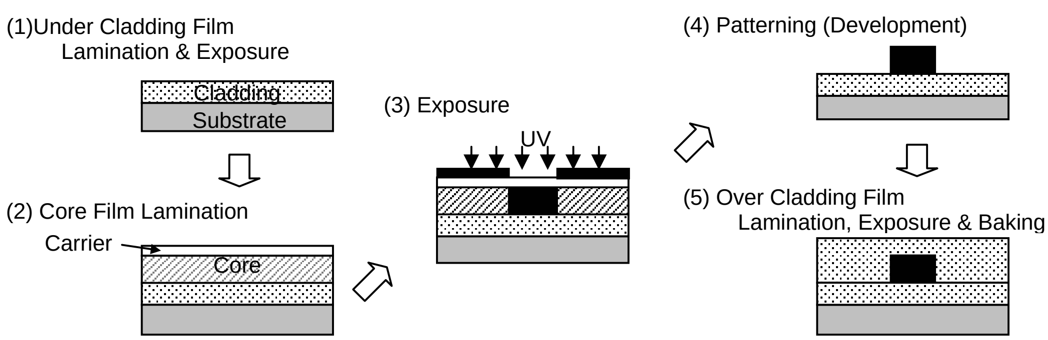


Figure 2 Fabrication Process

Figure 3 (a) shows a cross-sectional image of an optical waveguide fabricated on a glass-epoxy substrate (FR-4) for printed wiring board use, where a multimode optical waveguide with a core of 50 micron in width, 50 micron in height, and 250 micron in pitch, and with upper and lower cladding of 50 micron in thickness is formed. From the image, it is clearly seen that a rectangular core pattern and cladding are embedded without defects and the upper clad surface has a high flatness, which enables multi-layer optical waveguide as shown in Figure 3(b).

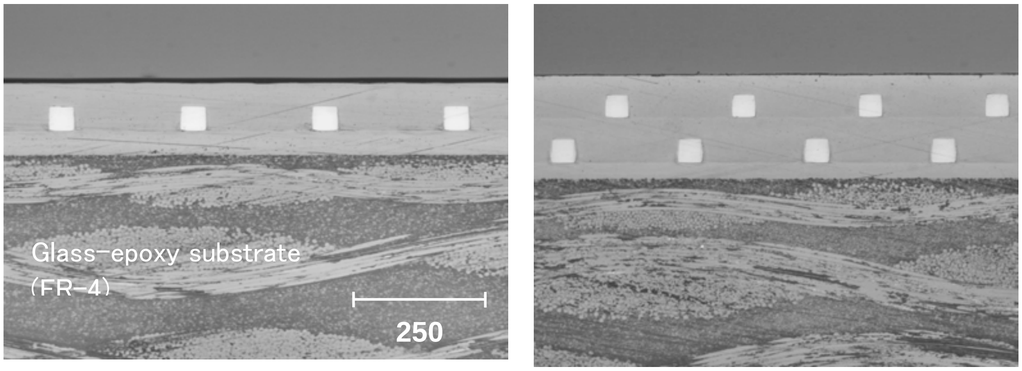


Fig 3(a) Fig. 3(b)

Figure 3 Cross-sectional Images of Optical Waveguides on substrates

4. Reliability and Flexibility

The reliability of developed materials was measured as follows. According to the lead-free solder reflow condition of IPC/JEDEC standard, where the maximum temperature is 265°C and the sustention time at temperatures above 260°C is 20 sec., reflow tests were executed three times under a nitrogen atmosphere to measure the change of the optical losses. A thermal cycle test between -55 and 125°C and a temperature-humidity test at 85°C and 85%RH were carried out to measure the change of the optical losses. The results are shown in Figure 4 (a)-(c).

The change of the optical losses are less than 0.03 dB/cm, after reflow tests, temperature-cycle tests, and temperature-humidity test, indicating that the developed materials have sufficient reliability and are appropriate to electronics application.

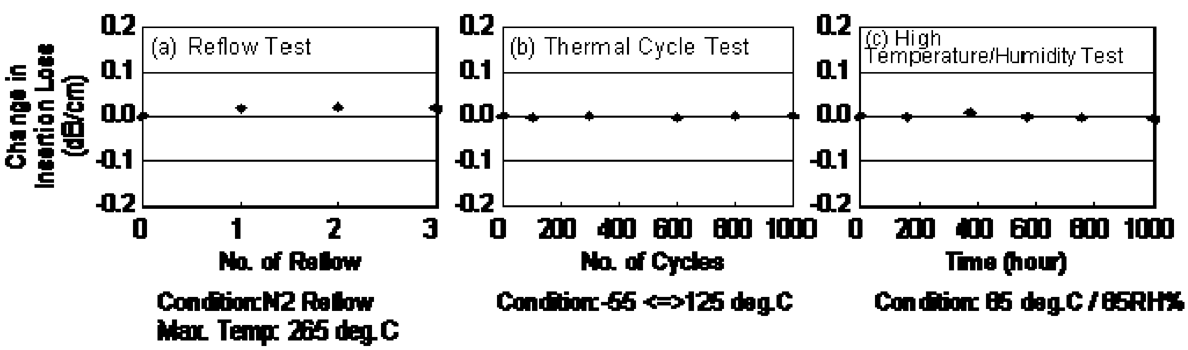


Figure 4 Reliability

Flexible optical waveguide is also fabricated to evaluate bending properties. Figure 5 shows a photo image of a flexible waveguide. Figure 5 also shows the effect of bending radius on the optical losses when the optical waveguides are bent by 360°. The increase of the optical losses is less than 0.1 dB at bending radii above 2 mm, indicating that the optical waveguides have a good bending property. It was also confirmed that the change of the optical losses after one million times bending was less than 0.1 dB, indicating that optical waveguides fabricated with the developed materials have a high elasticity.

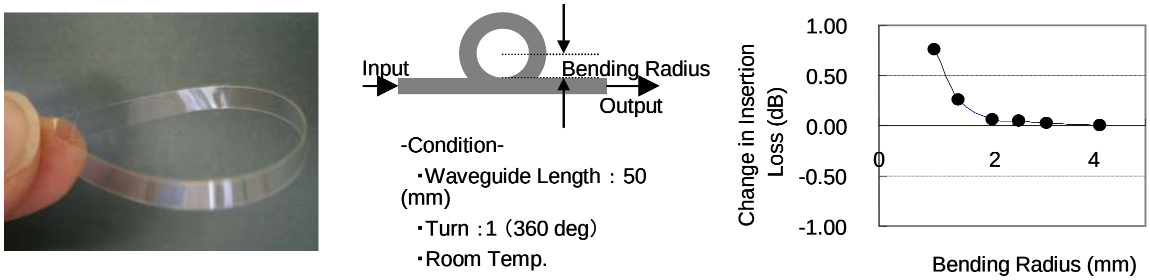


Figure 5 Bending Properties of Flexible Optical Waveguide

5. Optical signal transmission characteristics

To verify optical signal transmission properties of optical waveguides, we have fabricated a 10-cm-long optical waveguide on a glass-epoxy based FR-4 substrate[9].

Figure 6 shows experimental setup for 10 Gbit/s transmissions. 10 Gbit/s optical signal form an 850-nm VCSEL-based transmitter module (Tx) through the GI-50 multimode fiber (MMF) was coupled to the fabricated 10-cm-long waveguide. The propagated optical signal into the waveguide was received using a photo receiver (Rx).

Figure7(a) shows the optical waveforms after 10-cm waveguide transmission at 10 Gbit/s, compared with back-to-back waveform as a reference, shown in Figure 7(b). Little degradation observed in the waveform via waveguide transmission, indicating that the optical waveguides produced with developed materials enable the transmission of high-speed optical signals of 10 Gbit/s.

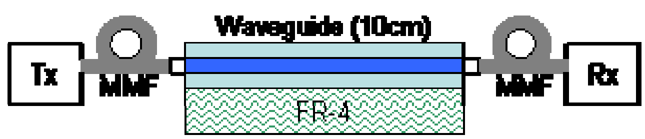
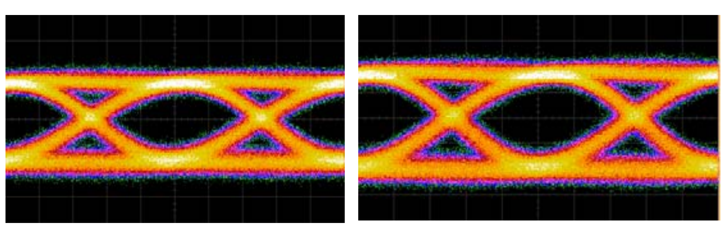


Figure 6 Experimental Setup of 10 Gbits/s transmission



(a)10cm-waveguide (b) Back-to-back

Figure 7 Optical Waveform of 10 Gbits/s transmissions

6. Conclusion

Novel photosensitive optical waveguide film materials have been developed for optical interconnections. The developed materials enable the fabrication of optical waveguides by lamination, exposure and development processing, thus leading to the production of optical waveguides with low optical losses and high reliability. We expect that optical waveguides fabricated with the developed materials may contribute to the progress of optical interconnections for high-end IT devices and high performance mobile terminals.

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