Organic Membrane Photonic Waveguide with Metal Grating Couplers

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Abstract: We made an organic-membrane waveguide with input/output metal grating couplers, a basic element of organic membrane photonic integrated circuits. The propagation loss and coupling loss were 1.4 dB/cm and 27 dB/coupler, respectively.
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1. Organic membrane platform opens new fields of photonic ICs

It is true that the first and orthodox application of photonic integrated circuits (PICs) is in the field of high-speed, large-capacity internet systems [1, 2]. However, the PIC can be expected to have many other potential applications that make use of optical functionalities. To open such new application fields, we have proposed the concept of organic membrane PIC (OMPIC), which is illustrated in Fig. 1(a) [3, 4].

Organic membranes have been introduced in recent years into the field of electronic devices, creating various new application fields that are impossible with conventional semiconductor devices [5, 6]. Similar developments can be expected for photonic devices. Using an organic membrane instead of conventional rigid platforms (GaAs, InP, Si, and glass) will provide flexible, lightweight, and wearable large-area PIC devices that are useful for sensing, monitoring, and data processing for security, biomedical, and healthcare applications.

In this paper, we give the structure of an organic-membrane transmission line (waveguide) with input/output couplers, as a basic element of our organic membrane PICs. After simulating its transmission characteristics, we made actual transmission lines and I/O couplers that were monolithically integrated in a several-micron-thick organic membrane and measured their operation. The following describes the results.

2. Simulating Transmission of Light in Organic-Membrane Transmission Line and I/O Couplers

Figures 1(b) and 1(c) show the structure of the transmission line and an input/output coupler formed in an organic film. The transmission line is a waveguide composed of a PMMA core and a CYTOP cladding formed on an ECRIOS substrate film (PMMA: polymethyl methacrylate, CYTOP: amorphous fluoropolymer by Asahi Glass Co., ECRIOS: colorless polyimide of Mitsui Chemicals [7]). For I/O coupling, a metal grating coupler was used to obtain strong coupling between the waveguide and external lasers/detectors.

We simulated the propagation of light in the waveguide. Figure 2(a) shows the results of mode analysis performed using the finite element method. Single mode propagation can be realized with, for instance, a 2-µm wide, 1-µm thick PMMA core. For the 2-µm wide, 1-µm thick core, bending loss was calculated using the time domain difference method. Figure 2(b) shows the result. In-plane bending loss is 0.2dB or lower for a bending radius of 80 µm, and out-of-plane bending loss is 0.2dB or lower for 30-µm bending radius.

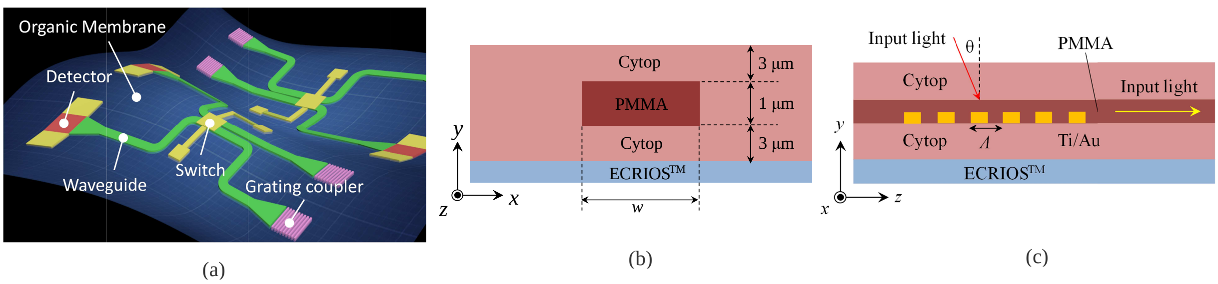

Fig. 1 (a) Schematic of organic-membrane PIC (OMPIC), (b) cross section of transmission line (waveguide). and (c) cross section of metal-grating I/O coupler. Light propagates in z direction in (b) and (c).

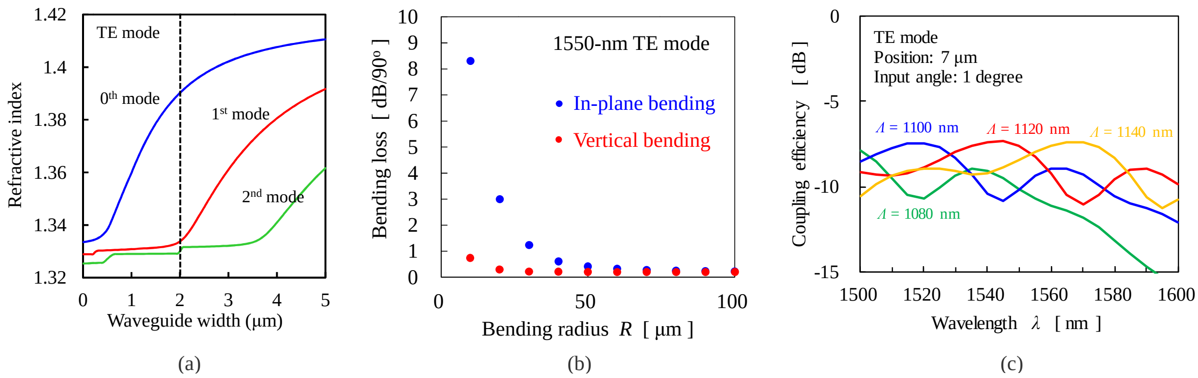

Fig. 2 Simulation of device characteristics. (a) Mode characteristic, (b) bending loss of transmission line (blue: in-plane bending, red: out-of-plane bending), and (c) coupling efficiency of I/O couplers as a function of wavelength.

We then calculated the coupling efficiency of the I/O couplers as a function of wavelength, using the time domain difference method. A metal grating was assumed to be a double layer consisting of 10-nm Ti and 30-nm Au. Figure 2(c) shows the result. For a metal gratings with Λ = 1120 nm and duty ratio = 50%, the coupling efficiency reaches the maximum at input light angle θ = 1 °. The maximum coupling efficiency is -7.5dB at 1550-nm wavelength.

3. Making and Measuring Actual Devices

On the basis of the simulation results, we made the organic-membrane transmission line (waveguide) having the I/O couplers. Figure 3(a) (upper) shows the planar pattern of the device. The transmission line and couplers are connected with tapered waveguides. The fabrication process was as follows. First, an ECRIOS layer was formed on a substrate, and a CYTOP layer thereon. Then, the metal grating (Ti-Au) and waveguide core (PMMA) were formed in this order on the CYTOP layer, using electron-beam lithography and lift-off processing. After that, a CYTOP layer was again formed thereon. Finally, the resultant multilayer was peeled from the substrate. Figure 3(b) shows the peeled film, the organic-membrane transmission line with couplers. The enlarged photograph is inserted in Fig. 3(b) (lower).

The propagation of light in the devices was measured with different waveguide lengths from 2 mm to 8 mm. Figure 3(b) (lower) shows the results at 1550-nm wavelength. From this, we calculated the propagation loss of the waveguide and the coupling loss of the coupler. The propagation loss and coupling loss were estimated to be 1.4 dB/cm and 27 dB/coupler, respectively.

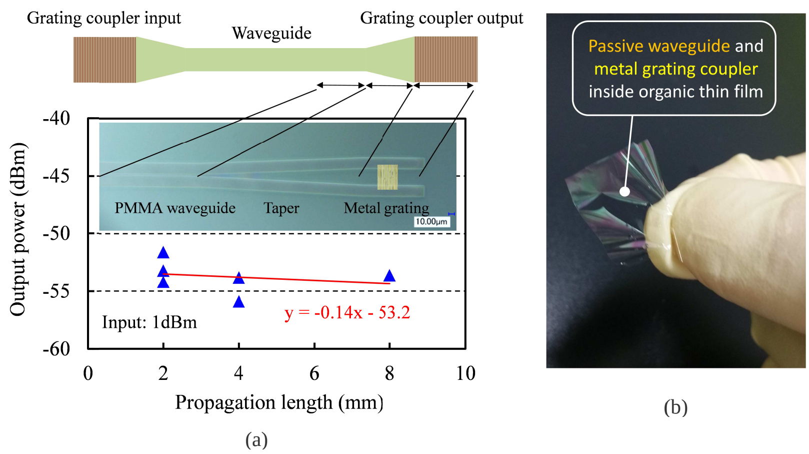

Fig. 3 Measurement of fabricated device. (a) Transmission of light in transmission line with I/O couplers, and (b) photograph of fabricated device.

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