H-5-02
Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp519-520

Analysis of SU-8/CYTOP membrane waveguide and metal grating coupler for organic membrane photonic integrated circuits

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Abstract

In this paper, we analyzed SU-8/CYTOP membrane waveguide and metal grating couplers for organic membrane photonic integrated circuits. As a result, bending loss of the waveguide was estimated to be 1dB or lower for a bending radius of 60 µm and the maximum coupling efficiency of the grating coupler to be -5.8dB at 1550-nm wavelength.

1. Introduction

A photonic integrated circuit (PIC) is a device that incorporates the multiple photonic functions needed for optical communication and processing on a single chip. PICs have many advantages over their discrete counterparts, such as their small size, low cost, high accuracy, and low power consumption. Therefore, various PICs have been developed, and these now dominate the market for optical systems and components.

As shown in Fig. 1, we have seen a free standing organic membrane as a new platform material for PICs [1]. Organic films have recently been introduced into the field of electronic devices, creating various new applications that were impossible with conventional semiconductor devices [2-4]. Similar developments can be expected for PICs. The use of free standing organic membranes instead of conventional rigid platforms such as InP [5], Si [6] will provide flexible, lightweight, wearable PIC devices for sensing, monitoring, and data processing in various healthcare applications.

In this paper, we analyzed a SU-8/CYTOP membrane waveguide and input/output (I/O) metal grating couplers, as a basic element of our organic membrane PICs. As a result, bending loss of the waveguide was estimated to be 1dB or lower for a bending radius of 60 µm and the maximum coupling efficiency of the metal grating coupler reached to be -5.8dB at 1550-nm wavelength. The following describes the details.

2. Analysis of SU-8/CYTOP waveguide

The inset of Fig. 2(a) shows the structure of a membrane waveguide consisting of a SU-8 core and a CYTOP cladding along a cross-section perpendicular to the direction of travel of the light. In simulation, the upper and lower cladding thicknesses are set to 4 µm, and dimensions of the SU-8 core

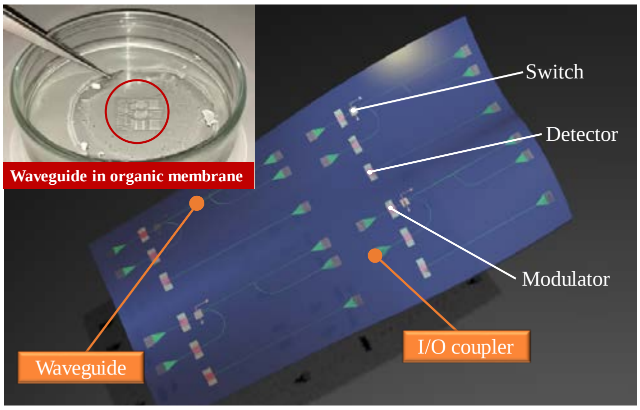
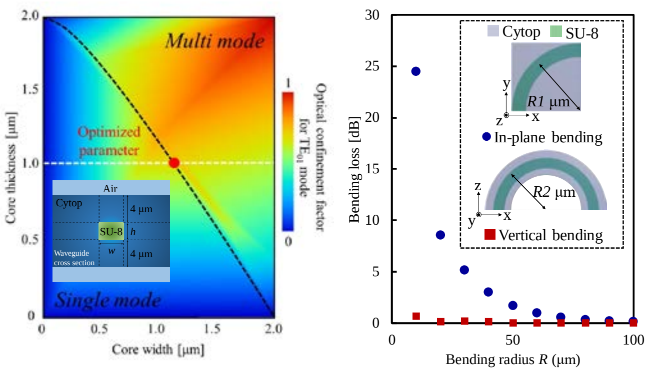


Fig.1 Schematic of organic-membrane PIC



(a) (b)

Fig. 2 (a) Calculated optical confinement factor of TE_{01} mode as a function of SU-8 core dimensions. Inset is cross section of waveguide; (b) In-plane and vertical bending loss at 90° bending as a function bending radius.

(i.e., width and thickness) were parameters. The refractive indices of SU-8 and CYTOP were assumed to be 1.58 and 1.34, respectively. We simulated the propagation of light in the waveguide using the finite element method at a wavelength of 1550 nm. Figure 2(a) shows calculated optical confinement factor of TE_{01} mode as a function of SU-8 core dimensions. In order to keep the confinement factor as large as possible while maintaining single mode propagation, the width and thickness of the SU-8 core were set to 1.0 µm and 1.2 µm, respectively (red point in Fig. 2(a)).

Next, we simulated the bending loss of the waveguide using the finite-difference time-domain (FDTD) method. In the case of organic membrane, we should consider vertical bending loss (i.e., physical bending of the film) in addition to in-plane bending loss (i.e., bending inside optical circuits). Figure 2(b) shows the calculated in-plane and vertical bending loss for TE mode at 90° bending as a function of the bend radius. In-plane bending loss is 1dB or lower for a bend radius of 60 μm, and vertical bending loss is lower than 1dB for a 10-μm bend radius. From Fig. 2(b), the vertical bending loss is quite smaller than the in-plane bending loss because the SU-8/CYTOP waveguide is sandwiched by the air with a low refractive index.

3. Analysis of I/O metal grating coupler

Figures 3(a) and (b) show the SU-8/CYTOP grating coupler and the buried metal grating coupler in the waveguide along a cross-section in the direction of travel of the light. To obtain a highly efficient coupling in organic membrane PICs, we used a thin gold grating buried in the SU-8 core of the SU-8/CYTOP membrane waveguide, which can easily be fabricated using standard processes. In the following, we discuss advantage of the metal grating coupler by comparing with a simple SU-8/CYTOP grating structure.

The coupling efficiency was calculated by using FDTD. In simulation, the grating thickness *h* (synonym with the SU-8 thickness in Fig. 3 (a), the metal thickness in Fig. 3 (b)) and the grating pitch Λ were set as parameters. Incident collimated light beam with a 2 μm diameter was applied to the coupler from 10 μm above the upper CYTOP cladding. The incident angle θ of the input light was set to 2°. Figure 4 shows calculated coupling efficiencies for 1550-nm TE mode, calculated as a function of the grating pitch Λ, with grating thickness *h* as a parameter. For the SU-8/CYTOP grating with Λ = 1.18 μm and *h* = 0.6 μm, the coupling efficiency showed the maximum value of -12.2dB at 1550-nm wavelength. For the metal grating with Λ = 1.1 μm and *h* = 80 nm, the coupling efficiency reached -5.8dB at 1550-nm wavelength. This fact suggests that the metal grating has a large coupling coefficient compared with the SU-8/CYTOP grating.

Finally, we calculated the wavelength dependence of each grating coupler with dimensions that give the maximum coupling efficiency at 1550 nm. Figure 5 shows the result. In the wavelength range of 1500-1600 nm, the coupling efficiency of the metal grating coupler changed from -9.7 dB to -5.8 dB.

4. Conclusion

We analyzed the SU-8/CYTOP membrane waveguide and I/O metal grating coupler, as a basic element of our organic membrane PICs. For the waveguide, in-plane and vertical 90° bending losses were 1dB or lower for bend radiuses of 60 μm and 10 μm, respectively. For the grating coupler, the coupling efficiency showed the maximum of -5.8 dB with the grating pitch of 1.1 μm and the metal thickness of 80 nm.

Acknowledgments

This research was financially supported by JST-CREST (JPMJCR15N6), and JSPS KAKENHI (#15H05763, #16H06082, #17H03247).

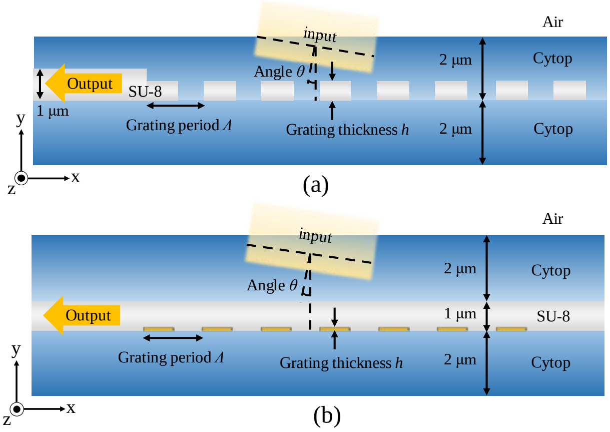


Fig. 3 Cross section of (a) SU-8/CYTOP grating coupler and (b) metal grating coupler. Light propagates in *x* direction in (a) and (b).

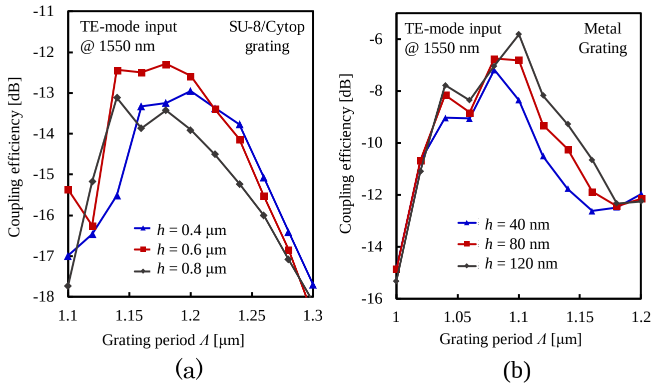


Fig. 4 Calculated TE-mode coupling efficiencies of (a) SU-8/CYTOP grating coupler and (b) metal grating coupler as a function of grating pitch Λ, with grating thickness *h* as a parameter.

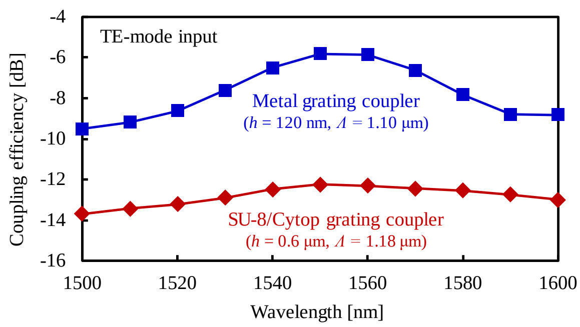


Fig. 5 Calculated TE-mode coupling efficiencies as a function of wavelength.

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