Design of Integrated Refractive Index Sensor Based on Bend Waveguide with a Trench Structure

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Abstract **– This study proposes a novel optical sensor structure based on a refractometer integrating a bend waveguide and an air trench. The optical sensor consists of a U-bend waveguide connecting four C-bends and a trench structure to expose the partial core layer. The U-bend waveguide consists of one C-bend with the maximum optical loss and three C-bend with minimum losses. A trench provides a quantitative measurement environment, and is aligned with the sidewall of a C-bend having the maximum loss. The intensity of the output power is dependent on the change of refractive index of the measured material.**

I. INTRODUCTION

To develop a high-performance optical refractometer, increasing the sensitivity of the sensor and improving the reliability through quantitative measuring environment are essential. A decreased curvature of the optical waveguide causes an increase of the evanescent field. Such characteristic generates a higher penetration depth, causing the optical device to react more sensitively to the refractive index of the external environment [1-4]. Note, however, that there is a certain limitation to the improvement of sensitivity from the radiation loss caused by a reduction of the bending radius. Moreover, volatile liquid has a limitation in securing a quantitative measurement environment. Therefore, integrated sensor technology with high sensitivity and reliability is required.

The aim of this study is to propose and design an integrated sensor structure that assures improved sensing sensitivity and reliability.

II. CONCEPTS OF THE INTEGRATED OPTICAL SENSOR

For this study, a refractive index sensor using a bend waveguide and a structure that partially exposes one side of the core layer to improve the sensitivity, integration, and reliability was designed. The sensor was designed and optimized using a beam propagation method (BPM). It has propagating characteristics that are dependent on the variations of the refractive index. The waveguide consists of four C-bends connected to create bending radiuses of R_1, R_2, R_3, and R_4. The C-bend with the R_2 bending radius was designed to expose the sidewall of the core layer. The part where the core layer is exposed was designed to create an air trench structure in a stable measurement environment. The R_1, R_3, and R_4 bending radiuses were designed to have minimum propagation losses, whereas the structure with the R_2 bending radius that is aligned with the trench structure was intended to have the maximum propagation loss. Figure 1(a) shows a schematic diagram of the proposed refractometric sensor, and Fig. 1(b) shows the U-bend structure of the connected C-bends.

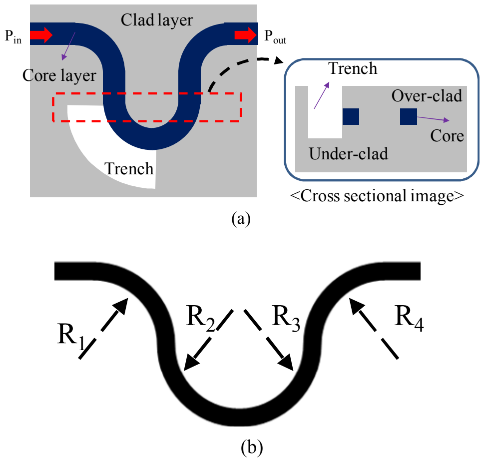

Fig. 1. (a) Schematic configuration of the integrated optical refractometer and (b) connected C-bend structures of the waveguide.

III. DESIGN OF THE OPTICAL SENSOR STRUCTURE

The optical refractometric sensor was designed as a 6 µm x 6 µm, and the difference in the refractive index between the core and the clad was 0.75% (the refractive index of the clad 1.4452) at a 1,550 nm wavelength. The sensor was designed based on the bending radius of the waveguide, optical characteristics according to changes in the trench refractive index. The bending radius of the sensor channel was changed from 0 to 12,000 µm at an interval of 100 µm, as shown in Fig. 2.

The increase in the propagation characteristics according to a bending radius increment of 100 µm was confirmed, with 1% propagation at 400 µm, 10% at 800 µm, and 90% at 2,900 µm. Based on the results in Fig. 2, radiuses R_1, R_3, and R_4 were set to 9,100 µm, which showed 99% propagation characteristics, and the R_2 bending radius was optimized. It was done in an S-bend structure connecting two C-bends involving 9,100 µm and a R_2 bending radius. The refractive index sensitivity according to the change in the bending radius of the waveguide and the effectiveness of the sensor was simultaneously assessed. The optical propagation characteristics were confirmed by aligning the waveguide, which has a R_2 radius and a trench structure.

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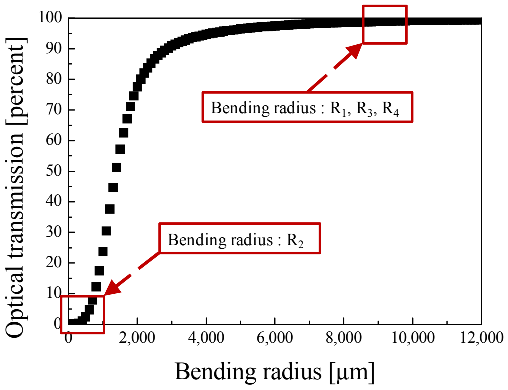
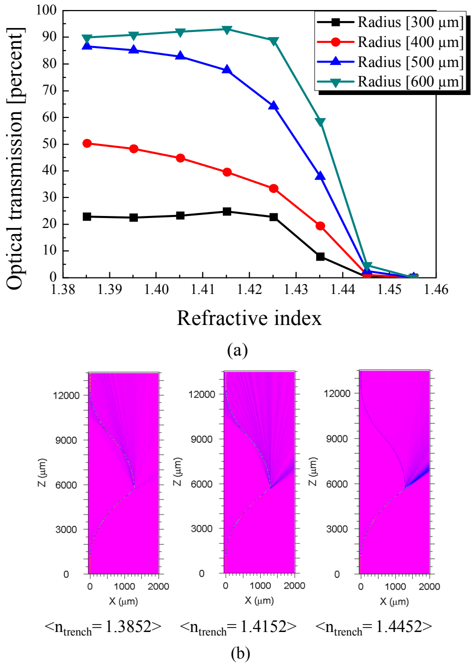


Fig. 2. Optical propagating characteristic according to the bending radius.

The trench establishes a quantitative environment, and a 1,000 µm width was set as the bending radius of R_2. Figure 3 shows the optical propagating characteristics of the bend waveguide with the trench aligned.

Optimization of the R_2 bending radius was performed within the range of 300 to 600 µm. The refractive indices varied within a difference range of -0.06 to +0.01 at the 1.4452 trench index. The loss was confirmed to have been reduced owing to the improved propagation characteristics as the bending radius increased. Although the propagation characteristics improved with a high index contrast at bending radius of 600 µm or more, no changes in optical propagation characteristics from a high index contrast were noted at an index difference of -0.03 or higher. Therefore, the R_2 bending radius was set to 500 µm. Figure 3 shows the optical propagation characteristics of the bend waveguide according to the refractive index.

The sensor characteristics according to the change in refractive index were confirmed. The sensor characteristics were observed to be in a refractive index range of 1.3852 to 1.4452 at a 1,550 nm wavelength. To evaluate the effectiveness of the designed sensor, it was designed at a refractive index of 1.0.



(a)

$<n_{trench}= 1.3852>$ $<n_{trench}= 1.4152>$ $<n_{trench}= 1.4452>$

(b)

Fig. 3. Optical propagating characteristics according to the refractive index of the trench: (a) variations of bending radius and (b) at the R_2 bending radius of 500 µm.

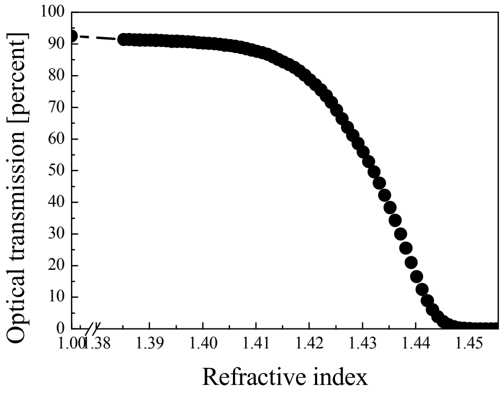


Fig. 4. Optical sensing characteristic according to the refractive index.

Figure 4 shows the optical propagation characteristics of the designed sensor according to the change in refractive index. A change from 91.4% to 0% was shown, corresponding to an insertion loss of 0.4 and 61.3 dB, respectively. Since the curvature of the waveguide was designed for the minimum propagation characteristics, the optical loss increased at a low index contrast and decreased at a high index contrast. With exposure to air, 0.3 dB insertion loss was confirmed. This result shows the extension range of the refractive index and indicates that the sensor proposed in this study can be applied to various areas.

IV. CONCLUSION

In this paper, a new structure for a refractive index sensor was proposed. The proposed sensor enables a high integration and reliability. To achieve these characteristics, a hybrid structure integrating a bending waveguide having the minimum propagation characteristics and a trench exposing the core was designed. The sensor proposed in this study can serve as a quantitative measurement environment, having a structure that enables measuring volatile matter stably.

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