A Study on the Design of Integrated-Optic Biosensor based on the Power Coupling of Two Modes utilizing Si_3N_4 Rib-Optical Waveguides

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***Abstract*-We proposed an integrated-optical biosensor configuration that operates at a wavelength of 0.63 µm based on the evanescent-wave and lateral two-mode power coupling of Si_3N_4 rib-optical waveguides formed on a $Si/SiO_2/Si_3N_4/SiO_2$ multilayer thin films.. The coupling between the two propagating modes in the sensing region produces a periodically repeated optical power exchange along the propagation. The light power was steered from one output channel to the other caused by the change of the cladding layer (bio-material) refractive index, which affect the effective refractive index (phase-shift) of two modes through evanescent-waves. The sensitivity 12~23 [au/RIU] was evaluated for the two-mode region of the width and length of 4 µm and 3841.46 µm, corresponding to the refractive index range 1.36-1.43.**

I. Introduction

Currently, most clinical diagnostic tests are expensive because of the complex procedures and the need for sophisticated equipment operated by specially trained personnel. Moreover, these tests often require a time-consuming labeling process to attach fluorescent or chemical luminescent markers to the biomaterial to be measured. On the other hand, biosensors constructed by combining with micro-fluidics systems in integrated optical waveguides based on the evanescent-wave principle overcome these shortcomings, and provide low-cost on-site diagnostics.

Therefore, in this paper, we proposed a biosensor operating at a wavelength of 0.63 µm with a structure consisting of one input, two outputs and lateral two-mode power coupling region utilizing a Si_3N_4 rib-optical waveguides.

II. BIOSENSOR CONFIGURATION and DESIGN

Fig. 1 shows the layout of the biosensor overall configuration proposed in this study utilizing the Si_3N_4 rib-optical waveguide. The rib-width, rib-thickness, and core-thickness of the input / output optical waveguide were set to 2 µm, 5 nm, and 175 nm, respectively. The width of the two-mode coupling region was fixed to 4 µm, and the length was designed to be variably set according to the refractive index measurement range of the bio-material.

The computational analysis was performed to confirm that power coupling occurs in the two-mode region of the Fig. 1 structure. Fig. 2 shows the specific dimensions of the structure applied to computational analysis and that the TE00 and TE01 mode are being propagated in the two-mode region.

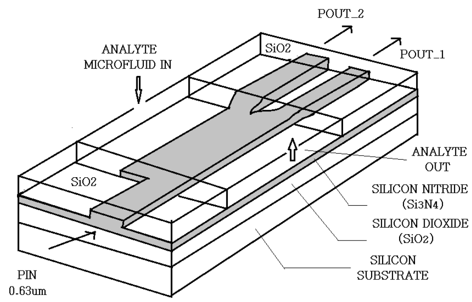

Fig. 1. The layout of biosensor based on Si_3N_4 rib-optical waveguides.

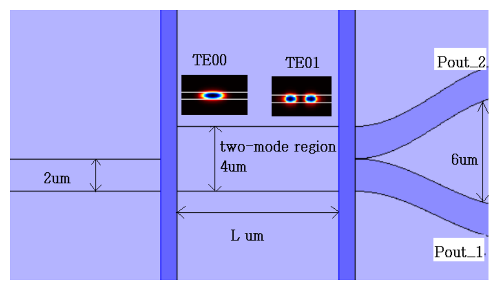

Fig. 2. The layout dimensions of biosensor for BPM computational simulation and two-dimensional mode profiles in the two-mode region for the cladding refractive index, 1.33.

The upper cladding refractive index of the two-mode region corresponding to the bio-material to be measured was set to 1.33 and computational analysis was performed utilizing Photon Design's FIMMWAVE and FIMMPROP. As expected, in the two-mode region, as shown in Fig. 3 (a) and (b), power coupling occurred, and it was confirmed that mode power was emitted to one of the two output stages according to the length of the two-mode region. Specially, fig. 3 (c) and (d) show the output as the light evolves to the Pout_2 output stage.

The key to the proposed biosensor design in Figure 2 is to determine the appropriate two-mode region length for the refractive index range (n1~n2) of the biomaterial to be measured. First, if the phase difference between the two modes in the n1 cladding refractive index is an integer multiple of 2π, there is no phase change between the two modes, so it is emitted to one of the two output stages. However, if the phase difference is an integer multiple of π, it is emitted to the other output stage from

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the former, so it is assumed to be an integer multiple of 2π for the refractive index, n1 and an integer multiple of π for the refractive index, n2 and can be expressed by the following equation. [1]

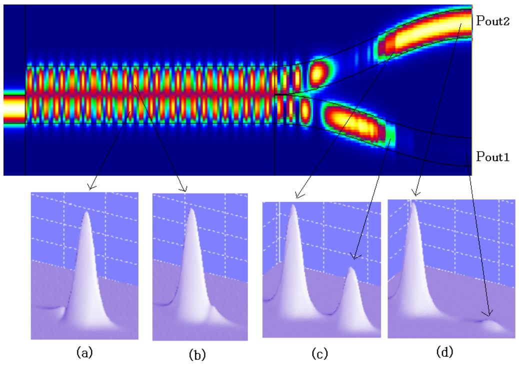

Fig. 3. Power coupling between two modes along propagation and mode evaluations in two-mode region and output waveguides

$$\kappa \cdot \Delta n_{eff}(n1) \cdot L = m \cdot (2\pi) \quad (1)$$

$$\kappa \cdot \Delta n_{eff}(n2) \cdot L = (2 \cdot m + 1) \cdot \pi \quad (2)$$

Here, m is an integer of 0, 1, 2 · · · and k = λ/2π is a propagation constant. From the difference between the two equations (1) and (2) above, the length L of two-mode region is derived as follows.

$$L = \frac{1}{2} \cdot \frac{\lambda}{|\Delta n_{eff}(n1) - \Delta n_{eff}(n2)|} \quad (3)$$

III. SENSITIVITY and DISCUSSIONS

The length of the two-mode region was calculated to be 3841.46 µm by applying equation (3) for the ranges of 1.36 to 1.43. Computational analysis was performed on the change of the optical power of the two outputs according to the change in refractive index, and ultimately, the result as shown in Fig. 4 was obtained. This show a very linear increase and decrease in two output power. On the other hand, the performance of the sensor can be evaluated as sensitivity, corresponds to the slope of the normalized optical power in Fig. 4 and can be expressed by the following equation. [2]

$$S = \left|\frac{\Delta P_{out}}{\Delta n}\right| = \frac{\left(\frac{P_{out1}-P_{out2}}{P_{out1}+P_{out2}}\right)_{n1} - \left(\frac{P_{out1}-P_{out2}}{P_{out1}+P_{out2}}\right)_{n2}}{n_1 - n_2} \quad (4)$$

Therefore, to calculate the sensitivity from Figure 4, the difference between the two outputs, | Pout1-Pout2 | was obtained as shown in Fig. 5. It overall show a linear characteristics, but a non-linear characteristics with a slight decrease in slope at the beginning and end. Again, when differentiating by applying equation (4) to the Fig. 5, the sensitivity was finally obtained as shown in Fig. 6. For the refractive index range of 1.36 to 1.43, the sensitivity shows a deviation of 12 to 23 [au/RIU].

IV. CONCLUSION

The proposed biosensors operating at a wavelength of 0.63 µm showed a sensitivity of 12-23 [au/RIU] based on the evanescent-wave of a rib-optical waveguide formed on a Si/ SiO_2 / Si_3N_4 / SiO_2 multilayer thin film and a two-mode power coupling.

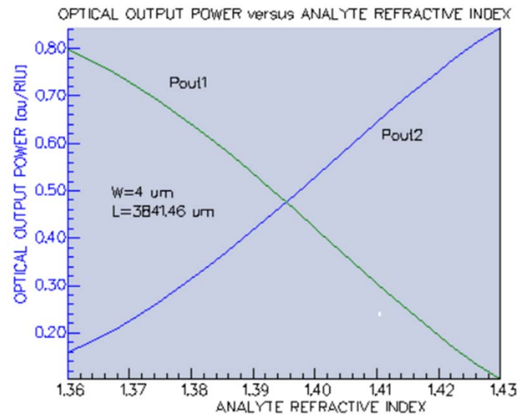

Fig. 4. The normalized two output power intensity versus the change of refractive index.

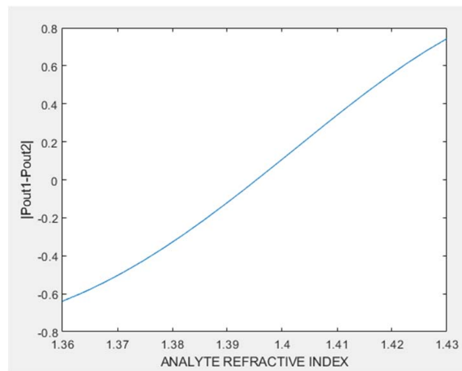

Fig. 5. The difference $|P_{out1}-P_{out2}|$ of normalized two output power intensity versus the change of refractive index.

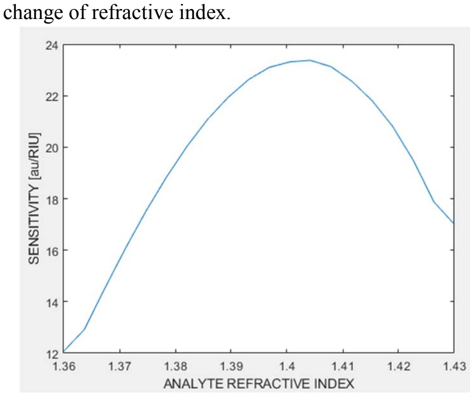

Fig. 6. The Sensitivity versus the change of refractive index

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REFERENCES

[1] G. Breglio, G. Coppola, A. Cutolo, A. Irace, and M. Bellucci, "Temperature optical sensor based on a silicon bimodal Y branch," Proc. SPIE vol. 4293, pp. 155-161, 2001.

[2] B. A. Irace and G. Breglio, "All-silicon optical temperature sensor based on Multi-Mode Interference," Optics Express, vol. 11, no. 22, Nov. 2003.