Design and Fabrication of Polymer Waveguide Sensor with Tin Oxide Thin Film

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***Abstract* - We proposed optical gas sensor based on polymer waveguide with tin oxide thin film on the top of core layer exposed by removing the upper cladding layer. The propagation losses of this device are analyzed using 2-D finite-difference time-domain method as a function of refractive index change of tin oxide thin film.**

I. Introduction

The gas sensors are of importance for a variety of environmental, industrial, medical, scientific and even domestic application. Apart from sensor systems merely providing an alarm signal, it is frequently required to obtain accurate real-time measurements of the concentration of a particular target gas, often in a mixture of other gases.

In recent years, these gas monitoring sensors using electronic and optical device have been mainly studied. Optical sensors exhibit clear advantages over other sensor technologies (chemical, electrical, micromechanical) owing to the high sensitivity and immunity to electromagnetic interference that they can offer. Recent developments on the integration of polymer waveguides for use in waveguide sensors have demonstrated the potential of cost-effectively. Further optical sensors using polymer waveguide can allow the formation of low-cost, highly-sensitive sensing devices for use in a wide range of applications [1-3].

Tin oxide (SnO_2), one of the semiconductor metal oxide film has drawn considerable interest because of their good electrical conductivity and optical property. SnO_2 has been widely studied for gas sensor [4-5]. It has a high reactivity to reducing gases at relatively low operating temperatures and an easy absorption of oxygen at its surface due to the natural non-stoichiometry. Most SnO_2 sensors are operated on the basis of the modification of the elecrical properties. However, SnO_2 sensors have some darwbacks which, in some cases, limit their use in practice. In particular, their operation principle and high operating temperature lead to high power comsumptions and the difficulty to be exploited in combustible and liquid environment. The use of optical waveguides with SnO_2 material could enable to overcome these drawbacks.

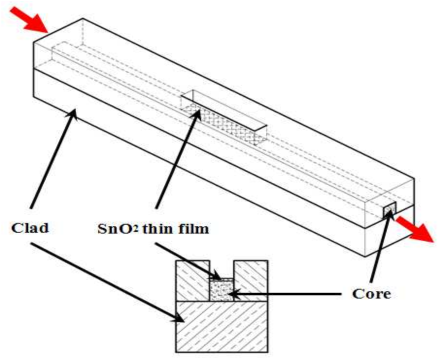

Fig. 1. Schematic view of the optical sensor chip based on polymer waveguide with SnO_2 thin film.

In this paper, we proposed and fabricated optical sensor for gas detection based on polymer waveguide with SnO_2 thin film. Their potential application as gas sensors are confirmed through computational simulation using the two dimensional finite-difference time-domain (2-D FDTD) method.

II. Simulation and Experimental Results

The principle operation of sensor is based on the change of the optical transmission characteristics of the polymer waveguides due to changes induced by specific molecules in the refractive index and optical absorption of the semiconductor metal oxide thin fim coated on the waveguide core surface. Part of the optical waveguides is exposed (no top cladding) so that the light field can interact with the SnO_2 thin film and allow gas detection.

The proposed optical sensor based on polymer waveguide with SnO_2 thin film is schematically shown in Fig. 1. The waveguide optical sensor consists of three parts: a single mode input waveguide section (A), a sensor area with SnO_2 thin film coated on the surface of core layer (B), and a single mode output waveguide section (C). The main parameters of waveguide optical sensor are the refractive index values of waveguide, size of waveguide, thickness of SnO_2 thin film, and refractive index change of SnO_2 thin film. Here, the transmission characteristics of the waveguide optical sensor were simulated using 2-D FDTD method as a fuction of refractive index change of SnO_2 thin film.

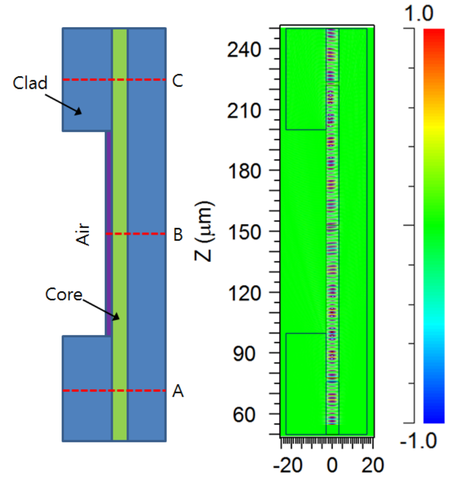

Fig. 2. Beam propagation field intensity profiles in the polymer waveguide with SnO_2 thin film.

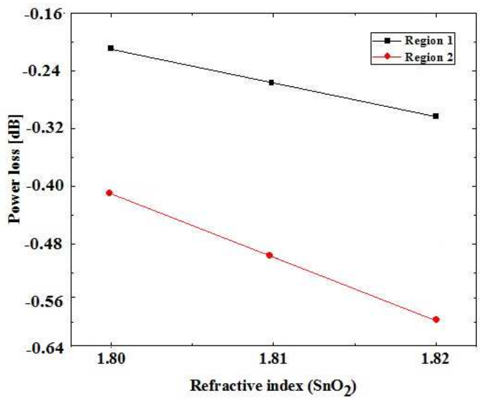

Fig. 3. Propagation losses of waveguide sensor as a function of refractive indices of SnO2 thin film.

The refractive indices of the polymer used for core layer and cladding layer were 1.4916 and 1.4804 at the wavelength of 850nm, repectively. The relative index difference between the core and cladding layers was 0.75%. The size of the single mode channel waveguides for input and output port was 6 μm × 6 μm.

SnO_2 thin film of 100nm thickness was placed on the surface of core layer exposed by removing the specific area of the upper cladding layer of 100 μm length and 15 μm width. In the simulation, the range of the refractive index of SnO_2 thin film was 1.50~1.52 at the wavelength of 850 nm.

Beam propagation of the polymer waveguide structure with different refractive indices of SnO_2 thin films was analyzed. Then propagation intensity profiles and propagation losses have been obtained.

Figure 2 shows the propagation intensity profile from the condition that the refractive index of SnO_2 thin film is 1.80. The propagation mode shifts to the cladding layer in the region of SnO_2 thin film because propagation mode is affected by refractive index of air rather than that of SnO_2 thin film. The calculated length of evanescent wave is about 1.4 μm in the region of SnO_2 thin film. However, the length of evanescent wave is about 10 μm in the region of the core surrounded by cladding layer. Also, scattering loss appears in the boundary between upper cladding layer and SnO_2 thin film.

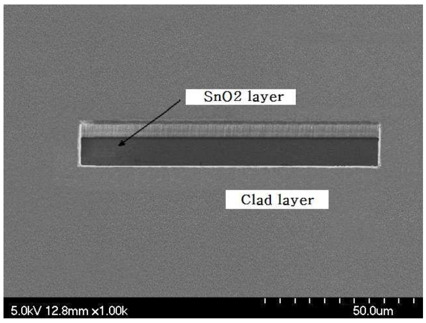

Fig. 4. Photograph of the sensor region exposed by removing upper cladding layer.

Figure 3 shows the propagation losses in the waveguide as a function of refractive indices of SnO_2 thin films. The propagation losses are monitored in the B and C when the optical power was injected into the A. Region 1 is interval from A to B. Region 2 is interval form B to C. As the refractive index of SnO_2 thin film increase, the propagation loss increase. It shows the propagation loss of 0.096 dB when the refractive index change of SnO_2 thin film is 0.01. Figure 4 shows SEM picture of fabricated optical sensor device based on polymer material. The top of core layer is exposed by removing the upper cladding layer.

III. Conclusion

A polymer-based waveguide optical sensor with SnO_2 thin film on the surface of core layer for gas detection was designed and fabricated. The analysis of beam propagation in the optical sensor structure was conducted as a function of refractive indices of SnO_2 thin films. The propagation loss of 0.1 dB was observed when the refractive index variation of SnO_2 thin film is 0.01. This technolgy enables the reduction of fabrication costs and can be used to realize various sensor devices integrated circuits in polymers.

References

[1] M. Hikita, R. Yoshimura, and S. Imamura, “Polymeric optical waveguides for optical interconnections,” *Thin solid Films*, vol.331, pp.303-308,1998.

[2] Y. N. Bamiedkis, R. V. Penty, I. H. White, T. Hutter, S. R. Ellliott, “Low-cost PCB-integrated polymer waveguide sensor for gas detecion,” in *Proc*. OSA/CLEO 2012, CThC5, 2012.

[3] M. Batzill and U. Diebold, “The surface and materials science of tin oxide,” *Prog. Surf. Sci*., vol. 79, pp. 147-154, 2005

[4] K. Arshak, E. Moore, G.M Lyons, J. Harris, and S. Clifford, ”A review of gas sensors employed in electronic nose applications,” *Sens. Rev*. Vol. 24, pp.181-198, 2004.

[5] A. Kolmakov, Y. Zhang, G. Cheng, and M. Moskovits, "Detection of CO and O_2 Using Tin Oxide Nanowire Sensors," *Adv.Mater*. vol. 15, pp. 997-1000, 2003.