

Fabrication of Straight Optical Waveguides Based on SnO₂ Nanomaterials

Asnawi^{1,2,*}, Gatut Yudoyono¹, Yono Hadi Pramono¹

¹Department of Physics, Sepuluh Nopember Institute of Technology, Kampus ITS Sukolilo, Indonesia

²Department of Physics, Universitas Negeri Surabaya, Kampus Unesa Ketintang, Indonesia

Copyright©2017 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

Abstract The manufacture technology of thin film waveguides had done by placing a solution of tin dioxide (SnO₂) on the glass substrate. The structure of the straight waveguide consists of a slide glass substrate, waveguide using tin oxide film, and the cover waveguide is the MMA (Methyl Methacrylate) film. The method for making this waveguides, the waveguide was fabricated using the spin coating method and photolithography technique. The method for making this waveguides, the waveguide was fabricated using the spin coating method and photolithography technique. Analysis of the intensity of the input and output on a straight channels waveguide is done by an optical microscope with the light source of He-Ne laser. The results have obtained the multimode waveguides with the average thickness of straight channels is 16.67 μm.

Keywords SnO₂, Spin-coating, Photolithography, Straight Channel Waveguide

1. Introduction

The development of telecommunications technology and optical data processing within ten years have been developed very rapidly [1]-[3]. The optical devices have many advantages when was compared either devices else based on the electrical or microwaves wave. These advantages are the relatively small size and lightweight, free of noise interference of electric field and magnetic field, the security of the transmission of information which more accurate, free from the interference of electromagnetic waves, as well as a very large bandwidth so the transmission capacity of the waveguide is also great. One of application of thin film waveguide is a power divider, and this device is a major component in the system of optical data processing and optical fiber communication systems. In the optical signal processing, the optical power divider which widely used is the Mach-Zehnder Interferometer [2]-[3], this Interferometer which required on optical power divider has good power

balance factor.

The structures of power dividers have been used in the waveguide device are Directional Coupler (DC), Multi-Mode Interference (MMI), Y-branch, and X-Crossing. The waveguide structure X-Crossing has four ports with one port as input and three other ports as output [2]. Similarly with the Y-branch which is an important instrument as a splitter and power divider [4].

The metal oxide materials have the physical and chemical properties that have very broad potential applications in various fields of optical electronics. Many researchers use ingredients based metal oxides for various fields of research, in particular for the fabrication of electronics and sensors. Metal oxide materials are very much researched, such as TiO₂, ZnO, and SnO₂. The characteristic that stands out from the transparent conductive oxide material is a low electrical resistivity and high transparency in the visible light wavelengths [5]. SnO₂ material is an oxide material which has a transparent conductive property [6]. As a semiconductor material, SnO₂ has a larger energy gap of 3.6 eV at room temperature with a tetragonal structure. In addition SnO₂ is a material that has potential for the fabrication of micron-size waveguide [7] because it has a high refractive index and good transparency to the wavelength of visible light up to wavelengths of infrared [8].

The preparation of a straight waveguide is carried out in two stages, the first stage is made the first layer on the substrate and then by making a straight core shape by means of dry etching, lithography and laser densification [9]. Several methods can be made for the manufacture of the waveguide with thin films, such as sol-gel method [10, 11, 12], Chemical Spray Pyrolysis [13-15], Chemical Bath Deposition [16], Chemical Vapor Deposition (CVD) [17].

The realization of development and optimization of an optical straight waveguide as a device in the present and the future does not only depend on the efforts to a discovery of new materials but also the fabrication method which are more effective, practical and economical. Therefore, in an effort to meet these needs, the study is conducted by the fabrication of ridge waveguide using nanomaterial SnO₂ and

Methyl Methacrylate (MMA). Growth thin film of SnO₂ is done by two methods, namely spin coating or spray methods and the photolithography process. Fabrication using the spin coating method can produce a minimum thickness of 500 nm [14]. The spin coating method is used because it is relatively easy but in general has been able to produce the waveguides. Fabrication using the spray method for manufacturing channel of the straight waveguide is also expected to produce growth of thin films equally well.

2. Experimental Details

The straight waveguide fabrication process was done using a combination of the spin coating methods and photolithography. The colloidal solution of SnO₂ for spin coating is made by dissolving 0.5 g ethyl cellulose from Sigma Aldrich-USA as the binder in the 30 ml isopropanol (J.T Baker) as the solvent and then was stirred for 1 hour at a temperature of 40°C. After the mixture between the solvent and binder completely mixed, the SnO₂ nanopowder <100nm particle size is with code 1002099194 (Sigma Aldrich, USA) was added as much as 1 gram and then was stirred for 1 hour at a temperature of 50°C. A colloidal solution of SnO₂ is deposited on a glass substrate using a spin coating technique. We use a substrate of microscope slide glass with the substrate size (20 mm x 10 mm x 1 mm) and before were used the substrate is cleaned with soap and acetone. The spin rate of the spin-coater was adjusted at 2000 rpm for 30 seconds, and then the film was heated at a temperature of 100°C. The photolithography process was done with deposition of a photoresist of the positive-20 on the film in a dark room, end then the film is heated at a temperature of 70°C for 20 minutes. Furthermore, the manufacture of masks was created by using tracing paper already printed pattern. Results of the printed image tracing paper were taped over the SnO₂ layer and irradiated by a UV lamp 9 Watt for 15 minutes with a distance of the film about 10 cm. The etching process was then performed with a solution of NaOH 10% for 60 seconds while shaking, then rinsed with distilled water and dried. When the straight waveguide was formed so the layer of SnO₂ unused was deleted, so that what left is the top of SnO₂ layer and a layer of the photoresist positive-20 with the appropriate path pattern protected. Finally, the photoresist positive-20 was cleaned by immersing the sample in a solution of acetone 15 seconds to form SnO₂ films. The straight waveguide of the SnO₂ films that had been formed, then the cover layer was deposited with a layer of MMA as much as two times so that the layer of MMA completely shut SnO₂ films. Then this layer was heated at 70°C for 15 minutes. The heating at 70°C is done for the polymerization of MMA into PMMA.

Characterization of nanomaterial SnO₂ powder is done with diffractometer XRD to determine the structure of SnO₂ nanomaterial used. The morphology of the SnO₂ powder was characterized by using Scanning Electron Microscope

(SEM). The spectra absorption of the colloidal SnO₂ solution was measured by spectrophotometer UV-Vis. The measurement of a film thickness of a straight channel waveguide was done by using an optical microscope. The output at each port of a straight waveguide was measured with a microscope webcam device. The beam of a He-Ne laser is launch to the single mode optical fiber and the other edge to insert into a straight channel waveguides were observed using a microscope webcam and was analyzed using software *Scan loop*.

3. Results and Discussion

Fig. 1 show the XRD pattern of the SnO₂ powder. Seen in the Fig. 1, that the main peaks around angle $2\theta = 26.55^\circ$; 33.88° , and 51.75° (JCPDS card file number:00-071-0652) were indicated for nanomaterials SnO₂. Crystallite size is determinate by measuring the broadening of a particular peak in a diffraction pattern associated with a particular planar reflection from the crystal unit cell, as the narrower the peak, the large the crystallite size. The particle size of the SnO₂ powder was analysis with using *Maud* software based on the XRD pattern, and the particle size is 50 nm.

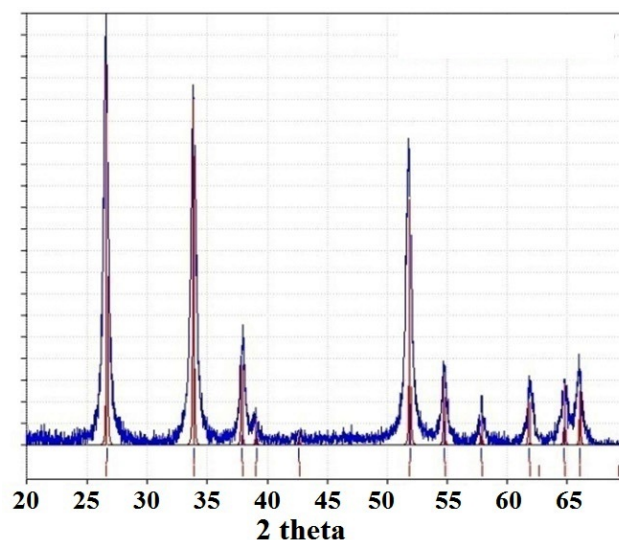


Figure 1. XRD pattern of SnO₂ powder

The SEM image of SnO₂ powder was shown in Figure 2, seen that appears the nanoporous formed from a collection of SnO₂ particles on the surface layer of a substrate. The observation SnO₂ grain size of the material in the image is larger than the particle size was measured with XRD pattern. It is possible to occur agglomeration of the crystals so SnO₂ grain size becomes large. Agglomeration is the process of combining the crystalline particles, the process is a process agglomeration could be expected or may also be a process that is not expected. Process agglomeration impact losses, because it makes the crystal grain size becomes larger and the resulting layer is not homogeneous, but that with the large grain size are more likely to an occurrence of scattering

that interferes with the propagation of the light waves. Scattering is also due to the porous particles of SnO₂ as indicated by the inter-pore and an inter-aggregate; this will make the layer to crack. This is what causes the large scattering in the waveguide which consequently could lead to the expansion of the resonance band.

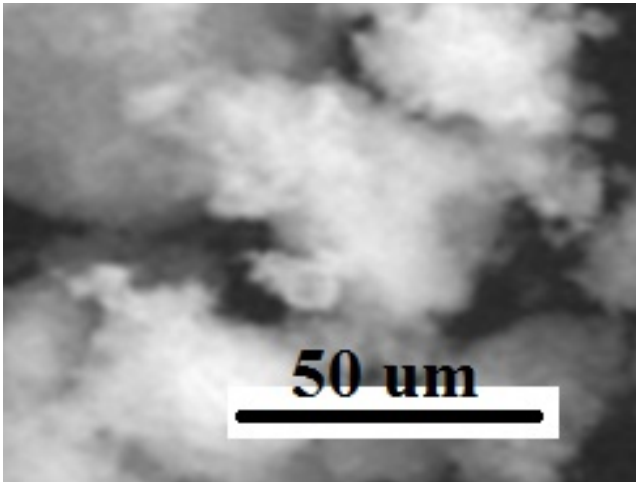


Figure 2. SEM image of SnO₂ powder

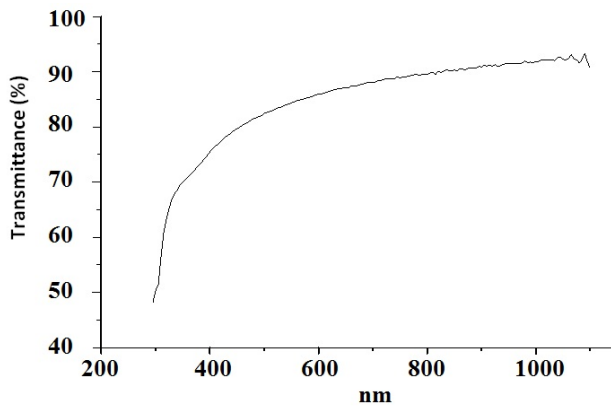


Figure 3. Transmittance spectra of colloidal SnO₂ solution

Figure 3 shows the transmission spectra of the SnO₂ solution in the UV-Vis-NIR (ultraviolet, visible, near infrared) spectrum. Seen in the picture that the transmittance in the spectrum range of the visible light is quite high, which includes 633 nm wavelengths that can achieve an 85% value of the transmittance, whereas in the NIR spectrum it has high transmittance as reported by Oleg Khallaf et al. [8]. The light beam with the wavelength of 633 nm is a beam of the He-Ne laser used in the characterizing of the straight waveguides. The transmittance of colloidal solution SnO₂ at this wavelength is high enough that SnO₂ nanomaterial can be used as a medium of the waveguide for 633 nm wavelength.

Photographic image of the samples cross-section of the slab waveguide not yet subjected to photolithography treatment are shown in Fig. 4. Seen in the figure that in SnO₂ layer formed on the substrates of the glass slide. Layer thickness was calculated using pixel shift method, and we

got the average thickness equal to 16.67 μm. While the measurement results of the width of a straight waveguide (Figure 5) is 2.34 μm. The use of the He-Ne laser ($\lambda = 633$ nm) as the light source in characterizing the fabricated waveguide with the above dimensions, the waveguide obtained is a multimode waveguide.

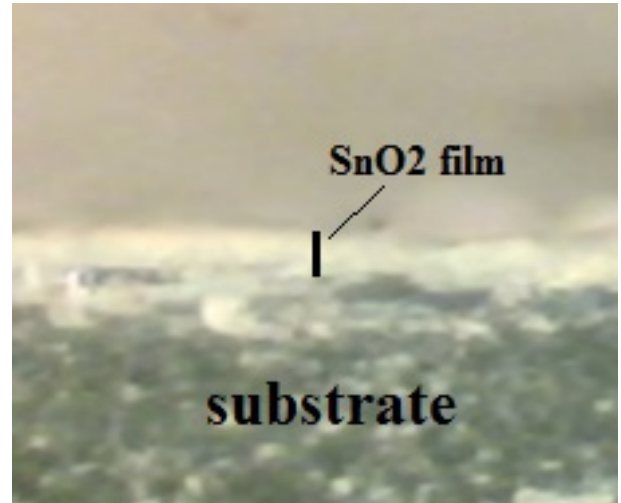


Figure 4. Optical microscope image of cross-section of the slab waveguide SnO₂ film

The straight waveguides were observed using an optical microscope was connected to a computer with the input source is the beam of He-Ne laser. The beam of the laser is transmitted through a single mode optical fiber, and the beam of the laser is out of the optical fiber is used as the input of the waveguide. Seen in Figure 5, the straight waveguides fabricated can guide the laser beam with fairly well. The layer of methyl methacrylate (MMA) as the cover of a waveguide in a straight channel of the waveguide SnO₂, this is done so that scattered light can be minimized in order to reduce the losses of the waveguides.



Figure 5. Optical microscope image of the straight waveguide

4. Conclusions

The waveguides with straight channels had been successfully fabricated with deposition on a glass substrate used the spin coating methods and a simple photolithography method. The core of waveguide is a SnO₂ nanomaterial and the cover of the waveguide is the layer of the methyl methacrylate (MMA). The characteristics of the waveguide with a straight channel (ridge waveguide) of SnO₂ material have been verified. The SnO₂ material is a nanomaterial that has a particle size of 50 nm, so this material can be used as the core of a straight channel waveguide. The layer thickness was calculated using the pixel shift method, and the average thickness is 16.67 μm, while the straight waveguide width is 2.34 μm. Based on the data of thickness and width of the waveguide, the straight waveguide is a multimode waveguide.

REFERENCES

- [1] YH Pramono, M Geshiro, T Kitamura, and S Shinosuke, "Self-switching in crossing waveguides with three channels consisting of nonlinear material," *IEICE transactions on electronics* 82 (1), 111-118, 1999.
- [2] YH Pramono, M Geshiro, T Kitamura, and S Shinosuke, "Optical logic OR-AND-NOT and NOR gates in waveguides consisting of nonlinear material," *IEICE transactions on electronics* 83 (11), 1755-1762, 2000.
- [3] YH Pramono and Endarko, "Nonlinear waveguides for optical logic and computation," *Journal of Nonlinear Optical Physics & Materials* 10 (02), 209-222, 2001
- [4] Rahal, A., Benhaoua, A., Jlassi, M., Benhaoua, B., 2015. Structural, optical and electrical properties studies of ultrasonically deposited tin oxide (SnO₂) thin films with different substrate temperatures. *Superlattices Microstruct.* 86, 403–411. doi:10.1016/j.spmi.2015.08.003
- [5] Yadav, A.A., Pawar, S.C., Patil, D.H., Ghogare, M.D., 2015. Properties of (200) oriented, highly conductive SnO₂ thin films by chemical spray pyrolysis from non-aqueous medium: Effect of antimony doping. *J. Alloys Compd.* 652, 145–152. doi:10.1016/j.jallcom.2015.08.197
- [6] Gordillo, G., Moreno, L.C., de la Cruz, W., Teheran, P., 1994. Preparation and characterization of SnO₂ thin films deposited by spray pyrolysis from SnCl₂ and SnCl₄ precursors. *Thin Solid Films* 252, 61–66. doi:10.1016/0040-6090(94)90826-5
- [7] RL Putri, YH Pramono, A Asnawi, and Y Gatut, "Fabrication of SnO₂ nanoparticles straight waveguide with isopropanol solvent", *Second International Seminar on Photonics, Optics, and Its Applications (ISPhOA)*, page. 101501B-101501B-6, 2016
- [8] Khallaf, H., Chen, C.-T., Chang, L.-B., Lupan, O., Dutta, A., Heinrich, H., Haque, F., del Barco, E., Chow, L., 2012. Chemical bath deposition of SnO₂ and Cd₂SnO₄ thin films. *Appl. Surf. Sci.* 258, 6069–6074. doi:10.1016/j.apsusc.2012.03.004
- [9] Nagano, M., Chemical vapor deposition of SnO₂ thin films on rutile single crystals. *J. Cryst. Growth* 67, 639–644, 1984. doi:10.1016/0022-0248(84)90060-5
- [10] Uysal, B.Ö., Arer, Ü.Ö.A., 2015. Structural and optical properties of SnO₂ nano films by spin-coating method. *Appl. Surf. Sci., SATF2014: Science and Applications of Thin Films, Conference & Exhibition 350*, 74–78. doi:10.1016/j.apsusc.2015.04.023N.M.
- [11] A Andriawan, YH Pramono, and A Masoed, "Fabrication slab waveguide based polymethyl methacrylate (PMMA) with spin coating method", *Second International Seminar on Photonics, Optics, and Its Applications (ISPhOA)*, page.101501H-101501H-5, 2016.
- [12] Zharvan, V., Daniyati, R., Ichzan N., Yudoyono, G., Darminto, "Study on fabrication of TiO₂ film by spin-coating and their optical properties", *AIP Conf. Proc.* 1719, 030018 (2016); doi: 10.1063/1.4943713
- [13] Kassim, M.H. Ibrahim, A.B. Mohammad, and M. Yacob, "Polymer Based Multimode Interference Optical Coupler," *Journal Universitas Teknologi Malaysia*, vol. 15, 2008.
- [14] T. Tahar, "Low loss Sol-Gel Thin Film for Waveguide Applications," *Coatings*, vol. 3, pp. 49-58, 2013.
- [15] K. Furuhashi, "Development of Microfabricated TiO₂ Channel Waveguide," *AIP advances*, 032102, 2011.
- [16] R. T. Ako, D. S. U. Peiris, P. Ekanayake, A. L. Tan, D. J. Young, Z. Zheng, and V. Chellappan, "DSSC with ZnO-TiO₂ Core-Shell Photoanodes Showing Improved Voc: Modification of Energy Gradients and Potential Barriers with Cd and Mg Ion Dopants," *Sol. Energy Mater. Sol. Cells*, vol. 157, page. 18–27, December 2016.
- [17] V. Nguyen, W. Li, V. Pham, L. Wang, P. Sheng, Q. Cai, and C. Grimes, "A CdS/ZnSe/TiO₂ nanotube array and its visible light photocatalytic activities," *J. Colloid Interface Sci.*, vol. 462, page. 389–396, Jan 2016.