SINGLE MODE RIDGE WAVEGUIDE USING HYBRID ORGANIC-INORGANIC SOL-GEL

AMIRJAN BIN NAWABJAN

UNIVERSITI TEKNOLOGI MALAYSIA

SINGLE MODE RIDGE WAVEGUIDE USING HYBRID ORGANIC-INORGANIC SOL-GEL

AMIRJAN BIN NAWABJAN

A thesis submitted in the fulfilment the
requirement for the award of the degree of
Master of Engineering (Electrical)

Faculty of Elecrical Engineering
Universiti Teknologi Malaysia

MARCH 2012

Specially dedicated to my beloved parents, my wife, Nurul Ain, and for all that supported me throughout finishing this thesis. All the continuous support, prayers, and understanding are appreciated.

ACNOWLEDGEMENT

Alhamdulillah, all praise to Allah S.W.T., for His guidance, perseverance and grace that fully assist me in every stage of this research work and finally come out with this essential and valuable manuscript.

It is my pleasure to express my deepest gratitude to my supervisors, Dr Mohd Haniff Ibrahim and Associate Professor Dr. Norazan Mohd Kassim and for their moral support, friendship and guidance during the critical period of this research. I am very much indebted for their effort and enthusiasm in reading the manuscript and commenting on the thesis. My appreciations are extended to my fellow researcher, Ahmad Sharmi Abdullah that helped me a lot during this research.

I am very much indebted to my external supervisor, Dr Zahid Abdul Malek from Advanced Material Research Centre, Kulim for his encouragement and understanding. His advice on the material itself helped a lot in finishing the project. Special acknowledgment is dedicated to his fellow researchers, Tarmizi and Shamsul for their support, assistance and friendship which makes my stay in AMREC as memorable one.

Finally, the financial support from Universiti Teknologi Malaysia and AMRECS's technical assistance are kindly appreciated.

ABSTRACT

Optical waveguides are structures that confine and direct optical signals in a region of higher effective index than its surrounding media. For integrated optics and photonic applications, it is often of importance to prepare waveguides in the form of thin film and channel structures. Hybrid sol-gel material is one of the interesting material in waveguide fabrication as it possess advantages such as low processing temperature, low fabrication cost, and ability of refractive index tuning. Main novelty of this research lies in the development of VTES based optical waveguides. Moreover, refractive index of selected material can be easily tuned by adjusting composition of TTBu in the synthesization stage. Behavior of light propagation and the confinement of light in a hybrid VTES based optical waveguide had been investigated. The characteristics of the waveguide had been simulated by BeamProp^{TM} to obtain the optimum structure for waveguide fabrication. Planar slab waveguides and single mode straight waveguides had been fabricated using low cost photolithographic techniques and wet chemical etching processes. The properties of the hybrid sol-gel material and the fabricated waveguides had been characterized. The experimental results have demonstrated optical waveguiding in the sol-gel material. Attenuation of single mode optical waveguides at 1310 nm and 1550nm with waveguide losses of 1.6dB/cm and 6.7 dB/cm have been obtained respectively. Even though the losses are rather high, the VTES based hybrid sol-gel material is suitable as a waveguiding material in the optical interconnect situations by optimizing the fabrication process.

ABSTRAK

Pandu gelombang optik adalah struktur yang membatas dan memandu tenaga optik dalam satu kawasan yang mempunyai indeks biasan yang lebih tinggi daripada medium yang mengelilinginya. Dalam aplikasi litar bersepadu optik dan fotonik, penyediaan pandu gelombang berbentuk struktur filem nipis adalah penting. Bahan sol-gel merupakan satu bahan yang menarik bagi pembinaan litar bersepadu optik kerana ia mempunyai kelebihan seperti suhu pemprosesan yang rendah, kos fabrikasi yang murah, dan keupayaan untuk menala indeks pembiasan. Pembaharuan utama yang terdapat dalam tesis ini adalah pembinaan pandu gelombang optik berasaskan bahan hybrid VTES. Selain itu, indeks pembiasan juga dapat ditala dengan mudah dengan mengawal komposisi TTBu dalam langkah sintesis. Litar optik padat boleh dibentuk dengan bahan sol-gel kerana ia menawarkan kontras indeks biasan yang besar. Bahan sol-gel berasaskan VTES telah dikaji bagi pembinaan pandu gelombang optik. Sifat perambatan cahaya dan pembatasan tenaga optik dalam pandu gelombang berasaskan bahan sol-gel VTES telah diselidik. Simulasi telah dilakukan mengunakan perisian BeamProp^{TM} untuk mengetahui dan mengaji sifat pandu gelombang serta mendapatkan satu struktur yang optimum bagi fabrikasi pandu gelombang. Pandu gelombang planar dan pandu gelombang monomod lurus telah dibina dengan proses fotolitografi yang murah dan teknik hakisan kimia basah. Sifat bahan sol-gel dan pandu gelombang yang dibina telah dikaji serta parameter optik telah diukur. Keputusan yang diperolehi menunjukkan sifat perambatan optik dalam bahan sol-gel ini. Pemerosotan kuasa sebanyak 1.6 dB/sm pada panjang gelombang 1310 nm dan 6.7 dB/sm pada panjang gelombang 1550 nm telah didapati dalam pandu gelombang monomod lurus. Walaupun pelemahan kuasa tersebut agak tinggi, bahan sol-gel ini didapati sesuai sebagai bahan perambatan optik dalam rangkaian optik dengan memperbaiki proses fabrikasi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

n	- Refractive index
T	- Thickness
E	- Time dependent electric field
H	- Time dependent magnetic field
D	- Electric displacement
B	- Magnetic induction
J	- Current density
P	- Charge density
TE	- Transverse electric modes
TM	- Transverse magnetic modes
$k0$	- Vacuum wave vector
c	- Speed of light
λ	- Wavelength of the light source
β	- Propagation constant along the z direction
θ	- Angle
tco	- Cut-off thickness
m	- Modes
Δx	- Rectangular mesh size at the x direction
Δy	- Rectangular mesh size at the y direction
B	- Normalized propagation constant
L	- Length
E	- Dielectric constant
μ	- Permeability

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Advances in electronics today in various fields enable the production of low cost integrated circuits in mass amount. However, bandwidth demands outgrowing performance of electronic in many applications. Telecommunication is field that clearly suffers from this limitation. Bandwidth expansion is desperately needed in the telecommunication applications. To overcome the bandwidth limitation, new communication revolution based on photonic technology was performed. Surely, photonic application has an extremely large information carrying capacity and very low transmission losses. Very small photonic devices can be faster and more reliable than a standard electronics. Photonic technology was successfully demonstrated in various applications including broadband communication. Originated from the invention of laser in 1958, photonic technology started to widely been applied. Coaxial cables were replaced with glass fibers. At the beginning, major problem that occurred from using optical fiber is the high attenuation value. However, if the optical fiber attenuation can be reduced to 20dB/km, it will be practical medium for communication [1]. In September 1970, a glass fiber with the attenuation less than 20 dB/km was successfully developed by Corning in the USA. With this achievement, optical fiber becomes viable technology to be used in telecommunication. The first field deployment of fiber communication system used multimode fibers with laser operating at wavelength of 850 nm. The system can transmit several kilometer with optical losses about (2-3) dB/km. It is then improved with laser operating at 1310 nm where optical loss was reduced to 0.5 dB/km in a single mode fiber (SMF). Finally, another wavelength window, 1550 nm was developed and SMF has minimal optical loss of 0.15 dB/km.

With the optical networks becomes billion dollar business, the bandwidth size becomes more and more demanding. For instance, application that only enabled by high speed optical network such as web browsing, Fiber to the Home (FTTH), medical image access, also broadband services needs wide bandwidth. When these demands become crucial, it forces researchers to search for new method of sending and processing information. A promising approach to increase the bandwidth in the network links are integrated optical (IO) interconnections. Using integrated optics, huge amount of information can be sent. Not only that, this technology is capable of high yield, but low cost manufacturing while delivering high performance and unique functions. IO circuits started when S.E. Miller from Bell Laboratories proposed the concept of integrated optics in 1969 [2]. He concerned with hybrid type integrated circuit, that is, the dielectric substrate OI circuits.

In the early 1970s, various material and processing technique was used to fabricate waveguide. However to realize an IO circuit, the optical devices or components therein have to be compact, small, reliable, with high mechanical and thermal stability, low power consumption and able to be integrated on a common substrate material [3]. Because of this, it is worth to state that the major performance of IO circuits relies on its waveguiding components. These requirements encourage numerous of studies on the thin film fabrication techniques as well as the new optical materials that suitable for this IO circuits [3].

Finding suitable material for use in optoelectronic application has started widely from 1970s due to need of material that can yield high performance output, nevertheless, it offers low cost production. Few materials with different advantages have been explored and used for the fabrication of optical waveguides, as well as the integrated components. For instance, III-V semiconductors (InP,GaAs), silica based material, polymer, lithium niobate (LiNbO3), silicon based materials, and also sol-gel material. All of these materials have their own advantage and disadvantage for the use in optoelectronic application. For example, silica has been a favorable material due to its high thermal stability, small coefficient of thermal expansion and low attenuation in the two main telecommunications windows (1.3 and 1.55 μm) [4-5]. However they utilize expensive, high temperature thermal treatment which is over 1000^{o}C, and also time-consuming processes such as chemical vapour deposition (CVD), vacuum deposition (VD), flame hydrogen deposition (FHD) and reactive ion etching (RIE) [6]. Alternatively, polymer materials put forward the low cost and simple step of optical devices fabrication [7]. They involve low temperature processing; have the ability of refractive index tuning, and able to produce flexible but strong film with low polarization sensitivity [8]. These materials however are prone to aging problems, poor mechanical resistance and low thermal stability which reduce its long-term reliability [9].

All these limitation and problems with silica and polymer lead to development of glass-like organic–inorganic hybrid materials due to their robustness and largely adjustable optical properties [10]. Sol-gel derived materials seem to offer material which properties range from pure silica glass to silicone rubber [11]. On top of that, sol-gel process is as well dealing with lower processing temperature and able to produce materials with high homogeneity and purity in several forms [12]. Started with just inorganic material with addition of titania (TiO_2) as part of sol-gel processing precursors, it evolved until the hybrid organic inorganic sol gel technique. The mechanical, optical and physical properties of this material have been widely studied [13]. Organic-inorganic hybrid sol-gel derived material has been discovered to be able to go about these drawbacks. The organic group that is introduced can functions as organic modifiers of the inorganic network and it can form the organic networks. These would lead to more flexible products and also decreases the problem of shrinkage significantly [14]. Other advantages and properties of this organic-inorganic hybrid sol gel material will be further discussed in chapter three.

Many types of fabrication techniques are proposed and currently being employed to fabricate these waveguides. These include classes of deposition techniques, ion exchange, thermal diffusion, ion implantation, epitaxial growth, lithographic patterning, dry etching and wet etching. However, the selections of these techniques are highly influenced by two reasons, suitability of material systems and cost effective deployment. For example, deploying dry etching technique is far more costly if we compare with wet etching technique. As for mass production, of course it will not be a practical approach. Therefore, the technique that can yield high productivity yet cost-effective was selected for this research.

With the rapid advent in the optical integrated circuit, importance of planar waveguide and channel waveguide, which are the fundamental element for realizing IO circuit, has been recognized. Hybrid organic-inorganic sol-gel based material which has huge advantage in term of processing temperature, cost effective, and largely adjustable optical properties chosen to be the material of interest. Knowledge and hand-on skills that gained from this research are needed for the future work of fabricating advanced passive and active devices.

1.2 Problem Statement

Motivated from the cost-effective nature of hybrid organic-inorganic sol-gel material, precursors chosen was vinyltriethoxysilane (VTES, Sigma-Aldrich, 99%) [$H_2C{=}CHSi(OEt)_3$], tetraethoxysilane (TEOS, 98% Fluka), and tetrabutoxytitanate (TTBu, 99% Across) based or what we can call VTT sol is chosen as the material of interest in this research. VTES act as organic component as it contains C=C in its structure. Primarily, this VTT sol is employed in the development of single mode optical channel waveguides which are the fundamental structure of any optical devices and further can be applied in the development of optical passive and active devices such as MMI and optical switches.

Based on previous literature surveys, it was found out that the proposed ridge waveguide devices based on the photosensitive VTES precursor can be considered as the first ever development work. As such, it is significant to mention the novelty of this research which can contribute to the enhancement of knowledge, predominantly in the field of sol-gel based photonic devices. VTES was chosen because of its shorter organic chain and it contributes to lower propagation loss [15] .

TEOS, photopatternable organic component with shorter organic chain VTES and refractive index modifier TTBu will be used to synthesis the hybrid organic-inorganic VTES/TEOS/TTBu (VTT) sol. Benzoin Isobutyl Ether (BIE ,Sigma-Aldrich,98%) and Aluminum Acetylacetone (AlAA, Sigma-Aldrich, 99%) as photoinitiator and catalyst respectively. The waveguides will be fabricated by means of spin coating, UV micropatterning, and wet chemical etching technique.

1.3 Research Objectives

The main objective of this research is to fabricate a single mode ridge waveguide using hybrid organic-inorganic sol-gel technique. In order to achieve this main objective:

1) Characterization of hybrid organic-inorganic sol-gel material based on VTES for use in photonic application was done.
2) Development and characterization of single mode ridge waveguide based on VTES in term of refractive index, thickness, and propagation loss was performed.

Single mode ridge waveguide fabricated using hybrid organic-inorganic sol-gel processing method, will be characterized in term of its performance. The fabricated waveguide will be further used to design an active device such as MMI device.

1.4 Project Scope

It is reasonably difficult for a single research with limited time constraint to cover the broad topic of the research. However, owing to the fact that a research is a continuing effort, the conducted research was focused on the scope as determined.

The literature review was done for the sake of understanding the research requirement, related tools, equipment, and material of interest. Through this, the basic understanding of the research was overviewed. The fundamental knowledge of the optical waveguide such as concept, and analysis method were studied. Mathematical modeling was done to gain the best structure and the ability of the waveguide to confine light. Through this, the optimal design that will guide the only single mode transmission can be obtained and simulated through software.

In the first stage of the waveguide development, suitable material portion of VTES, TEOS, and TTBu was investigated to yield the best material for fabrication. Planar structure was developed first to investigate the refractive index of the material. Equipments and parameters that affect the structure was investigated and controlled. For example, thickness of the resulting waveguide can be controlled by varying the spin coating speed. The best conditions for lithography and wet etching process was studied in order to gain the best resolution of the ridge waveguide structure.

Passive optical waveguides were fabricated and characterized. Refractive index measurement, geometrical inspection, structure profile, and light launching were successfully done. Fabricated ridge structure has demonstrated the ability to confine only single mode propagation, with low propagation loss.

1.5 Research Methodology

Before proceeding with the project, the planning or methodology has taken into account. The steps on how the research will take place were done carefully. Each step, starting from the simulation until loss measurement, was planned to gain better understanding of the project. Moreover, the methodology will keep research on track.

As for this project, first of all, the simulation was done to get the basic idea of ridge waveguide structure. Since the desired structure is the single mode ridge waveguide structure. However, in order for the simulation to be done, the refractive index value of the material must be obtained. Therefore, from the literature review, the approximate value of the materials refractive index was taken. The value was then fine tuned when the slab structure fabricated.

The slab structure was fabricated next for the refractive index and thickness measurement. From the measurement using prism coupling method, the exact refractive index value of the material was obtained. This value was then used to remodel the structure using the simulation software.

From the simulation, the exact dimension of single mode structure was obtained. The simplest structure of the ridge waveguide was fabricated. The fabrication process was varied in order to yield the finest structure of the ridge waveguide. Parameters such as the drawing speed, the exposure time, the etching time, and heat treatment temperature was varied for the purpose. Finally, the best parameters of the experiments was recorded and used for later experiments.

Thickness and refractive index was measured using spectroscopic reflectometer in the earlier stage, followed by prism coupling method for precise value. Geometrical inspection of the structure was done by scanning electron microscope (SEM). The surface roughness was measured using atomic force microscope (AFM).

Finally, the light launching was done to measure the propagation loss of the material. This final step will show the suitability of the material in photonic application. Two different wavelengths were used in the propagation loss measurement, 1310 nm and 1550 nm, pertaining to main telecommunication windows in the photonic application.

Figure 1.1 shows the flowchart of the whole process of the hybrid organic-inorganic sol-gel ridge waveguide fabrication and characterization.

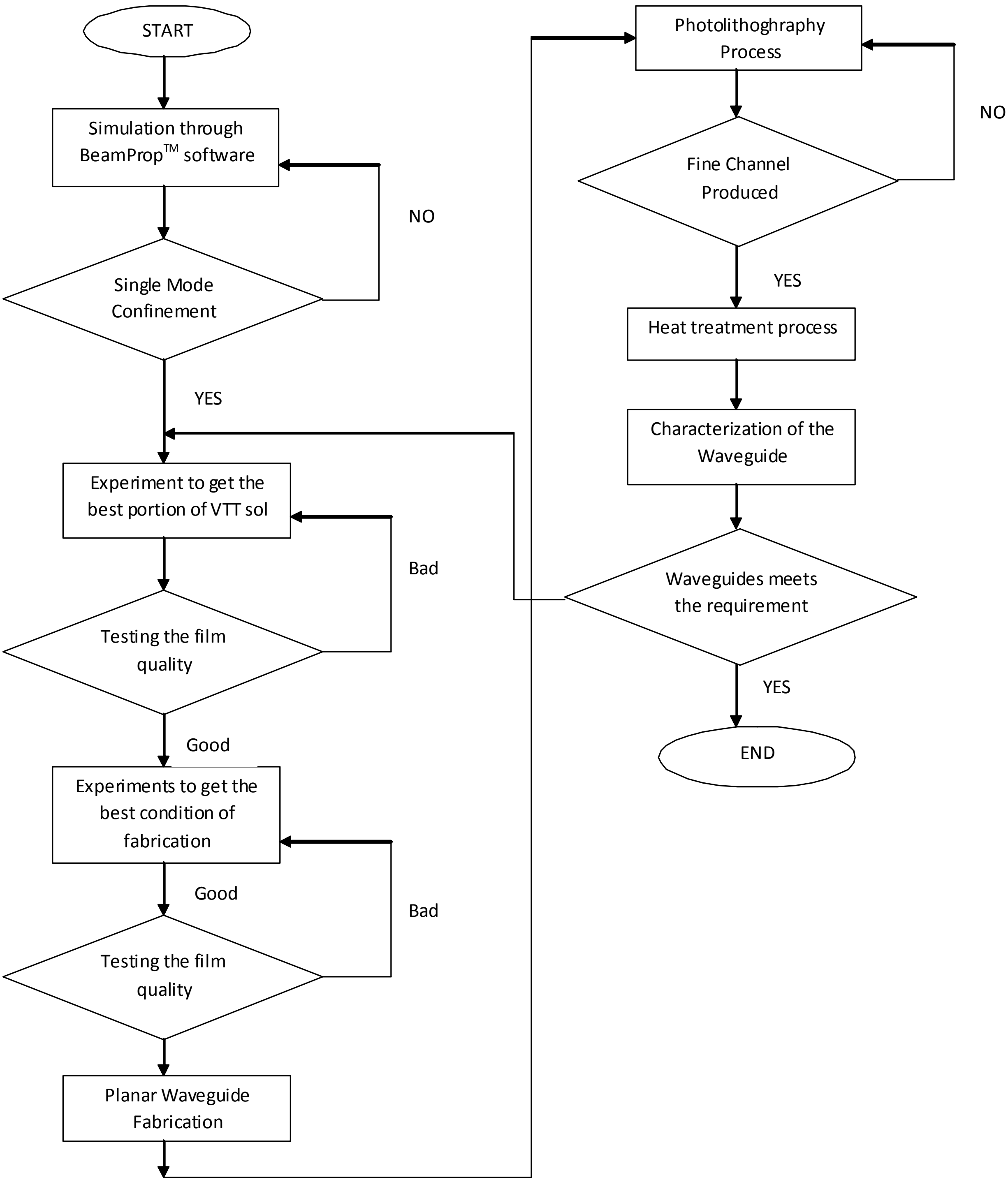

Figure 1.1 Flowchart of the research

1.6 Thesis Outline

Chapter 1 explains the brief history of the development in photonic technology. Research motivation, overview of research, objectives of research, and goals of the research were presented.

Chapter 2 consists of basic theory of optical waveguide, and analysis method. A simple mathematical modeling of the ridge waveguide was performed.

In chapter 3, several materials which are under intensive investigation for integrated circuit purposes were discussed. The detailed literature review was done, by providing the recent related work done by other researchers. The properties of VTES based organic-inorganic sol-gel material properties which is the material of interest in this research were presented.

The full fabrication and measurement procedure to fabricate the ridge waveguide is described in detail in chapter 4. The condition that must be fulfilled, the problem that occurs during fabrication process and precaution taken in fabrication process also presented in this chapter.

Results and discussion of the research are shown in Chapter 5. Data verifications were done in the sense of comparing our modeling and simulation result. Measurement results of fabricated waveguides are shown in this chapter.

Finally in Chapter 6, a concluding remarks and suggestions for future work are given. The contribution of this thesis also stated in this chapter. Fabrication skill obtained through this research could be applied for the future development of active optical devices.

REFERENCES

[1] J.Hecht, *"City of light, the story of the fiber optics". New York*: *Oxford University Press*, 2004.

[2] M. H. Hiroshi Nishihara, Toshiaki Suhara, *Optical Integrated Circuits* vol. 1: McGRAW-HILL, 1989.

[3] T. Tamir, "Recent advances in integrated optics," in *Integrated Optics*, ed, 1975, pp. 305-320.

[4] X. Orignac, "Silica-based sol-gel optical waveguides on silicon," *IEE Proceedings: Optoelectronics,* vol. 143, pp. 287-292, 1996.

[5] H. L. X. Zhang , M.Qian, X.Zheng., "Fabrication of microfluidic devices using photopatternable hybrid sol-gel coatings," *Journal of Sol-Gel Science and Technology,* vol. 48, pp. 143-147, 2008.

[6] M. H. Anhe He, Shuti Li, Haiying Xing,Wenjie Wang,Yang Li, "Develop-Free Solgel Fabrication of Low-Loss Embedded Channel Waveguide Array," *Lightwave Technology, Journal of,* vol. 28, pp. 735-738, 2010.

[7] L. Eldada*, et al.*, "Laser-fabricated low-loss single-mode raised-rib waveguiding devices in polymers," *Journal of Lightwave Technology,* vol. 14, pp. 1704-1712, 1996.

[8] K. Tamaki*, et al.*, "Recent Progress on Polymer Waveguide Materials," *Journal of Photopolymer Science and Technology,* vol. 16, pp. 639-648, 2003.

[9] P. Coudray*, et al.*, "Integrated optics based on organo-mineral materials," *Materials Science in Semiconductor Processing,* vol. 3, pp. 331-337, 2000.

[10] M. Q. X.Zhang, X.Zeng ,Z.Zhao ,J.Lasante ,P.Plante, "Design and fabrication of single mode rib waveguides using sol–gel derived organic–inorganic hybrid materials," *Journal of Sol-Gel Science and Technology,* vol. 45, pp. 103-107, 2008.

[11] R. Gvishi, "Fast sol-gel technology: From fabrication to applications," *Journal of Sol-Gel Science and Technology,* vol. 50, pp. 241-253, 2009.

[12] J. D. Mackenzie, "Sol-gel research - Achievements since 1981 and prospects for the future," *Journal of Sol-Gel Science and Technology,* vol. 26, pp. 23-27, 2003.

[13] I. H. A. Ulatowska-Jarza, K. Wysocka, H.Podbielska, "Silica-based versus silica-titania sol-gel materials - comparison of the physical properties: surface tension, gelation time, refractive index and optical transmittance," *Optica Applicata,* vol. 39, pp. 211-220, 2009.

[14] H. Scholze, "New possibilities for variation of glass structure," *Journal of Non-Crystalline Solids,* vol. 73, pp. 669-680, 1985.

[15] T. S. K. Tadanaga, A. Matsuda, T. Minami, M. Tatsumisago, "Micropatterning of inorganic-organic hybrid thick films from vinyltriethoxysilane," *Nippon Seramikkusu Kyokai Gakujutsu Ronbunshi/Journal of the Ceramic Society of Japan,* vol. 114, pp. 125-127, 2006.

[16] A. Boudrioua, *Photonic Waveguides: Theory And Applications* vol. 2: ISTE Ltd, John Wiley & Sons Inc., 2009.

[17] J. C. Richard Syms, *Optical Guided Waves and Devices. London*: McGraw-Hill Book Company, 1992.

[18] N. M. Kassim, "Optical Waveguides in Silicon Materials," Ph.D., Department of electrical and electronic engineering, University of Nottingham, 1991.

[19] K. Yasuo, "Microring Resonator and Its Application to Hitless Wavelength Selective Switch Circuits," 2009, p. IWB1.

[20] B. Syrett*, et al.*, ""SOI waveguide fabrication process development using star coupler scattering loss measurements" SPIE," Australia, pp. 1-12.

[21] S. R. Ramaswamy R.V., "Ion exchange glass waveguide:a review," *Journal of Lightwave Technology,* vol. 6, pp. 984-1002, 1988.

[22] S. Y. Gang, "Polymer Based Optical Waveguides," Master degree, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Malaysia, 2005.

[23] G. Roelkens*, et al.*, "Silicon nanophotonics : towards VLSI photonic integrated circuits," in *General Assembly of URSI, 29th, Proceedings*, 2008.

[24] J. Zarzycki, "Past and Present of Sol-Gel Science and Technology," *Journal of Sol-Gel Science and Technology,* vol. 8, pp. 17-22, 1997.

[25] G. C. Righini and S. Pelli, "Sol-Gel Glass Waveguides," *Journal of Sol-Gel Science and Technology,* vol. 8, pp. 991-997, 1997.

[26] H. Schmidt, "Considerations about the sol-gel process: From the classical sol-gel route to advanced chemical nanotechnologies," *Journal of Sol-Gel Science and Technology,* vol. 40, pp. 115-130, 2006.

[27] J. Zha and H. Roggendorf, "Sol–gel science, the physics and chemistry of sol–gel processing, Ed. by C. J. Brinker and G. W. Scherer, Academic Press, Boston 1990, xiv, 908 pp., bound—ISBN 0-12-134970-5," *Advanced Materials,* vol. 3, pp. 522-522, 1991.

[28] A. J.J Ebelmen, vol. 53, 1846.

[29] M. M. Michel A. Aegerter, *Sol-Gel Technologies for Glass Producers and Users* vol. 1: Kluwers Academic Publishers, 2004.

[30] S. K. Pani*, et al.*, "Fabrication of buried hybrid sol-gel optical waveguides by femtosecond laser direct writing," *Thin Solid Films,* vol. 504, pp. 336-340, 2006.

[31] J. Jabbour*, et al.*, "Characterization by IR spectroscopy of an hybrid sol-gel material used for photonic devices fabrication," *Journal of Non-Crystalline Solids,* vol. 354, pp. 651-658, 2008.

[32] W. Que*, et al.*, "Photo-patternable GeO2-contained organic-inorganic hybrid sol-gel films for photonic applications," *Opt. Express,* vol. 16, pp. 3490-3495, 2008.

[33] L. J. Q. Maia*, et al.*, "Er:YAl3(BO3)4 glassy thin films from polymeric precursor and sol-gel methods: Waveguides for integrated optics," *Thin Solid Films,* vol. 517, pp. 6584-6587, 2009.

[34] C. Y. Jia*, et al.*, "Preparation and optical properties of sol-gel derived photo-patternable organic-inorganic hybrid films for optical waveguide applications," *Thin Solid Films,* vol. 518, pp. 290-294, Nov 2009.

[35] P. Karasinski*, et al.*, "Rib waveguides based on the sol-gel derived SiO2:TiO2 films," *Photonics Letters of Poland,* vol. 2, pp. 40-42, 2010.

[36] N. J. Kim*, et al.*, "Optical and structural properties of Fe-TiO2 thin films prepared by sol-gel dip coating," *Thin Solid Films,* vol. In Press, Corrected Proof, 2010.

[37] A. Gorin, *et al.*, "Low loss optical channel waveguides for the infrared range using niobium based hybrid sol-gel material," *Optics Communications,* vol. 284, pp. 2164-2167, 2011.

[38] M. Oubaha, *et al.*, "Novel tantalum based photocurable hybrid sol-gel material employed in the fabrication of channel optical waveguides and three-dimensional structures," *Applied Surface Science,* vol. 257, pp. 2995-2999, 2011.

[39] P. Innocenzi, *et al.*, "Optical and surface properties of inorganic and hybrid organic-inorganic silica-titania sol-gel planar waveguides," *Journal of Non-Crystalline Solids,* vol. 259, pp. 182-190, 20 September 1998 through 23 September 1998 1999.

[40] K. Tadanaga, *et al.*, "Micropatterning of inorganic-organic hybrid coating films from various tri-functional silicon alkoxides with a double bond in their organic components," *Journal of Sol-Gel Science and Technology,* vol. 26, pp. 431-434, 2003.

[41] M. T. Z. Aishah Isnin, Nik Azmi N. A. Aziz and Mohamad Zahid A. Malek, "Micropatterning of Spin-Coated Hybrid Materials by Using an UV Polymerization Technique," *Journal of the Korean Physical Society,* vol. 52, pp. 1554-1557, 2008.

[42] D. K. Hans Bach, *Thin Film on Glass*. New York: Springer-Verlag, 1997.

[43] A. Moujoud, *et al.*, "Fabrication of sol-gel optical waveguide by hot-dip coating process," *Journal of Sol-Gel Science and Technology,* vol. 35, pp. 123-126, 2005.

[44] J. Xu and R. M. Almeida, "Preparation and Characterization of Germanium Sulfide Based Sol-Gel Planar Waveguides," *Journal of Sol-Gel Science and Technology,* vol. 19, pp. 243-248, 2000.

[45] A. L. Adan, "Integrated Optics Technology On Silicon: Optical Transducers," Ph.D., Universitat Autònoma de Barcelona, Barcelona, 2002.

[46] C. R. Pollock., *Fundamentals of Optoelectronics*. USA: Richard D. Irwn, Inc, 1995.

[47] S. A. A. A. N. M.Z.A. Malek, M.T. Zainuddin, N.M.A.N.A. Aziz, H.Hashim, A.Z. Shaari and A. Isnin, "optical properties and nanosurface morphology reconstructions during multi-spin coat of sol-gel derived organically modified

silane based," *progress revision in J. MASS 2008. (Proceeding in MASS 2008),* 2008.

[48] Y. Wang, Lin, Z., Zhang, C., Gao, F., and Zhang, F, "Integrated SOI Rib Waveguide Using Inductively Coupled Plasma Reactive Ion Etching," *IEEE Journal of Selected Topics in Quantum Electronics,* vol. 11, pp. 254-259, 2005.

[49] X. H. Wenxiu Que, J.Zhou, "Sol-gel fabrication of GeO2/ormosils organic-inorganic hybrid material channel waveguides," *Thin Solid Films,* vol. 484, pp. 278-282, 2005.