INVESTIGATION OF TEMPERATURE PROLIFE IN THE WAVEGUIDE

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ABSTRACT

The demand for data traffic has initiated the development of optical telecommunications. Due to explosive growth of optical network, has brought forward an increased need for guided-wave optical component. The purpose of this work is to investigate the temperature profile in the thermo-optic waveguide. Here, we use one and two dimensional model to analyze the thermal model. We focus on polymer waveguide since these technology is attractive for many advantages, including large thermo-optic coefficient (for Polyurethane (PUR): $dn/dt \sim -3.3^{-4}\ K^{-1}$) and low thermal conductivity (~ 0.19 W $m^{-1}\ K^{-1}$). The buried and rib waveguide structure is used for two dimensional model thermal analysis. We interested to see how heating the heater will change the refractive index and change the profile in the waveguide. Thermal coupling became next task of this project. We analyze the effect of heater to the nearby waveguide. To perform this analysis, we utilized a commercial finite element method (FEMLAB 2.0), which is a tool for PDE-based multiphysics modelling in an interactive environment-MATLAB. The simulated result will use one and two dimensional model respectively. Effective index change is dependency of heater size as well as distance between core to the heater. Increasing 1µm of heater width will reduce -0.1 of dn_{eff}/dt it also increasing the power consumption. Thermal coupling is related to waveguide spacing and depth. The coupling estimation is increase with the waveguide depth but decrease with the waveguide spacing. Apply trench structure can reduce the thermal coupling estimation, K .The temperature of heated waveguide decreases as the trench depth increases, therefore it requires less power in performing its function.

ABSTRAK

Perkembangan terhadap komunikasi optik bermula dengan permintaan terhadap pengangkutan data. Peningkatan yang cepat memberi peluang terhadap penggunaan komponen gelombang pandu. Matlamat di sini adalah untuk mencari kesan suhu terhadap gelombang yang di panaskan. Oleh itu, penggunaan satu dan dua dimensi digunakan didalam analisis kesan haba ini. Analisis ini dilakukan menggunakan bahan polimer kerana ia mempunyai pemalar haba optik yang tinggi($dn/dt \sim -3.3^{-4}\ K^{-1}$) dan juga pengaliran arus elektrik yang rendah ($\sim 0.19\ W\ m^{-1}\ K^{-1}$). Model haba menggunakan dua bentuk struktur gelombang yang berbeza iaitu penanaman (buried) dan juga melengkung (rib). Kami ingin melihat bagaimana haba memberi impak terhadap perubahan indek bias dan juga terhadap profil gelombang. Selepas itu, fokus terhadap perangkai haba (thermal coupling) di lakukan. Analisis pemanas terhadap gelombang yang bersebelahan dilakukan. Untuk melakukan semua analisis ini kami menggunakan komersial perisian iaitu FEMLAB 2.0 yang mana menggunakan asas fenomena fizik model dan juga persamaan matematik. Ia juga interaktif dengan perisian MATLAB. Simulasi akan menggunakan satu dan dua dimensi. Perubahan indek bias bergantung kepada saiz pemanas dan juga jarak di antara teras (core) kepada pemanas. Peningkatan sebanyak 1µm kelebaran pemanas akan mengurangkan -0.1 perubahan indek bias (dn_{eff}/dt) dan ini akan meningkatkan penggunaan kuasa. Manakala, perangkai haba (thermal coupling) amat bergantung kepada jarak di antara dua gelombang dan juga kedalaman teras. Nilai ini, K akan meningkat bergantung kepada jarak kedalaman gelombang dan mengurang sekiranya jarak di antara dua gelombang meningkat. Penggunaan kaedah perparitan (trench) akan mengurangkan nilai perangkai haba,K. Suhu gelombang yang di panaskan akan berkurang sekiranya kedalam parit (trench depth) meningkat. Oleh itu, ia akan menjimatkan penggunaan kuasa di dalam melakukan sesuatu fungsi.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	-	contact area
C	-	heat capacity
d	-	trench depth
d	-	distance of heat flow
K	-	thermal coupling estimation
k	-	thermal conductivity
H	-	distance from heater to waveguide core
h	-	waveguide depth
L	-	heater lenght
n	-	refractive index
Q	-	rate of heat flow
s	-	waveguide spacing
t	-	thickness of the polymer bottom layer
W	-	heater width
β	-	propagation constant
ε	-	relative permittivity
μ	-	relative permeability
Δ	-	temperature ratio different
Φ	-	change in polarizability with temperature
ρ	-	density capacity
λ	-	wavelength
γ	-	coefficient of volume expansion

CHAPTER 1

INTRODUCTION

Guided wave optics will play an increasing and important role in optical communication networks and optical sensor systems. In particular, polymeric waveguide devices are being developed; because the process can be low-cost, and high manufacturing output can be achieved. The low temperature fabrication process of polymer waveguide also gives the designer a large degree of freedom. Because most polymer materials have a thermo-optic coefficient an order of magnitude larger than that of silica, thus, they can be temperature tuned over a wider spectral range (Edwin Y. B. Pun and W.H. Wong, 2002).

In general polymer has a temperature dependent refractive index which is known as the thermo optic (TO) effect. Recently, the active optical glass waveguide utilizing the TO effect such as modulators and switches has been demonstrated (M.Haruna and J.Koyama ,1982). In 1989, there is published paper due to application of TO which is using polymer waveguide to make a switch. The author demonstrated that effective index changes at least one order higher than those obtained with the electro optic effect in $LiNbO_3$ are found (M.B.J. Diemeer, J.J. Brons and E.S. Trommel, 1989). Two years ago, the researcher (H.P. Chan, C.K. Chow and Alok K. Das 4, 2003), found that by using the polymer material in application of digital optical switch (DOS), there can reduces the crosstalk value.

Nowadays, there have a lot of research to find a robust material or versatile in optic communication application. Figure 1 shows the material that used until 2001, polymer contribute only few percentage.

Table 1.1: Integrated optics market in 2001 by material type (L. Gasman, 2001)

Material	**%**
Lithium niobate	30
Indium phosphide	22
Gallium arsenide	20
Silica on silicon	11
Polymer	5
Silicon	3
Other	9
TOTAL	**100**

1.1 Statement of the Problem

The explosive growth of the Internet, and the emergence of a strong wireless market are driving these changes, and optoelectronic components are fundamental enablers of this transformation. This combination of optical and electrical technologies allows data to be generated, transported and manipulated at high rates. Today, optoelectronics are being integrated into existing networks. By 2007, all-optical networks will most likely be needed (John Stafford, 2001).

Today's components and packages are too costly as well as too cumbersome. The industry will need to move to new technologies, such as flip chip instead of wire bond, and multichip modules to reduce package size (John Stafford, 2001). Still need a lot a research in this field due to demanding of optical communication.

As the new technology trends to increase the speed and the bandwidth for communications in wide area networks, the all optical network becomes a good choice as a solution for that problem. New devices and materials using linear or non linear effects of light are extremely useful for such networks because of their compatible speed (Mario L and Jose A.M. Pereira, 1996). Our project use polymer material to build optical waveguide. Recently, development on optical polymer waveguide will used electro –optic to implement the device. Because polymer has large TO coefficient, we will apply this effect to implement future device.

1.2 Integrated Optics in Polymers

Polymer materials are of great interest in integrated optics as they can be tailored to meet specific applications. The thermo-optic effect is large in these materials -1×10^{-4} K^{-1} to -4×10^{-4} K^{-1} which leads to power efficient dynamic components. They are potentially low cost and rapidly processed by direct photo patterning or reactive ion etching. Waveguide can be designed with very large or very small index contrast between core and cladding (0% – 35%). Polymer can also have very low optical loss <0.1dB/cm at the telecommunication wavelengths 1310 nm and 1550 nm (John M. Senior, 1992). Cross linked polymer systems operated above the glass transition temperature even allow for waveguides free of stress induced scattering and birefringence. Polymer material classes used in integrated optics include acrylates, polyimides, polycarbonates and olefins (Robert Blum, 2003).

Realized polymer devices cover a wide range of optical applications like switches, couplers, filters, attenuators, polarization controllers, dispersion compensators, modulator, laser and amplifiers (R.T. Chan,1993).Even 3D multi layer architectures of integrated circuits are possible as successive layers are deposited b simple spin coating (S.M. Garner et all, 1999).Table 2 compares several typical materials used in integrated optics. In almost all categories polymers exhibit excellent values. However, it is difficult to combine all these properties in single material.

Table1.2: Typical properties of waveguides in popular materials used in integrated optics. The refractive indices of the core and cladding materials are denoted by n_{cor} and n_{clad} respectively.

	Propagation Loss [dB/cm]	**Refractive Index**	**Index Contrast $(n_{cor}n_{clad})/n_{cor}$**	**Birefringence**	**T/O Coef.dn/dt [K^{-1}]**	**Max. Modulation Freq.**
Silica	0.1	1.5	0-1.5%	10^{-4}-10^{-2}	10^{-5}	1kHz (TO)
Silicon	0.1	3.5	70%	10^{-4}-10^{-2}	1.8×10^{-4}	1kHz (TO)
Polymers	0.1	1.3-1.7	0-35%	10^{-6}-10^{-2}	-1×10^{-4}- -4×10^{-4}	1kHz (TO)
Lithium Niobate	0.5	2.2	0-0.5%	10^{-2}-10^{-1}	10^{-5}	40GHz (EO)
Indium Phospide	3	3.1	0-3%	10^{-3}	0.8×10^{-4}	40GHz (EO)
Gallium Arsenide	0.5	3.4	0-14%	10^{-3}	2.5×10^{-4}	20GHz (EO)

Most serious problems in connection with polymers are environmental stability (temperature, humidity) and commercial availability. Thermal aging due to oxidation is often observed in organic materials as well as water incursion and the associated optical absorption from the overtone bands of the OH stretch (Robert Blum, 2003).However, these problems have been solved by many manufacturers (e.g. AlliedSignal, JDS Uniphase, Du Pont, Dow Chemical) and some materials even passed the Bellcore 1209 and 1221 test (R, Moosburger et all, 1996).

Unlike silicon, silica or InP, polymers are materials are designed by chemists to meet specific needs. Their usage is often hindered by patents and they are seldom sold or manufactured in small quantities as needed for integrated optics (J.D. Plumber, M.D. Deal and P.B. Griffin, 2000). Therefore commercially available polymers are usually built for other applications like microelectronics, display or furniture coating. By chance, some of them also show desirable optical characteristics like BCB (Cyclotene by Dow Chemical).

1.3 Scope of this Work

This project is about an investigation of temperature profile in the thermo-optic waveguide due to the effect of having thin film heater on top of polymer waveguide structure by using the one and two dimensional model. Here, we would like to determine the effective index change from the change of temperature. By heating the heater, it will distribute the heat in the surrounding area and cause increasing the temperature in the waveguide structure.

In the way to analyze the TO effect, we will design thermal model based on two different structure which is rib waveguide structure and buried waveguide structure. The lateral heat diffusion distance in both structures will be studied. Two phenomena will be studied seriously, which is the distance from heater to the core waveguide (H) affect the effective index change. We also interested to investigate how heater size would affect the key parameters in modelling waveguide structure.

Thermal coupling became an issue when we have two waveguides in parallel. The structure will consists of two square waveguide. Due to thermal phenomena, heat one of the waveguide will effects nearby waveguide. Actually, these are unwanted phenomena and will degrade the devices performance. The relationship between them is known as thermal coupling estimation. Here, we will determine these values and try to figure out the way to reduce these effects. One method is by applying the trench structure. All the simulation is done using software named FEMLAB. The result can be obtained by GUI (Graphical User Interface). This software apply finite element as a method to solve all the problems.

1.4 Overview of this Report

This section outlines the organization of the work contained in this thesis. Throughout this thesis we have seven chapters including the conclusion. A brief history of integrated optic is discussed in Chapter 2. Follow with the literature review of this project. Several papers are discussed under section 2.2 sub topics.

In Chapter 3, all the theory that applies for the project progress is explained briefly. The discussion start with phenomena that cause light can travel in the waveguide. Maxwell equation are introduces to get wave equation. Then, the types of the structure are discussed following with several type of control waveguide. But for this project, we focus on thermo-optic control. At the end of this chapter, the subtopic is on polymer waveguide.

Chapter 4 is about the methodology of the project. Since we used the numerical method in the way to get the result, a basic theory of finite element method is discuss. Thermal analysis, which is the heat transfer equation are explain due to the one and two dimension respectively. Thermal model including rib and buried waveguide structure is explained under section 4.3. Lastly, a quick step on simulation used FEMLAB software is shown.

The result section is divided into two sub topic which is thermal model and thermal coupling. Under thermal model we show the result for rib and buried structure. One dimensional is also shown under this sub topic. All the parameter that will be influence the performance of effective index change is shown in this topic. Discussion and analysis or data interpretation are shown in Chapter 6. A lot of issue is discussed here. Last chapter is about the conclusion of the project throughout this course.

REFERENCES

Abu Sahmah (2005).*Note Optical Communications*: Universiti Teknolog Malaysia.

B. A. Moller, L. Jensen, C. Laurent-Lund and C. Thirstrup (1993). Silica-Waveguide Thermooptic Phase Shifter with Low Power Comsumption and Low Lateral Heat Diffusion. *IEEE. Photonic Tech. Lett.* 5(12): 1415-1993.

C.K. Madsen and Jian H.Zhao (1999).*Optical filter design and analysis*: Wiley Interscience.

Cook R.D, Malkus D.S, and Plesha M.E. (1989). *Concepts and Applications of Finite Element Analysis*. 3rd Edition: John Wiley and Sons.

D. M. Burland, R.D. Miller and C.A. Walsh (1994). Second- Order Nonlinearity in Poled-Polymer Systems. *Chem. Rev*. 94(1):31-75.

Data sheet. OHIDA: *Technology Evaluation Report for Optical Interconnections and Enabling Technologies.*

Edwin Y. B. Pun and W.H. Wong (2002).Optical polymeric waveguides and devices; IEEE, 126-132.

F. Fernandez and Y. Lu (1996).Microwave and optical waveguide analysis by the Finite Element method. *Research Studies Press Ltd.*

G N Mercery and R O Weber (1997).Combustion waves in two dimensions and their one-dimensional approximation. *Combust. Theory Modelling 1*: 157–165.

H.P. Chan, C.K. Chow and Alok K. Das (2003). A wide- Angle X-Junction Polymeric Thermo optic Digital Switch With Low Crosstalk. *IEEE Photon. Technol. Lett*., 15(9).

Hiroshima Nishihara, Masamitsu Haruna and Toshiaki Suhara (1989).*Optical Integrated Ciucuits*:McGraw-Hill Optical and Electro-Optical Engineering Series.

Huihai Yao (2000). Polymer Waveguide based Optical Devices for Optical Communication. *Institude of Telecommunication*: Germany.

J. D. Plumber, M.D. Deal and P. B. Griffin (2000). *Silicon VLSI Technology.* New York: Prentice Hall.

J. Hecht (2002). *Understanding Fiber Optics*. 4th Edition: London: Prentice Hall.

John M.Senior (1992). *Optical Fiber Communications Principles and Practice.*2nd Edition: Prentice Hall.

John Stafford (2001). Optoelectronic Components Place New Demands on Packaging and Assembly. *Optoelectronics Technology Working Group for NEMI's 2000 Roadmap.*

K. Asatani (1989*). J. Lightwave Technol*.. 7: 1705.

K. Okamoto (2000). *Fundamental Optical Waveguides*. San Diego: Academic Press.

D. A. Anderson, J. C. Tannehill and R.H. Pletcher (1984). *Computational Fluid Mechanics and Heat Transfer*.Hemisphere, Washington D.C.

L.Eldada (2001). Advances in telecom and datacom optical components. *Optical Engineering.* 40.

L. Eldada and L.W. Scahacklette. Advances in Polymer integrated Optics. *IEEE J. Sel. Topics Quant. Electr.* 6(1): 54-68.

L. Gasman(2001). New Materials Renew Life for Integrated Optics. *WDM Solutions*:17–20.

M.B.J. Diemeer, J.J. Brons and E.S. Trommel (1989).Polymeric Optical Waveguide Switch Using the Thermo optic Effect. *J. Lightwave Technol*..(7): 449-453.

M. Cowin (2001). Telecoms poised to profit from polymer photonics. *FiberSystems International* . 2(9): 24-26.

M.Haruna and J.Koyama (1982). Thermo optic deflection and switching in glass. *Appl. Opt.*.(21):.3461-3465.

M. Kawachi (1990). Silica waveguides on silicon and their application to integrated-optic components. *Optical and Quantum Electronics*. 22:391-416.

M. N. J. Diemer (1998). Polymeric Thermo-optic Space Switch for Optical Communications. *Opt. Materials*. 9: 192-200.

M. N. O. Sadiku (1992). Numerical techniques in electromagnetics. *CRC Press Inc.*

M. Stahelin, C.A. Walsh, D. M. Burland, R. D. Miller, R. J. Twieg and W. Volsen (1993). Orientation Decay in poled second order nonlinear optical guest-host polymers: Temperature dependence and effects of poling geometry. *J. Apply Phys*. 73(12): 8471.

Mario L. Lacroix and Jose A. A M. Pereire (1996). Feasibility of optical waveguide construction using polymers. *Optoelectronic*:

Mohamed ElShayeb and Yeo Kiam Beng (2000). *Applications of Finite Difference and Finite Element Methods for thermal problems.* Malaysia: Universiti Malaysia Sabah.

P. Sewell, K. Biwojno, S. Sujecki and T.M. Benson (2002). A thermal Model for Silicon-On-Insulator-Based Waveguide Modulators. *IEEE Photonic Tech. Lett.*: 151-154.

R. F. Harrington (2001). *Time harmonic electromagnetic fields* : Mc-Graw Hill.

R.J. Mears, L. Reekie, I.M. Jauncey and D.N. Payne (1987). Low Noise Erbium-Doped Fiber Amplifier Operating at 1.54μm. *Electr. Lett*. 23(19): 1026-1028.

R.L. Espinola, M.C. Tsai, J.T. Yardley, and R.M. Osgood, Jr. (2003).Fast and Low-Power Thermo-optic Switch on Thin Silicon-on-Insulator. *IEEE Photon. Technol. Lett.* 15: 1366-1368.

R. Moosburger, G. Fischbeck, C. Kostrzewa and K. Petermann (1996). Digital Optical Switch based on oversize polymer rib waveguides. *Electronic Letters*. 32(6): 544-545.

R. Noe, D. Sandel, M. Yoshida-Dierolf, S. Hinz, V. Mirvoda, A. Schopflin et al (1999). Polarization mode dispersion compensation at 10, 20, and 40 Gb/s with various optical equalizers. *J. Lightwave Tech*. 17:1602.

R. T. Chen (1993). Polymer- based photonic integrated circuits. *Optics and Laser Technology*. 25(6): 347-365.

Ralf Hauffle (2002). *Integrated Optical Switching Matrices Constructed from Digital Optical Switches Based on Polymeric Rib Waveguide*: University Of Berlin : PhD. Thesis.

Robert Blum (2003).*Characterization and applications of polymers with variable refractive index for components in optical telecommunication*: University of Hamburg, Berlin: PhD. Thesis.

S. Johansson and E. Almstrom (2001). Characteristic of Optical Communication Systems. *Fiber Optic Communication Devices*: 1-20.

S. M. Garner, S. Lee, V. Chuyanor, A. Chen, A. Yacaubian, W. H. Steir and L.R. Dalton (1999). Three dimensional integrated optics using polymers . *Journal of Quantum Electronics*. 35(8): 1146-1155.

S. T. Hanic (2003). *Propagation Effects in Optical Waveguide Fiber and Devices.* Australian National University: Phd. Thesis.

T. Pliska, J. Meier , A. Eckau, V. Ricci, A.C. Le Duff, M. Canva and G. I. Stegeman (2000). Relative resistivities and poling of nonlinear optical polymeric waveguides. *Apply Phys. Lett*. 76(3): 265-267.

Takato, N.K. Jinguji, M. Yasu, H. Toba and M. Kawachi (1988). Silica based single mode waveguide on silicon and their application to guided wave optical interferometers. *IEEE J. Lightwave Tech*. 6:1003-1010.

Timo Aalto, Yakov S. Sidorin and Ari Tervonen (2003). Fast thermo-optical switch based on SOI waveguides. *SPIE*. 4987: 149-159.

U. Fischer, T. Zinke, B.Schuppert and K.Petermann (1994).Single-mode optical switches based on SOI waveguides with large cross-section. *Electron. Letters.*30: 406-408.

U. Siebel, R. Hauffle, J. Bruns and K. Petermann (2001). Polymer Digital Optical Switch with an Integrated Attenuator. *IEEE Photon. Techn. Lett.* 13(9): 957-959.

Vittorio M. N. Passaro and Francesca Magno (2005). Investigation of thermo-optic effect and multi-reflector tunable filter/multiplexer in SOI waveguides.*Optic Express*:3429-3437.

Y. Inoue, K.Katoh and M. Kawachi (1992). Polarization sensitivity of a silica waveguide thermooptic phase shifter for planar lightwave circuits. *IEEE Photon. Technol. Lett.*4: 36-38.

Y. Ren, M . Szablewski and G. H. Cross (2000). Waveguide photodegradation of nonlinear optical organic chromophores in polymeric films. Aplly. Optics. 39(15): 2499-2506.