OPTICAL Y-JUNCTION POWER SPLITTER

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To my beloved family and friends.

.."Only those who dare to fail greatly, can ever achieve success greatly."

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ABSTRACT

In terms of performance, communication by optical fiber is potentially the most rewarding of all communications. It has been suggested that if the full potential of fiber optic communication is realized, a single fiber would be sufficient to serve the needs of telecommunication users (heavy data traffic demands) throughout the world. Fiber optics is the channeled transmission of light through hair thin glass. The explosive growth of optical networks has brought forward an increased need for guided wave optical components for the sake of multiplexing and routing. Beam splitters are a basic element of many optical fiber communication systems often providing a Y-junction by which signals separate sources can be combined, or the received power divided between two channels. The purpose of this project is to investigate how an asymmetric Y-junction behaves as a power splitter using switching function called Thermo Optic Effect. The focus is made on the polymers used for making various layers of waveguide, geometry and design parameters of waveguide which make it better than other Y-splitters. Polymers are relatively cheap starting material and can be processed from solution, which offers additional potential for cost savings compared to other technologies and also have the advantage of having large thermo optic coefficient range. The polymers used are polyurethane (thermal coefficient: -3.3 x 10^{-4} K^{-1}, thermal conductivity: -0.19 W $m^{-1}K^{-1}$) and PMMA (thermal coefficient: -1.2 x 10^{-4} K^{-1}, thermal conductivity: -0.17 W $m^{-1}K^{-1}$). The 2D thermal analysis is made on buried type waveguide. The analysis is based on how heating of one of the arms change its refractive index leading to low crosstalk, insertion loss, low driving power, coupling length and optimum switching characteristics. All simulations are done using BPM (Beam Propagation Method) and FEMLAB (Finite Element Method) software. The results from this project is a structure of Y-junction Power Splitter which is compact in size, less power consumption, low crosstalk and insertion loss by varying various parameters like branching angle, spacing between the two arms of Y-junction, refractive index change of one of the arms by means of heating phenomenon and switching temperature.

ABSTRAK

Dari segi prestasi, komunikasi melalui fiber optik berpotensi memberikan ganjaran yang paling memuaskan untuk semua komunikasi. Cadangan pernah diutarakan sekiranya potensi fiber optik direalisasikan sepenuhnya, satu fiber mungkin sudah cukup untuk menampung keperluan pengguna telekomunikasi (permintaan trafik terhadap data yang padat) ke seluruh dunia. Fiber optik adalah saluran yang menghantar cahaya melalui kaca yang nipis. Ledakan pembangunan rangkaian fiber telah membawa kepada peningkatan terhadap penggunaan komponen optikal gelombang terpandu untuk permultipleks dan laluan (routing). Pecahan cahaya adalah elemen asas dalam kebanyakan sistem komunikasi fiber optik yang menjadikan penghubung-Y boleh berfungsi menyatukan isyarat yang datang dari sumber yang berasingan atau berupaya membahagikan kuasa yang diterima antara dua saluran. Tujuan projek ini adalah untuk mengkaji bagaimana penghubung-Y bertindak sebagai pecahan kuasa dengan menggunakan fungsi pensuisan yang dikenali sebagai Kesan Kepanasan Optik. Penekanan diberikan kepada penggunaan polimer dalam penghasilan kepelbagaian lapisan gelombang pandu, serta geometri dan parameter rekabentuk gelombang pandu yang mana menjadikan ia lebih baik berbanding penghubung-Y yang lain. Polimer merupakan material pengasas yang murah, yang mana berpotensi dalam penjimatan kos berbanding teknologi yang lain, dan juga memberikan kelebihan dengan mempunyai had pekali kepanasan optic yang besar. Polimer yang digunakan adalah poliureten (pekali kepanasan: -3.3×10^{-4} K^{-1}, kealiran kepanasan: -0.19 W $m^{-1}K^{-1}$) dan PMMA (pekali kepanasan: -1.2×10^{-4} K^{-1}, kealiran kepanasan: -0.17 W $m^{-1}K^{-1}$). Analisis kepanasan 2D akan dilaksanakan ke atas gelombang pandu yang tersembunyi. Analisis ini dibuat berdasarkan kepada bagaimana pemanasan pada satu lengan mengubah indeks pembiasan yang kemudiannya membawa kepada perbicaraan bersilang yang rendah, kehilangan penyisipan yang rendah, kuasa terpandu yang rendah, panjang perangkai dan ciri-ciri pensuisan optimum. Semua simulasi dilakukan menggunanakan perisian BPM (kaedah penyebaran cahaya) and FEMLAB (Keadah Elemen Terhad).

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A	-	contact area
C	-	heat capacity
d	-	waveguide arm spacing
K	-	thermal coupling estimation
k	-	thermal conductivity
H	-	distance from heater to waveguide core
h	-	thickness of core arm
L	-	Length of device
η	-	refractive index
Q	-	rate of heat flow
t	-	thickness of the substrate
W	-	Heater width
w	-	Core arm width
β	-	propagation constant
μ	-	relative permittivity
Δ	-	temperature ratio difference
Φ	-	change in polarizabilty with temperature

Θ	-	incident angle
λ	-	wavelength
ρ	-	density capacity
ε	-	relative capacity
γ	-	coefficient of volume expansion
L_d	-	Distance of symmetry in waveguide

CHAPTER 1

INTRODUCTION

1.1 Objective Of This Project

Today, optical network is developing rapidly as growing capacity demand in telecommunication system is increasing. Optical transmission systems are typically running at data rates of 2.5Gbits/s or 10Gbits/s per channel. There are many advantages for designing switching elements using optical components. These advantages include decreased switching time (less than 1/10 of a pico second (1012)), less cross talk and interference, increased reliability, increased fault tolerance, enhanced transmission capacity, economical broadband transport network construction, enhanced cross-connect node throughput, and flexible service provisioning.

There exists a demand of combining information from separate channels, transmission of the combined signals over a single optical fiber link and separation of the individual channels at the receiver prior to routing to their individual destinations. Hence, the application of integrated optics in this area is to provide optical methods for multiplexing, modulation and routing. More recently, interest has grown in these devices to divide or combine optical signals for application within optical fiber information system including data buses, local area networks, computer network links and telecommunication access networks. These functions may be performed with a combination of optical beam splitters, switches, modulators, filters, sources and detectors.

Beam splitters are a basic element of many optical fiber communication systems often providing a Y-junction by which signals from separate sources can be combined, or the received power divided between two or more channels. The objectives of this project are, therefore:

- Model formulation of Y-junction which involves study of Y-junction geometry, which makes it better than other beam splitters. To study how the length of switch effects the operation and behavioral characteristics of switch.
- Generation of Electric field modes within the waveguide.
- Simulation of propagation of light through Y-junction.
- Other optimum configurations like:
    - Branching /Opening angle formed exactly at the junction of Y-channel.
    - Switching characteristics like switching temperature, switching power, switching functions(Thermo optic effect, Acoustic optic effect, magneto optic effect, electro optic effect etc)
    - Power consumption meaning how much power is required for thermal

coupling to occur.

- Low crosstalk in Y-junction for lossless transmission through it.

1.2 Scope Of This Project

The aim of this project is twofold. Firstly, to study the effect of temperature on the refractive index of the thermo-optic waveguide. The waveguide is heated by means of a thin electrode which is placed on one of the channels of Y-junction. The electrode leads to heating of one of the channels of Y- junction, in turn changing the density of polymer, increasing the polarizability and variation in optical path from one channel to other of Y-junction. In this project, the buried waveguide is considered and the phenomenon of thermo coupling will be studied seriously.

The second investigation is to gain insight of the various design parameters of the Y-channel power splitter. Here, we would determine how by varying he opening/branching angle between to arms of Y-channel

- Effect the total length of the power splitter.
- Effect the power transmission in two channels of Y-junction.

The efforts will be made to keep the size of Y-junction power splitter small. However, very short switch can lead to worst cases of crosstalk of about 2.25dB (which in turn indicates the influence of interferometer effects on the device).All simulations are done by means of software named MATLAB and BPM.

1.3 Problem Statement

The use of visible optical carrier waves or light for communication has been common for many years. Simple systems like signal fibers, reflecting mirrors and signaling lamps have provided successful information transfer. The communication using optical carrier wave guided along a glass fiber has a number of extremely attractive features, several of which were apparent when the technique was originally conceived. These features include enormous potential bandwidth, small size, and weight, electrical isolation, low transmission loss, signal security, reliability, flexibility, potential low cost etc.

Due to these enormous features of Optical fiber communication in comparison to conventional electrical communication, there is seen an increase in the complexity of Optical modules. So, the demand of time is to provide structure that have below mentioned features.

Firstly, Optical device with simple compact structure meaning small in size and less in weight. The industry will need to more to new technologies, such as flip chip instead of wire bond and multi chip modules to reduce package size. Secondly, there exists a need to keep the excess loss associated to Optical module very low so that the obtained output power is approximately equal to the input power. Next is the demand to manufacture Optical structures with less polarization dependence. However, this can be achieved by making using of an appropriate switching function like thermo-optic effect which is polarization insensitive and can be easily implemented by usage of electrically driven by micro heaters. Finally, the Optical module should be such which can provide NxN structure for power splitting and combining if required. Sometimes a switching unit does not provide the desired value of some parameter; the Optical module must be such that by cascading it into various stages, the problem is overcome. For instance, if the crosstalk of a single 1x2 switching unit(for example, a DOS) is not sufficient, it can be improved by cascading several of these devices and thereby multiplying the crosstalk(in dB) by the number of cascaded stages.

This project use polymer material to build Optical waveguide. Since polymer has large range of thermo- optic coefficient, we will apply the thermo optic effect to overcome the above stated problem statement.

1.4 Project Background

The term Integrated Optics came into being since 1969 and was first discovered by Miller. The concept of Integrated Optics involves the realization of optical and electro-optical elements which may be integrated in large numbers on to a single substrate. The need of Integrated Optics is there because most of the equipments today are still based on electronic signals meaning that optical signal has to be converted first into electrical signal, amplified, regenerated or switched and then reconverted to optical signals. It is called Optical-to-Electronics-to-Optical (OEO) conversion. This is well explained in Chapter 3.

There are two major kinds of Integrated Optical Switch namely, Interferometer switch like Directional Coupler, Mach Zehnder etc and Digital Optical switch. For the concern of this project we consider DOS because of it's low polarization and wavelength insensitivity. Also unlike Interferometer switches, DOS doesn't require tight control of biasing condition and less sensitive to heat.

With the beginning of Integrated Optics many waveguide fabrication techniques have been proposed and used to form various optical waveguides on a variety of substrates. The great variety of potential applications for integrated optical devices have spurred intensive investigation of a large number of waveguide as well as substrate materials over the past two decades. Initially, semi conductive substrates were studied in the hope of facilitating easy interface with microelectronic or optoelectronic components. Glass substrates were investigated with intended applications as advance passive fiber-optical components. Electro-optical crystal substrates were explored for the development of optical switches, modulators, and optical signal –processing devices. Non linear optical materials were studied in the attempts to make high efficiency optical harmonic generators. But none of them fulfill all desirable criteria at the same time. An interesting alternative is polymers which offer some unique advantages.

Polymers are a relatively cheap starting material and can be processed from solution, which offers additional potential for cost savings compared to other technologies. Besides this polymers have wide range of refractive index from (-1×10^{-4} K^{-1} to -4×10^{-4} K^{-1}) which leads to power efficient dynamic components. 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 1310nm and 1550 nm(John M. Senior, 1992).At present polymers find their application widely in optical communication devices like switches, couplers, filters, attenuators, polarization, controllers, dispersion compensators, modulators, laser and amplifiers. Polymer materials have proved to have satisfactory light-guiding characteristics. In principle, it is possible to achieve low optical loss(infrared), high thermal and environmental stability, high thermo optic effects, low thermal conductivity, good adhesion to metals and silica, and refractive index tailoring.

Furthermore modifying the chemical structure or doping the polymers with guest molecules can tune the physical properties far simpler than in the case of semiconductors or dielectrics. Polymers with different functionalities can be integrated on the same chip and offer a versatile platform. Additionally, the processing of polymers is usually compatible with semiconductors or dielectrics, which allow hybrid integration.

Table 1. Some of the typical properties of waveguide material used in integrated optics is mentioned in the tabulated form.

	Propagation Loss(dB/cm)	Refractive Index	Index Contrast(η_{cor} η_{clad})/(η_{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}	**1.8x10^{-4}**	1kHz(TO)
Polymers	0.1	1.3-1.7	0-35%	10^{-6}-10^{-2}	**-1x10^{-4} - 4x 10^{-4}**	1kHz(TO)
Lithium Niobate	0.5	2.2	0-0.5%	10^{-2}-10^{-1}	10^{-5}	40GHz(EO)
Indium Phosphide	3	3.1	0-3%	10^{-3}	**0.8x10^{-4}**	40GHz(EO)

Furthermore modifying the chemical structure or doping the polymers with guest molecules can tune the physical properties far simpler than in the case of semiconductors or dielectrics. Polymers with different functionalities can be integrated on the same chip and offer a versatile platform. Additionally, the processing of polymers is usually compatible with semiconductors or dielectrics, which allow hybrid integration. Polymer materials have proved to satisfy specific applications and are thus of wide interest nowadays.

In this project we consider Polyurethane as core material (η_1= 1.573) and Polymethylmethacrylate as cladding (η_3 = 1.49 to 1.56). The Thermo optic effect will be studied over the refractive index of core in this project and also Thermo coupling of power in the two channels of Y-channel.

1.5 Overview Of This Project

This part of Introduction provides the work frame of Project 1. This report consists of four Chapters including the Introduction.

Chapter2 holds the discussion about the phenomenon of light traveling through a waveguide. Here, the propagation of light wave is expressed in terms of Maxwell Equations. The various types of Optical waveguides are discussed. However, for this project we consider buried type waveguide.

Chapter3 involves the methodology of the project. Here, the Operational principle of thermo-optic waveguide is discussed. There are certain numerical methods (formulas) which describe the relationship between many light propagation parameters and further used for simulation purpose.

Chapter 4 is about the design and geometry of Optical Y-junction power splitter. Chapter 5 holds the simulations for this project. All the results are produced using FEMLAB and BPM software. Future work for this project is discussed in Chapter 6.