Polymer Material for Optical Devices Application

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Abstract - In this paper, an overview of polymer material in optical waveguiding technology is presented. This include a review on the type of polymer being used worldwide in the development of optical devices, track record and performances of polymer based optical devices successfully being developed as compared to other optical materials and also on the external field control of the polymer material for active devices application. Further discussion will then include the current research in polymer based optical waveguiding technology held in our Photonic Research Group together with possible development and commercialization.

Keywords: Polymer material, optical devices, external field control

1. Introduction

Integrated optics are having an increasing impact on the development of lightwave communication systems with applications such as high speed broadband switching and high speed interconnects for local area network. It has been recognised that integration can enhance the overall system performance, improve the compactness, reliability and yield of components and simplify the packaging and assembly thus reducing the cost of manufacturing. Perhaps, the major performance of integrated optics rely on the waveguiding component. Many materials are currently being investigated for constructing passive and active integrated optic waveguide circuits and devices. Such materials and their properties are summarized in table 1 in Appendix A [1]. However, the demand in optical networking for photonic components that meet performance criteria as well as economic requirements has opened the door for novel technologies capable of high yield low cost manufacturing while delivering high performance and enabling unique functions.

Of that matter, polymer material has been widely accepted as a new generation material for optical integrated circuit due to its various advantages as compared to other optical materials. This paper is arranged as follows. Section 2 will state advantages of polymer materials on its applicability in the optical waveguiding purpose. Section 3 will focus on type of polymer material currently being used worldwide for the development of optical waveguide and devices. This will include both passive and active application. Current research on polymer material at Photonics Research Group of University Technology Malaysia (PRG-UTM) are described in section 4. Conclusion remarks will be given in section 5.

2. Polymer Materials

Most optical materials has been widely being used as a leading materials technology for application in integrated optics technology due to their certain unique advantages. For example, low-loss and high temperature stability exhibited by silica-on-silicon material [2], wide wavelength range of transparency and large electro-optic (EO) coefficient of $LiNbO_3$ [3] and tunability of material band gap energy over a wide range for the purpose of monolithic optical integration circuit of III-V and II-VI ternary semiconductor compounds [3]. However, certain drawbacks of these materials may then fueled research in polymer material system where selected polymer material can provide much advantages [1]-[3]. With regard to table 1, it can be deducted that polymer is the material of choice for integrated optics because, when synthesized and processed properly, it offers high performance in terms of low-loss, smaller

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birefringence, high tunability in terms of large thermo-optic (TO) coefficient, environmentally stable, high yields and low cost.

One of the important aspect for reliable optical material is low loss. Considering 3 major types of losses, i.e. absorption loss, scattering loss and radiation loss, polymers can be specially processed to exhibit low loss characteristics. According to Eldada [4], optical polymers can be highly transparent with absorption loss value below 0.1 dB/cm at all key communication wavelengths (840, 1310 and 1550 nm). Low scattering loss can be obtained by selecting proper fabrication technologies with excellent process control [5]. As opposed to silica technologies, polymer technologies can be designed to form stress free layers regardless of substrate composition which may then eliminate the problem of stress-induced scattering loss and stress-induced polarization effects [4]. Research by Shacklette et. al. [2] shows that several low loss characteristics such as low absorption loss, low loss through L band and low birefringence and polarization dependent loss (PDL) can be achieved by proper processing of polymer material.

The environmental stability of optical polymers (i.e. the stability of their optical and mechanical characteristics with temperature and humidity) is an important issue because most polymers do not have properties that are appropriate for operation in communication environments. However, extensive material research has yielded polymers that having high thermal stability [2] which is a great advantage in integrated optics technologies. Another important aspect is the refractive index tunability for the active device application. As polymers are having a large negative TO coefficient, which is 10-40 times larger than conventional optical materials such as silica, it results in low-power consumption thermally actuated optical elements.

From this discussion, it greatly reflects the applicability of polymer materials in integrated optics technology. The next section will then describe type of polymers being used and its commercial/prototype deployment.

3. Polymers and Devices

Optical polymers were engineered in many laboratories worldwide. Classes of polymers used in integrated optics include acrylates, polymides, polycarbonates and olefins (e.g. cyclobutene) [6]. These polymers may then divided into photosensitive and non-photosensitive which differs in fabrication technologies to realize the optical components. These type of polymers have been widely being used by researchers all around the world in fabricating both passive and active optical devices and components.

For passive components, several works have been reported. Amongst are multimode waveguide using UV curable resinas cor layer and PMMA as cladding layer [7], low loss optical waveguide with high thermal stability using polysiloxane [8], single mode waveguide using cyclotene polymer [9][10], single mode waveguide using perfluoropolymer [11], passive directional coupler using fluorinated polymide [12] and heat resistant single mode optical waveguide using fluorinated polymides [13].

Taking advantage of high TO coefficient for polymer, many works have been recorded on the development of polymer based active devices. For example, 2x2 digital optical switch based on TO effect using PMMA material [14], 1x8 digital TO switch and TO tunable filter using thermally controlled AWG [15], 4x4 TO directional coupler switch using PMMA [16], S-shape 1x2 TO switch using cyclotene polymer [17] and 2x2 directional coupler TO switch using acrylate polymer [18], just to name a few.

Motivated from this wide application of polymer material, our research in Photonics Research Group of University Technology Malaysia (PRG-UTM) is emphasized towards the development of optical components based on polymer material. The next section will describe on our current group tasks.

4. Research in PRG-UTM

Works on polymer material had been started in PRG-UTM since the last five years. Our specific approach is more towards the processing and fabrication of polymer based optical component using a chemical wet-etching techniques. The most important reason of directing towards this approach is because of low cost in terms of material processing while giving moderate, acceptable and workable performance of optical components. Several works have been done by our researchers using HD4000® polymide from HD MicroSystems Corp. The details on these works can be found elsewhere [19]. Apart from this polymide type polymer, the research is also dedicated towards the optical device development using CYCLOTENE ™ BCB-4024 photosensitive wet etching polymer from DOW® Chemical Company. Motivated from the future prospects of this polymer, works are actively carried out on the characterization of this polymer such as refractive index value at major optical wavelengths, film thickness characterisation at different spinning speed, loss measurement at major optical wavelength and thermo-optic coefficient measurement. These characterization process is very important in the future realization of optical devices. Using Optical Crown Glass (OCG) at 1.5000 of bulk refractive index as the material substrate, we manage to fabricate a slab and straight waveguide structure, in which both are being used in the characterization process. To produce a good quality waveguide, the fabrication processes is the most critical factor and need to be monitored carefully. With all the knowledge, skills and experiences that the researchers gain from this learning processes, the group is looking forward to be one of the major contributor in the research and development of photonics field in the country.

5. Conclusions

The paper has chronologically explained the research on polymer material in photonics device application. The discussion include comparisons with other optical materials, type of polymers being widely used in photonics application, succesfully developed passive and active device using polymers and finally the current research trend in PRG-UTM.

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Appendix A

Table 1: Properties of optical materials at 1550 nm optical wavelegth.

	Propagation Loss (dB/cm)	Pigtail Loss (dB/chip)	Refractive Index (n)	Birefringence ($n_{TE} - n_{TM}$)	Thermo-Optic Coefficient dn/dT (K^{-1})
Silica [SiO_2]	0.1	0.5	1.5	$10^{-4} - 10^{-2}$	10^{-5}
Silicon [Si]	0.1	1.0	3.5	$10^{-4} - 10^{-2}$	$1.8x10^{-4}$
Silicon Oxynitride [SiO_xN_y]	0.1	1.0	SiO_2 : 1.5 Si_3N_4 : 2.0	$10^{-3} - 5x10^{-6}$	10^{-5}
Sol-Gels	0.1	0.5	1.2-1.5	$10^{-4} - 10^{-2}$	10^{-5}
Polymers	0.1	0.5	1.3-1.7	$10^{-6} - 10^{-2}$	$-1 \rightarrow -4x10^{-4}$
Lithium Niobate [$LiNbO_3$]	0.5	2.0	2.2	$10^{-2} - 10^{-1}$	10^{-5}
Indium Phosphide [InP]	3	10	3.1	10^{-3}	$0.8x10^{-4}$
Gallium Arsenide [GaAs]	0.5	2.0	3.4	10^{-3}	$2.5x10^{-4}$