American J. of Engineering and Applied Sciences 2 (1): 127-132, 2009
ISSN 1941-7020
© 2009 Science Publications

The Polishing of Cutting-Edge Polymer-on-Glass for Pigtailing Preparation

Mohammad Syuhaimi Ab-Rahman, Fazlinda Ab-Aziz, Noor Azie Azura Mohd Arif,
Saiful Dzulkefly Zan and Seri Mastura Mustaza
Department of Electrical, Electronic and Systems Engineering,
Computer and Network Security Research Group,
Faculty of Engineering and Built Environment, University Kebangsaan Malaysia
43600 UKM Bangi, Selangor, Malaysia

Abstract: Problem statement: The high quality of cutting-edge surface is important in optical waveguide's efficiency. The perfect polishing of end surface is significant to deliver the best quality of light waves and minimize the device losses such as insertion loss and return loss. Hence, this research is concern on the parameters in polishing SU-8 polymer to increase the efficiency of waveguide. The main research is to study on how polishing parameter affect the cut length of the end surface of SU-8 polymer on silicon and determining the best parameters for polishing SU-8 polymer. **Approach:** Seven sets of rotation velocities were chosen which were 50, 100, 150, 200, 250, 300 and 350 rpm for the first part. The graph of cut length versus velocity at different sand paper size was plotted based on the data obtained from this experiment. Equation for each graph was acquired to determine relationship between these two parameters. For the second part, four samples were used. Each sample was polished with same rotation time and sandpaper size prescribed but with different rotation speed. Rotation speed is selected between 200 to 350 rpm with rotation time of 15 min using sandpaper with size of 0.3 µm. **Results:** We found that the cut percentage of each rotation velocity are as follows: 50 rpm: ≤0.5%, 100 rpm: 0.6-1.0%, 150 rpm: 3.8-4.8%, 200 rpm: 7.7-10.6%, 250 rpm: 15.7-18.3%, 300 rpm: 25.6-27.4%, 350 rpm: 40.0-43.7%. The rotation speed suitable for polishing SU-8 polymer is below 200 rpm and the rotation speed over the point (ex. 300 rpm) will cause cracking to the polymer although the silicon based layer look smooth. **Conclusion:** In this experiment it was found that the cut length increases as the rotation rate and the size of sand paper increased. It can also be concluded that polishing the sample at the speed of 200 rpm is the best polishing method for polymer SU-8 waveguide, at 15 min rotation time with the used of 0.3 µm Aluminium oxide sandpaper size. Despites giving the smooth surface, it also reduces the cutting time. The SU-8 polymer is not suitable to be polished at a high rotation speed as the surface may damage.

Key words: Waveguides polishing, SU-8 polymer, silicon substrate, rotation speed, sandpaper, length of cut

INTRODUCTION

Optical waveguide plays an important role in future high speed data transmission with speed as fast as light for transmission in vacuum medium. Nevertheless, the waveguide's efficiency is influenced by the surface structure of its side end. The best surface quality is needed for the alignment process between the fiber optic and the waveguide to increase the efficiency of fiber optic interface and waveguide. This shows that the polishing process is needed to optimize the performance and efficiency of the waveguide. A good polishing process shall optimize the performance and efficiency of the waveguide. Hence, this research is conducted to study on how the polishing parameters affect the surface structure of SU-8 polymer on silicon's side end and to find for the best polishing method in obtaining a smoother surface structure. The polishing process is a pre-process which is compulsory to align waveguide with the fiber.

The main demand of technological developments in this area is the fabrication of low-cost components for networks with high data rates[6]. Polymer waveguides have a potential of achieving the economic

Corresponding Author: Mohammad Syuhaimi Ab-Rahman, Department of Electrical, Electronic and Systems Engineering, Computer and Network Security Research Group, Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

requirement for low priced optical devices and of applying novel active devices. The developments of the polymer waveguide materials and their applications have been investigated since 1990s. The remarkable progress on the polymer waveguides is expected to realize the acceptance of polymer devices in optical communication network[4]. The polymer material enhances the production development of photonic circuits on a substrate planar[1]. Polymer based integrated fiber optic which contains passive and active elements are used in various coupling, routing, filtering and switching function. The manufacturing process of the polymer waveguide is easier and faster compared to the process of producing the silicon waveguide. Usually, the silicon waveguide production takes time and involves numerous fabrication processes. The result is unsatisfactory and damaging the stress-induced birefringence[2].

Optical-thermal constant is the key to polymer application. Optical polymers are soft and possess high linear expansion coefficients and poor thermal conductivities[7]. Polymer have a large negative optical-thermal constant ($dn/dT = -1\times10^{-4} \sim -4\times10^{-4}$) which is ten to forty times higher than the usual optical materials such as glass[9]. The transparent characteristic of optical polymer is very high with absorption loss of below 0.2 dB cm^{-1} along the communication wavelength (840, 1310 and 1550 nm)[1]. Dispersion loss in polymer waveguide can be minimized by optimizing the etching method during waveguide fabrication. Opposite from the glass planar technology, the polymer technology can be designed to produce an independent layer without calculating the substrate composition, which usually consists of glass, quartz, plastic, or circuit board with epoxy-filled glass.

With several important recent advances, polymers are fast in becoming an important material for optoelectronics. Considerable interest have been focused on SU-8 polymer waveguides due to its advantages of low temperature for fabrication process, ease of control on optical and mechanical properties and possibility of mass production. Significant examples include mechanically flexible ‘electronic paper’ and high efficiency light-emitting diodes based on electroluminescent conjugated polymers[10]. In addition to those, the wet coating process of the polymer waveguides allows fabrication at large areas, which will be utilized for the application of the optical interconnection[4]. Furthermore, the polymer materials can provide novel functionalities such as Thermo-Optic (TO) and Electro-Optic (EO) properties and have potentials of high speed optical switches and modulators with a low driving voltage[4,8].

In this study, we review a polymer waveguide material that is SU-8 polymer. SU-8 polymer has many advantages compare to other types of polymer. SU-8 is sensitive towards electron beam. Due to this characteristic, some of the finest devices are made out of this material. It has been applied in Micro-Electromechanical (MEMS) system, SU-8 Photoresistance (PR) and integrated Mach-Zehnder interferometer[5].

Polishing optical device: Optical device plays an important role in communications. End surface is polished perfectly so that it can deliver the best quality of light waves. By such, polished devices must fulfill the quality and specification which has been prescribed. Among the matters that need to be emphasized during the polishing process to achieve a quality polishing system is the movement or the position of surface material. If the optic material is not at equilibrium point while polishing, it would affect the device quality. Apart from that, manufacturing cost would rise due to the damage of the device and a waste in the sandpaper usage or any other material used to polish the device. A good polishing process should be carried out in circular or rotation form to obtain the best quality[3].

MATERIALS AND METHODS

This part describes the polishing process and outlines the flow of the process. Material used in this experiment was SU-8 polymer based planar waveguide with silicon acting as substrate. For the first part, our study focuses on how polishing parameter affect the cut length of the end surface of SU-8 polymer on silicon. Three samples were used to obtain the polishing rate as tabulated in Table 1. Samples were taken from the same material and differentiated based on the experiment parameters. The main parameter studied in this experiment was the rotation velocities. Seven different values used were 50, 100, 150, 200, 250, 300 and 350 rpm. Three sizes of sandpaper were used with surface coarseness of 1, 0.5 and 0.3 µm. Then, set 1-4 were polished with the selected rotation speed at 200, 250, 300 and 350 rpm respectively for determining the best polishing method. The process in second part started with sorting out all samples according to set.

Table 1: Samples of the experiment

Sample	Size of sandpaper (µm)	Rotation time (min)			
1	1.0	5	10	15	20
2	0.5	5	10	15	20
3	0.3	5	10	15	20

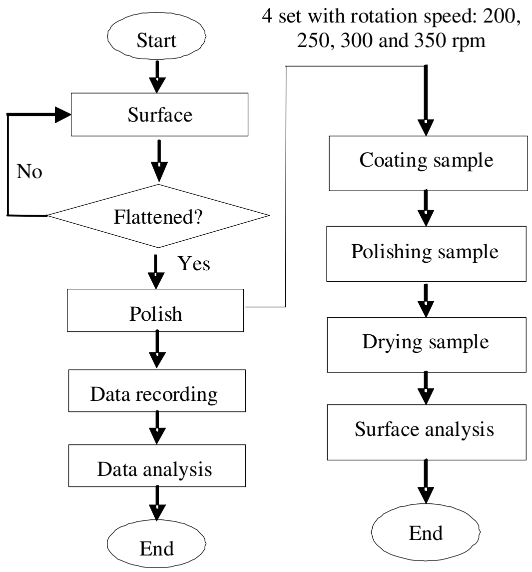


Fig. 1: Flow chart for the stage involved in the polishing process and the data analysis.

Each set was rotated for 15 min. Aluminum oxide sandpaper with the size of 0.3 µm was used in the polishing process. To dry the sample, the rotated sample was sticked to the aluminum stub and fully dried in oven at temperature of 35°C. Then, the dried sample was placed into the wrapping machine for 3 min. An aurum film was spread on the sample's surface. Finally, the aurum coated sample was placed into SEM to observe the surface's quality of each sample. Figure 1 simplifies the whole process in a flow chart.

Flow chart: Flow chart in Fig. 1 shows the process or stages to obtain the polishing rate of SU-8 polymer waveguide on silicon substrate.

RESULTS

Data obtained from the experiment of finding the polishing rate of the SU-8 polymer waveguide on silicon substrate was gathered and tabulated. Graph of the polishing rate versus velocities for all three samples was plotted. Table 2-4 show the changes in the cut length of the waveguide during the polishing process using sandpaper of the size of 1.0, 0.5 and 0.3 µm respectively for 5, 10, 15 and 20 min.

The excised waveguide produces a rugged surface as shown in Fig. 5a. This surface structure was flattened by using aluminum oxide sandpaper with size 16 µm. After being flattened, the waveguide surface is as shown in Fig. 5b. The difference of the surface side waveguide before and after polishing can be clearly distinguished.

Table 2: Polishing rate of sample 1 toward velocity by using sandpaper of size 1.0 µm

	Cut length (µm)			
Rotation velocity (rpm)	5 min	10 min	15 min	20 min
50	4	10	15	20
100	9	22	31	38
150	43	100	152	180
200	95	184	275	372
250	177	350	506	671
300	275	562	840	1106
350	464	925	1400	1850

Table 3: Polishing rate of sample 2 toward velocity by using sandpaper of size 0.5 µm

	Cut length (µm)			
Rotation velocity (rpm)	5 min	10 min	15 min	20 min
50	0	3	5	6
100	5	10	15	18
150	20	45	65	87
200	45	89	132	163
250	86	175	250	349
300	145	288	426	580
350	230	450	685	912

Table 4: Polishing rate of sample 3 toward velocity by using sandpaper of size 0.3 µm

	Cut length (µm)			
Rotation velocity (rpm)	5 min	10 min	15 min	20 min
50	0	1	2	4
100	3	4	7	11
150	15	30	46	55
200	33	64	100	127
250	50	110	165	228
300	81	173	252	320
350	130	255	394	504

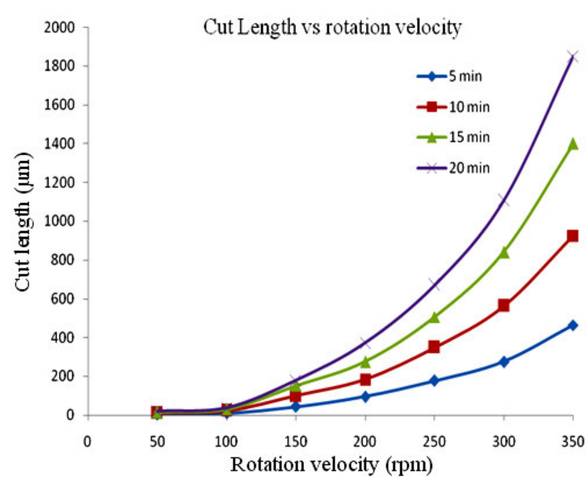


Fig. 2: Graph of cut length vs. rotation velocity using sandpaper of size 1.0µm

Figure 5c shows the side end surface for the excised waveguide after polishing. The polymer layer and silicon layer are focused in the surface analysis. The surface waveguide for set 1 to set 4 were zoomed in at 2000 times by SEM as shown Fig. 6 and 7.

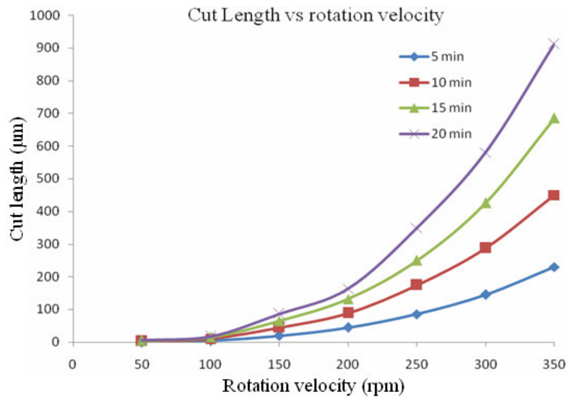


Fig. 3: Graph of cut length vs. rotation velocity using sandpaper of size 0.5µm

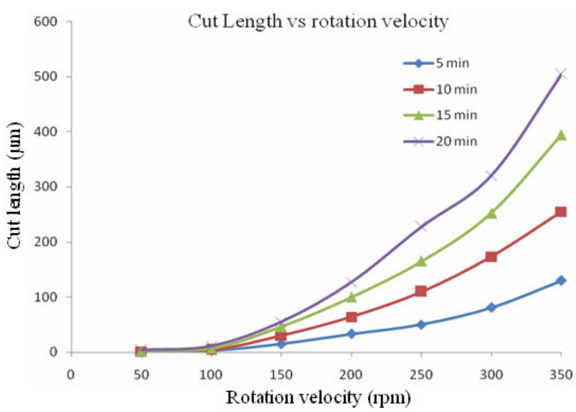
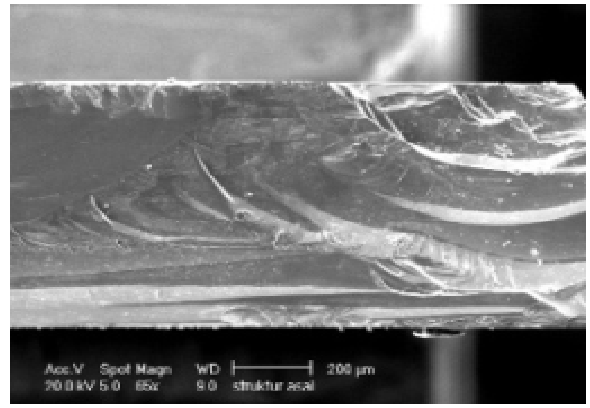


Fig. 4: Graph of cut length vs. rotation velocity using sandpaper of size 0.3µm

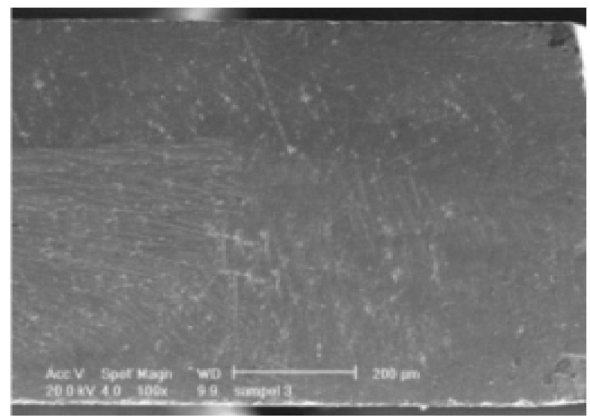
DISCUSSION

During this experiment it was found that the cut percentage of each rotation velocity are as follows: 50 rpm: ≤0.5%, 100 rpm: 0.6-1.0%, 150 rpm: 3.8-4.8%, 200 rpm: 7.7-10.6%, 250 rpm: 15.7-18.3%, 300 rpm: 25.6-27.4%, 350 rpm: 40.0-43.7%. Based on Fig. 2-4, the graph of cut length versus rotation velocity, it was found that the cut length increases as the rotation rate increased. The equation of the curve was obtained using Microsoft Excel. Table 5-7 are the outcomes of the analysis of all three samples.

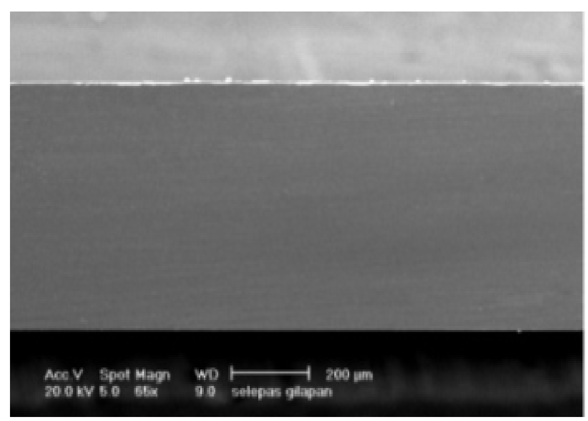
Set 1 shows the surface of the polymer SU-8 layer on top of silicon layer polished with rotation speed at 200 rpm. The surface of the silicon and polymer look smooth. The boundary line between the silicon and polymer is not affected by the speed of the polisher. This means that rotation speed 200 rpm is suitable for both silicon and polymer. While the polishing result for waveguide of set 2 with rotation speed of 250 rpm is shown in Fig. 6b. The polymer surface is less smooth than silicon surface. There are small cracks which can be seen at the upper side of the polymer layer.



(a)



(b)



(c)

Fig. 5: Cut end surface for the (a): Excised waveguide; (b): Excised waveguide after flattening; (c): Excised waveguide after polishing

Table 5: Result of analysis for sample 1

	Equation			
	$y = 0.0051x^2$ $-0.5292x$	$y = 0.0101x^2$ $-1.0118x$	$y = 0.0154x^2$ $-1.5912x$	$y = 0.0205x^2$ $-2.153x$
	Total cut			
Rotation velocity (rpm)	1067 µm	2153 µm	3219 µm	4237 µm
	Cut (%)			
50	0.4	0.5	0.5	0.5
100	0.8	1.0	1.0	0.9
150	4.0	4.6	4.7	4.2
200	8.9	8.5	8.5	8.8
250	16.6	16.3	15.7	15.8
300	25.8	26.1	26.1	26.1
350	43.5	43.0	43.5	43.7

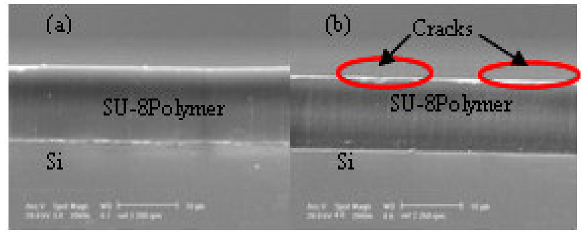
Table 6: Result of analysis for sample 2

	Equation			
	$y = 0.0026x^2$ $- 0.2796x$	$y = 0.005x^2$ $- 0.5046x$	$y = 0.0077x^2$ $- 0.8209x$	$y = 0.0104x^2$ $- 1.1085x$
	Total cut			
Rotation velocity (rpm)	531 µm	1060 µm	1578 µm	2115 µm
	Cut (%)			
50	0.0	0.3	0.3	0.3
100	0.9	0.9	1.0	0.9
150	3.8	4.2	4.1	4.1
200	8.5	8.4	8.4	7.7
250	16.2	16.5	15.8	16.5
300	27.3	27.2	27.0	27.4
350	43.3	42.5	43.4	43.1

Table 7: Result of analysis for sample 3

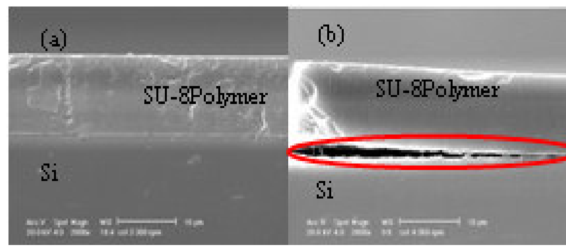
	Equation			
	$y = 0.0014x^2$ $- 0.1186x$	$y = 0.0027x^2$ $- 0.2153x$	$y = 0.0041x^2$ $- 0.3352x$	$y = 0.0052x^2$ $- 0.4036x$
	Total cut			
Rotation velocity (rpm)	312 µm	637 µm	966 µm	1249 µm
	Cut (%)			
50	0.0	0.2	0.2	0.3
100	0.9	0.6	0.7	0.9
150	4.8	4.7	4.8	4.4
200	10.6	10.0	10.4	10.2
250	16.0	17.3	17.1	18.3
300	26.0	27.2	26.1	25.6
350	41.7	40.0	40.8	40.3

However, boundary line of the silicon and polymer layer is still not affected. This shows that rotation speed of 250 rpm is still fit to polish silicon surface but not suitable on the polymer surface. Figure 7 a shows the set of silicon waveguide with polymer SU-8 layer polished at rotation speed of 300 rpm. The silicon surface looks smooth, but the polymer surface has damaged with cracks and rugged surface.



(a) (b)

Fig. 6: Waveguide Surface for (a): Set 1; (b): Set 2



(a) (b)

Fig. 7: Waveguide surface for (a): Set 3; (b): Set 4

However, boundary line between silicon and polymer is still not affected. This shows that rotation speed 300 rpm still fits for silicon but not suitable to be used on the polymer surface. Observation from waveguide set 4 in Fig. 7 b shows that polymer is no longer interlocked with silicon. Hence, polishing with rotation speed 350 rpm is not suitable to be used for silicon waveguide with a polymer SU-8 layer

CONCLUSION

In summary we would like to point out that the properties of a polished type SU-8 polymer are considerably affected by the rotation speed, rotation time and sandpaper size. From the experiment conducted, it can be concluded that the cut percentage of each rotation velocity increases as the rotation rate increased. The percentage ranges of the cut obtained are for the polishing process using sandpaper of Aluminum Oxide with the size of 1.0 µm, 0.5 µm and 0.3 µm. Therefore, the percentage usage has to take into account the size of sandpaper used. High rotation velocity has the advantage of cutting short the polishing time but with the cost of surface quality and causing various losses in waveguide. It also can be concluded that polishing the sample at the speed of 200 rpm is the best polishing method for polymer SU-8 waveguide, at 15 min rotation time with the used of 0.3 µm Aluminum oxide sandpaper size. Despites of giving the smooth surface, it also reduces the cutting time. The SU-8 polymer is not suitable to be polished at a high rotation speed as the surface may damage.

ACKNOWLEDGEMENT

The researchers would like to thank the Photonic Technology Laboratory in Institute of Microengineering and Nanoelectronic (IMEN), Universiti Kebangsaan Malaysia for their technical supporting on optical measurement of the materials and the devices.

REFERENCES

1. Eldada, L., 2002. Polymer integrate optics: Promise vs. practicality. Proc. SPIE., 4642: 11-22. http://adsabs.harvard.edu/abs/2002SPIE.4642...11E.
2. Hunsperger, R.G., 1995. Integrated Optics: Theory and Technology. 4th Edn., Springer Berlin Heidelberg, Publisher, ISBN: 978-3540594819, pp: 367.
3 Rubin, R., 2003. Fiber optic connectors: Meeting polishing demands. http://www.ultratecusa.com/PDFlibrary/Fiber-Photonics11-03.pdf.
4. Tamaki, K., H. Takase, Y. Eriyama and T. Ukachi, 2003. Recent progrees on polymer waveguide materials. J. Photopolym. Sci. Technol., 16: 639-648. http://www.jstage.jst.go.jp/article/photopolymer/16/5/16_639/_article.
5. Pelletier, N., B. Beche, N. Tahani, L. Camberlein, E. Gaviot, A. Goullet, J.P. Landesman and J. Zyss, 2005. Integrated mach-zehnder interferometer on SU-8 polymer for designing pressure sensors. Sensors, 3: 640-643. DOI: 10.1109/ICSENS.2005.1597780.
6. Frese, I., U. Schwab, E. Nahrstedt, T. Klotzbuecher, S. Kunz, U. Teubner and T. Doll, 2006. Polymer based optical interconnect component for high speed datacom approaches-micromachining supported manufacturing. Opt. Commun., 265: 434-440. DOI: 10.1016/J.Optcom.2006.03.064.
7. Degroote, J., 2003. Polishing PMMA and other optical polymers with magnetorheological finishing. Proc. SPIE., 96: 239-249. http://adsabs.harvard.edu/abs/2004SPIE.5180..123D.
8. Ziemann, O. and P.E. Zamzow, 2008. Optical Short Range Transmission Systems. 2nd Edn., Springer Verlag, Berlin Heidelberg. ISBN: 978-3540766285, pp: 884.
10. Paloczi, G.T., 2005. Polymer integrated optics: Device architectures and fabrication methods. Ph.D Thesis, California Institute of Technology Pasadena, California, pp: 1-151. http://etd.caltech.edu/etd/available/etd-05102005-112605/.