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The study of the good polishing method for polymer SU-8 waveguide

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This research focused on polish characteristic of polymer based waveguides. The aim of the research was to show how polishing parameters affect the cut length of the end surface of SU-8 polymer on silicon and to detemine the best parameters for polishing SU-8 polymer. Then, four samples were used for characterizing the polishing of polymer. Each sample was polished with the same rotation and sandpaper size but with different rotational speed. The experiment result shows that the best rotational speed for polishing polymer SU-8 sample on silicon is 200 rpm.

Keywords: waveguides polishing, SU-8 polymer, rotational speed, sandpaper, silicon, cut off length.

1. Introduction

The efficiency of waveguide is influenced by the structure of its side surface. The best surface quality is needed for the grafting process between the fibre optic and the waveguide to increase the efficiency of fibre optic interface and waveguide. This shows that the polishing process is needed to optimize the performance and efficiency of the waveguide. However, for the time being, there is no reference as to the waveguide polishing rate. Hence, this research has been conducted to show how polishing parameters affect the cut length of end surface of SU-8 polymer on silicon and to determine the best parameters for polishing SU-8 polymer.

1.1. Polymer waveguide

Expansion of photonic field is closely related to the progress made known in material fabrication and also the advanced knowledge in the field of physics. Research into multi-functional inorganic material has been actively conducted, and this includes silica (SiO_2), silicon (Si), silicon oxinitride (SiO_xN_y), sol–gel, polymer, lithium niobate ($LiNbO_3$), indium phosphide (InP) and gallium arsenide (GaAs) [1, 2]. Polymer offers more advantages compared to other earlier materials. Polymers have always been applied in optical networks apart from optical functionality they ensure low production cost.

Polymer waveguides have attracted much attention due to their cost-effectiveness, optical properties and processing possibilities [1–13]. Due to the remarkable progress in the polymer waveguides polymer devices are expected to gain acceptance in optical interconnects, integrated optics and optical communication systems [5, 6, 11, 12, 14, 15]. Considerable interest has been focused on SU-8 polymer waveguides since they offer such advantages as low temperature process for fabrication, ease of fabrication [2, 6, 7], highly flexible structures [6, 15], highly efficient solution for high speed short-reach interconnects [8], ease of control of optical and mechanical properties and mass production possibility [5]. The polymer has many desirable properties, *e.g.*, high refractive index, good adhesion to substrate, low dielectric constants, optical transparency in the infrared wavelength region as well as high glass transition and high thermal decomposition temperatures [2, 6, 16].

Furthermore, the polymers are versatile materials that can provide novel functionalities such as thermo-optic and electro-optic properties and have potential of high speed optical switches, biosensor systems, high density data storage, optical processing and modulator with a low driving voltage [5, 6, 10, 15, 17, 18]. Besides, the manufacturing process of the polymer waveguide is easier and faster compared to the process of producing other material waveguides. In addition, the important property of polymers is that they have a large negative thermo-optic coefficient ($\mathrm{d}n/\mathrm{d}T = -1\times10^{-4} \sim -4\times10^{-4}$) that is ten to forty times larger than that of other conventional optical materials, resulting in thermally-actuated optical elements characterized by low power consumption [2, 7].

1.2. Loss in optical waveguide

Low insertion loss is the most important characteristic of optical components, so that absorption of the materials should be as small as possible in the near-infrared region from 1.3 μm to 1.6 μm. A precise control of refractive indices for the waveguide materials is also an essential factor which affects the effective loss [5]. Loss in optical waveguide is usually related to three main mechanisms, that is, dispersion, absorption and radiation. Dispersion loss usually occurs in glass waveguide and dielectric waveguide. Absorption loss mostly occurs in semiconductor materials and crystal-based materials. Radiation loss only occurs when waveguides are bending or curving [3].

2. Methodology

The material used in this experiment was an SU-8 polymer based planar waveguide with silicon acting as a substrate. The sample was polished at different rotational speeds by using a 1.0, 0.5 and 0.3 μm sandpaper for 15 min. Then sets 1 to 4 were polished with the selected rotational speed of 200, 250, 300 and 350 rpm, respectively, for determining a good polishing method. Each set was rotated for 15 min and a 0.3 μm sandpaper was used in the polishing process. Finally, the aurum coated sample was placed into scanning electron microscopy (SEM) to observe the surface quality of each sample.

3. Experimental results and discussion

The data obtained from the experiment have been tabulated. A graph of the polishing rate versus speed has been plotted. Tables 1–3 illustrate changes in the cut length of

T a b l e 1. Polishing rate by using sandpaper of size 1.0 μm with the total cut 3219 μm.

Rotational speed [rpm]	Cut length [μm]	Cut percentage [%]
50	15	0.5
100	31	1.0
150	152	4.7
200	275	8.5
250	506	15.7
300	840	26.1
350	1400	43.5

T a b l e 2. Polishing rate by using sandpaper of size 0.5 μm with the total cut 1578 μm.

Rotational speed [rpm]	Cut length [μm]	Cut percentage [%]
50	5	0.3
100	15	1.0
150	65	4.1
200	132	8.4
250	250	15.8
300	426	27.0
350	685	43.4

T a b l e 3. Polishing rate by using sandpaper of size 0.3 μm with the total cut 966 μm.

Rotation speed [rpm]	Cut length [μm]	Cut percentage [%]
50	2	0.2
100	7	0.7
150	46	4.8
200	100	10.4
250	165	17.1
300	252	26.1
350	394	40.8

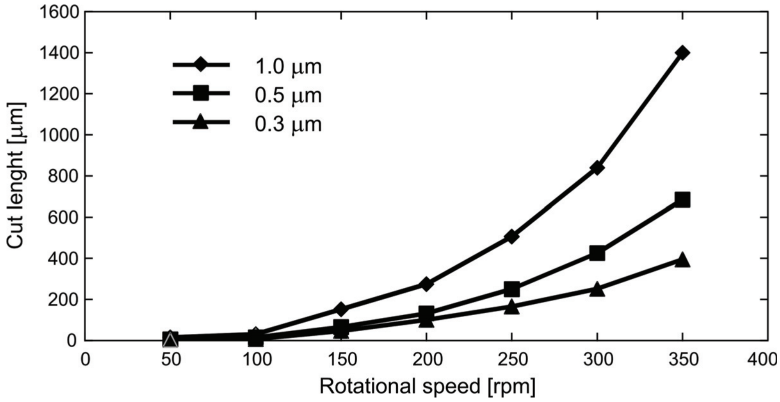
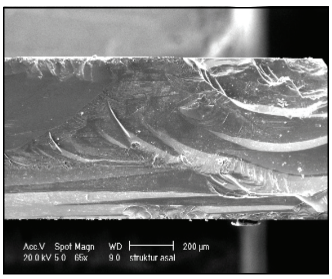
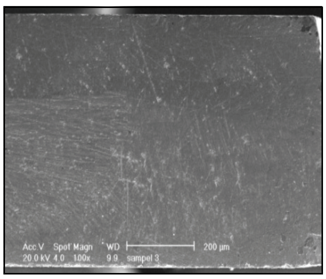


Fig. 1. Graph of cut off length *vs*. rotational speed using sandpaper of size 1.0 μm, 0.5 μm and 0.3 μm. The equation of the curve $y = 0.0041x^2 - 0.3352x$.

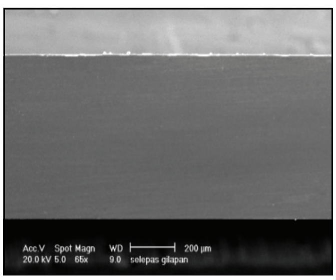
the waveguide during the polishing process with the use of sandpaper differing in size (1.0 μm, 0.5 μm and 0.3 μm). The tables also show the outcome of the analysis of the sample. The equation of the curve, $y = 0.0154x^2 - 1.5912x$, $y = 0.0077x^2 - 0.8209x$ and $y = 0.0041x^2 - 0.3352x$, was obtained using Microsoft Excel. It can be seen clearly from the tables that the cut percentage for each rotation velocity is as follows: 50 rpm: 0.2–0.5%; 100 rpm: 0.7–1.0%; 150 rpm: 4.1–4.8%; 200 rpm: 8.4–10.4%; 250 rpm: 15.7–17.1%; 300 rpm: 26.1–27.0%, and 350 rpm: 40.8–43.5%. From Fig. 1 it follows that the cut length increases with the rotation rate. The cut length also increases with the sandpaper grit size increasing.



a



b



c

Fig. 2. Cut end surface for: excised waveguide (**a**), excised waveguide after flattening (**b**), and excised waveguide after polishing process (**c**).

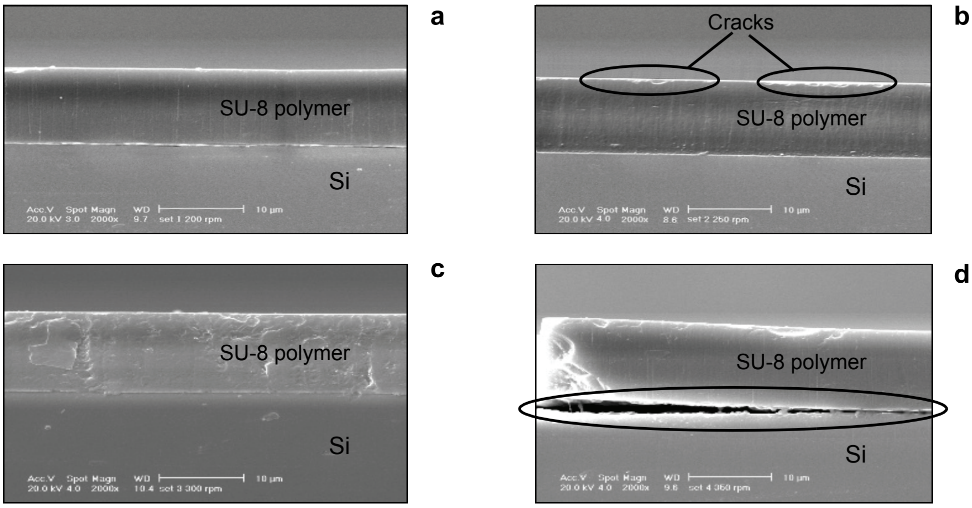


Fig. 3. Waveguide surface for set 1 (**a**), set 2 (**b**), set 3 (**c**), and set 4 (**d**).

The four samples were cut using a diamond cutter. The mechanical cut caused roughness at the cutting edges. The coarse cutting caused roughness at the cutting edges as shown in Fig. 2**a**. The fabricated waveguide topography has been inspected under a high power microscope. An inspection is needed during the fabrication process to control the fabrication condition from time to time. Then, the roughness surface structure will be flattened by using aluminium oxide sandpaper with size 16 μm. The waveguide surface after being flattened is shown in Fig. 2**b**. An optical device with roughness would contribute to high insertion loss if light injected to the device. So, that is why, after cutting step, the device needs to be ground and polished to achieve minimum roughness. Figure 2**c** shows the side end surface for the excised waveguide after polishing. The difference of the surface side waveguide can be distinguished clearly before and after polishing. Now, the polymer layer and silicon layer are focused in the surface analysis. The process was carried out by continuous inspection under high power microscope to ensure that the polished edge was getting smoother and no crack appeared. The surface waveguides for sets 1 to 4 are zoomed 2000 times by SEM as depicted in Fig. 3.

Set 1 shows the surface of the polymer SU-8 layer on top of silicon layer polished with rotational speed of 200 rpm. The surface of the silicon and polymer look smooth as shown in Fig. 3**a**. The boundary line between the silicon and polymer is not affected by the speed of the polisher. The sample has no crack or splinter. This means that rotational speed of 200 rpm is suitable for both silicon and polymer. It is excellent when polishing a sample composed of different materials or hardness. The polishing result for waveguide of set 2 with rotational speed 250 rpm is shown in Fig. 3**b**. The polymer surface is less smooth than silicon surface. There are small and minimum cracks seen at the upper side of the polymer layer. However, the boundary line between the silicon and polymer layer is still not affected. This shows that rotational speed of 250 rpm is still suitable for polishing silicon surface but not suitable for the polymer surface. Figure 3**c** shows the set of silicon waveguides with polymer SU-8 layer polished at a rotational speed of 300 rpm. The silicon surface looks smooth, but the polymer surfaces have been damaged with cracks and rugged surfaces. However, the boundary lines between silicon and polymers are still not affected. This shows that rotational speed 300 rpm is suitable for silicon but it is not to be used on the polymer surface. The observation from waveguide set 4 in Fig. 3**d** shows that polymer is no longer interlocked with silicon. Hence, polishing with rotational speed 350 rpm is not suitable for silicon waveguide with a polymer SU-8 layer.

4. Conclusions

Polishing is the final and important process in manufacturing optical devices. This is because, due to the light injection configuration, it is essential that cross-section surfaces have as minimum roughness as possible. Otherwise, there would be greater insertion losses. It can be concluded that polishing the sample at a speed of 200 rpm is a good polishing method for polymer SU-8 waveguide layers, at 15-minute rotation time with the use of a 0.3 μm aluminium oxide sandpaper size. Despite of giving a smooth surface, it also reduces the cutting time. The SU-8 polymer is not suitable for being polished at a high rotational speed as the surface may undergo damage. A non-slip surface hinders the coupling between the waveguide and optical fiber.

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