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OPTICAL WAVEGUIDES IN BENZOCYCLOBUTENE (BCB 4024-40) POLYMER

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Abstract. The fabrication and characterization processes of single mode optical waveguide based on photosensitive BenzoCyclobutene (BCB 4024-40) polymer are described. The polymer film thickness for various coating speed and refractive index are measured by the method of prism coupling. The waveguide is fabricated using the photolithography and chemical etching technique on BK7 glass substrate with a thin layer of SiO_2 as cover. The waveguide loss is measured using the conventional cut back method which results on an average loss of 3.5 dB/cm.

Keywords: BenzoCyclobutene polymer; spin coating technique; chemical etching technique; prism coupling; cutback method

Abstrak. Proses fabrikasi dan pencirian bagi pandu gelombang optik mod tunggal yang berdasarkan bahan polimer sensitif cahaya, BenzoCyclobutene (BCB 4024-40) dibincangkan. Ketebalan filem polimer bagi pelbagai kelajuan putaran enapan dan indeks biasan polimer diukur menggunakan kaedah prisma gandingan. Pandu gelombang ini difabrikasi menggunakan kaedah fotolitografi dan punaran kimia basah di atas bahan kaca BK7 dan lapisan nipis SiO_2 sebagai pelindung. Kehilangan pandu gelombang diukur menggunakan kaedah konvensional 'cut back' yang menghasilkan purata kehilangan sebanyak 3.5 dB/cm.

Kata kunci: Polimer BenzoCyclobutene; kaedah putaran enapan; kaedah punaran kimia basah; prisma gandingan

1.0 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 recognized 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. Undoubtedly, the major performances of integrated optics rely

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on the waveguiding component. Many materials are currently being investigated for constructing passive and active integrated optic waveguide circuits and devices.

Polymeric materials are particularly attractive in integrated optics because of their ability to be processed rapidly, cost-effectively, and with high yields [1][2]. Polymeric materials are allowed to form compact optical circuits by offering large refractive index contrasts. Optical polymers were engineered in many laboratories worldwide and some are available commercially. Classes of polymers used in integrated optics include acrylates, polyimides, polycarbonates and olefin (e.g., cyclobutene).

In this paper, we will report on the fabrication and characterization process of optical waveguides using organic BenzoCyclobutene (BCB 4024-40) polymer from Dow™. This type of polymer is photodefinable and thus, it is attractively applied as board-level interconnects. The negative acting properties allows the waveguides to be fabricated following steps similar to photoresist processing without the need for any plasma or reactive ion etching. The only report of devices based on similar material is the ridge optical waveguide by Kane and Krchnavek [3], but the processes they used are quite different. The motivation of this paper is to visualize the possibility of applying BCB 4024-40 as a candidate for optical material as it will lead to extremely lower cost manufacturing of optical waveguides and devices.

2.0 MATERIAL CHARACTERIZATION

Prism coupling method has been widely used as the method of characterizing thin film optical waveguide [4][5][10]. For the purpose of material characterization, slab layer of BCB 4024-40 films were spin-coated on BK7 glass substrate with measured refractive index of 1.50101 for transverse electric (TE) polarization at 1550 nm. Few slab samples were fabricated according to the spin speed of 1500-6000 rotation per minute (rpm). The fabricated structures were then measured for the average refractive index and film thickness. In order to characterize for the slab loss, the fiber probe method is applied in which the fiber is moved along the slab to measure the power [6]. Figure 1 shows the relation between coating speed and polymer slab thickness. The average refractive index obtained is 1.5556 for TE polarization. The average value of slab loss is measured to be 1.01 dB/cm, showing the BCB 4024-40's ability in optical guiding application. In order to view the uniformity of polymer coating, the atomic force microscope (AFM) is used. The result is given in Figure 2 which gives a surface roughness in root mean square (rms) of 0.551 nm, which indicate good coating quality.

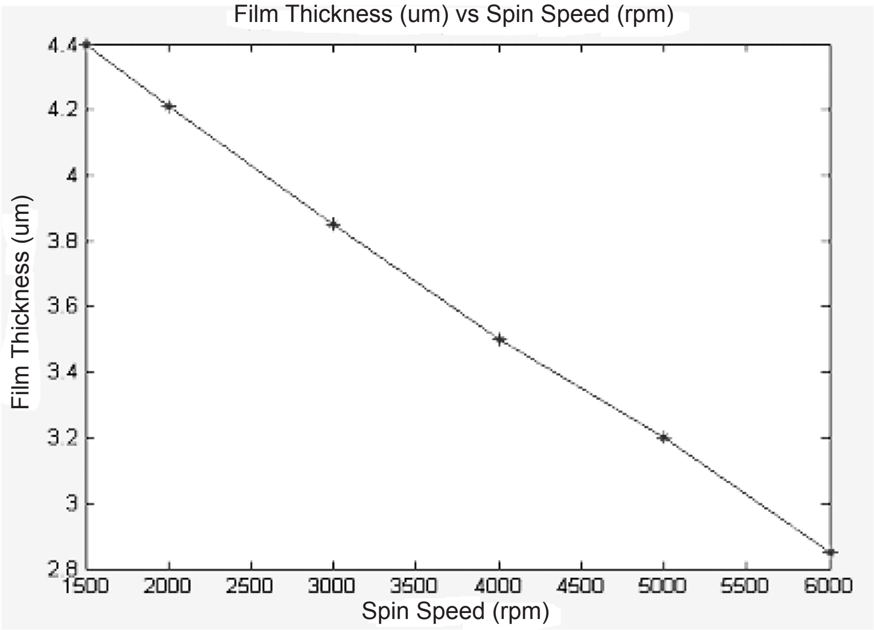

Figure 1 Relation between polymer film thickness and coating speed for BCB 4024-40

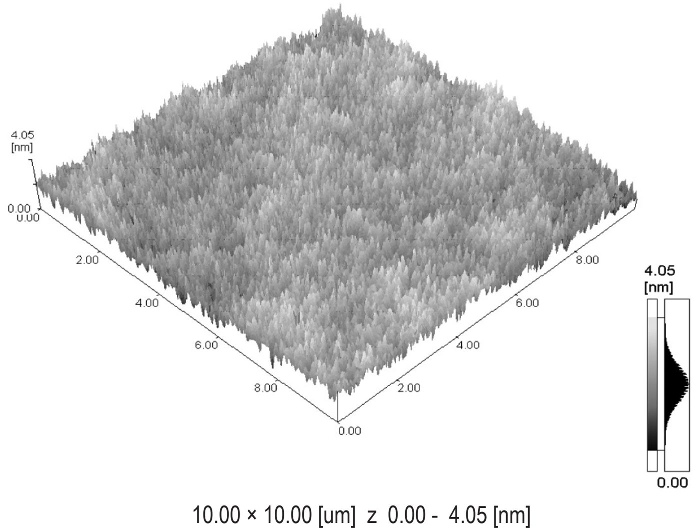

Figure 2 Atomic force microscope (AFM) image of polymer film surface roughness

3.0 WAVEGUIDE FABRICATION

The process scheme that is being developed for the fabrication of optical waveguide using BCB 4024-40 is similar to a thin film multi-chip module process. The starting material is a yellow amber liquid that is kept refrigerated at temperature below -15°C and brought to room temperature before processing. The whole fabrication process was carried out in clean room environment, where the concentration and size of particles, the temperature and humidity of the environment were controlled according to a standard to prevent the fabrication processes being affected by the contamination. A proposed waveguide structure is a ridge BCB 4024-40 on BK7 glass substrate together with thin layer of SiO_2 as a cover. According to our previous simulation [7][8], to produce a single mode waveguide using this material structure, the core thickness need to be about 4 μm. Hence, the coating speed of 3000 rpm and 4 μm of mask opening are chosen to realize a single mode square structure.

The process start with a substrate cleaning by washing them with DI water in an ultrasonic cleaner which were then cleaned using the IPA solvent. High pressure nitrogen was then used to dry the substrates. In order to maintain good adhesion with the substrate layer, AP3000 adhesion promoter was spin coated on the substrates before polymer coating. BCB 4024-40 resins were spun onto the substrates directly after the adhesion promoter application and spin dry.

After the spin coating, the films were heated on a hotplate for a specific time and temperature to drive out the residual solvent. The time and temperature are depending on the film thickness as to prevent any film wrinkle. This is followed by the photolithography which is the process of transferring the two-dimensional patterns on the photomask to the polymer film. As the BCB 4024-40 is a negative acting polymer, a dark field mask was utilized. A mask aligner having I-line UV exposure at 365 nm wavelength was used to crosslink the exposed polymer region. The mask aligner power density was set to $3mW/cm^2$ and the exposure time was 20 seconds.

After exposure, a pre-develop bake was carried out to increase the etching resistance and film adhesion to the substrate. The pre-develop bake temperatures were 10°C lower than the pre-exposure bake. Etching process was then carried out to selectively remove the unmasked area. The chemical etching or developing process of BCB 4024-40 polymer requires the puddle development process. In this process, a DS2100 developer solvent was dispensed onto the sample surface. After 30 seconds of puddle time, sample was then rinsed for 10 seconds and spun at high speed to remove the developer solvent. To further dry the film and stabilize the side wall, the sample was baked on a hot plate immediately after developing. Finally the sample was cured in a box oven at 250°C to remove residual solvents and harden the polymer. Note that neither photoresist nor RIE or plasma etching is necessary. However, the drawback of this chemical etching method is reduced quality of sidewall resolution of the waveguide [9].

In order to reduce the refractive index difference, a one-micron thick layer of SiO_2 was deposited on top of the polymer using the plasma enhanced chemical vapor deposition (PECVD) technique. The deposition process was carried out at 60°C for one hour. Finally, the waveguide sample was polished at the facets for optical coupling.

4.0 EXPERIMENTAL RESULTS

The microscope and Scanning Electron Microscope (SEM) images of fabricated waveguides are shown in Figures 3 and 4 respectively. The photopatterned waveguides in both figures exhibit smooth polished end facet but a bit rough at the sidewall.

In order to characterize for a waveguide loss, a measurement apparatus has been setup. A conventional cutback method has been adopted in the loss measurement. This requires the output power of a waveguide to be measured and related to input power to determine insertion loss, for a series of different guide lengths [10]. A single mode fiber is used to couple 1550 nm laser source into the polished end facet of the polymer waveguide. The output is measured using the Germanium (Ge) photodetector and the near field profile is imaged onto an infrared camera integrated with beam analyzer software. Figure 5 shows the image of output beam with 1550 nm laser coupled at the waveguide input. The single lobe obtained gives a clear indication that only single mode is supported for respective waveguide structure and laser wavelength.

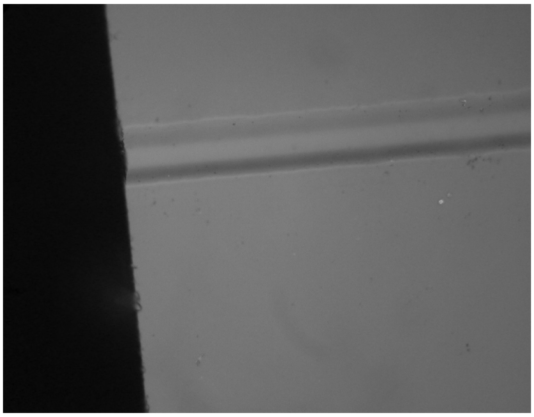

Figure 3 Microscope images of fabricated polymer waveguide

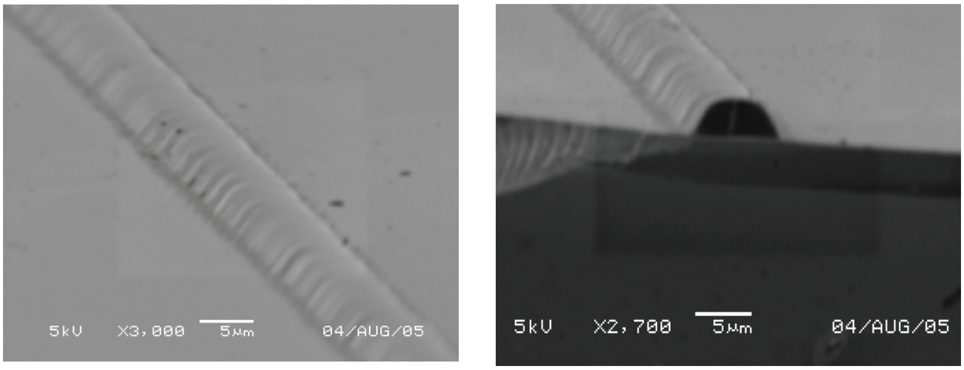

Figure 4 SEM images of fabricated polymer waveguide

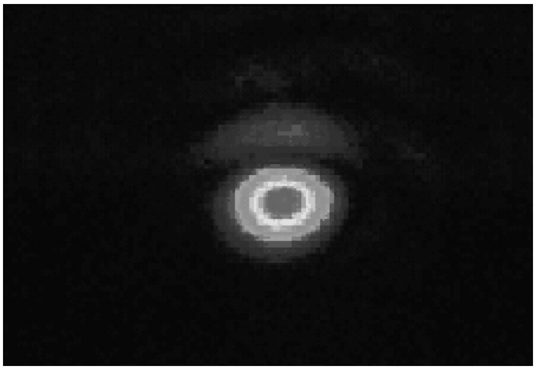

Figure 5 Image of waveguide output for 1550 nm laser coupling (random polarization)

Few waveguide samples with different length were prepared and measured for its output power. The results of a cutback loss measurement performed on BCB optical waveguides are shown in Figure 6. The slope of the line indicates that the propagation loss in the waveguides is 3.5 dB/cm and the coupling loss is 10.5 dB.

5.0 DISCUSSION

As shown previously, the fabricated waveguide exhibit roughness at the sidewall. This roughness is presumed due to minor corrugation at the mask opening. Furthermore, the shape of the waveguides is not perfectly rectangular due to chemical etching limitation together with diffraction effects associated with mask opening and film thickness, which is practically observed in chemical etching technique as observed by Dagli and Fonstad [11].

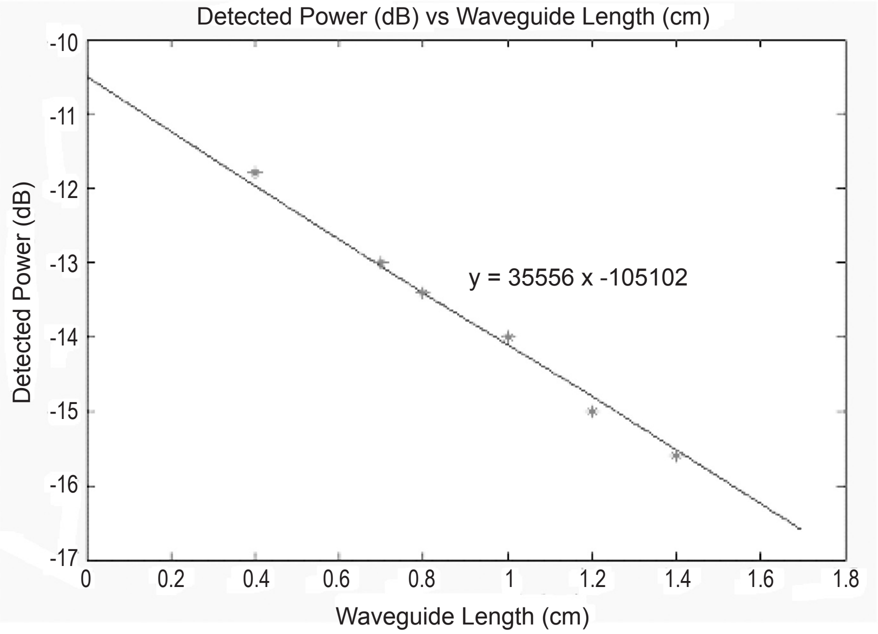

Figure 6 Measured output power for several waveguides length

The relatively high propagation loss is presumably due to scattering from the sidewall roughness which results in mode scattering effects and further reduces the detected power. The high value of coupling loss is mainly due to the size mismatch between the fiber (core diameter of 9 μm) and the waveguide modes. The problem can be easily rectified by adopting substrate and cover materials having slightly lower refractive index as compared to BCB 4024-40 index. The sidewall roughness can be reduced by utilizing less corrugated mask opening and high precaution measures during the fabrication process. With the measured loss of 3.5 dB/cm, the polymer waveguides are suitable for relatively short optical interconnect applications.

6.0 CONCLUSION

Optical waveguides based on organic BCB 4024-40 polymer have been demonstrated utilizing BK7 glass as a substrate and thin layer of SiO_2 as a cover. Polymer characterization using prism coupling technique provides useful ideas on its abilities in optoelectronic applications. The photolithography and chemical etching technique were utilized throughout the fabrication process, without the need for costly dry etching technique. For single mode application, a core dimension of 4 μm was fabricated which is further characterized for loss using the cutback method. However, due to the photomask quality, the resulting sidewall roughness yielded a relatively high propagation loss of 3.5 dB/cm. Nevertheless, we have shown that BCB 4024-40 polymer is a low loss material suitable for relatively short photonic devices.

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