Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 662-663

P13-5

Fine Processing in Heat-Resistant Polymer by Electron-Beam Lithography and Thermal Development

Masahiro Tomiki, Okihiro Sugihara, Hisashi Fujimura, Naomichi Okamoto

Shizuoka University, Graduate School of Electronic Science and Technology
3-5-1 Johoku, Hamamatsu-shi, Shizuoka, 432-8561, Japan
Phone: +81-53-478-1121 Fax: +81-53-478-1121 E-mail: n2841910@ipc.shizuoka.ac.jp

1. Introduction

Recently, polymeric optical waveguides have attracted by the high potential application in the optical communication. Polymeric materials have many advantages over other materials, ease of processing, high flexibility, ease of refractive index control, and high consistency to Plastic Optical Fiber (POF) [1]. Consequently, there are many reports of optical circuit application using the polymer materials. However, the most of polymeric materials have the problem of heat-tolerance. In this study a highly heat-resistant polyarylate U100 is used. We report that U100 is superior in thermal stability of transparency and refractive index, and can be processed by using electron-beam (EB) exposure and thermal development, where it is treated as a positive resist. This process method is advantageous [2] because of a dry process without further etching process. Moreover, we fabricate a surface relief grating with sub-micrometer period on U100 film, which can be applied in the field of optical communication.

2. Polyarylate Polymer, U100

The polymer we chose in this experiment was a kind of polyarylate (U100) with high glass-transition temperature (Tg:193℃). The chemical structure of U100 is shown in Fig.1. U100 has the high optical transparency especially in visible region, high elasticity, and low moisture absorbency. Not only optical property but also heat-resistance is necessary for realization of the polymer-based optical waveguide. Therefore, we investigated the thermal stability of the refractive index and the optical absorption of U100. Table I lists the measured refractive indices. It is resulted that no remarkable change of index was observed through heat-treatment. Moreover, no difference of the absorption spectrum was observed in the film between before and after heating at 100℃ for 100 hours or 200℃ for 10 minutes. These results suggested that U100 is excellent in the heat-resistance.

The fabrication process of U100 thin film was as follows: The solution including the polymer was spin-coated onto a Si wafer or a glass-slide substrate with transparent indium-tin-oxide (ITO). Then, it was dried in the oven at 150℃ for 30 minutes.

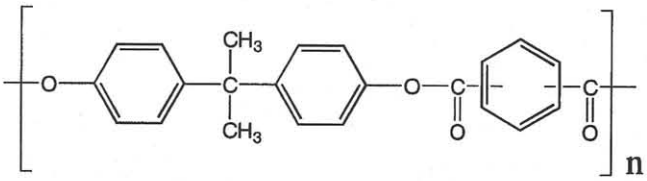

Fig. 1 Chemical structure of Polyarylate U100.

Table I Measured Refractive indices

	TE	TM
As prepared	1.606	1.598
10℃ 100hours	1.603	1.588
200℃ 10min	1.602	1.587

Measured by m-line method with He-Ne laser (λ=0.633μm). TE and TM mean transverse-electric mode and transverse-magnetic mode, respectively.

3. Experiments and Results

Optimum Condition of EB exposure

In this study, we optimized the conditions of EB lithography for fine processing. The grating pattern was fabricated on the U100 film by EB exposure and thermal development using an EB device (JEOL-5000LS). We controlled the electron dose to optimize the energy deposition in polymer film. We investigated the relationships between the depth of development and the EB dose under several conditions. The depth of development was defined as the depth, which was shown in Fig.2. The depth influences the diffraction efficiency [3]. Fig.3 shows the relationship between the dose and the depth of development at different temperatures. The U100 film could be effectively processed around the Tg. It could not be developed in the room temperature and the shape changed and the depth decreased over Tg. Consequently, Tg is the optimum temperature of thermal development. Fig.4 shows the relationship between dose and depth of development with different thickness. The depth became deeper with increasing the film thickness. However, there is the optimum value on the ratio of the depth for film thickness. This ratio is the important parameter that decides the performance of the diffraction

grating. We conclude that the optimum conditions of EB exposure and thermal development are as follows: (1) The film thickness is about 2.0 μm. (2) The EB dose is 2000μC/cm^2.

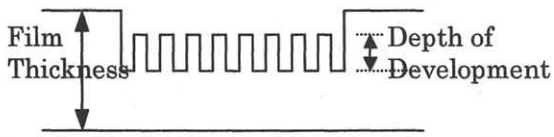

Fig. 2 Definition of the depth of development.

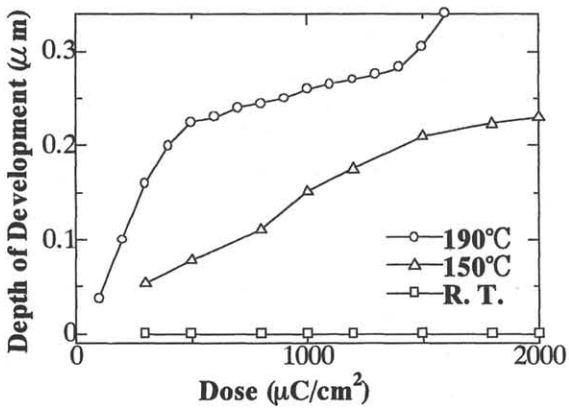

Fig. 3 Relationship between EB dose and depth of development at different temperatures.

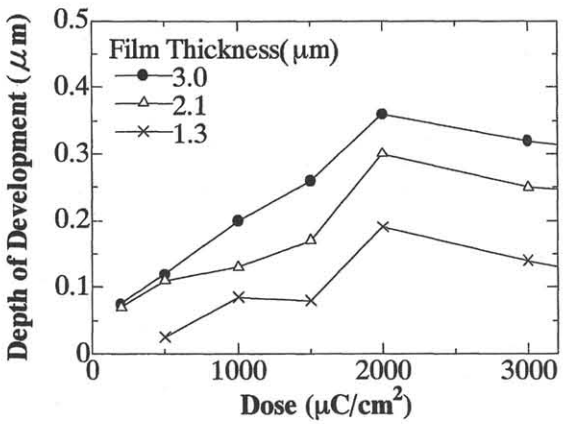

Fig. 4 Relationship between EB dose and depth of development on films with different thicknesses.

High-Resolution Surface Relief Grating

We fabricated the high-resolution surface relief grating in the film of U100. The film thickness and the period were 1.9 μm and 0.8 μm, respectively. The temperature of thermal development was 190°C and the time was 15 min. The EB dose was 2000 μC/cm^2 that was the optimum value at this condition.

Fig.5 shows an AFM image of the actually fabricated grating. It is a clear grating pattern without any remarkable defects. The depth of the grating was measured as 0.04μm.

Then, we measured the diffraction efficiency of the grating by inserting the He-Ne laser (λ=0.633μm) as the light source. The diffraction efficiency is determined as a ratio between first diffracted light power and input light power in vertical incidence. The diffraction efficiency was 4.1%. Moreover the efficiency did not change by heating this grating at 100°C for one hour.

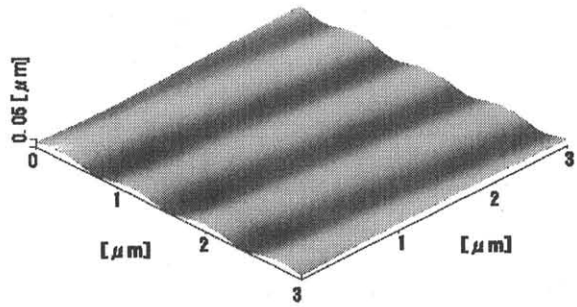

Fig. 5 AFM image of fabricated grating on thin film of polyarylate, U100.

4. Conclusions

We depicted that U100 had the heat-resistance for realization of polymer optical waveguide. And U100 film can be finely processed by EB exposure and thermal development. We fabricated the high-resolution surface relief grating in U100 thin film with 0.8-μm period and 0.04-μm depth, respectively. We measured that the grating had the 4.1% diffraction efficiency. Considering these results, fine processing in the U100 film by EB exposure and thermal development is promising technique for the fabrication of optical waveguide.

Acknowledgments

The authors gratefully acknowledge Unitika Co. Ltd. for providing the U100 polymer.

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