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Study on Electron Beam Lithography with Dye-doped Polymer Material

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We report the study on electron-beam(EB) lithography with a dye-doped poled polymer. The mechanism of absorption spectrum change and nonlinear characteristics after EB exposure are investigated. A $\chi^{(2)}$ diffraction grating is successfully fabricated in this guest-host polymer material based on direct EB irradiation technique.

Keywords: electron-beam lithography; guest-host polymer; absorption spectrum; diffraction grating

INTRODUCTION

Electron-beam (EB) lithography due to its usefulness as a high-spatial resolution technique has been applied to the development of advanced optical waveguide device fabrication in some polymers[1]. Recently, creation of periodic quasi-phase-matching (QPM) structure in $LiNbO_3$ for frequency conversion was reported[2]. However, there have been very few studies[3],[4] of poled polymer by EB lithography. In this paper, we report the mechanism of absorption spectrum change and nonlinear characteristics of dye-doped poled

PMMA after EB exposure. Moreover, a $\chi^{(2)}$ diffraction grating via direct EB irradiation in the dye-doped polymer is fabricated.

RESULTS AND DISCUSSION

A glass slide with indium tin oxide (ITO) on one side was used as the substrate. SiO_2 was first coated on the surface of the ITO substrate as a buffer layer, and DR1/PMMA (5wt%) film was spin-coated before corona-poling. The detailed procedure of sample preparation and EB exposure are similar to that shown in reference 3.

We studied the absorption spectra of DR1/PMMA film, which were measured at different conditions and shown in Fig. 1.

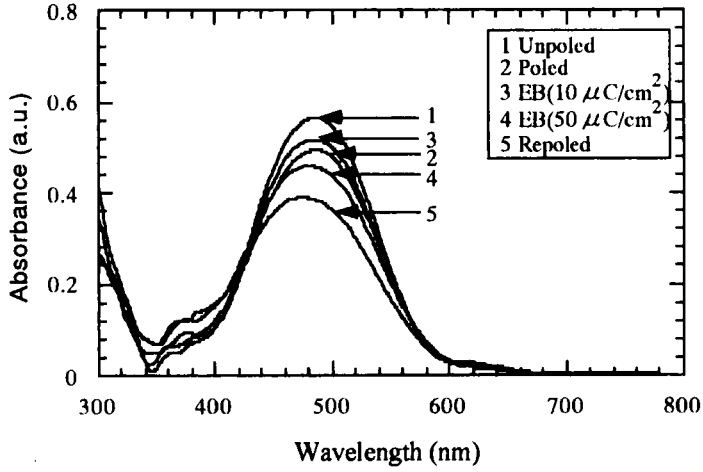

FIGURE 1 Absorption spectra of DR1/PMMA film at different conditions.

The absorption spectrum of DR1/PMMA film before poling was shown as curve 1. As we know, the corona-poling process results in the decrease of

absorption peak shown as curve 2 because the dye molecules are oriented by the electric field to the direction which is parallel to the field. Then the peak absorption in curve 3 (irradiated at a low dose of $10\mu C/cm^2$) was higher than that in curve 2, and that in curve 4 (irradiated at $50\mu C/cm^2$) was less than that in curve 2. An equi-absorbing point at 430nm was observed throughout the poling and irradiation process.

The change of absorption spectra can be explained in two ways: thermal effect and the break of N=N bond in DR1 molecules. It is well known that the instantaneous high temperature caused by the EB irradiation induces the trans-cis isomerization. At the same time, partial depolymerization of PMMA occurred under a low dose condition, resulting in the relaxation of the molecular dipoles. On the other hand, the N=N bonds in DR1 molecules were broken when plenty of electrons with energy larger than 4.3eV were provided. Thus the absorption peak decreased and blue shift occurred because new materials were produced. For confirming, repoling process was carried out and shown as curve 5, which suggests that the remaining DR1 molecules were reoriented. This phenomenon was also observed in an azo-dye-substituted polymer.

The second-harmonic (SH) intensity of the poled polymer film was measured with the Maker-fringe technique using a Q-switched Nd:YAG laser (1064nm) as a fundamental wave. The second-order nonlinearity was almost erased when the EB dose was larger than $100\mu C/cm^2$. This result enabled us to attempt to fabricate the $\chi^{(2)}$ grating using this method. As an example, a $\chi^{(2)}$ grating of $6\mu m$ period was performed as shown in Fig. 2. This method can easily meet the high resolution ($\sim \mu m$ order) in order to

obtain the first-order QPM frequency conversion in poled polymer waveguide.

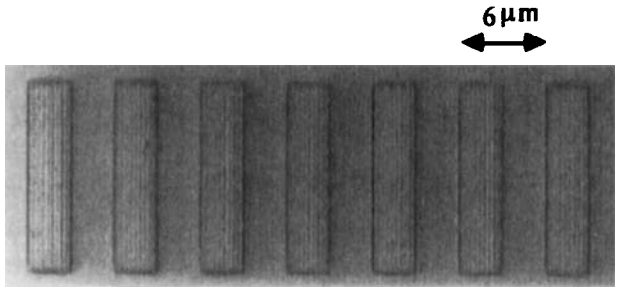

FIGURE 2 A profile photograph of $\chi^{(2)}$grating with the period of 6 μm.

CONCLUSION

The mechanism of absorption spectrum change in dye-doped poled polymer after EB exposure has been studied. Two kinds of mechanism were suggested. Nonlinear characteristics was also investigated, and a $\chi^{(2)}$ diffraction grating was fabricated based on direct EB irradiation technique. It is shown that direct EB irradiation in dye-doped polymer has great potential application in frequency conversion and/or electro-optic modulation.

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