Photoinduced Surface Relief Grating on Polysilane Thin Films and its Application to Alignment Layer for Liquid Crystal Cells

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1. Introduction

Polysilanes are well-known functional polymers with high quantum efficiency of photoluminescence (PL), high hole drift mobility, a variety of photochemical reactions, which are associated with σ -conjugation along the Si-Si main chain.[1-2] In particular, the photodecomposition of polysilanes has been applied to photoresists and opto-electronic devices such as optical waveguides with photoinduced refractive index change. We have investigated the photo-fabrication of nano-porous surface from polysilane-silica and -titania hybrid thin films so far.[3-8] These nano-porous inorganic thin films are prepared by photodegradation of polysilane molecularly dispersed in inorganic matrices.

In this work, surface relief gratings (SRGs) whose pitch was several hundred nanometers on polysilane thin films were fabricated by either a holographic method or a phase-mask method. These gratings have been applied to alignment layers for liquid crystal cells and their anchoring energy has been measured.

2. Experimental

The toluene solution of poly(methylphenylsilane) (PMPS) synthesized by a Wurtz reaction was spin-coated on glass or ITO substrate with about 100nm thickness. Gratings were fabricated by either a holographic method or a phase-mask method using He-Cd laser (325nm) (the grating pitch of PMPS fabricated by the phase-mask method was 400 nm). After the He-Cd laser irradiation, the irradiated substrates

were developed with hexane. The surfaces of PMPS were observed with an AFM (Seiko SPA 300).

The sandwich-type liquid crystal cells were prepared by parallel arrangement of two PMPS gratings on ITO substrates, as shown in **Figure 1**. The thickness of the liquid crystal cells was about 19 μ m. Liquid crystalline compound, 4-cyano-4'-n-pentylbiphenyl (5CB), was introduced into the cells at its isotropic phase.

Figure 1. Structure of liquid crystal cells.

3. Results and Discussion

In this work, two methods for generating gratings, (a) holographic and (b) phase-mask

methods, were employed. The interference fringe formed by the holographic method gave fine gratings. When the incident angle of a He-Cd laser light was 30° , the grating pitch was 325 nm, identical to the irradiation wavelength. On the other hand, the phase-mask had slits of 400nm pitch on SiO_2 substrates, and the incident angle of the He-Cd laser was 16° . The interference fringe of first-order light was formed on the PMPS substrate. The pitch of grating on substrate was 400 nm. **Figure 2** shows the AFM images of gratings prepared by using the phase mask.

Figure 2. AFM image of PMPS grating prepared by a phase-mask method (pitch : 400nm).

The grating depth for different irradiation times of a He-Cd laser with intensity of $20\text{mW}/\text{cm}^2$, measured with an AFM, is shown in **Figure 3**. In the case of 5sec irradiation, the deepest grating (20nm) is obtained, and it is found that the depth can be controlled by the irradiation time. However, the longer irradiation time, the more PMPS was photo-decomposed, which leads to the reduction of the height of convex part.

Figure 3. Grating depth of PMPS for different UV irradiation times.

The texture of the liquid crystal cells, in which 5CB was introduced between two parallel grating substrates ($19\mu\text{m}$ in thickness), was observed by a polarizing microscope. **Figure 4** shows the polarizing-microscope images of the liquid crystal cells, which were set to the direction making 0° or 45° the angle between the polarizer and the groove direction of the PMPS grating. Setting at diagonal angle (45°), the transmission light intensity is increased, therefore, it is found that liquid crystal molecules are aligned parallel to the grating grooves. Furthermore, from these results, it is confirmed that even 20nm depth of grating is effective for alignment layers of liquid crystal molecules.

Figure 4. Polarizing-microscope images of liquid crystal cells.

The surface anchoring energy A was determined from the measurements of the saturation voltage, at which liquid crystalline molecules are oriented completely to the direction

of the applied electric field, according to the equation derived by Sugimura *et al.*: [9]

$$A = \frac{V_s \sqrt{\epsilon_0 \Delta \epsilon K_3}}{l}$$

V_s : Saturation voltage

ϵ_0 : Dielectric permittivity of vacuum (8.85×10^{-12})

$\Delta \epsilon$: Dielectric anisotropy (10.9)

K_3 : Elastic constant (8.4 pN)

l : Cell thickness

The saturation voltage V_s is determined under the condition of zero optical retardation based on the transmission light intensity using a 632.8nm He-Ne laser as a light source. We find that for the liquid crystal cells with 7 to 20 nm grating depth, the anchoring energy ranges from 8.46×10^{-5} to 1.27×10^{-4} J/m². It could be noted that the values of the anchoring energy of 5CB grating cells are in the range of the so-called weak anchoring energy. These findings indicate that photoinduced surface relief gratings on PMPS thin films are applicable to the alignment layers for liquid crystal cells with weak anchoring energy, whose electro-optic properties are improved in comparison with the conventional liquid crystal display devices (for instance, the operation voltage of liquid crystal cells with weak anchoring energy is considerably reduced).

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