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Weak anchoring of nematic liquid crystals on photo-induced surface relief gratings of organic polysilane

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ABSTRACT

Surface relief gratings on organic polysilane thin films are fabricated by holographic exposure of ultra-violet light, and Au gratings are subsequently prepared on polysilane gratings by vapor deposition of Au. The anchoring energies of 4-pentyl-4′-cyanobiphenyl (5CB) nematic liquid crystal on the fabricated gratings are determined with a saturation voltage method. The anchoring energies of Au gratings are weaker than those of organic polysilane gratings because of suppression of π–π interaction between the liquid crystal and the alignment layer. The polar anchoring energies of Au gratings are also weaker than those reported in literature.

1. Introduction

Surface anchoring energy of nematic liquid crystal (LC) on alignment layer is of great importance in the fundamental physics of LC and the application to LC devices [1,2]. The surface anchoring energy determines the ability of the surface director to deviate from the direction of easy axis. The characteristics of LC devices are influenced by the anchoring energy such as voltage–transmission curve, response time and viewing angle. In a normal LC display with strong anchoring, LC molecules are rapidly and stably returned to the initial state when the external field is removed. However, a higher voltage is needed to align the director normal to the substrate surface. On the other hand, the weak anchoring surface allows LC molecules on the surface to rotate along the external field easily, which results in lower operating voltage and faster switch-on time in comparison with the conventional strong anchoring LC devices. Several studies concerning weak anchoring effects have been reported such as low voltage operation [3,4] and bistable [5] and multi-stable [6] optical switching. However, these studies mainly dealt with the application of weak anchoring effects to LC devices, and very few studies have been conducted on the fabrication of weak anchoring boundaries. From the viewpoint of application of LC, it is important to make a weak anchoring boundary with LC and control the anchoring energy.

In this paper, we demonstrate the weak anchoring of nematic LC on photo-induced organic polysilane and Au surface relief gratings as alignment layers. Weak interaction between organic polysilane and LC molecules is expected because polysilane is a chainlike polymer with σ conjugation along Si–Si bond and does not have the extended π-conjugation. π-conjugation as in polyimide strongly interacts with LC molecules. In order to fabricate further weaker anchoring boundary with LC, Au gratings are subsequently prepared onto polysilane gratings. It is expected that Au layer suppresses molecular interactions such as π–π interaction and steric interaction between LC molecules and polysilane. Chemical bonding is weak between LC molecules and Au surface [7].

2. Experiment

The toluene solution of organic polysilane, poly (methylphenylsilane) (PMPS), was spin-coated on an indium tin oxide (ITO) substrate with about 100 nm thickness. Surface relief gratings were fabricated by a holographic exposure method using a He–Cd laser light at 325 nm. The interference pattern was produced on PMPS thin film by two coherent beams. After the He–Cd laser exposure, the irradiated substrates were developed with hexane. Subsequently Au gratings are prepared onto PMPS gratings by vapor deposition of Au. The thickness of Au is about 20 nm. The profiles of the gratings were observed using an atomic force microscope (AFM) (Seiko SPA 300).

3. Results and discussion

Fig. 1 shows AFM images of surface relief PMPS and Au gratings with a pitch of 400 nm and a depth of 20 nm. Here the UV exposure condition of PMPS grating is 5.1 mW/cm^2 for 5 s. Regular gratings have been successfully fabricated on the surfaces of PMPS thin films. As the irradiation time increases, the grating depth of PMPS approaches maximum values of about 40 nm. The grating pitch can be also varied

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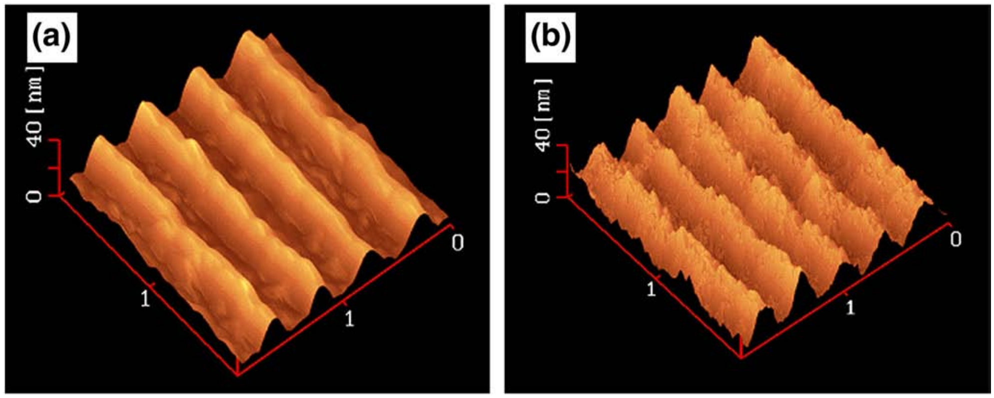

Fig. 1. AFM images of 400-nm pitch surface relief gratings of (a) PMPS and (b) Au thin films.

from 250 to 950 nm by changing the angle between two laser beams. Au grating is easily prepared on PMPS by deposition of Au and almost the same pitch and depth as PMPS grating but the surface roughness of Au gratings is larger than that of PMPS gratings. Larger roughness of Au gratings is likely to result from the island growth of Au. Grating surface is described by a sinusoidal wave, and the undulated shape of grating is preserved as sinusoidal function curves at different grating depths. This photo-induced fabrication method of grating is very easy using a low power UV light, and enables us to precisely control grating depth and pitch by adjusting the light exposure condition.

The sandwich-type LC cells were prepared by parallel arrangement of two fabricated PMPS or Au gratings, which were used as homogeneous alignment cells. The thickness of LC cells was about 15 μm. The cells were filled with a nematic LC 4-pentyl-4′-cyanobiphenyl (5CB) in the isotropic state. The textures of the LC cells were observed by a polarizing microscope under crossed polarizers. Fig. 2 shows the textures of the LC cells observed by a polarizing microscope under crossed polarizers. It is found that LC molecules align well on the surfaces of both PMPS and Au gratings. It is also found that LC molecules on the fabricated gratings align parallel to the grating grooves due to the minimization of the elastic strain energy of the LC. The polarizing microscope images shown in Fig. 2 are essentially the same in the temperature range of 23–34 °C (the temperature range of nematic phase of 5CB), indicating that the alignment of LC on PMPS and Au grating surfaces is thermally stable. Alignment of LC on photo-induced surface relief grating is an attractive technique free from a conventional rubbing method to make LC director alignment at the substrate surface [8–10].

The surface anchoring energies of 5CB on the fabricated gratings were determined with a saturation voltage method [11,12]. In this method on the basis of a general Rapini and Papoular model [13], the surface anchoring energy is generalized to describe an interfacial energy, in which the anchoring energy is not separated into polar and

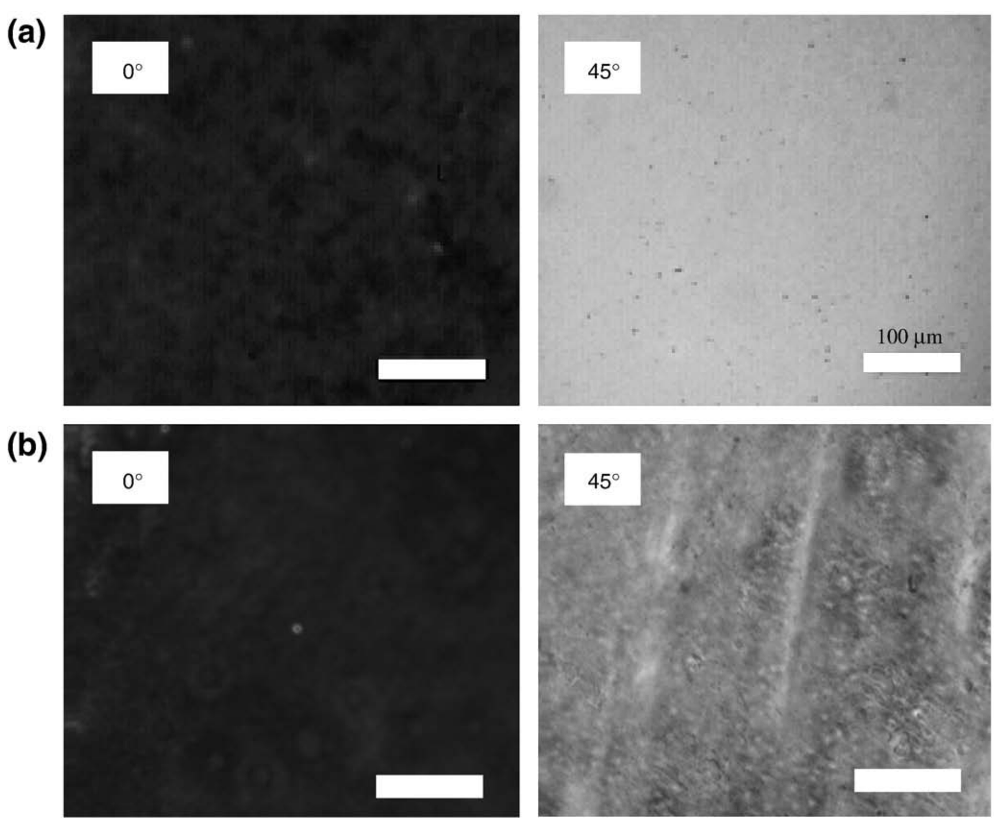

Fig. 2. Polarizing microscope images of LC cells with (a) PMPS and (b) Au gratings under crossed polarizers. LC cells are set up at 0° (left) and 45° (right) with respect to the polarizer. The white bar shows 100 μm.