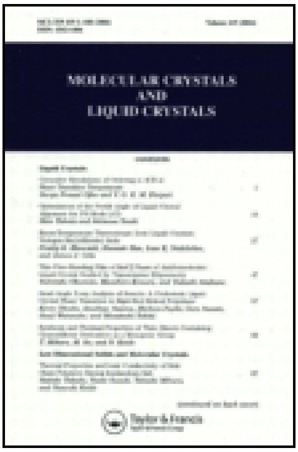

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Magnetically Induced Alignment of Ferro-Nematic Suspension on PVCN-F Layer

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We have observed magnetically controlled anchoring of ferro-nematic suspensions (FNS) on a fluoro-poly(vinyl)-cinnamate (PVCN-F) layer. We found that with the application of a weak magnetic field to a cell filled with the ferro-suspension, we could induce an easy (orientational) axis of weak anchoring energy on the polymer surface. By varying the direction of the magnetic field, one can change the easy axis orientation of liquid crystal (LC). We believe that the magnetically induced alignment of the ferro-nematic suspension is caused by the precipitation of ferro-particles on the polymer substrate. As a result, this alignment can be manipulated by a small magnetic field. The developed system is very promising for ultra-sensitive magnetically controlled LC devices for information processing and storage.

Keywords: ferro-nematic suspension; magnetically induced alignment.

INTRODUCTION

Research into ferromagnetic particles suspension in liquid crystals (LCs) began in 1970 with the work of Brochard and de Gennes[1]. They proposed to increase the magnetic sensitivity of nematic LCs by doping them with small ferromagnetic grains. The following experimental and theoretical studies[2-7] confirmed this idea and showed that director of ferro-nematic suspensions (FNS) can be effectively reoriented by extremely weak magnetic field (1-10 Gs). Unfortunately, a real application of ferro-nematic suspensions is restrained by their low stability due to a strong agglomeration of the ferro-grains.

In all studies known to us, the ferro-particles were distributed in the LC bulk but their possible precipitation on substrates did not play an essential role in orientational effects. At the same time, it is reasonable to suggest that a magnetically induced reorientation of ferro-particles precipitated on the substrate may effectively control the orientation of LC bulk. An analogue would be the well-known effect of LC reorientation due to light-induced changes of LC anchoring[8].

In the present work, we report on the effect of LC alignment control in a cell using a magnetic field applied to a layer of ultra-fine magnetic particles precipitated on the aligning polymer surface.

EXPERIMENTS AND DISCUSSIONS

We studied a suspension of magnetic particles, Fe_3O_4, in the nematic LC, pentyl-cyanobiphenyl (5CB, *BDH Ltd.*). The needle-like ferromagnetic particles of ~1 μm length were mixed with a surfactant at a ratio of 1:2 and milled in a vibration mill (Fritsch "Pulaerisette") for 120 hours. After the milling, we mixed the surfactant-covered ferro-particles with 5CB at a ratio of 1:65 while at a temperature, $T_0 = 36^{o}C$, above the clearing point of 5CB.

The symmetric cells (thickness, $L = 50$ μm) consisted of identical glass substrates. To obtain planar conditions on the surface, both substrates were covered with a spin-coated PVCN-F layer, then heated to $T = 120^{o}C$ for 2 hours. The substrates were then irradiated with non-polarized UV light from a *Hg*-lamp (intensity 10 mW/cm^2) for 45 min. The cells were filled with pure 5CB or FNS in the isotropic phase ($T = 70^{o}C$) and cooled down to room temperature by placing one substrate side (the command substrate) on the cold base in order to have temperature gradient through LC cell. This method of cell preparation resulted in the precipitation of ferro-particles on the cold command surface, which we observed in microscope.

Non-homogeneous quasi-planar alignment of either 5CB or FNS was observed in the polarizing microscope. We placed the cells into a magnetic field parallel to cells substrate. A magnetic field of $\vec{H}_0 \geq 5$ kGs produced a uniform alignment of LC in the cell with pure

5CB. In the case of the suspension, a lower field of $\vec{H}_0 \geq 1.2$ kGs was enough to align the FNS uniformly. The LC director, $\vec{d}$, aligned parallel to the magnetic field vector both in the pure LC cells and the FNS cells.

The magnetically induced monodomain structures in the cells with pure 5CB or FNS behaved differently in the magnetic field. We placed the cells between the magnet poles so that the magnetic field of $\vec{H} = 1.5$ kGs was aligned at 45^o with respect to the LC director, $\vec{d}$, in the cells' plane. It resulted in the reorientation of the director toward $\vec{H}$. After removal of the magnetic field, the pure LC relaxed to its original orientation whereas the FNS did not relax but rather, remained parallel to the direction of $\vec{H}$. Moreover, the orientation of the director of FNS could be readjusted to any angle using the magnetic field. This new alignment of FNS disappeared in several days after the removal of the magnetic field.

The quasi-stable alignment of FNS by a magnetic field suggests that the magnetic field aligns the ferro-grains on the surface that results in the easy orientation axis of the LC on the PVCN-F surface. A change in the direction of $\vec{H}$ leads to the reorientation of the ferro-grains and, in turn, to a new position of the easy axis. To confirm our idea, we removed the FNS solution from the magnetically aligned cell and then re-filled this empty cell with a pure LC. We observed the restored magnetically induced alignment of the LC in the newly filled cell. We found that LC is oriented along the same axis as the magnetic particles, which we observed on PVCN-F surface after we removed the FSN from the cell. Therefore, we can conclude that the easy axis is produced on the command polymer surface through the precipitation of the ferro-particles on that surface.

To obtain quantitative information about the characteristics of the magnetically induced alignment, we carried out the experiments with a combined cell (thickness, $L = 50$ μm) consisting of reference and command surfaces. The reference substrate was coated with rubbed polyimide that produced a low tilt angle (1-2^o) planar alignment of strong anchoring energy with either pure 5CB or FNS parallel to the rubbing direction, $\vec{d}_{ref}$. The substrate that was covered with the heated and irradiated PVCN-F layer was used as the command surface. The cell was filled with pure 5CB or FNS in the isotropic phase and cooled down asymmetrically as mentioned above. Due to the temperature gradient created by placing the command surface on the cold base, we obtain a migration of the ferro-particles to the command surface that is a precipitation of the Fe_3O_4-particles onto substrate. The pretilt angle measured by the crystal rotation technique [9] equalled $\theta = 1.5^o$ (for pure 5CB) and $\theta = 2^o$ (for FNS). As a consequence of the strong anchoring on the rubbed surface and the low pretilt angle of the command surface, we have a planar orientation throughout the LC cell.

The cell was placed between the poles of the magnet according to the geometry depicted in Fig.1. The rubbing direction, $\vec{d}_{ref}$, on the reference surface made an angle of $\varphi_0 = 45^o$ with the magnetic field vector. The polarisation of the input beam was parallel to the direction $\vec{d}_{ref}$ on the reference surface. The polarisation direction of the transmitted beam coincided with the director on the command surface, $\vec{d}_{test}$, and could be determined by the rotation of the analyser.

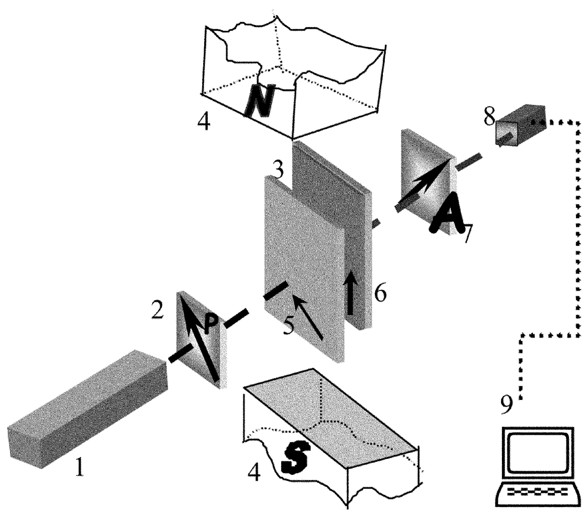

FIGURE 1. Experimental set-up: 1 – *He-Ne* laser; 2 – polariser; 3 – LC or FNS cell; 4 – S, N magnetic poles; 5 – $\vec{d}_{ref}$; 6 – $\vec{H}$-induced easy axis on the command surface; 7 – analyser; 8 – photodiode; 9 – computer.

The application of a magnetic field caused a reorientation of the magnetic particles on the polymer surface, a reorientation of the director on the command surface, and reorientation in the LC bulk. It resulted in the production of a twist structure in the combined cell. The dependence of a stationary value of the director reorientation angle, φ_{com}, at the command surface on magnetic field intensity is shown in Fig.2. The director turns *toward* the magnetic field in all cases. An increase in the ferro-particle concentration resulted in a higher sensitivity of the cell to a magnetic field.

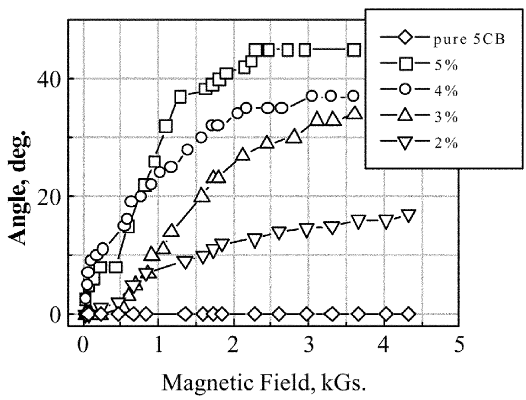

FIGURE 2. Dependence of LC orientation on the command surface upon magnetic field at different concentration of the particles.

After the magnetic field removal, the director on the command surface relaxes for a duration of tens of minutes to a quasi-steady value $\varphi_{com} \approx 6\text{–}7^{\circ}$ (Fig.3). This time is much longer than the known characteristic time of relaxation for the twist deformation in our cell in the case of a strong anchoring [10]. Slow relaxation to the equilibrium alignment after the removal of the magnetic field can be explained if we suggest that not only the ferro-grains align the liquid crystal, but also LC rearranges the ferro-grains on the PVCN-F surface. In this case, relaxation of the twist deformation of the director involves a reorientation of the ferro-grains and a drift of the easy axis to the equilibrium position.

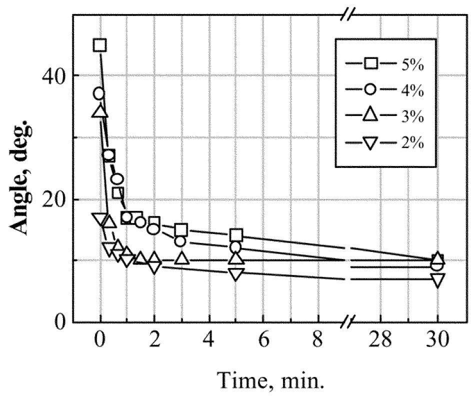

FIGURE 3. Relaxation of magnetically induced twisted structure after switching-off the magnetic field at the different concentration of the particles.

CONCLUSIONS

We have produced liquid crystal alignment by a layer of magnetic particles agglomerated to a polymer surface. Application of a magnetic field results in the orientation of FNS along the magnetic field vector. The value of the magnetic field required for the orientation of FNS is less then half of that required for a pure LC. The magnetically induced orientation on the polymer surface is multi-stable and is characterised by a weak anchoring energy. The orientation of the director of FNS could be readjusted to any angle using the magnetic field. The experimental data obtained allows us to state that magnetically induced alignment of the ferro-LC suspension is caused by a precipitation of the ferro-particles on the surface. We believe that the magnetically controlled alignment is very promising for ultra-sensitive magnetically controlled LC devices for information processing and storage.

Acknowledgement
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