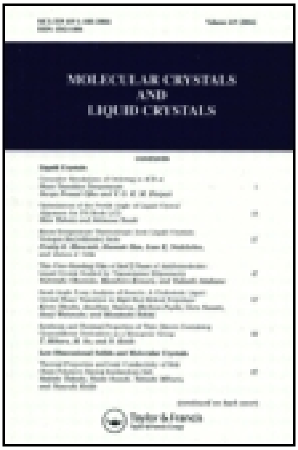

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

# Liquid Crystal Aligning Capabilities and EO Characteristics of the TN-LCD with Ion-Beam Exposure on a New Diamond-like Carbon Thin Film Layer

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Version of record first published: 18 Oct 2010

*Mol. Cryst. Liq. Cryst.*, Vol. 410, pp. 319/[847]–327/[855], 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490433091



# LIQUID CRYSTAL ALIGNING CAPABILITIES AND EO CHARACTERISTICS OF THE TN-LCD WITH ION-BEAM EXPOSURE ON A NEW DIAMOND-LIKE CARBON THIN FILM LAYER

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*Liquid crystal (LC) alignment capabilities with ion beam (IB) exposure on a diamond like carbon (DLC) layer were studied. A high pretilt angle of 3.5° with IB exposure on the DLC layer can be obtained. Superior LC alignment with the IB alignment method on the DLC layer was observed until an annealing temperature of 200°C. Also, excellent voltage-transmittance (V-T) curve of the ion beam aligned twisted nematic (TN) cell with oblique ion beam exposure on the DLC surface for 1 min was observed. The fast response time of the ion beam aligned TN cell with oblique ion beam exposure on the DLC surface for 1 min can be achieved. The residual DC property of the ion beam aligned TN cell with ion beam exposure on the DLC layer for 1 min is almost same as that of the rubbing aligned TN cell on a rubbed polyimide (PI) surface.*

*Keywords*: diamond-like carbon; EO characteristics; ion beam alignment; pretilt angle; TN-LCD

## INTRODUCTION

A rubbing method has been widely used to align LC molecules on the PI surface. LCs are aligned due to the induced anisotropy on the substrate surface. Rubbed PI surfaces have suitable characteristics such as uniform

This work was supported by the National Research Laboratory program (MI-0203-00-0008).

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alignment and a high pretilt angle. However, the rubbing method has some drawbacks, such as the generation of electrostatic charges and the creation of contaminating particles [1]. Thus, rubbing-less techniques for LC alignment are strongly needed in LCD technology. Recently, the LC alignment effects by using the photodimerization [2–9] and photodissociation [10–15] have been reported. Most recently, the LC aligning capabilities by IB exposure on the DLC layer have been successfully studied by P. Chaudhari, *et al.* [16]. This article will report on the pretilt angle generation with ion beam exposure on the DLC layer and EO characteristics of the ion beam aligned TN-LCD with oblique ion exposure on the DLC surface.



## EXPERIMENTAL

The DLC films were coated on indium-tin-oxide (ITO) coated glass substrates by remote plasma enhanced chemical vapor deposition (RPECVD). The glass substrates were presputtered due to the Ar plasma in chamber. The DLC film was deposited using the $C_2H_2$:He gas for 10 min. The $C_2H_2$ and He gas were floating 3 sccm and 30 sccm in chamber at room temperature, respectively. The thickness of the DLC layer was $3 \sim 15$ nm. The ion beam (Kaufman type Ar ion gun) exposure system is shown in Figure 1. The ion beam energies used were 100, 150, 200 eV. The LC cells were

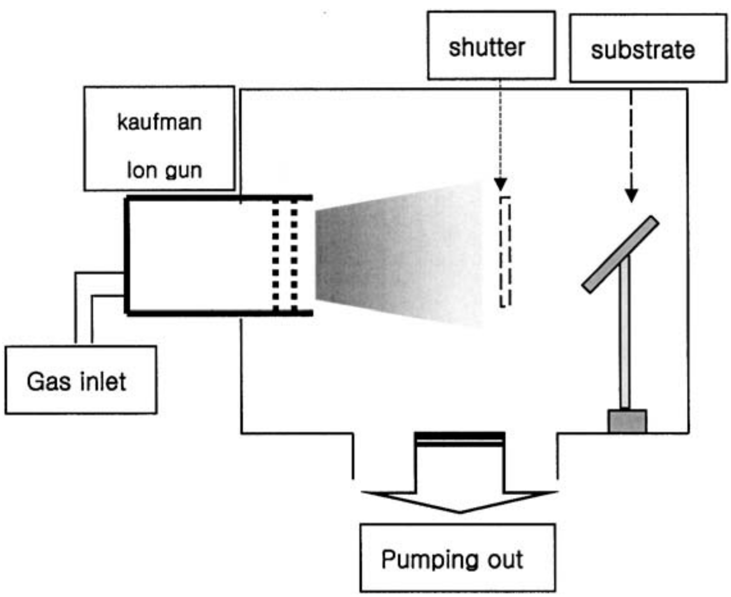


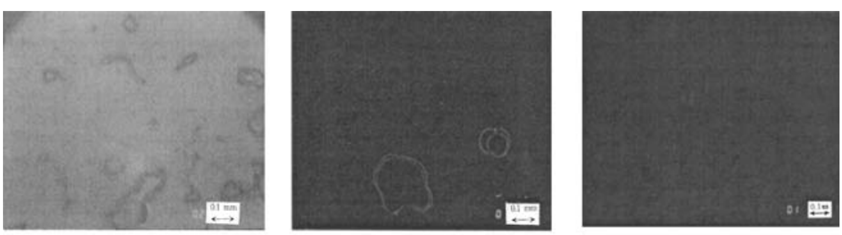

**FIGURE 1** Ion beam exposure system.

assembled by an anti-parallel structure to measure the pretilt angle. The thickness of the LC cell for pretilt angle was 60 μm, and the cell thickness of the ion beam aligned TN-LCD was 5 μm. The LC cells were filled with a fluorinated mixture type NLC without a chiral dopont (Tc = 72°C, MJ97359, from Merck Co.). Also, the rubbed polyimide (PI) cell was fabricated to be compared with LC cell by ion beam exposure on the DLC film. LC alignment ability was observed using a photomicroscope. Lastly, the pretilt angle of an anti-parallel cell was measured by a crystal rotation method, and V-T and response time characteristics of the ion beam aligned TN-LCD were measured by a DMS (Display Measurement System, from Autronic Co.) equipment.

## RESULTS AND DISCUSSION

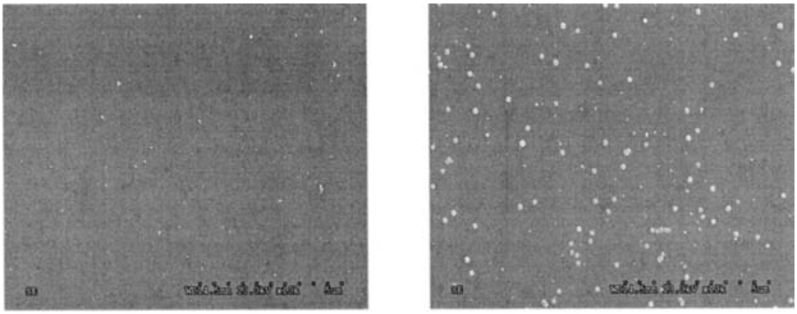
Figure 2 shows the microphotographs of aligned LC with ion beam exposure on the three kinds of DLC layers by ion beam energy intensity. In Figure 2(a) and (b), the LC alignment defects were measured with ion beam exposure on the DLC layer (ion beam energy intensity, 100 and 150 (eV)). However, excellent LC alignment was observed via ion beam exposure on the DLC layer (ion beam energy intensity, 200 (eV)) as shown in Figure 2(c). It is considered that the stable LC alignment can be obtained on the DLC with an ion beam energy intensity 200 (eV). Also, the transmittance on the DLC film was measured using the UV-VIS-NIR spectrometer. The energy band gap on the DLC film was estimated by a Tanc equation from measured transmittance. The energy band gap estimated was about 2 eV and, then, this value was observed to be an $sp^3$ bond.

Figure 3 shows the SEM photographs of LC cell with ion beam exposure on the DLC layer (ion beam energy intensity 200 (eV)). It is shown that the particles were observed with ion beam exposure on the DLC layer for



(a) 100 (eV) (b) 150 (eV) (c) 200 (eV)

**FIGURE 2** Microphotographs of aligned LC with ion beam exposure on the three kinds of DLC layers as a function of ion beam energy intensity (in crossed Nicols).



(a) ion beam exposure (1 min)

(b) ion beam exposure (5 min)

**FIGURE 3** SEM photographs of LC cell with ion beam exposure on the DLC layer (ion beam energy intensity 200 (eV)).



5 min. However, few particles were observed with ion beam exposure on the DLC layer for 1 min. It is considered that the particle is attributable to the surface roughness with increased ion beam exposure time. Figure 4 shows the transmittance versus incident angle in the NLC with ion beam exposure at an oblique direction of 45 degree on the DLC layer for 1 min (ion beam energy intensity, 200 (eV)). The pretilt angle was measured as degree of gap between axis of symmetry of graph and actuality turning axis of symmetry. The pretilt angle of an anti-parallel cell was measured about 3.5°.

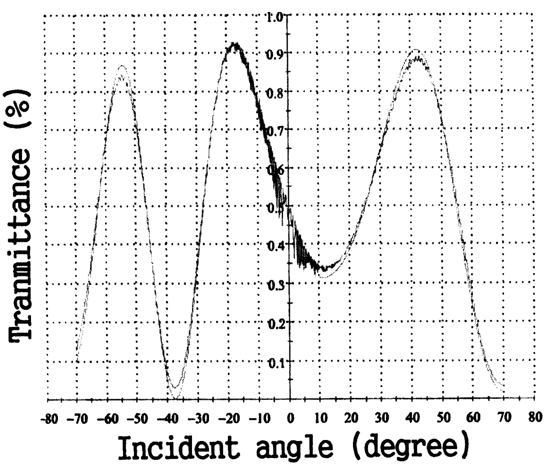



**FIGURE 4** Transmittance versus angle of incidence in the NLC with ion beam exposure on the DLC layer.

The LC pretilt angles with ion beam exposure on the DLC layer (ion beam energy intensity 200 (eV)) for 1 min as a function of the incident angle are shown in Figure 5. It is shown that the LC pretilt angle generated was about 3.5° with ion beam exposure at an oblique direction of 45° on the DLC layer for 1 min. In addition, the pretilt angle decreases with an increasing incident angle at over incident angle of 45°. It is clear that the high LC pretilt angle can be achieved with incident angle of 45°.

Figure 6 shows the LC pretilt angles with incident angle of 45° on the DLC layer (ion beam energy intensity, 200 (eV)) as a function of exposure time. The results revealed that the high LC pretilt angle was achieved by ion beam exposure on the DLC layer for 1 min, and the pretilt angle rapidly decreased with increasing ion beam exposure time over 1 min. The peak point of the LC pretilt angle was observed with ion beam exposure time on the DLC film for 1 min. Also, the LC pretilt angle decreased due to the increase in surface roughness at over ion beam exposure time of 1 min. Therefore, the high pretilt angle on the DLC layer can be controlled.

Figure 7(a) shows the microphotographs of the aligned LC with ion beam exposure on the DLC layer for 1 min at various annealing temperatures. In Figure 7(a), good LC alignment with ion beam exposure on the DLC layer was observed until an annealing temperature of 200°C, and the alignment defect of LCs were observed above an annealing temperature of 220°C. Also, the microphotographs of aligned LC on the rubbed PI layer at various annealing temperatures (in crossed Nicols) are shown in Figure 7(b). Superior LC alignment on the rubbed PI layer was observed until an annealing temperature of 200°C, and the alignment defect of the LCs were

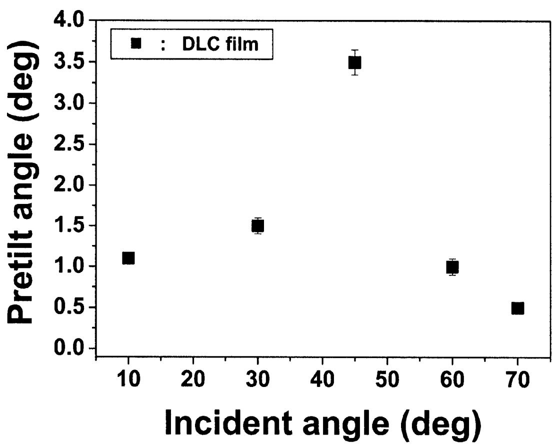



**FIGURE 5** LC pretilt angles with ion beam exposure on the DLC layer for 1 min as a function of incident angle.

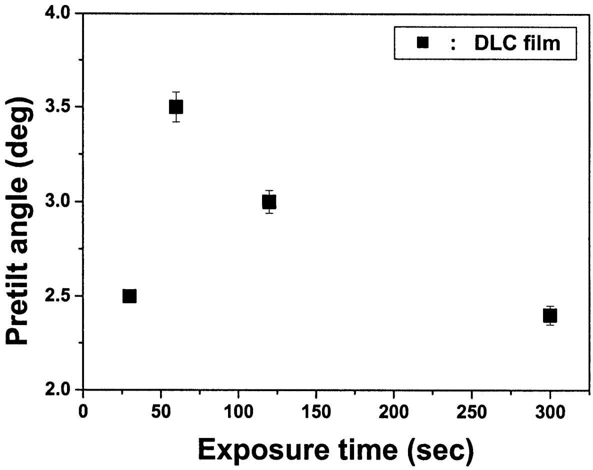



**FIGURE 6** LC pretilt angles with ion beam exposure on the DLC layer as function of exposure time.

observed above annealing temperature of 220°C. From these results, the thermal stability of LC alignment with ion beam exposure on the DLC layer was almost the same as that of the rubbed PI layer. Therefore, superior LC alignment and thermal stability via ion beam exposure on the DLC layer can be achieved.

Figure 8 shows the microphotographs of the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC layers for 1 min. Monodomain alignment of the ion beam aligned TN-LCD can be observed.

Figure 9 shows the V-T curves of the ion beam aligned TN-LCDs with oblique ion beam exposure on the DLC surface. An excellent V-T curve can be achieved in the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC surface for 1 min. The transmittances of the ion beam aligned TN-LCD on the DLC surface decreased by increasing the ion beam exposure time. Consequently, this system suggests that the best ion beam exposure time needed to achieve good V-T characteristics of the ion beam aligned TN-LCD is about 1 min.

Figure 10 shows the response time characteristics of the ion beam aligned TN-LCD with ion beam exposure on the DLC surface. It reveals that the response time characteristics of the ion beam aligned TN-LCD on the DLC surface improved by decreasing ion beam exposure time over 1 min. A low transmittance level was measured in the ion beam aligned TN-LCD with ion beam exposure on the DLC surface for 2 min. Therefore, stable response time characteristics for the ion beam aligned TN-LCD with ion beam exposure on the DLC surface for 0.5 and 1 min can be produced.

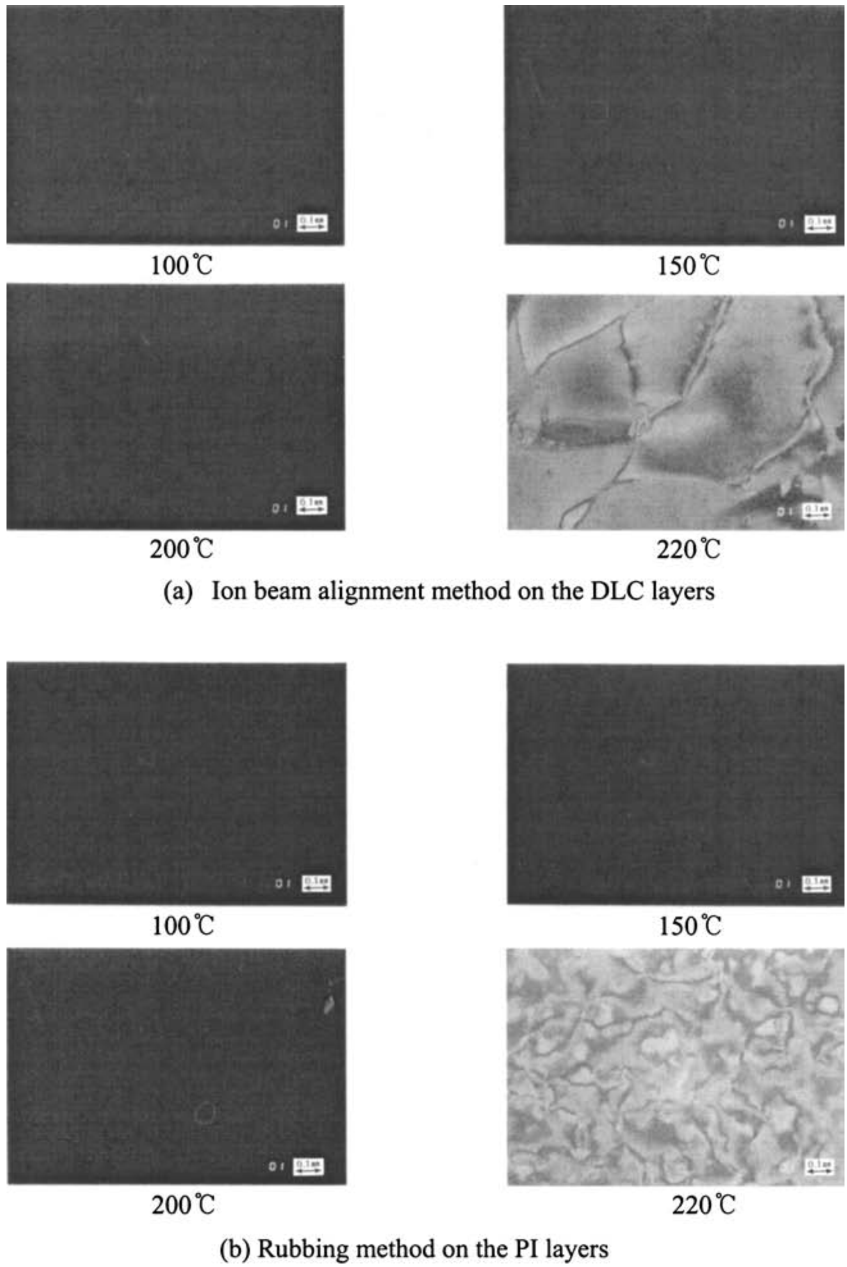



**FIGURE 7** Microphotographs of aligned LC with ion beam exposure on the DLC layer for 1 min at various annealing temperatures (in crossed Nicols).

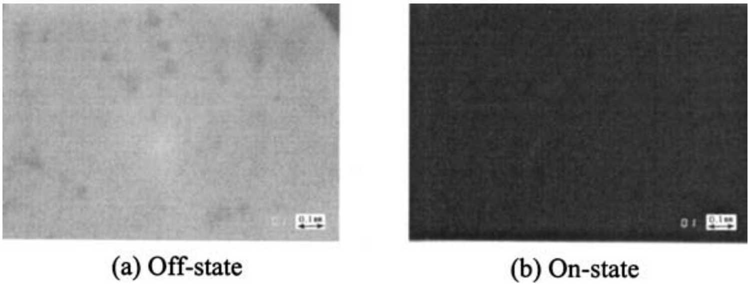



**FIGURE 8** Microphotographs of the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC layers for 1 min (in crossed Nicols).

From these results, it is contended, herein, that the ion beam exposure time needed to achieve a good V-T curve and response time characteristics is about 1 min, as shown in Figures 9 and 10.

Table 1 shows the response times for the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC thin film surface and for the rubbing aligned TN-LCD on a PI surface. The fast response time of the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC thin film surface for 1 min. Optically measured at about 18.3 ms.

Figure 11 shows the capacitance-voltage characteristics of the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC surface and the rubbing aligned TN-LCD on the PI surface. The low residual DC voltage

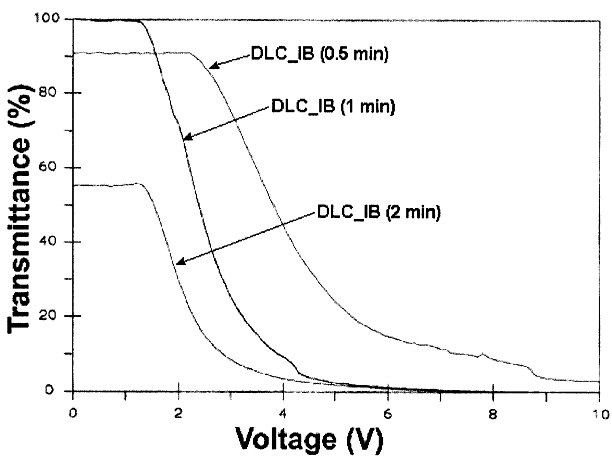



**FIGURE 9** V-T curves of the ion beam aligned TN-LCDs with oblique ion beam exposure on the DLC surface.

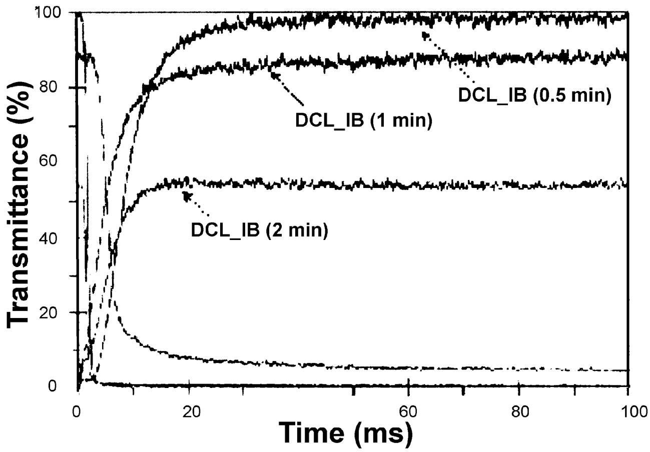



**FIGURE 10** Response time characteristics of the ion beam aligned TN-LCDs with oblique ion beam exposure on the DLC surface.

of the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC surface for 1 min was measured as shown in Figure 11(a). Figure 11 shows the C-V curves of the ion beam aligned TN-LCD on the DLC surface were asymmetric as compared with that of the rubbing aligned TN-LCD on the PI surface. It can be concluded that the asymmetric C-V characteristics of the ion beam aligned TN-LCD on the DLC surface are attributable to the inner ion of the LC cell. The residual DC voltage of the TN-LCD strongly depends on the condition of the alignment layer. Therefore, the residual DC property of the ion beam aligned TN-LCD on the DLC surface can be improved by the conditions of the DLC film and the ion beam exposure. Consequently, the EO characteristics of the ion beam aligned TN-LCD with oblique ion beam exposure on the DLC surface for 1 min are almost the same as that of the rubbing aligned TN-LCD on the PI surface.

**TABLE 1** Response Times for the Ion Beam Aligned TN-LCD on the DLC Thin Film Surface

| | Response time | | |
|---|---|---|---|
| Alignment layer | $\tau_r$ (ms) | $\tau_d$ (ms) | $\tau$ (ms) |
| DLC_IB (0.5 min) | 11.7 | 11.9 | 23.6 |
| DLC_IB (1 min) | 2.3 | 16.0 | 18.3 |
| DLC_IB (2 min) | 1.9 | 9.5 | 11.4 |

$\tau_r$ (rise time), $\tau_d$ (decay time), $\tau$ (response time).