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Microrubbing technique to produce high pretilt multidomain liquid crystal alignment

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We disclose a microrubbing (μ -rubbing) technique to create multidomain alignment in liquid crystal displays. A small metallic sphere under sufficient load is used to directly rub a polyimide alignment layer that is known to enforce homeotropic boundary conditions of the liquid crystal. We demonstrate a 47 μm linewidth and a 10° pretilt with respect to the substrate plane. We report on the electro-optic performance properties and viewing angle characteristics of four domain samples, where the midplane angle of the director is oriented in four different directions. © 2004 American Institute of Physics. [DOI: 10.1063/1.1773375]

In the liquid crystal display (LCD) industry much attention is focused on improving the viewing angle. The quality of the viewing angle has become even more important with the recent launch of LCDs into the large area display market. The viewing angle problem in conventional twisted nematic LCDs, arises from the fact that the midplane liquid crystal director angle (optic axis) is uniformly oriented in one direction creating a highly anisotropic viewing cone. Due to the inherent birefringence of liquid crystal material, different viewing directions give varying degrees of birefringence, resulting in optical transmission behavior being strongly dependent on the viewing direction. Furthermore, the electro-optic switching characteristics of uniformly aligned TN displays are strongly dependent on the viewing angle, a serious problem for stable gray scale performance, which is a prerequisite for full color, high resolution displays. There are many approaches to overcome the poor viewing angle performance in LCDs, which involve compensation films integrated on the outside of the display,^{1,2} inside the display cell modifications involving multidomain alignment,³⁻⁶ vertical alignment,⁷⁻⁹ and alternative modes of operation such as the in-plane switching IPS.¹⁰⁻¹² Multidomain alignment requires a number of lithographic steps,³⁻⁶ which is unattractive for manufacturing; therefore researchers have been focused on accomplishing the same goal using patterned photoalignment,¹³ oblique evaporation of silicon oxide^{14,15} and writing with atomic force microscopy (AFM) tip.^{16,17}

Here we report a method for fabricating multidomain twisted nematic cells by utilizing a microrubbing (μ -rubbing) process. The μ -rubbing process has recently been used for fabricating liquid crystal gratings.¹⁸ The μ -rubbing technique utilizes a metallic sphere (1 mm diameter) to physically rub an alignment layer. We utilize a polyimide alignment layer that induces homeotropic anchoring of the liquid crystal in the unrubbed state. A metallic sphere comes in direct contact with the homeotropic layer as shown

in Fig. 1(a). The metallic ball is in direct contact with the alignment layer as it traverses across the alignment layer (substrate) creating micrometer sized rubbed lines. After this process is complete, we find that the orientation of the liquid crystal that comes in contact with the surface is planar with a large surface pretilt angle. The linewidth (pixel size) can be controlled by modifying the applied load or by changing metallic sphere diameter. In this experiment we employed a constant 150 g load.

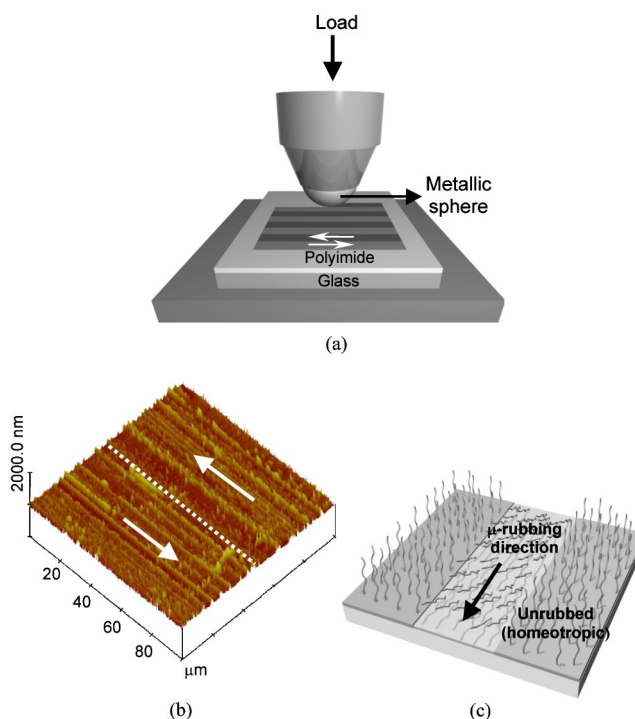


FIG. 1. Illustration of experimental setup for the μ -rubbing process, the arrows show the direction of μ -rubbing (a). Atomic force microscopy image of the μ -rubbed surface where homeotropic polyimide having two lines with opposite rubbing direction are adjacent to each other (b). A schematic illustration of a μ -rubbed surface, rich in aliphatic moieties (c).

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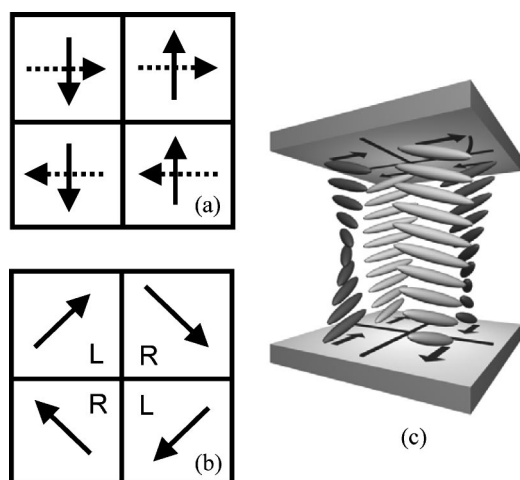


FIG. 2. Orientation of liquid crystal directors in four different domains. Solid and dotted arrows indicate the rubbing direction of top and bottom substrates (a). The direction of the midplane directors in the four domains, *L* and *R* indicate left and right twist of the liquid crystal (b). Four domains schematically showing the opposite twist sense in each subpixel (c).

We used our μ -rubbing technique to create multiple domain pixels by rubbing the surface in such a way that neighboring alignment regions are rubbed in opposite directions as schematically depicted in Fig. 1(a). Figure 1(b) shows the atomic force microscopy image of the μ -rubbed surface. The single line width is found to be $\sim 47 \mu\text{m}$ with an average surface roughness of $40 \pm 2 \text{ nm}$ as determined AFM. As can be observed from our AFM measurements in Fig. 1(b), μ -rubbing generates grooves on homeotropic polyimide on a micrometer scale.

We propose the following physical mechanism for the modification of the alignment surface from homeotropic (before μ -rubbing) to a planar alignment with large pretilt (after μ -rubbing). Polyimides that are known to induce homeotropic anchoring are either doped with long chain aliphatics or they are functionalized with long chain aliphatic molecules. When aliphatic chains pack on a substrate parallel to the substrate normal (highly aligned, compact assembly of aliphatic chains), they are known to induce homeotropic alignment of liquid crystal molecules coming in contact with them. We conjecture that the μ -rubbing process unidirectionally aligns the aliphatic chains at a specific angle as schematically shown in Fig. 1(c). This mechanism leads to a dramatic change in the anchoring direction for liquid crystal molecules interacting with the surface.

We generated μ -rubbed patterns in such a way that the neighboring lines were rubbed in antiparallel directions (the neighboring lines were directly adjacent to each other). Liquid crystal cells were constructed with $5 \mu\text{m}$ thickness cell gap in which the top and bottom substrate were oriented such that the μ -rubbed directions are orthogonal. Figure 2(a) shows the rubbing directions on the top and bottom substrates and Fig. 2(b) shows the midplane tilt direction in the center of the cell. A three-dimensional rendition of a multi-domain pixel is depicted in Fig. 2(c). Due to the difference in the rubbing direction in this multidomain configuration, we have two left-handed and two right-handed subpixels.

The two different bias tilt directions on each substrate define the appropriate sense of the four subtweisted pixel configuration. On the macroscopic scale, the optical anisotropies of the differently aligned midplane tilt angles of the four

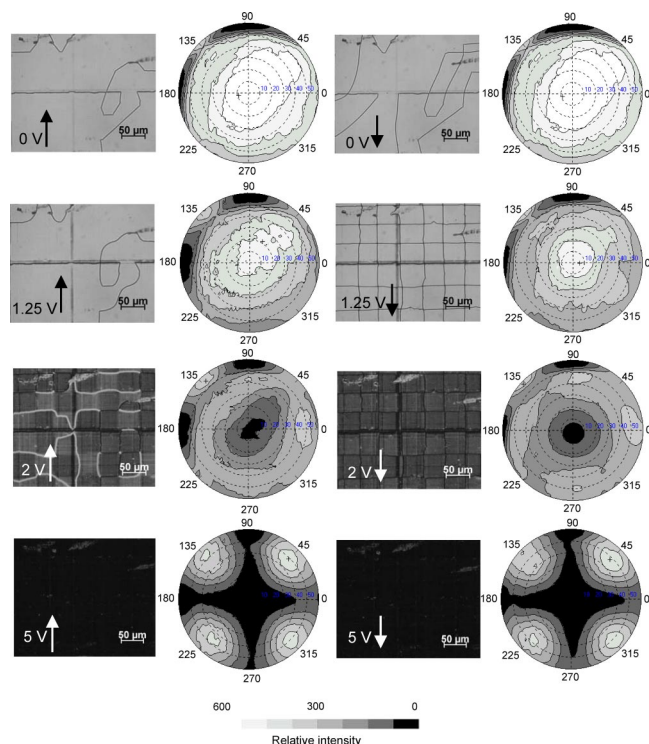


FIG. 3. Optical microscope photograph of a four-domain twisted nematic cell created by the μ -rubbing process situated between crossed polarizers and subjected to an applied voltage, left side, $0 \text{ V} \rightarrow 5 \text{ V}$ and right side $5 \text{ V} \rightarrow 0 \text{ V}$. The contrast as a function of viewing angle of the four-domain TN cell under the same voltage are also shown.

subhelices compensate each other as shown in Figs. 2(b) and 2(c). The angular dependence of a four-domain display is significantly reduced as compared to conventional single domain TN LCDs.¹⁵ Since we engineered our samples to have a $47 \mu\text{m}$ pixel size, we were unable to measure the pretilt angle directly in a given subpixel using the crystal rotation method.¹⁹ Therefore, we constructed single domain cells so that we could carry out the pretilt angle measurements. Antiparallel rubbed cells were constructed with a cell gap of $18 \mu\text{m}$ and filled with liquid crystal E7. The pretilt was measured directly using an Autronic, TBA 107 instrument. The pretilt was measured to be $9.8^\circ \pm 0.5^\circ$.

Figure 3 presents the polarizing optical microscope photographs of four domain TN cell and its viewing angle characteristics measured with an Eldim conoscope as a function of applied voltage. The left part of the diagram represents increasing voltage ($0 \text{ V} \rightarrow 5 \text{ V}$) and the right part of the diagram represents decreasing voltage ($5 \text{ V} \rightarrow 0 \text{ V}$). When the sample is switched from 0 to 5 V in small increments we observe the formation of disclination lines at 2 V and it transforms into a perfectly dark state at 5 V (homeotropic). The four domain structure is stabilized for voltages $> 2 \text{ V}$. When we slowly reduce the voltage from 5 to 0 V we could see the clear disclination lines in the four domains even for lower voltage level. The larger dark lines in Fig. 3 (left) at 2 V are due to a small gap between two μ -rubbed lines (splay configuration with one surface having homeotropic alignment and other surface having parallel alignment). The occurrence of this is due to the spatial resolution of our laboratory μ -rubbing apparatus. The viewing angle measurements of TN cell at four different voltages are also presented in Fig. 3. At a voltage of 1.25 V, when coming from high

voltage, we can observe the symmetric nature of the isointensity curves, inherent of the multidomain twisted nematic configuration;^{13,14} however, the microscope photographs reveals that the four domain mode is not stable.

The twisted states in our samples are completely determined by the pretilt angle; therefore, a large surface pretilt angle is required to offset the energy cost of the generation of twist disclinations. In order to ascertain the stability of our four-domain samples in zero field, one needs to compare the free energy cost associated with forming disclination lines and the wrong handedness subpixel orientations that cost splay energy. In our polarizing microscope photographs shown in Fig. 3, unstable disclination lines are still visible at 2 V when increasing from low voltage, whereas when decreasing from high voltage stable disclination lines are visible.

Using a simple model proposed by Chen and co-workers¹⁴ based on the tilt angle θ , subpixel dimensions $L \times L$, and the cell gap d , from the known elastic and defect properties of nematic liquid crystals, the stability condition can be expressed by the following equation: $\theta^2 \geq \pi d/L$.

Using $L=50 \mu\text{m}$ and $d=5 \mu\text{m}$, the predicted minimum pretilt angle, θ_{min} , to stabilize the structure is $\theta_{\text{min}} \sim 30^\circ$. Since our cells only have a pretilt of $\sim 10^\circ$, our zero field structures do not have four domain stable structures. Although this model is simple, it is consistent with the findings in the literature.^{14,15} Therefore, in our sample in the zero voltage and low voltage states where the disclination lines disappear or are unstable, the four domain essentially transforms into a two domain reverse tilt sample. It is possible to stabilize the four domain structure using a voltage initialization process and driving the sample with bilevel voltages. This scheme can completely lock-in the motion of disclination lines.¹⁵ We essentially demonstrated this phenomena by reducing the voltage after domains were formed at high voltage. However, with our μ -rubbing process, we believe that large pretilt will be possible by optimizing the applied load. We have found that rubbing pressure is correlated to pretilt angle. In this contribution we applied 150 g load and obtained a $\sim 10^\circ$ pretilt. We have applied lower loads and have measured larger pretilt angles which is a subject of a future publication.²⁰

In conclusion, we have fabricated multidomain twisted nematic configuration using a reverse μ -rubbing process.

The μ -rubbing process can be used to generate a multidomain configuration with a high surface pretilt angle, in our case 10° . The sample cells fabricated with this μ -rubbing technique appear robust with no noticeable differences in electro-optical performance characteristics over a period of 1 year. A more through investigation on sample degradation and temperature dependence is a subject of future study.²⁰ Our μ -rubbing technique is straightforward, flexible, economical, and simple to execute. We believe this technique can be scaled up and used in the production of large area displays.

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