P-133: Variable Liquid Crystal Pretilt and Azimuth Angle using Stacked Alignment Layers

Chung-Yung Lee, Yuet-Wing Li and Hoi-Sing Kwok

Center for Display Research,
Department of Electronic and Computer Engineering
Hong Kong University of Science and Technology
Clear Water Bay, Hong Kong

Abstract

A new alignment layer is developed. This alignment layer is capable of generating arbitrary pretilt and azimuth angles for the liquid crystal. It is based on stacking both photo-aligned polymer and rubbed polyimide together. The alignment produced is robust. Moreover, the processing window is also maximized.

1. Introduction

Heterogeneous surface for liquid crystal (LC) alignment has become increasingly attractive in recent years [1-2]. It is because such alignment surfaces are capable of generating arbitrary pretilt angles, especially in the range of 30º-60º. Many applications can be made possible if such pretilt angles are available, such as bistable display devices [3] and no-bias-bend fast switching display devices [4]. This type of alignment surface comprises two kinds of domains favoring different LC orientation. The arrangement of those surfaces can be in alternating stripped or checkerboard patterns. Alternatively a random nanostructure formed by precipitation can be used.

In this work, we propose a new alignment surface based on stacked alignment layers. The stacked alignment layers comprise of both photo-aligned horizontal polymer and rubbed vertical polyimide. The advantage is that photoalignment can be used so that further patterning of the pixel is possible. Here we show that this alignment layers are able to fill the technology gap which produce arbitrary multiple pretilt and azimuth angles on the same alignment substrate. The alignment produced is robust. Moreover, the processing window is also maximized.

2. Stacked Alignment Surface

The structure of the proposed stacked alignment layers is shown in Figure 1. The stacked structure consists of 2 layers of alignment materials. The bottom alignment layer is continuous, while the upper alignment layer is discontinuous.

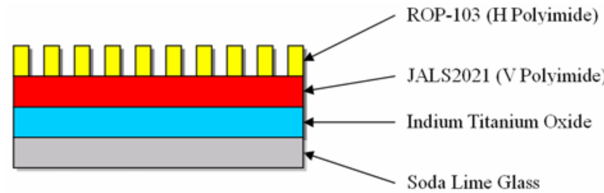


Figure 1. An overview of the proposed stacked alignment structure.

The most crucial step is to obtain the discontinuous alignment layers on top of the continuous layer reliably, without disturbing the alignment properties of the underlying continuous layer. Our proposed method relies on convection in the liquid layer. Convection is the well known phenomena of fluid motion induced by buoyancy when a fluid is heated from below. Consider a fluid layer place on a flat substrate. The upper surface of the fluid is open to air and is heated uniformly from below. In consequence, the warm fluid tends to rise and the cool fluid tends to sink. Obviously both cannot happen together without interference. As a result, there will be locations where the fluid rises and some locations where it sinks. In fact, this impasse results in the spontaneous formation of a pattern of convection polygonal cells. In each cell the fluid circulates in a closed orbit. Eventually, the polygonal cells become array of almost perfect hexagons. The centre of each hexagonal cell is a region of upwelling warm fluid and which spreads out over the upper surface and sinks at the perimeter, where adjacent cells are joined. This effect was introduced by J. R. A. Person [5]. Figure 2 depicts such phenomenon.

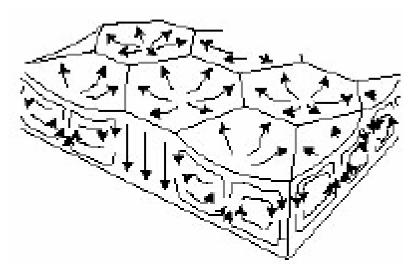


Figure 2. Convection inside the liquid layer.

The onset of the convection is determined by the critical Marangoni Number M_c. M_c is equal to the surface tension gradient force divided by the product of the viscous drag and the rate of heat diffusion.

$$M_c = (\gamma \Delta T d) / (\rho \nu \kappa) \qquad (1)$$

where γ denotes the temperature derivative of the surface tension, ρ is the density at a reference temperature, ν and κ are the kinematic viscosity and the thermal diffusivity respectively. It is well known that convection begins when the Marangoni number exceeds a critical value, $M_c = 81$ in weightlessness (g=0). If there is no convection, the alignment material will always uniformly distribute inside the fluid. A continuous alignment layer can be obtained under this case. However, if convection occurs (i.e. $M > M_c$), the fluid circulation which is elicited by the temperature gradient, causes non-uniform distribution of alignment material inside the solvent after the solvent evaporated, the alignment material will deposit on the substrate according to the concentration distribution. Such phenomenon results in a discontinuous alignment layer. According to the literature [5-6], the wavelength of the hexagonal cell is a function of fluid thickness and temperature gradient. In other words, the wavelength of the pattern can be extremely uniform by controlling the experimental environment carefully. Such features allow large scale and large size display panel fabrication to be possible.

3. Experimental Results

In order to verify the theory, several experiments have been done. The following describes the details of the experiment procedure. Firstly, an ITO glass substrate is prepared. Figure 3 shows the AFM picture of the ITO crystalline pattern.

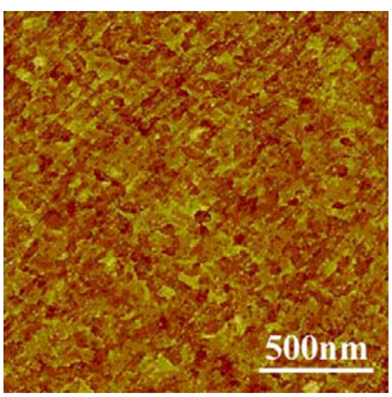


Figure 3. AFM picture of the ITO crystalline pattern.

Secondly, the vertical alignment polyimide JALS2021 form JSR Corporation is spin coated on the substrate. Then it is baked inside the oven, actually it is just the standard procedure for conventional polyimide alignment layer preparation. The main solvent of the JALS2021 is N-Methylpyrrolidone (NMP) which has a high viscosity constant, 1.67cPa. It is expected no convection will occur during the baking. Figure 4 shows the AFM picture of the vertical alignment polyimide after the baking.

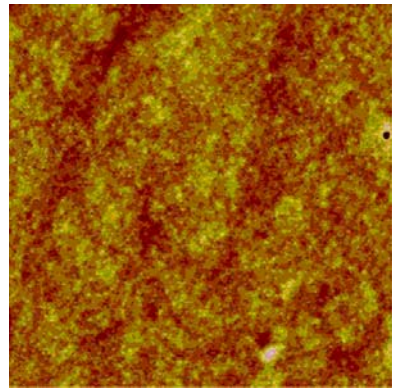
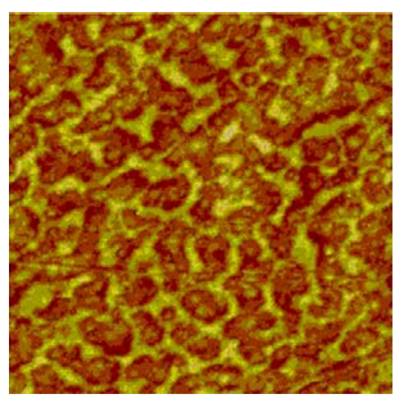
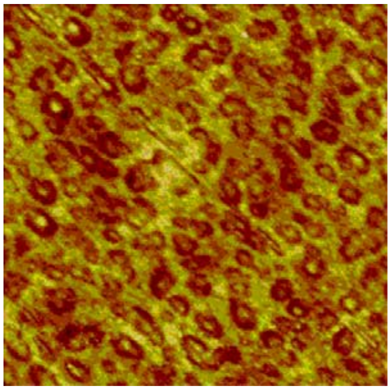


Figure 4. AFM picture of the continuous vertical alignment layer

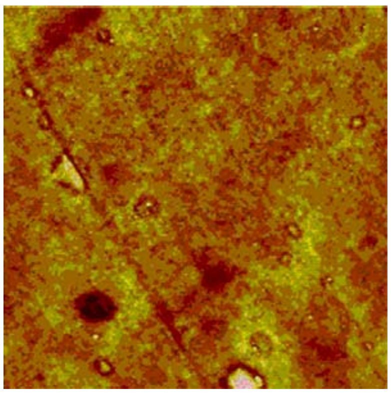
The vertical alignment polyimide completely covers the ITO crystalline pattern. The substrate is then rubbed so that the first principle pretilt θ_1 and azimuth ϕ_1 angles are obtained. Thirdly, the substrate is spin coated with different concentration of a photo-alignment material: ROP-103 from Rolic Ltd. The concentration of the ROP-103 can be adjusted by the solvent cyclohexanone. The viscosity of the cyclohexanone is 0.898cPa. After that, the substrate is put on a hot plate for soft baking. At the end, the substrate is exposed by a linearly polarized light with a wavelength of 340nm. So that the second principle pretilt θ_2 and azimuth ϕ_2 angles are obtained. Since a low viscosity solvent is applied, convection is expected to occur during the baking procedure. Figure 5(a)-(c) show the AFM pictures of the stacked alignment layers with different concentration of ROP-103. It can be seen that the upper photo alignment layers are indeed discontinuous and the wavelength of the cells are quite uniform with a hexagonal pattern. As the concentration of the ROP-103 increase, the viscosity of such solution will also increase. Eventually, the solution cannot undergo convection during the baking. Figure 5(c) shows a continuous ROP-103 alignment layer.



(a)



(b)



(c)

Figure 5. AFM pictures of the upper photo alignment layers with different concentrations of ROP-103 solutions. (a) 6% (b) 8% (c) 10%.

By using the stacked alignment layers, 2 principle alignment directions (θ_1=82°, ϕ_1) and (θ_2=0.5°, ϕ_2) can be generated by using JALS2021 and ROP-103 respectively. The resultant pretilt angle θ_H is measured by the crystal rotation method [7]. Figure 6 shows the relationship between the p and θ_H, where p is the area ratio of different ROP-103 concentrations and $|\phi_1-\phi_2|$=0. The relationship is linear, hence the processing window is maximized.

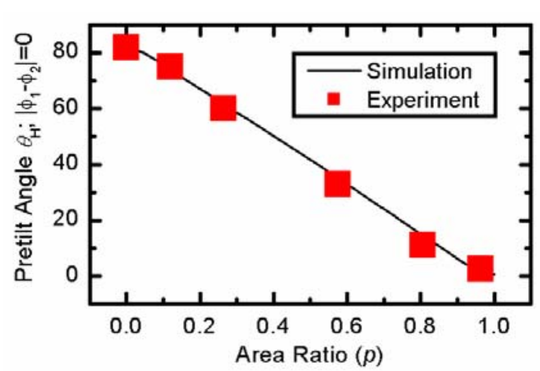
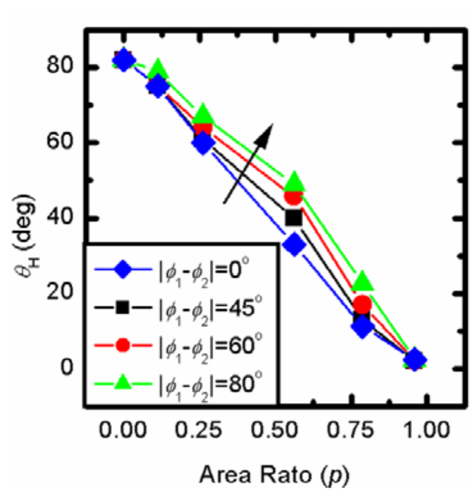
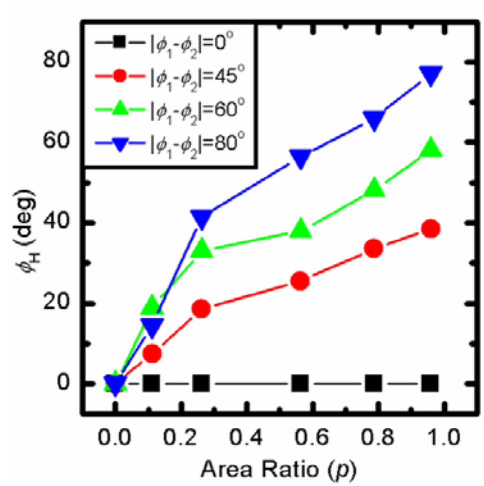


Figure 6. Homogenized pretilt angle θ_H versus area ratio p.

For the case $|\phi_1-\phi_2|$>0, a new parameter is induced, homogenized azimuth angle ϕ_H. Figure 7 shows the effect of the case $|\phi_1-\phi_2|$>0 on the homogenized pretilt and azimuth angle (θ_H, ϕ_H). It can be seen that as $|\phi_1-\phi_2|$ becomes larger, the θ_H with the same area ratio will always get slightly higher. This phenomenon is due to the twist elastic energy. The θ_H has to increase, so that the elastic energy caused by the twist effect can be minimized. Furthermore, as the concentration of ROP-103 increase, ϕ_H will switch from ϕ_1 to ϕ_2.



(a)



(b)

Figure 7. Effect of $|\phi_1-\phi_2|$>0 on (a) θ_H and (b) ϕ_H.

The anchoring energy values of different θ_H are also measured by high voltage method [8], as shown is Figure 8. The average value is about 1.2mJ/m^2. Such value is high and is similar to conventional polyimide.

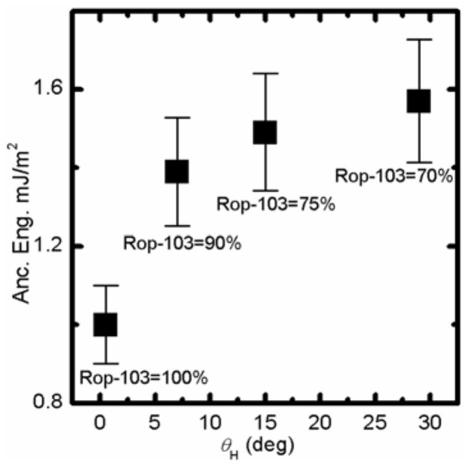


Figure 8. Anchoring energy of different θ_H.

We have also checked the repeatability of the stacked alignment layers. Specimens of different concentrations of ROP-103, 0%, 2%, 4% and 6% are tested. For each concentration, ten samples have been fabricated. The pretilt angle θ_H is then measured by crystal rotation method.

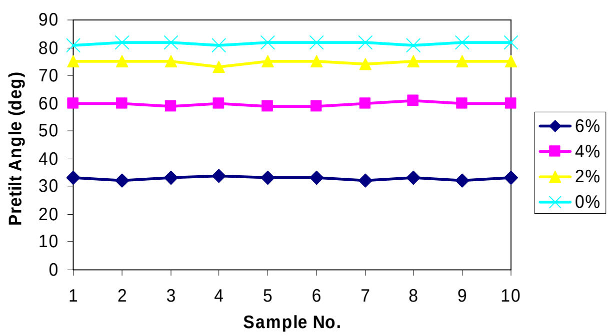


Figure 9. Stability of the pretilt angle θ_H.

From Figure 9, it can be seen that the pretilt angles produced by the stacked alignment surface are very stable. It should be the case, as the pretilt angles are controlled by the hexagonal cells of the upper discontinuous photo-aligned horizontal polymer layer. The sizes of such hexagonal cells are uniform, since they are formed by convection of fluid, and only depend on the fluid thickness and temperature. Those parameters can be precisely controlled in the fabrication processes easily. As a result, pretilt angles produced by the stacked alignment layers are highly repeatable.

The operating temperature range of this stacked alignment layer is quite wide. Figure 10 shows an example of a concentration of 6% or ROP-103 sample cell between operating temperatures of 10°C and 80°C. The pretilt angle remains almost constant throughout the test. In fact, this temperature behavior is similar to the original polyimide. Thus the new alignment layers described here are practical to manufacture common liquid crystal displays.

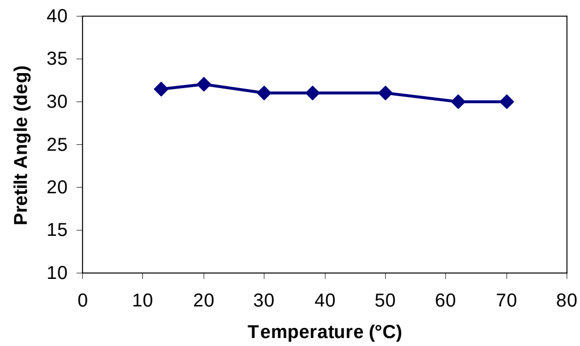


Figure 10. Pretilt angle θ_H as a function of operating temperature.

4. Conclusion

We have demonstrated a new alignment surface that is capable of generating arbitrary pretilt and azimuth angle for liquid crystal. It is achieved by stacking two alignment materials. The processing window is maximized and the results are highly repeatable. Such alignment layer is particularly useful for large pretilt angles and multi-domain applications due to the use of photoalignment materials. Bistable displays, fast switching LC modes, switchable focal LC lenses, wide viewing angle displays and waveguide devices are examples of possible applications.

5. Acknowledgement

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6. References

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