23.2: High Pretilt Angles by Nano-Structured Surfaces and their Applications

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Abstract

We propose and demonstrate a nano-structured alignment layer which is capable of producing pretilt angles of any value from 0^{o} to 90^{o}. This alignment layer is robust, stable, reliable and highly manufacturable. We utilized these alignment layers to obtain ~45^{o} pretilt angles to make a pi-cell which is in the bend alignment with no bias voltage. This No-bias bend (NBB) cell has a total response time of <2ms. We have also applied this method to fabricate a bistable bend-splay display successfully.

1. Introduction

There is much demand for an alignment layer that can produce high pretilt angles in the range of 30-60^{o}. Many applications can be made possible if such large pretilt angles are available. Two of such applications are: (1) A no bias voltage pi-cell for fast LCD TV. (2) Bistable bend-splay displays [1].

Traditionally, the best method of obtaining large pretilt angles is by oblique angle SiO_2 evaporation. However this technique is not amenable to mass production. There have been other proposed methods including photoalignment and special polymers blends and co-polymers as the alignment layer [2-5]. None of them has been proven useful so far.

In this work, we propose and demonstrate the application of nano-structured surfaces as the alignment layer. We show that such surfaces can indeed provide any pretilt angles between 0^{o} and 90^{o}. The anchoring energy is also strong, being comparable to ordinary rubbed polyimide (PI). In fact, ordinary PIs are employed as the ingredient in making such nano-structured surfaces.

Using these alignment layers, we have achieved large pretilt angles in the range of 40-55^{o} reliably. Using these alignment layers, no-bias voltage pi-cells and bistable bend-splay displays have been successfully made and tested. In the case of fast LCD, total response times of less than 2ms were measured. Application to fast LCD TV is possible.

2. Theory of nano-textured surface

The basic idea is to use a nano-structured or nano-textured surface as the alignment layer. Such surface consists of domains or network structures that are sub-micron in size. This is somewhat counter-intuitive since it is usually desirable to have a uniform alignment layer for LCD. Texturing may lead to non-uniformity of the alignment and hence visually defects. However, if the domains are small enough, the LC alignment will become uniform as we shall show below.

Consider a surface consisting of regular domains of vertical (V) and horizontal (H) alignment materials. The liquid crystal near the surfaces are aligned either vertically or horizontally. Away from the surface, however, the liquid crystal will realign themselves to minimize the elastic deformation energy. The situation is as depicted in Fig. 1 which shows the calculated director field as a function of cell distance (z-direction) along the surface (x-direction).

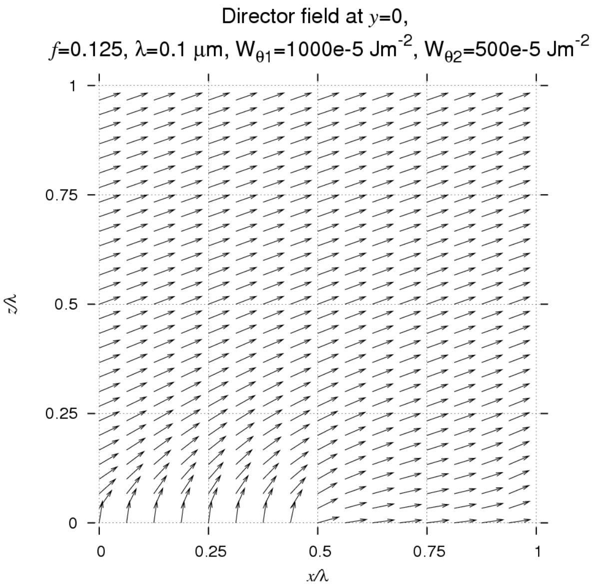
Director field at y=0,
f=0.125, λ=0.1 μm, $W_{\theta 1}$=1000e-5 Jm^{-2}, $W_{\theta 2}$=500e-5 Jm^{-2}

Figure 1. The calculated director field as a function of cell distance along the surface

Here λ is the length scale of the nano-domains. $W_{\theta 1}$ and $W_{\theta 2}$ are the polar anchoring energies of the V and H domains respectively. It can be seen that a uniform pretilt angle is achieved in a critical distance of less than 0.25λ. It is easy to see that if the domains are randomly distributed, the same uniform pretilt angle will also be achieved. This final pretilt angle will depend on the area ratio of H and V domains, the relative anchoring strengths as well as the elastic constants of the LC.

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Fig. 2 shows the calculated pretilt angle at large distances as a function of the area ratio *p* of the V and H domains. Here $q_{\theta 2} = 1000/\lambda$, where $q_{\theta 2}$ is a measure of the absolute anchoring strength and is defined as

$$q_{\theta i} = K_{11} / W_{\theta i} \qquad (1)$$

It has the dimension of length and can be defined as the extrapolation length. The pretilt angle should depend on the ratio of the polar anchoring energies. However, it can be seen that for the range of ratios (from 0.5 to 5.0), the calculated average pretilt angles are more of less the same. This is because of rather strong anchoring is used. For weak anchoring, the dependence on the ratio of $W_{\theta 1} / W_{\theta 2}$ will be strong.

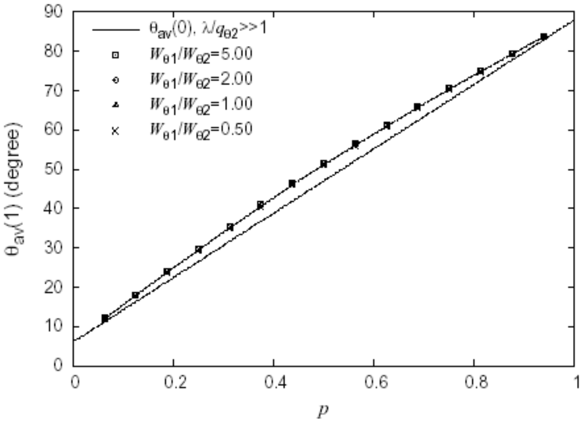

Figure 2. Calculated average pretilt angle as a function of area ratio of V and H domains.

If the domain distribution is random, then there will be a distribution of the pretilt angles at any distance. This distribution is more random near the surface and should be more uniform as z increases. Indeed, it is the case. The standard deviation of the distribution of θ can be half of the average value at z=0, and decreases to near zero at z=λ.

3. Experimental results

To realize these surfaces and verify the theoretical calculations experimentally, we made many nano-textured surfaces using various methods. One of the straight-forward method relies on phase separation of the PI upon drying. We dissolved H and V polyimides in special solvents that allow them to mix together. The resulting liquid is then coated onto the substrate and is allowed to solidify in a controlled environment. The different solubilities of the polyimides ensure that they precipitate at different times and form nano-domains in a random fashion. The size of the domains and the relative area ratio depends critically on the rate of evaporation of the solvent and the relative solubilities. Fig. 3 shows examples of such a nano-structured surface. The top picture was taken with a high resolution microscope with the width of the picture being 50µm, while the bottom picture was taken with an AFM with a max scale of 5µm. In the top picture, the dark domains correspond the V polyimide while the lighter color background is composed of the H polyimide.

By varying the volume ratio of the H and V materials, we can change systematically the area ratio of V:H as well. Notice that the volume ratio and the area ratio are not necessarily the same due to the precipitation process. Fig. 4 shows the measured pretilt angle as a function of the volume ratio of the V material.

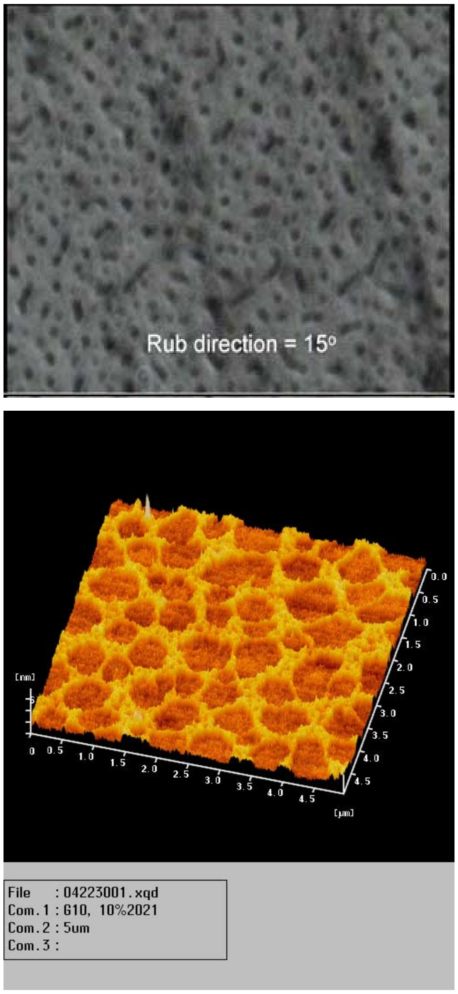

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Figure 3. Examples of nano-structured surfaces.

It can be seen that indeed any pretilt angle can be generated. The anchoring energy of the LC on these special surfaces has also been measured. However, special methods have to be developed since these pretilt angles are too large for traditional approaches. The measured anchoring energies are in the range of 1-2x10^{-3} J/cm^2 which is the same as ordinary rubbed PI. We have also checked that these alignment layers are stable against temperature cycling up to 180°C. Thus the new alignment layers described here are quite practical.

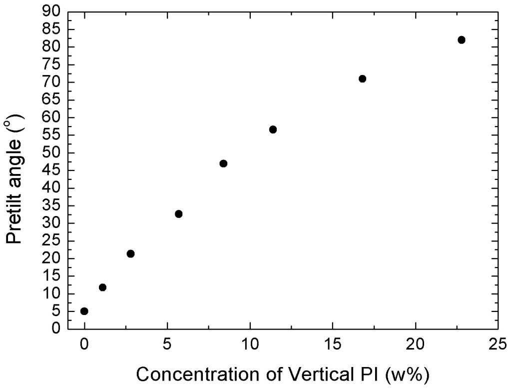

Figure 4. Measured pretilt angle as a function of the volume ratio of the V material

4. Applications

4.1 Fast LCD for TV (NBB)

The availability of a reliable method of producing large pretilt angles is important for many applications. The most important one is the fabrication of pi-cells with no bias voltage. We shall call these no-bias bend (NBB) cells. As is well known, conventional pi-cells are actually stable in the splay deformation. A critical voltage is needed to transform the splay cell into a bend cell [6]. Such "priming" is critical to the function of a pi-cell and there are several approaches to this difficult problem. However, if the pretilt angle is large enough, the pi-cell can be stable in the bend deformation even without a bias voltage.

Fig. 5 shows a calculation of the elastic deformation energy of a splay cell and a bend cell having the same pretilt angles on both sides. For low pretilt angle, the splay cell is more stable with lower deformation energy. For large pretilt angles near 90°, the bend cell is more stable. It can be seen that in this figure, a NBB cell can be obtained at pretilt angles larger than 45°.

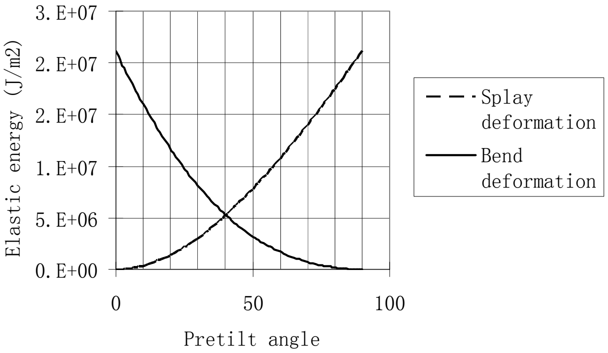

Figure 5. Elastic deformation energy of a splay and a bend cell.

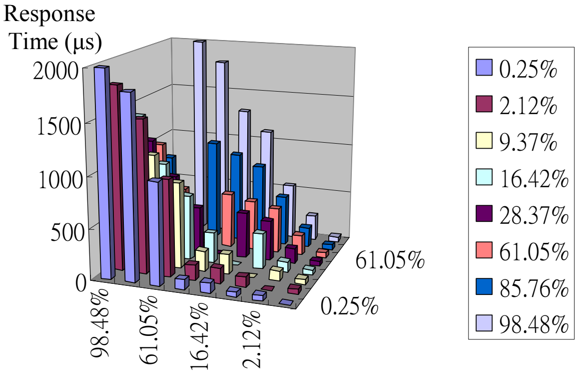

Figure 6. Gray-to-gray switching speed of NBB pi-cell

We have made a NBB pi-cells using nano-textured alignment surface to give a 50° pretilt angle. The operating voltages of this NBB cell are similar to a conventional pi-cell except that we do not need a critical bias voltage on the cell constantly. Being a pi-cell, this NBB cell can have a fast response time. Fig. 6 shows the gray-to-gray switching speed of this pi-cell. The plot shows the total on and off switching times. It can be seen that the total response time is faster than 2ms for the worst case. The average is about 1ms. It is good enough for LCD TV application to overcome the troubling blurring problem.

We have also made a LCOS based on this NBB operating mode. Because of the thinner cell gap due to reflective nature of LCOS, the response time is even faster. The total on and off times are less than **0.7ms**. This is good enough for many time sequential color operation.

4.2 Bistable LCD

There are many bistable technologies vying for the portable low power display market. The common ones are cholesteric displays, BTN and ZBD. Last year, we introduced the bistable bend-splay BBS display [1]. This display is based on Fig. 5. At the critical pretilt angle, the elastic deformation energies of the bend and splay cells are the same, thus leading to bistability.

We have fabricated a bistable bend-splay LCD using the new nano-structured alignment surfaces. Indeed large area bistable BBS can be obtained. This method is much better and more manufacturable than the evaporated SiO_2 method we employed before. This alignment technique, together with the dual frequency driving technique [7], should make the bistable bend-splay display a serious contender in the field of e-book and signage applications against other technologies such as BTN and ZBD.

5. Conclusions

In summary, we have demonstrated a new method of obtaining high pretilt angles for making LC cells. This method is based on the fabrication of a nano-textured surface using vertical and horizontal alignment materials. It is robust, does not involve untested new materials and is compatible with existing manufacturing techniques. It should find many applications in LCD fabrication, particularly in making fast LCD for TV. It can be applied to the fabrication of bistable displays as well.

Acknowledgements

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