Variable liquid crystal pretilt angles by nanostructured surfaces

Fion S. Yeung, Jacob Y. Ho, Y. W. Li, F. C. Xie, Ophelia K. Tsui, P. Sheng, and H. S. Kwok[a)]
Center for Display Research, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

(Received 23 August 2005; accepted 13 December 2005; published online 31 January 2006)

Variable liquid crystal pretilt angles of any value from 0 to 90° can be obtained by using a nanostructured alignment layer. This layer is robust and reliable. The pretilt angles obtained are stable against high storage and operating temperatures, and have strong anchoring energies. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2171491]

Liquid crystal displays (LCDs) are conventionally aligned by rubbing of a polyimide (PI) layer. Pretilt angles of 0–10° are usually obtained for homogeneous alignment PI. Vertical alignment PI can give a pretilt angle of 85–90°. However, there is much demand for an alignment layer that can produce intermediate high pretilt angles in the range of 30–60°. Many applications can be made possible if such large pretilt angles are available.

Traditionally, the best method of obtaining large pretilt angles is by SiO_2 evaporation.[1] However, this technique is not amenable to mass production and for large display panels. There have been other proposed methods including photoalignment technology, special polymer blends and block copolymers as the alignment layer.[2–4] But none of them has proven useful so far.

We have recently described a nanostructured alignment surface based on a random distribution of vertical and horizontal polyimide domains.[5,6] In this letter, we report new results on these nanostructured surfaces to prove their usefulness in making novel liquid crystal displays. In particular, as the alignment layer for LCD, we show that such surfaces can indeed provide any pretilt angles between 0 and 90°. The polar anchoring energy of such surfaces is also very strong, being comparable to ordinary rubbed polyimides. In fact, ordinary polyimides are employed as the main ingredient in making such nanostructured surfaces. With these alignment layers, no-bias voltage π cells and bistable bend-splay displays have been successfully fabricated.[5]

The basic idea of employing a nanostructured surface is by mixing horizontal (H) polyimide and vertical (V) polyimide in a solvent that allows them to mix together. The resultant solution is coated onto a glass substrate by various standard methods such as spin coating or printing. The liquid film is then allowed to solidify under a controlled environment. The solid film formation process is the crucial step in determining the structure of the resultant film. Essentially, since the H and V polyimides are generally not miscible in the solid form, a segregation process occurs during drying of the liquid film. The rate of precipitation, the relative solubilities in the solvent, the surface properties of the polyimides all play an important role in determining the final structure of the film.

We have tried many combinations of commercially available H and V polyimides in our experiment. The results reported here were obtained with JALS9203 and JALS2021 from the Japan Synthetic Rubber Company. When these polyimides are mixed in a solution and coated onto glass substrates, they form nanostructured domains naturally upon drying. After the standard rubbing treatment to define the alignment directions, controlled pretilt angles can then be obtained. Theoretically, it can be shown that if the H and V domains are randomly distributed on the substrate, a uniform pretilt angle of the LC can be achieved at a short distance away from the alignment surface.[5,6] The final pretilt angle depends on the area ratio of the H and V domains, the relative anchoring strengths of the domains as well as the elastic constants of the LC. Details of this calculation are shown in Ref. 5.

The size of the domains and the relative area ratio depend critically on the rate of evaporation of the solvent and the relative solubilities of the polyimides. Figure 1 shows an example of such a nanostructured surface. The light colored domains correspond to the V polyimide while the darker background is composed of the H polyimide. Theoretically, the LC molecules are either vertically or horizontally aligned immediate at the alignment surface. They relax to a uniform tilt angle in a short distance which is determined by the size of the nano-domains. In general, the tilt angle becomes very

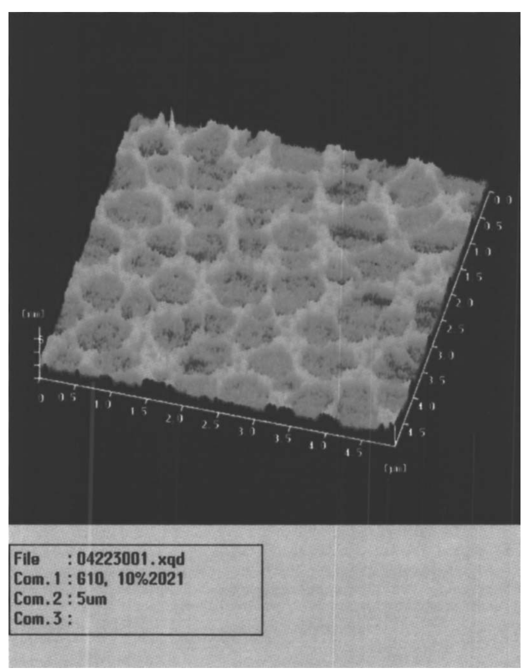

FIG. 1. Atomic force micrograph of the nanostructured surface. Light colored region corresponds to vertical PI.

[a)]Author to whom correspondence should be addressed; electronic mail: eekwok@ust.hk

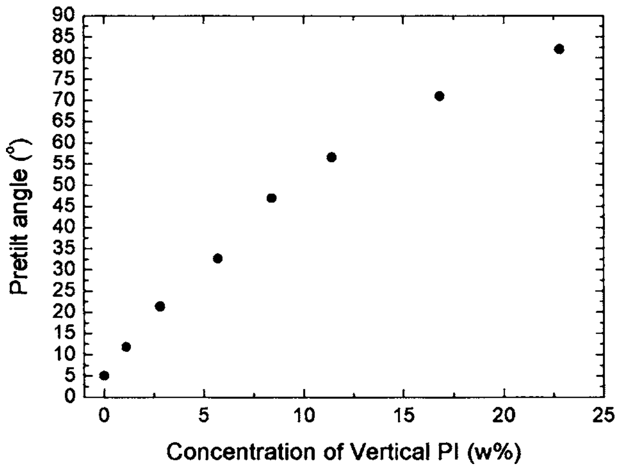

FIG. 2. Measured pretilt angle as a function of concentration of the vertical PI.

uniform, with a standard deviation of less than 10%, in a distance of 0.2λ, where λ is the average size of the individual domains. Thus if the domains are 200 nm on the average, then the region of nonuniform tilt angle is 40 nm. Since LCD usually has a cell gap of a few microns, this 40 nm does not affect the electro-optic properties of the LC cell significantly.

By varying the volume ratio of the H and V polyimides, the area ratio of V:H can be changed. Thus various pretilt angles can be obtained. Notice that the volume ratio and the area ratio are not necessarily the same due to the differential precipitation process. For example, if the V material precipitates at a later stage after the H material has all precipitated, then it is possible that the film will be entirely covered by the V material and the area ratio becomes unity no matter what the original volume ratio in the liquid film. Figure 2 shows the measured pretilt angle as a function of the volume ratio of the V material for the particular condition used.

It can be seen from Fig. 2 that indeed any pretilt angle can be generated by using this method. The polar anchoring energy of the LC on these special surfaces is measured using the high voltage method we have developed.[7] The anchoring energy is measured as a function of the pretilt angle of the LC cell. The results are shown in Fig. 3. It can be seen that

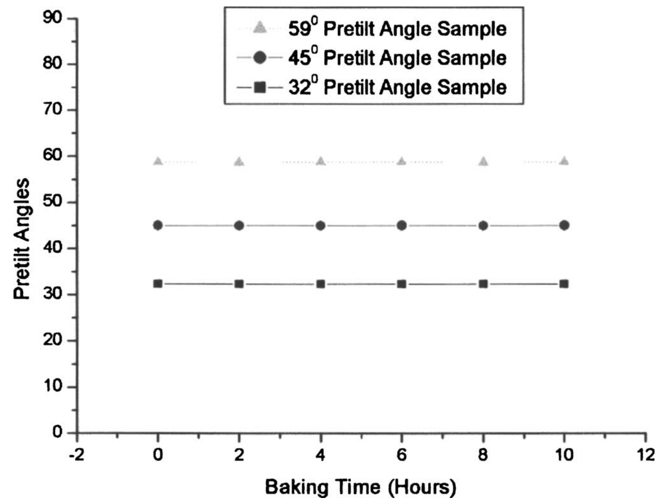

FIG. 4. Stability of the pretilt angle as a function of baking time at high temperature.

the measured anchoring energies are in the range of $1-2 \times 10^{-3}$ J/cm^2 which is the same as ordinary rubbed polyimides. The results indicate that the polar anchoring energy is independent of the pretilt angle. Actually the measurement of the polar anchoring energy for high pretilt angle samples is not a trivial exercise. The method developed in Ref. 7 has to be modified in order to improve the accuracy of this measurement. Details of this method will be given elsewhere.[8]

We have also checked that these nanostructured alignment layers are stable against temperature cycling up to 180 °C for several hours. The results are shown in Fig. 4. Three different samples with different pretilt angles as shown were put into a 180 °C oven. The samples were taken out and their pretilt angles checked at 2 h intervals. It was found that the pretilt angles remained almost unchanged throughout the experiment. In fact, this temperature stability is to be expected since the individual polyimide is stable against temperature cycling. There is no reason for the nanostructured layer to be unstable against temperature cycling.

The operating temperature range of these nano-surfaces alignment layers is quite wide. Figure 5 shows an example of a 45° pretilt sample cell between operating temperatures of

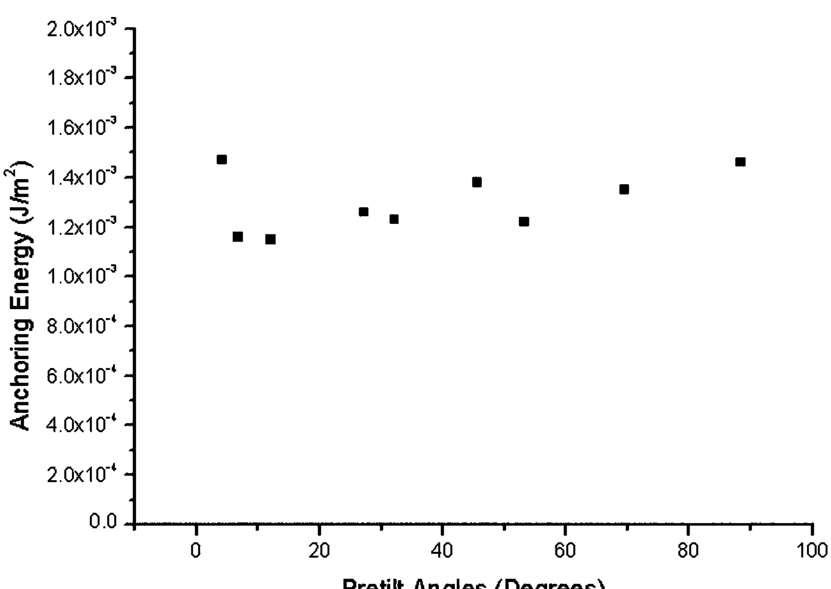

FIG. 3. Measured anchoring energy as a function of pretilt angle.

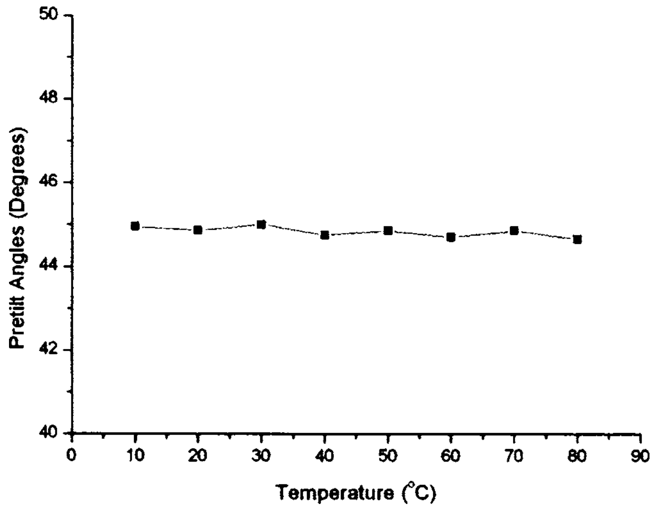

FIG. 5. Pretilt angle as a function of operating temperature.

10 and 80 °C. The pretilt angle remains the same throughout the test. In fact, this temperature behavior is similar to the original PI. Thus the new alignment layers described here are practical to manufacture common LCD.

The availability of a reliable method of manufacturing large pretilt angles is important for many applications. The most important one is the fabrication of π cells with no bias voltage.[5] The other application is in the fabrication of bistable bend-splay LCD where the pretilt angle has to be precisely adjusted to be 50°.[9]

In summary, we have demonstrated a new method of obtaining high pretilt angles for making LC cells. This method is robust, does not involve untested new materials and is compatible with existing manufacturing techniques. Most important, this alignment surface is practical in the sense that it is temperature insensitive in operation and can withstand high temperature recycling in storage.

This research was supported by the Hong Kong Government Innovation and Technology Fund and the Research Grants Council.

[1]T. Uchida, M. Ohgawara, and M. Wada, Jpn. J. Appl. Phys., Part 1 **19**, 2127 (1980).
[2]R. W. Filas and J. S. Patel, Appl. Phys. Lett. **50**, 1426 (1987).
[3]M. Schadt, H. Seiberle, and A. Schuster, Nature (London) **381**, 221 (1996).
[4]M. Nishikawa, B. Taheri, and J. L. West, Proceedings of the Society for Information Display International Symposium, 1998, Vol. 29, p. 131.
[5]F. S. Yeung, F. C. Xie, H. S. Kwok, J. Wan, O. Tsui, and P. Sheng, Proceedings of the Society for Information Display International Symposium, 2005, Vol. 36, p. 1080.
[6]J. T. Wan, O. K. Tsui, H. S. Kwok, and P. Sheng, Phys. Rev. E **72**, 021711 (2005).
[7]V. Chigrinov, A. Muravski, H. S. Kwok, H. Takada, H. Akiyama, and H. Takatsu, Phys. Rev. E **68**, 061702 (2003).
[8]F. S. Yeung, A. Muravski, Y. W. Li, V. Chigrinov, and H. S. Kwok (unpublished).
[9]F. S. Y. Yeung, Y. W. Li, and H. S. Kwok, Proceedings of the Society for Information Display International Symposium, 2005, Vol. 36, p. 1770.