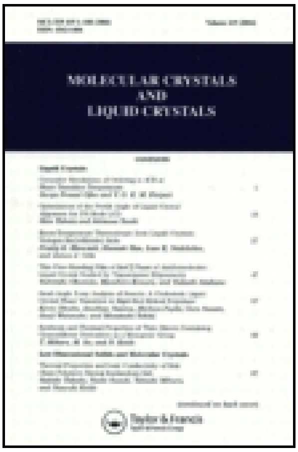

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Evaluation of Liquid Crystal Alignment Ability of Polyimide by Analyzing the Black State of Homogeneous Alignment Liquid Crystal Display

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Evaluation of Liquid Crystal Alignment Ability of Polyimide by Analyzing the Black State of Homogeneous Alignment Liquid Crystal Display

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We evaluate precisely the light leakage from the black state of homogeneously aligned liquid crystal displays, putting emphasis on the molecular alignment ability of polyimide films. We clarify the optimal fabrication condition for polyimide materials to obtain a better black state. In addition, we investigate the effect of embedded dielectric nanoparticles in a polyimide material on the degree of light leakage. It is shown clearly that the degree of light leakage depends on the polyimide materials and its fabrication condition, whereas only a limited improvement is obtained by adding nanoparticles into the alignment layers.

Keywords Alignment layers; black state; contrast ratio; LCDs; nanoparticles; polyimide

1. Introduction

In-Plane Switching mode [1] is one of the leading device modes of the current liquid crystal displays (LCDs) because of its wide viewing angle, low color shift, and good color performance. However, there remains a problem in that the contrast ratio, defined as a ratio of the transmittance of a white state to that of a black state, is not as good as that of another leading LCD, e.g., Vertically Aligned (VA) LCDs. It is known that the lower contrast ratio of IPS-LCDs is attributed to the light leakage in the black state of a LCD [2–6]. There are several factors which yield the light leakage such as depolarized light scattering of the LC layer, color filters, polarizers, surface morphology of thin-film transistor, non uniformity of molecular alignment at alignment layers, and rubbing angles. For a better contrast ratio, suppressing the light leakage must be necessary. Many research efforts have been performed for the improvement of the contrast ratio of IPS-LCDs [7–10].

In this study, we clarify the relation between the degree of light leakage from a black state of IPS-like, homogeneously aligned LCDs and the materials property

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of polyimides (PIs) used for alignment films of LCDs. Another purpose of the present study is to investigate the effect of nanoparticles embedded in polyimide alignment films on the polyimide performance, i.e., molecular alignment associated to the black state of the IPS-like LCDs. So far, we have studied the effect of addition of a variety of oxide nanoparticles into the alignment films of polyimide on the electro-optical performances of LCD [11,12]. These studies suggest that the presence of nanoparticles in the alignment films affects the LC molecular alignment and the proper kind of nanoparticles provides the improvement of the performance of LCD such as remarkable enhancement of the contrast ratio of TN-LCDs. Therefore it is worthwhile to study the effect of nanoparticles on the black level of IPS-LCDs.

2. Experimental

2.1. *Materials Used and Cell Preparation*

Two kinds of polyimide materials, SE-130 and RN-1199 (Nissan Chemicals) both giving a low pretilt angle around 2° were used in this study. Both polyimides are of the precursor polyamic acid type. The difference between them is their polymer crystallinity. It is known that the crystallinity of RN-1199 polyimide is much higher than that of SE-130. Namely, RN-1199 is more rigid but brittle, whereas SE-130 is more amorphous. Making use of these two types of PIs, homogeneously aligned LCD test cells with 20 μm gap, which can be regarded as IPS-LCDs in a fixed state, were fabricated under a variety of fabrication conditions. The first factor of the fabrication condition is the baking temperature and time of PIs. We here applied 200°C, 1 hour or 250°C 1 hour. The difference in the baking temperature leads to that in imidization rates. The second factor is the rubbing strength which is characterized by many parameters. Here we change the pile impression and the rotational speed of the rubbing roll. As a moderately strong rubbing condition, referred to as the condition (A), we set the pile impression of 0.35 mm and the rotational speed of the rubbing of 1000 rpm. In the other condition as a moderately weak rubbing condition (B) those two parameters are 0.15 mm and 100 rpm. As for other parameters used in common, the rubbing cloth is rayon and the speed of the sample stage is 450 mm/min. Hence we have four sets of the test empty LCD cells for each polyimide material. Then a well-known nematic mixture, ZLI-4792 (Merck) was injected into the cells. The fabrication was done in the clean room.

For nanoparticle-embedding experiments we prepared the nanoparticle-dispersed PIs of two kinds of polyimide materials. We used two different lots of Barium Titanate nanoparticles supplied as powder by different suppliers. The center of size dispersion is 20 nm and 60 nm. Hereafter we refer to them as TK-20 and SC-60. The concentration of nanoparticles with respect to the PI content is 5.0 wt% for both types of PIs. To obtain homogenous mixtures, we stirred and sonicated each PI varnish with nanoparticles enough. Following the same procedure described above, we fabricated various sets of the test LCD cells with nanoparticle-embedded alignment films for each polyimide material. In this experiment the rubbing condition applied to the nanoparticle-embedded alignment film is restricted to the relatively strong rubbing one (A). Hence we have four sets of the test LCD cells with nanoparticle-embedded alignment layers for each polyimide material.

To ensure statistical accuracy, we have done the whole experiment twice. Thus, we fabricated two groups of the sixteen sets of the test LCD cells. For each group, the number of the test cells is more than four for each set of the cells.

2.2. *Measurement: Evaluation of the Degree of Light Leakage*

For evaluating the degree of light leakage from the black state of a test LCD cell, we measured very precisely the transmittance profile of the cell utilizing the LCD evaluation system, LCD-5200 (Otsuka Electronics). The light source is a halogen lamp and the detector is a spectrophotometer with a highly sensitive photodiode array. The measurement was done in the following steps. First the intensity of the light which passes through the parallel polarizers only is set to 100%. This is the reference state. Second the transmittance of the crossed polarizers only (without a cell) was measured, which is defined as the idealized black state (~0.0015%). Then keeping the crossed polarizers, a test LCD cell was located between them. Third the transmittance of the cell was measured as a function of horizontal rotation angle (0.1 deg. step) with respect to the crossed polarizers. Finally, the lowest transmittance and the highest one at a certain horizontal angle are obtained as a black and white state of the cell. The degree of light leakage corresponds to the increment of the transmittance at a black state by comparison with the idealized black state. Namely, the higher transmittance of the black state of a test LCD cell means the higher degree of light leakage. An example taken from the obtained data giving the black state is shown in Figure 1.

3. Results and Discussion

3.1. *The Relation Between the Contrast Ratio and the Black Level*

Before we examine the full detail of the result concerned on the black state, we should first check what the main factor which aggravates the contrast ratio is. Figure 2 shows an illustrative result obtained from the first cycle of the experiment

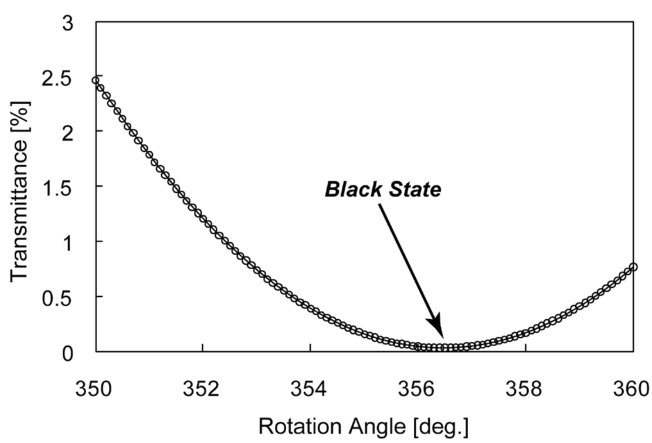


Figure 1. An example of transmittance profile as a function of horizontal rotation angle. The polyimide material for alignment layers is RN-1199 and the rubbing condition is (A).

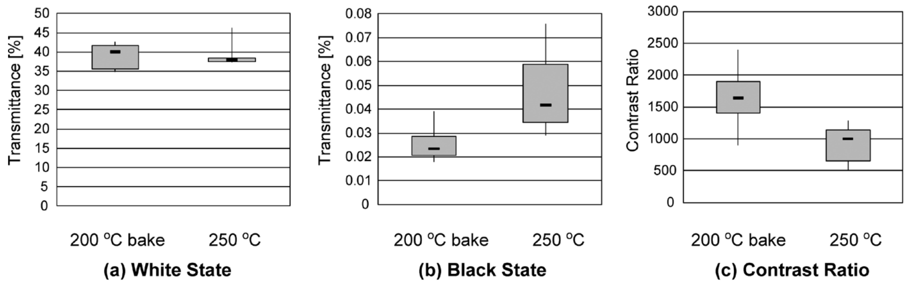


Figure 2. An illustrative result which shows the transmittance of a white state, that of a black state, and a calculated contrast ratio.

which compares the transmittances and the contrast ratio of two sets of test LCD cells with alignment films of RN-1199 baked at different temperatures. The rubbing condition of PI films is the relatively strong one (A). The result is depicted as a box-and-whisker plot. The box indicates the data range after cutting off 25th and 75th percentiles. The whiskers indicate the maximum and the minimum of the data. The bar inside each box means its median. In the case of white state, both sets of cells show almost the same transmittance, while there is clear difference in the transmittance of the black state. Thus it can be concluded that the grade of the black state basically determines the contrast ratio of the test LC cells. This is also the case for the cells with nanoparticle-alignment films. This means that at least the presence of nanoparticles in the alignment films gives no degradation of the white state of a test LC cell.

3.2. *The Black Level at Different Fabrication Conditions*

Figure 3 shows the result of the transmittance of the black state of the test cells fabricated at different conditions. The combined data is shown which was taken from all the two cycles of the experiment. As can be seen from the figure, the case of SE-130 baked at 250°C under the relatively weak condition (B) gives the lowest median which is the best black state. The transmittance of RN-1199 baked at 200°C also shows the comparably better black state regardless of the rubbing condition. Comparing the data of the same PI, it is clear that the higher baking temperature is better for SE-130, whereas the lower baking temperature is better for RN-1199. The weaker the rubbing strength is, the better black state is obtained for the SE-130 case. RN-1199 is delicate for the rubbing when baked at higher temperature. On the whole, it seems that each PI material has an optimal fabrication condition.

3.3. *The Black Level of Cells with Nanoparticle Embedded PIs*

Figure 4 illustrates the black level of the test LCD cells with nanoparticle-embedded alignment layers. For all the experiment, the rubbing condition applied to the test LCD cells is (A). As we can see from the figure, the addition of nanoparticles into the PI alignment films does not show very apparent effect on the black state except for the case of SE-130 cells under the 200°C, 1 hour baking condition shown in Figure 4(a). Rather the result shows the tendency to a worse black state by

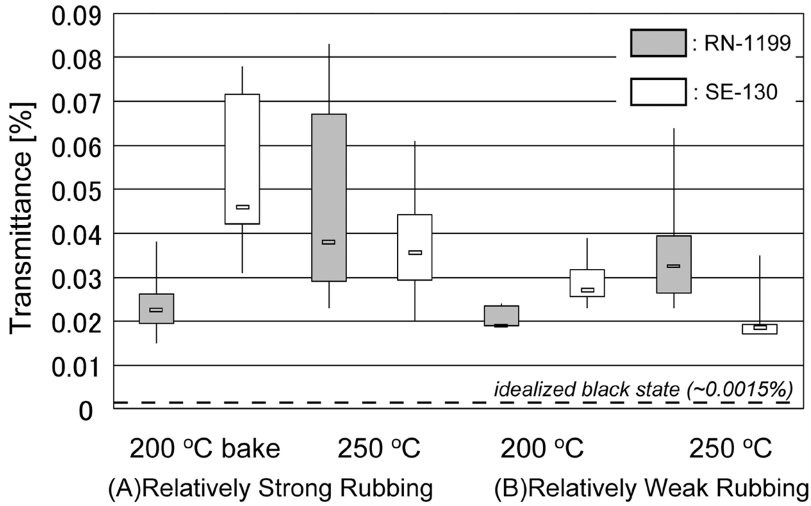
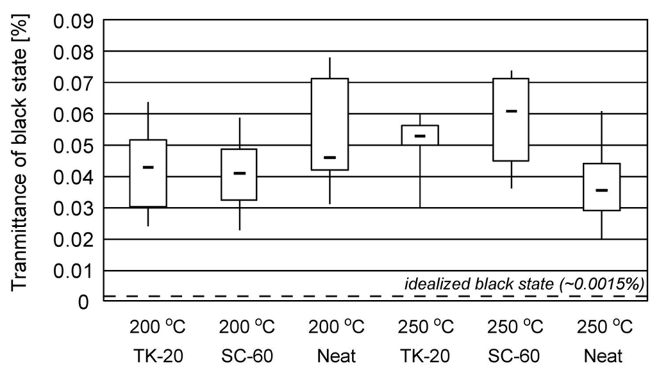
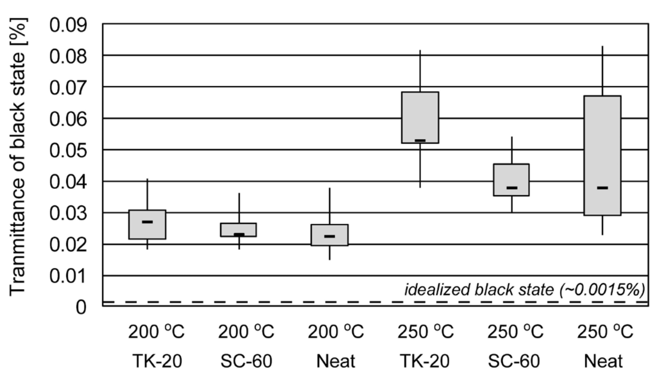


Figure 3. The black level of the test IPS-like LCD cells at various fabrication conditions without nanoparticles.



(a)



(b)

Figure 4. The black level of the test IPS-like LCD cells with nanoparticles. (a) SE-130, (b) RN-1199.

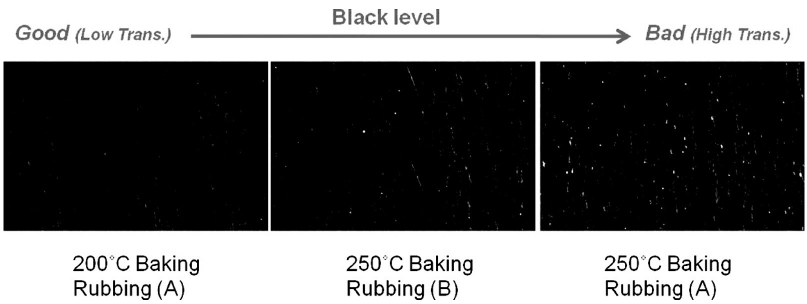


Figure 5. Polarizing Optical Microscopic images of the textures of the test LCD cells with RN-1199 PI material.

embedding nanoparticle into the PI films. This result implies that no apparent improvement of the LC molecular alignment is achieved. Only in the case of SE-130 baked at the lower temperature, a little improvement is obtained. The transmittance of the black state improves 20∼25% on average although the scattering of data is not small. This improvement seems remarkable. But it should be noted that in this case the original black state of the cells without nanoparticles shows the worst black level.

3.4. *Polarizing Optical Microscopic Observations of the Sample Cells*

Next we took the polarizing optical microscope images of the cells to characterize the difference in the result of the black state described in the preceding subsections. Figure 5 shows a series of images of the test LCD cells with RN-1199 alignment films. In the texture of the cell giving the worse result, we can see many bright spots and scratches which yield the degradation of the transmittance of the black state. The number of spots increases as the baking temperature is high and the rubbing is strong. These flaws are attributed to the brittleness of RN-1199 baked at too much high temperature; it is easily exfoliated by rubbing. On the other hand, as shown in Figure 6, there are few bright spot observed in the images of SE-130 textures regardless of showing the better or worse result of the black state. Thus the exfoliation of PI

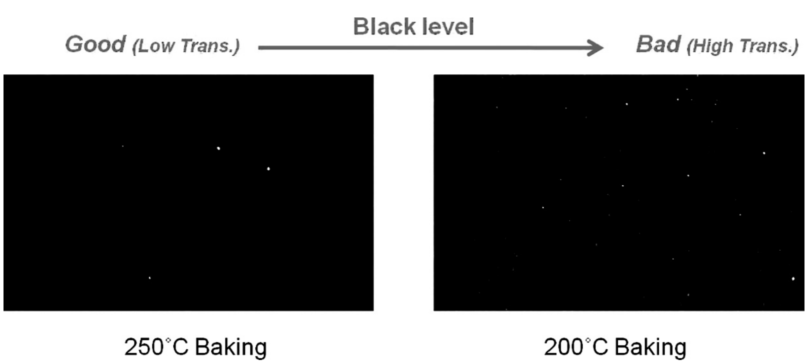


Figure 6. Polarizing Optical Microscopic images of the textures of the test LCD cells with SE-130 PI material.

material is not the reason for a worse black state of the cell with SE-130 alignment films baked at lower temperature. The scratch is obvious in the worse case. We also observed the texture of the test LCD cells with nanoparticle-embedded alignment films, and found the same tendency of the PI materials dependence. However, no remarkable change of the texture was induced by the addition of nanoparticles into the PI alignment films.

4. Discussion and Conclusions

We have done the precise measurement on the light leakage of IPS-like homogeneously aligned LCDs fabricated under various conditions characterized by the polyimide materials used for alignment films with different baking temperatures and rubbing strengths. Consequently, the black level of IPS-like LCDs is sensitive to the condition of PI materials. RN-1199 which exhibits high crystallinity generally gives a better black state of an IPS-like LCD if it is possible to prevent exfoliation. This means that the highly crystalline PI has high alignment ability of LC molecules but it becomes very brittle if baked at too much high temperature and is easily peeled off by rubbing. These flaws are the main cause of aggravation of the black level in the case of RN-1199. On the other hand, SE-130 which has low crystallinity also provides a better black state, but the fabrication condition is very strict. There are two points to obtain the better black state by using SE-130. First one is the rubbing process. The rubbing should be done very carefully for SE-130 films. Too much strong rubbing probably causes non uniformity of rubbed state of the PI surface. Second one is the imidization rate. The lower baking temperature is not enough for complete imidization of precursor polyamic acid in a SE-130 raw material. Hence the baked alignment films probably contain some ratio of polyamic acid which has less ability to align LC molecules. In these aspects, the nanoparticles contained in the PI may play some role in the case where we found the improvement of the black state. In that case, however, the original black level (without nanoparticles) is worse since the imidization is not complete and the strong rubbing induces non uniform alignment. It means that the fabrication condition is not optimal originally. Therefore, we conclude that the effect of embedded nanoparticles is very limited, and the fabrication process is much more important for obtaining the better black state of IPS-LCDs.

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