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Comparison of Friction Characteristics on TN and VA Mode Alignment Films with Friction Force Microscopy

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SUMMARY Using frictional force microscopy (FFM), the friction surface characteristics were compared between twisted nematic (TN) mode and vertical alignment (VA) mode alignment films (AFs). The friction asymmetry was detected depending on temperature conditions on TN mode AF, but not on VA mode AF. The difference between two modes was explained by leaning intermolecular repulsion caused by the pre-tilt angle uniformity and the density of side chain. No level difference according to temperature conditions appeared when the pre-tilt angle were measured after liquid crystal (LC) injection.

key words: *frictional force microscopy, FFM, frictional asymmetry, alignment film, pre-tilt, LCD*

1. Introduction

FFM, which is new measurement technology designed on the base of atomic force microscopy (AFM), can measure friction force by scanning in the lateral direction with the subtle load of the probe. With the invention of FFM, the experimental friction research at atomic level was reported [1]. Overney et al., first introduced the frictional anisotropy on an organic layer [2]. The frictional asymmetry was detected when the probe scanned in one direction, which cannot be related to the molecular tilt intuitively [3], [4]. FFM allows to determine the tilted directions of molecular species as well as to detect the instability of the surface of material. The control of LC alignment has been recognized as important substrate technology in LC display (LCD).

Indication MURA due to the instability of the pre-tilt uniformity caused by the temperature conditions and rubbing process has crucial effects on decreasing the LCD production. The mechanism of the pre-tilt angle has been explained by the interaction between AF surface energy [5] and LC molecular [6], and the effect of polymer side chain conformation [7]. However, although the experiment to compare mechanism quantitatively has been performed [8], the discovery of the LC alignment control ability of the pre-tilt angle mechanism is not clear yet. Unlike in IPS mode, the LC pre-tilt angles are respectively about 4 degrees and 90 degrees in TN and VA mode. It is generally understood that the major factors influencing the LC pre-tilt angle are the width, length, and side chain of the polymer forming the AFs. Therefore, the direct analyses of the side chain molecular on the AF surface, which describe this specifically, are required.

In this study, the surface friction characteristics of side chain molecular according to the prebake conditions of the TN and VA mode AFs which form the different pre-tilt angles, were analyzed with the FFM. The TN mode AF was scanned in the rubbed slop direction, and the VA mode AF was scanned in the state of film formation without rubbing. The pre-tilt angle were evaluated in the same condition. It is needed not only to understand the basic properties in friction but also to review over whether the FFM measurement is useful in the evaluation and application of the thin film phase of the functional polymer or not.

2. Experimental

The TN and VA mode AFs cured on ITO substrate in 230°C that coated with a temperature condition of prebaking from 60°C to 90°C. It is used that the TN mode AF materials SE07 series (Nissan CO., Ltd.) and VA mode AF material is AL06 series (JSR CO., Ltd.). The rubbing cloth of TN mode AF is adapted rayon. The rubbing conditions were the spin speed 1000 rpm, stage speed 50 mm/sec and pile contact depth 0.3 mm. The VA mode AF was not treated rubbing process. The characteristics of the structure of the film were analyzed with AFM/FFM. NanoScope IV AFM of Digital Instruments was used in FFM mode. Needle of Si_3N_4 fixed number of the vertical direction was 0.12 N/m was used. Probe of the FFM analysis is scanned of by a course of rubbing showing the orientation nature, the normal load was set at 12.57 nN on AFs. A topographic and friction images in two scan directions were recorded at the same time. We showed size of the friction of this time in friction loop. The friction loop showing the torsion (friction signal) of the cantilever was also recorded. The direction of tilt on the surface of AF was measured by detecting frictional asymmetry though FFM probe (Fig. 1(b)).

3. Results and Discussion

3.1 Frictional Property at TN Mode Alignment Film

Figure 1(a) shows the SEM result at the TN mode AF. The double layer (polyimide: PI + Polyamic acid: PAA) of TN mode AF was formed, independent of temperature unlike

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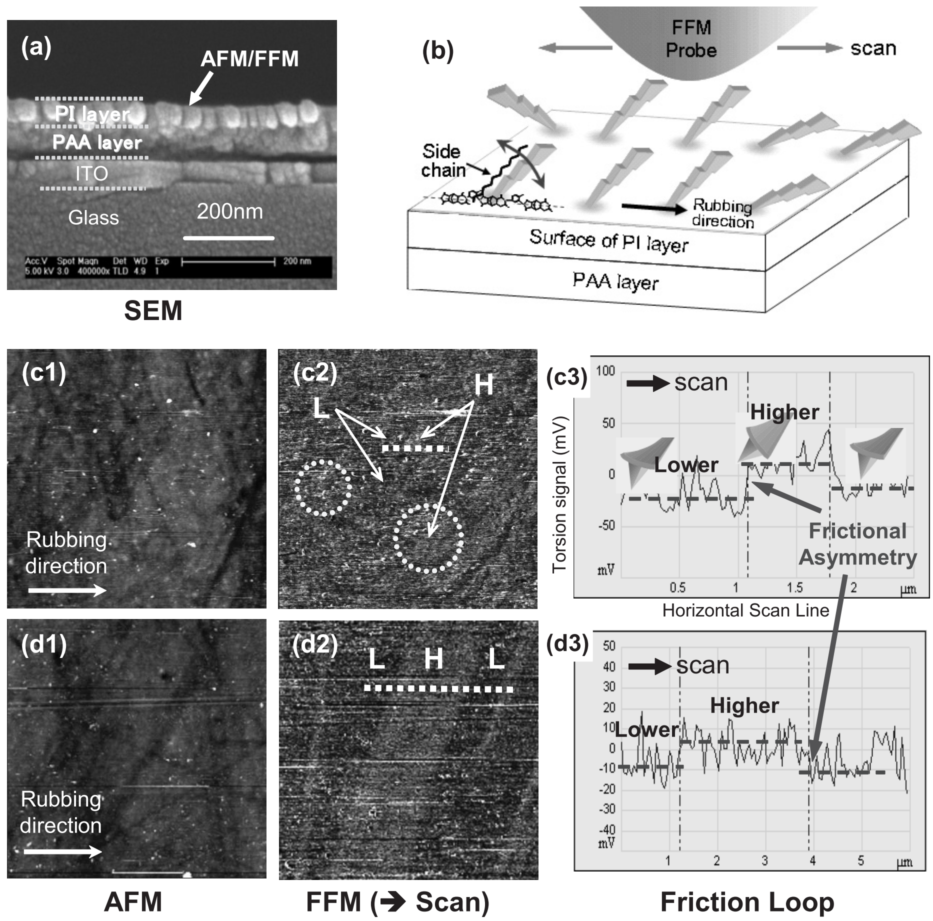

Fig. 1 SEM and AFM/FFM images (scan size: $10\,\mu$m × $10\,\mu$m) of TN mode alignment film (a) SEM image: Double layer structure at hybrid AF in TN mode was definitely observed. (b) Estimated side chain molecular on PI layer surface. Friction loop was recorded along the broken line in (c2), (d2) (prebake condition 90°C). The letters H and L indicate higher and lower friction. Friction loop recorder during forward and reverse of the probe in rubbing direction at PI surface. Frictional asymmetry was detected. It was interpreted when disorder of the direction of tilt is inclined and arranged of side chain in the molecule surface.

in plane switching (IPS) mode AF [9]. In AFs, side chain molecular structure was designed on PI layer to form the pre-tilt angle.

In the TN mode AF, the location of the side chain molecular was able to be found through observing double layer (PI+PAA) directly [10]. It used in this study has side chain with alkyl functional group. The analysis of the PI layer surface with the FFM showed that the characteristic of the friction was changed in the high temperature, 90°C. FFM images in Figs. 1(c2) and (d2) show that the contrast of the friction between the dark and bright was changed when the probe scanned in the rubbing direction. It was found to be round-shaped like an island (c2) as well as the plate-shaped (d2) by the places. The frictional asymmetry due to the instability of the side chain molecular arrangement on the PI layer was detected by the frictional loop.

3.2 Frictional Property at VA Mode Alignment Film

Figure 2 shows the result of SEM and AFM/FFM images of the VA mode AF formed with the PI type single layer. In the analysis of the SEM, there was no variation, but correlative similarity in the structure of the PI layer according to the conditions of the prebake temperature. The friction contrast on the FFM image did not show the friction difference on the surface by the side chain molecular instability, unlike the TN mode. Also, the friction loop showed the stable data without the dependence on temperature.

How can we explain the difference of the frictional characteristics on the PI layer? The main difference was explained by the difference of the density and structure of the side chain molecular between the TN mode and VA mode on the PI layer. Figure 3 shows the expected mechanism. In the TN mode, there are just one or two side chains per ten dianhydrides to form the low pre-tilt angle (Fig. 3(a)). Also, it is weak in the temperature stability since the side chain molecular has alkyl structure [11]. As a result, the frictional asymmetry is caused by the angle of the side chain molecular, as shown in Figs. 1(c3) and (d3).

However, in the VA mode, the side chain forming the

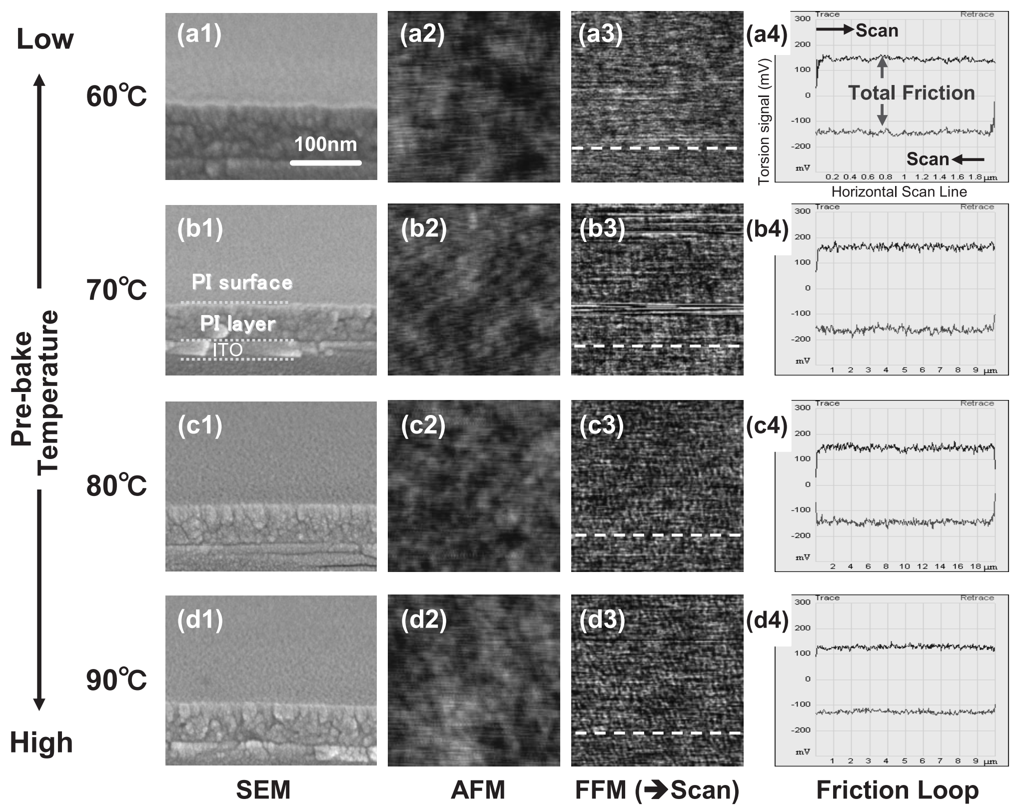

Fig. 2 SEM and AFM/FFM images (scan size: $1\,\mu m \times 1\,\mu m$) of VA mode alignment film. Friction loop was recorded along the broken line in FFM image from 60°C (a3) to 90°C (d3). The friction contrast (FFM image) and frictional asymmetry (friction loop) was not detected with friction difference by a slant of side chain in the molecule side being reversed.

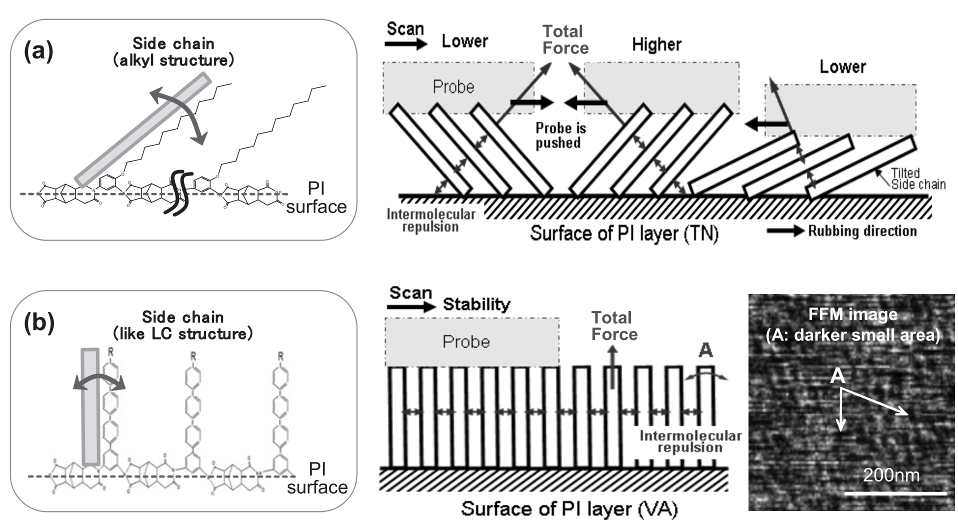

Fig. 3 Comparison of imagination mechanism with of friction characteristics of prediction mechanism: Interaction between the FFM probe and molecular layer. The molecular layer will resist against compression in that direction due to intermolecular repulsion.

pre-tilt on the PI layer surface has higher density than in the TN mode, which forms 9–10 side chains like LC structure, and regular arrangement in the vertical direction on the AF surface (Fig. 3(b)). Therefore, the friction loop is observed to be stable when the probe scans the side chain by the intermolecular repulsion energy forming the long chain molecules [12]. This is similar to the phenomenon that people are less likely to fall down in the crowded subway than in the empty one. It appears that a little difference of the contrast in the small area of the FFM image, which corre-

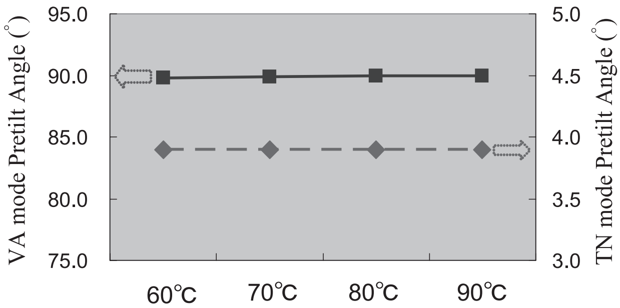

Fig. 4 Result of TN and VA mode pre-tilt angle.

sponds to the 10–20 nm sized block dots, is caused by the end of the side chain pressed by the probe resisting against the vertical direction. The density of the side chain in the TN mode is lower than that in the VA mode, and that it causes spatial differences of the alignment caused by rubbing strength. Consequently, when nothing but the pre-tilt uniformity is considered in LCD production, it is advantageous to increase the density of the AF side chain molecular structure.

3.3 Pre-tilt Angle

Figure 4 shows the pre-tilt angles in the TN and VA modes. In measuring the pre-tilt after the LC injection, few level differences according to the temperature conditions showed. The pre-tilt angle of TN and VA modes are each 90 degree and 3.8 degree not related with temperature conditions. It was tested to understand how the surface friction characteristics affect the pre-tilt angle, but direct influence was not appeared. However, the investigation AF in itself like friction characteristics could be important, as well as pre-tilt angle value by LC driving characteristics.

4. Conclusions

The friction characteristic was compared between the TN and VA modes of the AFs surface. In the TN mode, the friction asymmetry according to the temperature conditions was detected, but not in the VA mode. It was interpreted that it was caused by the density differences of the side chain forming the pre-tilt. Meanwhile in the VA mode, the range of fluctuation was smaller than that in TN mode due to the repulsion energy of the long chain molecules in the vertical direction on the AF surface. No level differences according to the temperature conditions showed in the evaluation of the electrical characteristics and the pre-tilt angle after the LC injection. The rubbing process is the important technology that controls the alignment of the LC in the current practical uses. However, it is needed to analyze directly the alignment stability in the rubbing process. FFM analysis is highly expected to be useful in the alignment evaluation of the AF with its direct analysis. In addition, through these evaluation methods, chemical structural design to form the uniform pre-tilt angle in the rubbing strength and temperature changes is expected.

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References

[1] C.M. Mate, G.M. McClelland, R. Erlandsson, and S. Chiang, "Atomic-scale friction of a tungsten tip on a graphite surface," Phys. Rev. Lett., vol.59, pp.1942–1945, 1987.
[2] R.M. Overney, H. Takano, M. Fujihira, W. Paulus, and H. Ringsdorf, "Anisotropy in friction and molecular stick-slip motion," Phys. Rev. Lett., vol.72, pp.3546–3549, 1994.
[3] K. Miura and Y. Shukuya, "Comparison between atomic force microscopic images of ionic crystal surfaces in air and in dry argon," Jpn. J. Appl. Phys., vol.32, pp.4752–4753, 1993.
[4] M. Liley, D. Gourdon, D. Stamou, U. Meseth, T.M. Fischer, C. Lautz, H. Stahlberg, H. Vogel, N.A. Burnham, and C. Duschl, "Friction anisotropy and asymmetry of a compliant monolayer induced by a small molecular tilt," Science, vol.280, no.5361, pp.273–275, 1998.
[5] M. Gazardand, A. Zann, and J.C. Dubois, "Liquid-crystal orientation induced by polymeric surfaces," J. Appl. Phys., vol.47, pp.1270–1274, 1976.
[6] T. Sugiyama, S. Kuniyasu, and S. Kobayashi, "Temperature dependence of pretilt angle in nematic liquid crystal cell," Mol. Cryst. Liq. Cryst., vol.231, pp.199–214, 1993.
[7] S. Lee, B. Chae, H. Kim, B. Lee, W. Choi, S. Kim, T. Chang, and M. Ree, "New clues to the factors governing the perpendicular alignment of liquid crystals on rubbed polystyrene film surfaces," Langmuir, vol.19, no.21, pp.8735-8743, 2003.
[8] D. Chung, T. Fukuda, Y. Takanishi, K. Ishikawa, H. Matsuda, H. Takezoe, and M. Osipov, "Competitive effects of grooves and photoalignment on nematic liquid-crystal alignment using azobenzene polymer," J. Appl. Phys., vol.92, p.1841, 2002.
[9] M. Kwak, H. Chung, J. Lee, J. Choi, K. Kim, S. Hong, C. Park, S. Choi, S. Lee, and C. Lee, "Characteristics of hybrid type alignment film in color TFT-LCD," IDW'07, LCTp7-8, pp.1735–1738, 2007.
[10] M. Kwak, H. Chung, J. Choi, H. Kwon, J. Kim, D. Han, C. Park, S. Lee, C. Lee, and S. Cha, "Studies of frictional properties on TN mode alignment film surfaces with AFM/FFM," Mol. Cryst. Liq. Cryst., vol.507, pp.129–136, 2009.
[11] K. Sawahata, EKISHO, vol.8, no.4, pp.216–224, 2004.
[12] M. Kwak and H. Shindo, "Frictional force microscopic detection of frictional asymmetry and anisotropy at (10-14) surface of calcite," Phys. Chem. Chem. Phys., vol.6, pp.129–133, 2004.

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