Poster: Liquid Crystal Alignment Effect on the Polymer Surface using Thin Plastic Substrate

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Abstract

We have investigated the generation of pretilt angle for a nematic liquid crystal (NLC) alignment with rubbing alignment method on the two kinds of polyimide (PI) surfaces using thin plastic substrates. The NLC pretilt angles generated on thin plastic substrates are higher than that on the glass substrate. We study that AFM (atomic force microscope) image of rubbed PI surface with polymer film has formed the micro-groove. Also, EO characteristics of the TN-LCD with a rubbed PI surface based on polymer are almost the same as that of the TN-LCD with a rubbed PI surface based on glass.

1. Introduction

Flexible displays based on polymer substrates for liquid crystal displays (LCDs) have several advantages over displays using glass substrates: they only exhibit 1/6 of the weight of glass substrates, flexible displays are virtually unbreakable, and their flexibility allows for elegant styling by designers [1]. Although flexible displays have many advantages, their production volume is still low and the costs for plastic substrates are high. Polymer films used in flexible displays so far are polycarbonate (PC), polyarylate (PAR), and polyethylenterephtalate (PET). The thermal stability of these polymer substrates is low: the available maximum process temperature has to be below 180℃. Therefore, unlike rigid glass substrates, flexible displays based on polymer substrates need low temperature processing [2-4].

Presently a rubbing process is widely used to align LC molecules on alignment layers [5,6]. Usually polyimide films are used for the alignment layers of LCDs. In order to obtain good polyamide films, a high-temperature of about 180℃ is needed for the baking process. However, flexible LCDs must be formed at a low temperature because polymer substrates have thermal instability. [7] These low temperature processes affect the LC alignment. In particular, they have significant effects on the generation of the pretilt angle and the electo-optical (EO) performance. Therefore, the alignment mechanism of LC molecules on a rubbed polyimide film using polymer substrate is very important for both fundamental LC research and applications. However, the mechanism of the pretilt angle in NLC on a rubbed polyimide based on polymer film for flexible displays in low temperature processes has not yet been reported.

In this paper, we report the generation mechanisms of pretilt angles in NLC with positive dielectric anisotropy on a rubbed polyimide surface based on polymer and glass substrates, investigate the pretilt angle generated between the synthesis of organic-solvent solvent PI and other polyamic acids, and study the electro-optical (EO) characteristics of twisted nematic (TN)-LCDs with a rubbed polyimide based on polymer and glass substrates in the low temperature process.

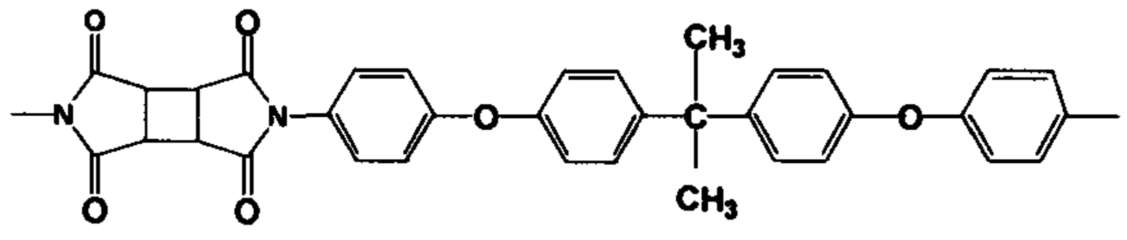
2. Experiment and Results

In this experiment, two types of polyimide (PI) were used as follows

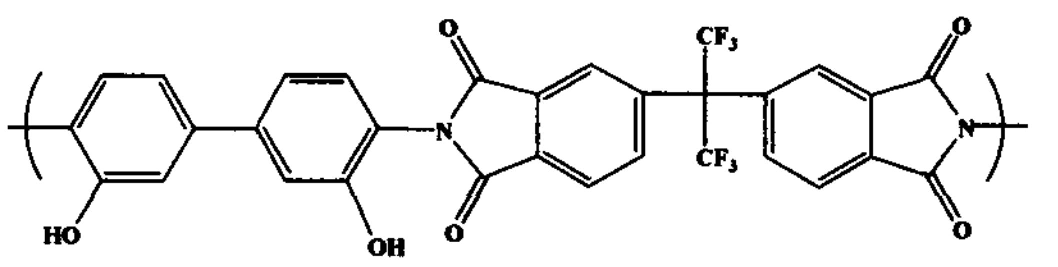
PI-1: Polymer of polyamic acid (PA) type that is currently used in the industry (from Nissan Chemical industries)

PI-2: Polymer of the synthesis of organic-solvent solvent PI type that is used in the alignment layer. The polymer was synthesized for this experiment [19].

We used a polycarbonate (PC) film (200 μm) as the substrate. The chemical structures of the two kinds of PIs used in this study are shown in Fig. 1. The polymers were uniformly coated on indium-tin-oxide (ITO) electrodes using the spin-coating method, and imidized at 120℃ for 1 h. The thickness of the PI film was set at 500Å. The substrate surfaces were rubbed with a rubbing machine. The rubbing strength (RS) has been defined in some previous work[5-6)]. To measure the pretilt angle, the cell was fabricated as a sandwich with anti-parallel structure, and the thickness of the cell was 60 μm. The cell thickness of the rubbing-aligned TN-LCD was 5[μm] [17,18]. After fabricating the cell, a mixture of NLC was injected in isotropic phases. The LC cells were then cooled to room temperature. The NLC had a positive dielectric anisotropy ($\Delta\varepsilon$ = 8.2, from Merck Co.). The pretilt angles were measured using the crystal-rotation method at room temperature. The voltage-transmittance and response time characteristics of the rubbing-aligned TN-LCD were also measured.



(a) polyamic acid type PI



(b) soluble type PI

Fig. 1. Chemical structure of the polymer.

Figure 2 shows the relationship between the curing temperature and the imidization ratio of polyimides (PIs). The imidization ratio of PI-1 cured at 120 ℃ is constant at 0 %. As the curing temperature of PAs increases, the imidization ratio increases. However, the imidization ratio of PI-1 cured at 220℃ is constant at about 55 %.

On the other hand, the imidization ratio of PI-2 is constant at 68 % even if the PI is cured at 120℃. The order of the imidization ratio of the polyamic acid type PI at the curing temperature of 120℃ is lower than that of the soluble type PI [8].

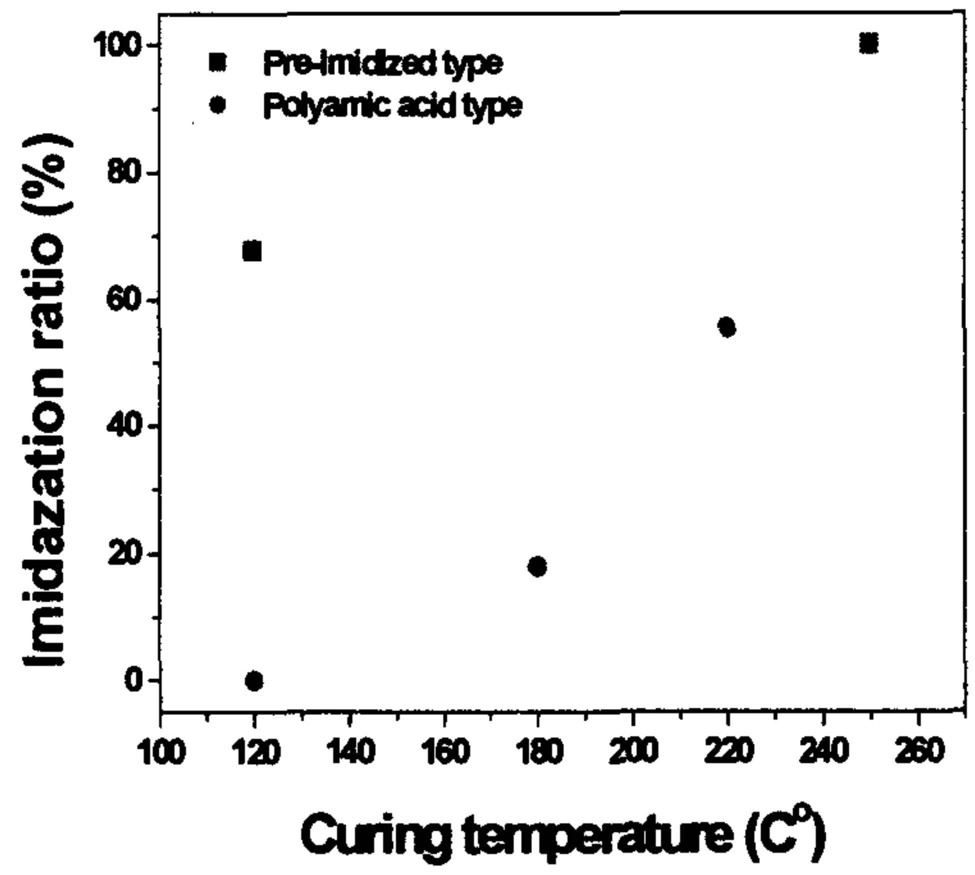
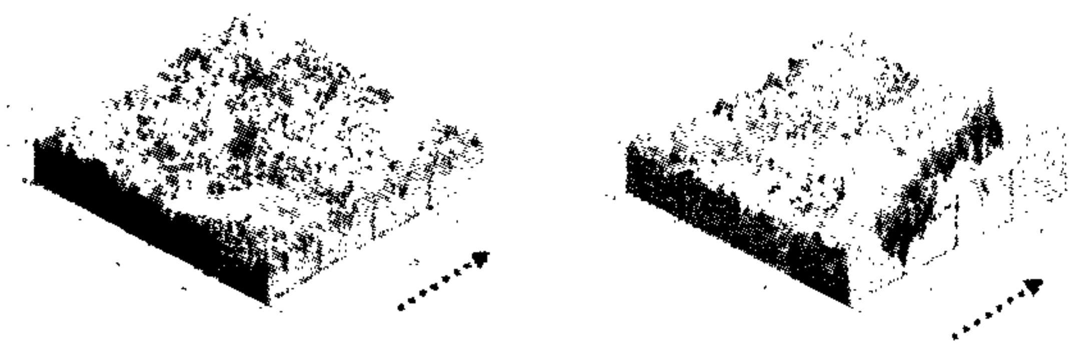


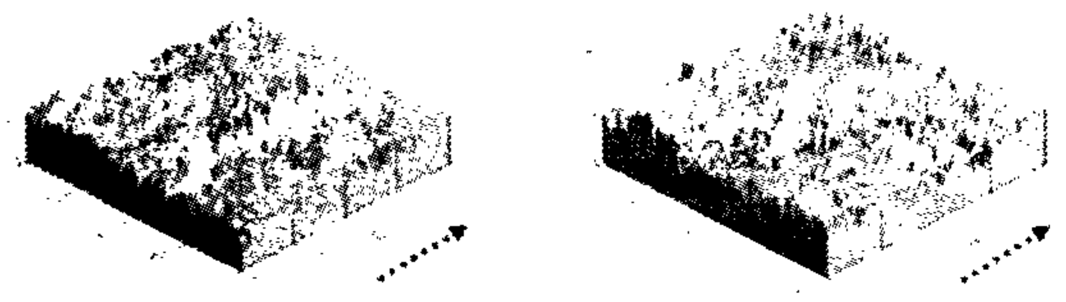
Fig. 2. Relationship between curing temperature and imidization ratio of polyimides.

2.1Generation of pretilt angles using glass substrates

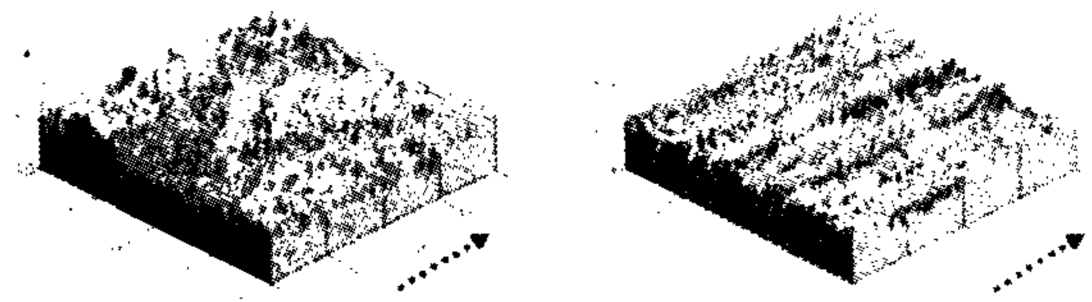
Figure 3 shows the AFM images of unrubbed and rubbed PI-1 films using the glass substrate according to curing temperatures. Firstly, in the cases of the PI-1 surface cured at 120℃ and 180℃, the micro-groove structure in the PI-1 surface has not formed after the rubbing treatment. In this state, PI-1 exhibited a constant imidization ratio of 0 % and 20 %, respectively. Secondly, in the case of the PI-1 surface cured at 220 ℃, the formation of the micro-groove structure in the PI-1 surface began to appear after the rubbing treatment. In this state, PI-1 exhibited a constant imidization ratio of 68 %. Lastly, in the case of the PI-1 surface cured at 250℃, the micro-groove structure in the PI-1 surface was definitively formed after the rubbing treatment [9-11]. The micro-groove structure was formed as the PA curing temperature increases, Also, the micro-groove structure depended on the imidization ratio of the PI-1. Finally, low imidization ratios of the PI do not affect the formation of the micro-groove structure, but high imidization ratios of the PI do affect the formation of the micro-groove structure.



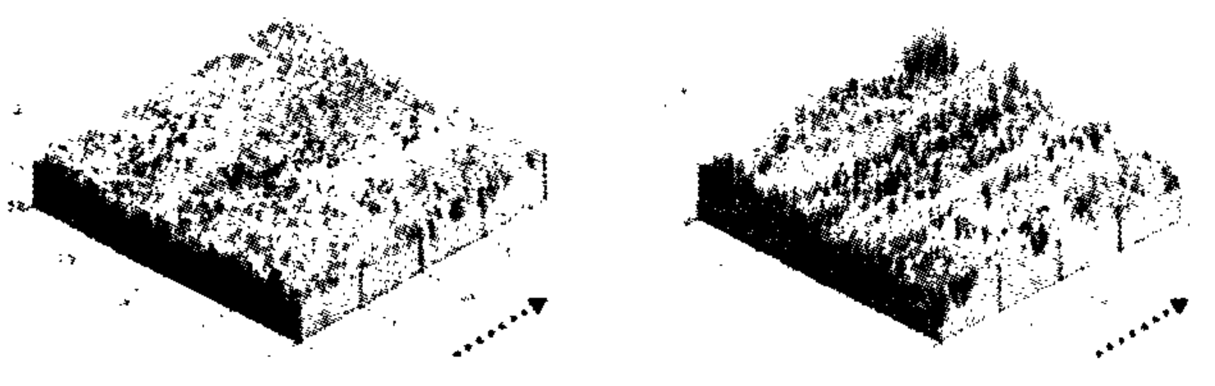
(a) at curing temperature (120℃)



(b) at curing temperature (180℃)



(c) at curing temperature (180℃)



(d) at curing temperature (180℃)

Fig. 3. AFM images on PI surface with glass substrate: (a) at curing temperature (120℃), (b) at curing temperature (180℃), (c) at curing temperature (120℃), (d) glass at curing temperature (250℃).

The generation of the pretilt angles in NLC on the rubbed PI-1 surface with different baking temperatures (120℃~250℃) as a function of the rubbing strength using glass substrates is shown in Fig. 3. It is shown that the low pretilt angle is generated on the PI surface cured at 120℃, and it tends to increase as the curing temperature increases. The rubbing treatment generates the obliquely inclined force to the alignment layer formed PI structure. At low temperatures, most polymers consisted of a polyamic acid state. These polyamic acid chains have flexible groups such as acryl polymer. Since this flexible structure has not formed the micro-groove substrate, low pretilt angles are generated. However, at high curing temperatures, the PI chains contain components of fused rings, rings linked only by direct carbon-carbon bonds. After the rubbing treatment, the rigidity of the resulting polymer chains has caused the formation of the micro-groove structure. We obtained high pretilt angles with the PI structure cured at high temperatures. The roughness of the micro-groove substrate may be attributed to the PI conformation change by the rubbing treatment. As mentioned above, the rubbing treatment generates the obliquely inclined force to the alignment layer formed PI structure [16].

These results imply that the imidization ratio of polyamic acids depends on the generation of the pretilt angle on the linear alignment of polyimides by the rubbing treatment.

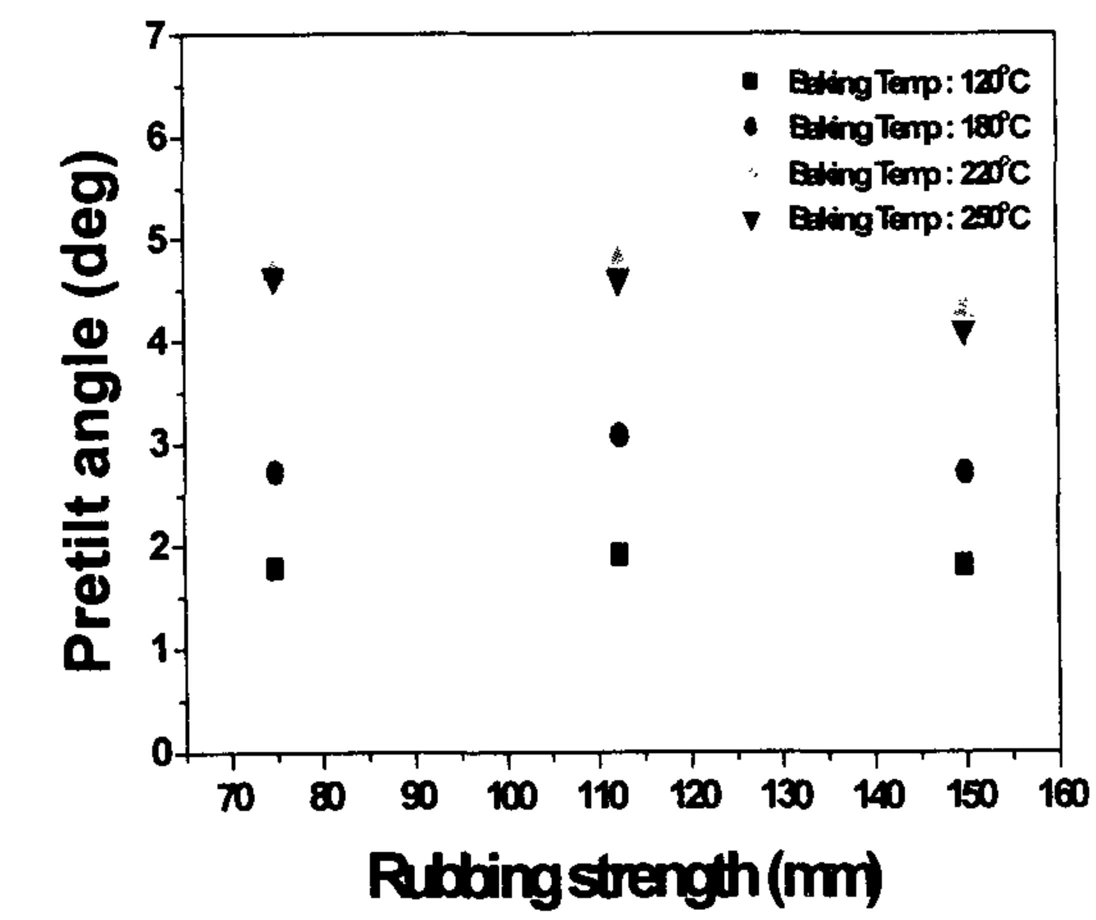


Fig. 4. Generation of pretilt angle in NLC on PI surface with different baking temperature as a function of rubbing strength with glass substrate.

2.2 Generation of the pretilt angle using polymer substrates

Figure 5 shows the AFM images of unrubbed and rubbed PI films using polymer and glass substrates at a low curing temperature. In the case of the PI-1 surface cured at 120℃ using a glass substrate, the micro-groove structure was not formed after the rubbing treatment. However, with a polymer substrate at the same curing temperature, the micro-groove structure was formed by the rubbing treatment. The surface roughness of the polymer substrate is higher than that of the glass substrate. It is considered that this formation of the roughness on the substrate by the rubbing may be due to the initial surface roughness on the polymer substrate.

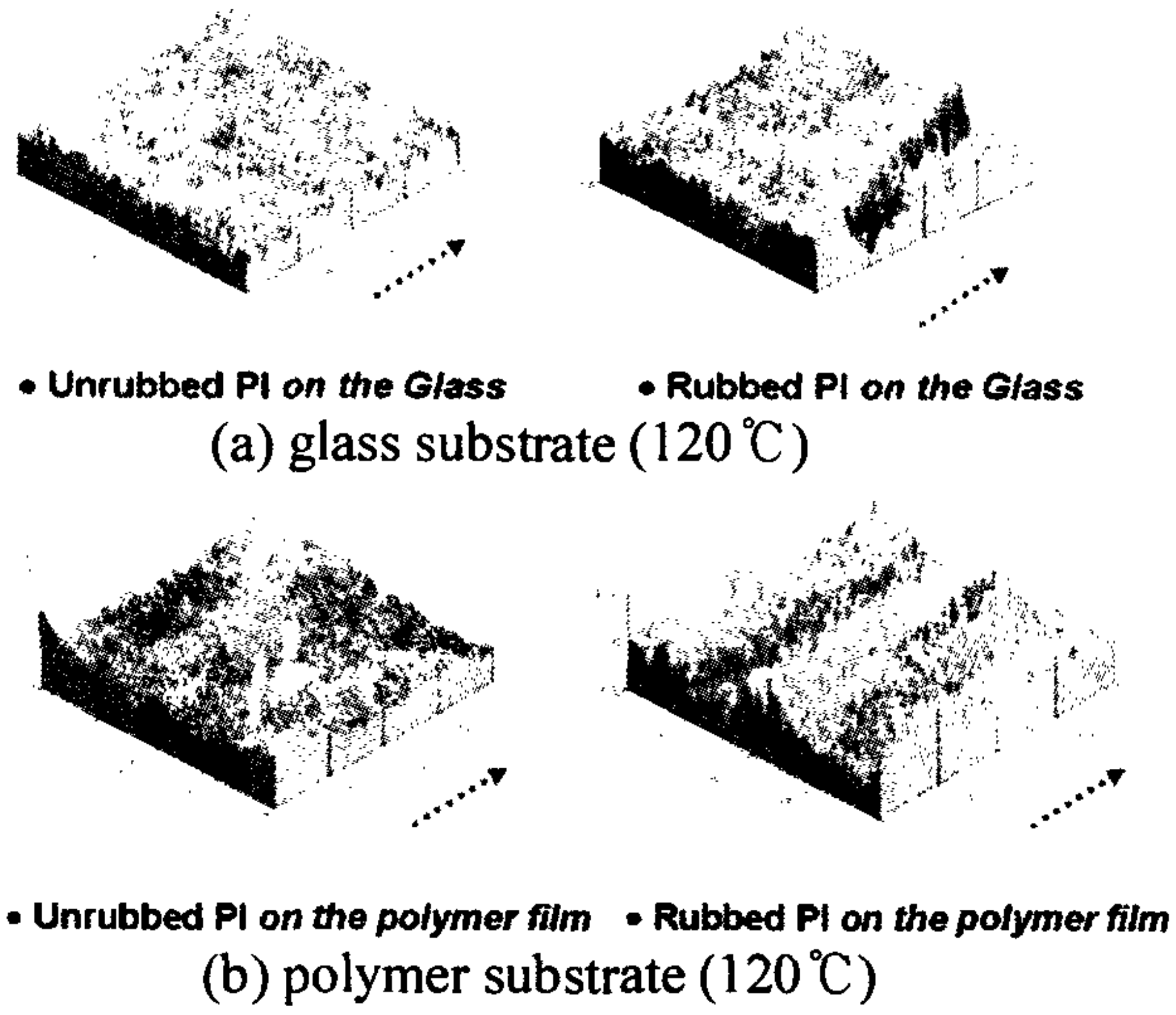


Fig. 5. AFM images on PI surface with two kind of substrate: (a) glass substrate (120℃), (b) thin plastic substrate (120℃)

Figure 6 shows the NLC tilt angles on a homogenous polyamic acid type PI surface with different substrates as a function of rubbing strength at a relatively low temperature of 120℃. This relationship is needed for studying the generation of the pretilt angle on the alignment layer at a low temperature using glass and polymer substrates, because the polymer substrate has low thermal stability and the alignment layer usually must have a high temperature baking process to obtain rigid polymide films. It is shown that a larger LC pretilt angle is generated when using a polymer substrate than a glass substrate; the pretilt angle on the rubbed PI-1 surface using a polymer substrate shows a very high value that reaches 3 degrees in the weak rubbing region (RS=75mm), and then it decreses with the increasing RS. However, the pretilt angle measured is about 1.7 degrees smaller on the glass substrate than on the polymer substrate. This phenomenon in particular illustrates the reason why the pretilt angle on the polymer substrate was larger than that on the glass substrate. It is considered that this increase of the pretilt angle may attribute to the roughness of the micro-groove substrate by the rubbing. These results demonstrate the theory that the topographical structure of the alignment layer contributes to the LC alignment.

Previous work has showed that the pretilt angle is generated by the micro-asymetric triangular structure of the polymer on the rubbed PI surface [12-16]. However, we suggest that the pretilt angle is generated differently because there are surface roughness differences between glass and polymer using the same PI material. As a result, the pretilt angle was larger on the polymer surface with higher roughness (surface roughness=50~60 Å), while the pretilt angle was lower on the glass surface with lower roughness (surface roughness=11 ~ 13 Å). Therefore, we suggest that the generation of the pretilt angle caused by the micro-asymmetric triangular structure of the polymer, as discussed in the previous work, is in addition attributed to the surface topography of the micro-roughness in the substrate.

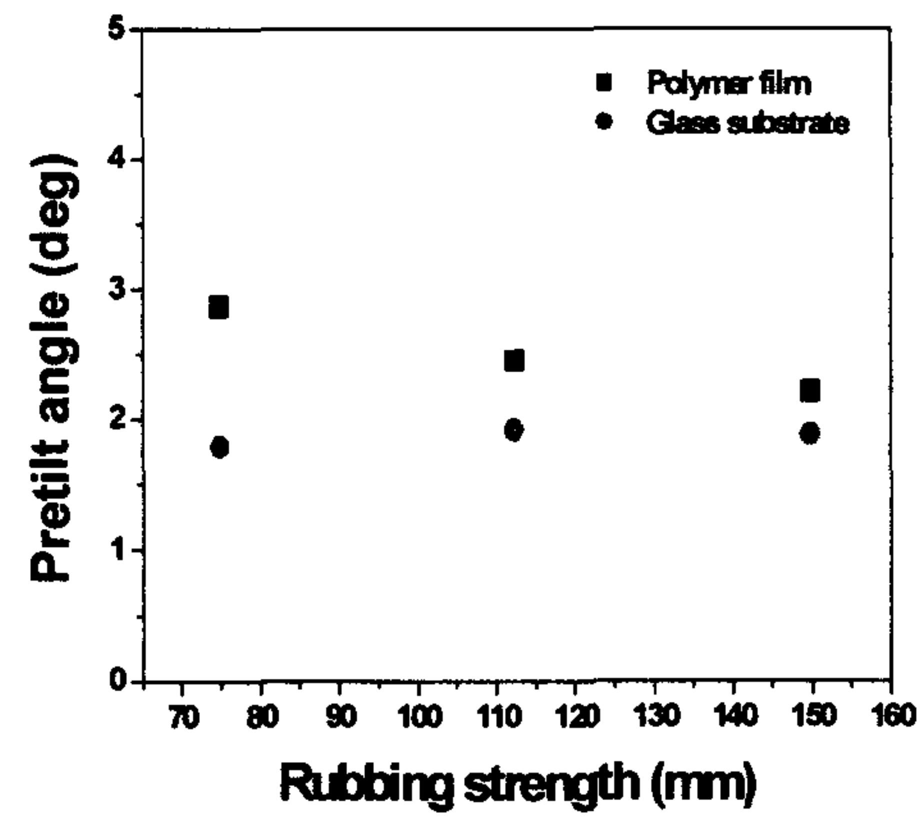


Fig. 6. NLC pretilt angles on homogenous polyamic acid type PI surface with different substrates as function of rubbing strength at low curing temperature (120℃).

surface topography of the micro-roughness in the substrate.

Figure 7 shows the pretilt angles on the two kinds of PI surfaces with different substrates as a function of the rubbing strength at a low temperature (120℃). These effects do to obtain larger pretilt angles at a low temperature. Comparing the PI-1 and PI-2 surfaces on the same substrate, the pretilt angles generated on the soluble type PI surfaces are larger than that on the polyamic acid type PI surfaces. It can be concluded that the pretilt angle generated is attributed to the imidization ratio of the PIs as shown in Fig. 2 and Fig. 4. It is shown that a large LC pretilt angle is generated when the polymer substrate and soluble type PI are used. The pretilt angle on the rubbed soluble type PI surface using a polymer substrate shows a very high value reaching 4 degrees in the weak rubbing region (RS=75 mm), and it decreases with increasing RS. The smallest LC pretilt angle is generated when a glass substrate and polyamic acid type PI are both used. Therefore, for the low temperature process to generate a high pretilt angle as the flexible displays based on polymer substrate, it may be suggested that the alignment layer use the soluble type PI, rather than the polyamic acid type PI. Consequently, flexible LCDs better use the alignment layer of the soluble type PI at a low temperature.

Therefore, we have shown that the generation of the pretilt angle usually has disadvantages at a low temperature when the polyamic type PI is used. So we showed that it is advantageous to use the organic-solvent PI when generating the pretilt angle.

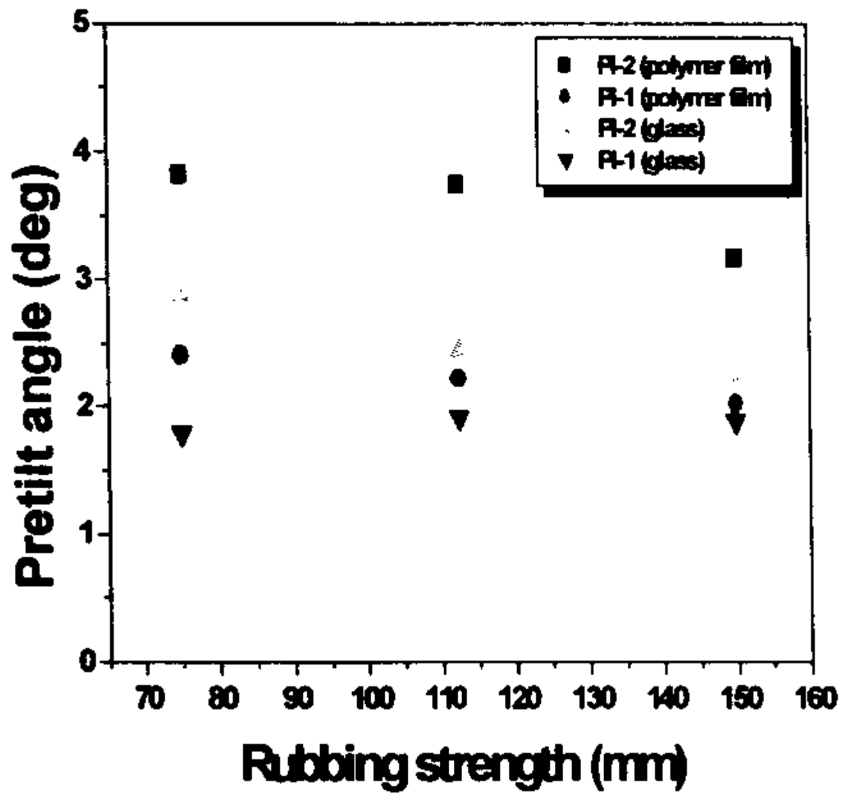
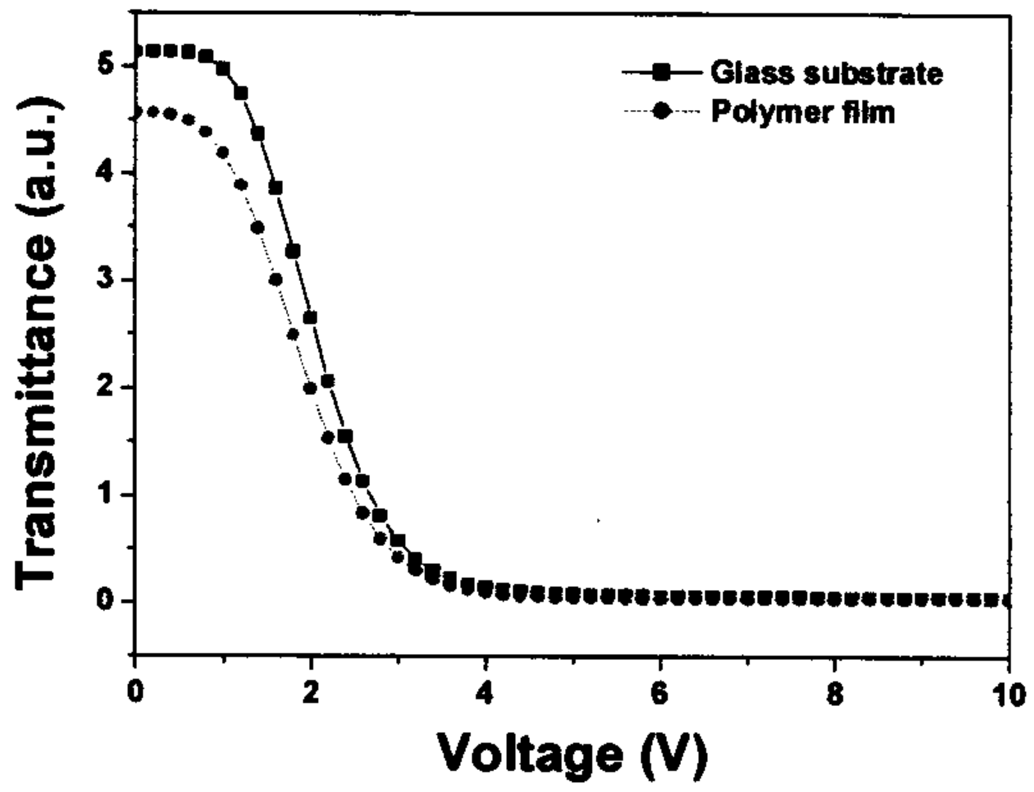


Fig. 7. NLC pretilt angles on the kinds of PI surfaces with different substrates as function of rubbing strength at low curring temperature (120℃).

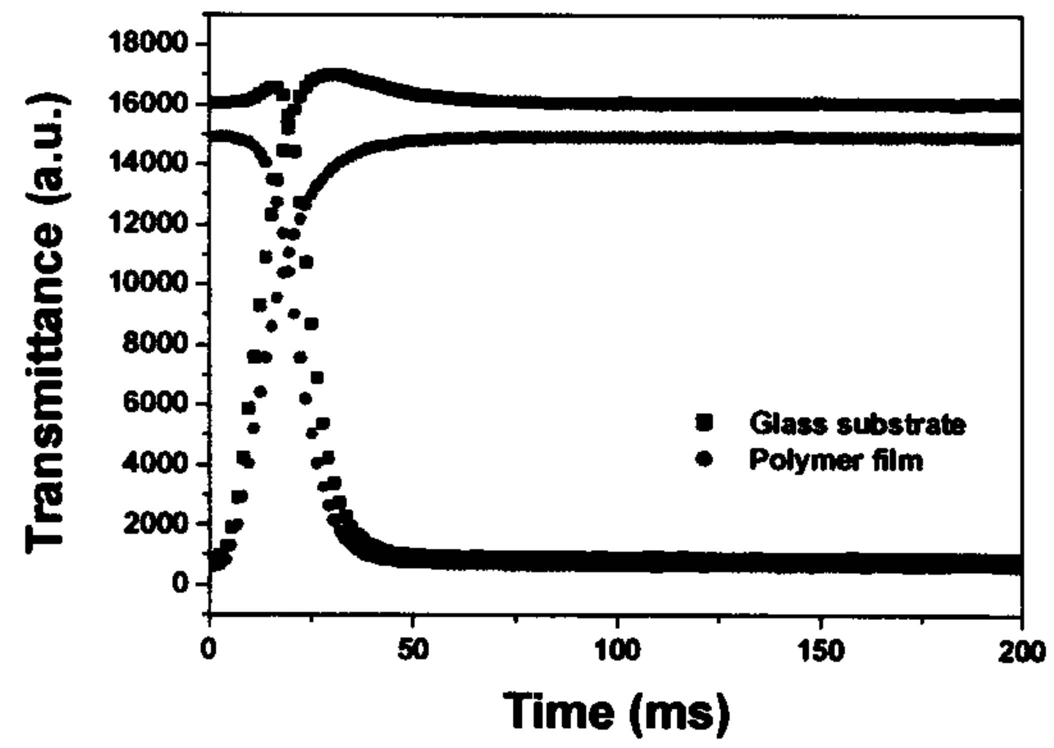
2.3 EO performance of the TN-LCD using polymer and glass substrates

Figure 8 shows the voltage-transmittance and the response time characteristics of the TN-LCD with a rubbed PI surface based on polymer and glass substrates generated at a low temperature (120℃). The Voltage-transmittance (V-T) curve without any backflow bounces in the TN-LCD with a rubbed PI surface based on polymer was observed as shown in Fig 8 (a). The response time characteristics of the TN-LCD with the polymer film exhibited a more stable special quality than that with the glass substrate. The response time of the TN-LCD using the polymer substrate was measured to be about 18ms, and the response time of the TN-LCD using the glass substrate was measured to be about 25 ms. It is considered that the fast response time of flexible LCDs may be attributed to the arrangement of the PI chains in the alignment layer. However, the transmittance level is lower on the polymer substrate than that on the glass substrate. In order to maintain the cell gap of flexible LCDs, the flexible LCDs should use a lot of spacers. We think that these spacers may help decrease the transmittance.

On the occasions when polymer film is used, the pretilt angle characteristics were higher than they were on the glass substrates, and the EO performances of the TN-LCD using the polymer substrate is almost the same as that of the TN-LCD using the glass substrate.



(a)VT



(b)RT

Fig. 8. Voltage-transmittance (VT) and Response time (RT) characteristics of the TN-LCDs with a rubbed polyimide surface based on polymer and glass substrates at low curing temperature (120℃)

3. Conclusion

In conclusion, we have investigated the generation of the pretilt angles on two kinds of PIs with different types of substrates as a function of RS. It has been shown that the pretilt angle on the rubbed soluble type PI surface with a higher imidization ratio using the polymer substrate shows a very high value that reaches 4 degrees in the weak rubbing region (RS=75 mm), and then it tends to decrease with increasing RS. However, the smallest LC pretilt angle was generated when the glass substrate and the polyamic acid type PI with 0 % imidization ratio were used. It can be concluded that the high pretilt angle may be attributed to the roughness of the micro-groove substrate and the high imidization ratio of the PI. We obtained an AFM image of the rubbed PI surface with a polymer film, which formed the micro-groove structure at a low curing temperature (120°C). However, no grooves were formed on the glass substrate at the same temperature. It is considered that this alignment may be attributed to the roughness of the micro-groove substrate. Therefore, the LC alignment is affected by the topographical structure.

Also, a good V-T curve for the TN-LCD was observed using the polymer substrate at the low curing temperature. The EO performance of the TN-LCD using the polymer substrate is almost the same as that of the TN-LCD using the glass substrate.

4. Acknowledgement

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5. References

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