High Image Quality Panel Technology - Ion Beam Alignment

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Abstract

In the conventional process of LCD panel fabrication, glass substrates are rubbed by a buffing cloth to align liquid crystals uniformly between the substrates. The "ion beam alignment technology" introduced in this paper is a liquid crystal alignment process that employs an ion particle beam accelerated at high speed, instead of the buffing cloth. Its extremely accurate processing capability allows the LCD panel to render high contrast and smooth images. The key to this technological development is that the materials and the process conditions have been optimized by evaluating the liquid crystal alignment anchoring strength using a newly established evaluation technology. The prototype LCD panel succeeded in achieving a contrast ratio of 1200:1 (25% higher than in conventional panels).

Keywords

LCD panel, image quality, contrast ratio, manufacturing technology, alignment, rubbing, ion beam, anchoring, anchoring strength, evaluation technology

1. Introduction

The LCD panel is a key component of LCD panel TVs and computer monitors, and its production process can be divided roughly into three stages: 1) array process; 2) cell process; 3) module process. The array process 1) consists of forming horizontal and vertical arrays of thin-film transistors (TFTs) for switching pixels and creating signal lines and scanning lines for driving on the glass substrate. The cell process 2) consists of preparing the surface of the array substrate and the separately acquired color filter substrate (CF substrate) for aligning liquid crystals in the specified direction, joining the two substrates to each other and sealing the liquid crystal material in the space between them. The module process 3) consists of attaching the peripheral drive circuit board and backlight module to the above to complete the LCD panel.

This paper introduces the ion beam alignment technology[1)], which is one of the technologies used in the cell process 2) to improve the image quality of the LCD panel.

2. Ion Beam Alignment Technology

The ion beam alignment technology is a new alignment technology that is designed to replace the traditional rubbing technology. First of all, let us review the traditional rubbing technology.

As described above, the LCD panel is built by stacking the array substrate and CF substrate and sealing the liquid crystal material in the space between them. With this structure, it is required that the liquid crystals are aligned uniformly and in an orderly manner between the two substrates and this is achieved by means of the chosen alignment processing method. Currently the process that is generally used for this purpose is the rubbing technology. With this technology, the substrate surfaces are coated by printing alignment films onto them, which is composed of an organic substance such as polyimide. They are then rubbed in a single direction using rollers wrapped with buffing cloths (**Fig. 1**). This process makes it possible to align the liquid crystal uniformly on the alignment film surfaces.

The rubbing based alignment technology is already established for use at actual production sites. However, there remain some problem issues that are yet to be solved. One of the problems for example is the contamination of the substrates and production line due to the alignment film debris and tissues of the buffing fabric that are stripped during rubbing. In addition, there are still other problems to be overcome in order to improve the image quality even further into the future. These include the need to eliminate the random scratches left by rubbing on the alignment film surfaces that make it hard to obtain a contrast ratio above a certain level, and the roughness or stripe-pattern irregularities in the rubbing direction that are observed during the display of black images under special display conditions, including display in a darkroom.

Based on the above background, NEC LCD Technologies, Ltd. has been tackling development of the "ion beam align-

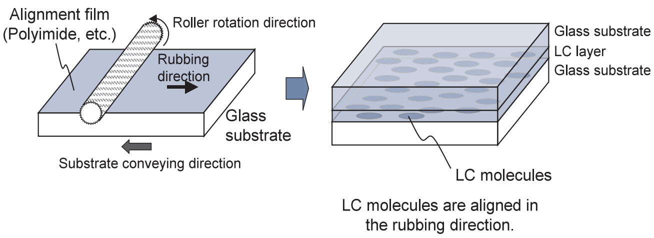


Fig. 1 Liquid crystal alignment using the rubbing process.

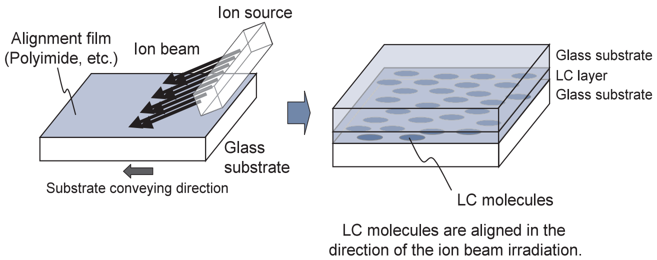


Fig. 2 Liquid crystal alignment using the ion beam process.

ment technology," which is a new alignment technology free from mechanical contact. This innovative technology has been designed for use in high-end applications where high reliability and image quality are both required, such as in medical and broadcasting monitors.

With the ion beam alignment technology, the alignment films are not rubbed with rollers but are exposed to irradiation from the oblique direction of the ion beam (Ar ions, for example,) which is accelerated in an electric field. The ion beam provides the alignment film surfaces with an anisotropic property that aligns the liquid crystals **(Fig. 2)**[2-6]. While the diameter of the tissues used for the buffing cloths of the ordinary rubbing rollers is of the order of some tens of micrometers, the diameter of the Ar ion is less than its 1/100,000th, so this technology can process surfaces at an extremely accurate level and at a high density. The process is therefore attracting attention as a technology that will not leave scratches on the alignment film surfaces and offers high contrast and smooth black images without roughness or irregularities.

3. Development of the Alignment Anchoring Strength Evaluation Technology

One of the keys to the development of new alignment technologies such as the ion beam technology is the capability of manifesting sufficient alignment anchoring strength (force for regulating the uniform alignment of liquid crystals on a surface). The establishment of a suitable technology for its evaluation is also important.

At SID '05, the BOE HYDIS research group reported the results of a characteristic analysis of an ion beam irradiated polyimide film[6]. The group also introduced the results of an alignment anchoring strength study, in which the anchoring force obtained was equivalent to that of the rubbing technology. **Fig. 3** shows the evaluation results measured using the traditional technique called the torque balance method. This method measures the alignment anchoring strength by fabricating liquid crystal cells so that their alignment directions are realigned by a specified angle between the upper and lower substrates. The actual twist angle of the liquid crystals is also measured and the deviation of the measured angle is identified with respect to the intended angle. This method is called the torque balance method because the actual twist angle is determined by the balance between the recovery torque produced by the elasticity of the liquid crystals and the elastic anchoring strength of the alignment film boundaries.

Evaluation of the orientation anchoring strength using the torque balance method is widely used because of its simplicity. However, this method has also been criticized due to problems such as the difficulty in obtaining a reliable value due to the large variance in the measurement values. Such variances can also be seen in the measurement results shown in Fig. 3. Improvement of the measurement method based on the torque balance has been attempted recently, but this method still necessitates a certain effort to obtain accurate evaluation and it is still at the development stage[7].

The main alignment anchoring strength evaluation methods including the torque balance method identify the anchoring of liquid crystal molecules on the alignment film boundaries using the "elastic model." Namely, these methods assume that

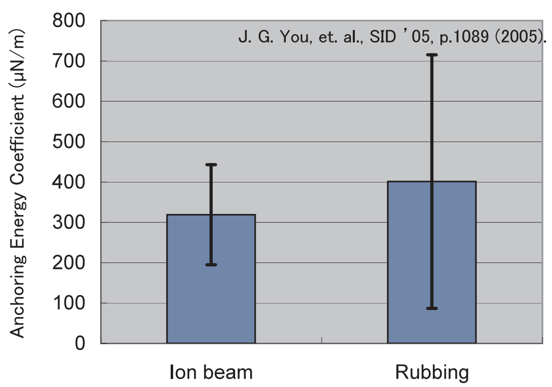


Fig. 3 Example of the reported alignment anchoring strength evaluation.

the liquid crystal molecules are anchored to the alignment film boundaries elastically, or in a spring-like manner, and they measure the strength of the spring (anchoring energy coefficient).

On the other hand, some research teams have reported on the phenomenon of "non-elastic alignment deviation"[8-10]. This phenomenon occurs when a strong torque generated by an external field (electric, magnetic, etc.) is applied to the liquid crystals for a sufficiently long period of time. It consists of the non-elastic alteration of the liquid crystal alignment direction on the alignment film boundaries. This process may be explained as a result of the mechanism with which the repetition of the desorption/re-adsorption of individual liquid crystal molecules adsorbed on the boundaries tends to affect the alignment direction in steps (or gradually from a macroscopic viewpoint).

We have developed an orientation anchoring strength evaluation technique by observing the non-elastic orientation deviation phenomenon[1]. **Fig. 4** shows the scheme of this evaluation technique. First, a voltage is applied to the liquid crystal cells having electrodes arranged in a herringbone pattern in order to rotate them in the direction of the electric field, and this status is retained for a long time. Next, the electric field is removed, the liquid crystal cells are left for a certain time and the alignment directions of the liquid crystals on both sides of the herringbone pattern boundary are measured at several points and averaged. Finally, the differences of the averaged alignment directions on both of the sides are divided by 2 in order to obtain the alignment deviation from the initial state, $\Delta\Phi$.

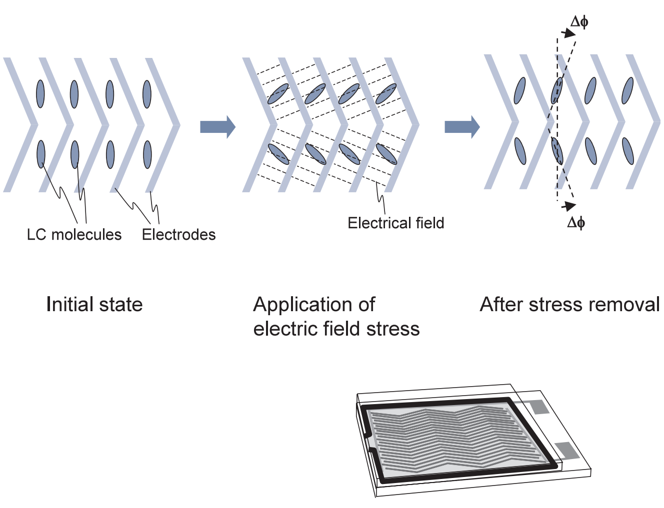


Fig. 4 Alignment anchoring strength evaluation using non-elastic model.

As this technique makes it possible to eliminate the errors that may be produced when the liquid crystal cells to be evaluated are fixed on the measurement stage, measurements of high accuracy and reproducibility are enabled. Another advantage of this technique is that it can be correlated easily with the actual characteristics because it applies the SFT technology*, which employs liquid crystal cells that feature a similar structure to the actual LCD panel.

*SFT technology: SFT stands for Super Fine TFT. It refers to the NEC LCD Technologies, Ltd. high image quality LCD technology that features an ultra-wide angle of view, low color shifting and high response speed. At the core of this technology is the IPS (In-Plane Switching) technology, which applies a lateral electric field to operate the liquid crystal molecules in a plane that is horizontal with respect to the substrate surface.

4. Optimization of Materials and Process Conditions

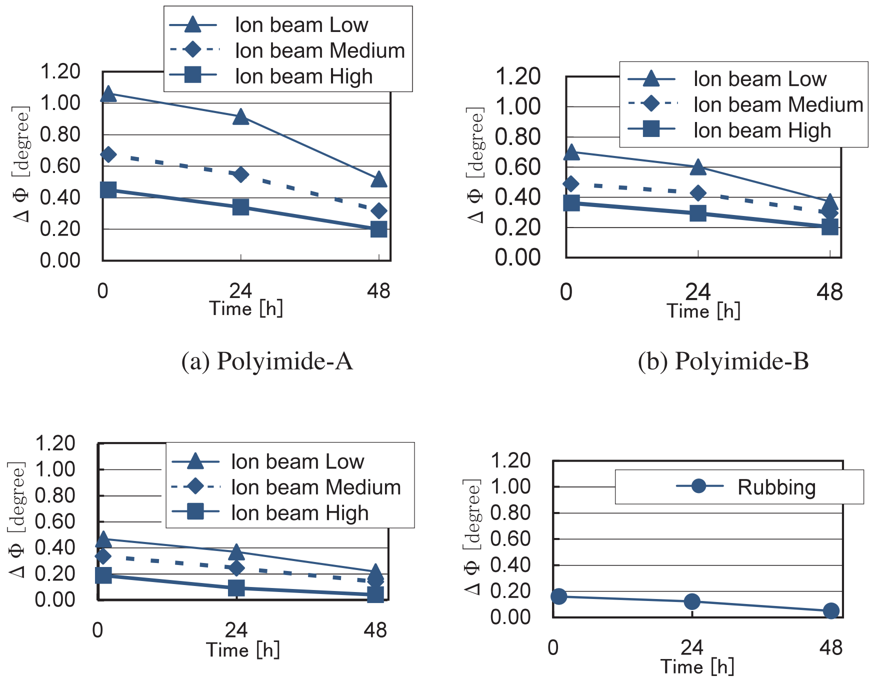
Using the alignment anchoring strength evaluation technique described in Section 3 above, we optimized the alignment film material and process conditions of the ion beam alignment technology.

Fig. 5 shows some of the experiment results in the form of graphs. We used three kinds of polyimides (polyimide-A, polyimide-B and polyimide-C) and fabricated liquid crystal cells by varying the ion beam accelerating voltage at three intensities (Weak, Medium and Strong). We then applied a voltage equivalent to the actual LCD drive voltage for 24 hours, removed the voltage and measured the alignment deviation ($\Delta\Phi$) at 1, 24 and 48 hours after the voltage removal. Fig. 5 also shows the results obtained with the liquid crystal cells prepared using the rubbing technology.

Under the condition with the largest alignment deviation ("polyimide-A" and "ion beam Weak"), an alignment deviation after 24 hours of electric field stress was as large as 1.1 degrees. The deviation gradually recovered after that but restoration to the original alignment was not observed for at least 48 hours. On the other hand, under the condition with "polyimide-C" and "ion beam High," the obtained alignment anchoring strength was in no way inferior to that obtained with the rubbing technology.

5. Prototyping

Based on the experiment results described in Section 4, we fabricated the prototypes (10.4-inch monochrome panel with



(a) Polyimide-A (b) Polyimide-B

(c) Polyimide-C (d) Rubbing (Polyimide-D)

Fig. 5 Recovery over time of alignment deviation $\Delta\Phi$.

1,024 × 768 pixels and 21.3-inch monochrome panel with 1,600 × 1,200 pixels, etc.) by applying the condition of “polyimide-C” and “ion beam High.” The prototyped LCD panels achieved a contrast of 1200:1, which was 25% higher than for the panel fabricated using the rubbing technology for comparison (950:1). We also confirmed that the image quality during black displays was very smooth and without any irregularities. For other characteristics, we found little difference from the panel fabricated using the rubbing technology and also confirmed that there was no influence on the response speed, etc.

6. Conclusion

As described in the above, NEC Technologies, Ltd. is developing an alignment technology based on the ion beam process as one of the technologies for high image quality LCD panels. In the future, we will advance the development of details aiming at the application of this technology in the manufacture of high-end products, for which high reliability and image quality are required, such as for medical and broadcasting monitors **(Fig. 6)**.

To conclude, we would like to express our thanks to the members of E&TS-AP, IBM Japan, for their support, which has included their execution of the associated ion beam processing.

Fig. 6 Example of an application of the ion beam alignment technology.

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