Ion Beam Irradiation System for LC Alignment Process

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ABSTRACT

We have developed an ion beam irradiation system to control liquid crystal (LC) alignment for LC display production and investigated its performance such as the spatial uniformity of the ion beam. The spatial distributions of current density, incident angle, divergence angle of the ion beam, and the substrate potential are shown to be quite uniform. We successfully demonstrate that a large-sized test panel fabricated by the present system shows almost comparable display quality to that by a conventional rubbing method.

INTRODUCTION

In the liquid crystal display (LCD) industry, rubbed polyimide has been generally used as alignment films. However, the rubbing method has drawbacks such as the generation of dust particles and electrostatic charges, and an alternative method is strongly demanded. A new alignment method using an ion beam is a non-contact alignment method and does not have these problems. Several research groups have reported on the ion beam alignment method applied to polyimide films [1, 2] and inorganic films [3-6]. They indicated that the method had a high potential as an alternative way of producing alignment films instead of the conventional rubbing method.

In order to employ the ion beam alignment method in the LCD industry, the development of an ion source with a large beam size is indispensable because the display panel size has become larger. At the same time, uniformity of the ion beam is a key for a high quality alignment film production.

We have developed an ion beam irradiation system called "Beam Aligner" which is designed for alignment film production and equipped with a large-sized ion source applicable to a glass substrate size of up to 400 x 500 mm^2. We reported a basic performance of the Beam Aligner and several results of the twisted nematic mode test cells in the previous paper [7]. In this paper, we focus on the ion beam uniformity of the Beam Aligner. In addition, a next-generation Beam Aligner that we are developing is outlined.

SCHEMATIC DIAGRAM AND SPECIFICATION OF THE BEAM ALIGNER

Figure 1 shows a schematic diagram of the Beam Aligner. A substrate is placed on the sample setting table at a loading stage and is transferred into a load lock chamber. After the load lock chamber is evacuated, a gate valve opens and the substrate is transferred to a process chamber. In a process chamber, an ion source producing a low-energy ion beam is equipped. A hot filament neutralizer is also mounted in the chamber to neutralize ion beam charges accumulated on a substrate surface. The ion source is placed with its longitudinal dimension parallel to the y-axis. A substrate is moved horizontally at a constant speed in a process chamber, during which the substrate is irradiated with low-energy Ar ion beam from an appropriate oblique direction. After finishing an ion irradiation process, the substrate is moved back to a load lock chamber.

Tilting the ion source inside the chamber controls ion incident angle to a substrate surface. This motion is mechanically performed using a motor

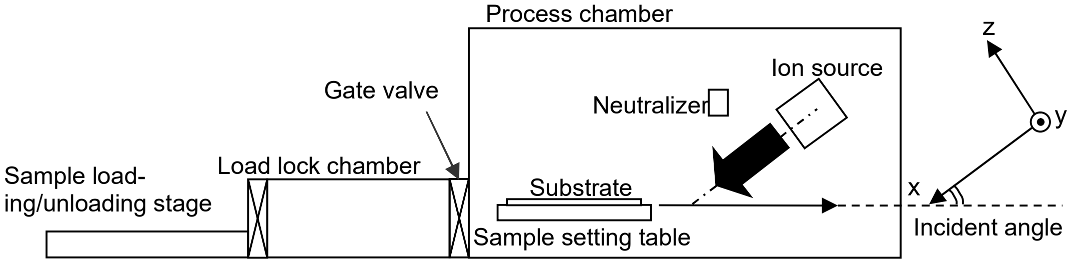

Fig. 1 Schematic diagram of the Beam Aligner.

Table 1 Specification of the Beam Aligner.

Items	Comments
Maximum Substrate Size	400 x 500 mm^2
Ion Incident Angle	15 – 90 deg
Ion Species	Ar^+
Ion Energy	200 – 1000 eV
Maximum Ion Beam Current Density	500 μA/cm at 500 eV
Beam Uniformity	(Max-Min)/(Max+Min) < ±5% (640 mm width)
Beam Monitoring System	Beam Uniformity Monitor Beam Incident & Divergence Angles Monitor
Operation	Semiautomatic

without breaking the vacuum environment of the chamber. This is helpful for research that requires frequent changes in ion incident angle.

Table 1 shows the specification of the Beam Aligner. This system is used to process a substrate size of up to 400 x 500 mm^2. The sample setting table is rotatable to set the substrate at any angle. The ion incident angle to a substrate surface is variable from 15 to 90 deg. The acceleration energy of an ion beam ranges from 200 to 1000 eV. The maximum ion beam current density per unit length along the y-axis is 500 μA/cm at 500 eV. Uniformity of the ion beam density along the 640 mm width is better than 5%.

In the process chamber, a multiple Faraday cup array is placed to measure the spatial distribution of ion beam current density. We can check the distribution before the ion beam irradiation and adjust parameters for the ion source operation if necessary. In addition, the Beam Aligner has a beam monitor, which enables us to measure the spatial distribution of the incident and divergence angles of the ion beam along the 640 mm width.

The ion source is controlled through the computer. Since there are quite a few parameters for ion source operation, it is troublesome to input all the parameters each time. To avoid this, it is possible to register a set of those parameters as one recipe and use it to operate the ion source instead of inputting the parameters each time.

RESULTS AND DISCUSSION

Figure 2 shows a typical spatial distribution of the ion beam current density along the y-axis. The excellent beam uniformity of 2.8% and 3.2% over 640 mm was observed at the ion acceleration energy of 500 and 250 eV, respectively. Since the ion source has multiple filaments whose currents are adjusted individually, we can make ion beam current distribution uniform even if it becomes worse for any reason.

We measured incident angle distribution of the ion beam by the monitor described above. It is capable of measuring these angles in the x-y plane. Asahara et al. reported that the incident angle in the x-y plane had a significant influence on the alignment direction of liquid crystal in the plane of the film, which is known to directly correlate with the uniformity of the image of a LCD panel [6]. The typical incident angle uniformity of the ion beam at an ion energy of 500 eV was ±0.15 deg over a width of 640 mm.

We also measured divergence angle of the ion beam. Collimated ion beam is preferable to produce alignment films with a high anchoring energy because the divergence angle of an ion beam determines the degree of orientation of LC molecules. The average angle and its uniformity along the 640 mm width was 1.4 deg and ±0.1 deg at ion energy of 500 eV, respectively.

In the Beam Aligner, the spatial distribution of the beam density, incident and divergence angles are automatically measured and recorded by the computer before the irradiation of a substrate with ions. This logged data can be used for the purpose of quality management and process development.

The Beam Aligner uses positive ions to produce alignment films. Positive ions accumulate on the

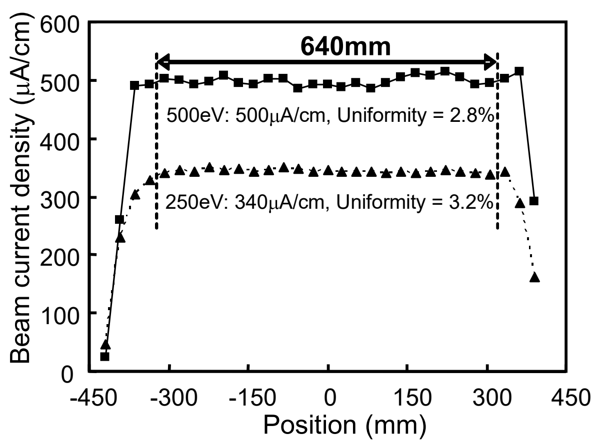

Fig. 2 Typical distribution of the ion beam current density.

surface of the alignment film and increase the surface potential. The high potential could cause a problem of the destruction of thin film transistors during the irradiation process. To avoid this, the Beam Aligner has hot tungsten filaments to emit electrons and neutralize the potential. We investigated the effect of the neutralizer on the surface potential induced by the ion beam irradiation according to the following procedure.

On a 400 x 500 mm^2 glass substrate, we placed metal probes which were connected to voltmeters of a 4 GΩ impedance. The probes were arranged in line along the y-axis so that we could investigate the uniformity of the surface potential. The substrate was fixed in the chamber while irradiated with ions at an angle of 30 deg to the surface. The ion energy and the ion beam current density were 500 eV and 410 μA/cm, respectively. The neutralizer filament current controlled the electron emission current.

Figure 3 shows the average surface potential dependence on the emission current. Without the electron emission, the potential was about 110 V, and it decreased gradually with the increase in the emission current. At 50 mA, the potential was nearly 0 V, indicating that these hot filaments successfully neutralize the positive surface potential induced by the ion beam irradiation. The potential distribution along the y-axis was uniform, as shown in Fig 4. The position of y=0 mm is at the center of the substrate in this measurement.

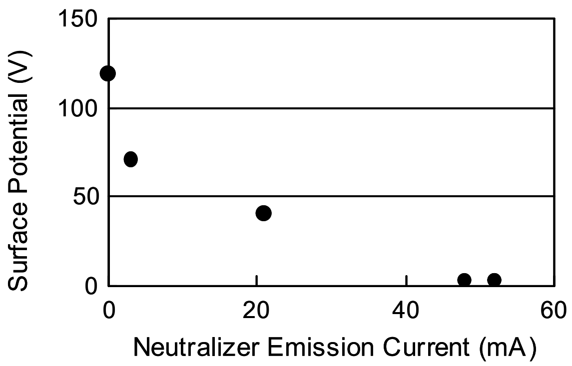

Fig. 3 Dependence of the average surface potential of a glass substrate on the neutralizer emission current.

We have found that the neutralizer also has an influence on the ion beam divergence angle as well as the surface potential. The divergence angle decreased as the emission current increased, as shown in Fig. 5. This is most likely that a space potential produced by an Ar^+ ion beam is neutralized by electrons from the neutralizer filaments. Without the emission, ions from the ion source diffuse because of the Coulomb repulsive force. The electrons lower the space potential and weaken the repulsive force, so that ions can travel more straight in a space.

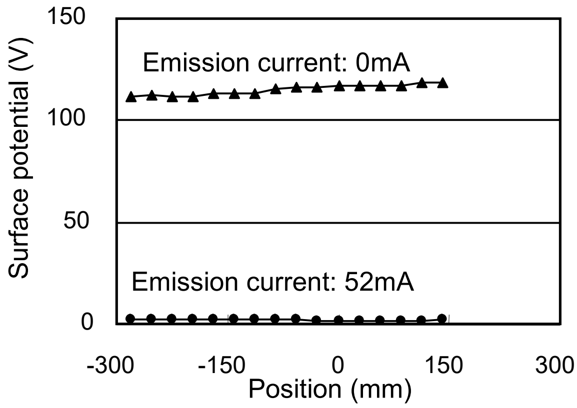

Fig. 4 Surface potential distribution along the y axis.

As shown above, the Beam Aligner has quite uniform distributions of the current density, the incident angle, the divergence angle and the surface potential. This large and uniform ion beam ensures its applicability to the alignment process of 400 x 500 mm^2 substrates. Actually, we successfully assembled a large-sized test panel, which displayed almost comparable image quality to panels produced by a conventional rubbing method.

We are developing a next-generation Beam Aligner aiming at treating larger glass substrates and mass production. This Beam Aligner, which processes substrate size of up to 730 x 920 mm^2, has an upright substrate transfer to avoid dust particle accumulation on a substrate and has fully automated operation. Once an operator sets a glass cassette, substrates are sequentially taken in the vacuum chamber, irradiated with ions, and brought back to the cassette. The only thing the operator

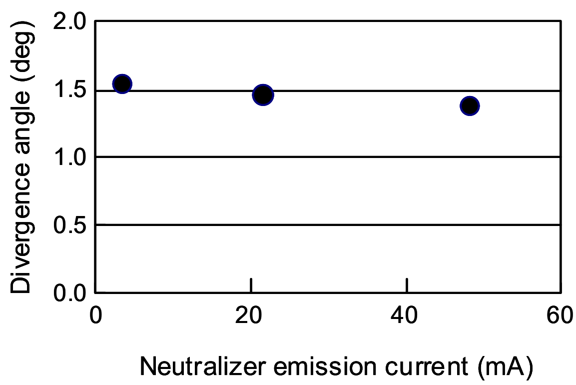

Fig. 5 Dependence of the ion beam divergence angle on the neutralizer emission current.

has to do is to choose a recipe of ion source operation parameters.

CONCLUSION

We have developed an ion beam irradiation system for an alignment process of liquid crystal displays and investigated the performance of the system such as spatial uniformity of the ion beam. The spatial distributions of current density, incident angle, divergence angle of the ion beam, and substrate potential demonstrated to be quite uniform. We successfully assembled a large-sized test panel displaying images as uniform as panels produced by the rubbing method.

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