Active-matrix display using ion-beam-processed polyimide film for liquid crystal alignment

by S.-C. A. Lien
P. Chaudhari
J. A. Lacey
R. A. John
J. L. Speidell

Ion-beam bombardment was developed as a substitute for mechanical rubbing of polyimide film as a noncontact liquid crystal (LC) alignment technique. The ion-beam technique was applied to a high-resolution thin-film-transistor-addressed liquid crystal display (TFT/LCD) panel. The results showed that LC alignment was achieved and that the display is capable of showing high-quality images.

Introduction

Through two decades of research and development effort, the thin-film-transistor-addressed liquid crystal display (TFT/LCD) [1] panel has become a key component for the portable notebook computer because it offers light weight, low power consumption, and reasonably good image quality. Because of its success in the notebook computer application, the TFT/LCD panel is now beginning to penetrate the desktop monitor market.

The manufacturing process for a TFT is similar to the semiconductor integrated circuit (IC) process, but with a much larger substrate size. The LCD process is different from the semiconductor IC process, especially with respect to a polyimide (PI) rubbing process for LC alignment and the spacer-ball spraying process. The rubbing process involves rubbing the polyimide film with a cloth attached to a rotational roller. This process may cause damage to the TFT devices and the bus lines through mechanical and electrical static discharge (ESD). It also creates cloth-fiber particles and polyimide flakes which must be removed by post-rubbing cleaning, increasing the number of process steps. The spacer-ball spraying process involves charging the spacer balls with a high voltage (typically 100 kV), then forcing them through a nozzle with compressed air. The spacer balls are repelled from one another by static electric forces and land on the substrate surface randomly. Since the positions and distributions of the spacer balls are not controllable, cell-gap uniformity is less controllable. If these two LCD cell fabrication steps can be replaced with more controllable processes, the panel production yield and the display performances can be further improved. Recently, some studies have been carried out on the replacement of the spacer-ball sprayer process with post spacers [2]. The post spacers are made by a photolithographic patterning

0018-8646/98/$5.00 © 1998 IBM

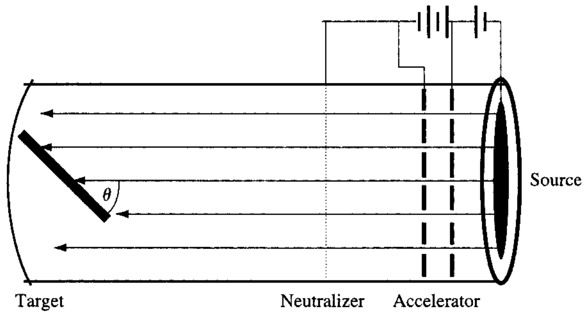

Figure 1

Schematic diagram of an ion-beam machine.

process, and their locations and distributions can be well controlled.

Replacement of the rubbing process with a more controllable and cleaner process is strongly desired. A number of methods have been proposed in attempting to replace the rubbing process: a Langmuir–Blodgett film [3], a grating structure produced by microlithography [4], oblique-angle deposition of SiO_x [5], and polarized UV radiation of polymer films [6]. However, none of these methods have been adopted for volume production, either because the process is not applicable to the TFT/LCD panel or because the LC alignment result does not reproducibly satisfy LC alignment requirements.

In this paper, we study ion-beam treatment of the polyimide surface for LC alignment.[1] It is a noncontact alignment process. First, the test panels were fabricated with various ion-beam processing parameters to study the alignment quality and the pretilt angle as a function of these processing parameters. On the basis of this study, a suitable process condition of the ion-beam treatment on the polyimide film was applied to a high-resolution color SXGA (1024 × 1280 × 3) TFT/LCD panel to replace the conventional rubbing process. The panel had a color subpixel pitch of 54 μm × 162 μm. The results of this experiment show that the LC molecules are well aligned by the ion-beam-treated PI and that the display is capable of showing high-quality images.

Requirements for good liquid crystal alignment

Although alignment by rubbing has some disadvantages, such as possible ESD, mechanical damage, and the process being dusty, it is widely used in the LCD industry because it offers many advantages. Therefore, any new alignment technology to replace the rubbing method must have the advantages of the rubbing method while eliminating the disadvantages. More specifically, the requirements for a new alignment technology are as follows:

1. It is capable of producing an LC pretilt angle of 3–5° to reduce the area of the reverse-tilt domain.
2. It has good alignment uniformity.
3. The alignment is stable and reliable.
4. It causes no ESD or mechanical damage.

Experiment on test panels

- *Test-panel preparation*

To develop an ion-beam treatment process on the polyimide (PI) film for liquid crystal alignment, indium–tin-oxide (ITO)-coated glass substrates with a substrate dimension of 100 mm × 75 mm × 1.1 mm were used to fabricate the test panels. The substrates were edge-beveled and cleaned with a detergent[2] solution in distilled water by a substrate-cleaning machine. The substrates were then spin-coated with a Nissan polyimide at 3000 rpm for one minute. The PI films were baked at 80°C for 10 minutes, cured at 180°C for 60 minutes, and then bombarded by ion beams. (The schematic diagram of an ion-beam machine is shown in **Figure 1**.) An electrical field was used to accelerate the ion particles, which then passed through a neutralization zone before bombarding the PI-coated substrate surface. The ion-beam species used for this study was argon. The substrate orientation is adjustable, as are the ion-beam species, the beam current, energy, and bombarding time on the substrate.

Two types of test panels have been fabricated: the antiparallel test panel, for pretilt angle measurement, and the twisted nematic (TN) test panel, for electro-optical measurement. For antiparallel test panels, the directions of the ion-beam bombardment on the top and bottom substrates are antiparallel to each other; for TN test panels, they are at 90° to each other. For each test panel, after both PI-coated substrates were bombarded by the ion beam, 5-μm spacer balls were applied to the PI surface of one substrate using a dry-spacer-applying machine. An edge seal pattern of ultraviolet (UV)-light-curable epoxy was applied to the PI surface of the other substrate. Then the two substrates were assembled and exposed to the UV light to cure the edge seal epoxy. The assembled panels were then filled with Merck LC ZLI-5080 without a chiral agent for the antiparallel test panels and with Merck LC ZLI-5080 blended with 0.3% ZLI-811 (a left-hand chiral agent) for TN test panels. Finally, the same UV-curable epoxy was used to seal the LC filling port, making the test panel complete and ready for measurements.

[1] P. Chaudhari, J. Lacey, A. Lien, and J. Speidell, unpublished work.

[2] 0.3% Micro (Cole-Palmer Instrument Co.).

• *Measurement of pretilt angle*

The pretilt angle of an antiparallel cell was measured by the crystal-rotation method [7]. The optical apparatus was arranged in the following sequence: light source, filter, focusing lens, entrance polarizer, test panel (mounted on a rotational stage driven by a motion controller), exit polarizer, and spot photometer. The filter transmitted a monochromatic light with a 560-nm central wavelength and 10-nm bandwidth. The test panel was oriented so that the ion-beam bombardment direction was perpendicular to the rotational axis of the stage. The entrance and exit polarizers were stationary, with their surfaces perpendicular to the direction of light propagation, and their transmission axes made an angle of 45° with respect to the rotational axis of the rotational stage. The transmission axis of the exit polarizer was perpendicular to that of the entrance polarizer. The transmission read by the spot photometer was recorded as a function of the rotation angle of the test panel. A symmetric offset angle [7], which is related to the pretilt angle, was determined from a plot of transmission versus sample rotational angle.

• *Measurement of transmission versus applied voltage*

To measure transmission versus applied voltage, a TN test panel was used. The apparatus for this measurement was similar to that for pretilt angle measurement, except that the test panel was stationary, with its surface perpendicular to the direction of the propagation of light. A square wave was applied to ITO electrodes of the test panel, and the optical transmission was recorded by the spot photometer for each applied voltage.

• *Measurement of charge retention*

The charge-retention measurement determines the percentage of voltage (or charge) the pixel can hold for a period of a frame time (for instance, 16.7 ms) after the pixel is charged to a given voltage. This is one of the methods used to monitor the interaction of the alignment PI layer and the liquid crystal. Since the PI film is exposed to the ion beam, we must determine whether the ion bombardment on PI film causes degradation of the liquid crystal resistivity.

• *Results and discussion*

The first set of antiparallel test panels were fabricated with the ion-beam energy varied while the substrate orientation, bombardment time of the beam on the substrate, and beam current were fixed. The pretilt angle for each panel was measured. A plot of the pretilt angle as a function of ion-beam energy is shown in **Figure 2**, in which the incident angle of the beam with respect to the substrate surface is 30°, the beam current is 100 mA [which is equivalent to the argon flux of 1×10^{15} particles/(cm^2-s) on the substrate surface when the substrate surface is normal to the beam direction], and substrate is exposed to the ion beam for one minute. The curve shows that the test panels fabricated with a beam energy of 400 eV or greater have a low pretilt angle.

The second set of antiparallel test panels were fabricated with the ion-beam time varied and with the beam energy, beam current, and substrate orientation fixed. The pretilt angle as a function of bombardment time is plotted in **Figure 3**, in which the incident angle of

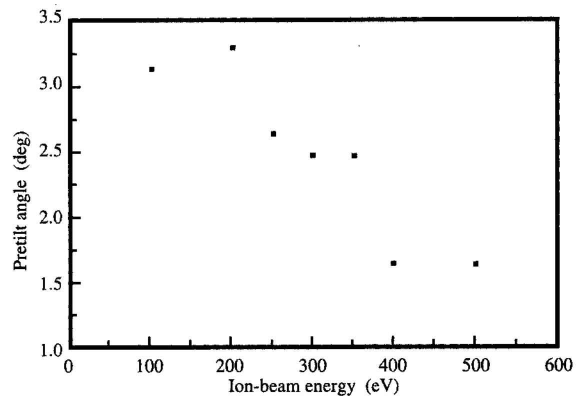

Figure 2

Pretilt angle as a function of ion-beam energy. The data are taken as the ion-beam incident angle is 30° with respect to the substrate surface, the beam current is 100 mA, and the substrate is exposed to the beam for one minute.

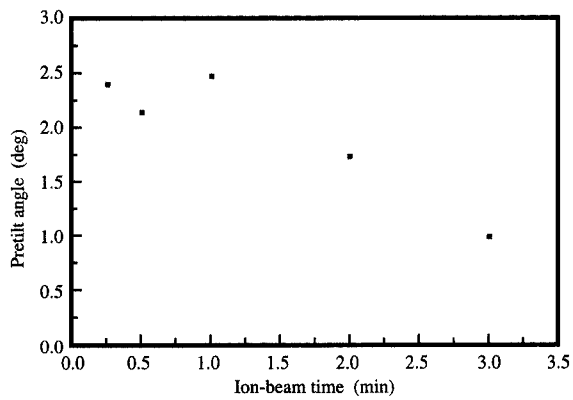

Figure 3

Pretilt angle as a function of ion-beam bombardment time. The data are taken as the ion-beam incident angle is 30° with respect to the substrate surface, the beam energy is 300 eV, and the beam bombardment current is 100 mA.

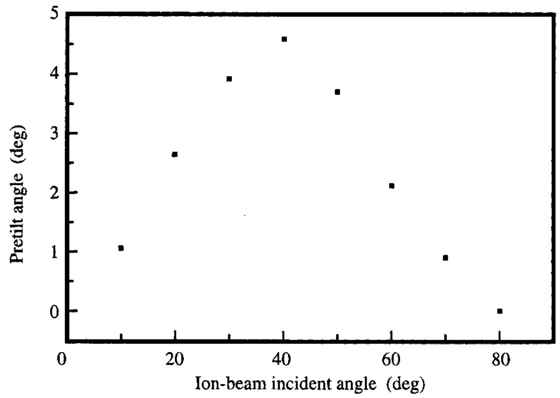

Figure 4

Pretilt angle as a function of ion-beam incident angle. The data are taken as the ion-beam energy is 300 eV, the beam current is 100 mA, and the beam bombardment time is one minute.

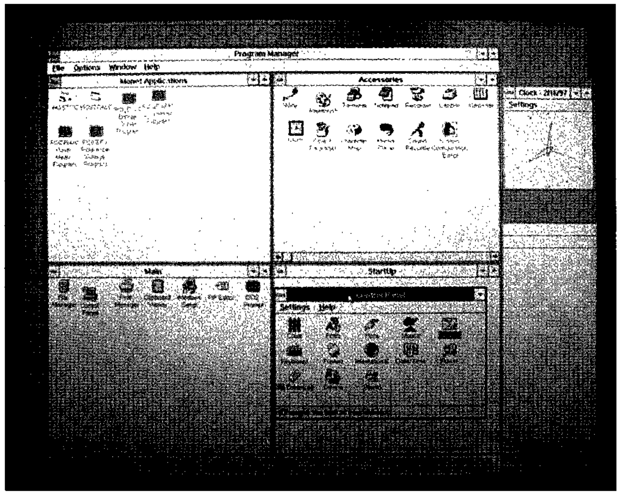

Figure 6

Photograph taken from an image displayed by an ion-beam-aligned TFT/LCD panel.

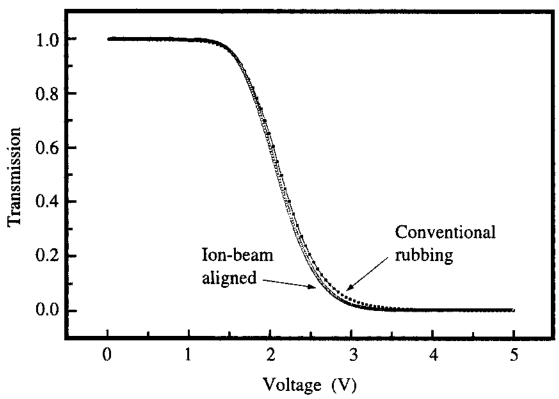

Figure 5

Transmission vs. applied voltage curves for an ion-beam-aligned TN test panel and for a conventional rubbing-aligned TN test panel. Maximum transmissions are normalized to 1.

the ion beam with respect to the substrate surface is 30°, the beam energy is 300 eV, and the beam bombardment current is 100 mA. The curve shows that it would take less than two minutes to obtain a reasonably high pretilt angle. In fact, if the substrates are exposed to the ion beam too long, the pretilt angle becomes too small.

The third set of antiparallel test panels were fabricated with the incident angle of the ion beam with respect to the substrate surface varied and with the beam energy, current, and exposure time fixed. The pretilt angle as a function of ion-beam incident angle was plotted in **Figure 4**, in which the ion-beam energy is 300 eV, beam current is 100 mA, and bombardment time is one minute. The cell process condition of the third set of test panels is slightly different from that of the first and second sets of test panels. After ion-beam treatment, the first and second sets of test panels were cleaned in deionized water and then baked in an oven at 120°C for 30 minutes. (The cleaning and baking processes generally reduce the panel pretilt angle.) For the third set of test panels, the deionized water cleaning and oven baking steps were omitted. This, in fact, is the desired cell process for the ion-beam-aligned panel, since ion-beam treatment would not create cloth and polyimide debris as would mechanical rubbing. To keep the panel surface free of contamination, the ion-beam process and all other cell process steps should be performed in a clean room, and the substrates should not be removed from the clean room before the entire cell process is finished. The curve of Figure 4 clearly shows that the pretilt angle peaks at the ion-beam incident angle around 45°. We have repeated this experiment for other ion-beam energies, and the pretilt angle also peaks at an ion-beam incident angle around 45°. As mentioned above, a pretilt angle between 3° and 5° is required to reduce the reverse-tilt domain of an LCD panel. Therefore, the optimum ion-beam incident angle is 45° with respect to the substrate surface.

We also visually observed the alignment quality of each panel and found that ion-beam treatment with a suitable machine and a proper set of process parameters can lead to good LC alignment and uniform pretilt for the entire panel. It is interesting to note that the LC pretilt direction produced by ion-beam alignment is the opposite of that produced by rubbing alignment. In other words, the LC pretilt direction produced by rubbing follows the rubbing direction, but the LC pretilts toward the ion-beam source in ion-beam alignment.

From the results of the above measurements and visual observations, we chose a set of good process parameters for further study: ion-beam energy = 300 eV; beam current = 100 mA; beam time = one minute; and beam incident angle = 45° with respect to the substrate surface. We fabricated two types of TN test panels, one aligned by ion-beam-treated PI with the above chosen process parameters, and the other aligned by conventional rubbed PI. **Figure 5** shows curves for transmission versus applied voltage for the ion-beam-aligned TN test panel (open circles) and for the conventional rubbing-aligned TN test panel (squares + solid line). These curves are very similar; the discrepancy is due primarily to the difference in pretilt angle. Visually, the alignment quality of these types of TN test panels is about the same. We also measured the charge retentions of these two test panels. The ion-beam-aligned TN test panel has a charge retention of 95–98%, and the rubbing-aligned TN test panel has a charge retention of 95–99%; basically, they are not different.

Application of ion-beam alignment to high-resolution TFT/LCD panels

By using the test panels and selecting suitable ion-beam process parameters, a procedure for aligning liquid crystals on polyimide film was developed. To test whether this ion-beam alignment method works for a real TFT panel and whether the ion beam causes any damage or degradation of TFT devices, the process was applied to a high-resolution color SXGA (1024 × 1280 × 3) TFT/LCD panel, replacing the conventional rubbing process. The panel had a color subpixel pitch of 52 μm × 162 μm. The PI-coated TFT substrate and PI-coated color-filter substrate were exposed to an ion beam using process parameters similar to those for the TN test panel. The TFT substrate was tested using an array tester [8] before and after ion-beam bombardment; the test results show that the TFT devices were neither damaged nor degraded by the bombardment. The ion-beam-treated TFT substrate and color-filter substrate were assembled to become a color TFT/LCD panel which showed that LC molecules are well aligned by the ion-beam treatment. **Figure 6** is a photograph of an image displayed by this panel, clearly demonstrating that the ion-beam-aligned TFT/LCD is capable of displaying a high-quality image.

Conclusion

We have developed an ion-beam treatment of the polyimide surface for LC alignment. With a set of proper process parameters, we can achieve stable, reliable, good-quality alignment with a pretilt angle of 3–5°. This alignment method was successfully applied to a high-resolution color SXGA (1024 × 1280 × 3) TFT/LCD panel. The TFT devices and bus lines were not damaged by ion bombardment, and the panel is capable of showing good-quality images.

Acknowledgments

We acknowledge the array process group for providing the high-resolution TFT panel for this study and the electronics group for providing the driving electronics for this TFT/LCD panel. We are also grateful to J. Ritsko, R. L. Wisnieff, S. W. Depp, H. Inoue, and S. Odahara for many useful discussions.

References

1. P. M. Fryer, E. G. Colgan, E. Galligan, W. Graham, R. Horton, D. Hunt, K. Latzko, R. Nywening, L. Jenkins, R. John, P. Koke, Y. Kuo, F. Libsch, A. Lien, I. Lovas, R. Polastre, M. E. Rothwell, J. Souk, J. Wilson, R. Wisnieff, and S. Wright, "A Six-Mask TFT–LCD Process Using Copper-Gate Metallurgy," *Digest of Technical Papers*, Society for Information Display International Symposium, 1996, p. 333.
2. H. Yamashita, Y. Saitoh, S. Matsumoto, and M. Kodate, "Precise Cell-Thickness Control by Spacer-Ball-Free Structure and Its Application to Large-Size TFT–LCDs," *Digest of Technical Papers*, Society for Information Display International Symposium, 1996, p. 600.
3. Y. Ikeno, A. Oh-saki, M. Nitta, N. Ozaki, Y. Yokoyama, K. Kakaya, and S. Kobayashi, "Electrooptic Bistability of a Ferroelectric Liquid Crystal Device Prepared Using Polyimide Langmuir–Blodgett Orientation Films," *Jpn. J. Appl. Phys.* **27,** L475 (1988).
4. M. Nakamura and M. Ura, "Alignment of Nematic Liquid Crystals on Ruled Grating Surfaces," *J. Appl. Phys.* **52,** 210 (1981).
5. J. Ianning, "Thin Film Surface Orientation for Liquid Crystals," *Appl. Phys. Lett.* **21,** 173 (1992).
6. M. Schadt, K. Schmitt, V. Kozinkov, and V. Chigrinov, "Surface-Induced Parallel Alignment of Liquid Crystals by Polymerized Photopolymers," *Jpn. J. Appl. Phys.* **31,** 2155 (1992).
7. H. Birecki and F. Kahn, in *The Physics and Chemistry of Liquid Crystal Devices*, G. J. Sprokel, Ed., Plenum Press, New York, 1980.
8. L. C. Jenkins, R. J. Polastre, R. R. Troutman, and R. L. Wisnieff, "Functional Testing of TFT/LCD Arrays," *IBM J. Res. Develop.* **36,** 59 (1992).

Received April 9, 1997; accepted for publication March 17, 1998

Shui-Chih Alan Lien *IBM Research Division, Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598 (salien@us.ibm.com).* Dr. Lien received a B.S. degree in physics from the National Taiwan Normal University, Taipei, Taiwan, in 1977, and an M.S. degree in electrical engineering and Ph.D. degree in physics from the University of Minnesota, Minneapolis, in 1984. From 1984 to 1987, he worked at Optical Imaging Systems, Inc., Troy, Michigan, where he was involved in the development of large-area active-matrix liquid crystal displays. In 1987, Dr. Lien joined IBM at the Thomas J. Watson Research Center, where he is currently a Research Staff Member in the Flat Panel Display Technologies group. His research interest is in liquid crystal display physics and technology. He is an author or coauthor of five U.S. patents and 70 technical papers. Dr. Lien is currently a member of the Board of Directors of the International Liquid Crystal Society and a member of the Liquid Crystal Technology Subcommittee of the Society for Information Display.

Praveen Chaudhari *IBM Research Division, Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598 (chaudha@us.ibm.com).* Dr. Chaudhari received a B.S. (Honors) from the Indian Institute of Technology (1961), and an M.S. (1963) and an Sc.D. (1966), both in physical metallurgy, from the Massachusetts Institute of Technology, Cambridge. Since joining the IBM Thomas J. Watson Research Center as a Research Staff Member in 1966, he has held various management responsibilities in science and science-related technologies such as optical storage, magnetic bubbles, and the Josephson program. He was appointed Director of the Physical Sciences Department in 1981, Vice-President for Science and Technology, IBM Research Division, in 1982, and a member of the Corporate Technical Committee in 1989. Dr. Chaudhari has worked on the structure and properties of amorphous solids, mechanical properties of thin films, defects in solids, quantum transport in disordered systems, superconductivity, and on magnetic monopole and neutrino mass experiments. He has received several IBM awards, and was the first recipient of the Leadership Award (1986) of the Metallurgical Society of AIME for his contributions to advancing the science and technology of electronic materials. He received the George E. Pake Award of the American Physical Society (1987) for his personal contributions to science and management of science. Dr. Chaudhari is a member of the American Association for the Advancement of Science, the American Institute of Mining, Metallurgical and Petroleum Engineers, and the National Academy of Engineering. He is a Fellow of the American Physical Society.

James A. Lacey *IBM Research Division, Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598 (jalacey@us.ibm.com).*

Richard A. John *IBM Research Division, Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598 (johnra@us.ibm.com).* Mr. John holds an A.A.S. degree from the RCA Institute and attended City College of New York. Since joining IBM in 1967, he has worked on a variety of research projects including integrated-circuit packaging, gas-panel displays, and LED, ink-jet, thermal, and color electrophotographic printing. He is currently involved in the design and fabrication of high-resolution color liquid crystal displays. Mr. John is the author or coauthor of three U.S. patents and several published papers.

James L. Speidell *IBM Research Division, Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598 (jspeidel@us.ibm.com).* Mr. Speidell is a Senior Engineer; he manages the Central Scientific Services Microfabrication Laboratory at the IBM Thomas J. Watson Research Center. He joined IBM in 1977, receiving an A.A.S. degree in electrical technology from Westchester Community College in 1978 and a B.S. degree from Manhattan College in 1983. Mr. Speidell's work has involved the areas of silicon micromachining, microelectronic fabrication, advanced mask technologies, and thin-film vacuum processing. He has received six IBM Invention Achievement Awards and two IBM Outstanding Technical Achievement Awards.