Prospects of LCD Panel Fabrication and Inspection Equipment Amid Growing Demand for Increased Size

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OVERVIEW: LCD panels have various desirable characteristics such as a slim construction, light weight and high resolution, and are making rapid inroads into the PC display market. In the future, it is predicted that growth in the liquid crystal market will be driven by the TV market where increasing use is being made of flat panel displays. As the primary application of LCDs switches from PCs to TVs and displays become larger and less expensive, these displays are being made from mother glass with larger dimensions so that they can be produced more efficiently. At Hitachi High-Technologies Corporation, we offer a comprehensive line-up of system solutions incorporating the latest fabrication and test equipment for larger LCD panels.

INTRODUCTION

IN the LCD (liquid crystal display) panel market, there is a growing demand for large-scale panels of 15–20 inches due to market trends such as the switch from CRT (cathode ray tube) displays to flat panel displays in desktop PC (personal computer) monitors. The TV (television) market also has a growing need for larger displays, and recently there has been a growth in demand for panels of 40 inches or more.

From a production line viewpoint, simultaneously realizing reduced costs and larger panel sizes requires that further improvements in production efficiency are made by using larger mother glass substrates and processing them more quickly. There is consequently a need for the construction of new production lines that meet these requirements.

Here, we discuss the prospects of LCD panel fabrication and test equipment for the production of larger size panels (see Fig. 1).

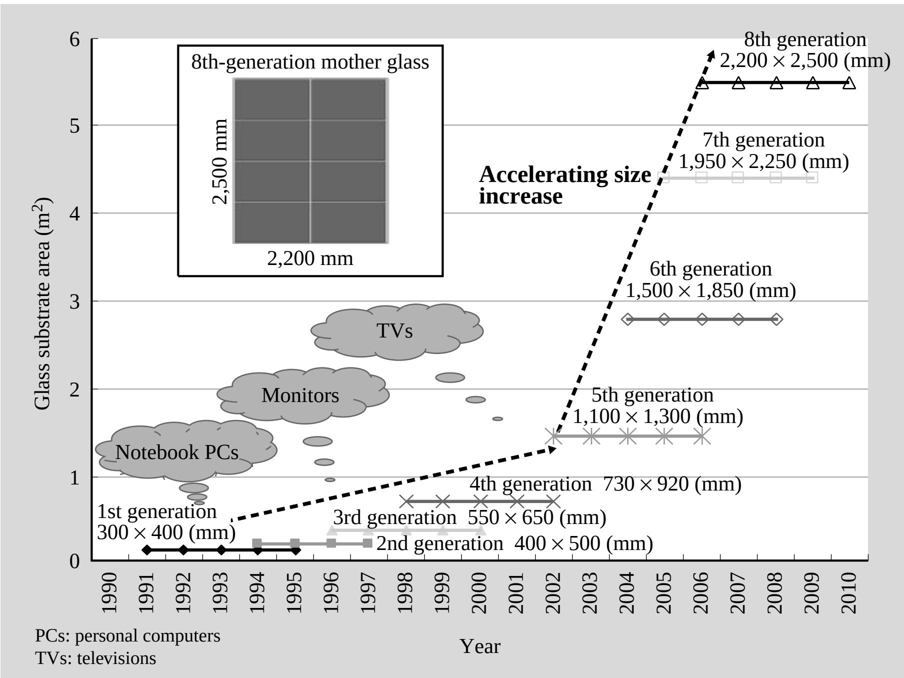


Fig. 1—Growth in the Size of Mother Glass Substrates for LCD (liquid crystal display) Panels.
LCD panels are made from a sheet of glass called the mother glass. Normally, a single mother glass is used for multiple panels, and is cut to the final display size (notebook PC, monitor, TV, etc.) after the mother glass has been processed. By fabricating multiple panels on a single mother glass, the cost per panel can be reduced. In LCD applications such as PCs and TVs, rapid progress is being made towards larger screen sizes and lower costs. For this reason, the mother glass substrate size has been increasing in recent years in order to improve productivity and increase the number of panels processed at one time.

CHANGES IN APPLICATIONS OF LCDS AND DEVICE MARKET

There was significant growth in the market for large-screen TFT (thin film transistor) LCDs in the 1990s, mainly for notebook PC applications. In the latter half of the decade, the market for desktop PC monitors began to migrate rapidly from CRTs to flat panel displays. Today, the largest market for LCDs is for TVs.

In TV applications, the screen size is accelerating faster than in PC applications.

The market scale of large-screen TFT LCDs reached 6 trillion yen in 2006 and is expected to continue growing strongly in the future. Furthermore, the proportion of TV applications is continuing to grow rapidly and will exceed 50% of the market for large-screen TFT liquid crystal displays in 2008.

The market for Japanese LCD fabrication equipment accounted for roughly 15% of the panel market scale up to 2005, but in the future it is predicted that further reductions in the cost of panel displays will lead to increased pressure on equipment costs. There is consequently a need for the development of fabrication equipment with a much higher cost/performance ratio. It is also necessary to not only increase productivity by increasing the size of the mother glass, but also to make substantial cost savings through process innovation (see Fig. 2).

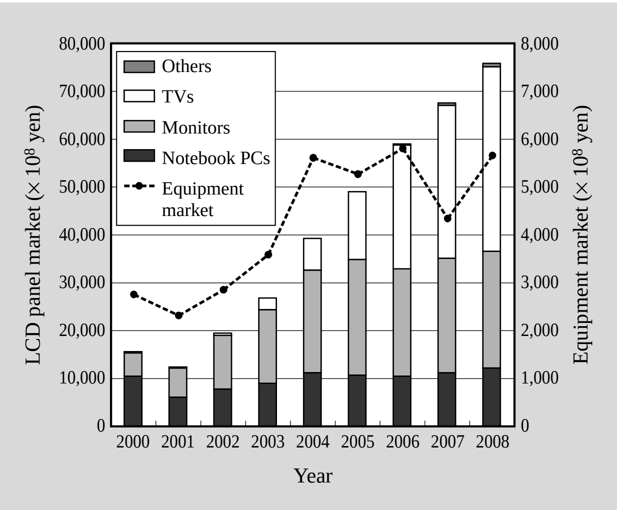


Fig. 2—The Markets for LCD Panels and LCD Fabrication Equipment.
The data for LCD panels is based on a market survey conducted by DisplaySearch in the US, and the data for the equipment market was published by the SEAJ (Semiconductor Equipment Association of Japan) in January 2007.

LCD PANEL FABRICATION PROCESSES AND EQUIPMENT

LCD Panel Fabrication Processes

TFT LCD panels are fabricated by a combination of four processes: an array process, a color filter process, a cell fabrication process, and a module assembly process (see Fig. 3). These are described in detail below.

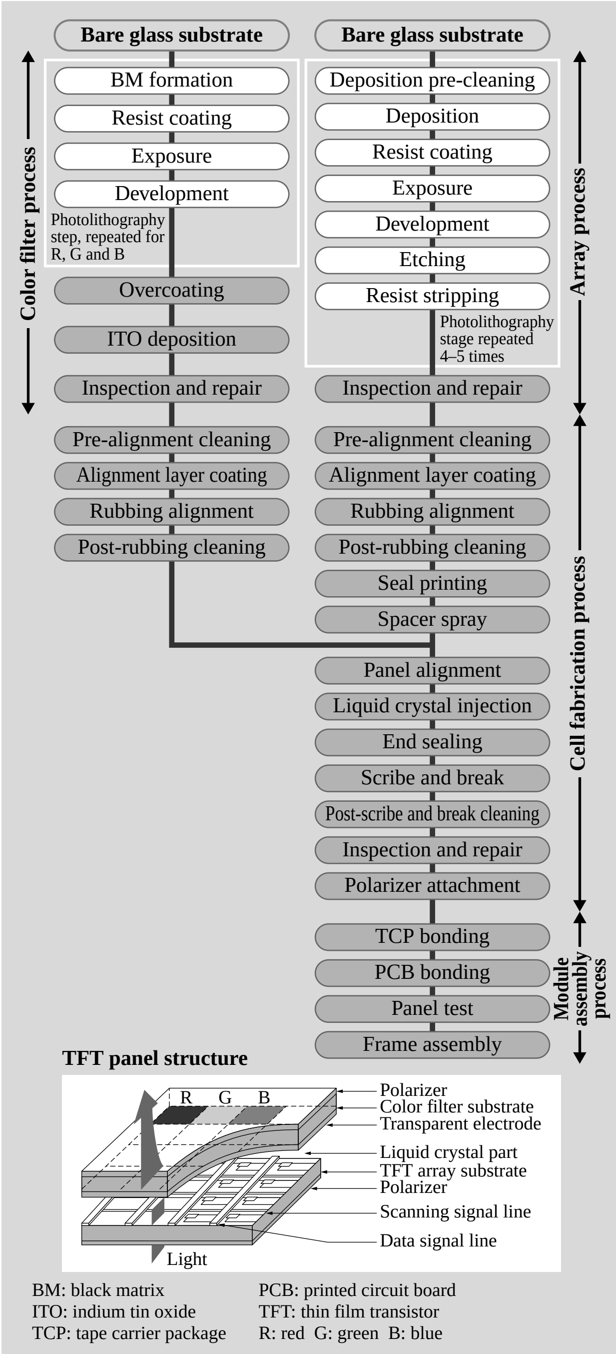


Fig. 3— TFT LCD Fabrication Stages and Panel Structure.
The TFT LCD fabrication process consists of an array process, a color filter process, a cell fabrication process, and a module assembly process.

Array process

A color TFT LCD panel consists of two glass substrates—a TFT array substrate and a color filter substrate.

On the TFT array substrate, transistors (TFTs) that control the amount of light transmitted by the LCD are arranged in the form of a matrix. The array process is a photolithography process in which a pattern is formed by repeating the steps of pre-cleaning, deposition, resist coating, exposure, development, etching, and resist stripping.

Originally, the photolithography step was performed between six and nine times, but with recent developments in fabrication processes, almost all panel manufacturers now use a process with four or five photolithography steps.

Color filter process

To allow the LCD to produce colors, the color filter consists of a substrate coated with an opaque BM (black matrix) regular arrangement of red, green and blue regions. Modern color filters are also subjected to additional processing to form structures such as ribs to produce a wide viewing angle and photo spacers to control the cell gaps. This results in displays that work better but require more complex fabrication processes. In the color filter process, photolithography is generally used to form each of these layers.

Cell fabrication process

The cell fabrication process consists of six steps: (1) forming alignment layers on the patterned array substrate and color filter substrate, (2) a rubbing step to achieve directional alignment, (3) a screen printing or dispenser application step to apply an adhesive such as epoxy resin to the seal parts, (4) high-precision panel alignment of the array substrate and color filter substrate, (5) injection of the liquid crystal, and (6) precise application of polarizer plates. In this process, the display quality is directly affected by factors such as dust, static electricity and alignment precision.

Module assembly process

In the module assembly process, an ACF (anisotropic conductive film) is used to make an electrical and mechanical connection between the electrodes of the LCD panel (cells) and the TCP (tape carrier package) that acts as the driver IC (integrated circuit). At the TCP's other electrodes, an ACF is used to connect a PCB (printed circuit board) mounted with a control circuit, interface circuit and so on.

LCD Panel Fabrication Equipment Line-up

Hitachi High-Technologies Corporation provides a range of equipment necessary for each process in the fabrication of LCD panels. The main items of equipment needed for the fabrication and testing of LCD panels are shown in Fig. 4. Our line-up includes the very latest 8th-generation fabrication and inspection equipment for the array process, color filter process, cell fabrication process and module assembly process, which can be used in the proposal of manufacturing systems.

The following section discusses the exposure system, which is the most important piece of equipment in the photolithography step, and the glass substrate inspection system that is used in each process.

Fig. 4— The Main Items of LCD Panel Fabrication and Inspection Equipment.
We offer a full line-up of fabrication and inspection equipment from the array process to final module assembly.

8TH-GENERATION EXPOSURE SYSTEM

LE0200SD Large-size Glass Substrate Exposure System

Our newly developed LE0200SD large-size glass substrate exposure system is an efficient high-speed proximity exposure system that is capable of XY step exposure and can handle so-called 8th-generation glass substrates measuring up to 2,200 × 2,500 mm.

An external view of this system is shown in Fig. 5.

Fig. 5 — Exposure System for Large-format Glass Substrates (LE0200SD).
The figure shows the external appearance of the proximity exposure system — which enables XY step exposure for handling 8th-generation glass substrates.

Technical Issues of Large-size Substrate Exposure

One of the issues that need to be addressed with large-size glass substrates measuring 2 m^2 or over is to develop precise high-speed stage technology compatible with large substrates.

This requires the establishment of a larger stage stroke compatible with large-size glass substrates, a more powerful stage motor, reduced weight, and substrate chuck processing technology. It is also essential to increase the overall rigidity of the system including the stage so as to counteract the vibration caused by acceleration and deceleration of the stage due to the increased stage speed.

The increased mask size makes it necessary to compensate the increased mask flexure resulting from the self-weight of the mask, and the larger exposure area makes it necessary to develop exposure light sources with higher output power in order to achieve the same throughput as before.

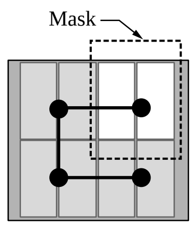
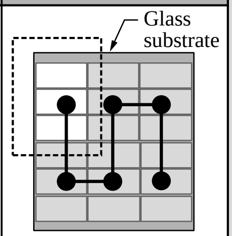
No. of shots	4 shots	6 shots
No. of panels	46-inch (about 117 cm) wide screen × 8	32-inch (about 81 cm) wide screen × 18
XY step exposure		

Fig. 6 — Examples of Panel Layouts.
Combining XY step exposure with both 0°- and 90°-rotated substrates efficiently provides a flexible arrangement of panels.

Characteristics of Large-size Substrate Exposure

To cope with larger glass substrates in the LE0200SD 8th-generation large-size glass substrate exposure system, Hitachi not only developed components such as a high-speed and high-precision large-size stage for performing XY step exposure, a high-intensity exposure light source and a high-speed glass substrate transfer mechanism, but also increased the speed of parts employed in our earlier equipment, such as the pre-alignment, proximity gap control and auto-alignment mechanisms. Together with the negative pressure type mask flexure compensation mechanism and a range of cleaning and temperature control functions, Hitachi arrived at an exposure system that contributes to the production of high-quality LCD with improved yield.

To improve the exposure step in the formation of the BM, the line-up also incorporates a laser length measurement unit whose output is fed back to improve the dimensional precision.

(1) XY step control

Large-size glass substrates can be exposed by the step movement of a stage in the X and Y directions. Depending on the size of the panel to be exposed, more than one exposure may be required.

Some examples of panel attachment configurations are shown in Fig. 6.

(2) Mask flexure compensation

To eliminate the flexure of large-size masks under their own weight, Hitachi developed a negative-pressure mask flexure compensation technique to even out the gap between the mask and the glass substrate, thereby realizing greater stability in proximity exposure.

The negative pressure compensation mechanism and its effects are illustrated in Fig. 7.

(3) Exposure illumination system

To ensure that the mask pattern is transferred uniformly and with high precision over the entire surface of the glass substrate, exposure is performed with a mirror illumination optical system having uniformly collimated light and intensity distribution.

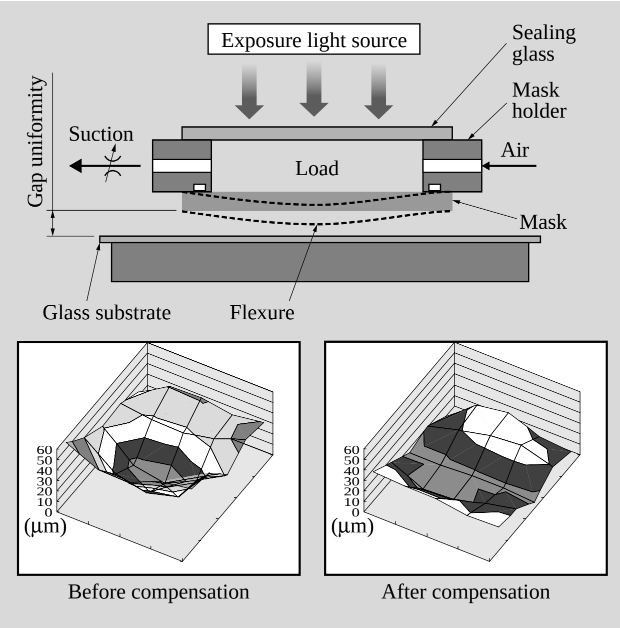


Fig. 7—Mechanism for Compensation of Mask Flexure Due to Self-weight.
A seal is formed on top of the mask, and negative pressure is formed inside this seal to pull the mask up and compensate the flexure.

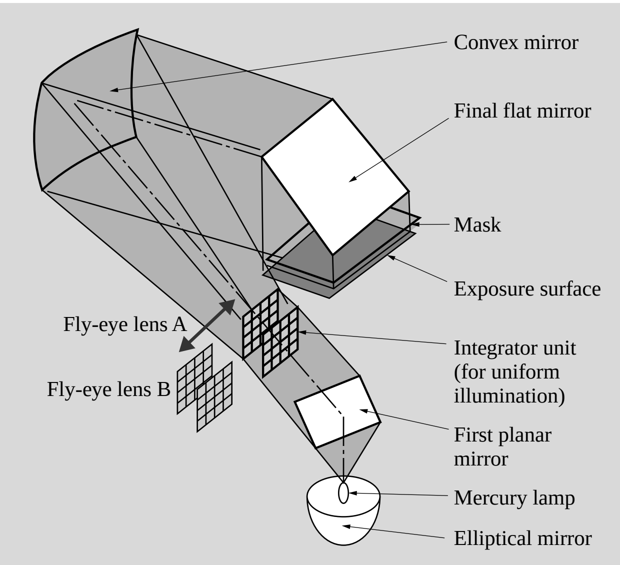


Fig. 8—Optical Path Configuration of Exposure Lighting System.
Light collected by a mirror is reflected by a first planar mirror and passes through a fly-eye lens via a concave lens and a final flat lens to produce a parallel beam of light on the exposure surface. By employing two types of switchable fly-eye lens, the exposure can be set to a suitably efficient value for the shot size.

This optical system uses an optimally designed optical path consisting of lenses and mirrors in order to improve the optical characteristics.

The exposure area can easily be changed by selecting a different fly-eye lens, allowing for efficient exposure according to the number of panels attached to the system.

The optical path configuration of the exposure illumination system is shown in Fig. 8.

GI7500 GLASS SUBSTRATE INSPECTION EQUIPMENT

To cope with the increasing resolution and picture quality of LCD panels and the increasing dimensions of the mother glass used to make them, contamination management is becoming increasingly important in order to improve product yields and there is a growing demand for quantitative control in the inspection equipment market. Against this background, Hitachi has developed the GI7500 series of glass substrate inspection equipment that is adapted to the production processes of larger and thinner LCDs, including increased throughput and more precise contamination detection performance (see Fig. 9).

Objectives of Contamination Management

Important aspects of contamination management include the following five items:

(1) Setting the process conditions when the fabrication line is started up. This includes equipment particle contamination control at each processing stage, and evaluation before and after cleaning.

(2) Checking for the occurrence of dust when parts are introduced into the fabrication equipment.

Fig. 9—External View of the GI7500 Glass Substrate Inspection Equipment.
This equipment can scan large-scale 8th-generation glass substrates with high reliability and detection sensitivity.

(3) Performing process monitoring to prevent large amounts of defects from occurring in mass production stages.
(4) Preventing defective parts produced in one processing step from being carried on to the next processing step.
(5) Quantitative evaluation and time-series evaluation of processing steps.

The above items are all aimed at improving the product yield, and involve monitoring the production process for defects caused by contamination.

As the interconnect patterns become more intricate with increasing display resolution, the TFTs are introduced to produce faster displays, and color filter substrates are made with narrower gaps, defects caused by contamination of the substrate become a more frequent cause of short circuits and open circuits.

The defect details differ depending on the nature of these contaminants, and on the stage of the fabrication process during which the contaminants become adhered to the glass substrate. To maximize the yield at each step in the fabrication of LCD panels, it is essential to use inspection equipment to quantitatively ascertain the level of adhered contamination, and to take suitable countermeasures when necessary.

Required Specifications in TV Applications and Large-size Glass

In processing equipment for large-size glass and for TV applications, manufacturers also have to consider the following items:
(1) Due to the large surface area of each individual panel and the fact that the slightest defect-causing contamination can render the entire panel defective, high levels of reproducibility and detection sensitivity are a must.
(2) Since it is inevitable that contact is made with the back surface of a large-size glass substrate when it is carried, it must be possible to selectively inspect certain parts of the device surface.
(3) Since it is essential to provide prompt feedback to processes, high-speed test and analysis performance is required.

Characteristics of the GI7500

The characteristics of the GI7500 glass substrate inspection equipment Hitachi developed are as follows:
(1) High detection sensitivity: sub-micron detection (0.3 μm)
(2) Inspection repeatability: ≥ 95%
(3) Top and bottom surface discrimination performance: 0.3:50 (this means the equipment is capable of ignoring back surface contaminants measuring 50 μm or less when detecting contaminants with a sensitivity of 0.3 μm on the front surface).
(4) Inspection time (when operating in high-speed mode): 150 s per 2,200 × 2,500 (mm) substrate
(5) Compatible with CIM (computer integrated manufacturing). Contamination management information can be comprehensively controlled and managed using a network.
(6) Includes observation functions. This allows the details of contamination to be confirmed promptly for quick feedback.
(7) Space-saving equipment design. The equipment has a footprint of approximately three times the maximum size of glass substrate [2,200 × 2,500 (mm)], which can reduce the investment costs involved in utilities and clean rooms.

Contamination Detection Technique

Fig. 10 shows the main parts of the detector used to improve the detection sensitivity and the top and bottom surface discrimination.

In the glass substrates used for LCDs, since contamination adhering to the surface of the glass substrate where the pattern is formed can cause defects,

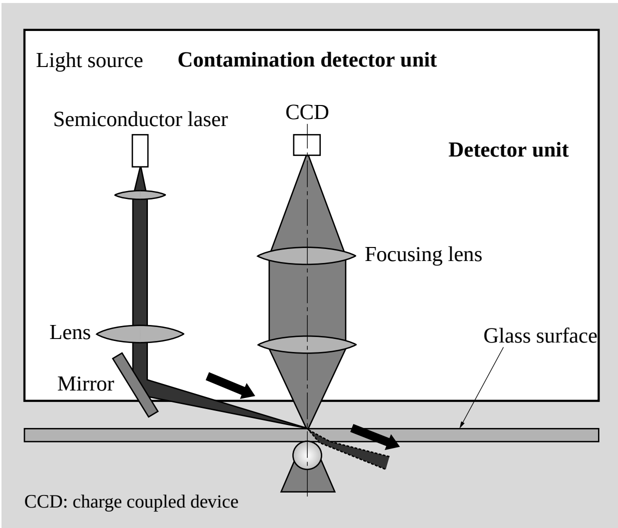


Fig. 10—Glass Substrate Inspection Equipment Detector Unit.
Using a semiconductor laser as the light source, the surface of the glass substrate is lit at a shallow angle via a lens and mirror. Any particles on the surface produce scattered light which is picked up by a CCD imaging element via an objective lens and detected as a particle signal. Any contamination on the back surface of the glass is missed by the laser, so contamination on the back surface (up to 50 μm) is not detected.

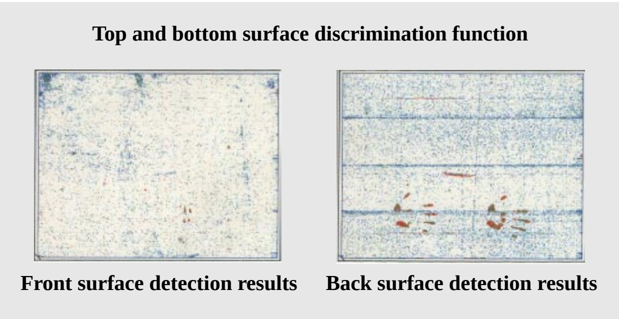


Fig. 11—Detection Results Obtained with Glass Substrate Inspection Equipment.
The map on the left shows the results obtained from the front surface of the glass with a sensitivity of 0.3 μm, and the map on the right shows the results obtained from the back surface of the glass with the same sensitivity. The hand prints on the back surface were put there intentionally for testing purposes.

it is necessary to detect contamination separately on the front and back surfaces. This equipment uses an optical detection method as one of the contamination detection methods. Light from a laser is shone onto the surface of the glass substrate at a shallow angle, and the light scattered from surface contaminants is picked up by a CCD (charge coupled device) element and detected as a contamination signal.

Fig. 11 shows the confirmation maps produced by the top and bottom surface discrimination function.

The source of defects is contamination adhering to the surface where the pattern is formed (front surface). On the other hand, although the back surface is frequently contaminated when the substrate is carried, it is seldom a source of defects. It is thus necessary to detect and manage contamination separately for the front and back surfaces. These two maps show the result of measurements made from the front and back surfaces of the same substrate with a sensitivity of 0.3 μm.

The map is drawn using three different colors to indicate small, medium and large sizes, and in the measurement results for the back side, it is possible to detect the traces created by contact with the rollers while conveying the substrate, and the traces of contamination caused by hand contact.

However, when this substrate is measured from the front side, the equipment ignores not only the small sized roller marks on the back surface but also the large sized hand prints. It can be seen that the equipment is capable of distinguishing between particles adhering to the front and back surfaces even to the point where hand prints can be distinguished.

CONCLUSIONS

We have discussed the future prospects of equipment for the fabrication and inspection of LCD panels which are rapidly becoming larger.

As the market for LCDs expands, their price is rapidly decreasing. Under these circumstances, LCD panel manufacturers are constructing 8th-generation production lines that have high investment efficiency and are capable of producing low-cost panels.

Hitachi High-Technologies Corporation has developed a range of wet processing equipment and inspection equipment including an exposure system that forms the core of the LCD panel fabrication process. Common themes in the field of LCD fabrication equipment are the improvement of productivity and reduction of costs regardless of the type of equipment. With this in mind, we hope to make further contributions to the advancement of the LCD industry by continuing with the development of technology for next-generation innovative processes and of fabrication and inspection equipment for larger screen sizes.

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