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Current Applied Physics 6 (2006) 84–90
Current Applied Physics
An official journal of the KPS
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Detection of amorphous-silicon residue generated in thin-film transistor manufacturing process using a high spectral response of amorphous-silicon layer on green light source

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Received 19 August 2004; received in revised form 13 September 2004; accepted 7 December 2004
Available online 25 January 2005

Abstract

In a thin-film transistor-liquid crystal display, screening that plays an important role in detecting manufacturing process faults before processing the next step is highly important to improve a total yield and reduce the cost. Present testing that applies to the electrical signal and uses red light has a weakness in detecting an amorphous-silicon (a-Si) residue due to the residue of the incident light being less sensitive. From studies, we have found that a-Si residue is highly sensitive to green light such that the leakage of photocurrent occurs responding to the light. Therefore, we use the green light in an array testing system in addition to red light used in conventional systems. Consequently, a detecting ratio of the a-Si residue is improved by more than 90% compared to the conventional array testing system.
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PACS: 81.70.Fy; 81.05.Hd; 84.30.Qi
Keywords: Thin-film transistor; Screening; a-Si residue; Photocurrent

1. Introduction

Recently, the thin-film transistor (TFT)-liquid crystal displays (LCDs) are being used a lot in many application fields such as personal digital assistants (PDAs), notebooks, monitors and LCD televisions. In addition, the size of the mother glass substrate is becoming bigger and bigger from the first (300 mm × 400 mm) to the seventh generation (1870 mm × 2200 mm) to improve outputs [1]. However, control of each process without a defect and bypassing defects from one process to the next becomes more complicated. Besides, the price of TFT-LCD is likely to decline as time progresses. Therefore, to reduce the manufacturing cost, filtering defects in each process are very important.

In the TFT-LCD manufacturing process, the array testing system located at the final position in the array process screens all kinds of electrical defects generated in the array process and must not flow array substrates with defects into the next cell manufacturing process. However, the conventional array testing system, which uses a red light in the array testing system, has a serious problem in that it cannot detect a-Si Residue pixel defect. Since the pixel defects flow into the next cell or module manufacturing process, this problem decreases the manufacturing yield and increases the manufacturing cost. Also this can be one of the major reasons that the product quality decreased. Furthermore, the recent customer trend has changed from admitting a few pixel defects existing in the TFT-LCD panel to no pixel

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doi:10.1016/j.cap.2004.12.008

defects at all in the TFT-LCD panel. Consequently, manufacturing the TFT-LCD with no pixel defects is one of the important themes on the TFT-LCD manufacturing side.

In this paper, we show how to solve this problem with effective screening of a-Si residue pixel defects at the array testing system by applying a new testing concept.

2. Background of array testing system

In general, the TFT-LCD manufacturing process is composed of four processes [2]. Those are the array process making the TFT array on bare glass, the color filter process making a red, blue, and green color pattern on bare glass, the cell process injecting liquid crystal after assembling the TFT array and color filter glasses, and the final module process attaching the driver IC for electrical operation to cell and backlight for a light source. In each process, a fine and detailed test of the screen defects is performed.

In the array process, two types of tests such as the pattern inspection system and the array testing system exist. The pattern inspection system is located at each array process and has functions detecting remain defects. The array testing system is located at the final array process and has functions that detect all kinds of electrical defects caused by the array process. The array repair system has functions that can convert defects to a good status using laser-cutting techniques. In the cell process, cell testing in which the cell is observed under a relatively strong light such as about 4000 nit and the cell repair systems exist. The cells testing system is located at the final cell process and has functions that can detect all kinds of electrical and visual defects by human eyes. The cell repair system is also located at the final cell process and has functions that can convert various kinds of defects to a good status by cutting or welding techniques using laser technology. In the module process a module testing system and module repair system exists. These functions are similar with the cell testing system and the cell repair system. The overall flowchart related to the process, testing, and repairing is described in Fig. 1. Nevertheless, all electrical defects are not screened by the array testing system, and about 50% of all defects caused by the array process are detected at the cell testing system and about 25% of all defects caused by the array process are detected at the module testing system, as shown in Fig. 1 [3]. The major reason for this is that the array testing system has weak points for detecting pixel defects caused by a-Si residue. This causes manufacturing costs greatly increase.

The array testing system is the equipment that tests all electrical defects caused by the TFT-LCD array manufacturing process. Two kinds of defects in the array testing system largely exist. One is line defect and the other is the pixel defect. Pixel defects are the faults which operate abnormally due to remains such as indium-tin-oxide (ITO), active layer, and other metal layers, as shown in Fig. 2(a), (b), and (e), respectively. Line defects are an interlayer short or data and gate open defects mainly caused by particles, as shown in Fig. 2(c), (d), and (f), respectively. The array testing system tests these all for electrical defects and only lets good substrates flow into the next cell process.

The testing principle of the array testing system uses voltage imaging optical system (VIOS) concept. This technology is a key, which allows the in-process test system to perform non-contact testing on active arrays used in active matrix LCDs. As shown in Fig. 3, the technique employs a proprietary electro-optical material that can convert an electrical signal on the LCD pixels

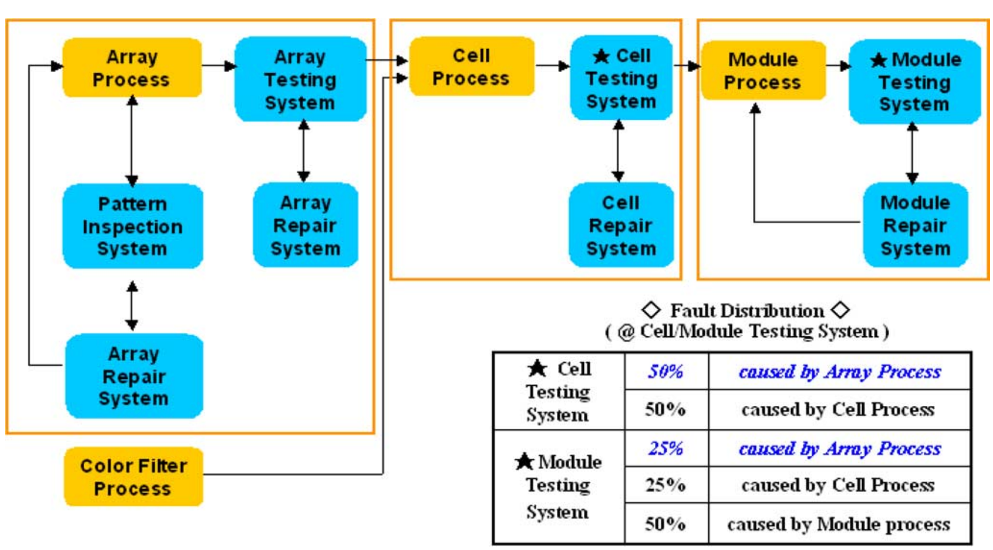

Fig. 1. Flow chart describing the manufacturing process, testing, and repairing of TFT-LCD.

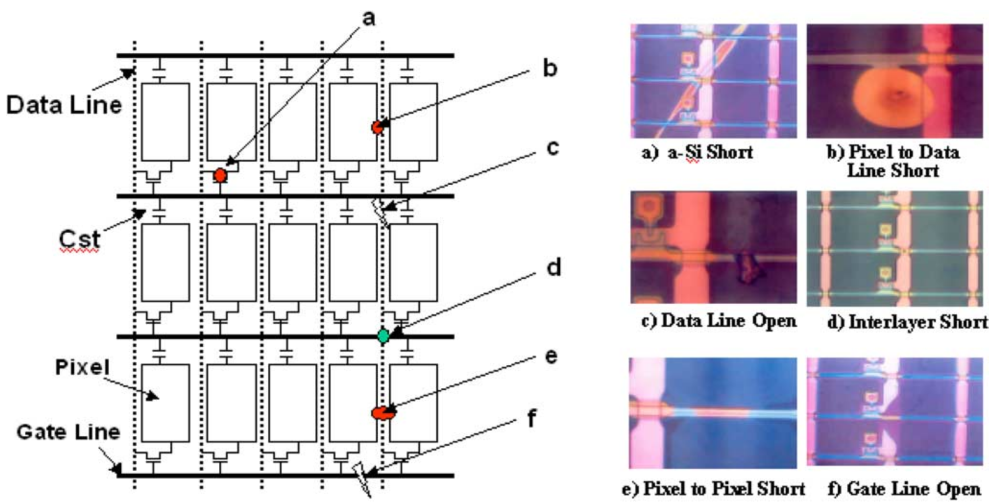

Fig. 2. Examples of defects detected by the array testing system.

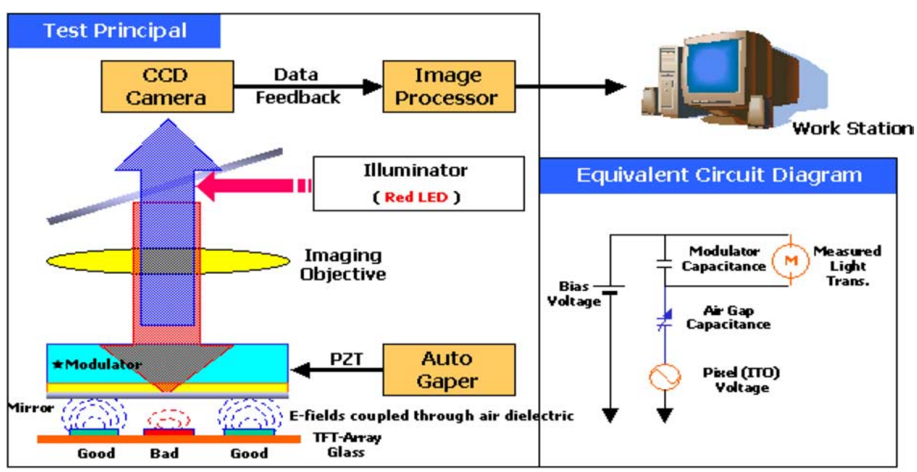

Fig. 3. Configuration of the conventional array testing system.

to an optical signal, which is then imaged onto a CCD camera. The video signal is digitized and processed in an image processor and the host computer to generate the voltage image of the LCD pixels. Defective pixels can be determined by comparing the pixel voltages against the preset threshold levels. The array testing system can accurately locate the pixel locations, defect levels, and types of defects [4].

The modulator is an electro-optic material, which is a core part of the array testing system and it is composed of polymer dispersed liquid crystal (PDLC). The detail structure of the modulator is shown in Fig. 4. In the

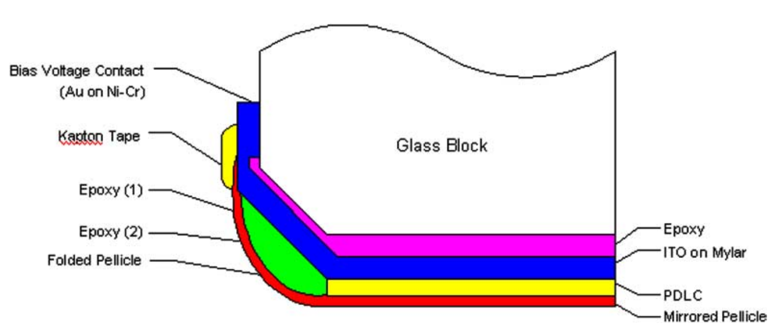

Fig. 4. Detailed structure of the light modulator.

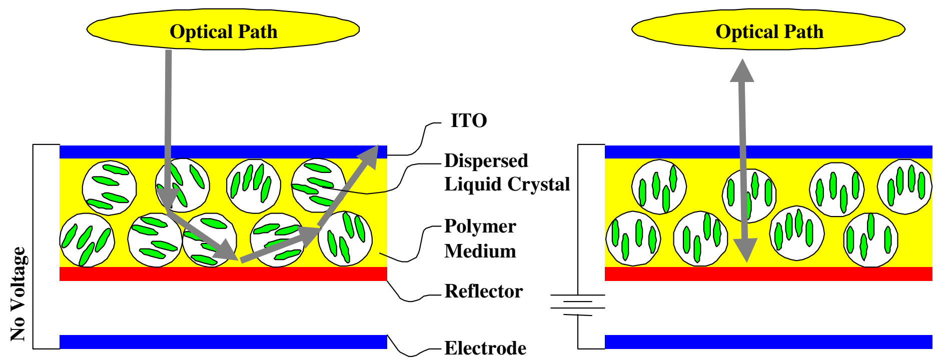

Fig. 5. PDLC modulator showing an optical path without and with applied voltage.

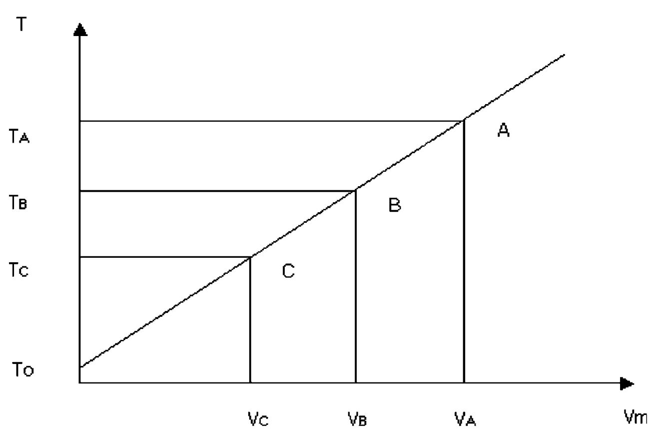

Fig. 6. Voltage-dependent transmittance curve showing the operating property of the modulator.

PDLC, the incident light scatters due to a mismatch of birefringence between LC droplets and the polymer matrix before a bias voltage is applied. However, if the bias voltage applies to both sides of the PDLC, the LC orients parallel to the field direction so that the light can propagate without scattering and then it is reflected from the mirrored pellicle attached on the bottom side of the modulator, as shown in Fig. 5 [5–7]. Here, the mirrored pellicle's material is composed of compound materials with 11 layers such as ZrO_2–SiO_2–ZrO_2–. . ., and its reflectance is above 91% for an incident red light source with 660 nm.

Next, the electro-optical process that exists in the modulator is briefly discussed. The property of the electro-optical material can be understood as exhibiting a linear relationship between the light transmittance, T, and the bias voltage, V_m, as shown in Fig. 6. It can also be mathematically expressed as

$$T = T_0 + aV_m, \quad (1)$$

where T_0 is the transmittance detected at 0 V and a is the slope of the line.

As shown in Fig. 7, the pixel voltage V_p on TFT active array affects light transmittance by an electrical field crossing the air gap and the signal is capacitively coupled with the electro-optical material. Here, C_m is the capacitance of the PDLC, and C_a is the capacitance of the air gap. And V_b means the bias voltage. If bias voltage V_b is applied, the PDLC operates into optimum status, which is in the most linear region of the $T - V_m$ curve, as shown in Fig. 6. The voltage V_m actually dropped voltage on the capacitor C_m, and the

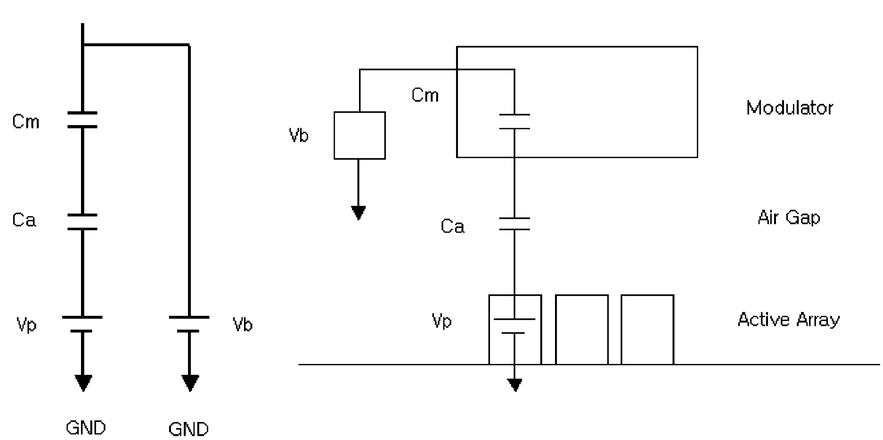

Fig. 7. Circuit diagram showing capacitive coupling.

relationship between them can be described as the following equation:

$$V_m = (V_b - V_p) * \{C_a/(C_a + C_m)\}. \quad (2)$$

When the pixels are at ground state ($V_p = 0$ V), the PDLC exhibits transmittance T_B as shown in Fig. 6. When the voltage V_p is charged on the pixels, it will cause the PDLC to change its transmittance to T_A or T_C according to the level of pixel voltage, as shown in Fig. 6. When the modulator is illuminated by a constant light source, the pixel voltage V_p is changed between $+|V_p|$ and $-|V_p|$, the imaging optics will make two images, I_A and I_C for T_A and T_C respectively. Then, the two images are digitized and stored in the image processor. The difference between the two images ΔI is related to the transmittance difference and the pixel voltage by the following relationship:

$$\Delta I = I_A - I_C = K(T_A - T_C) = Ka(V_A - V_C), \quad (3)$$

where K is a proportional constant that includes the light collection efficiency from the modulator to the CCD camera. As shown in Eq. (3), the voltage imaging is one of the differential measurement techniques.

3. Experimental results and discussions

From empirical results, we have found that there is a large difference in screening ability on a-Si residue defects between the array testing system and the visual testing system as shown in Table 1, where the visual testing system means cell testing and module testing system of TFT-LCD panel under a backlight [3]. As indicated, the screen ability of the array testing system to detect the defect is very low (under 10%), but the screen ability of the visual testing system is perfect, that is, 100%. The reason is as follows. The array testing system uses a red light source for testing and the red light is reflected above 91% by mirrored pellicle attached at the end of a modulator (see Fig. 4) so that it cannot be transferred to a-Si residue defect remaining in the TFT-array glass. On the other hand, the visual testing system uses the light source called the backlight under the TFT-LCD panel including the TFT-Array Glass. Therefore, the light source that has a visible wavelength is directly applied to a-Si residue defects, as shown in Fig. 8, which is a major reason for the big difference in detection between the array testing and visual testing system.

Next, the reason why a-Si residue defects are greatly dependent on the light source is considered. In general, a relationship exists between a-Si TFT photocurrent and the thickness of a-Si:H such that the photocurrent changes very sensitively depending on the thickness change of a-Si [2,8,9]. Normally, a-Si thickness in TFT-LCD is about 1700 Å. Here, the photocurrent I_{ph} is given as follows:

$$I_{ph} \propto 1 - \exp(-\alpha t), \quad (4)$$

Table 1
Comparison of detection level of a-Si residual defect between array testing system and visual testing system

	Array testing system	Visual testing system (cell/module testing system)
Target	*TFT army patterned glass* after array process	*LCD panel attached color filter* after cell/module process
Test item/subject	Electrical defect/machine	Electrical + optical defect/human eye
Light source	No use	Use
Detection about a-Si residue fault	Poor (under 10%)	Perfect (100%)

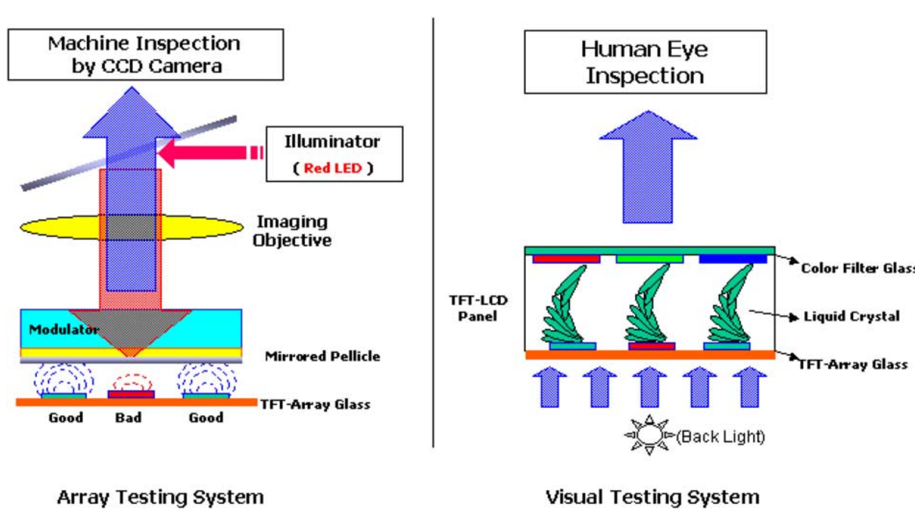

Fig. 8. Comparison between array testing system vs. visual testing system.

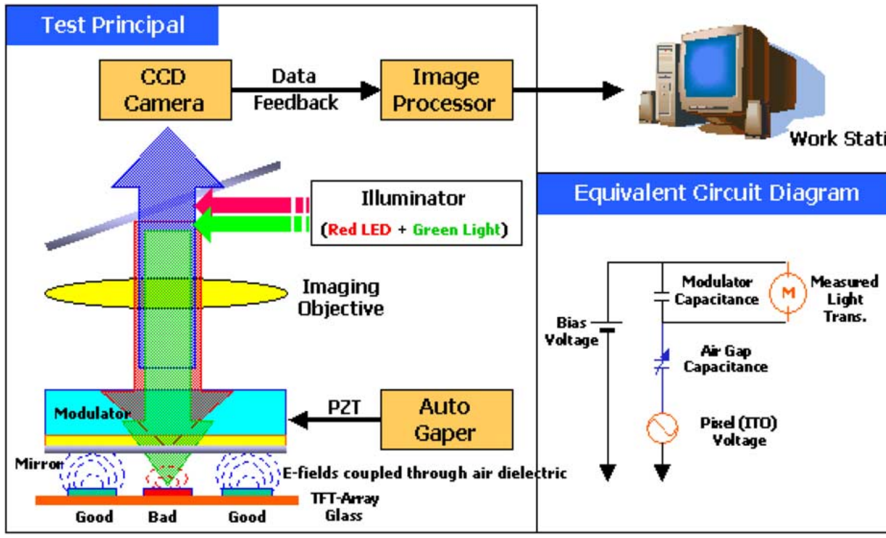

Fig. 9. Principle of new array testing system.

where α is the absorption coefficient of hydrogenated a-Si and t is the thickness of thin film. This tell us indirectly why a big difference exists in screening ability of a-Si residue defect between the array testing system and visual testing system since the incident light on the defect causes the photocurrent and thus it is not an insulator any more.

To apply this relationship to improve screening ability of the defects effectively, selecting a proper light source for testing is necessary. Previous works [2] show the spectral response relationship of a-Si:H diode and report that the wavelength for high level of sensitivity on a-Si:H diode is around 550 nm. Therefore, in this experiment, a green light lamp with 532 nm is selected to achieve screening capability effectively while the conventional testing system uses a red light source LED with 660 nm only. So to detect a-Si residue fault effectively, a green light lamp with 532 nm is applied to the array testing system in addition to the conventional red light source. If mixed light sources with red and green light apply to LCD pixels, more than 91% of red light and 30% of green light is reflected by mirrored pellicle, as shown in Fig. 9. Then, 70% of green light can be applied to a-Si residue defect, and thus this light source increases photocurrent and off-current of TFT, causing an electrical characteristic of the residue to be conductive. Consequently, the electric field intensity in pixels

Table 2
Detection ratio depending on the use of green light

	Conventional system	Green light (50%)	Green light (100%)
a-Si residue detection voltage	4.5 V	2.5 V	0.12 V
Detection ratio	5%	42%	95%

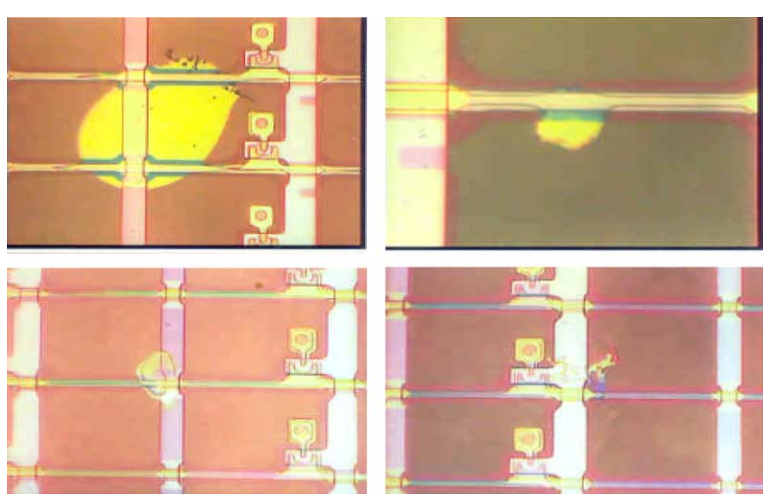

Fig. 10. Newly detected a-Si residue defects.

with a-Si residue reacted by green light, influences applied voltage to the PDLC and then light intensity reflected by mirrored pellicle on the modulator is changed. This reflective light is then imaged onto a CCD camera and the video signal is digitized and processed in an image processor and the host computer to generate the voltage image of the LCD pixels. Defective pixels can be determined by comparing the pixel voltages against the preset threshold levels. Consequently we can get a much-improved screening ability on a-Si residue than with the conventional array testing system.

To confirm effectiveness of use of green light, the light intensity is increased step by step as 0% → 50% → 100% (100% indicates a light intensity of 192 cd), and then the effectiveness is checked and analyzed. In case of green light intensity with 0% (conventional array testing system) screen ability was 5%, however, with green light intensity of 50% the screen ability was 42%, and further, with green light intensity of 100%, the screen ability was increased to 95%, as summarized in Table 2. Fig. 10 shows various a-Si residue defects detected using the new array testing system, which could not be detected using the conventional array testing system.

4. Summary

Testing and detecting various defects observed at the TFT-LCD manufacturing process are studied. Especially, to improve the screening ability on pixel defects due to a-Si residue, a green light LED source with conventional red light was applied and tested on the array testing system without changing any part of the modulators. As a result, the light increases the photo-leakage current in TFT and thus, the electrical defects due to a-Si residue was easily caught. With this approach, detection ratio was improved by more than 90% compared to the conventional testing system that only uses a red light source. Consequently, this can effectively cut off a-Si residue defects flowing into the next process cell or module process, improving the yield and reducing the cost.

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