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In-line Automatic Defect Repair System for TFT-LCD Production

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Abstract

An automated circuit repair system was developed for enhancing the yield of nondefective liquid crystal panels, focusing on the resist patterns on the circuit material layer of thin-film transistor (TFT) substrates prior to etching. The developed system has an advantage over the parallel conventional system: In the former, the repair conditions depend on the type of resist whereas in the latter, the repair parameters must be fine-tuned for each circuit material. The developed system consists of a resist pattern defect inspection system and a pattern repair system for short and open defects. The repair system performs fine corrections of abnormal areas of the resist pattern. The open-repair system is equipped with a syringe to dispense resist. To maintain a stable resist diameter, a thermal insulator was installed in the syringe system. As a result, the diameter of the dispensed resist became much more stable than when no thermal insulator was used. The resist diameter was kept within the target of 400±100 μm. Furthermore, a prototype system was constructed, and using a dummy pattern, it was confirmed that the system worked automatically and correctly.

Keywords: TFT, defect repair, resist pattern, thermal stability, syringe

1. Introduction

There is a strong demand for large flat-panel displays [1]. In the manufacturing process of thin-film transistor (TFT) substrates for liquid crystal panels, foreign particles can cause circuit defects and partial operation errors in pixels. Therefore, a technology for repairing circuit defects is essential to enhance the yield of TFT substrates [2].

Fig. 1 shows the pixel structure of a TFT substrate for a liquid crystal panel. In the said figure, the short defect on the amorphous silicon (a-Si) island short-circuits the drain and the source so that the TFT will not function as intended. Furthermore, there is an open defect in the drain line.

The conventional inspection and repair systems are intended only for metals and not for the passivation layer and a-Si [3, 4]. Such systems cannot selectively remove a target material; a suitable circuit defect repair system that can do so has yet to be developed. In addition, the conventional methods require the development of a different recipe for each kind of metal in a circuit, and the actual repair process has not been automated.

These authors developed an automated circuit defect repair method that can be used regardless of the circuit material, focusing on the resist patterns on the circuit material layer of TFT substrates prior to etching, as well as a repair system for short defects, the major type of defect in resist patterns [5]. Based on the research conducted by these authors, a prototype repair system for TFT substrates that repairs open and short defects was developed, and it was confirmed that the system functions automatically.

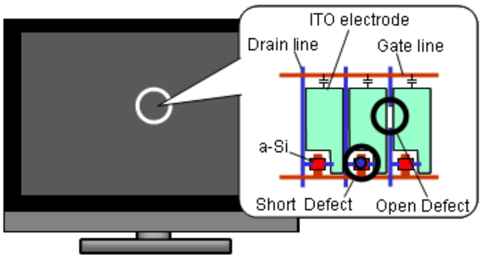

Fig. 1. Pixel structure of, and defects in, a TFT.

2. Experiments

Principle of the pattern defect repair procedure

Fig. 2 compares the proposed resist pattern defect inspection and repair system with the parallel conventional systems. Circuit defect inspections are conventionally performed after thin-film deposition, exposure, and etching, and repairs are made based on the inspection results. In such systems, the inspection and repair parameters must be

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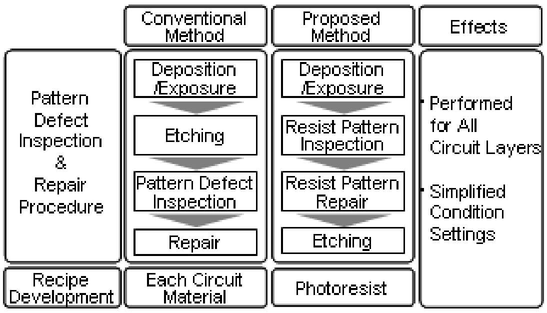


Fig. 2. Comparison of the conventional and proposed pattern defect inspection and repair procedures.

fine-tuned for each circuit material. In contrast, the pattern defect inspection and repair system described in this paper performs defect inspection after thin-film deposition and exposure. The abnormal resist patterns detected by the system are repaired at this point, prior to etching; this order allows the system to inspect and repair the whole layer independently of the circuit metal. As the inspection and repair parameters depend only on the type of resist, the suitable inspection conditions are much easier to determine and set.

The wavelength absorption characteristics of the resist patterns used in TFT liquid crystal panels were investigated, and it was found that the absorption of a positive resist exhibits a peak near 300 nm.

Fig. 3 shows the result of fine patterning for thin resist and metal films using an yttrium aluminum garnet (YAG) laser. The results of the resist film patterning performed via fourth-harmonic generation (FHG) yielded good consistency between the laser irradiation pattern and the resist patterning, as well as high patterning precision. In contrast, when third-harmonic generation (THG) was used, scattered debris and carbonization were observed near the laser irradiation region. The patterning precision was also relatively poor compared with that when FHG was used. The results of the metal thin-film patterning using FHG show that a fivefold or greater patterning energy is required for metal patterning compared to the patterning of thin resist films. Additionally, more debris was generated, and the patterning precision was lower. Based on these results, it can be concluded that the fine patterning of thin resist films via FHG offers advantages in terms of patterning energy and precision. Therefore, the resist repair system is suitable for the TFT process.

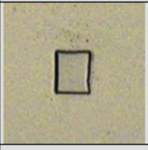
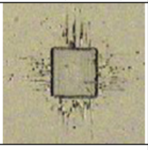
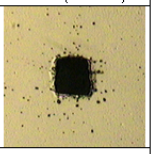
	Photoresist Film		Metal Film
Wavelength	**FHG (266nm)**	THG (355nm)	FHG (266nm)
Patterning Condition			
Patterning Energy	1	–	5
Debris	Excellent	Poor	Poor
Pattern Precision	Excellent	Good	Poor
Other	–	Film Carbonization: Poor	Patterning Burrs: Poor

Fig. 3. Comparison of photoresist patterns.

Proposed system configuration and function of the repair system

Fig. 4 shows the configuration of the resist pattern defect inspection and repair system. The basic concept of this system is to perform inline inspection and repair by linking the system directly to the photolithographic process line.

The system consists of a resist pattern defect inspection system and a pattern repair system. The former system takes images of the resist pattern formed on a glass substrate using inspection cameras and then stores the resulting images on a personal computer (PC). The PC then analyses these images by comparing adjacent pixels to detect abnormal resist patterns. The coordinates and images of the defective regions are sent to the resist pattern repair system. The open-defect repair system is equipped with a resist syringe unit. The short-defect repair system incorporates a laser unit with a resist ablation mask (partial-exposure mask). This mask has a regular circuit pattern and can irradiate a laser beam over a 500x500-μm^2 area. The short-defect repair system uses a resist ablation method to remove excess resist. The laser repair system moves and aligns the laser unit and resist ablation mask to the coordinate of the defect based on the defect data, and fires the laser beam through the resist ablation mask.

The repair accuracy depends on the accuracy of the short-defect repair system with the resist ablation mask. Although it is not necessary to fine-tune the resist-dispensing accu-

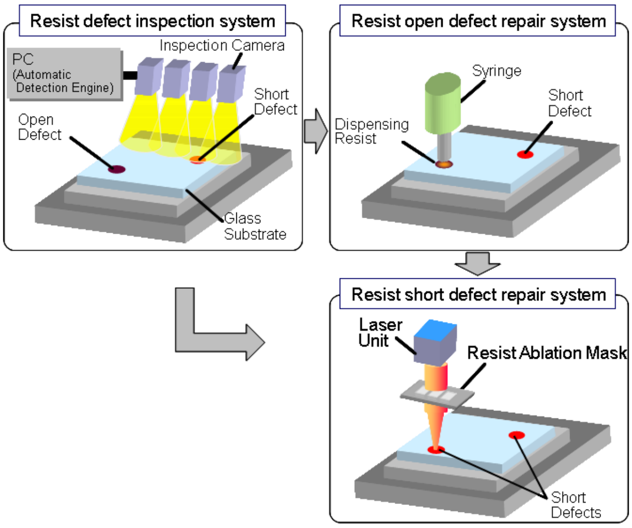


Fig. 4. Resist defect repair system.

racy, the amount of resist dispensed should exceed the defect size and should not cover an area greater than the ablation area. Therefore, the target size was set at 400±100 µm.

Experimental-system configuration

The resist pattern defect repair method was evaluated using a prototype automated open- and short-defect repair system. In this experiment, the development of an open-repair method with a syringe system was focused on. In particular, an attempt was made to stabilize the dispensing of the resist. Although the accuracy of the shape of the dispensed resist is not as critical as the accuracy of the shape of the TFT patterns, it is essential to dispense a constant amount of resist to maintain stability in the repair process.

Fig. 5 shows the open-repair-system configuration and an image of the resist dispensed onto the glass substrate. The syringe dispense system was used to apply resist to a defect site. The syringe system consists of a glass syringe, a piston for expelling the resist, and a nozzle with a sapphire tip with inner and outer diameters of 200 and 300 µm, respectively. A stepping motor is used to move the piston in the syringe. The control over syringe resist dispensing is correlated with the amount of resist. Therefore, the advantage of the syringe system is that it facilitates the supply and handling of the resist.

First, the syringe is contacted on a TFT substrate. The piston then expels the resist onto the defect site. The diameter of the amount of resist is approximately 400 µm. Therefore, the resist dispenser of this system enables the effective repair of open defects. A semiconductor laser beam with a wavelength of 830 nm is used to cure the resist. The throughput for this run totalled 50 s per defect point: 15 s for alignment, 15 s for dispensing the resist, and 20 s for curing the resist.

The TFT substrate is then moved to the short-defect repair system, which uses a laser unit with an ablation mask for the regular circuit pattern. The short-defect repair system fires a laser beam through the resist ablation mask and removes any excess resist that was dispensed to the open defect.

3. Results and Discussion

To achieve stable resist dispensing, the resist-dispensing characteristics were evaluated under various conditions. The problem with this method is that the diameter of the dispensed resist differs depending on the site and the area where dispensing is to be performed. For example, the diameter of a dispensed resist may be 100 µm at one site and 900 µm at another site. This fluctuation in the data makes it difficult to perform repairs automatically.

The variations in the ambient temperature lead to variations as well in the volume of the resist in the syringe, thereby causing the diameter of the dispensed resist to fluctuate. Based on the results of these authors' research on the temperature fluctuations near the syringe, a thermal insulator was installed on the exterior of the syringe to stabilize the temperature within it.

Fig. 6 shows the ambient temperature measured on the syringe surface as a function of elapsed time. Without the thermal insulator, the temperature changed sharply from 23.5 to 23.9°C in just 200 s. With the thermal insulator, the temperature remained almost constant, with only 0.02°C fluctuations.

Fig. 7 shows the diameter of the dispensed resist as a function of temperature fluctuation with and without a thermal insulator. The diameter of the dispensed resist is unstable owing to the temperature fluctuations when there is no thermal insulator. With a temperature rise of only 0.25°C, the diameter of the dispensed resist increases from 150 to 1000 µm. This instability is believed to be due to the resist expansion and contraction in the syringe. To substantiate this theory, the thermal expansion and contraction of the resist were calculated. The estimated line as a function of temperature fluctuation is shown in Fig. 7. A close agreement was found between the regression line and the

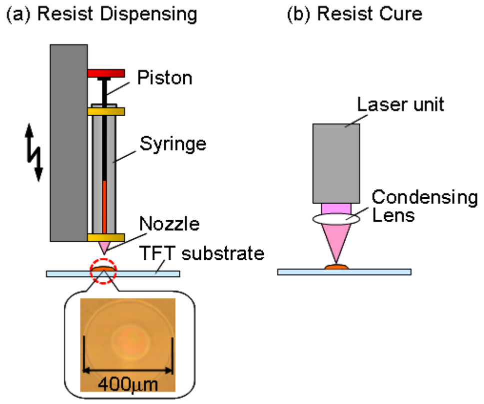


Fig. 5. Configuration of the open-defect repair system.

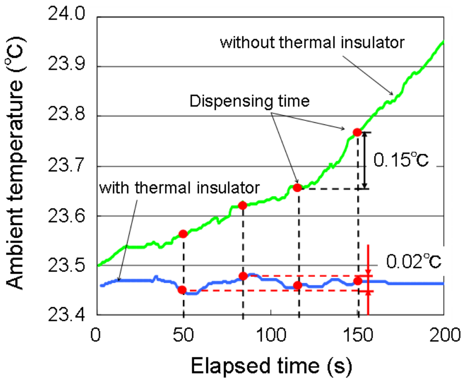


Fig. 6. Ambient temperature as a function of elapsed time.

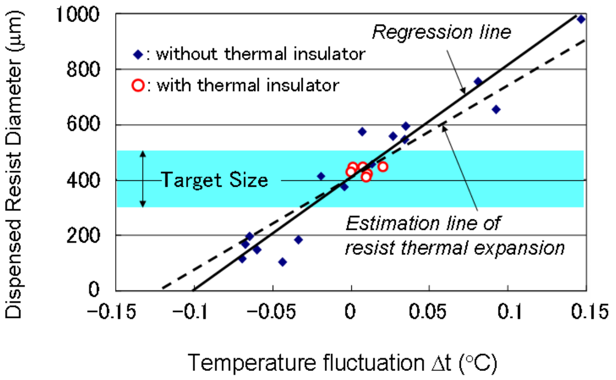


Fig. 7. Resist-dispensing diameter as a function of temperature fluctuation.

estimated line.

A thermal insulator was thus installed in the syringe system to ensure a stable resist diameter. As a result, the diameter of the dispensed resist became much more stable than when there was no thermal insulator. To ensure the reliability of the open-repair method, the syringe must be insulated from heat.

Fig. 8 shows the repair experiment results. Fig. 8(a) is an image of a resist open defect. The centre of the image shows a break in the resist pattern. Fig. 8(b) shows an image of a dispensed resist. Resist was dispensed to the defect site, and then a laser beam was fired through the resist ablation mask. Fig. 8(c) shows an image of the repair. The repaired area has a regular resist pattern.

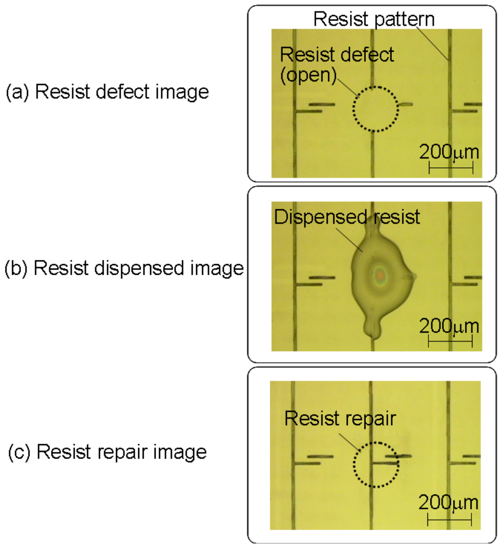


Fig. 8. Result of the resist open-defect repair experiment.

4. Conclusions

Based on the knowledge of the automated circuit defect inspection and repair method of TFT substrates, a repair system that can be adapted to any circuit material was developed. In particular, the thermal stability of the open-repair system was improved through the use of a thermal insulator. Furthermore, the patterning precision was evaluated using a dummy pattern. It is expected that directly incorporating the developed method in the photolithographic process lines will realize the automatic inspection and repair of circuit defects. This method will enable TFT-LCD panels to be produced with a high yield and at a low cost.

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