Real-time automatic inspection of macro defects in in-line TFT fabrication process

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Abstract: In this article, an automatic detection and judgement method for macro defects in thin film transistor (TFT) fabrication process is proposed using a high-resolution line charge-coupled device camera as a preliminary inspection method for TFT liquid crystal display (TFT-LCD) panel. Macro defects are classified primarily into four types. Relevant detection and judgement methods are then applied according to the type of macro defect using different criteria such as diffraction pattern shifts, just noticeable differences, and the gradient of inspection images. The proposed method is verified with industrial experiments. In the experiment, 559 TFT glasses are used, which are sampled among the glasses and were judged as PASS (i.e. non-killer-defected glass) in the TFT fabrication process by a conventional human inspection method, but were judged as REJECT (i.e. killer-defected glass) in the module process. All macro defects in the sampled glasses were detected and rejected in the TFT fabrication process using the proposed method.

Keywords: inspection, macro defect, thin film transistor liquid crystal displays, thin film transistor fabrication process

1 INTRODUCTION

More accurate and faster detection and judgement of defects in flat panel displays (FPDs) such as thin film transistor liquid crystal displays (TFT-LCDs), plasma display panels, and organic electro luminescence displays is a very important issue for manufacturing companies to obtain a high production yield and a low production cost in order to become a leader in the competitive FPD market [**1**].

The TFT-LCD manufacturing process is mainly divided into three subprocesses (Fig. 1): (a) fabrication process, which fabricates pixel arrays of TFT and colour filter (CF) on bare glass; (b) cell process, which assembles the fabricated TFT and CF glasses into one glass and then divides the assembled glass into several cells; and (c) module process, which assembles several filters, driving circuits, and backlights. In each sub-process of the TFT-LCD manufacturing process, there are also many successive processes; for example, there are, usually, seven subprocesses in the TFT fabrication process, as shown in Fig. 1. There are defect inspection processes after every subprocess for high-quality control and less-manufacturing cost (Fig. 1) [**2**].

There are two kinds of defects in TFT-LCD manufacturing process which are the micro and macro defects. The size of the micro defects is generally less than a few tens of micrometres, while the macro defects are more than a few millimetres in size [**3**].

Usually, most of the defects occur in the TFT and CF fabrication processes. Particularly, the growing

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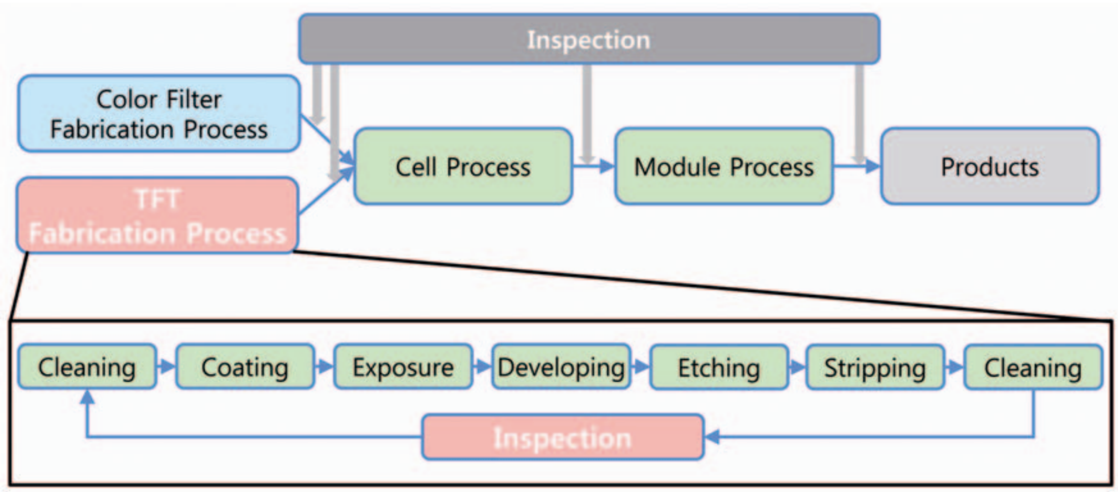

Fig. 1 TFT-LCD manufacturing and inspection process

size of TFT-LCD glasses increases the probability for macro defects (also called as Mura) and it makes the inspection process more difficult because any macro defect is hard to be inspected directly with traditional methods such as edge detection. If defects are detected in a cell or a module during the cell or module processes respectively, the cell or the module is discarded if the detected defect is a killer defect and cannot be repaired [**4**, **5**]. On the other hand, in the fabrication process, most of the glasses with killer defects can be repaired or can be cleaned as bare glasses. It will, therefore, be helpful in increasing the production yield and decreasing the manufacturing cost if the macro defects can be inspected in the fabrication process before assembling the module (i.e. cell and module processes). The inspection in the fabrication process is also called in-line inspection [**4**, **5**]. From a technical point of view, the in-line inspection of macro defects has more difficulties such as uneven surfaces of glass due to pixel patterns, as shown in Fig. 2, which can give rise to scattered illumination for imaging the glass, and less inspection time due to a faster manufacturing process than in the cell or module processes.

Many studies have been conducted for the automatic inspection of macro defects in the cell or module processes [**2**, **6–10**]. From the perspective of the in-line inspection, there have been some recent studies on defect inspection in the TFT fabrication process [**4**, **5**] and CF fabrication process [**1**]. However, Liu et al. only focused on the inspection of micro defects in references [**4**, **5**] and Son et al. [**1**] dealt with the inspection of macro defects in the CF fabrication process.

There are very few papers that deal with the automatic inspection of the macro defects in the TFT

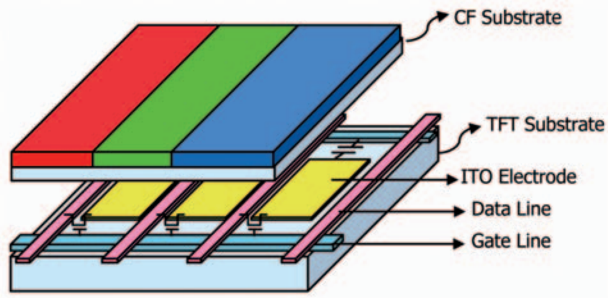

Fig. 2 Structure of TFT-LCD

fabrication process. Most of the research studies on the development of an automatic inspection method for macro defects involve the development of efficient image processing algorithms to enhance the contrast of image of the macro defects. However, in our research study, it is focused on how the optical imaging system can be made with high contrast. Therefore, the detection performance of the proposed method can be enhanced using the already developed image processing algorithms. Moreover, it is also focused on how the abnormality of the detected macro defects can be judged (i.e. killer macro defects) in a simple and efficient way, which needs no additional optical system or hardware and could be applied in any real production system. Also, the proposed judgement method can be compared with a conventional method, because no judgement algorithms have yet been developed for the macro defects in the TFT fabrication process. Therefore, judgement method can be compared with that of the human inspector's method in the module process, which is the most efficient method available.

Hence, in this article, development of an automatic inspection method, which deals with both the detection as well as the judgement of macro defects in the

TFT fabrication process is focused. At first, macro defects of the original TFT glass substrate after exposure and strip processes are detected using optical imaging techniques. Second, the non-uniformity of TFT patterns is measured quantitatively using image processing algorithms. The detected macro defects will be classified primarily into four types of macro defects such as lens-type macro defect, which occurs in exposure process, vertical and horizontal line-type macro defects, as well as point-type macro defect. Finally, to judge each panel in the TFT substrate as to whether each panel is in/out of a specification (i.e. PASS/REJECT), the panel judgement index (PJI) is proposed and its reliability and efficiency are verified by a mutual comparison with the judgement results by the human inspector in the module process.

2 INSPECTION METHOD

2.1 Detection method

Macro defects in TFT fabrication process occur due to a size difference of the patterned TFT pixels such as the GATE, DATA, and ITO patterns shown in Fig. 2, which result from a photo-mask misalignment in the exposure process. The size difference of each GATE and DATA pattern produces a non-uniformity of brightness in TFT-LCD panel because size difference of patterned pixel causes non-uniform transmission of backlight. The ITO pattern has a function that controls an angle of liquid crystal. Therefore, similar to the GATE and DATA patterns, a non-uniform size of the ITO pattern also produces non-uniformity of brightness in TFT-LCD panel. However, unlike the GATE and DATA patterns, it is very difficult to detect the macro defect caused by size difference of ITO patterns by a conventional optical inspection method because transparent materials such as Al are used for ITO patterns.

The macro defects caused by the size difference of the GATE and DATA patterns are detected by reflective optical system based on the phenomenon of the shift of the diffraction pattern [**1**] and the size of patterns is measured due to the amount of the reflected light. The configuration of the reflective optical system is shown in Fig. 3(a). The angle of camera and illumination, θ_1 and θ_2, respectively, are changed and they are adjusted according to the defect type including the distance from inspection area to the camera L_1, and the illumination, L_2. Quartz pole is equipped and light sources of illumination are installed on both the sides of the quartz pole to illuminate the whole area of TFT substrate uniformly. Metal halide illumination is used for bright and clear imaging.

The image processing procedure is divided into three steps as shown in Fig. 3(b). In the first step, the uniformity of brightness is increased by eliminating a noise which arises from the non-uniformed illumination due to large size of quartz pole. The visualization process makes the defects visible to human operator by stretching the band of histogram. Macro defects are detected, measured quantitatively, and classified in the final step which is the defect emphasis processing step. The detected macro defects are classified as lens-type, vertical line-type, horizontal line-type, and point-type defects based on the size, shape, and intensity of defects.

2.2 Judgement method

Any human inspector detects and judges the macro defects based on the difference of brightness between normal and abnormal areas and the sizes of abnormal areas in the module process. The proposed judgement method is developed based on the same concept of the human inspector's method. In module process, the concept of just noticeable difference (JND) has been widely used. Therefore, the size and brightness difference of defects with the JND concept have been combined. However, different parameters are used for computing the JND corresponding to different defect types.

A two-dimensional gradient algorithm is used to find and quantify the brightness difference of defects in the emphasis processing step, as shown in Fig. 3(b). The proposed judgement index of macro defects, named as the defect judgement index (DJI), for four types of macro defects is as follows

$$\begin{aligned}
\mathrm{DJI}_{\mathrm{Lens}} &= 0.5 \times \mathrm{Grey}_{\max} + 0.5 \times \mathrm{Gradient}_{\max} \\
\mathrm{DJI}_{\mathrm{V-Line}} &= 0.3 \times \frac{\mathrm{Size}}{v} \times 100 + 0.7 \times \mathrm{Gradient}_{\max} \\
\mathrm{DJI}_{\mathrm{H-Line}} &= 0.3 \times \frac{\mathrm{Lx}}{h} \times 100 + 0.7 \times \mathrm{Gradient}_{\max} \\
\mathrm{DJI}_{\mathrm{Point}} &= 0.3 \times \frac{\mathrm{Area}}{M} \times 100 + 0.7 \times \mathrm{Gradient}_{\max}
\end{aligned} \tag{1}$$

where v, h, and M represent the vertical length, the horizontal length, and the area of defect, respectively. $\mathrm{Gray}_{\max}$ and $\mathrm{Gradient}_{\max}$ signify the maximum grey level in the visualization processing step and the maximum gradient level in the gradient processing step, respectively.

If there is more than one macro defect, the TFT panel is judged as REJECT regardless of the defect type in the TFT panel. Therefore, the final judgement index or PJI is proposed as given in (2)

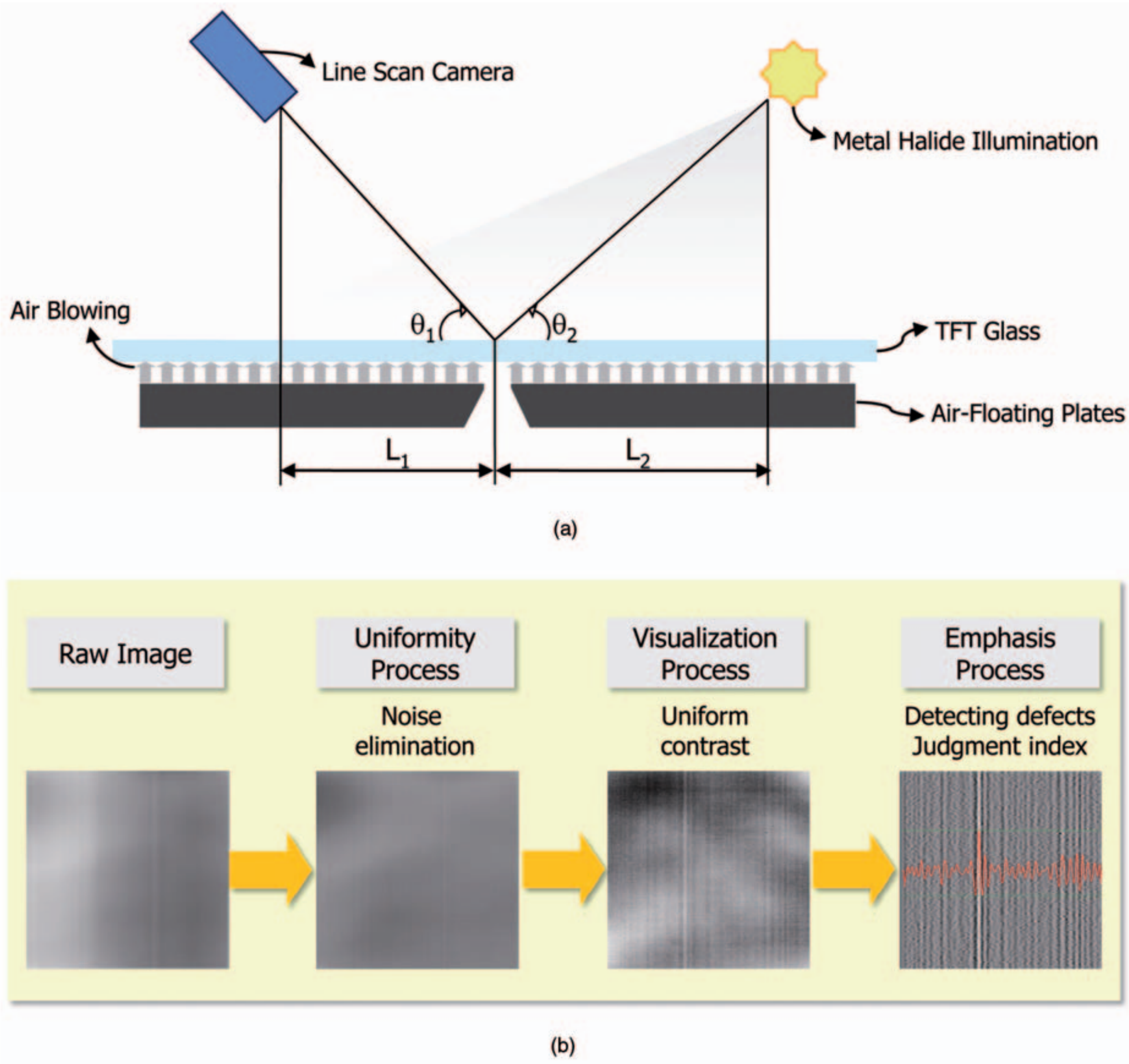

Fig. 3 Automatic detection system of TFT macro defects: (a) configuration of inspection optics and (b) image processing procedure

$$
\begin{aligned}
&\text{PJI} = \max(\text{DJI}_{\text{Lens}}, \text{DJI}_{\text{V-Line}}, \text{DJI}_{\text{H-Line}}, \text{DJI}_{\text{Point}}) \\
&\text{if} \quad \text{PJI} < \text{Th}_{\text{REJECT}}, \quad \text{then} \quad \text{Judgement : PASS} \\
&\text{else} \quad \text{Judgement : REJECT}
\end{aligned} \tag{2}
$$

Using the proposed PJI, every detected macro defect is judged as PASS or REJECT based on whether the calculated PJI is larger than the judgement threshold, as defined in (3). In addition, the judgement of TFT substrate depends on the number of rejected panels on the TFT substrate. This, however, depends due to varied management plans and production yields. Finally, the judgement thresholds for each TFT substrate and each process are saved in a database of message execution system for future use in similar TFT substrates and processes.

3 EXPERIMENTAL RESULTS

The proposed detection and judgement method is evaluated using 559 TFT panel samples, which are chosen regardless of macro defects. In the experiment, $v = h = 200$ and $M = 400$ are selected to calculated the DJI according to a quality control specification. These values denote the minimum size of macro defects, which can be detected by human inspector.

The detection and judgement experimental results are summarized in Tables 1 and 2, respectively. To verify the proposed method efficiently, all the 559 TFT panels are inspected using the proposed method in the in-line TFT fabrication process and then, after the cell process, the inspected TFT panels are checked again by the human inspector in the module process. Seventeen glasses are judged as REJECT in the module process using human inspection method.

It is noted from Table 1 that all 17 glasses in the module process, which are judged as REJECT by the human inspector are detected by both conventional and proposed methods in the TFT fabrication process. More glasses were detected by the proposed method, which are, actually, non-killer defected glasses. Every detected and rejected panel in the module process is detected in the in-line TFT fabrication process using the proposed detection method, while the conventional method by human inspector did not detect some of those defects. Moreover, the conventional method judged all detected glasses as PASS. This is because a human cannot detect some macro defects as he/she has some difficulties in the judgement in TFT fabrication process, even though human eye-based inspection shows the best inspection ability.

However, too many glasses are detected without any judgement method with the proposed method. The judgement experiment results are summarized in Table 2. The number of glasses judged as REJECT according to the change of judgement threshold is also presented in Fig. 4. Based on Fig. 4, it can be concluded that there is an exponential decrease of the number of 'REJECT' glasses when Th_{REJECT} is larger than 40. The judgement threshold, therefore, has to be selected as over 40 to increase the efficiency

Table 1 Summary of detection experiment results

'REJECT' panels in module process	TFT fabrication process	
	Conventional method	Proposed method
17	503	559

Table 2 Summary of judgement experiment results

'REJECT' panels in module process	TFT fabrication process				Module process Human inspection
	Conventional method	Proposed method			
		PJI	$Th_{REJECT}=61$	$Th_{REJECT}=71$	
–	–	0–30	0	0	–
		31–40	0	0	
		41–50	0	0	
		51–57	0	0	
		58–60	0	0	
		61–70	34	0	
		71 ~	2	2	
17	0	Total	36	2	17

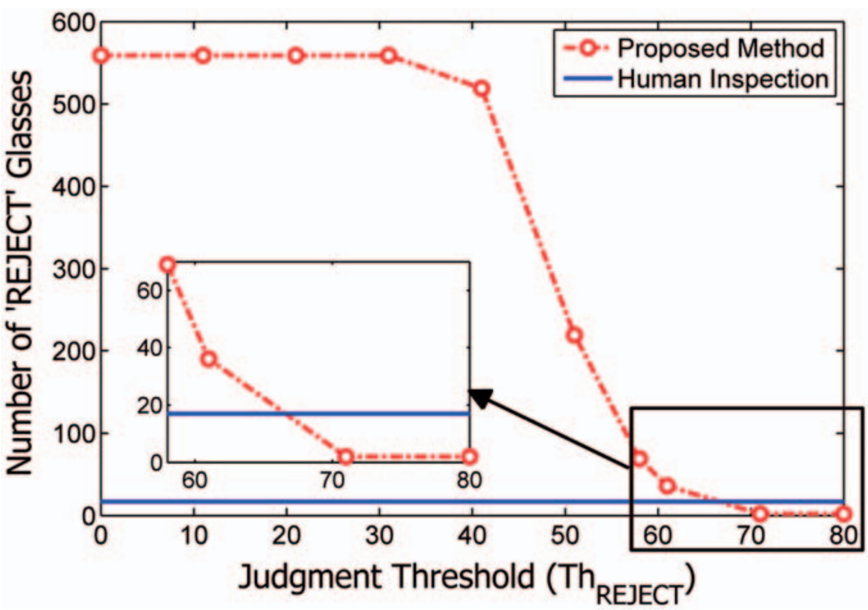

Fig. 4 Change in the number of 'REJECT' glasses according to the judgement threshold, Th_{REJECT}

of judgement. If the judgement threshold is set as $Th_{REJECT} = 61$, then four panels which are judged as REJECT in the module process are judged as PASS in the TFT fabrication process. In the case of $Th_{REJECT} = 51$, there is no possibility to miss the panel, which has to be rejected but the efficiency of the judgement method is decreased. Therefore, there is a tradeoff between the performance and efficiency of the proposed method. The experimental results show that the proposed method can detect macro defects, which are difficult for humans to detect using the conventional inspection system, and can also judge the macro defects as PASS/REJECT in a simple but effective way using the quantitative values.

If it is analysed from another point of view, it can be seen that every macro defect detected in the module process did not occur in the TFT fabrication process, rather, some of the defects occurred in the CF or cell process. From this fact, it is assumed that panels of $51 \leq \text{PJI} \leq 61$ need to be judged as PASS in the TFT fabrication process. Therefore, the most efficient judgement threshold in this experiment has to be selected from the range 61–70. Finally, the detected defects and judgement results in each of the TFT, CF, cell, and module processes should be monitored and the findings should be fed back to other processes to select the judgement threshold in the most reasonable way.

4 CONCLUSIONS

A real-time automatic inspection method is proposed for the inspection, i.e. the detection and the judgement of macro defects in the TFT fabrication process. The proposed detection method can detect TFT macro defects in the TFT fabrication process using the phenomenon of shift of the diffraction pattern through the physical insights and manufacturing field know-how. Additionally, the proposed judgement method is very efficient and robust against any vibration of glass, because it uses a very simple equation and employs the concept of just noticeable difference (JND) based on the well-known theories of psychophysics. Further, it needs no additional optical system and has much less calculation time. Therefore, the proposed method is highly suitable for in-line TFT-LCD production systems. Finally, the proposed inspection method is verified with industrial experiments.

The developed method can be implemented in any real world industry due to its high efficiency and trustworthy performance characteristics as well as due to the need of less inspection time than the conventional human inspection methods. Since it is possible to detect the preliminary macro defects before the module process using the proposed inspection method, a high production yield in the module process and a low production cost in the overall TFT-LCD production can be achieved.

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