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Automatic inspection method for macro defects in TFT-LCD color filter fabrication process

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Abstract: Defect inspection of thin film transistor liquid crystal displays (TFT-LCDs) is divided into two steps: detection and judgment. This letter proposes an automatic detection and judgment method for macro defects in the TFT-LCD color filter (CF) fabrication process using the diffraction pattern shift and chromaticity, respectively. The proposed method is verified via experiments using sampled CF glasses with macro defects, which were judged as PASS (no defect) in the CF fabrication process by a human operator who inspects CF glasses using conventional inspection systems, but were rejected in the module process. Seventeen rejected glasses were used in the experiments. All macro defects, including non-uniformity under 300 Å, were detected and are judged as REJECT (defect) using the proposed method.

Keywords: inspection, macro defect, thin film transistor liquid crystal displays, color filter
Classification: Science and engineering for electronics

References

[1] Y. J. Lee and S. I. Yoo, "Automatic Detection of Region-Mura Defect in TFT-LCD," *IEICE Trans. Inf. Syst.*, vol. E87-D, pp. 2371–2378, 2004.
[2] P. C. Wang, S. L. Hwang, and C. H. Wen, "A Study of Human Vision Inspection for Mura," *Human-Computer Interaction, HCII 2007, LNCS*, vol. 4552, pp. 747–754, 2007.
[3] Y. Kuo and T. Yang, "A Case Study on the Operator Allocation Decision for TFT-LCD Inspection and Packaging Process," *J. Manuf. Technol. Manag.*, vol. 17, no. 3, pp. 363–375, 2006.
[4] D. M. Tsai, P. C. Lin, and C. J. Lu, "An Independent Component Analysis-Based Filter Design for Defect Detection in Low-Contrast Surface Images," *Pattern Recognition*, vol. 39, pp. 1679–1694, 2006.
[5] H. D. Lin and S. W. Chiu, "Computer-Aided Vision System for MURA-Type Defect Inspection in Liquid Crystal Displays," *PSIVT 2006, LNCS*, vol. 4319, pp. 442–452, 2006.
[6] L. C. Chen and C. C. Kuo, "Automatic TFT-LCD Mura Defect Inspection using Discrete Cosine Transform-Based Background Filtering and 'Just Noticeable Difference' Quantification Strategies," *Meas. Sci. Technol.*, vol. 19, pp. 1–10, 2008.

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[7] Y. Mori, K. Tanahashi, and S. Tsuji, "Quantitative Evaluation of 'Mura' in Liquid Crystal Displays," *Optical Engineering*, vol. 43, no. 11, pp. 2696–2700, 2004.
[8] K. N. Choi, N. K. Park, and S. I. Yoo, "Image Restoration for Quantifying TFT-LCD Defect Levels," *IEICE Trans. Informat. Syst.*, vol. E91-D, pp. 322–329, 2008.
[9] H. Liu, S. J. Lin, Y. L. Hsueh, and M. J. Lee, "Automatic Target Defect Identification for TFT-LCD Array Process Inspection using Kernel FCM-Based Fuzzy SVDD Ensemble," *Expert Systems with Applications*, vol. 36, pp. 1978–1998, 2009.

1 Introduction

In order to monitor the manufacturing process by reviewing, classifying, and analyzing the trends of defects and to guarantee the display quality of various flat panel displays (FPDs) such as thin film transistor liquid crystal displays (TFT-LCDs), plasma display panels (PDPs), and organic electro luminescence displays (OLEDs), the inspection (i.e. the detection and judgment) of defects is a critical task in the manufacturing process. In particular, more accurate and faster defect detection and judgment of TFT-LCDs is a very important issue for manufacturing processes to obtain a high production yield and a low production cost in order to become leader in the competitive FPD market.

Defects are roughly classified into two categories: micro and macro defects in TFT-LCD manufacturing process. Micro defects include pinhole, particles, and scratches. The size of micro defects is generally under a few tens micrometers. A macro defect is a relatively large defect that affects multiple display pixels [1]; its size can even be a few hundred millimeters. Generally, manual inspections using visual perceptions of an inspector and experience are performed to inspect macro defects. Most of TFT-LCD companies use the human eye-based inspection method because it shows best inspection efficiency. However, the inspection results using this method can vary with the human operator due to the limitations of inspection time, sensitivity, differing inspection skills, and experience of each inspector [2]. Especially, the growing size of TFT-LCD glasses increases the probability for macro defects and inspector errors. Therefore, a high performance automatic inspection system for macro defects is needed to obtain high productivity, high quality, and low production costs.

Defect inspection is performed after every sub-process in the manufacturing process of TFT-LCDs [3]. In previous research, most automatic detection systems were developed for macro defects in the module process [1, 4, 5, 6]. There has also been research on the detection of macro defects in the cell process [7], and various quantification methods has been developed to judge macro defects as PASS or REJECT [6, 7, 8]. However, macro defects also need to be detected in the fabrication process because many occur in the TFT fabrication process resulting from photomask misalignments in the ex-

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posure process and non-uniform coating of the colored photo resist (PR) in the coating process of the color filter (CF) fabrication process. Moreover, if macro defects are inspected in the fabrication process, it will be helpful in increasing the production yield and decreasing the production cost. Recently, for this reason, there has been some research on defect inspection in the TFT fabrication process [9]. However, Liu et al. only focused on the inspection of micro defects because photomask misalignments can cause micro defects. On the other hand, in the CF fabrication process, non-uniform coating of the colored PRs do not make micro defects. Papers dealing with the automatic inspection of these kinds of macro defects are rare. Therefore, in this paper, we focus on the development of an automatic inspection method, not only detection but also judgment, for macro defects in the CF fabrication process. At first, we detect macro defects using optical imaging of the CF glass based on the shift of diffraction pattern that occurs in the display pixel array. Secondly, we quantitatively measure the non-uniformity of the colored PR coating using the chromaticity of each display pixel. Then, a specification of the in/out (i.e. PASS/REJECT) judgment of the macro defects is performed using the measured data.

2 Inspection method

2.1 Detection method

A general grabbed image of the glass in the fabrication process is not desirable to detect defects because there is non-uniformity of illumination due to the large glass size and the scattering light resulting from the pixel arrays. Therefore, the difficulty of detection of macro defects increases when using a general optical system for the non-uniform brightness of the image.

Macro defects in the CF fabrication process occur due to a height difference of the patterned red, green, and blue pixels which results from a non-uniform coating of the colored PR. Generally, these kinds of macro defects cannot be imaged using a conventional optical imaging system because the height difference between uniform and non-uniform coated patterns is very small to make a contrast in grabbed image. Hence, macro defects can be optically imaged via a line scan camera using the phenomenon of the shift of the diffraction pattern, as shown in Fig. 1 (a). Moreover, in order to clearly detect macro defects of the CF glass using light diffraction, coherent light is required. Coherent light is realized, practically, by using long distance illumination of more than 2 meters. A clear diffraction pattern can then be obtained. Metal halide illumination is used for bright and clear imaging.

2.2 Judgment method

The judgment method for the detected macro defects is illustrated in Fig. 1 (b). Essentially, the judgment is performed using the measurement data of the chromaticity of each patterned pixel which are red, green, and blue pixels. The chromaticity is also measured at approximately twenty points across the boundary of the macro defect using a color area scan camera and

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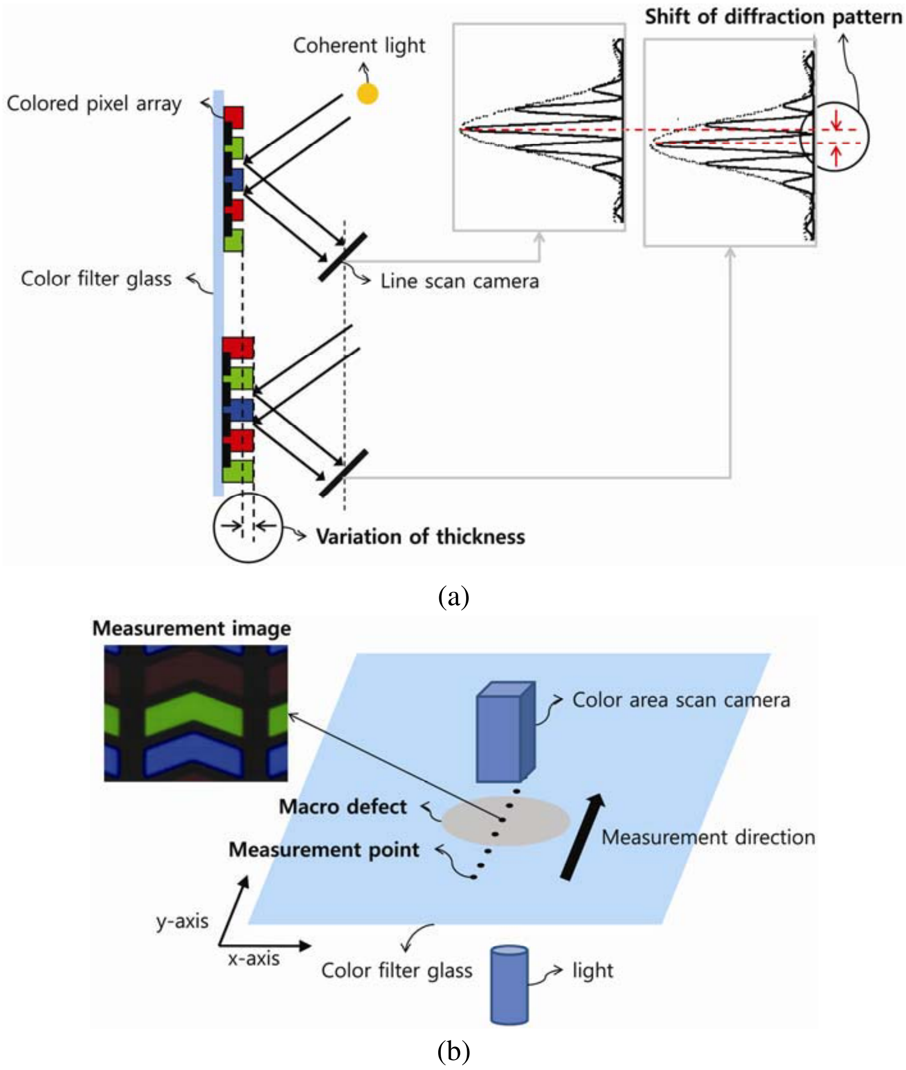

Fig. 1. Inspection method. (a) Optical imaging of macro defects using the variation of diffraction patterns. (b) Configuration of automatic judgment system for macro defects.

moving the glass. The chromaticity of each pixel is calculated using (1).

$$x = \frac{X}{X+Y+Z} \ \textit{and} \ y = \frac{Y}{X+Y+Z}$$
$$\textit{where} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = T \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.607 & 0.174 & 0.201 \\ 0.299 & 0.587 & 0.114 \\ 0.0 & 0.066 & 1.117 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

where R, G, and B are the primary tristimulus values; T is a transformation matrix to the CIE XYZ system; and x and y is chromaticities. Chromaticity measurement is generally carried out using high density CCD sensors of more than 10 bits. The proposed measurement system shows similar measurement accuracy using (1) even when 8-bit CCD sensors are used. In addition, the proposed measurement algorithm can highly reduce the measurement time because 8 bit CCD sensors need less exposure time and (1) is very simple 3×3 matrix calculation. Then, using the trend of the measured chromaticity, we

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can judge whether the macro defect is a critical defect, which is a detect that is insufficient to represent the correct color. For the judgment of the red pixel, the chromaticity of x, which is represented as Rx, is used. The chromaticity of y is used to judge the green and blue pixels, which are represented by Gy and By respectively, is used. For a normal CF manufacturing process, a chromaticity difference of over 0.0008, which is generally related to a height difference of 500 Å, is considered to be a critical defect.

3 Experimental results

The proposed method was evaluated using seventeen industrial CF glass samples that had macro defects. The seventeen glasses had been passed by human operators who inspect CF glass in the CF fabrication process using the conventional inspection equipment and then rejected by human inspection in the module process. This is because human cannot detect macro defects even though human eye-based inspection shows best inspection ability. Figure 2 (a) shows the optically detected image of a white spot-type macro defect in the red pixel array and the chromaticity measurement graph. The increase of Rx indicates that the red pixel height becomes relatively high compared with the normal red pixel. In this case, the detected macro defect is a critical defect because the maximum difference of Rx is approximately 0.001. Detection image and chromaticity measurement graph for a stripe-type macro defect in green pixels is shown in Fig. 2 (b). Various kinds of macro defects in green pixels and blue pixels are also detected and judged as REJECT using the proposed method. A summary of the experiment results is shown in Table I. The experimental results show that the proposed method can detect macro defects, which are difficult for humans to detect using the conventional

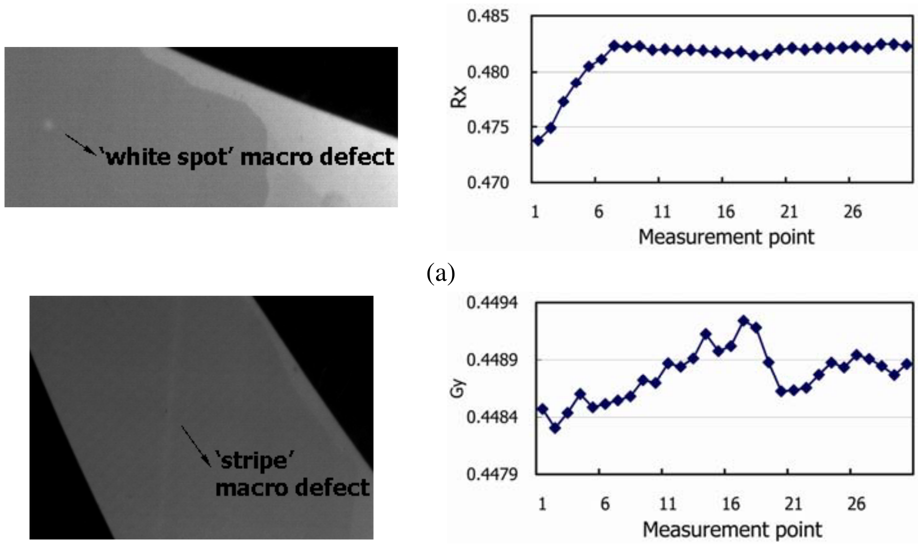

Fig. 2. Experimental results: detection image and chromaticity measurement graph. (a) White spot-type macro defect in red pixels. (b) Stripe-type macro defect in green pixels.

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inspection system, and can also judge the macro defects as PASS/REJECT in a simple and effective manner using their quantitative values.

Table I. Summary of experiment results.

Pixel Array	Defect Type	Detection Result		Judgment Result
		Conventional	Proposed	
Red	White-spot	Not detected	Detected	0.0009
	White-spot	Not detected	Detected	0.0034
	Stripe-type	Not detected	Detected	0.0017
Green	White-spot	Not detected	Detected	0.0023
	White-spot	Not detected	Detected	0.0008
	White-spot	Not detected	Detected	0.0010
	Dual-spot	Not detected	Detected	0.0022
	Dual-spot	Not detected	Detected	0.0021
	Stripe-type	Not detected	Detected	0.0011
	Stripe-type	Not detected	Detected	0.0015
	Aligned Stripe-type	Not detected	Detected	0.0007
Blue	White-spot	Not detected	Detected	0.0012
	White-spot	Not detected	Detected	0.0008
	White-spot	Not detected	Detected	0.0024
	Dual-spot	Not detected	Detected	0.0021
	Stripe-type	Not detected	Detected	0.0012
	Stripe-type	Not detected	Detected	0.0009

4 Conclusion

An automatic inspection method is presented for the detection and judgment of macro defects in the TFT-LCD CF fabrication process and is verified with industrial experiments. The proposed method is developed based on the analysis of the causes of macro defects. Therefore, the developed method is highly efficient and trustworthy and requires smaller inspection time. It can, therefore, be easily implemented in industrial applications. Finally, a high production yield and a low production cost can be achieved using automatic inspection of macro defects in the CF fabrication process with the proposed method.

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