An Improved Fast Self-Comparison Algorithm for High-Speed Defect Detection of ITO Circuits

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Abstract—For PCTP ITO circuit defect detection based on template matching, usually the templates in DXF format cannot be used directly. Because the sensed images will be deformed, then the effectiveness of comparison algorithm will be adversely affected. Based on FFT a self-comparison algorithm for high-speed defect detection of ITO circuit in PCTP is developed in which a faultless template is extracted from sensed images. 1-D FFT and 2-D FFT are compared for the practicability, and the effectiveness of the algorithm is analyzed for the detection of sensed images with different brightness. The experiment results show this algorithm is applicable and fast.

Keywords- defect detection; self-comparison algorithm; ITO circuit; Digital image processing

I. INTRODUCTION

ITO (Indium tin oxide), as one of TCO (Transparent Conductive Oxide) materials, has played an important role in semiconductor manufacturing [1]. Especially because of its high light transmittance (more than 90%) and low electrical resistivity (below 10$^3$cm), the ITO material has been largely used in PCTP (Projective Capacitive Touch Panel) to form transparent circuit. Unfortunately, defects caused by all of current etching methods on its surface are inevitable in PCTP manufacturing. Moreover, with the increase of competition, every PCTP manufacturers have been making efforts to improve product yields. Thus, how to automatically and accurately detect all kinds of defects in ITO circuit is a complex and challenging task.

Currently, sampling visual inspection is still a main method in real manufacturing, however, due to its inefficiency and low accuracy, it is gradually unable to meet the modern requirements of manufacturing. Nowadays, with the development of automatic technology, AOI (Automated Optical Inspection) has become a major way for surface defect detection in semiconductor filed. For example, Hou and Zhou et al. proposed a pattern matching method based on mathematical morphology for detecting IC defects [2]. In their method, the differences between sensed image and template image are calculated and made into a binary image first. Then, the differences are processed by mathematical morphology, which is taken as defects. The pattern matching method based on the quantile–quantile plot (Q–Q plot) was also proposed for IC defect detection [3]. In the Q–Q plot, the quantiles in the sensed image are plotted against the corresponding quantiles in the template image. The resulting Q–Q plot is then used as the quantitative measure of similarity between two compared images to detect defects. Xie and Guan [4] proposed a template self-reference method for detecting defects in a patterned wafer. Spectral estimation is used first to extract the periods of repeating patterns from an input image in horizontal and vertical directions. Then, a faultless template is generated. Finally, a pixel-to-pixel subtraction between the sensed image and the template is used to identify the defects. Tsai and Lai [5] proposed independent component analysis (ICA) for detecting defects in TFT-LCD at a fine resolution. The sensed 1-D line image are first divided into two segments of equal length. And then, the de-mixing matrix obtained offline from a faultless line image by applying an ICA model is used to recover the signals with well aligned translation. The normalized cross-correlation is finally adopted to measure the similarity between two compared segments and located the defects.

From above, it is concluded that these methods either need prior knowledge or are several complicated algorithms combined together to detect defects. In this application, because the ITO circuit needs fast and full inspection in real practice, the AOI system can only be established by line-scan cameras. However, on the one hand, the line-scan system inevitably leads to mechanical vibration, which will cause sensed images deformed, therefore, the sensed image cannot accurately match the template image in DXF format. On the other hand, the complicated algorithms are time-consuming. Hence, to address this issue, an improved fast self-comparison algorithm are investigated in this paper by taking full advantage of template matching method. The real faultless template is obtained from sensed images instead of DXF files, which can have approximate imaging conditions of sensed images so as to be applied in real inspection. Moreover, the defects can be quickly and straightforwardly extracted by FFT. The experiments demonstrate the method is fast, accurate and applicable.

II. THEORY OF THE IMPROVED FAST SELF-COMPARISON ALGORITHM

The core concept of the proposed fast self-comparison algorithm in this paper is extracting a faultless template from sensed images. In PCTP manufacturing, the defects are considered to be random distribution and the probability of defects in same postion of different ITO substrates is very low. A real template can be extracted from three sensed images by replacing the defective pixels by the pixels of the same position in another image. Furthermore, in order to save time, Fast Fourier Transform (FFT) is adopted to extract real
template. FFT is wildly used in many areas [6, 7]. Particularly in speech signal denoising [8]. The spectrum of speech signal with no noise can be acquired by the spectrum of real speech signal substrate the spectrum of noise, similarly, the spectrum of noise can be acquired by the spectrum of real speech signal substrate the spectrum of speech signal with no noise.

In this study, similar to the defect detection on IC [9] and speech signal denoising, a sensed ITO circuit image can be identified as the speech signal with noise, a real template image can be identified as the speech signal with no noise, and defects are identified as the noise. Then, defect spectrum can be acquired by the sensed image subtract the real template, and the defects can finally be found by anti-Fourier transform (IFFT).

A. Theory of extracting template

Assuming that S1, S2 and S3 (shewn in Fig.1 (a)-(c), respectively) are three sensed images in the same position of different substrates, these images contain typical defects such as open, short, pinhole and particle. Then, a real faultless template can be extracted from the three sensed images by

\[
D_{12} = FFT(S_1) - FFT(S_2) \quad (1)
\]

\[
D_{23} = FFT(S_2) - FFT(S_3) \quad (2)
\]

In the above, D_{12} contains the defects of S1 and S2, and D_{23} contains the defects of S2 and S3. The defects of one image can be obtained by

\[
D_1 = +(|IFFT D_{12}| - |IFFT D_{23}|) \quad (3)
\]

where the meaning of “+” is: if the gray value in D_1 is less than 0, then it is set to 0. Even though D_1 only contains the defects of S1, the defects are not distinct because the defective gray value are little greater than normal pixels. Therefore, a power transform is adopted here by

\[
C = \max D_1, \quad D = D_1^r * C^{a-r} \quad (4)
\]

where D is the result of power transform on D_1, C is the maximal gray value in S1, “*” represents multiplication, and the power r is greater than 1. After the power transform on D_1, a binary image can be obtained easily by taking the following threshold processing

\[
D_b = \begin{cases} 
1, & \text{if } D - a < \sigma \\
0, & \text{if } D - a > \sigma 
\end{cases}, \quad a = \max D \quad (5)
\]

Where D_b is the binary image of D, a is the maximal gray value in D, and \( \sigma \) is the threshold value. Since some error points are existed in D_b, a morphological filter are used to remove these error points. The real defect image can be obtained by

\[
E = \text{MFILTER } D_b \quad (6)
\]

In the above, E only contains the real defects of S1, MFILTER represents the morphological filter, and the size of this filter is set by manufacturers depending on the real practice. Then, a real template can be extracted by replacing the defective pixels in S2 with the pixels of the same position in S1, the expression is

\[
S_1(x, y) = S_2(x, y) \quad (7)
\]

Where (x, y) is the coordinates of all defects in S2. By operating Eq.(1)-(7), a faultless template can be obtained quickly from sensed images.

B. Theory of detecting defects

Suppose T is the real faultless template, S is a sensed image, and then, the defects can be detected by

\[
D_t = FFT(T - S) \quad (8)
\]

\[
D_t = IFFT(D_t) \quad (9)
\]

where D_t represents the spectrum differences between T and S, and the defects in S can be found by taking Eq. (8)-(9) and (4)-(6). Particularly, the algorithm complexity is close to FFT. As the processing speed of FFT is very fast and it has been applied in solving many engineering problems, the presented algorithm can be used to detect defects of ITO circuit in real manufacturing.

III. EXPERIMENT RESULTS

From the above, we can see the method is set to two steps: faultless template extraction and defect detection. For verifying the validity of this method, a series of experiments are taken. Three sensed images are shown in Fig.1. By using the proposed method, the experiment results are shown in Fig.2.
Fig. 2 (a) is the real template image, and Fig. 2 (b)-(c) are defects in the three sensed images of Fig. 1 respectively. For the convenience of displaying, the image size in this paper is 604×403 pixels, and with the memory of 4G and the CPU of 2.49 GHz, the time of faultless template extraction is 0.42s, the time of defect detection is 0.23s. The experiment results show the processing speed is fast, accurate and the complexity is closed to FFT.

In real inspection, because the brightness of light source will be inevitably affected by the environment, the gray values located in the same position between sensed images are different. Unfortunately, even if the differences are slightly, wrong detection will occur. In order to extract a faultless template from images with different brightness and accurately detect defects, one of the three sensed images is set to be a reference. The gray value histograms of the other two images are matched to the reference, and then the brightness of the three sensed images are consistent. So, the algorithm presented above can also take a faultless template.

![Image](https://via.placeholder.com/150)

(a). reference image  (b) darker than (a)  (c) brighter than (a)

Figure 3. Images with different brightness

The three sensed images with different brightness are shown in Fig. 3. Comparing with Fig. 3 (a), the Fig. 3 (b) is darker and the Fig. 3 (c) is brighter, then the Fig. 3 (a) is appropriate to be the reference.

![Image](https://via.placeholder.com/150)

(a). The faultless template of Fig. 3

Figure 4. The detection results of three different brightness images

By use of brightness matching method combined with our presented algorithm, the Fig. 4 (a) represents the faultless template extracted from three sensed images of Fig. 3, and the Fig. 4 (b)-(d) are the defects of Fig. 3 (a)-(c). The experiment results show that the faultless template extracted from the three sensed images with different brightness are applicable and the defects can be found correctly.

![Image](https://via.placeholder.com/150)

(a). defects of Fig. 3 (a) by 1-D FFT  (b) the 3-D diagram of (a)

(c). defects of Fig. 3 (a) by 2-D FFT  (d) the 3-D diagram of (c)

(e). the differences between (a) and (c)

Figure 5. The contrast of 1-D and 2-D FFT in this method

Fig. 5 shows the results of defect detection by 1-D FFT and 2-D FFT, respectively. Fig. 5 (a) and (c) represent the result defect detection of Fig. 4 (a) by 1-D FFT and 2-D FFT, respectively. However, not only the defects itself, but also their corresponding 3-D diagrams (Fig. 5 (b) and (d)) and the differences between each other (shown in Fig. 5 (e)), all of the results show almost the same. Furthermore, for the same sensed image (Fig. 4 (a)), the time of defect is about 0.07ms and 0.13ms by 1-D and 2-D FFT, respectively. Thus, in summary, 2-D FFT is more complex than 1-D FFT, costs more time and cannot provide more effective result than 1-D FFT, the 1-D FFT is a better choice in this algorithm. Therefore, in this application, 1-D FFT is used.

IV. CONCLUSIONS

An improved fast self-comparison algorithm for defect detection of ITO circuit in PCTP is developed in which the
A real faultless template is extracted from three sensed images. The experiment results prove the ITO circuit defects in sensed images with different brightness can be detected by means of the real faultless template, and the method is applicable and fast.

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