Development of Defect Inspection System for PDP ITO Patterned Glass

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The formation degree of sustain (ITO pattern) determines the quality of a PDP (Plasma Display Panel). Thus, in the present study, we attempt to detect 100% of the defects that are larger than 30 ㎛. Currently, the inspection method in the PDP manufacturing process is dependent upon the naked eye or a microscope in off-line mode. In this study, a prototype inspection system for PDP ITO patterned glass is developed. The developed system, which is based on a line-scan mechanism, obtains information on the defects and sorts the defects by type automatically. The developed inspection system adopts a multi-vision method using slit-beam formation for minimum inspection time and the detection algorithm is embodied in the detection ability. Characteristic defects such as pin holes, substances, and protrusions are extracted using the blob analysis method. Defects such as open, short, spots and others are distinguished by the line type inspection algorithm. It was experimentally verified that the developed inspection system can detect defects with reliability of up to 95% in about 60 seconds for the 42-inch PDP panel.

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1. Introduction

Television has been the most important medium of news communication in daily life since the development of the CRT (Cathode Ray Tube) in the 1890s. With consumer's demand for large-sized display products in accordance with their elevated standard of living, the display companies pay attention to fairly large size FPD (Flat Panel Display), which is 40 inches or more in size. The PDP products take advantage of the phenomenon of plasma. The plasma of PDP products is typically generated by an electric discharge method rather than a heating method. A thin-film of ITO (Indium Tin Oxide) is coated while considering the transmissivity and resistivity of the electrode in the front glass of the PDP so that the electric discharge can be maintained by the subsequent pulse.[1, 2]

The display quality of the PDP product is estimated by the formation of pattern, thickness, gap, etc in the surface of the ITO coated glass, which is used as the basic material of the PDP. At present, however, a display quality and its measure are dependent on a lighting test performed in the final stage of the manufacturing process.[1] Defects that occurred due to contamination of raw materials, inflow of impurities, and carelessness of workers while the ITO coating process affect the display quality due to the disturbance of the continuous plasma discharge. However, at present, the ITO coating inspection process depends solely on examination with the naked eye. Therefore, in the present study, given that the whole surface of the ITO and pattern coating quality inspection depend largely on the skill of the worker, we have developed an automatic inspection system. The developed equipment detects and sorts defects according to shape, and systematically analyzes the position, type, and size of the defects. The data for our study is applied to the inspection system. An optical line-scan mechanism and a PDP ITO inspection algorithm in consideration of the process variables are employed.

2. PDP ITO Process Analysis

The sustain electrode is composed of x, y electrodes on the PDP front panel plays an important role in continuously maintaining plasma by the next pulse. The sustain electrode is mainly made of ITO because high transmissivity of 88 percent and low face resistivity between 10 and 20 Ω are needed.[3]
Up to now, though several PDP ITO coating methods have been used in display industry, Sputtering Thin Film Deposition,[4] where a thin film is coated to harness the high energy of the plasma, is recognized and studied as the most reliable method. It is easy to control the reduction in production time through the in-line process and increase the adhesive strength of the thin film. The whole surface ITO coated PDP glass of equal thickness for the pattern formation of the ITO sustain electrode is achieved through a photo etching process based on the respective know-how of PDP manufacturing companies in consideration of the distance and thickness of the pattern.[3, 5]
As shown in Fig. 1, taking advantage of the sputtering method, firstly, the ITO sputtering process is deposited on the PDP front glass after which a light-sensitive photo resist is applied. In the last

process, the etching process removes the unwanted parts for the formation of the pattern.[6]

The PDP luminescence efficiency is remarkably deteriorated by a variety of pollutants and unequal deposition that occur during the ITO deposition process. The minor surface cracks or protrusions disturb the normal deposition of an organic thin film. The formed dark spots also affect the key factor for defect occurrence. There are also instances where scratches occur by the inflow of impurities. Therefore, the surface of the ITO must be ground precisely after the ITO coating operation on the glass panel, because the requirements are below 300Å in flatness and 50Å in roughness.[7]

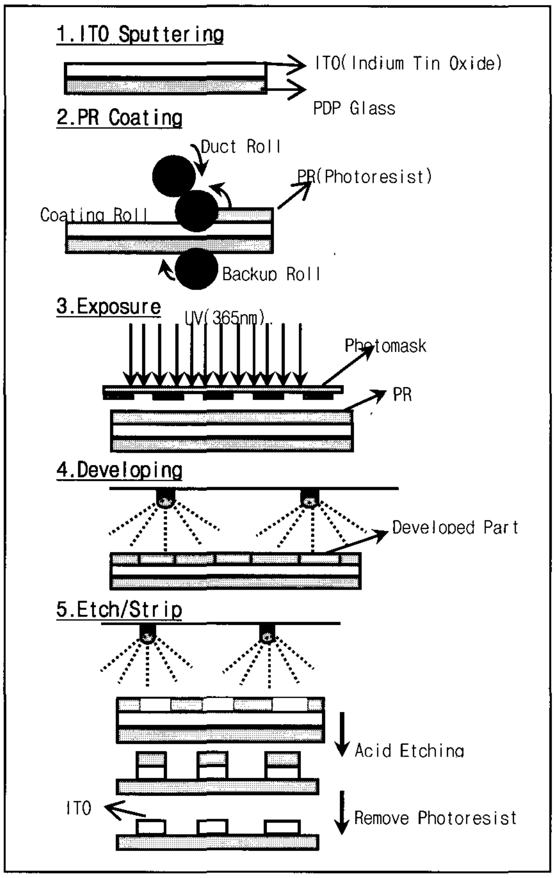


Fig. 1 Process of photo etching

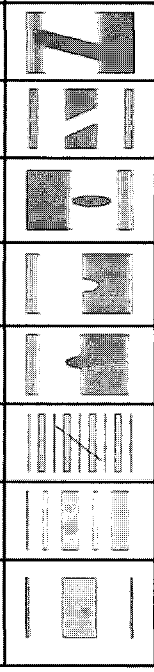
Quality inspection at present detects the defects by converting an irregular shape into a numerical value for the whole surface ITO coating or the ITO pattern in the PDP ITO process. The defects are typically defined as open, short, pin holes, protrusions, substances, particles, and so on, as shown in Fig. 2. Also, scratches and spots can be the focus of defects.

The factors that lead to the occurrence of these defects are damage of the coating film caused by pollution of the raw material, dust in the clean room, handling carelessness by operator, insufficient washing facilities, and so on. It has also been reported that these defects are related to poor pattern formation or defects in external appearance by light diffusion.

Therefore, the PDP panel manufacturing plant must provide automatic inspection of quality in the manufacturing process and every defect should be analyzable in the manufacturing system. This paper presents the foundation of a process optimization technique for minimizing the occurrence of defect.

3. Development of PDP ITO Inspection System

For detecting the above-mentioned defects, we devised a PDP ITO inspection system that operates an automatic on-line inspection method utilizing a vision sensor. The proposed system can yield information on defects that was previously unattainable by manual quantitative inspection. The main part of the developed system



Article	Image	Cause of sampling
Open		· Processing-type defect · ITO pattern perforation
Short		· Processing-type defect · ITO pattern connection
Pin Hole		· Processing-type defect · Closed edge is on the ITO pattern
Protrusion		· Processing-type defect · Open edge is on the ITO pattern
Substance		· Processing-type defect · Open edge is on the glass
Scratch		· Handling-type defect · Line across the pattern
Spot		· Handling-type defect · Concentrated points or lines
Particle		· Handling-type defect · Lower than minimum defect size at inspection parameter setup

Fig. 2 Representative defects of PDP ITO glass

consists of an inspection sensor, a drive stage, and an illumination component, as shown in Fig. 3.

In particular, we placed great importance on determining the most suitable system design and a composition for the suitable FOV (field of view) between cameras.

The inspection sensor part is composed of a dual type line-scan camera (Takenaka, TL-5150UFD) as a primary sensor for consecutive image acquisition and inspection time decrease, and an appended review camera (Moritec, MSG6-2200S) for thorough examination of specific defects after completion of the inspection.

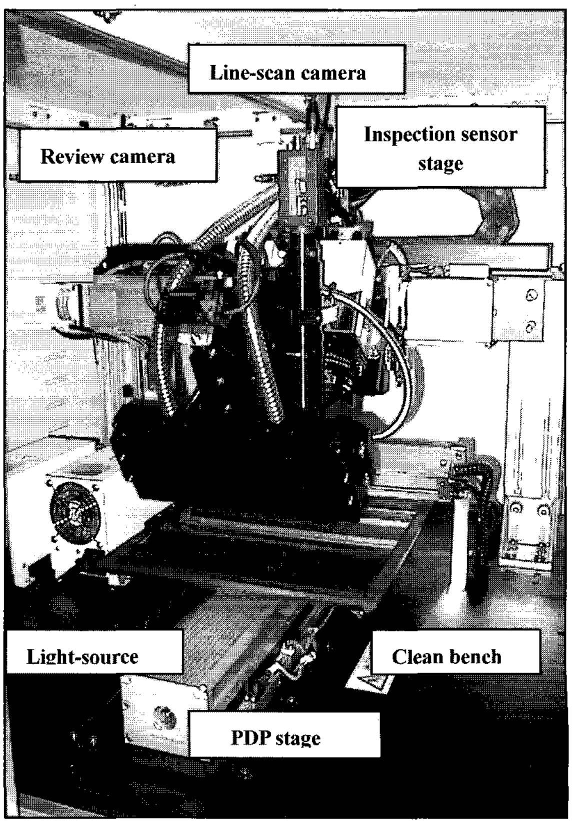


Fig. 3 Layout of PDP ITO inspection system

The drive stage that is prepared for the inter-process inspection in the ITO manufacturing process, namely, the wide area inspection, is composed of an inspection sensor stage (X-axis drive), a PDP stage (Y-axis drive), and the vacuum chuck attaches the PDP ITO patterned panel as the inspection target. The stage is capable of precision-feeding within a repeated accuracy of $\pm 5\,\mu m$ during the precise correspondence of the feeding speed of the PDP and line-scan camera. Furthermore, the system employs a cross-roller bearing and a step motor for prevention of qualitative deterioration when the surface of the PDP is tilted.

If the scan speed is varied or the illumination has a lower frequency than the image acquisition speed despite of utilizing the same illumination conditions, then the inspection efficiency is adversely affected on account of the difference from the radiation intensity in the property of the line-scan camera. Therefore, the illumination of the inspection system is comprised of a 100W-rate halogen lamp as the light source for illumination efficiency, and the optical fiber with a clad diameter that is smaller than the plastic is used for the light guide. Also, the aperture of the line-scan camera was minimally opened to ensure uniform FOV, as shown in Fig. 4. For illumination, a condenser lens is installed at the tip of the lighting guide to compensate for the weak points in the optical fiber (Numerical Aperture: 0.5), which has the characteristics of spreading the light.

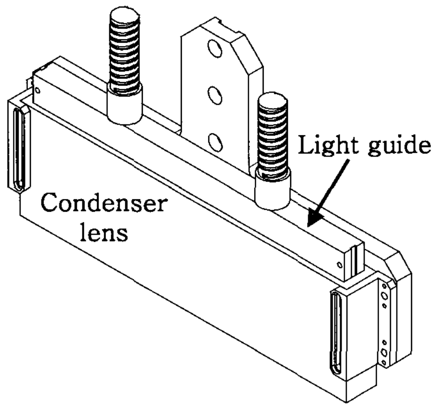


Fig. 4 Structure of designed light part

The length L of the designed line-illumination was based on Eq. (1).

$$L = F + \left(2 \cdot \left(\frac{WD \cdot NA}{1-(NA)^2}\right)\right) \quad (1)$$

where, F : FOV of line-scan camera(≈40mm)
WD : Working distance of the condenser lens
NA : Numerical aperture of optical fiber

Because the developed system uses a dual type line-scan camera, the practical length of the lighting guide is 2L. Fig. 5 shows the luminance profile of the designed illumination. The central part shows relatively low luminous intensity.

We developed the inspection system with the design criteria stated above, and added S/W with control, an inspection algorithm and estimation; an analysis function for adjustment-complement of the condition variables (FOV, WD and so on) and monitoring of the inspection process.

In the current PDP manufacturing process, the defect size is set on the basis of under 100 μm for the ITO whole surface coating and under 50 μm for the ITO pattern coating. The developed system, based on the inspection standard as stated above, utilizes an inspection software that finds defects less than 30 μm at the rate of more than 95%, and can easily display the inspection results (defect distribution and so on) in the total inspection time of approximately 60 seconds, including creation time of the defect map.

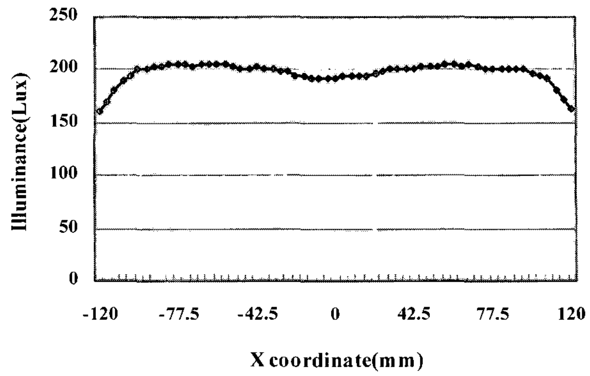


Fig. 5 Luminance profile of light guide part

4. Inspection Algorithms and Management Software Development

4.1 Inspection Algorithm Development

In this study, as shown in Fig. 6, we devised a defect inspection algorithm with consideration of process variables peculiar to the PDP with an inspection system as the key-technology. When we look into the unfolding method of the developed algorithm, the position and distance of the ITO pattern are estimated in order to take advantage of the average brightness value of the vertical direction and obtain the binary of the image process. In order to acquire information on defects, the blob analysis method, which determines the position and gap of pattern and defect size, is applied to utilize the average value of the brightness difference.

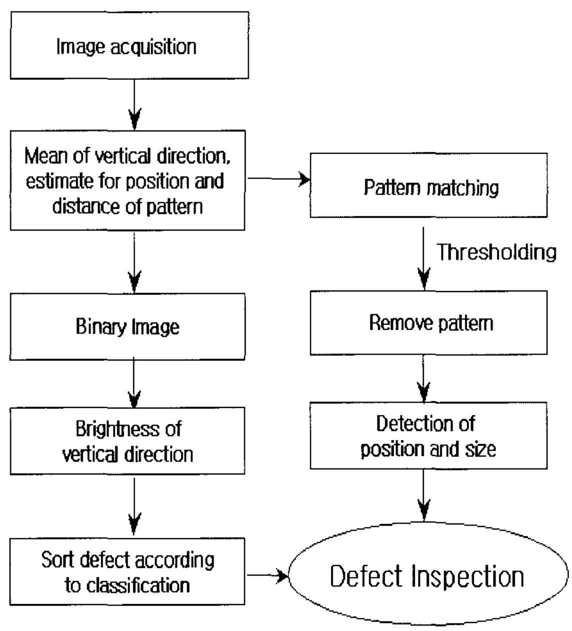


Fig. 6 Inspection algorithm of PDP defects

In general, the threshold value that removes the useless objects in the image process is set within limits that do not significantly consume objects between the two peaks of a histogram that expresses the object and the background.

However, in case of defects existing in the image when the pattern of the ITO electrode is included in the background, the whole brightness value is not regular under the pattern and defects possess an irregular brightness value. Hence, the pattern that keeps a uniform brightness value is removed from the image. Second, the remainder of the image must be analyzed for defects, as shown in Fig. 7. At this time, the whole extent of the brightness value that represents a domain of pattern is included in the threshold (256 Level, 193 ~ 216) by Eq. (2).

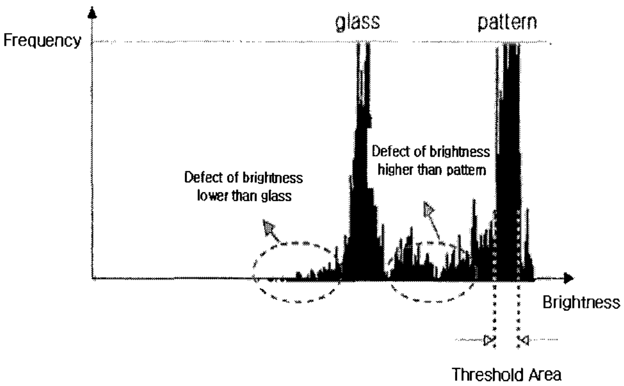


Fig. 7 Threshold value selection for PDP inspection

$$P_{\min} \leq P\_Thre \leq P_{\max} \tag{2}$$

In Eq.(2) P_{min} is the least brightness value of the pattern, P_Thre is the thresholding domain of the pattern, and P_{max} is the greatest brightness value of the pattern.

Because the defect is isolated as a target for inspection through the removal of the ITO pattern as an object of the threshold domain in the acquired image, it is possible to acquire the size of a pixel unit and coordinate value of the defect.

The algorithm for assortment by type compares the period that shows the average value variation of the vertical direction from the binary image with vertical brightness variation, which occurs as a result of the defect. It then sorts the defects as Open, Short, Pin Hole, Substance, Protrusion, Scratch, Spot, or Particle according to the brightness variation from the ITO pattern and edge of the ITO pattern.

4.2 Analyses and Estimation S/W Development of Inspection System

In this study, basic factors of defect occurrence in the PDP manufacturing process are assumed as process variables. These variables yield feedback for process improvement. The inspection system, as stated above, makes a data table that represents the characteristic data of the defects in terms of position, size, and type, and materializes the creation of the defect map. This map allows for a visible review of defect distribution by the X, Y coordinate values, as shown in Fig. 8.

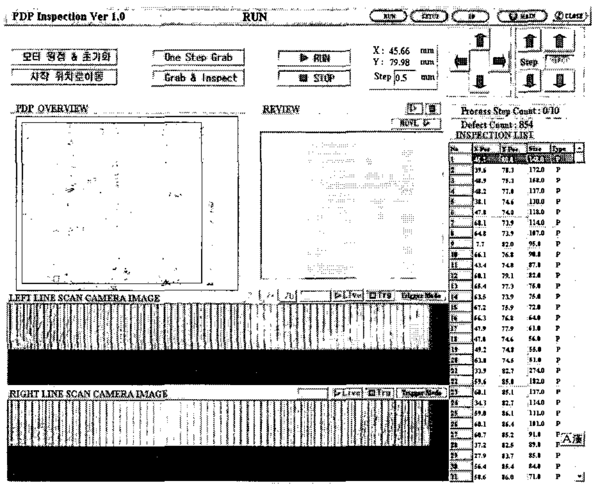


Fig. 8 Defect map of PDP ITO glass

The operation S/W of the developed inspection system is developed to modify each parameter, because each PDP manufacturing company has various inspection standards. The parameter of the Camera Parameter Setup menu defines the camera resolution (mm/pixel) and width/line of a grab unit for the size modulation of the acquired image. Further, it is possible to easily reset each offset and FOV of the camera in consideration of the worker interface in case of camera parameter modification.

In addition, the Inspection Parameter Setup menu can set up the least defect area and threshold value of the defect for application of different know-how in each PDP manufacturing company. The greatest inspection area is also included with the inspection category parameter for application of various size PDP panels in the in-line process.

5. Performance Test and Defect Map Analysis

5.1 Performance Test

Contrary to the existing off-line inspection system, the developed PDP ITO inspection system places more weight on an inter-process inspection system in the process, namely, high speed and detection reliability. Hence, the efficiency goal of the inspection system, namely, inspection ability of over 95% (defects 30 ㎛ or more) and inspection time of roughly 60 seconds (in a 40 inch PDP panel), is ascertained through simulations and inspection tests.

The developed system, a 12-inch PDP panel oriented prototype system, can inspect 300mm×300mm as the maximum inspection area. We then find the inspection time (scan time / a time × scan frequency) from a 230mm×220mm area as the real inspection area of the 12 inch PDP panel, and estimate the inspection time from 921mm×518.4mm as the real size of a 42 inch PDP panel, as shown in Fig. 9.

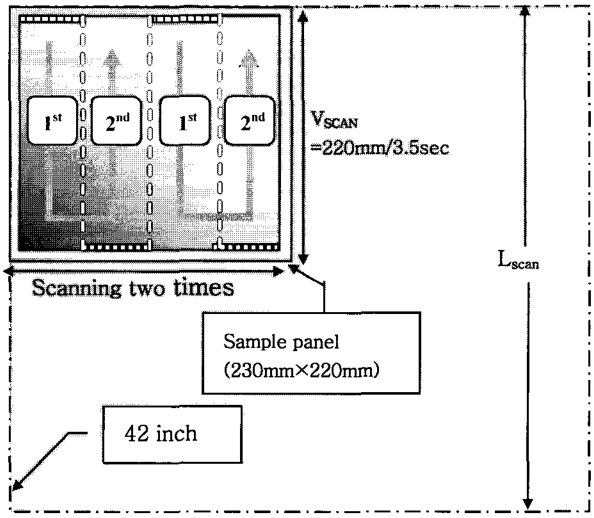


Fig. 9 Estimation of inspection time for 42" PDP

In the developed system, the image acquisition, which utilizes a dual-type line-scan camera, is synchronized with the inspection process. With the minimum defect map generation time, as shown in Fig. 8, we estimate the inspection time based on Eq. (3) from a 42 inch PDP. The defect inspection time was 65 seconds at a line-scan camera scan speed of Vscan =3.5 ㎜/s and a scan frequency of Nscan=8.

$$T_{tact} = N_{scan}\left[\frac{L_{scan}}{V_{scan}}\right] = 8\times\left[\frac{518.4[mm]}{62.85[mm/\sec]}\right] \approx 65\sec \tag{3}$$

where, N_{scan} : Scan frequency of line camera
L_{scan} : Vertical length of a object PDP
V_{scan} : Scan speed of line camera(mm/sec)

Meanwhile, we compare the number of defects of ten sample blocks that passed the inspection algorithm with the number of defects detected using a microscope for the estimation of detect ability of the inspection system. From the results(Table 1), it is confirmed that the developed inspection system attains an inspection rate of over 95% of defects that are 30μm or greater in size, thus meeting the goal of this study.

Table 1 Detection efficiency of developed system

Block	Defect Number at Microscope, A	Defect Number at Inspection System, B	Inspection Ratio, B/A
1	42	40	95%
2	26	25	96%
3	35	33	94%
4	16	15	94%
5	23	22	96%
6	46	45	98%
7	46	46	100%
8	32	31	97%
9	82	81	99%
10	42	41	98%
		Average	97%

5.2 Defect Map Analysis

Defects such as coating film damage by raw material pollution, particles in the clean room, careless work processes, and insufficient equipment cleaning, and so on occur during the PDP electrode formation process. This can be related to revision of standard for floating dust value in the workroom and strengthening the regulations about raw material transportation, delivery of goods, and storage.

The main defect factor during the process is the uniformity degree of film thickness resulting from weaknesses in the roll coating process using a PR (photo resist) coating in the ITO film formation process. Hence, instability of pattern precision occurs when the PR coating is not formed rapidly after the ITO coating. In the case of proximity exposure equipment in using a full size PDP panel, the support of the mask and the maintenance of distance between the mask and the panel are important issues, because the size of the mask is more than 40 inches. The problems, when employing an exposure method in the bus electrode formation process, result in decrease in reliability stemming from diffusion and discoloration of the electrode, shorts, gas cavity, and so on. The relation between the factors causing defects as stated above and their relative importance is shown in Fig. 10.[8]

Manufacturing process	Cause of an occurrence	Type of defects							
		Open	Short	Pin hole	Substance	Protrusion	Scratch	Spot	Particle
Panel Material	Damage of coating	○		●	○				
	Fliating dust								●
	Careless handling						○	○	○
	Clean apparatus							○	●
ITO Thin Film	Film thickness	○		●	○				
	Pattern formation				●	●			
Photomask	Impurities		○			●			
	Bad pattern	○		●	●				
Bus Electrode	Spreading		○			●			
	Change of color	○		●					
	Short			○	○				
	bubble			●					●

●: High frequency

○: Low frequency

Fig. 10 Relationship between PDP process and defect

Reconstructing the distribution of defects by type from the PDP panel, we can confirm that Pin Holes, Substances, and Protrusions occur most frequently, as shown in Fig. 11. Analyzing at the process level, we identified the following problems: particles existing on the mask or panel, inflow of impurities from the PR film formation process, and diffusion of the electrode from the exposure process. These problems occur due to floating dust in the clean room and equipment pollution in the chamber. They can be applied to the data that modulate the cleaning period in the chamber or the changing period of equipment, and to estimate and systematically analyze the process variables.

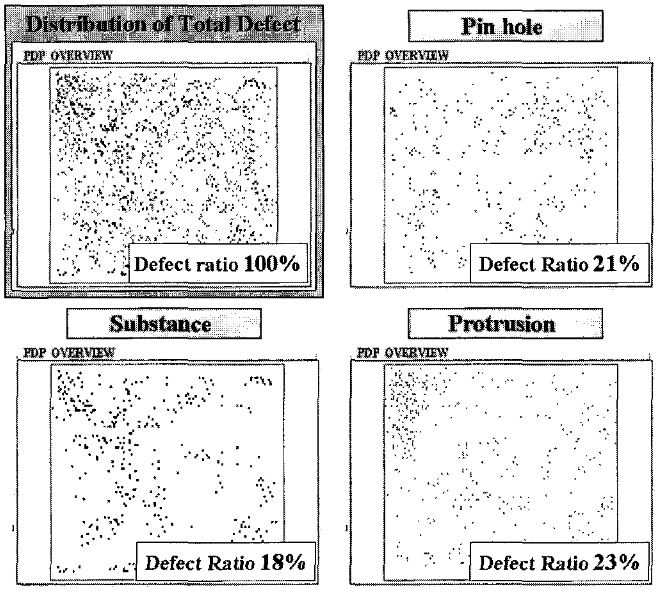


Fig. 11 Analysis of defect distribution

In future work, we plan to develop an inspection system with a practical model, as well as improve the cleanliness of the inspection environment. Further, if we improve the analysis function of the inspection result and identify correlations of particular process variables in the manufacturing process, it will be possible to contribute to higher productivity of PDP, yield, and quality improvement.

6. Conclusions

Because the formation precision of an ITO (or bus pattern) electrode determines the quality of the final product, we have endeavored to achieve a detection rate of 100% with defects of at least 30 μm in size. Therefore, in this study, we developed an algorithm that performs automatic inspection, because the existing method depends on examination with the naked eye, and the quality of product was determined according to the level of expertise in-line. A prototype-inspection system that can gather defect data sorted by defect type was developed. The system can detect and sort defects as holes, particles, open, shorts, speckles, etc. on the ITO.

Experiments verified that the developed system can inspect defects that are greater than 30μm with an inspection rate of 95% and inspection time of about 60 seconds from a 42 inch PDP panel. We reconstructed the distribution chart based on the data of property information, such as position, size, type, and so on, of the defects from the defect map. We also calculated the relative importance to prepare for the development of monitoring diagnosis technology and relation with the process variables. We re-sorted the defects according to handling defects and processing defects by the occurrence factor to optimize the process variables based upon the formation of relative importance of the defect and the distribution chart. We also presented a scheme to obtain the optimum manufacturing process by information-oriented results

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