A System for PCB Automated Inspection Using Fluorescent Light

YASUHIKO HARA, HIDEAKI DOI, KOICHI KARASAKI, AND TADASHI IIDA

***Abstract*—Research was performed on the detection of faults such as shorts, cuts, and nicks in a printed circuit board pattern. A printed circuit board pattern is made of copper, which is easily damaged or discolored. In order to automatically detect defects, technology which can accurately detect patterns is necessary. For this purpose we investigated the possibility of detecting a pattern by illuminating a printed circuit board with violet or ultraviolet rays and detecting the pattern using the (yellow or other) fluorescent light emitted by the base material consisting of glass-epoxy or glass-polyimide etc. It was found that the pattern could be detected clearly by selecting an optical filter that would separate the emitted fluorescent light from the illumination, and using a detector consisting of a high-sensitivity TV camera that produces a silhouette image in which the base material is bright and the pattern is dark.**

A printed circuit board pattern inspector using fluorescent light for pattern detection was developed. Two patterns are placed on an *XY*-stage, the pattern are detected and inspected as the stage is advanced in steps. The inspection takes 18 minutes for a 500 × 600 mm surface, and linear faults as narrow as 10 μm can be detected. Test operation of the inspector in a plant demonstrated that it does consistently good pattern inspections.

***Index Terms*—Automated visual inspection, fluorescent light optics, machine vision systems, printed circuit board inspection.**

I. Introduction

A PRINTED circuit board is a basic component part of many electronic devices. The reliability of circuit boards directly affects the reliability of the devices in which they are incorporated. To assure their reliability, it is necessary to inspect the circuit patterns visually (for shorts, cuts and mousebites), and repair any defects (Fig. 1). Visual inspection takes a great deal of time and is not completely reliable, so there is a great demand for an automatic inspector. A method for detecting patterns by reflected light has previously been developed and put into practice [1].

In existing inspectors, the pattern is illuminated vertically, and the reflected light is detected by a CCD linear image sensor. In this reflected light method, the detected image is easily affected by the surface state of the pattern. In order to accurately detect the pattern, special care has to be taken to keep the pattern surface clean. In addition, it is difficult to detect defects where the surface has become blackened.

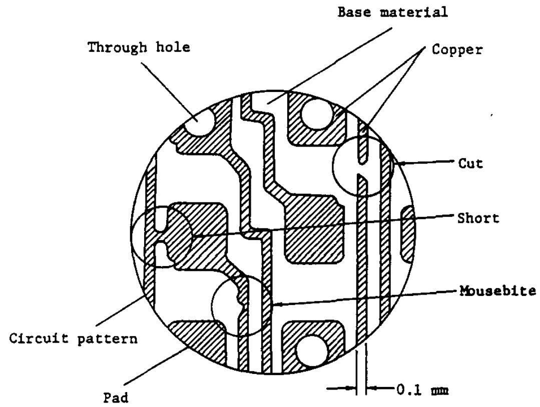

Fig. 1. Magnified image of printed circuit board pattern and defects.

Meanwhile, every year, printed circuit board patterns are being made finer and finer, making it necessary to detect very small defects with greater and greater reliability. In the present research, a method of consistently detecting faults in a printed circuit, the surface of which is easily damaged or blackened, has been developed. In this method, a circuit board is illuminated with violet or ultraviolet radiation from a super high-pressure mercury lamp, fluorescent light emitted from the base material is detected by a TV camera. The resulting silhouette image clearly shows the pattern. The pattern inspector which employs this method is also reported on here.

Recently a great number of printed circuit board pattern inspectors have been developed. These are made by the Optrotech company (Israel), the Orbot company [2] (also in Israel), and others [3]–[6]. All of these use reflected light detection systems. One that uses fluorescent light for pattern detection is made by the Lincoln Laser company (U.S.). This uses a helium–cadmium laser and scans the circuit board with laser light, then uses the fluorescent light that is emitted to detect the pattern. When a laser is used, depending on the type of base material it is sometimes impossible to select the optimum excitation wavelength, in which case the signal-to-noise ratio in the detection signal will be poor.[1] Also, this system has the drawback that the lifetime of a helium–cadmium laser is short.

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[1] *Circuit Manufacturing*, p. 24, June 1985.

II. Emission of Fluorescent Light by Printed Circuit Board

Illuminated by Excitation Radiation

Circuit boards used in electronic computers are so called multilayer circuit boards in which several to about 10 inner layer circuit boards, each consisting of a base material such as glass-epoxy or glass-polyimide about 0.1 mm thick with circuit patterns formed in this copper films several tens of μm thick on both sides, are stacked and connected together.

In pattern inspections, both the inner layers and the surface of multilayers must be inspected. In particular, the large number of inner layers makes it necessary to automate the inspection.

The circuit board base material is made by making sheets by weaving glass fibers together, then impregnating the sheets in, for example, epoxy. It is known that polymers such as epoxy have the property of emitting fluorescent light when excited by short wavelength radiation [7].

Fig. 2 shows the spectral characteristics of fluorescent light emitted by glass-epoxy, glass-polyimide, and etching resist which is used to form the copper patterns, when illuminated by radiation of wavelength 360–540 nm. In order to use fluorescent light for pattern detection, it is desirable that a large amount of fluorescent light be emitted and that the wavelengths of the excitation radiation and the fluorescent light be separated. For these reasons it can be seen that excitation radiation of wavelength about 360 nm is appropriate for glass-epoxy. Similarly, excitation radiation of wavelength about 488 nm is appropriate for glass-polyimide, and 540 nm for etching resist.

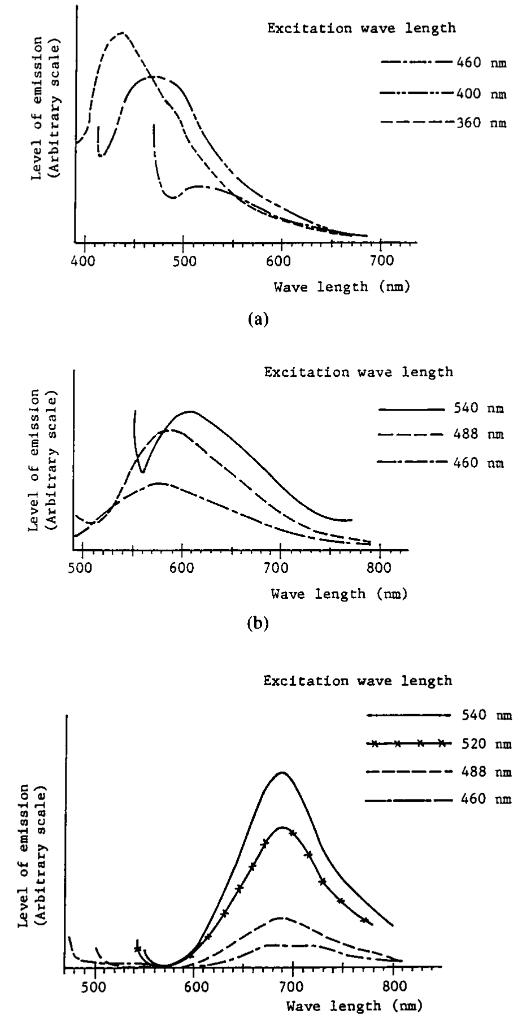

Fig. 2. Spectral distribution of emitted fluorescent light (Measured by Hitachi spectral photometer Model 850). Material: (a) glass epoxy (Hitachi chemical MCL-E-608), (b) glass polyimide (Hitachi chemical MCL-I-67), (c) etching resist (Du Pont Riston T-1220).

III. Pattern Detection Using Fluorescent Light

The principal problem in using fluorescent light for pattern detection is that the amount of fluorescent light emitted is small. In the present research we have attempted to detect patterns using the fluorescent light emitted by the base material itself, without adding fluorescent material to it.

An existing reflected light detection system and our fluorescent light detection system are shown in Fig. 3. In the case of a reflected light detection system, the circuit board is illuminated by a super high-pressure mercury lamp, and the reflected light is detected by a CCD linear image sensor. In fluorescent light detection, since the fluorescent light is weak a CCD sensor cannot be used. Therefore, an image tube type TV camera, which has higher sensitivity than a CCD sensor, is used.

Various types of filters are used in a fluorescent light detection system. This is to completely separate the excitation radiation from the fluorescent light and to obtain an adequate fluorescent light detection signal. The detection of fluorescent light emitted by a glass-polyimide base material will be discussed here as an example. As shown in Fig. 4(b), two exciter filters are used, both of which [filter (1) and filter (2)], are violet colored glass bandpass filters. These exciter filters remove wavelengths of 500 nm and below from the radiation emitted by the super high-pressure mercury lamp. Next, a dichroic mirror which reflects short wavelength radiation is used in place of a half mirror. It reflects nearly 100 percent of the excitation radiation and transmits nearly 100 percent of the fluorescent light to the detection element. A colored glass filter which is transparent to long wavelengths is used as the fluorescent light pass filter [Fig. 4(c)].

Different types of image tube type TV cameras have different spectral sensitivity characteristics [Fig. 4(d)]. A Saticon® has high resolution, and also low sensitivity in the infrared, so it can detect only the pattern shown by

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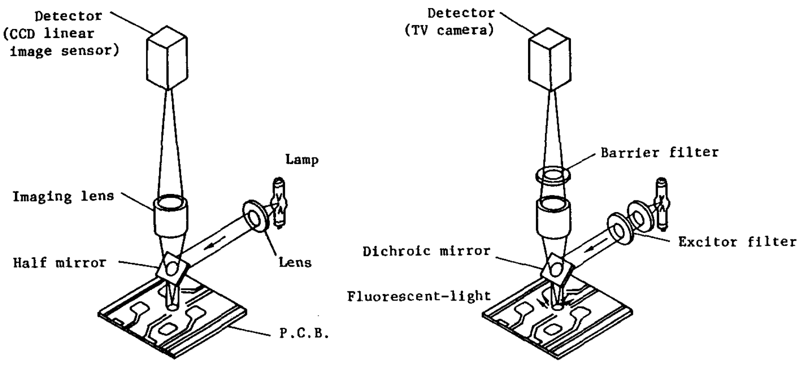


Fig. 3. Illustration of (a) reflected- and (b) fluorescent-light detection method for pattern detection.

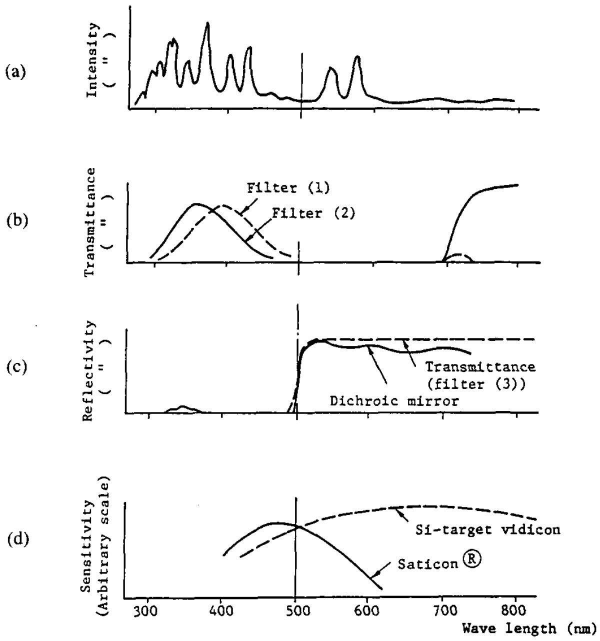


Fig. 4. Spectral characteristics of illumination lamp, optical elements, and TV cameras. (a) Spectral distribution of super high-pressure mercury lamp light. (b) Transmittance of excitor filter. (c) Reflectivity of dichroic mirror and transmittance of barrier filter. (d) Sensitivity of TV cameras.

(a) (b)

Fig. 5. Detected image of a short-circuit defect by reflected-/fluorescent-light detection methods. (a) Reflected-light image (combined bright-field and dark-field illumination [1]). (b) Flourescent-light image.

the fluorescent light without being affected by infrared radiation which passes through the excitation filters.

The patterns detected by reflected light and fluorescent light detection systems are shown in Fig. 5. Fig. 5(a) is gotten by a combination of bright-field and dark-field illumination used in the formerly developed inspector [1]. In Fig. 5(a) it is seen that sufficient contrast is not obtained to show a short circuit the surface of which has become blackened, but the silhouette image in Fig. 5(b), obtained with a fluorescent light detection system, shows it clearly. This detection system also reliably detects thin copper remnants. The differences between the detection signals obtained with the two detection systems are shown in Fig. 6. Fig. 6(a) shows the signal obtained with a reflected light system. Since the system is sensitive to small variations in the reflectivity of the surface of the pattern, the noise component in the detection signal is large. Fig. 6(b) shows the signal obtained with a fluorescent light detection system. Comparing it to Fig. 6(a), there is less noise, the signal is more stable, and the signal-to-noise ratio is improved from about 2 to about 10. The fluorescent light detection system makes it possible to obtain stable pattern detection, unaffected by the small details of the shape of the pattern surface.

Fig. 7 shows the modulation characteristics of detection signals obtained for patterns of different line widths. Comparing the modulation curve for gaps M_{gap}, with that for lines M_{line}, M_{gap} is smaller than M_{line}, remarkably for small lines. For this reason, a line-shaped defect (such as a short circuit) is easier to detect than a gap-type defect such as a cut. Since short circuits are the principal type of defect encountered on printed circuit boards, this characteristic is desirable. The reason the modulation drops in the case of a narrow gap is as follows. Since the base material is translucent, the excitation radiation incident on a narrow gap penetrates into the base material, and fluorescent light is emitted. Since only part of the fluorescent light that is emitted passes through the surface of the base material to the outside, the level of the fluorescent light that is detected is low. When the gap is wide, flu-

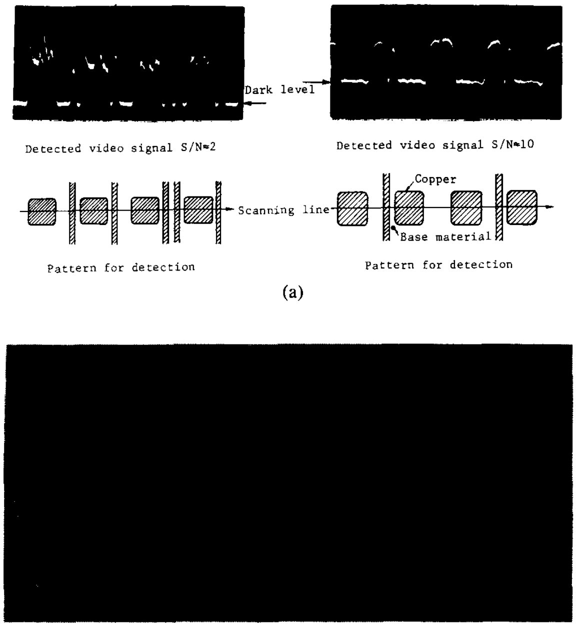


Fig. 6. Detected video signals, applied (a) reflected- and (b) fluorescent-light detection method.

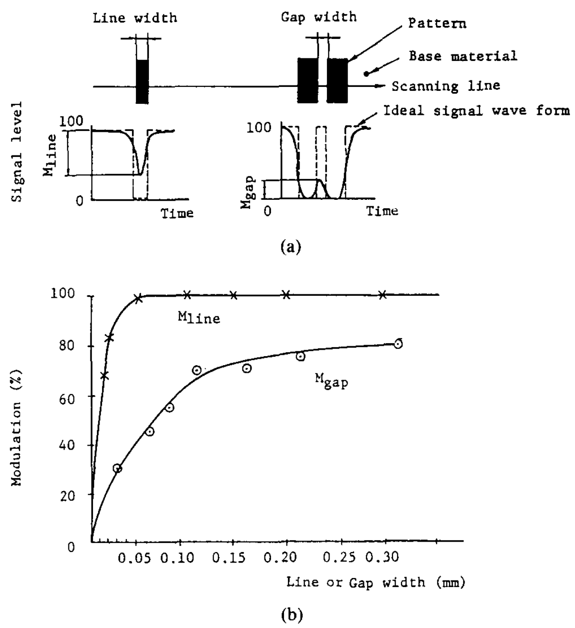


Fig. 7. Detected signal modulation for lines and gaps, measured by fluorescent-light detection method. (a) Detected signals and definition of M_{line} and M_{gap}. (b) Detected modulation.

orescent light emitted from different locations becomes superimposed so the fluorescent light detection level is high.

In order to overcome the lower modulation characteristics, floating thresholding method is introduced and is working effectively. The thresholding method is mentioned in Section IV-C.

The fluorescent light detection system can be used not only for copper patterns on glass–epoxy and glass–polyimide, but also for detecting solder patterns and etching resist patterns.

IV. PCB Pattern Inspection System

A. *The Inspection System*

A printed circuit board pattern inspector using a fluorescent light detection system has been developed.

Fig. 8 explains the principle of operation of the inspection system. Fluorescent light from the corresponding parts of two printed circuit patterns f, g is detected by a pair of TV cameras, and the images obtained are converted to electrical digital images and are compared each other. Differences between the two patterns f, g reveal defects. This is the same as the principle used in a reflected light inspection system. The defect detection algorithm is not so simple as to just judge any difference in the two patterns f, g to be a defect. Rather, as in shown in Fig. 9, the boundaries F_K, G_K and narrow sections F_B, G_B of the pattern are selected and compared. Details are mentioned in [1], [8], and [10]. This way, even if there is some deformation in the patterns or they are not in perfect registration, line-shaped defects which seriously affect circuit operation can be detected.

These image processing is all performed by pipelined real-time hard-wired logic circuits. The basic circuit system is shown Fig. 10 [1]. Features of image like boundaries F_K, G_K, etc. are extracted from temporary local image memories (b) in Fig. 10 by way of wired logic circuit operators H_{KY}, H_{KX} $\cdots$. An example of boundary extraction operator circuit H_{KY} is shown in the figure. Comparison of a pair of feature extracted patterns F_K, G_K, etc. are also performed by logic circuits wired to local image memories (c), which is shown in [10].

Table I gives a comparison of the characteristics of automatic inspectors using reflected light and fluorescent light detection systems. When a reflected light detection system is used, defects such as cuts can be detected, as shown in a–d, but copper remnants of which the surface is blackened are difficult to detect. Also, as shown in f–h, it is easy to obtain false alarms in which nondefects are mistaken for defects. The fluorescent light detection system essentially resolves these problems, with one exception. Defects in which the upper surface of the copper pattern is separated, as shown in *d*, cannot be detected. The reason for this is that the fluorescent light detection system detects the pattern as a silhouette image; surface separation defects do not appear as changes in the pattern that is detected.

One possible way to detect surface separation defects is to use both fluorescent and reflected light for pattern detection. The reflected light detection system detects the tilted part of the defect cross-section, which appears black.

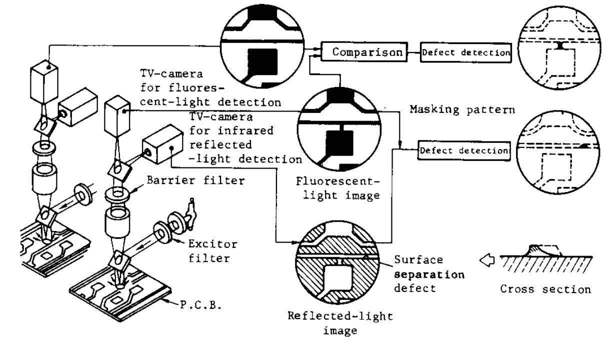


Fig. 8. Scheme of defect detection method for the PCB pattern inspection system.

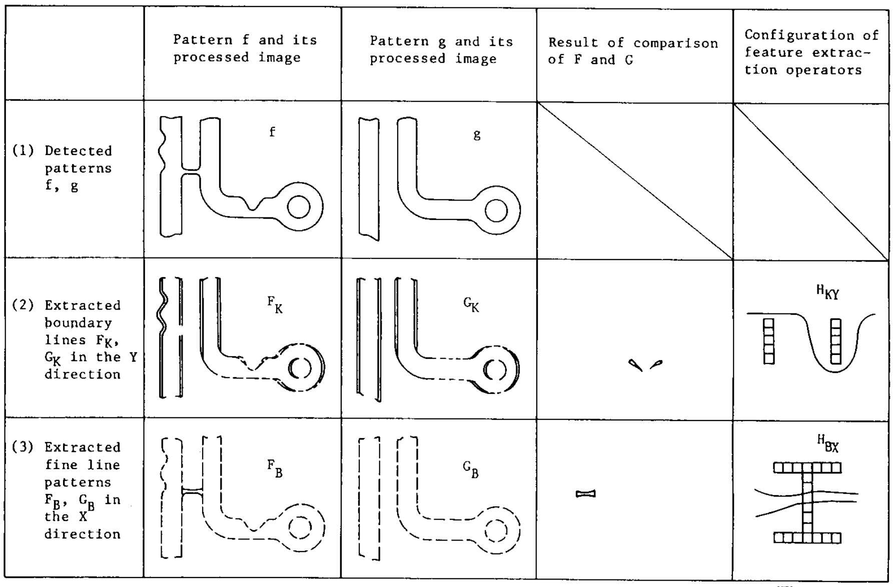


Fig. 9. Extraction of features and comparison of extracted feature patterns for defect detection.

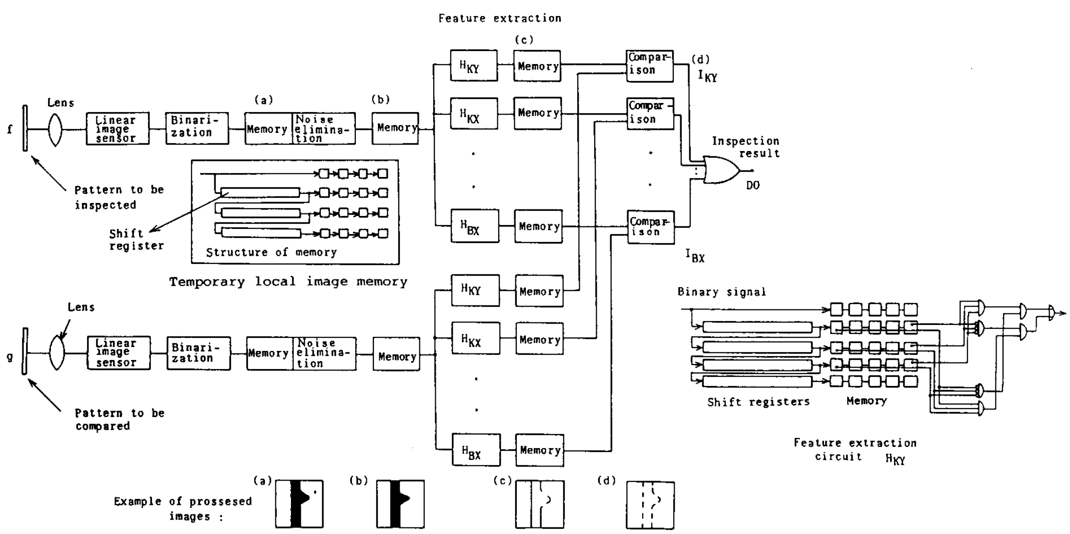
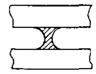
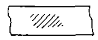
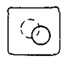


Fig. 10. Real-time hard-wired logic circuits for the defect detection system.

TABLE I
DEFECT DETECTION CHARACTERISTIC OF AUTOMATIC INSPECTOR WHEN REFLECTED LIGHT AND FLUORSCENT LIGHT ARE USED FOR DETECTION

		Category	Reflected light	Fluorescent light	Remarks
Defect	a	Cut	Detected	Detected	
	b	Short	Detected	Detected	
	c	Nick	Detected	Detected	
	d	Surface separation	Detected	Defect not detected	
	e	Blackened copper remnant	Defect not defected	Detected	
No defect	f	Discoloration	False alarm	No false alarm	
	g	Surface scratches	False alarm	"	
	h	Through-hole position shift	False alarm	"	

False alarm: The system erroneously indicates the existence of a defect although there is not any.

Fig. 8 shows a system for detecting surface separation defects which uses both reflected light and fluorescent light detection systems. Pattern detection using reflected light was done using the infrared TV camera (Silicon Vidicon) shown in Fig. 8. Infrared radiation of wavelengths 700 nm and longer which leaks out from the violet excitation filter [filter (1) and filter (2)] shown in Fig. 4(b) can be used for illumination. When a reflected light detection system is also used, it is desirable to avoid bringing its defects into the combined system as much as possible. With this in mind the following inspection system was conceived.

Fig. 11 shows the process of detecting a surface separation defect. Image j is the fluorescent light detection image. Image j is shrunk just enough so that the next wiring pattern disappears (image k). Then the image is enlarged to obtain image of only the pad. Meanwhile, image j is shrunk to produce a narrower wiring pattern (image m). Image n which shows only the wiring pattern can be obtained from image l and image m. The amount of shrink/expansion is set before inspection for each specific line pattern so that only wiring pattern can be extracted. Then the surface separation defect is detected as follows.

The light reflection rate on the wiring pattern in image i is monitored with image m. Places where the light reflection rate is low are judged to be defects (images o, p). This procedure prevents the false alarms shown in Table I g and h where light due to surface scratches and displacements of through-hole positions are misinterpreted as defects. It still sometimes happens that discoloration of the pattern surface is misinterpreted as a defect, but by using infrared illumination the false alarm rate can be minimized [8].

The image processing shown in Fig. 11 can also be performed by pipe-lined real-time hard-wired logic circuits. An example of shrinkage operation circuit is shown in Fig. 12. Expansion operator can be got by using OR logic, instead of AND logic in the figure.

By using a fluorescent light detection system together with a reflected light detection system as discussed above, success was achieved in detecting all types of defects. However, if the rate of defects could be reduced through improvements in the printed circuit board manufacturing process, it would not be necessary to use both detection systems together. This in turn would greatly simplify the system.

B. The Inspector

The automatic inspector consists of an XY-stage on which two printed circuit boards are placed and scanned in the X and Y directions, a pattern detection section (illumination sources, image lenses and TV cameras), a defect recognition signal processing section and a system control section. When patterns are inspected, it is stepwise-fed through the XY stage at a rate of about 5 mm/0.14 s, and the patterns are detected. A photograph of the XY-stage and detection section is shown in Fig. 13. Since this system compares two patterns, accurate registration of pattern positions is important. Before the inspection starts, position registration marks are detected and the patterns are prealigned. While the inspection is in progress, deviations from perfect registration are detected and the circuit boards are continuously kept in registration by slight motion of one in the X direction (ΔX) and of the other in the Y direction (ΔY). This fine adjustment permits the system to compensate for slight expansion or contraction of the circuit boards. By additionally shifting the stored images electrically, registration to an accuracy of one picture element (10 μm) can be obtained.[2]

Some printed circuit boards have many through-holes. Even in the case of such a circuit board, by opening many holes in the table surface and removing air with a blower, it was possible to apply enough suction to the circuit boards to maintain their flatness.

When a defect is detected, its position coordinates are stored on a floppy disk. In addition, the detected image and the defect image are displayed on a TV monitor in pseudocolors.

The printed circuit boards being inspected are then set in a separated defect confirmation unit. The table on which the circuit board lies in positioned in accordance with the defect position coordinates stored on the floppy disc, and the section including the defect is displayed on the TV monitor. An operator watches the TV monitor, confirms that there is a defect, and repairs it.

The system specifications are given in Table II. The automatic inspector can detect a line-shaped defect of width 10 μm. The time required for inspection is 18 minutes for a printed circuit measuring 500 × 600 mm, when picture element size is 10 μm.

[2] Y. Hara *et al.*, "Study of automating inspection of aluminium circuit pattern of LSI wafers." *Electron. and Telecommun. in Japan Part 2*, vol. 70, no. 3, pp. 46-58, 1987.

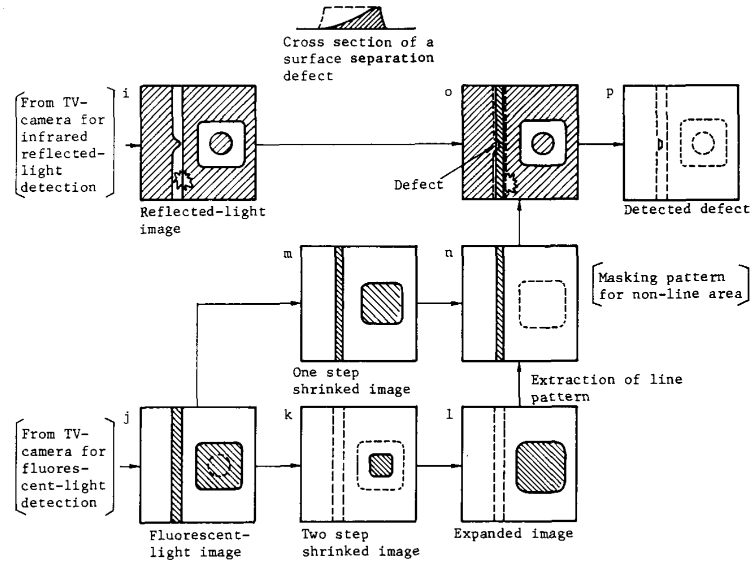


Fig. 11. Detection method for a surface separation defect.

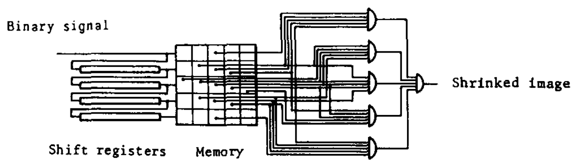


Fig. 12. Shrinkage of logical "1" portion.

Fig. 13. Photograph of the PCB pattern inspection system, applied fluorescent-light detection method.

TABLE II
PERFORMANCE SPECIFICATIONS OF THE AUTOMATIC INSPECTOR

Item	Specification
Width of pattern to be inspected	0.08 mm or more, when picture element size is 0.01 mm
Minimum detectable defect	Detection of line defect of width 0.01 mm or more is possible
Inspection time Position register accuracy	18 minutes for 500 x 600 mm area ±0.04 mm (mechanically) ±0.01 mm (electrically)
Holding of circuit boards	Blower suction
Defect information storage	Data are transferred to defect confirmation unit and stored on floppy disc.
Display	The pattern and defect image are stored, and displayed on a TV monitor (patterns in blue and green; defects in red)

C. Results of Defect Detection Experiment

In order to test the system's ability to detect defects, aritificial defects were created and the circuit board then inspected. The results are shown in Fig. 14. This illustrates the probability of defect detection, when the system tried ten times inspection of the same defects with different sizes. The artificial defects shown in Fig. 14(a)–(f) are line-shaped, square-shaped, nicks, and mousebites.

In the case of copper line pattern (a), irregularities 10 μm or more in width were regarded as defects. Linear defects include short circuits, so it is particularly important that the detection system be highly sensitive to them. In the case of copper square pattern (c), irregularities 20 μm or larger were regarded as defects. This system has the capability of removing isolated pattern up to 60 μm as noise; the data shown here are for the case when this noise-removal capability is suppressed. For the nick copper patter (e), irregularities 50 μm and larger were regarded as defects; Deformations on the pattern boundary have little effect on the circuit, so the detection threshold can be set somewhat larger for the defects.

In the case of gap pattern (b), irregularities 20 μm and larger were regarded as defects; Since the degree of modulation of a detection signal is lower for a gap pattern that for a line pattern (Fig. 7), this result was obtained. For a pinhole pattern (d) irregularities 30 μm and larger, and for a mousebite pattern irregularities 50 μm and larger, were regarded as defects.

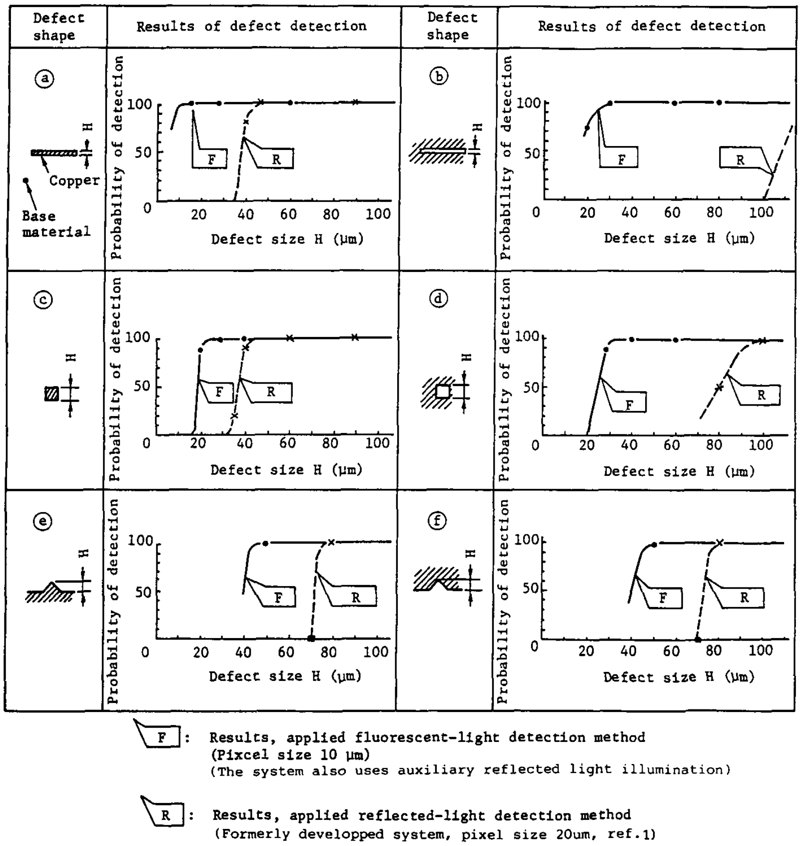
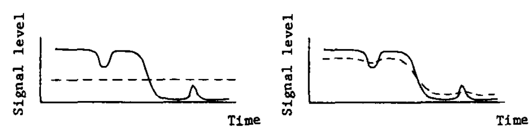


Fig. 14. Results of artificially formed defect detection.

In Fig. 14 the result of reflected light (bright-field plus dark-field illumination) is also shown. The result is obtained by the formerly developed reflected-light inspector [1]. The new fluorescent-light inspector detects finer defects than the reflected-light inspector. This is due to difference in thresholding method and in pixel size (10 μm and 20 μm, respectively) and in signal contrast.

The formerly developed inspector uses fixed thresholding method, which misses binarization of low modulation signals. The new inspector uses floating thresholding method which enables binarization of low modulation signals. These thresholding methods are shown in Fig. 15 [9].

In the results that were actually applied to inspection of printed circuit boards, it became clear that the inspection not only resulted in circuit boards being passed or failed, but also that the inspection is very effective for process monitoring to control the quality level of the manufacturing process. Essentially 100 percent of defects were detected, that is proven by comparing the inspection result with that of electric testing, while false alarms are kept approximately 5 points per 500 $\times$ 600 mm PC board. False alarms are mostly attributed to the existence of foreign particles; our system showed higher capability than any comparable inspection system in existence. However, defects resulting from photomask defects could not be detected. This is because this system compares patterns on actual circuit boards. To detect defects resulting from photomask defects it would be necessary to compare patterns made from different photomasks.



(a) (b)

Fig. 15. Thresholding methods. (a) Fixed thresholding. (b) Floating thresholding.

The system was developed in order to inspect the company's produced PC board, however, it has been proven it can inspect open market PC boards without too careful change of filters.

By introducing this system, it will be possible to do inspections in 18 minutes that formerly required 10 hours or more for a human worker using an enlargement projector (and even then could not be done to perfection). This system can be considered indispensable and highly reliable for the manufacture of high-density printed circuit boards. Future development work will concentrate on increasing the speed.

VI. Conclusions

Research was performed on automatic detection of printed circuit board defects with high accuracy, and the following results were obtained.

1) In order to consistently detect defects of copper patterns, which are easily damaged and discolored on the surface, a method was investigated in which the circuit board is illuminated with short wavelength radiation (violet, ultraviolet) and the fluorescent light emitted by the circuit board base material (glass-epoxy, glass-polyimide, etc.) is used for detection.

2) When radiation from a super high-pressure mercury lamp was passed through filters which passed wavelengths of 300-500 nm and then used to illuminate a glass-polyimide circuit board, yellow fluorescent light of wavelength about 580 nm was emitted. This was separated from the excitation radiation by a filter and detected by a TV camera, producing a clear silhouette image in which the base material was bright and the pattern was dark. With this method it is also possible to detect thin copper remnant defects.

3) An automatic printed circuit board pattern inspector in which fluorescent light is used for pattern detection was developed. This system compares corresponding positions of two printed circuit patterns. The system has the capability to set and keep the two detected pattern images accurately in registration, and can detect line defects down to a minimum width of 10 μm. The inspection time is 18 minutes for a printed circuit covering an area of 500 $\times$ 600 mm (the same inspection done visually requires 10 hours or more).

4) As a result of test operation in the plant, it was found that this system is effective for inspecting a high-density printed circuit board pattern for defects. It saves labor, preserves the reliability of printed circuits, and provides valuable information about the manufacturing process.

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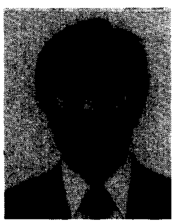
Yasuhiko Hara was born on May 15, 1945 in Shizuoka Prefecture, Japan. He received the B.S. degree in physics from Tokyo Science University in 1968, the M.S. degree in physics from Tokyo Institute of Technology in 1970, and the Ph.D. degree in instrument engineering from the University of Tokyo in 1985. His dissertation research was concerned with automation of visual inspection of circuit patterns, like LSI photomasks, LSI wafers, and printed circuit board patterns.

In 1970 he joined Hitachi, Ltd., where he has been engaged in research of sensing and image processing technology for developing machine visions for automated production at the Production Engineering Research Laboratory (PERL), Hitachi, Ltd., Yokohama, Kanagawa Prefecture, Japan. From 1974 to 1975, he was a Visiting Researcher at the Institute of Industrial Science, University of Tokyo, and from 1975 to 1976 he was with Carnegie-Mellon University, Pittsburgh, PA, to study image processing technology. He is now a Senior Researcher at the PERL, Hitachi, Ltd.

Dr. Hara is an editor of the *Journal of the Japan Society of Precision Engineering*. He is a member of the Japan Society of Applied Physics and the Institute of Electronics, Information and Communication Engineers of Japan. He received the Kanagawa Prefecture Governor's Award in 1986 for inventing a precision alignment method for semiconductor aligners.



Hideaki Doi was born on August 16, 1957 in Tokyo, Japan. He received the B.E. and M.E. degrees in electrical engineering from Waseda University in 1980 and 1982, respectively. He studied electrical conductivities of insulating materials, such as polyethylene, polystyrene or other high-molecular polymers, for three years at Waseda University.

He joined Hitachi, Ltd. in April 1982. Since then he has been a Research Member of the Technical Staff at the Production Engineering Research Laboratory (PERL), Hitachi, Ltd. in Yokohama, Kanagawa Prefecture, Japan. For the first two years, he was one of the research members engaged in the research and development of an automated photomask inspection system. From 1983 to 1986, he developed an automated inspection system for defects on thin layers on magnetic bubble memory substrates. Since 1984, he has been engaged in the research and development of automated visual inspection systems for printed circuit boards. He has had deep ties with pattern recognition and image processing through his works in Hitachi, Ltd. He plans to continue researching artificial intelligence technology, computer science, and image acquisition systems as well as the research fields above. He is now a Researcher at the PERL, Hitachi, Ltd.

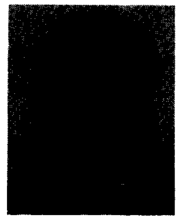
Mr. Doi is a member of the Institute of Electronics, Information and Communication Engineers of Japan.

Koichi Karasaki was born on May 29, 1947 in Osaka, Japan. He received the B.E. degree in metallurgy from the University of Osaka in 1971.

In 1971, he joined Hitachi, Ltd. From 1971 to 1977, he engaged in improvement of chemical process for manufacturing high-density printed circuit board for computers. From 1978 he has been engaged in development of automated inspection systems for PCB manufacturing processes, as his experience motivated him the need of quantitative data for quality control of PCB's.

He has developed inspection systems for PCB's, photomasks, and green sheets in cooperation with the Production Engineering Research Laboratory, Hitachi, Ltd. He is presently a senior engineer at Kanagawa Works, Hitachi, Ltd.

Mr. Karasaki is a member of the Institute of Electronics, Information and Communication Engineers of Japan and the Japan Institute of Printed Circuit. In 1986, he received an award from the Japan Institute of Invention and Innovation for inventing a high contrast illumination system for PCB pattern image acquisition.



Tadashi Iida was born on October 4, 1960 in Niigata Prefecture, Japan. He received the B.S. degree in chemistry from Sophia University, Tokyo, in 1983.

In 1983, he joined Hitachi, Ltd. From 1983 to 1986, he engaged in development of automated inspection systems for PCB's in cooperation with the Production Engineering Research Laboratory and Naka Works, Hitachi, Ltd. He is now working on development of new technology to form finer patterns on PCB's. He is presently an engineer at Kanagawa Works, Hitachi, Ltd.