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FACTORS AFFECTING VISUAL INSPECTION
OF THIN FILM NETWORKS

Topical Report

R. E. Hines, Project Leader

Project Team:
C. W. Berry

Published January 1978

Prepared for the United States Department of Energy
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FACTORS AFFECTING VISUAL INSPECTION OF THIN FILM NETWORKS

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Prepared by R. E. Hines, D/142

A study was made of various factors that affect the visual inspection of thin film networks. The effect of various types of reflected illumination, the effect of defect size or shape, the time required for inspection, and the inspection uniformity were evaluated. The use of polarized light is recommended for the visual inspection of thin film networks.

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SUMMARY

Utilizing Quality engineers to simulate visual inspectors, an investigation was made of various factors that affect the capability of an inspector to visually inspect thin film networks (TFNs). The factors that were examined were those that will be important to the inspection of future TFNs at Bendix Kansas City: the effect of various types of reflected illumination; the effect of defect size or shape; the time required for inspection; and the uniformity of the inspection operation.

Polarized light was shown to provide a significant improvement over standard illumination by increasing the visibility of certain defects, especially voids in resistors. In this study, 83 percent of all defects were detected when polarized light was used, while only 51 percent were detected under standard illumination. Several of the inspection microscopes have been equipped with polarized-light adapters; others will be similarly equipped as the need arises. Indications are that some critical defects, mostly hairline-type voids, occasionally will be missed because of their shape or small minor dimension.

From the results of this investigation, the estimate has been made that from four to five minutes will be required to visually inspect most TFNs, excluding vias. Other results of the study indicate that overall inspection uniformity will be influenced more by variations among different inspectors than by variations in the work of a single inspector. This will be of importance in the future when production quantities require the use of multiple inspectors to perform the same visual-inspection task.

DISCUSSION

SCOPE AND PURPOSE

Automatic HMC Visual Inspection has the objective of automating as much of the hybrid-microcircuit (HMC) and thin-film-network (TFN) visual-inspection task as possible. This could range from automating merely such time-consuming housekeeping tasks as device positioning to automating the entire defect detection and classification operation. Effort under this project has been concerned with investigating and assessing the capability of various combinations of human, mechanized, and automated visual inspection systems.

This report describes a study that was made of a group of Quality engineers working with a minimum of mechanical aids to visually inspect TFNs similar to those which Bendix Kansas City will produce in the future.

PRIOR WORK

Visual-inspection studies have been reported by several investigators.^{1,2} A previous Bendix project developed some techniques which were useful in the inspection of printed circuit boards and hybrid microcircuits.³

ACTIVITY

An experiment was conducted to determine the approximate capability of inspectors to visually detect defects on TFNs when restricted to the use of reflected illumination only. This experiment had the following three objectives:

- To provide information for comparison with data obtained from various automated inspection systems;
- To determine whether certain defects are difficult for the inspector to visually detect because of their size, shape, location, or illumination; and
- To determine what techniques might be employed to improve the inspector's ability to detect visual defects.

Experimental Method

Five members of the Advanced Inspection Engineering Department were used to simulate visual inspectors. These people ranged in ability from some having only minor visual-inspection experience

or acquaintance with the type of defects to be found on TFNs to others who had acquired some measure of experience through previous engineering projects. Although trained visual inspectors were not used in the experiment, their capability was thought to be reasonably well indicated by the results obtained from the more experienced subjects.

Several TFNs were carefully searched for visual defects and were used as samples during the experiment. The types of critical defects on these samples included resistor voids, bridged paths, excess material between paths, damaged lead-frame pads, and contamination.

The inspection equipment used in the investigation simulated that which is being utilized in the Bendix TFN inspection area, except that backlighting was prohibited since it cannot be used for the inspection of future TFNs having backplane metallization. A Bausch and Lomb stereo-zoom microscope was used with an average magnification of 15X, although the inspector was permitted the discretion of varying the magnification from 7 to 30X. A standard Bausch and Lomb illuminator was provided which could be used at any angle or direction desired. In addition, a separate polarized-light illuminator was provided (Figure 1).

During previous investigations of various types of reflected illumination for automatic image analysis, polarized light was found to improve the contrast ratios among gold, tantalum, and ceramic materials. Therefore, polarized light was investigated to determine whether it might improve the visibility of certain types of TFN defects for the visual inspector.

The method that was used consisted of first placing a certain area (subview) of a TFN (7.62 by 7.62 mm, or 0.3 by 0.3 inch) within the field-of-view of the microscope under the standard illuminator. The inspector was given approximately 45 seconds to report any critical or marginal defects that were observed. The polarized illuminator then was switched on in place of the standard illuminator, and the inspector was asked to determine whether the previously detected defects were still visible and whether any other defects could then be observed. This method was repeated for 13 different areas on several circuits. Two of these views were repetitions of previous views, thus providing an indication of inspection repeatability for the individual inspector.

The experimental method and analysis that were used are similar to the Inspection Job Sample Technique described by other investigators.¹ The results of the investigation are summarized in Tables 1 and 2 with respect to illumination, defect size, and defect shape.

Figure 1. Microscope and Illuminator With Polarized-Light Adapters

Effect of Illumination

Illumination with polarized light greatly improved the visibility of voids in resistors (Table 2) by canceling some of the bright specular reflections and improving the tantalum-to-ceramic contrast. Many of these voids were not observed under standard illumination.

One very critical hairline-type resistor void (Figure 2) was missed a total of ten times out of ten chances (two chances for each of five inspectors) under standard illumination; however, it was rapidly detected each time that polarized light was used. The

Table 1. Data-Collection Matrix for Defects Detected and Missed

Defect	Standard Light, With Inspector Indicated					Polarized Light, With Inspector Indicated				
	1	2	3	4	5	1	2	3	4	5
Resistor Pinhole Void	-*	X**	-	-	-	X	X	X	X	X
Resistor Pinhole Void (Large)	X	X	-	X	X	X	X	X	X	X
Resistor Pinhole Void	-	X	-	-	-	X	X	X	X	X
Resistor Crack Void (Small)	-	-	-	-	-	-	-	-	-	-
Resistor Crack Void	-	-	-	-	-	X	X	X	X	X
Resistor Crack Void (Preceding View Repeated)	-	-	-	-	-	X	X	X	X	X
Conductor Void	X	X	X	X	X	X	X	X	X	X
Conductor Void	X	X	X	X	X	X	X	X	X	X
Excess Material	-	X	-	-	X	X	X	-	-	X
Conductor Short (Large, Camouflaged)	X	-	-	-	X	X	-	-	X	X
Conductor Short (Preceding View Repeated)	X	-	-	-	X	X	-	X	-	X
Gold on Resistor (Small)	-	-	-	-	-	X	X	-	X	X
Gold on Resistor	X	X	X	X	X	X	X	X	X	X
Lead-Frame Damage	X	X	X	-	-	X	X	X	-	-
Bad Laser Cut Through Resistor	X	X	X	X	X	X	X	X	X	X

Table 1 Continued. Data-Collection Matrix for Defects Detected and Missed

Defect	Standard Light, With Inspector Indicated					Polarized Light, With Inspector Indicated				
	1	2	3	4	5	1	2	3	4	5
Contamination (Five Locations)	4	4	2	2	4	4	5	3	5	5
Total Defects Detected	12	13	7	7	12	18	17	14	16	18
Percentage Detected	60	65	35	35	60	90	85	70	80	90
Overall Percentage Detected	51					83				
*Defect missed:-										
**Defect detected:X (or numeral)										

Table 2. Percentage of Defects Detected Within Each Defect Category

Defect Category	Standard Light (Percent)	Polarized Light (Percent)
Resistor Pinhole Voids	40	100
Resistor Crack Voids	0	67
Conductor Voids	100	100
Excess Material	40	60
Conductor Short (Camouflaged)	40	60
Gold on Resistor	50	90
Lead-Frame Damage	60	60
Bad Laser Cut	100	100
Contamination	64	88
Total	51	83

view presented under standard lighting (Figure 2A) shows the resistor void to appear very low in contrast and to be completely obscured by glare. Backlighting (Figure 2C) would be the ideal method for detecting this type of defect, but the opaque backplane metallization on future TFNs will prohibit its use. Polarized illumination (Figure 2B) made the resistor void appear almost as visible as did backlighting, while preserving the usefulness of reflected light in showing conductor scratches and the colors of the elements of the TFN.

The visibility of small pinhole voids in resistors also was improved by the use of polarized light (Figure 3). Only one inspector detected these voids under standard illumination; all five readily detected them under polarized light.

Some resistors have irregular edge definition and appear with backlighting (Figure 4C) to be nonuniform in thickness. These characteristics are not visible under standard illumination (Figure 4A), but they are quite distinct with polarized light (Figure 4B).

Gold on tantalum, small hairline resistor voids, large resistor voids, and contamination with foreign material are all visible with polarized light (Figure 5). Neither standard illumination

Text continued on page 16.

Figure 2. Hairline-Type Resistor Void Under Various Conditions of Illumination

Figure 3. Pinhole Resistor Voids Under Various Conditions of Illumination

Figure 4. Irregular Edge Definition and Nonuniform Thickness of Resistors Under Various Conditions of Illumination

Figure 5. Hairline Resistor Void (Arrow), Large Resistor Void, Gold on Tantalum, and Foreign Material Under Various Conditions of Illumination

nor backlighting provides sufficient contrast for the inspector to adequately characterize all of these defects.

Excess tantalum which bridged more than half of the space between adjacent conductor paths (Figure 6) was detected by only two inspectors using standard illumination, while three people detected it with polarized light. The remaining inspectors, less experienced than the others, either overlooked the defect or failed to classify it as critical. However, after this defect had been called to their attention, all agreed that it was significantly more visible under polarized illumination.

No single type of illumination has proven to be ideal for detecting conductor scratches (Figure 7). Because of their excessive specular reflectance, scratches usually can be easily detected, but they are difficult to classify because of the difficulty in discerning whether tantalum or ceramic is exposed by the scratch. Occasionally, a scratch will cause material to be smeared from one path to another, thus creating a potential short circuit. This condition can be easily seen with polarized light.

Standard illumination and polarized light are about equally effective for inspecting conductor paths; however, polarized light seems to present a more pleasing view that is less tiring to the eye. The conductor defects shown in Figure 8A were readily detected by all five inspectors under both types of illumination; however, most thought that polarized light presented a more discernible view.

Gross defects, such as nonmetallic foreign material between circuit paths (Figure 8B) or large areas of gold on tantalum (Figure 8C), also can be readily detected under either type of illumination. Polarized light, however, seems to provide a more distinct view of the laser trim path in resistors (Figure 8A and C).

Effect of Defect Size

Some defects are difficult to detect when their minor dimension is less than approximately 0.0127 mm (0.0005 inch)--assuming that the technique and equipment used in this experiment are employed--especially under standard illumination. The hairline void at the end of the narrow resistor in Figure 5 (indicated by the arrow in View B) is such an example. Although it almost completely interrupts the resistor, it was not detected under standard illumination by any of the five inspectors. Even with the use of polarized light, only two of the five reported the defect.

Other defects that are difficult to detect include very thin bridges of tantalum between circuit paths; these are caused by either unetched material or smearing. Thin gold bridges are slightly

Figure 6. Bridging Tantalum Under Standard Illumination and Polarized Light

Figure 7. Conductor Scratches Under Standard Illumination and Polarized Light

Figure 8. Various Defects Under Polarized Light and Standard Illumination

easier to detect, although the narrow bridge shown in Figure 8D was reported by approximately only half of the inspectors.

Effect of Defect Shape

A previous hypothesis had been that a primary technique used by visual inspectors for the detection of defects consisted of looking for artifacts possessing shapes that should not occur on an acceptable product. For TFNs in which all pathwork is 0.127 mm (0.005 inch) or greater in width with straight edges and right-angle bends, artifacts having irregular or oblique edges pinpoint possible defects which the inspector soon becomes reasonably efficient in detecting. However, when the inspectors were asked to view an area which, at first glance, appeared to be a normal part of the circuit, only two of the five people reported it as a defect. As shown in Figure 8D, this gross defect was almost as wide as a normal path and had rather straight edges.

Although not tested in this experiment, a defect which consisted of missing pathwork with straight, regular edges at the break might also prove difficult to detect. However, the occurrence of this type of defect is probably rare.

Required Inspection Time

This study provided several indications of the time that is required to visually inspect a 25.4- by 25.4-mm (1- by 1-inch) TFN. One of the more experienced inspectors was provided with four TFNs and was instructed to inspect each under first standard illumination and then polarized light. He also was instructed to take as much time as he felt necessary to adequately inspect the part. The results of this inspection are shown in Table 3.

A second inspector also took approximately four minutes to inspect a single TFN. Four minutes therefore appears to be the approximate average time that an inspector will take to visually inspect a somewhat complex TFN when he is allowed to take as much time as desired. Conceivably, comparable inspection accuracy could be achieved if the inspector were paced through the inspection in less time.

The following two aspects of this experiment should be noted since they might tend to decrease the indicated inspection time from the amount of time that would be required in a normal production situation: (1) no vias (plated-through holes) were visually inspected; and (2) the test consumed less than one hour--the pace indicated might be impossible to sustain for an entire eight-hour shift.

Another indication of the required inspection time can be obtained by scaling the time allowed to inspect a single subview, as

Table 3. Time Required by One Inspector to Visually Inspect Four TFNs

Type of Illumination	Average Time (Minutes)	Time Range (Minutes)	Comments
Standard	4	3-1/2 to 5	Failed to detect a broken conductor and several resistor voids.
Polarized	4	2-1/2 to 5	

previously described in this report. This time allowed was 45 seconds per subview and, in some cases, defects were not detected even though they were clearly visible. Since from 9 to 16 of these subviews would be required to cover a full TFN, the inspection time required would total 7 to 12 minutes.

From the results of this study, most defects should be detected within four minutes if the inspector is provided with appropriate equipment and illumination to make the defects visible. Quite possibly, however, some defects will not be detected, even if two to three times as much inspection time is allowed.

Inspection Uniformity

Visual inspection tends to be an inherently subjective task which usually must be made as objective as possible. Two basic operations are required to perform most visual inspections for specific defects: (1) the inspector must have sufficient sensitivity to detect or recognize potential defects, and (2) he must then judge whether the recognized condition meets the criteria of an actual defect and, if so, report it as such. When several inspectors are performing the same visual-inspection task, the uniformity of the inspection is dependent upon at least two variables: (1) whether the individual inspector always applies the same sensitivity and criteria to each unit that is inspected, and (2) whether all members of the group of inspectors apply the same sensitivity and criteria.

This investigation made only a small attempt to measure the repeatability of the individual inspector. Unknown to the five inspectors, two different subviews of the TFNs were presented to each of them a second time (Table 1). In eight of the ten presentations using polarized light, the inspection results were repeated. However, because this small sample size utilized only

a few specific defects, it may not be indicative of the general detection repeatability for all defects.

Some information can be obtained from Table 1 concerning the detection uniformity of a group of inspectors performing the same inspection operation. Neglecting the contamination category, there were 15 specific defects that should have been detected. With the use of standard illumination, all five inspectors reported identical results on seven occasions (four, all defects detected, and three, all defects missed) for a uniformity of 47 percent. With polarized illumination, all five reported identical results on ten occasions (nine, all detected, and one, all missed) for a uniformity of 67 percent.

These results indicate that a significant amount of overall visual-inspection nonuniformity can be expected when a group of inspectors having varying levels of experience are employed. This is especially true when the inspection tools are only marginally able to show the defects of interest. These results are similar to those which have been reported by other investigators.²

ACCOMPLISHMENTS

Some of the factors which affect the visual inspection of TFNs were investigated. Emphasis was placed on the following factors that will be of importance in the inspection of TFNs on future programs:

- Reflected illumination must be used, since the use of a TFN backplane will prohibit the use of transmitted light; and
- Increased quantities of TFNs will require the use of additional inspectors working as fast as possible without sacrificing accuracy.

The following conclusions, accomplishments, and recommendations are offered as a result of this investigation.

- Polarized light provides a significant improvement over standard illumination in inspection accuracy, especially for the detection of resistor voids (83 percent versus 51 percent).
- Several of the microscopes in the HMC inspection areas have been supplied with polarized-light adapters; more will be supplied in the future, as needed.

- Polarized-light adapters which were provided to the TFN manufacturing department were found to significantly improve the examination of laser trimming and resistor-deposition uniformity.
- An estimated savings of \$2,000 per month in scrap costs will be achieved through the use of the recommended polarized illumination (based on conservative estimates of production schedules, defect-rate history for resistor voids and conductor shorts, and scrap value).
- Some critical defects may not be detected because of their shape or small minor dimension.
- Indications are that an inspector will take approximately four minutes to visually inspect a nondefective TFN (excluding via inspection and the keeping of necessary records) when not being paced or assisted with a positioning device.
- Test results indicate that inspection uniformity will be influenced more by variations among different inspectors than by variations in the work of a single inspector. This will be of importance in the future when multiple inspectors are required to perform the same visual-inspection task.

FUTURE WORK

Future effort will be devoted to the development of several techniques to assist in the visual inspection of HMCs. Methods of improving inspection accuracy, speed, and uniformity are being investigated. The application of visual scanners and computers to make visual inspection totally automatic is also being investigated.

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SPECIAL PROJECTS: Microcircuit Visual Inspection

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