



IN-PROCESS VERIFICATION OF MLC SUBSTRATES

Jens Müller, Johann Klein

Micro Systems Engineering GmbH
D-95180 Berg/Germany
Phone ++49 (0)9293 78 64

jmueller@mse.biotronik-erlangen.de, klein@mse.biotronik-erlangen.de

Joe Rayho

MIDAS Vision Systems, Inc.
77 Green Street
Foxboro, Mass. USA

jrayho@midasvision.com

Abstract

Circuit features on multi-layered ceramic (MLC) substrates used in microwave applications, such as wireless handheld devices, are decreasing in size and pose significant challenges to manufacturers. Features of 50-micron lines and spaces on MLC substrates are now common and the circuits on the substrates are more complex. These trends towards miniaturization and circuit density emphasize the changing requirements of the verification and monitoring of registration tolerances throughout the manufacturing process. To effectively manage yields, manufacturers must verify that punching and printing is consistent and uniform while maintaining careful process controls to avoid substrate shrinkage and print screen stretch. The common method of visual inspection cannot achieve the precision or consistency that is necessary to assure the precise registration of dense multi-layer circuitry. Automated Optical Inspection (AOI) addresses the shortcomings of visual inspection and provides additional process improvements. This method of inspection verifies print integrity against a digitized standard, confirms print registration and detects common print defects such as voids, shorts, mouse bites, and other print process defects. Employing AOI during critical stages of the manufacturing proves to be instrumental in providing critical feedback necessary to correct in-process errors. This feedback is essential for manufacturers specializing in shorter production runs that must identify and understand process abnormalities immediately.

1. Introduction

Multi-layered ceramic (MLC) is being used for high-density circuits with stringent electrical and thermal performance requirements. The outstanding properties of ceramic circuits up to microwave frequencies and their ability to integrate passive components make them suitable for a variety of commercial applications. Additionally, MLC offers a cost effective alternative to standard technologies used to manufacture microwave circuits. Screen-printing and a parallel process flow for the layer fabrication are major advantages to obtain low costs and high product yields.

During manufacturing, each layer passes through three inspections performed by an Automated Optical Inspection (AOI) system. The initial inspection occurs after the punching of vias. A subsequent inspection occurs

after the vias are filled with a metallic paste. During each of these inspections, the system confirms both via registration and dimensional tolerances. Another inspection detects common printing errors or faults, as well as registration errors of printed features with respect to the punched and filled vias. Print defects can be either repaired immediately after inspection or the defect data can be stored for statistical process control and analysis.

2. Requirements for RF-circuits

RF and microwave component design constraints include shape, dimensions, and electrical properties of the materials used. The tape and paste materials determine the electrical properties of a circuit. Variations of material permittivity, tape thickness, and printing tolerances of the circuit features can adversely affect the electrical performance. Fortunately, tape manufacturers have the

material permittivity well under control. Tape thickness may vary to a small degree from lot to lot and can be easily verified by inspecting incoming material. However, MLC circuit manufacturers need to control the structural tolerances.

Printing accuracy and stacking alignment of multi-layer components define these structural tolerances. Fig. 1 shows a detail of a microwave circuit used for LMDS (Local Multipoint Distribution System) applications [1]. The accuracy of line width is important for impedance matching of all ports. Deviations in line width can cause changes in the working frequency and conversion losses—thus reducing the signal-to-noise ratio. The shape and quality of the flip chip bonding pads in the center must be tightly controlled to avoid signal reflections.

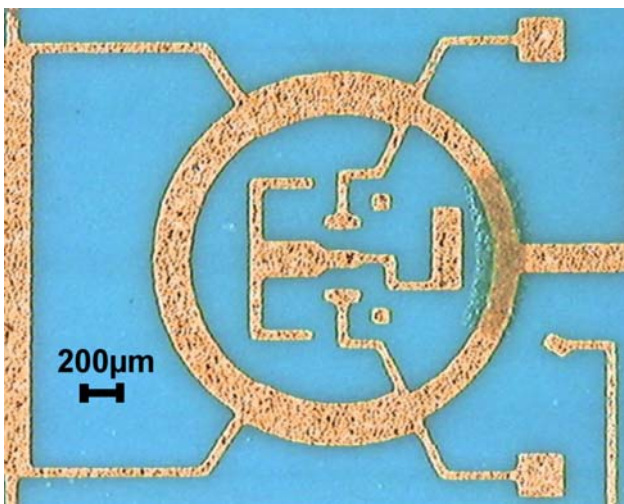


Fig. 1: Printed mixer structure with 50 μm lines

Layer to layer alignment is crucial for multi-layer components like 3D-inductors or multi-layer capacitors (Fig. 2). The stacking operation itself or distortion (from mishandling) within a single layer can cause improper alignment. Manufacturers can use optical alignment methods to optimize the stacking process and eliminate the need for inspection. However, a human inspector cannot detect stretched tape. This critical inspection is only possible by using an AOI system that inspects both the fidelity of the structures and their defined location on the layer.

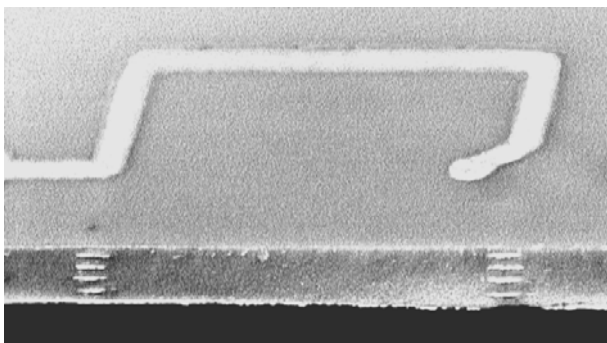


Fig. 2: Cross sectional view of a multi-layer inductor

Excess material on the tape like conductor paste splatter is another factor that can limit the circuit performance. This type of defect would not affect digital or dc-applications as long as bridging did not occur; however, it may disturb wave propagation in microwave applications.

In addition to these dimensional and positional requirements, the following screen-printing defects should be detected as well:

- opens (conductor, under-filled via, missing or clogged via)
- shorts
- mousebites
- smears (vias, conductors, resistors).

3. Need for Inspection

Each layer of a complex multi-layered circuit must be aligned to avoid producing defective products. This requirement demands 100% inspection if manufacturers are to achieve exceptional yields. Human inspectors can detect most screen-printing defects, but cannot detect positional defects, such as tape stretch, because there are no obvious variations in the circuit pattern.

Leading MLC manufactures interested in process improvement have compared the efficiencies of human inspection versus an AOI inspection system relative to lot yield. Fig. 3 shows the results of a typical comparison that demonstrates an AOI system with a 50% higher yield than human inspection. The substrate is manufactured in a 6-up-array with 4 layers LTCC printed with Au metallization. Clogged vias caused the tremendous yield drop in lot #18.

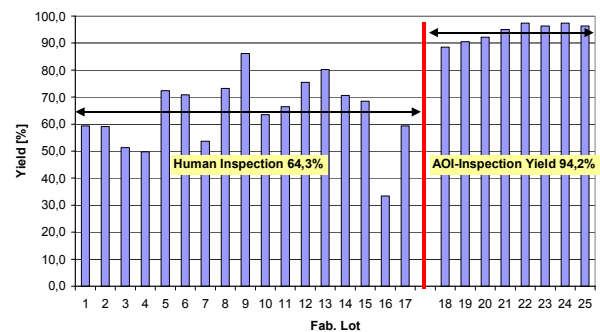


Fig. 3: Yield improvement by introduction of AOI

When compared to traditional inspection techniques performed by humans using microscopes, an AOI system detects defects with more precision and speed. Human inspectors require costly training, make subjective decisions, are subject to fatigue, and cannot detect positional defects.

4. Benefits of AOI

Improving yields is the obvious benefit and motivation of using an AOI system. Manufacturers

typically realize an improvement by detecting defects that were previously missed during human inspection. Another possible beneficial application of AOI is to introduce it to a step in the process in which human inspection was not practical because of efficiency or cost. Fig. 4 shows an AOI system.



Fig. 4: AOI System

Immediate process feedback is another advantage of using an AOI system. By distributing multiple inspection systems throughout a process line, an engineer can quickly identify the step in the process that is introducing defects. The engineer can then take the necessary corrective action and avoid laminating defective layers. The cost of an AOI system, when compared to

employing human inspectors and producing lower yields, makes this distributive inspection approach practical.

5. Principles of AOI

The AOI inspection principle is based on comparing a layer to a perfect template. This inspection template is actually a composite of an inner and outer template. During an inspection, if the system detects any differences between the template and the layer, it identifies the difference as a defect and then logs the location of the defect in a database. The information in the database can be used by either a process engineer for SPC analysis or by a technician for locating and repairing the defect.

Typical use of the AOI system can be divided in two process categories— *setup* and *inspection*. Setup refers to procedures pertaining to the creation of an inspection template, which are usually performed by an engineer. Inspection refers to the actual inspection of sheets, which includes tasks performed by the system and its operator.

The AOI system uses a look-and-learn approach for creating a template of an ideal print pattern known as a golden sample. The source of a golden sample can be either a perfect production lot sample, or a CAD-derived image of a layer. Converting CAD files to inspection templates is the preferred method because of the possible production variances inherent in lot samples.

To create a template, an engineer specifies the desired inspection tolerances for the entire layer or a region of the layer. The system then rapidly creates the inner and outer templates that comprise the inspection template.

The engineer now has the option to optimise the tolerances to detect all errors while minimizing the potential for ‘false defects’. Tolerance settings for inner

and outer line widths are set by layer or regionally as required for any conductor pattern.

Two defect characteristics, absence of a conductor where it is required (void) and presence of a conductor where it is forbidden (excess) are set independent of line tolerances. During an inspection, the system identifies excess and voids by variations in a given region and can detect these characteristics inside or outside a conductor pattern. Fig. 5 shows the two types of defects relative to the inner (green) and outer (blue) templates. The system displays excess defects in red and void defects in magenta.

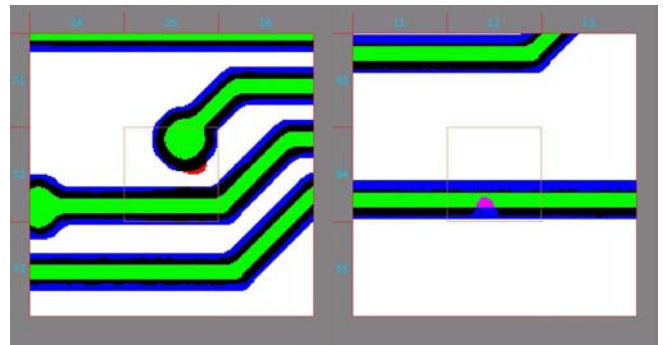


Fig. 5: Excess (left), Void (right)

In addition to layer-wide settings, the engineer can place arbitrary windows throughout the layer to create tighter or looser inspection parameters. An option for "don't care" regions is also available if the engineer determines certain features should be omitted from the inspection.

The upper image in Fig. 6 shows a printing defect within a meshed ground plane that does not affect the electrical performance of the circuit. The defined ‘don't care’ region in the lower image in Fig. 6, omits this failure for all following sheets. The template file is saved with any modifications and stored on disk. An operator selects the template file prior to inspecting a production run of the layer.

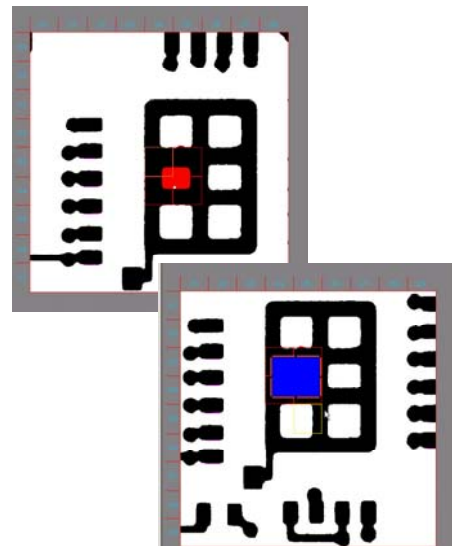


Fig. 6: Omitting Features

The inspection step requires an operator to place tapes on an XY-stage and then simply start the inspection. The system compares the layer to the template stored in memory and an intuitive graphical user interface displays defect characteristics during the inspection. The operator has the option to stop and view each defect or to view individual defects after the inspection is complete.

6. AOI in MLC production

Micro Systems Engineering has integrated a MIDAS inspection system in their MLC manufacturing line for a 100% control of each LTCC layer. Depending on the complexity of the circuit, up to four inspection steps are performed (Fig. 8).

The first optional inspection is done on the blanked green sheet. This step is considered as material incoming inspection and finds casting defects and foreign material on the tapes. This inspection is effective for tape layers with a high number of vias.

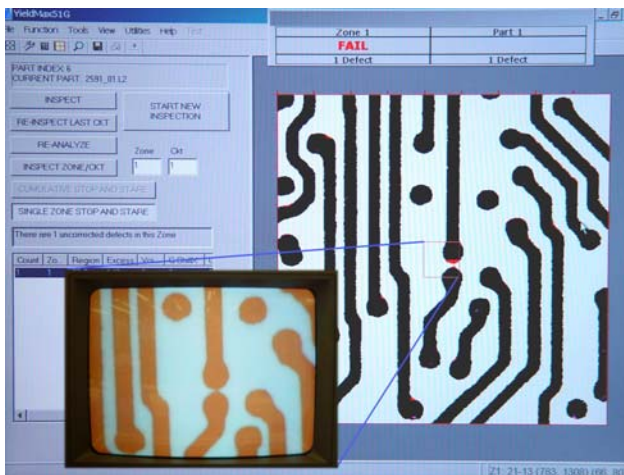


Fig. 7: Example of short detection between vias (computer and control screen)

After via-punching, the second AOI is done with only backlighting. This step is necessary to find missing vias (broken punch needle), clogged vias (via post is drawn back into the hole by the punch tool), misplaced vias (positioning problem of the puncher) and irregular via shapes (worn out punch needle). Immediate inspection after the punching operation saves costs due to the fast feedback to this process, which is essential to avoid manufacturing defective layers.

The quality of via-fill and conductor printing is inspected together during the third AOI step (Fig. 8). In this inspection step, all other failures mentioned are detected. Depending on the layout complexity and the seriousness of the failure, defective layers can be repaired and then inspected again.

The last optional inspection is performed after the printing and firing of all post-fire layers (including resistors). Careful set up of the inspection template is required to avoid false defects due to the typical shrinkage distortion of the sintered LTCC body.

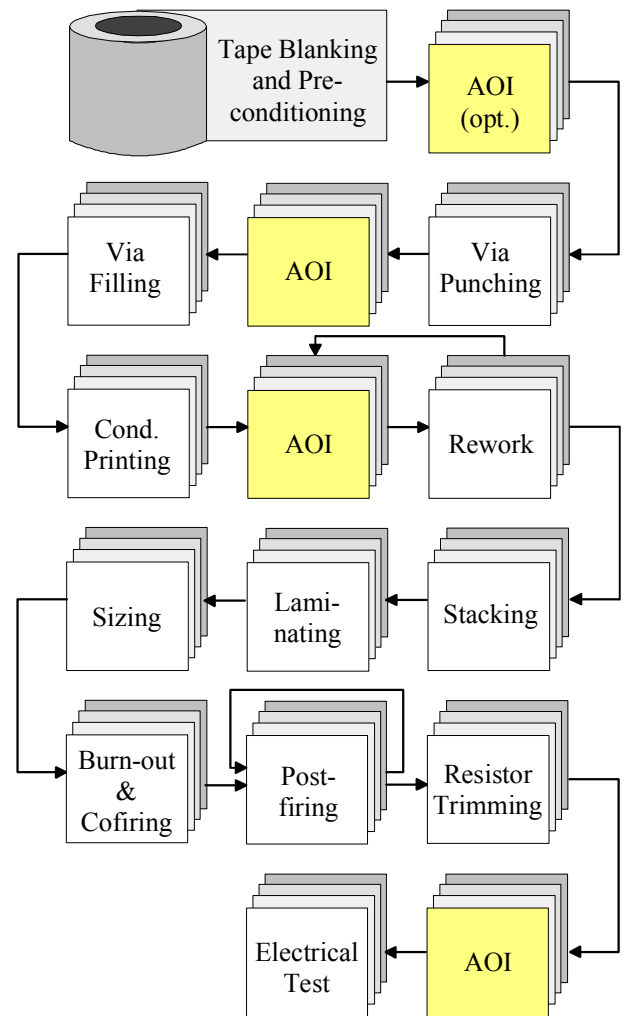


Fig. 8: LTCC manufacturing flow with AOI

The rapid increase of manufacturing yield lowers the cost for finished circuits. Depending on the product throughput and complexity (number of layers, material system etc.) the return on investment for the AOI system is between several months and 1.5 years. Fig. 9 shows the return-of-investment-curve for a 10 layer LTCC module with low production volumes. Return of investment of various LTCC devices are summarized in [2].

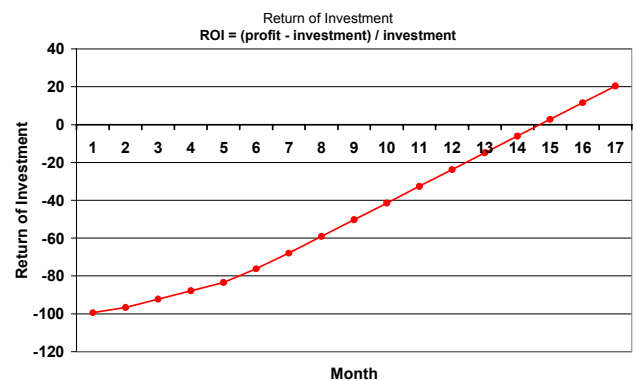


Fig. 9: Return of investment for one product

7. Next Generation AOI

Developers of AOI systems are keeping pace with the industry trend of smaller circuits with more complex patterns and features. Faster image processing and improved imaging techniques are a matter of course. However, there is a growing demand for AOI systems that offer seamless integration. This integration requires innovative sheet handling techniques combined with the networking of all process equipment. This seamless solution will provide manufactures with complete process control, lower production costs, and unprecedented yields.

References

- [1] DuPont Thick Film News: "Highly-integrated mm-wave modules use LTCC and metallised plastic covers," DuPont Horizons, No. 18, Dec. 2001
- [2] Hospod, T.: "Increasing Yields in High-Density MCM-C Substrate Manufacturing", Proceedings of the International Conference on High-Density Interconnect and Systems Packaging, pp. 22-25, Santa Clara /Ca., April 2001.