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System Considerations in Production Environment for Laser Trimming of Embedded Passive Components

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ABSTRACT

The trend of embedding passive components in printed circuit boards continues. Laser trimming has shown to be a very effective way to bring the tolerances of these embedded components values to the required range. As the demands for PCBs with embedded components grow, volume production is in order. The industry therefore requires a laser trimming system that not only gives precision trimming, edge smoothness, and resin integrity, but has all other characteristics of a true production machine tool, including full automation for 7/24 operation, high throughput and precision, simple set up, and operator-friendly interface with local language support.

First focus of the paper is to give an overview of the research and development efforts that were made, over the past two years, to develop such a turnkey, single button laser trimming system for production.

Second focus of this paper is on the testing aspect of the laser trimming technology. As laser-trimming equipment can only be as accurate as its measurement system, precision in the measuring system is important. At the heart of the measuring system is probing that connects the component to be trimmed to the measurement hardware. It plays a vital role in determining the ultimate trimming precision and accuracy. Different aspects of probing for the embedded trimming system will be analyzed and some test results will be presented.

INTRODUCTION

The continuous demand for better performances and lower costs is leading to the development of technologies that place discrete components, all passive such as resistors and capacitors, on the internal layers of multilayer Printed Circuit Boards (PCB) [1,2].
A wide variety of techniques are being proposed to form those embedded components. For resistors, they include screen-printing of thick-film, either organic or inorganic, pastes as well as sputtering or electro-less plating of thin-film metal alloys.
For tolerances in the order of ±1%, trimming of those embedded components is required. Laser trimming of thin film, thick film and chip resistors is a well-established technology, which spans over twenty years. The integration of this technology to PCB manufacturing is done, by adjusting passive components on top of the inner-layer of a multilayered PCB. While the passive components are on top surface of the panel, they can be tested and trimmed [3,4]. Subsequently, those trimmed components become embedded as they go through lamination.
This paper discusses some aspects of the integration of the laser trimming technology to the PCB industry.

SYSTEM REQUIREMENTS for PCB LASER TRIMMING

This section details some of the challenges a laser trimming system must meet for PCB Embedded Passives (EP) applications and solutions that were provided to overcome those.

Fig.1: GSI Lumonics EP laser trimmer

To account for the variety in panel sizes and thicknesses, the GSI Lumonics EP laser trimmer is equipped with a large X/Y motion table capable of handling panels as big as 534mm x 625mm. The X/Y table is used to accurately position the panel beneath the laser beam and probes. It is equipped with a lightweight vacuum chuck that holds the panel in place while moving. The vacuum is automatically adjusted to maintain a set vacuum pressure on the panel.

The system can also accommodate to any PCB thicknesses by adjusting a motorized telescope to bring the laser beam into focus. At focus, the laser spot size is 30µm, which is small enough to trim components as small as 250µm x 250µm.

The system is equipped with a Nd:YAG laser at a wavelength of 1.064µm. This laser has been found flexible to trim the different materials that are currently under prospect for EP.

The laser beam is positioned via high speeds galvanometers with an overall accuracy of ±25µm over a field of 100mm x 100mm and with a resolution as low as 1.5µm. The system is also using a through-the-lens vision system that allows easy calibrations of the scan field. A built-in laser power meter allows automatic laser power measurements and calibration.

Via its vision system, the EP laser trimmer uses several automatic visual alignment inspections in order to compensate for panel placement errors such as X/Y offsets and rotation as well as warp/shrink/stretch/skew factors. Those corrections are especially important in PCB applications due to the dimensional instability of the boards as well as placement inaccuracy of embedded components. A coarse field camera locates two fiducial marks, and determines the approximate panel positioning. Then, a fine field camera is used to locate up to four fiducial marks in order to accurately locate the panel. The result of this operation is the ability to transform nominal circuit coordinates into system coordinates. An optional alignment step can perform a local 1-point alignment at specific circuit locations, in order to further ensure probing and laser beam-positioning accuracy.

To account for speed and accuracy measurement requirements, the EP laser trimmer uses, for ohmic measurements, the field-proven GSI Lumonics V900 four wire (full Kelvin) forced voltage current nulling bridge. Measurement accuracy is 0.02% over a wide range of resistor's values. A programmable switching matrix interfaces to the probes, using either partial-Kelvin or full-Kelvin measurements, as well as optional guard pin to measure resistor networks. The chuck surface is non-conductive, ensuring that resistor measurements remain true, even if there are vias that connect the resistors to the backside of the panel.

When configured for fixed probing, The EP laser trimmer accommodates industry standard 165.1mm (6.5inches) probe cards. The probe card is mounted onto a probe frame with a theta motion axis used to align the probe card to any small rotation of the panel, as well as to enable probing of circuits that are positioned at different angles 0,90,180,270 degrees. The probe frame is moved up and down using a Z motion axis. The probe height is adjustable based on the panel thickness and amount of overdrive chosen.

Finally, all of the sub-assemblies of the system are controlled via software. The software controls the sequence of events, such as panel alignment, probing, measuring and trimming. It also provides utilities to convert Gerber or IPC-D-356B file formats to facilitate the application setup. It also logs the trimming information to a database that can be conveniently queried from a web-based graphical application.

TESTING ASPECTS of PCB LASER TRIMMING

Testing correctly is of the utmost importance for laser trimming. Major requirements for testing are speed and accuracy. Accuracy in the measurement is obviously required to meet the ±1% tolerances required by the PCB design. Probing accuracy is also required, as probes need to precisely move in X/Y/Z in order to make contact to the testing pads.
As for speed requirements, lasers are able to trim at repetition rates in excess of 10kHz. To make full use of the laser's trimming speed, the measurement system must therefore be designed to make measurements in less than 0.1ms.
Probing speed is also important as it affects the overall throughput and cost of ownership of the system. In this regard, cost analysis comparison between flying probes and fixed probes systems reveals the notion of a break-even point. For low volume production, a flying probe system is more economical as it does not incur the fixed costs of having to build probe cards. On the other hand, for high volume production, the ability to probe several components at the same time makes a fixed probe system more appealing as overall throughput per board is higher. Cost analysis shows that the break-even point is around a few hundreds boards [5].

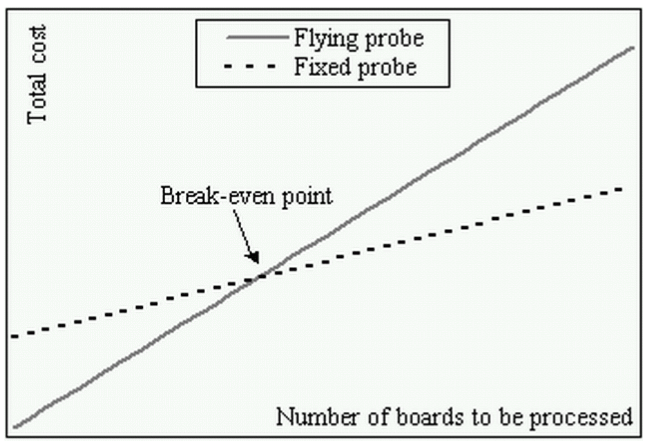

Fig.2: Speed/cost relationship for flying probe and probe card systems

Another important consideration for any laser trimming applications is that probes must be designed such that they do not block the laser beam. In this regard, there are two main types of probe technologies, the first based on cantilever mechanics, the second on vertical probes. Because of their low profile, cantilever type probes are generally preferred for laser trimming applications.

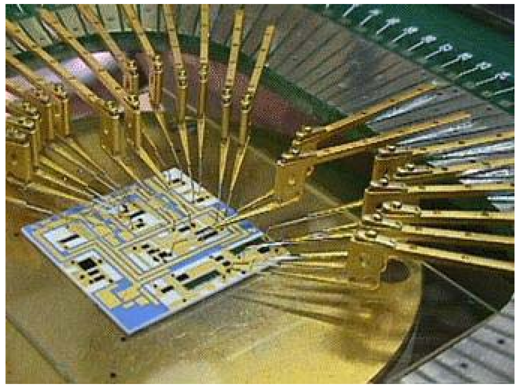

Fig.3: Cantilever type probes

Other testing requirements for laser trimming that are unique to the PCB industry are the result of the large panel sizes involved and also the use of copper for trace and pad interconnect.

While flying probes systems can move to any location on a large PCB, this is not the case for typical fixed pattern probe cards, which are optimized for devices up to $10000mm^2$. This is also not the case for the laser beam, which has a limited range of motion due to optical constraints and is optimized for devices up to $8000mm^2$. Last two technologies therefore rely on a step-and-repeat motion table to position the device under the probe card and within the laser beam range.

Copper is an extremely good conductor and enhances the electrical characteristics of interconnects, but oxidizes quite quickly and unlike other materials where the initial oxidation seals the surface against further oxidation, copper suffers continuous oxidation.

To ensure electrical contact during probing, it is necessary for the probe action to scrub through any surface oxidation in order to reach the underlying base material, reduce contact resistance and ensure reliable measurements. The geometry of cantilever type probes ensures that they scrub forward when a vertical movement or overdrive is applied to the probing system. Typically, a cantilever probe will scrub forward at a rate of 10% of the overdrive applied, and hence a typical 250µm of overdrive will lead to 25µm of forward scrub at the point of contact.

Another concept important to probing relates to Kelvin measurements. A single probe in contact with a pad will provide a reasonable measurement interface to the device under test, however accuracy will be impaired through variations in the electrical characteristics of the leads and other elements in the transmission path to the device. Kelvin terminal or four-terminal resistance measurement techniques are used to increase measurement accuracy, particularly when small impedances are being measured. Two sets of leads are used at each test point, similar with respect to thickness, material and length; one set carries the test signal and the other connects with the measuring instrument. The effect of resistance in the leads is thus eliminated. Four terminal leads are often specified for low ohm current sensing applications where lead resistance is a significant factor in total resistance. The Kelvin connection removes the voltage drop error in the current leads, since the sensing leads are attached at a fixed point and carry no large current. The closer the four terminals can get to the actual device under test the more accurate the measurement. This technique affords resistor measurement with an accuracy of better than 0.1%.

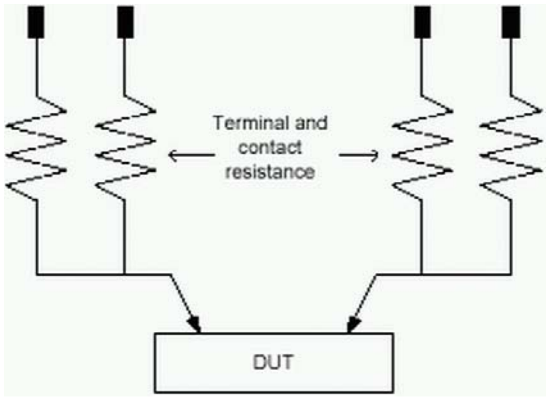

Fig.4: Partial 4T Kelvin measurement

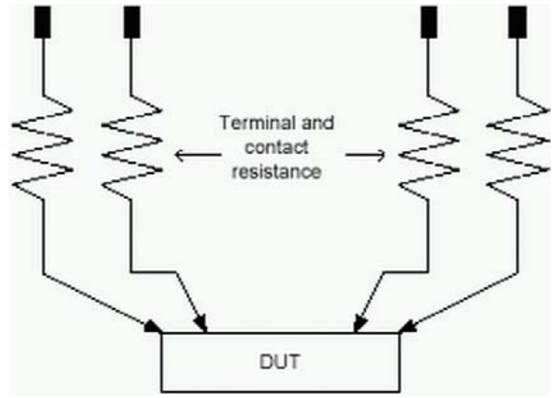

Fig.5: Full 4T Kelvin measurement

A final and important consideration to the achievement of test and measurement efficiency is to ensure that the probes are regularly cleaned and maintained. Oxidation on the surface of the pads attaches to the probe tips, which requires regular cleaning to ensure test accuracy. Beryllium copper (BeCu) probe tips have partial self-cleaning properties and will generally require less cleaning than Tungsten and other harder materials that are used in probe needles. Cleaning can be accomplished using abrasive cleaners sometimes incorporated into the probing system or by the placement of an abrasive film on the chuck in lieu of the substrate. Alternatively aerosol based cleaners such as Asahiklin 225 provide excellent cleaning capabilities without degrading the electrical characteristics of the probe card assembly.

EXPERIMENTAL

Tests to verify some of the unique issues involved in probing PCB materials and to recommend appropriate probing solutions were carried out. A test probe card with Kelvin z-adjustable probes using both tungsten and beryllium copper probe types and different probe needles was constructed. A number of PCBs with embedded resistors were manually probed with the test card and measurements made using a precision ohmmeter test set. Experiments unveiled the criticality of breaking through the surface oxidation on the copper pads for accurate measurements. Too little overdrive, less than 50µm, which corresponds to a forward scrub of 5µm, can lead to the probe not breaking through these contaminants resulting in inaccurate measurements. Additionally, too much overdrive, more than 500µm, can potentially damage the pad through excessive force and may lead to the probe falling off the pad into other substrate areas or circuit trimming areas. Excessive overdrive can also wear out the probe tips earlier than normal. Experiments were repeated for both tungsten and BeCu probes with similar results.

In order to see the effects of various copper treatments on the trimming ability of the EP laser trimmer, resistor trimming was carried out on 4 different sets of 8 panels. The

layout for all panels was identical, the only differences between the 4 sets being the resistor's material and the copper material used for probing as detailed on table 1. The layout of the PCB was made of 156 resistors with various geometries and target values. All the resistors were made out of thin film metal alloys with sheet resistivity of 100Ω/square. Target values ranged from 30Ω to 2880Ω corresponding to aspect ratios ranging from ¼ to 24 squares.
Probing was performed using full-Kelvin probes. The tips of the full-Kelvin probes were made out of beryllium copper and had a diameter of 125µm. 375µm of overdrive was applied to insure proper scrubbing action and contact. For each of the 1248 trimmed resistors, its nominal value was expressed as a percentage of its respective target value. The distribution of those values is presented on figure 4 for panels 3. The average, standard deviation and "3 x standard deviations" were then calculated. Those values are presented in table 1.

Panels	EP material	Copper treatment	Average (% from target value)	Standard Deviation after trimming (%)	3 Standard Deviation after trimming (%)
1	NiCr	Plain	-0.1	0.16	0.49
2	NiCr	Reversed treated	-0.1	0.16	0.47
3	NiCrAlSi	Plain	0.2	0.13	0.39
4	NiCrAlSi	Reversed treated	0.0	0.16	0.47

Table 1: Description of panels and corresponding trimming results

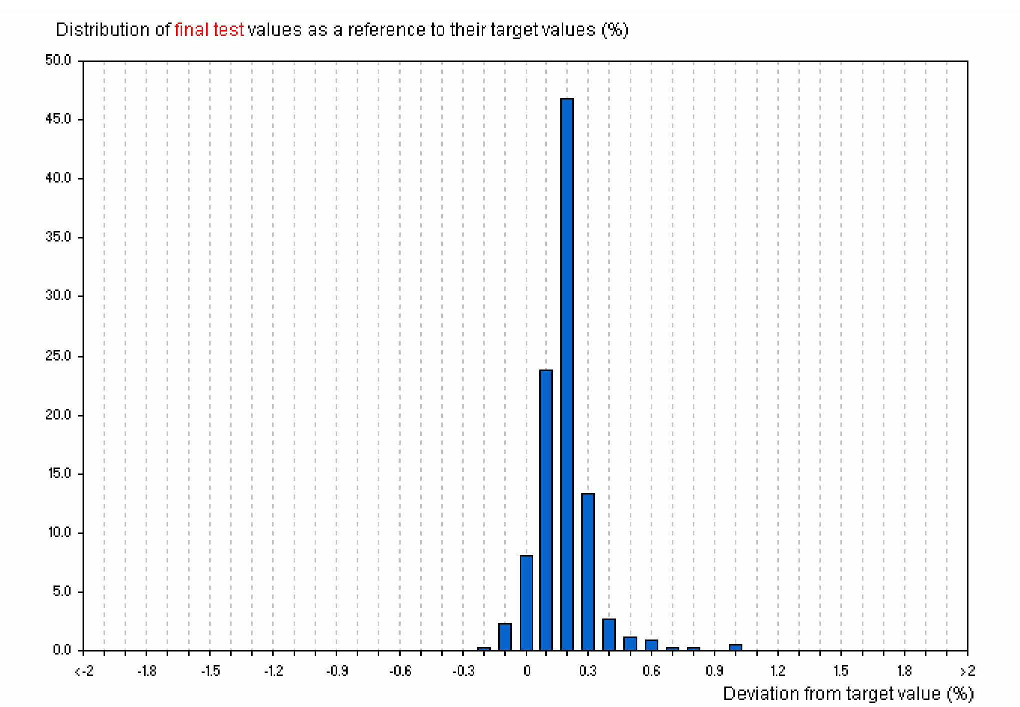

Fig.6: Post-trim distribution for panels 3

CONCLUSION

Trimming of embedded passives on large printed circuit boards raises a number of specific issues not addressed by the crop of well-established laser trimming systems currently available on the market.

This paper reviews some aspects of laser trimming specific to PCB manufacturing. First part of the document describes the different features and functionalities of the GSI Lumonics EP laser trimmer highlighting, for each one of them, what makes it specific to the PCB industry.

Second part of the document addresses the testing and probing aspects of the EP laser trimming on PCB. Contact resistances of probes on copper pads were measured. Effects of probe tip material and copper pad materials were investigated. Experiments revealed the importance of the probes scrubbing action in order to insure proper contact.

To complete first sets of experiments, trimming experiments were also performed on panels with differently treated copper pads. Results show no evidence that copper pad treatments significantly affects the trimming performances as long as probes are overdriven properly.

ACKNOWLEDGMENTS

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REFERENCES

[1] J.Savic, R.T. Croswell, A. Tungare, G. Dunn, T. Tang, R. Lempkowski, M. Zhang and T. Lee, “Embedded passives technology implementation in RF applications”, Proceedings of IPC Printed Circuit EXPO2002, 2002, S09-3

[2] R. Croswell, J. Savic, M. Zhang, A. Tungare, J. Herbert, K. Noda, W. Bauer, P. Tan, “Embedded mezzanine capacitor technology for printed wiring boards”, Proceedings of IPC Printed Circuit EXPO2002, 2002, S14-1

[3] A. Naumov, A. Kitai, P. Tibbles, “Implementation of embedded resistor trimming for PCB manufacturing”, Proceedings of IPC Printed Circuit EXPO2002, 2002, S14-3

[4] A. Naumov, A. Kitai, S. Purger, W. Bauer, “Laser trimming of embedded resistors for PCB manufacturing”, Proceedings of IMAPS Passive ATW, June 2002

[5] ATG Test Systems GmbH web site at www.atg-test-systems.de/products/decision.htm