TRI White Paper

Dynamic Imaging Technology -- Improved Solution for 3D Solder Paste Inspection (SPI) Technology

Version 1.0.0
November 11, 2010

Dynamic Imaging Technology -- Improved Solution for 3D Solder Paste Inspection (SPI) Technology

v. 1.0.0

Prepared by: Lynn Parker, TRI Marketing Dept.

The following are trademarks or registered trademarks of Test Research, Inc.

TRI innovation, 德律科技 & TRi

The absence of a product or service name or logo from this list does not constitute a waiver of TRI's trademark or other intellectual property rights concerning that name or logo. Agilent is a registered trademark and TestJet is a trademark of Agilent Technologies All other trademarks and trade names are the property of their owners.

For any comments to this paper, please address them to – sales@tri.com.tw with "SPI White Paper" in the Subject field.

www.tri.com.tw

1 Introduction

Test Research Inc. (TRI) designs, manufactures and markets precision test equipment for the world's leading electronics manufacturing service (EMS) companies. Product lines include Automated Optical Inspection (AOI) and Automated X-Ray Inspection (AXI), In-Circuit Testers, Board Testers, Solder Paste Inspection, Manufacturing Defects Analyzers (MDA), and Integrated Circuit Testers.

The purpose of this white paper is to provide an overview of solder paste inspection (SPI) and to introduce dynamic image technology which is an improved solution for SPI optical inspection. Dynamic imaging measures surface profiles of solder paste for printed circuit boards (PCBs). It uses the technology of phase-shifted fringe patterns to perform inspections when there is relative motion between a target and the imaging system so there is no need to stop and go during the inspection process.

2 Background of Solder Paste Printing

Circuit board manufacturing operations involve a stencil printer used to print solder paste onto a circuit board. A circuit board having a pattern of pads or other conductive surfaces onto which solder paste will be deposited is delivered into the stencil printer and one or more small holes or marks on the circuit board, called fiducial marks, is used to align the circuit board with a stencil or screen of the printer prior to the printing of solder paste onto the circuit board. After the circuit board is aligned, the board is raised to the stencil or in some configurations the stencil is lowered to the circuit board. Solder paste is dispensed onto the stencil, and a wiper blade/squeegee traverses the stencil to force the solder paste through apertures formed in the stencil and onto the board.

In some art stencil printers, a dispensing head delivers solder paste between first and second wiper blades, wherein during a print stroke one of the wiper blades is used to move or roll solder paste across the stencil. The first and second wiper blades are used on alternating boards to continually pass the roll of solder paste over the apertures of a stencil to print each successive circuit board. The wiper blades are typically at an angle with respect to the stencil to apply downward pressure on the solder paste to force the solder paste through the apertures of the stencil. While in some other art stencil printers, the dispensing head is pressurized to force solder paste through the apertures, and the wiper blades are employed to scrape excess solder paste from the stencil during a print stroke.

3 Solder Paste Inspection vs. Solder Joint Inspection

Prevention of an error is far better than having to correct one. This lesson is also very true for the board soldering process as well. Although verification has typically been at the final solder joint inspection step, many companies now find that they are more cost effective by performing solder inspection and solder paste screening before it is too late and they are left with poor quality solder-joint quality later. After all, solder paste defects can be fixed in less than five minutes by merely wiping off the solder paste printed on the circuit board and then the process can be started again.

The last inspection of PCBs usually includes a complete physical verification of the X-ray solder joint inspection methods. Solder joint defects exist in the use of these methods include tomb-stoning, solder bridges, bad connections, no connections and voids.

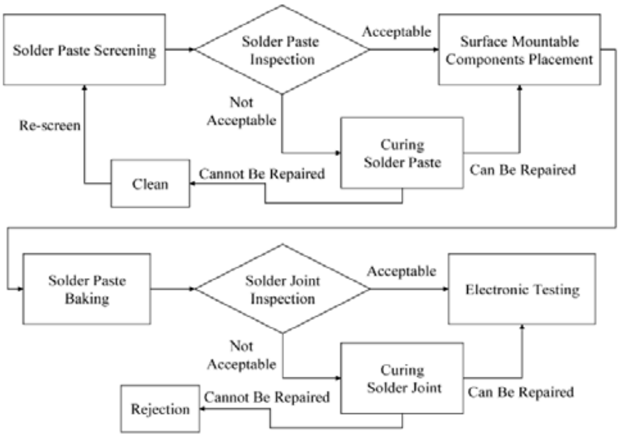


Figure 1. – Solder Inspection in Surface Mount Technology

The perfect solder joint depends on proper reflow conditions, component placement and solder paste deposition. With appropriate solder paste deposition and component placement it can be assured that before the reflow, the solder joint inspection should provide information mainly on the reflow process. However, in practice, the solder joint inspection is often used to discover the defects without studying the source of the defects. While checking solder joints following reflow can be important to ensure the integrity and reliability of assembled boards, it may also be prohibitive if the error rate is very high (figure 1).

4 Optical Inspection

After solder paste has been deposited onto a circuit board, an imaging system is employed to take images of areas of the circuit board for the purpose of inspecting the accuracy of the deposit of solder paste on the pads of the circuit board. Consistent modeling of solder paste on a substrate, e.g., the circuit board, is required to facilitate the imaging performance of the vision system, as well as subsequent inspections based on these images, irrespective of variations in geometry, definition, or general qualities of the deposit being imaged.

Well-defined solder paste deposits have nearly vertical sides and relatively flat top surfaces that are perpendicular to an optical viewing axis (i.e., an axis is generally perpendicular to a plane of a circuit board). Finely textured paste surfaces having this generally perpendicular orientation may be imaged with relative consistency using traditional illumination techniques that illuminate surfaces with on-axis white light. With on-axis illumination, the strongest components of scattered light from the top surface of the solder paste deposit are directed back along the optical viewing path and are collected by the imaging system (Figure 2).

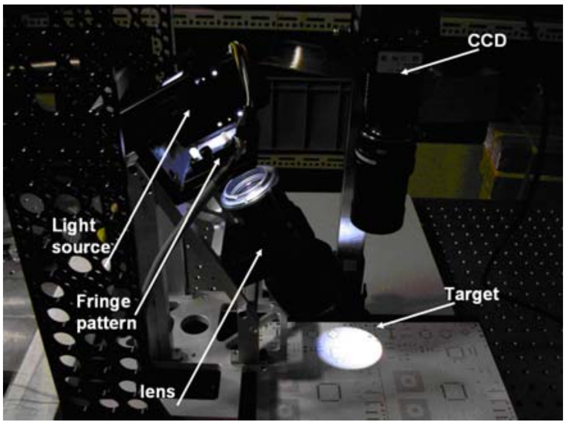


Figure 2. – Solder Paste Inspection Imaging System

In contrast, when on-axis illumination strikes a surface that is not generally perpendicular to the angle of incidence, the strongest components of scattered light from the surface are directed away, or off-axis, from the optical or on-axis viewing path and are not collected by the imaging system. Specifically, the sloped sides and irregular top surfaces of poorly shaped solder paste deposits are less efficiently illuminated and therefore more difficult to view using only on-axis illumination only.

5 Understanding the 3D Laser SPI Illumination

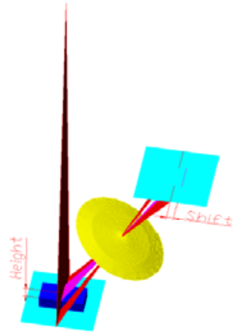


Figure 3 – Single-Sided Laser Triangulation Method.

In single-sided laser triangulation, a spot of light from a laser diode is pointed onto the surface of the target under inspection. The reflected laser enters into the window of a light sensitive digital detector array. The height of a point of the target can then be found by triangulation. In practice, a line of laser is projected instead of a laser spot. When the projecting device moves across the target, a camera is used to capture a number of images at even time interval. If high resolution is required, then more images (and also measurement time) are required, which is a time consuming method (Figure 3).

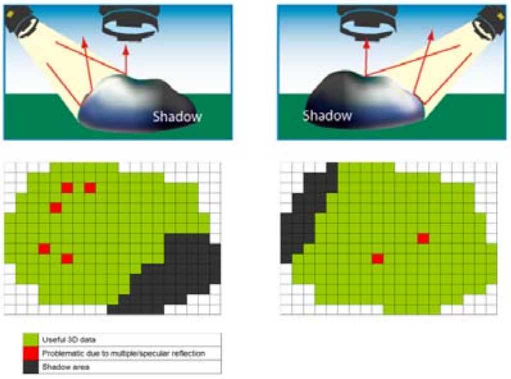


Figure 4 – Shadow Effect.

Essentially, this single-sided approach has its disadvantage. With only one source (a single laser) in use the actual values of the solder past volume can not be accurately computed. This observable fact is called shadow effect, which is due to the geometric landscape of the structure. This blend of a single angle laser beam and camera sometimes results in blind spots on the opposite sides of the solder deposit to the laser (Figure 4). However, despite this accuracy gauge repeatability and reproducibility (GR&R) is still good.

6 TRI's Improved Solution for 3D Solder Paste Inspection

TRI uses a new technology, referred to as dynamic imaging. It uses the principle of dual sinusoidal patterns projection which processes images using phase-shifted fringe patterns. Dynamic imaging offers an improved solution for 3D SPI in term of accuracy, speed and field of view (FOV). The main advantage of dynamic imaging is that inspection is performed fast because the inspection system continuously scans therefore there is no need to stop and go during the inspection process. Also, better accuracy is achieved by algorithms that automatically compensate for variations in 3D profiles of solder paste.

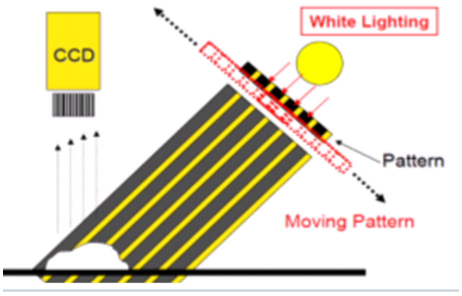
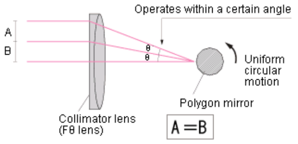


Figure 5. – Fringe lines viewed through a telecentric imaging system

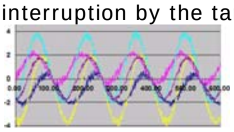
Dynamic imaging takes 3D profiles of solder paste based on fringe pattern image reconstructions that are obtained when projecting a pattern of lines onto an object and then viewing those contour lines from a different direction. The surface height of targets is measured relative to a reference surface. The reference surface is a plane if the projected fringe lines are straight and equally spaced at the object and viewed with a telecentric[1] imaging system (figure 5).

Figure 6. – Two white lights steered by pulse length modulation alternate to illuminate both sides of the solder paste eliminating the shadow effect

TRI uses dual-sided four/eight* phase-shifted dynamic imaging; where PCB boards are scanned when sinusoidal[2] patterns are projected with two Xeon white lights. The structured white lights patterns rhythmically flash light (in which all durations of light and darkness are equal) onto the solder paste's surface (figure 6). During the scanning a camera captures the patterns deformed on the target at every incremental pitch of light movement.



[1] A telecentric lens enables the outer dimension of a target to be measured based on the timing of the shadow produced due to fringe interruption by the target.



[2] The sine wave or sinusoid is a mathematical function that describes a smooth repetitive oscillation.

**optional*

The imaging process forms four phase maps and the differences of the four phase maps have a direct relationship with the 3D surface profile of the target. The resulting images are reconstructed to yield summary measures such as height, volume, area, registration, co-planarity, maximum height range, and surface contours (figure 7).

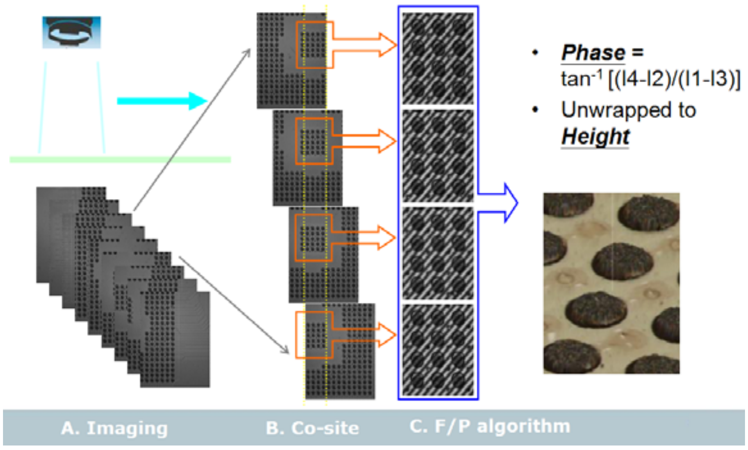
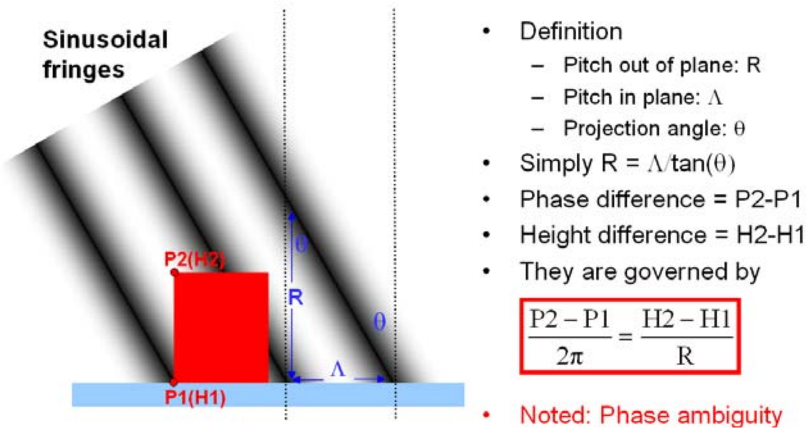


Figure 7. – Four phase-shifted fringe pattern scanning

The value of the phase difference of the fringes between on the reference plane and the target are measured, and the surface profile of the target then can be determined accurately. The relation between the intervals (pitch) of the fringes on the reference plane along the x-axis and the z-axis denote the intervals of the fringes on the reference plane along the x-axis, and at an incidence angle that corresponds to approximately 90 degrees of phase change of the fringes, respectively. The intervals of the fringes along the x-axis represent arbitrary phases that relate to the height of the target (figure 8).



- Definition
  - Pitch out of plane: R
  - Pitch in plane: Λ
  - Projection angle: θ
- Simply R = $\Lambda/\tan(\theta)$
- Phase difference = P2-P1
- Height difference = H2-H1
- They are governed by

$$\boxed{\frac{P2-P1}{2\pi}=\frac{H2-H1}{R}}$$

- Noted: Phase ambiguity

Figure 8. – Sinusoidal Fringe Pattern

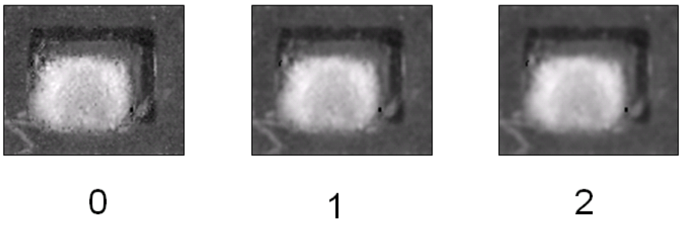


Figure 9. – Reconstructed Height Map image composites showing the differences of when no filters vs. filters were used, where 0 was none.

3D reconstructions of solder paste can be affected by distortion of lenses and the imperfectness of the projector. So, this can cause phase increment and non-ideal sinusoidal characteristics for the four generated patterns. Consequently, the reconstructed targets can contain parts which were wrongly formed having small-amplitude, high-frequency, and impulsive features. The solution to normalize these wrongly formed 3D reconstructions is to apply an averaged amplitude filter that involves intensity normalizing the plurality of reference images within each phase set (figure 9).

7 Introduction to TRI'S 3D SPI model 7007

The new TR7007 is the industry's fastest solder paste inspection (SPI) system. It is a 64-bit, 3D SPI system for mid- to high-volume manufacturing. The TR7007's inspection speed is a blazing 171cm2/sec at 14 micrometers resolution and 87cm2/sec at 10 micrometers resolution. In addition, the TR7007 implements a new technology which processes images using dual phase-shifted fringe patterns that eliminates shadows and provides the best possible defect detection. The TR7007 uses a linear motor and linear scale for smoother, more accurate imaging than other competitors that use ball screw motor and linear scale (figure 10).

TR7007 uses phase-shifted fringe pattern to measure height profiles of solder paste deposited upon a circuit board prior to placement. The TR7007 is able to acquire images it uses for 3D fringe pattern while it continuously moves across a target because a strobe illuminator provides short timed exposures; thus, essentially setting images motionless. The TR7007 combines sets of 3D data with two structured white lighting to achieve a stable 3D profile and eliminate any shadowing areas at the same time (creates a similar affect as two cameras). The TR7007 camera is capable of 200 frames per second, 100 frames for each side respectively.

Figure 10. – Test Research, Inc. 3D SPI System TR7007

TR7007 FEATURES

- Inspection Speed up to 171cm2/s @14µm, 87cm2/s @ 10µm
- Fringe Pattern Technology, Shadow Free
- Available 2D Color Images
- Linear motor and linear scale create an even-more precise and stable X-Y table motion system
- Excellent 3D inspection and operation technology with warp auto-tracking system, provides outstanding defect-detecting ability
- Great inspection ability of lead-free manufacturing process and fine-pitch/01005 components
- Smooth Automatic Test Program Generator (ATPG) flow lets users create inspection programs quickly and easily
- PC system calculates the statistical data and provides statistical reports
- Available to link with YMS to integrate and analyze the data of TRI systems across all production lines

TR7007 Series			
Resolution	10um	14um	7um/17um Options
Maximum Inspection Area	510 x 460 mm (20"x18")	510 x 460 mm (20"x18")	850 x 610 mm (Large Format)
Scan Width	23.2mm	32.5mm	
Max. Inspection Speed	Up to 87 cm2/sec	Up tp 171 cm2/sec	
Scan Time (254x148 sq.mm)	8.7s	5.1s	
Scan Time (330x250 sq.mm)	16.0s	9.6s	
Shadow Free Inspection	Yes	Yes	
Smallest solder capable	01005	0201	

Test Research, Inc. 3D SPI System TR7007 Specifications