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# INSPECTION TO IMPROVE LEAD-FREE SOLDER TECHNOLOGIES

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## ABSTRACT

Lead-free solders are said to cause various problems such as lack of self-alignment, bridges, solder balls, insufficient wetting, dendrites, pits, voids and peeling of soldering land. Also, on miniaturized lands, there may occur insufficient melting of solder paste. Even though these problems have not yet been resolved, lead-free soldering technologies have already been introduced at mass production sites. Most of these problems basically arise from heightened packaging temperature requirements in line with higher melting points of soldering materials.

Inspection of manufactured products to determine quality of the temperature profile and proper solder connection needs to be done with a high performance inspection system.

This technical paper and presentation will go over defects that can be uncovered by a high performance inspection system and merits of capturing images of such defects early during the assembly process. Without detection there may be a risk of damaging PCBs or parts that require rework. As well, serious quality problems or failures in the market after production may occur. The longer the lag time in detection of the defects, the higher the percentage of PCBs that may be scrapped. Therefore, inspection should take place at the earliest possible stage. Current technology available with a high end digital microscope will allow for immediate and thorough discovery of these defects which is of vital importance for SMT assembly.

Since lead-free solders were introduced to PCB assemblies, many soldering issues have arisen and for many, remain unsolved. This case study introduces the advantages of utilizing the digital microscope to identify soldering defects and root causes to improve productivity of lead-free soldering.

Although leaded and lead-free solders are different in their melting point, the basic theory in the SMT process, including temperature profiles, is still the same. However, the spreading property of lead-free solder is inferior to leaded solders. Therefore, determining good lead-free solder joints requires more detailed inspections than lead ones.

The appearance of flux residue helps to provide enough information for the temperature conditions of the solder joints being inspected. If wrong temperature conditions are used during the soldering process, there is a good chance of voids and insufficient spreading of solder. Observation of flux residue in addition to light reflection and shape of solder fillets are essential in the inspection of lead-free solder joints.

The following will provide the reader with many examples and various uses of a Digital Microscope as an exterior inspection as well as defect analysis tool for SMT. It is important as well to consider in the following pages, a comparison between Stereo Microscopy, lighting techniques, and use of adapters to aid inspection.

Key words: Digital Microscope**,** 360° Rotational Adapter**,** BGA Inspection Lens

## LEAD-FREE SOLDER AND DIGITAL MICROSCOPY

### Exterior Observation Using a Digital Microscope System

Excluding temperature profile graphs and X-ray imaging, all of the following images provided for visual aid of PCB components and BGA's were captured with a Digital Microscope. The multiple oblique angles shown in the images are made possible by a 360° rotational adapter attached to the end of the Digital Microscope Lens itself. A specialized BGA lens allows for 90° inspection of BGA's by means of a thin, flexible, plastic prim chip adapter. The benefit of using the 360° rotational adapter over stereo microscopy is in the rotation. Varying the angle of inspection on lead-free solder enhances assessment of solder shape and provides changes in reflection to help determine temperature profiles. This technique is not possible on lenses other than a Digital Microscope without configuring the lens, stage, and sample to fit the desired angle. In addition, by using a specialized BGA inspection lens, the same process described above can be applied when determining BGA shape and temperature profile. This simple yet beneficial approach to exterior observation can improve product quality on the production line. The addition of a Digital Microscope as a part of production rather than post- production Quality Control or Failure Analysis can support and expand the foundation of a company's philosophy of quality and drive down costs on the product assembly line. The following nine sections will discuss the usefulness of a Digital Microscope as a part of PCB production and the potential effect its use can impart to product quality.

## BRINGING THE DIGITAL MICROSCOPE TO THE PRODUCTION FLOOR

Any inspection done in-line during product assembly has to be quick, easy, and accurate in order to be seamlessly inserted into a company's current standards for production. A Digital Microscope can cover both of these necessities while providing high quality images wherein observations and judgments can be made in seconds, observing defects before they reach Quality Control or Failure Analysis Divisions. This can potentially save time and money by integrating aspects of QC/FA into the production line, as well as help Process Engineering Teams attain solutions to problems more quickly.

The first portion to follow begins with examples concerning flux residue, and the ability of the 360° rotational adapter to gain information that up until now could not be easily gathered and stored by a stereo microscope. The sections following that will further support the use of a Digital Microscope, its rotational adapter, and the BGA inspection lens directly on the production line.

### Judgment of Thermal Balance with Inspection of Flux Residue

Note: To see flux residue easily, leads were intentionally shifted from the lands (Figure 1A, 1B).

Access to these views have not been obtained by shifting or angling the PCB in any way, but were identified and captured using the 360° rotational adapter without having to manipulate the PCB in any way. Such rotation can easily show the flux residue as in these examples: showing flux spattering, Figure 1A (before pre-heat fan speed change), normal flux residue, Figure 1B (after pre-heat fan speed slow down), normal flux residue condition, Figure 2A and flux bridging, Figure 2B. Solder melts and flows in accordance with the flux only reaching areas that the flux exists. Flux moves from the resist to the heated land by its tension, and if kept from deteriorating in pre-heating, lead-free solder will be more likely to self-align to the heated land by its surface tension (Figure 3).

**Figure 1A:** Spattered flux residue may indicate voids.

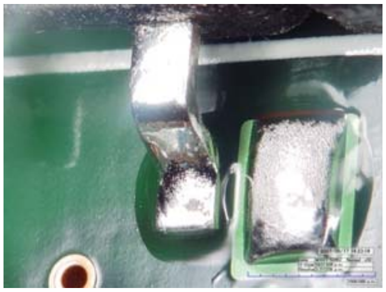

**Figure 1B:** Improved by slowing down pre-heat fan speed.

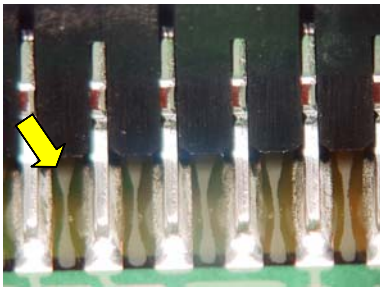

**Figure 2A:** Normal flux residue condition

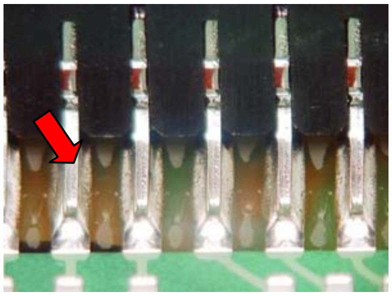

**Figure 2B:** Flux bridging (e.g. due to improper thermal condition in leads)

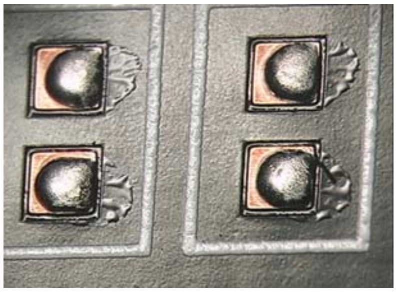

**Figure 3:** During reflow, melted solder shifts to the area where flux moves.

### Detection of Voids

X-ray imaging in detection of voids is helpful to a certain extent. A Digital Microscope should be considered to work alongside, and not in place of or as alternative inspection equipment. Manufacturers striving to gain the highest quality should consider X-ray and Digital Microscope equipment as a pair. Detecting voids is a helpful example of this relationship.

During pre-heating, voids can occur due to deteriorated flux. This can result in low flowing solder causing gas pockets.

The surface of flux residue and shine of solder joints may indicate possible voids (Figure 4A and 4B).

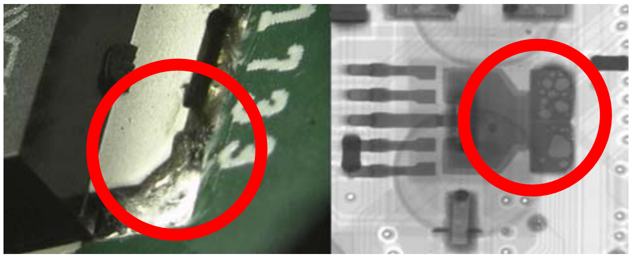

**Figure 4A:** Uneven solder joint surface and spattered flux are observed by Digital Microscope (left)
Voids confirmed by X-ray (right)

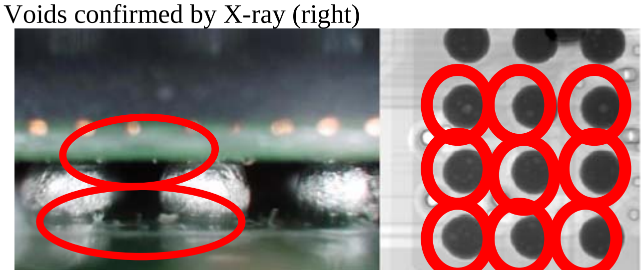

**Figure 4B:** Spattered flux and solder particles are observed by Digital Microscope (left)
Voids confirmed by X-ray (right)

During reflow, air current that is too hot and strong deteriorates flux and causes voids (Figure 5A). The specialized BGA inspection lens for the Digital Microscope can work side by side with X-ray inspection, detecting possible voids. Adjusting air current can contribute to the reduction of void occurrence (Figure 5B). X-ray is an important aid for void detection and until now has been considered an alternative and separate solution apart from both stereo and digital microscopy. Inspection of BGA properties and defects should be considered from a combination of potential solution providers.

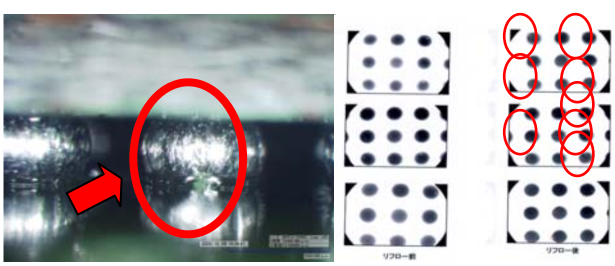

**Figure 5A:** Possible voids after reflow
Confirmed by X-ray (right)

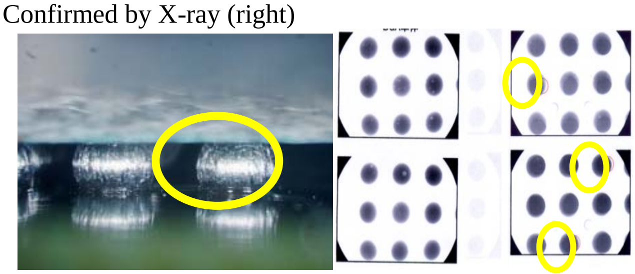

**Figure 5B:** After adjusting temperature profile and air current, deterioration of flux is prevented and solder melts properly (left). Confirmed by X-ray (right)

**Judgment of Defects by Exterior Inspection**

BGA exterior inspection allows access to the hardest to reach places on the PCB. The highly accessible prism adapter for the Digital Microscope BGA Lens can squeeze between components and look directly at the BGA from the side on heavily populated boards with minute pitches. Utilizing a metal halide bulb (discussed below), will greatly enhance the information retrieved from this style of observation. The following section as well will provide further examples of how specific reflections further support conclusions and information gathering. Without even the aid of X-ray technology it is possible to determine defects caused by over extended pre-heating and reflow (Figure 6). Common among these issues of over-heating are oxidization and visible damage to the ball itself (Figure 7). Exterior inspection goes beyond defects, aiding as well in the correction of temperature profiles.

**Figure 6:** Insufficient melting due to oxidation resulting from flux deterioration. (e.g. due to long pre-heat)

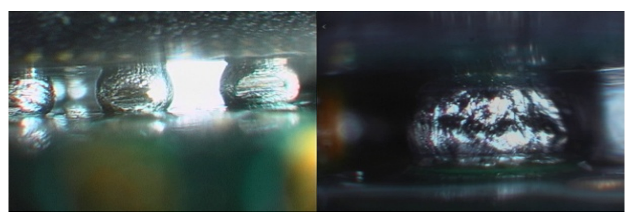

**Figure 7:** Damaged ball (left), Oxidized ball (right)

**Properties of Temperature Profiles by Exterior Inspection**

Temperature profiles and exterior inspection can supplement each other providing a communication bridge to show where adjustments in pre-heating should be made (Figure 8, Table 1). As well, lead-free solder that has been properly pre-heated will show uniform reflection (Figure 9, Table 2). As discussed above, both light source and angle of inspection promote data gathering and accurate observation. When the BGA inspection lens is combined with a metal halide bulb, some unique effects can be observed on the BGA and component surface.

Proper temperature profiles will produce a light reflection effect on solder balls that is uniform and horizontal across the ball's center (Figure 10, Table 3). Overheating causes component warping and solder ball distortion shown characteristically by the non-uniform light reflection at the bottom of a solder ball aiding in further identification of improper temperature profiles (Figure 11, Table 4).

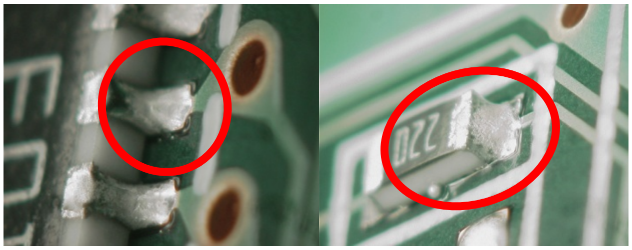

**Figure 8:** Excessive pre-heating with loss of solder joint shine, and the occurrence of side balls.

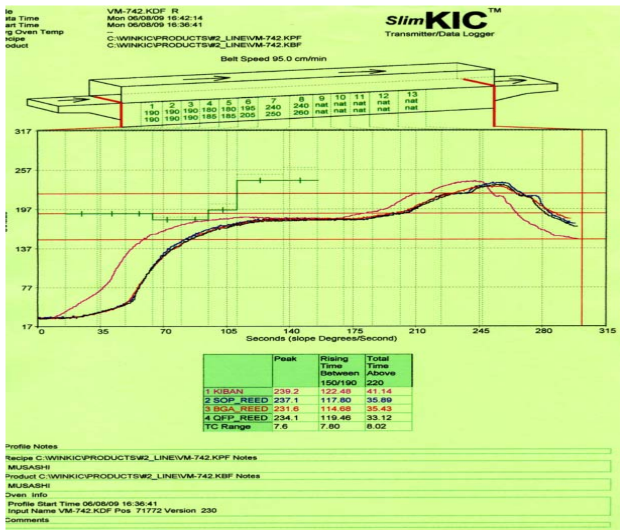


**Table 1:** Temperature profile indicating pre-heating error.

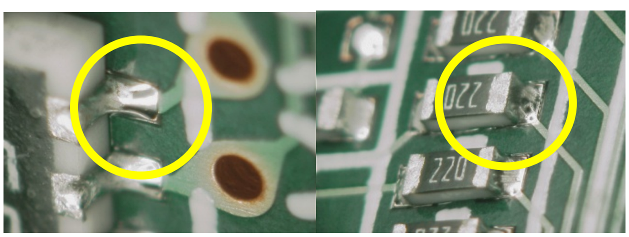

**Figure 9:** Improved solder joint shine and elimination of side balls due to shorter pre-heating.

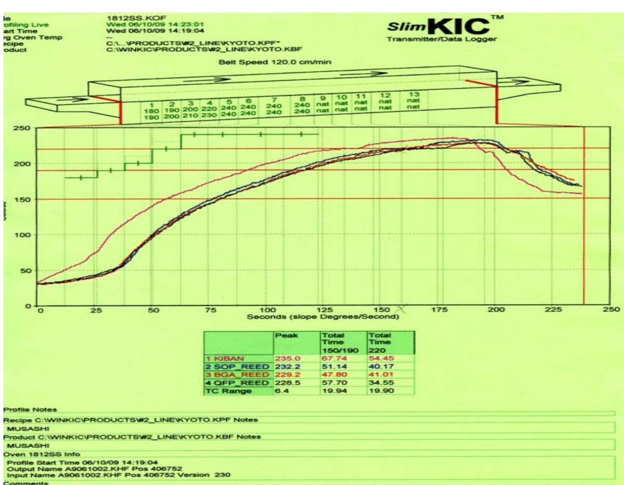


**Table 2:** Acceptable temperature profile

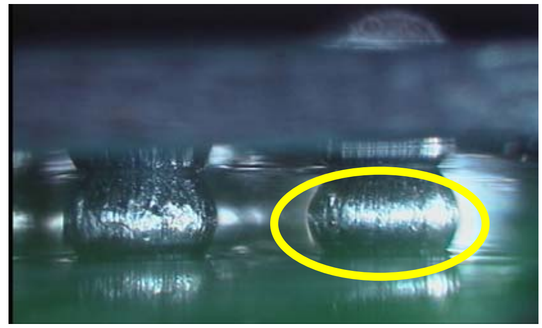

**Figure 10:** Light reflection is uniform and centered

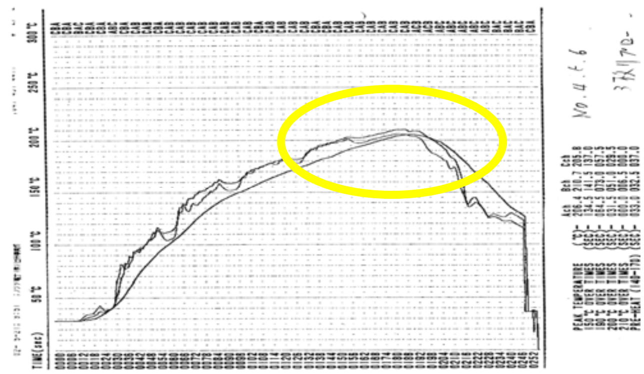

**Table 3:** Acceptable temperature profile

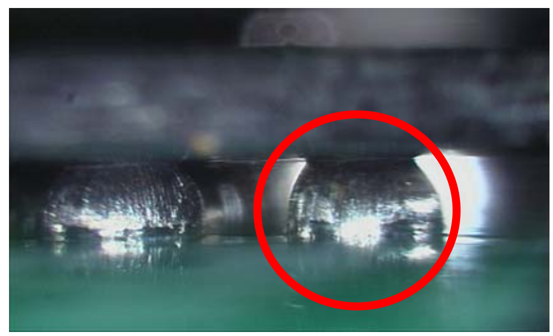

**Figure 11:** Non-uniform light reflection

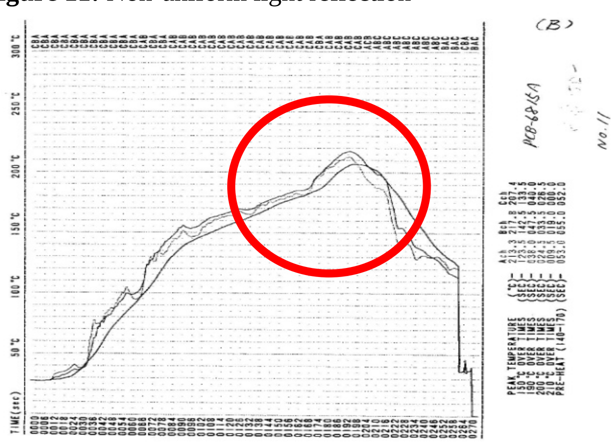

**Table 4:** Improper temperature profile

**Temperature Profile of BGA**

An appropriate temperature profile creates an environment for the BGA conducive to strong self- alignment and minimal difference in the delta-T between the BGA and lands outside. Therefore, accurate and quick inspection can be achieved by assessing the shape and light reflection of the balls on the four corners (Figure 12), which are exposed to the most amount of heat. This inspection enables a thermal balance evaluation, which cannot be determined by X-ray inspection (Table 5).

**Figure 12:** Unmelted solder (left), and corner BGA inspection (right)

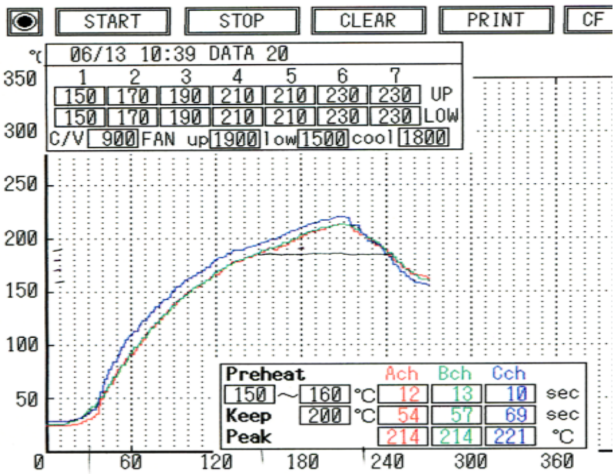


**Table 5:** BGA temperature profile

**Amount and Conditions of Printed Solder**

It is important to always print the recommended amount of solder. Insufficient amounts of printed solder will cause a smaller amount of flux, dramatically reducing the range of solder reflow as well as where it can melt. Severe acceleration of particle deterioration and oxidization in pre-heating can also occur. Both stereo and digital microscopes are capable of identifying solder that has been affected in this way. However, the availability of quick image storage, access to multiple angles of view with the 360° rotational adapter, and a par focal lens capable of zoom type magnification can enhance the accuracy and speed at which these observations can be made (Figure 13). Figure 14 is the example of small components like the 0402 chip, which uses small amounts of solder, and reflow settings must be carefully considered in order to ensure the force of self-alignment effect.

**Figure 13:** Unmelted solder and insufficient flux (left). Insufficient amount of solder (right).

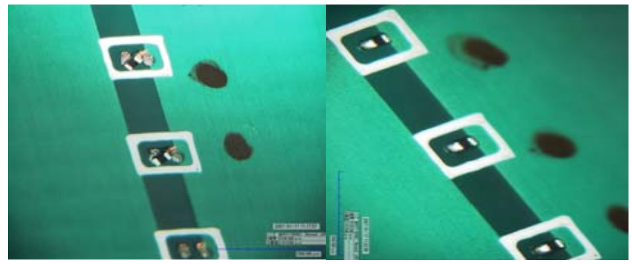

**Figure 14:** 0402 chip components

**Example of Judgment by Exterior Inspection**

Insufficient amounts of printed solder are not the only factors contributing to solder defects. Excessive preheating and high air flow levels can also oxidize solder particles preventing solder from melting at normal reflow temperatures (Figure 15, left). Proper reflow profile can help reduce occurrences of oxidization (Figure 15, right).
Judgments of height and depth through external inspection become increasingly more important as these types of defects are identified through these methods of heating. Images in (Figure 16) indicate the rugged surface on fillet results from insufficient temperature and that strong air flow melts the surface of the solder without the heat reaching inside the solder. Therefore, voids are formed and accordingly solder fillet swells.

Since lead-free solder has less spreadability, the heat must be transmitted to the solder without deteriorating the flux.

The capacitor lifts due to poor board design (Figure 17, left), improper temperature (Figure 17, middle), and land oxidization (Figure 17, right), may not be as easily seen from a traditional straight view lens.

Closely zoomed rotation on leads as well can provide detailed information in determining repelled solder, how far flux spreads, and lead oxidization (Figure 18, 19).

Most of the circumstances and assessments described above would require a configuration enabling a tilting XY stage or moving the PCB itself to gain access to varied angles of inspection with a stereo microscope. Even then, issues of working distance and overall accessibility of such a setup may cause a lag in the process of visual inspection. Motorized changes in the angle of inspection coming from the lens itself, without manipulation of the stage or sample can produce lighting changes that completely alter what is able to be seen on the surface of a PCB component at any given moment (Figure 20).

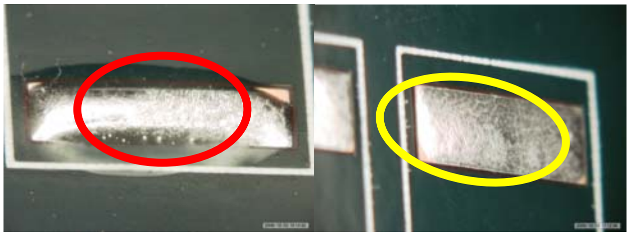

**Figure 15:** Solder particles are observed (left)
No solder particles are observed (right)

**Figure 16:** Solder defects captured with the 360° rotational adapter.

Figure 17: Uplifted capacitors due to varying factors.

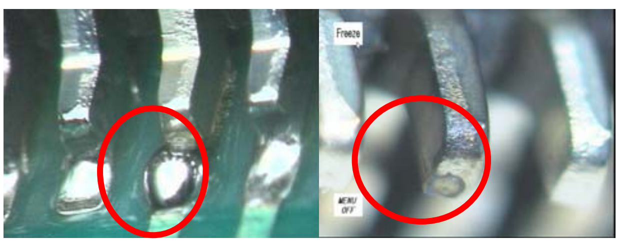

**Figure 18:** Repelled solder and lead tip oxidization.

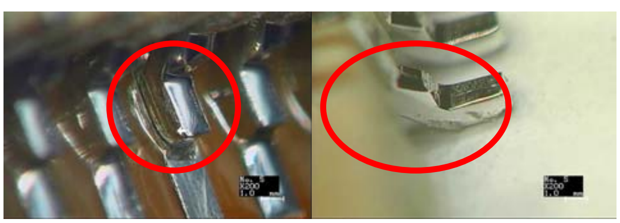

**Figure 19:** Solder covered lead (left), solder repulsion from lead bottom oxidization (right).

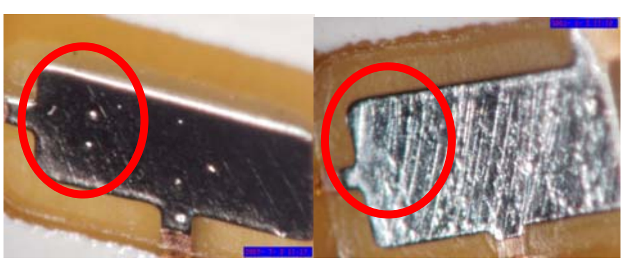

**Figure 20:** Varied angles on the same surface provide different inforamtion.

The rotational adapter's ability to reveal defects not seen from the straight down view likewise can reveal potential and actual pinholes, voids in the flux residue, and gas releasing blowholes (Figure 21). Conditions pointing to void presence can then be more thoroughly ascertained by X-ray. Peeled lands as well can seem non-existent unless inspected at an angle (Figure 22).

Finally, and perhaps the most elusive cause of defects are tin whiskers (Figure 23). Only partially observable with stereo microscopy, these small but problematic objects can be identified and inspected from many angles by using the Digital Microscope's 360° rotational adapter.

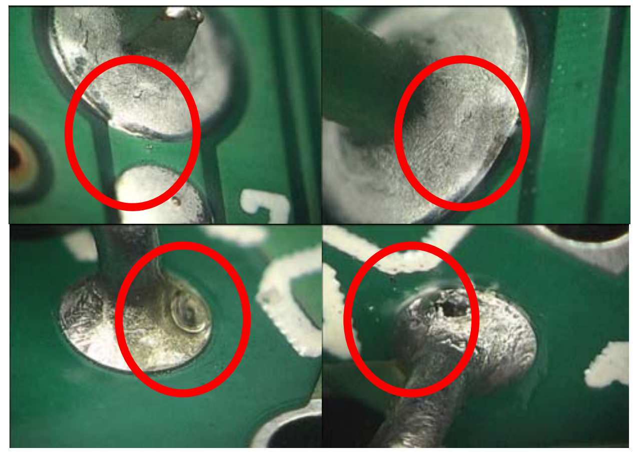

**Figure 21:** Examples of pinholes and blowholes.

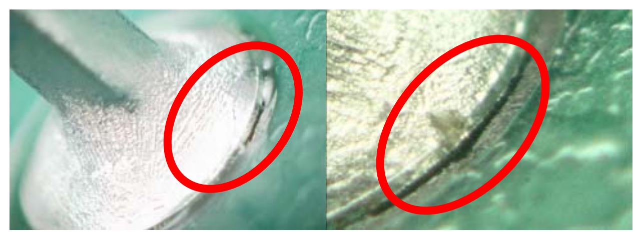

**Figure 22:** Peeled land after 255C° solder bath (both images are of the same component, zoomed to show detail).

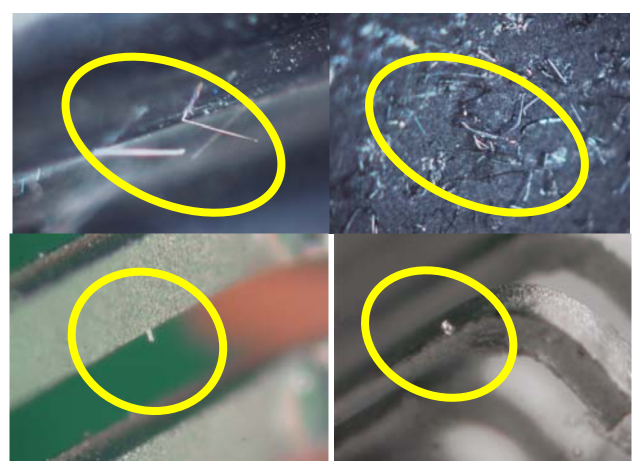

**Figure 23:** Multi angle inpection of whiskers.

## CONCLUSION

In assessing the shape and integrity of BGA's, the light source used for inspection contributes to the information that can be gathered through external inspection and should be one of the first considerations for SMT and digital microscopy. For an optical inspection system, a halogen lamp does not provide the same image quality that metal-halide can when observing residual flux. With metal-halide, it is easy to observe light reflection of residual flux especially when using a rotational multi-angle observation lens adapter.

External visual inspection on the production line is important. The inspection system should prevent the recurrence of the defects in the most efficient and timely manner. Conventional visual inspection only judges what is good or bad and determines the product that should not be released for shipment to end users. An addition of a Digital Microscope with the ability to utilize a rotational adapter and BGA observation lens directly on the assembly line can help identify good and bad components while providing the information needed to resolve the issue behind recurring defects.

Most modern Digital Microscopes are intuitive, easily operated, provide high quality images and quick storage on multiple media. As long as a digital microscope is capable of changing the angle of view, rotating 360 degrees, and perform BGA inspection, detailed primary analysis can be done during production. These tools can become standards on the production line to aid in saving time and reducing waste. Decreasing the loss of raw materials due to recurring defects, minimalizing labor, and increasing product quality are important factors in PCB assembly.