The greatest challenge with BGA socket test is avoiding damage to the solder balls while maintaining a high compression force and a stable contact resistance.

Here is a thoughtful analysis of how to avoid contact degradation. Recommended to all users of BGA Test Sockets utilizing pogo pin type contacts.

Carole Booth
Pres., Prime Distributing Co.

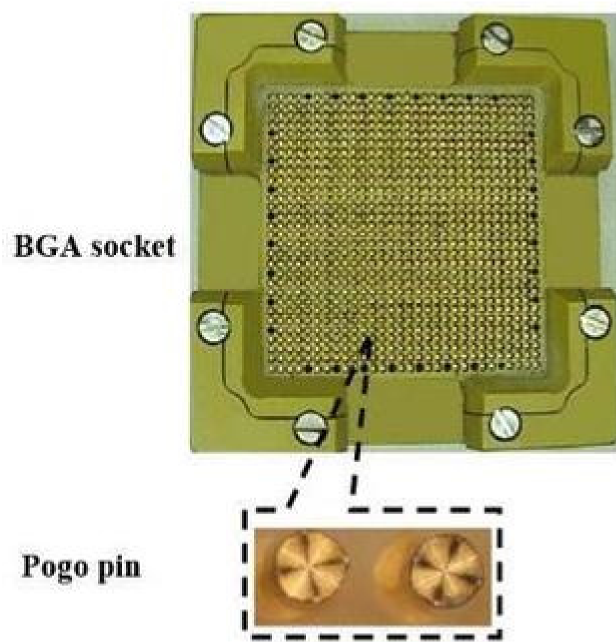

Figure 1. Photograph of BGA socket and pogo pins

Testing the Reliability of BGAs

By Ching-Mai Ko, Ming-Kun Chen, Yu-Jung Huang, and Shen-Li Fu, I-Shou University

The greatest challenge with BGA socket test is avoiding damage to the solder balls while maintaining a high compression force and a stable contact resistance. Determining the contact resistance distribution plays a vital role in assessing the operating reliability of the device. Socket contact degradation can significantly degrade first test yield and increase retest time. The contact degradation studied in this work can be used as a good contact clean guideline.

Experimental analysis of failure site conditions for the final testing of BGA packages, focusing on touchdown-times-related worn-out changes in BGA sockets, is presented. Electrical characteristics BGAs are generally tested using a pogo-pin socket. A low and stable contact resistance must be maintained between the pogo pin and the solder ball of the BGA package. In conventional final test, BGA sockets are punctured against the solder ball to obtain a low contact resistance by mechanically breaking down the interfacial oxide layer on the solder ball. Here, we provide an experimental procedure for investigating the effect of particle contamination and the worn-out of crown tip in final testing of BGA packages.

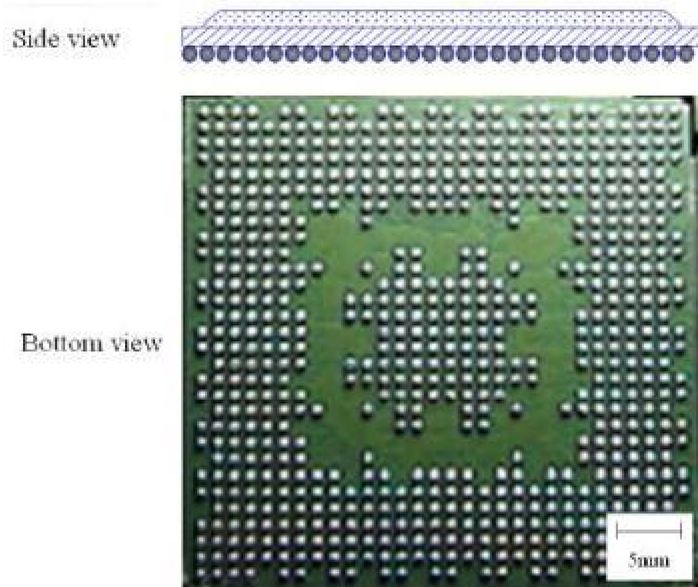

Figure 2. Simplified outline of a PBGA package

Demand for BGA packages continuously grows because of their low cost and high pin-count density. As product quality and production capability requirements increase, BGAs present a popular packaging alternative for high I/O devices. Having no leads to bend, the plastic-overmolded BGA (PBGA) has greatly reduced coplanarity problems and minimized handling issues. BGAs are available in a variety of other types as well.[1,17] BGA testing ensures performance and quality, but it also makes up a large portion of production cost. Significant loss is generated when circuits are proven faulty after the packaging processes. BGA test sockets are separable interconnection between BGA-type packaging components and a load board. Establishing temporary connectivity to a solder ball on a BGA pin is becoming increasingly difficult with decreasing feature size, increasing operations frequency, and new technical concerns. The greatest challenge of BGA sockets is to avoid damage to the solder balls while maintaining a contact force and a stable contact interface.[3] To ensure accurate measurement results, it is essential that a low and stable contact resistance is maintained between the pogo pin and the BGA solder ball. In general, contact resistance of less than 20 mΩ is desirable, depending on the particular application.[1,2,3]

Table 1. Summary of the relevant BGA-type socket technologies

Contact mechanism	S-shaped	Pogo pin	Metal filled
Force (grams)	10-25	65-145	90-180
Resistance (mΩ)	<10	<20	~20
Inductance (nH)	<1	<3	Not available
Capacitance (pF)	<0.1	<0.1	<0.1

In conventional final testing of BGAs, the socket pins puncture the solder balls to obtain a low contact resistance by mechanically breaking down the interfacial oxide layer. However, variations in the magnitude and stability of the contact resistance are observed following repeated contacts between the pogo pin and the solder balls, as a result of interfacial phenomena between the crown tip and the oxide layer and the accumulation of particles from lead-free solder balls on the crown surface. To maintain a low contact resistance and a stable electrical contact, increase the drive force concurrently with the pogo pin contamination, and clean the crown tip on a regular basis. However, an excessive drive force creates large puncture marks on the solder ball, which not only increase the risk of permanent pogo pin deformation, but may also adversely affect package performance and reliability.

Furthermore, frequent abrasive cleaning reduces the socket's service life. An appropriate tradeoff is required between contact resistance and the number of allowable touch contacts between cleaning operations.

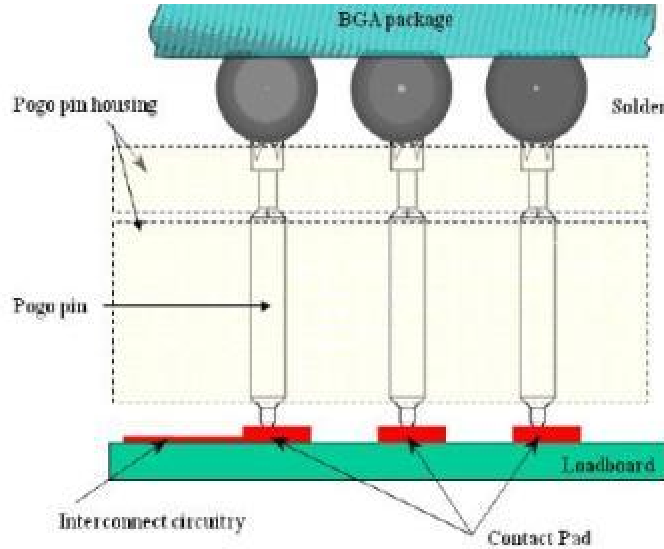

Figure 3. Schematic cross-sectional drawing of the BGA package and test socket structure.

This article covers the behavior at the contact surface via surface failure analysis. An experiment was carried out to clarify the effect of the contact failure on the IC testing. Test sockets touch down and contact the solder ball of the BGA package. At the same time, the power supply and input test pattern was applied to the device under test (DUT). Then the relationship between the contact force and the vibration was active during final testing. The contact zone of BGA socket and the surface-flattening effects on the crown tip are assessed using optical microscope (OM), scanning electronic microscope (SEM), and energy dispersive X-ray spectrometry (EDX) techniques after test, and the influence of these changes on the contact resistance is correlated. Conclusions about the instability effects on the contact pin phenomenon and the influence of the contaminations on the socket are based on the experimental results.

Design of Experiment (DOE)

The commonly used 32-mm^2 356-ball PBGA package is the assembly vehicle for this study. The package can match a mass production impact on high-speed applications. The substrate core material is a four-metal-layer copperclad BT laminate. Its solder mask thickness is 70-µm and BT resin core thickness is 150 µm. Its prepreg thickness is 100 µm with the inner layers' copper trace at 37 µm thick compared to the outer layers' 30-µm-thick copper trace. Eutectic Sn/Pb solder comprises the 0.63-mm-diameter balls on a 1.0-mm pitch.

Table 2. Experimental conditions

Package substrate	BT
Solder ball	63/37 Sn/Pb
Pin coating	Au (Plated)
Contact force per pin	25g
Temperature	23~25℃

Spring-style (vertical or pogo type), metal filled (Elastomer), and cantilever (S-shape) are the main contact BGA-type package technologies.[4,5,6,7,8] The BGA test socket provides a separable electrical and mechanical connection between BGA-type packaging and loadboard. The basic structures of a socket include plastic housing and metal contact pins. [9,10, 17]

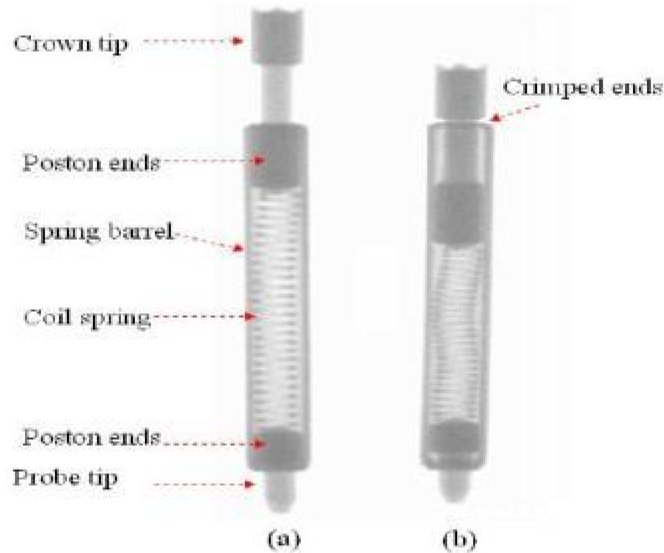

Figure 4. Spring Contact Pin of BGA (a) free position and (b) testing position

The test socket has the same footprint and overall size as the BGA. The loadboard layout is the same for the BGA package and the test socket. The socket is built from copper-clad contact pins in a 32 × 32 mm array with 356 pins on a 1.0 mm pitch; socket shape is often determined by pin-count of the device under evaluation. It provides power/ground array, and signal pins designed to offer 348 signal lines. Every solder ball on the package aligns with a socket pin. The floating plate allows the spherical connecting terminals of the BGA package to be brought into contact with the pins in the receivers. When solder balls are pressed into the socket, the sharp edge penetrates the oxidation film on the ball and forms a good contact with the soft underlying solder.

Table 3. Sample worn-out analysis

	Touchdown number
Day 1	6830
Day 2	13630
Day 3	20810
Day 4	27550
Day 5	36580

The spring contact pin consists of an outer barrel, an inner coil spring, a plunger and a four-point crown head. X-ray micro-imaging system has been implemented to observe the in-situ behavior of spring pins while in normal free position and compress testing position. The most widely used material for contact pin is gold-plated beryllium/copper (BeCu), which enhances the contact's tensile strength, electrical performance, and contact life. This plating of hard gold prevents oxidation of the base contact material and helps prevent solder build-up.[10] To create a self-contained contact assembly, the outer barrel is crimped around the plunger and crown head. The inner coil spring is designed to create a biasing effect inside the barrel, forcing the crown tip to stay in intimate contact with the inner surface of the barrel. Using this biasing feature, current flow follows a crown-barrel-plunger path and keeps the spring out of the conductive path.[11] The contact pin's crown head enables a reduction in the damaging contact to the solder ball.

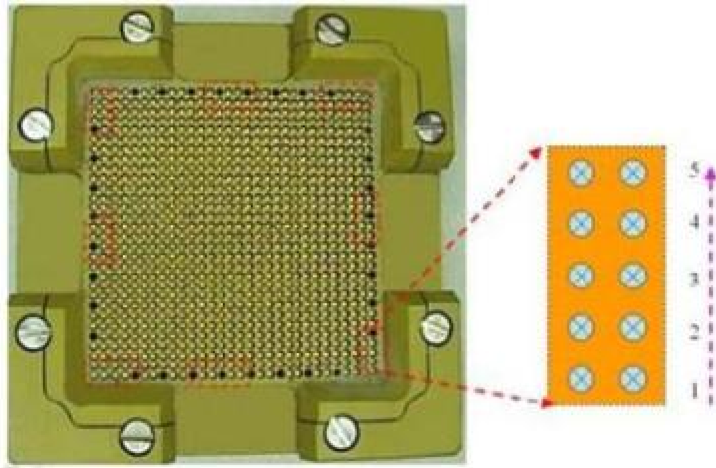

Figure 5: The pin of experiment takes a sample in the position and the sequence

Apparatus and Experimental Procedure

A lot of contamination impact can be found on the contact failure phenomena. Accordingly, the results based on the peripheral area found here can be extended further as an inference point to other socket positions. The analysis samples of wear rate chosen for the surface and electrical studies were tested for one day on a production line. The touchdowns were scrubbed against the surface of solder ball for 6830, 13630, 20810, 27550, and 36580 contacts, respectively. To ensure that the worn-out conditions were representative of those obtained in industrial socket pin tests, the contact point of the crown tip on the solder ball surface was cleaned using an air gun for every 2000 touchdowns.

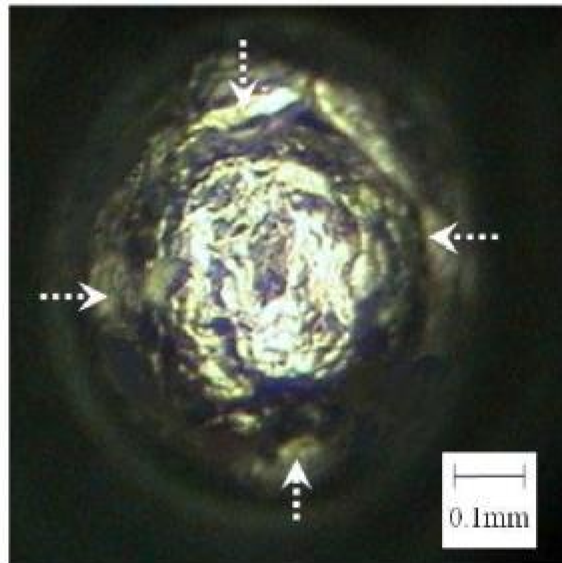

Figure 6. The mark image of solder ball after the crown tip touchdown

Results

Analysis was performed in a multi-technique surface analysis apparatus using OM, SEM, and EDX. The decomposition elements on the contact surface were observed by OM and SEM to analyze the morphology and elemental composition of the solder ball, contact, and socket surface. Surface analysis of the BGA socket helped investigate possible deterioration of the surface with contamination from the socket. The properties of the contact surface on the solder ball play an important role during final testing. Surface properties and removal rates were assessed by analyzing the contaminate material.

The solder ball after crown tip touchdown (taken with OM) is shown in Figure 6. The arrows in the image indicate the region where the contact marks the solder ball after final testing. In BGA applications, the surface of the solder ball must not be seriously disturbed or damaged by the test socket. If a damage mark, dent, or pocket is formed on the solder ball surface, flux may be trapped, leading to a poor interconnect during the reflow process. In addition, any disruption to the bottom of the solder ball may increase the overall coplanarity error of the device, interfering with device placement.

Figure 7. Optical micrograph of contaminated socket surface

Researchers used OM to observe a failed contact surface (Figure 7) after 2 hours in the final testing line. The particles dispersed in the socket and contact pin surface. The contact point surface becomes a contamination layer. Therefore, the pollutants increased gradually with touchdowns, causing contact failures. SEM image analyses performed on the used-socket and BGA substrate had a magnification of 150 ×. The magnification allows for optimum identification of the contaminated area.

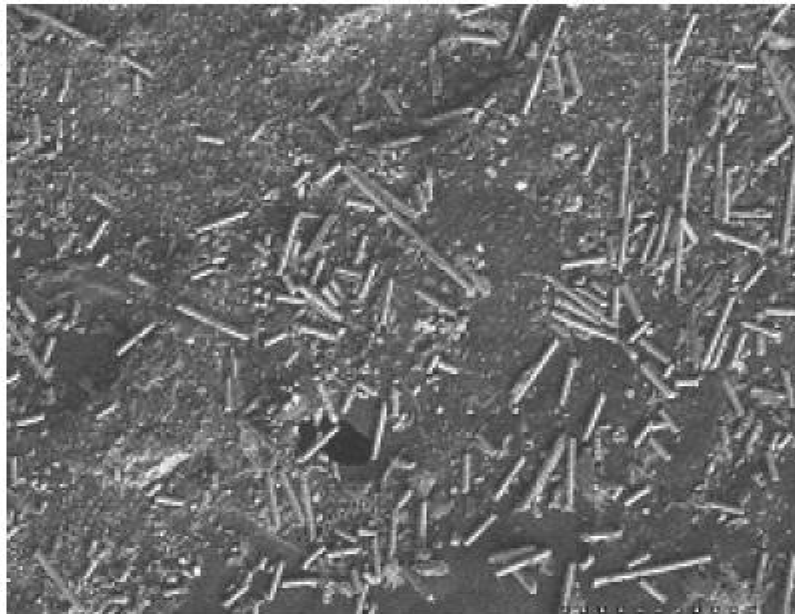

Figure 8. SEM images of the socket surface deposit and the intermediate layer of the substrate

Figure 8 shows the SEM images of socket surface deposit and the intermediate layer of the substrate. The results confirm that the socket's surface contamination was from repeated final testing. As discussed above, this contamination increases the contact resistance between the pogo pin and the solder ball, and therefore the socket must be periodically cleaned to obtain reliable measurement results, though it is infeasible to establish an appropriate cleaning schedule by quantifying the precise number of particles adhered to the crown tip. Therefore, this study concentrates on the BGA package substrate contamination. A suitable cleaning schedule can be established by examining the tradeoff between the first testing yield, the compress force, and the number of touchdowns.

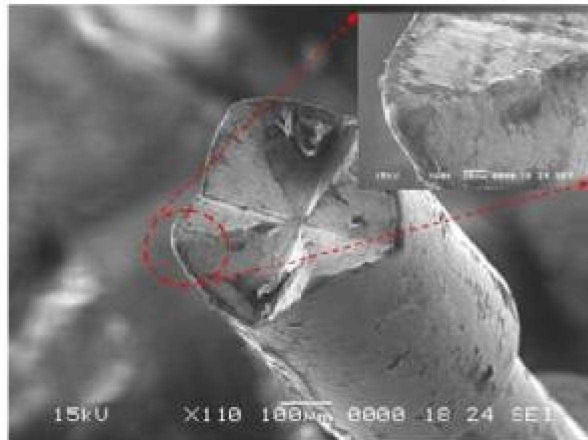

Figure 9. SEM images showing worn-out of crown tip after 6,830 touchdowns

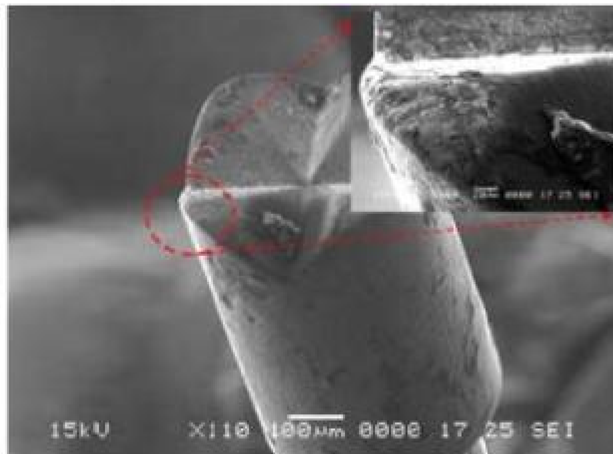

Figure 10. SEM images showing worn-out of crown tip after 36,580 touchdowns

In general, compression force is specified in the socket housing in conventional final testing. However, more compression may be required to achieve a stable contact resistance when the crown tip is contaminated with surface particles. Figures 9 and 10 present SEM images of the tungsten crown tip in 6830 contacts and 36580 contacts, respectively. The surface-flattening effects on the crown tip are significant from Figure 9 to 10. The correlation between surface-flattening effects and touchdowns per day with testing conditions is important. After five days of touchdown operations in IC testing, the height of crown head decreases (Figure 11). Average tip length and worn-out length measurements indicate that abrasion on the crown tip is dependent on the number of touchdowns.

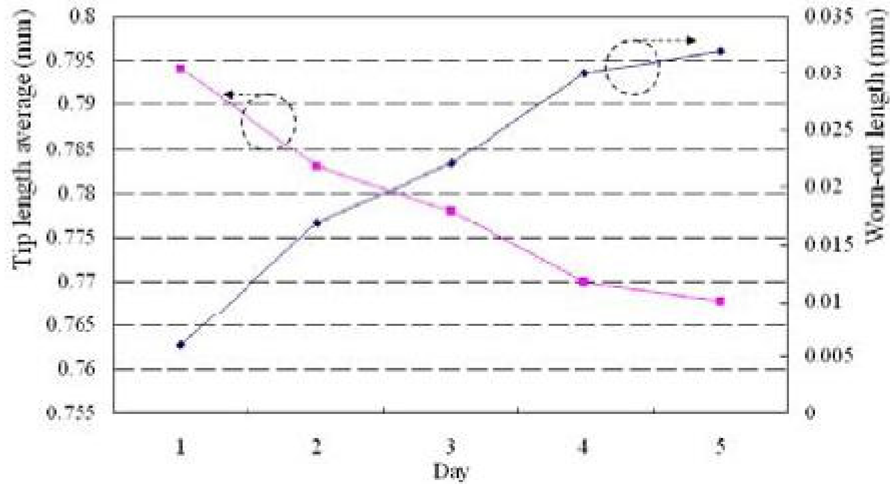

Figure 11. Variation of touchdowns for crown tip worn-out

The contact pin was gold-plated for good electrical contact. We can observe the gold peak from EDX measurement at 6830 touchdowns. When the crown tip of the contact pin was worn-out at 36580 touchdowns, the EDX shows the nickel element, which is the composite of the contact pin without gold plating. The worn-out and contact area of crown tip increase, but also become less stable for testing. The fretted surface was irregular and rough. As discussed above, wear on contact pins is the result of motion and can lead to a degraded contact interface, affecting contact resistance stability. A burnished surface is desirable for initial mating. The effect of a dust particle at the burnish area of the crown tip can be magnified as an area of influence; a particle lying inside the actual area of contact may increase the contact resistance and decrease the depth of penetration into the solder ball. In practical electrical interfaces, electrical contact is made at discrete spots determined by localized asperities of the surface roughness.[12,13] If the interface is clean, contact resistance arises from the constriction of electrical current at contact spots. The contact resistance of these spots depends on the mechanical contact load[12] and generally varies from sub-micron to several tens of microns. The contact resistance distribution for an individual crown tip in the high resistance area has a remarkable influence on signal transmission reliability.

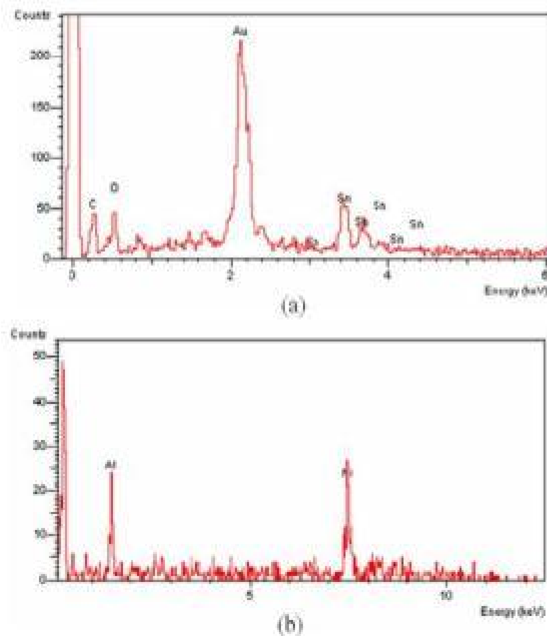

Figure 12. EDX pattern of the worn-out crown tip (a) for 6,830 touchdowns in Figure 9 and (b) 36,580 touchdowns in Figure 10

The contaminant layer deteriorates electrical signal reliability, increasing contact resistance. Even with the contact surface covered with oxidation films, it is possible to recover low contact resistance by using higher spring compression force and handler pusher force. The contacts pins are brought in mechanical contact with solder balls and electrical contact is made as the contacts scrub through the oxide and contaminants on the crown surface. Scrub damage can adversely impact the SMT quality at PCB assembly and add extra costs by lowering assembly yields.

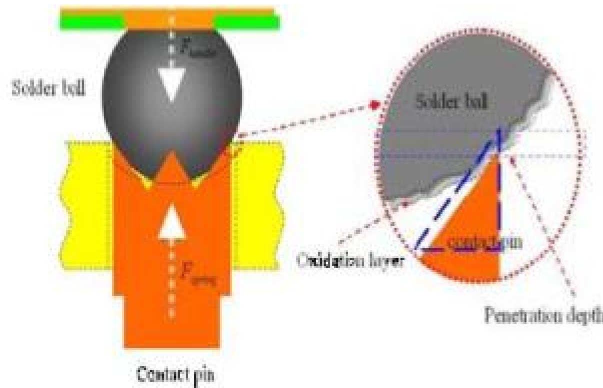

Figure 13. Schematic illustration of the contact resistance by the micro-motion and the penetration depth

A faulty socket can be due to broken, worn-out, or contaminated contact pins. The major cause of test rejection is a contaminated contact surface. Dust particles cause electric contact failures that seriously influence device reliability.[14,15,16] Determining the contact resistance distribution plays a vital role in assessing the operating reliability of the device.[17] When a contact force is applied, the real contact area is generally less contaminated than the surrounding area. However, micro-motion, which is caused by vibration of handler and tester, may possibly move the real contact to the contaminated area, causing contact failure. This micro-motion is shown in Figure 13. It is noted that this contact failure is due to the combined effect of vibration and contamination. Thus, it could not be found in the vibration or impact testing of a new socket.

The greatest challenge with BGA socket test is avoiding damage to the solder balls while maintaining a high compression force and a stable contact resistance.[3] A high compression force caused a lower initial value of the contact resistance; this is to be expected because of the decrease of the constriction resistance (R_C). The contact resistance of plated contact members with conducting contamination file can then be expressed as[12,18]

$$R_C = \frac{\rho_b p_p}{2}\sqrt{\frac{H\pi}{F_C}} + \frac{\rho_f d_f}{F}$$

where F_C is the contact force, H is the hardness of the contact material, b_ρ the specific resistance of the contact material and b_p is the plating factor of the contact finish material to the base metal, f_ρ is the electrical resistivity of the conducting contamination film at the contact interface, and f_d is the thickness of the conducting contamination film at the contact interface. Therefore, the contact resistance is a function of touchdown force and spring force.

Conclusion

Socket contact degradation can significantly degrade first test yield and increase retest time. The performance of electrical contacts in final testing is dependent on the mechanical and electrical stability of the interface mating. Due to oxidation, contamination, or electrical instability, BGA solder ball degradation can occur. Comparisons done with surface analyses of contact pins and socket base with a BT layer of substrate indicate a layer of fiber debris from a punch surface on the substrate and socket surface. The fiber debris buildup on the contact pin crown forms a high electrical resistance between the crown tip and the solder ball, creating the most common

failure conditions for the low yield of IC testing. The contact degradation studied in this work can be used as a good contact clean guideline. A good clean socket can contribute to the overall performance and profitability by reducing retest rates. In addition, it can reduce the cost of maintaining test fixtures, improve final test reliability, increase first pass yields, reduce retest time, and eliminate false "good parts" readings.

ACKNOWLEDGEMENTS:
This research was partially supported by National Science Council, Taiwan, R.O.C., under Grant NSC97-2218-E-214-001.

REFERENCES:
1. R.C. Marrs et al., Ball Grid Array Technology, McGraw-Hill Book Company Inc., (USA, 1995), pp. 6-36.
2. Advanced Semiconductor Engineering Inc., http://www.asetwn.com.tw/.
3. Siliconware Precision Inc., http://www.spil.com.tw/.
4. Qiao, Q., et al, "Development of a Wafer-Level Burn-In Test Socket for Fine-Pitch BGA Interconnect," Proceedings, 50th Electronic Components and Technology Conference, May 2000, pp. 1147-1151.
5. Chowdhury,S. et al, "A MEMS socket system for high density SoC interconnection," IEEE International Symposium on Circuits and Systems, 2002. ISCAS 2002. Vol. 1 (2002), pp.I-657-I-660.
6. Shih, D.Y. et al,, "New ball grid array module test sockets," Proceedings 46th Electronic Components and Technology Conference, May 1996, pp. 467-470.
7. Chan, B. and Singh, P., "BGA sockets-a dendritic solution," Proceedings, 46th Electronic Components and Technology Conference, May 1996, pp. 460-466.
8. Chan, B. and Singh, P., "BGA sockets-a dendritic solution," Proceedings, 46th Electronic Components and Technology Conference, May 1996, pp. 460-466.
9. W. Liu, M. Pecht and R. Martens, "IC Component Sockets: Applications and Challenges," IMAPS, Vol. 24, No. 1, First Quarter (2001), pp. 61-67.
10. Chen, M.K. et al, "Electrical Characterization of BGA Test Socket for High-Speed Applications," 4th International Symposium on Electronic Materials and Packaging, Kaohsiung, Taiwan, 2002, pp. 123-126.
11. R. Knudsen, "Good Contact Design Improves Test Performance in BGA/CSP Applications," Chip Scale Review, May 1998.
12. Holm, R., Electric Contacts, Theory and Applications, Springer-Verlag, (Heidelberg, 2000).
13. R. Mroczkowski, Electronic Connector Handbook: Theory and Applications, McGraw-Hill, (New York, 1998), pp. 210-236.
14. Zhang, J. G., Wen, X. M., "The Effect of Dust Contamination on Electric Contacts," IEEE Trans-CHMT, Vol. CHMT-9, No. 1 (1986), pp.53-58.
15. Boyer, L. et al, "Electrical and Physical Modeling of Contact defect Due to Fretting," IEEE Trans-CPMT, Vol. 17, No. 1 (1994), pp. 134-140.
16. Xie, J. et al, " Assessing the Operating Reliability of Land Grid Array Elastomer Sockets," IEEE Trans-CPMT, Vol. 23, No. 1 (2000), pp. 171-176.
17. W. Liu and M. Pecht, IC Component Sockets, John Wiley & Sons, (New Jersey, 2001), pp. 100-137.
18. Wu, J., and Pecht, M.G., "Contact Resistance and Fretting Corrosion of Lead-Free Alloy Coated Electrical Contacts," IEEE Trans-CPMT-A, Vol. 29, No. 2 (2006), pp. 402-410.

Ching-Mai Ko, Ming-Kun Chen, Yu-Jung Huang, and Shen-Li Fu, department of electrical engineering, I-Shou University, Kaohsiung, 84008, Taiwan, R.O.C., may be contacted at yjhuang@isu.edu.tw and mkchen25@ms75.hinet.net.