An Investigation of the Contact Resistance of a Commercial Elastomer Interconnect Under Thermal and Mechanical Stresses

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***Abstract*—The contact behavior of a commercial elastomer interconnect, composed of silicone rubber and silver particles, was evaluated under thermal and mechanical stresses. Its contact resistance demonstrated a linear relationship in a log-log plot with contact force at room temperature; however, a deviation of the trend occurred when temperature was changed. With the interconnect compressed under a constant force, a fluctuation in contact resistance was initiated by a change of temperature. This phenomenon may be attributed to the inherent conduction mechanisms of the elastomer interconnect. The multiple interfaces between metal particles make the contact sensitive to a variety of factors. This sensitivity may have a direct impact on its long-term reliability.**

***Index Terms*—Contact resistance, elastomer interconnect, reliability, socket.**

I. Introduction

ONE OF THE trends in the integrated circuit industry involves the use of area array technologies for very high I/O pin counts to help in device and product development, as well as in test and burn-in, more socket manufacturers are shifting to elastomer technology to provide interconnect solutions with high compliance, high cost effectiveness, and high manufacturability. Two major types of elastomer designs are the wire-in-elastomer and the particle-in-elastomer. The former utilizes metal wires, such as gold, brass, nickel, and even steel, embedded in the elastomer matrix. This design is mainly used for test and burn-in applications. The latter utilizes metal particles, such as silver and nickel, and is used for production as well as test and burn-in applications.

The metallized particle interconnect (MPI) developed by Thomas and Betts [1] has attracted wide attention and interest. This design uses silver particles embedded in silicone rubber. The mixture is molded into arrays of small buttons on a Kapton carrier. This design is known for its high I/O capability (5000 I/Os projected), low cost (one cent per contact projected), and high contact compliance.

A challenge for implementing the elastomer sockets is concern about reliability, largely associated with the elastomer matrix. Elastomers are known for their high stress relaxation, high creep, high coefficient of thermal expansion (CTE), and high compression set [2], [3]. These properties are highly dependent on thermal and mechanical stress states. An understanding of these conditions and their associated effects on contact behavior will ensure a successful application.

Previous studies have shown that, in order to prevent problems associated with the high stress relaxation and high CTE of the elastomers, constant-force clamping hardware is recommended [3]. However, using this hardware will not necessarily eliminate the problems. Under constant force, the elastomer interconnect is subject to creep, which in turn may cause a continuous change of contact interface parameters, such as contact area. These interfaces are not only the "primary" interfaces between the interconnect and the package or board pads, but also the "secondary" interfaces between metal particles. During elastomer creep, the positions of the metal particles may undergo continuous change, as will the contact area between them. Under power or temperature cycling conditions, a quick temperature change may lead to a sudden shift or even separation between metal particles, causing contact problems.

Unfortunately, we still do not have a fundamental understanding of the contact behavior of the elastomer interconnects under a variety of environmental conditions. Furthermore, qualifying elastomer sockets based on EIA standards does not necessarily mean that they will survive the intended application lifetime. That is, qualification without having appropriate acceleration factors provides no information concerning the useful life of the socket in the actual application [4], [5].

Studies are needed to provide insight into the potential failure mechanisms of the contacts, to reveal the acceleration factor of the elastomer interconnects under accelerated test conditions, and to yield the technology margin—such as operating temperature limits and operating deflection range—in which the elastomer interconnects should work reliably.

This paper discusses a recent study of a commercially available particle-in-elastomer interconnect. The purpose of this study is to probe the contact behavior of the elastomer interconnects under mechanical and thermal loading.

II. Experiment

The study was conducted on an MPI1 socket designed by Thomas and Betts (acquired by Tyco in 2000). Fig. 1 shows a land grid array (LGA) elastomer socket with 787 silver-particle-filled elastomer buttons housed on a Kapton carrier, and Fig. 2 shows the cross section of an elastomer button.

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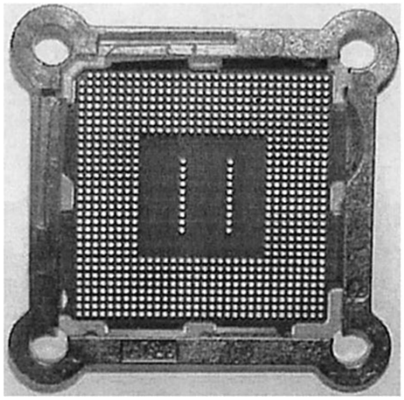

Fig. 1. Top view of an LGA elastomer socket. (Courtesy of Thomas and Betts.)

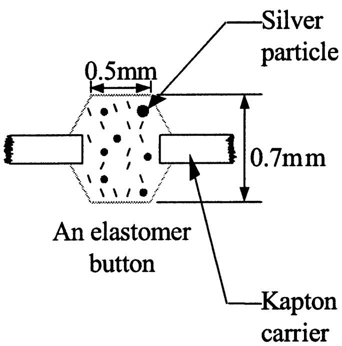

Fig. 2. Cross section of an elastomer button.

The study was composed of two experiments. First, the contact resistance versus contact force was examined at different temperatures. Second, the contact resistance was investigated as a function of temperature under constant loads, to simulate real applications in which the elastomer interconnects are clamped under a constant force. The experiments were conducted on single interconnects, with a sample size of five interconnects for each experiment.

A controlled-strain testing instrument was used to measure the button stiffness and creep. During the measurement of interconnect stiffness (defined as the applied force over the apparent deformation), an actuator deforms an interconnect at a preset compression rate and a transducer measures the corresponding force. For creep testing, the actuator deforms the interconnect until the preset force is reached; afterwards, the actuator maintains the force at a constant value. A host computer controled all the measurements.

In order to measure the contact resistance simultaneously, a steel substrate and probe were mounted on the sample stage of the testing instrument. The substrate and probe were plated with 0.76-μm gold over 2.54-μm nickel. Since the substrate does not have holes in which to insert the socket alignment pins, the socket interposer was peeled away from the socket frame so the interposer could lie evenly on the substrate. Tape was used to bind the interposer to the substrate to prevent its movement. Then the substrate was moved to align an interconnect in the center of the interposer with the probe.

Fig. 3 shows a schematic of the experimental setup (only one interconnect is shown). The measured contact resistance of the elastomer button is composed of three parts: the interfacial resistance between an interconnect and the probe, the bulk resistance of the interconnect, and the interfacial resistance between the interconnect and the substrate. The bulk resistance consists of constriction resistances between metal particles, tunneling resistance at the contacts, and the intrinsic filler resistance through each particle. Many papers have discussed the electrical resistance of composite materials and showed that it is strongly temperature dependent [6]–[8].

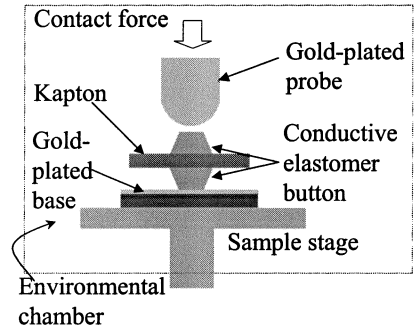

Fig. 3. Experimental setup.

The experimental procedures investigating the contact behavior under thermal and mechanical stresses are described in the following.

1) Examine the contact resistance as a function of contact force at different temperatures. After aligning a button with the probe, the probe was lowered to touch the button surface. The chamber was closed and the temperature was increased. During the temperature ramp-up, the elastomer will expand or contract due to the CTE of the elastomer buttons. Therefore, it is necessary to adjust the probe position simultaneously to offset the contact displacement and maintain a zero initial force. After the temperature was stabilized and no thermal stress was recorded, the elastomer interconnect was compressed at a strain rate of 0.1% per second. The contact resistance was monitored simultaneously using the four-wire Kelvin method.
2) Examine the contact resistance as a function of temperature with the contact force kept constant. This corresponds to the real scenario where support hardware, usually metal springs, applies a constant force on the elastomer interconnects. This measurement utilized the stress relaxation function of the instrument. After reaching the preset contact force for 30 s, a temperature profile (either increasing or decreasing) was imposed. The contact resistance, deformation, and contact force were monitored simultaneously.

III. Results and Discussion

Figs. 4 and 5 show the average contact resistance versus contact force at different temperatures. At room temperature, the contact resistance shows a trend of linear reduction on a log-log scale with contact force until the contact force reached 80 g. Above 80 g, the contact resistance shows a small increase and becomes flattened. The experiment did not go beyond 100 g, since the application force is likely to be less than 100 g.

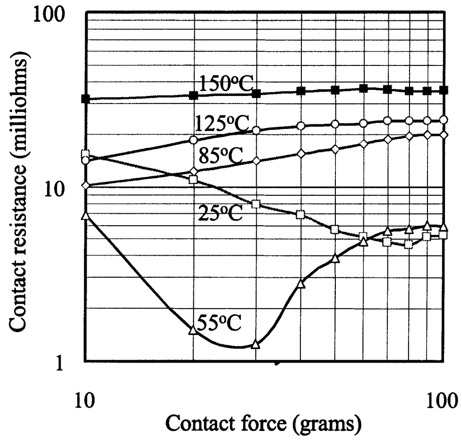

Fig. 4. Contact resistance as a function of contact force and temperature over 25 °C.

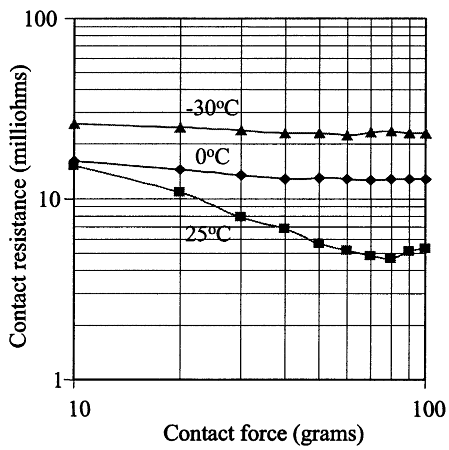

Fig. 5. Contact resistance as a function of contact force and temperature below 25 °C.

The flattening phenomenon seems to be associated with the lateral spreading of the elastomer buttons. When an elastomer button is compressed, it expands laterally, while its height reduces. This lateral expansion will cause a separation between the silver particles, even though the height reduction will bring the particles closer. These two trends will compete against each other. At low force conditions, the height reduction will dominate; however, at a high force, the lateral spreading may become a more important factor—from the figure, the turning point is around 80 g.

When the temperature increases, the elastomer buttons become softer; therefore, we can expect a reduction in the turning point. At 55 °C, the turning point was around 25 g, and the contact resistance showed an increase. However, the increase rate of the contact resistance seemed to slow down when the temperature reached 150 °C. One possible reason is that the increase in temperature increases the electrons' capability to overcome the barrier between particles.

When the temperature was lowered below the ambient, the contact resistance showed a linear decrease on the log-log scale when contact force increased, in contrast to the phenomena observed at higher temperatures. Presumably, the higher rigidity of the elastomer interconnects at lower temperatures makes them resistant to lateral spreading and thus prevents an increase of contact resistance in the measured range. However, it is possible that contact resistance will tend to increase when the force goes beyond 100 g.

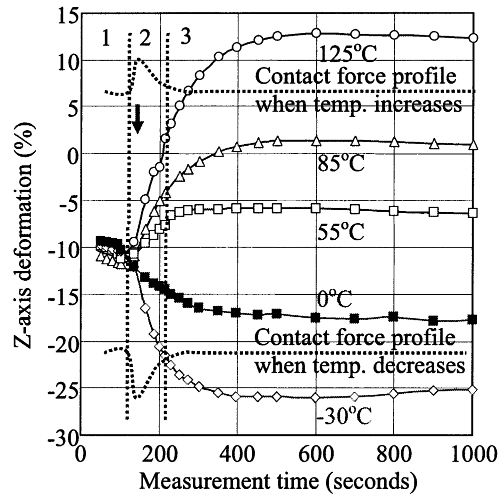

Fig. 6. Z-axis deformation as a function of temperature. The temperature is divided in three zones: zone 1, initial temperature; zone 2, temperature ramp; zone 3, final temperature.

Another observation is that the curves of contact resistance versus contact force shifted upwards at temperatures of −30 °C, 0 °C, 85 °C, 125 °C, and 150 °C, as compared with contact resistance at room temperature. When the temperature increases, the elastomer will expand. This expansion will separate the metal particles, and an upward shift may result. However, 55 °C is an exception. At this temperature, the decrease in contact resistance caused by increased electron energy may be dominant enough to override the increase in contact resistance caused by thermal expansion. When the temperature is lowered, the electrons will be deactivated, therefore the resistance rises. However, the condensation of water on the contact interface when the temperature is lowered must be considered in reliability analysis.

Contact behavior under temperature change conditions was also examined. In actual applications, the sockets may experience a number of temperature cycles, not only due to ambient temperature changes during usage and transport, but also due to power cycling. This change may cause micromotion at contact interfaces and affect contact stability. In our previous paper [3], a constant-force clamping mechanism was recommended for this elastomer socket design; therefore, in this study we applied a contact force (30, 50, and 80 g, respectively) on the elastomer interconnects while subjecting them to changing temperatures. Fig. 6 shows the change of contact z-axis deformation (with regard to the original height of the interconnects) and Fig. 7 shows contact resistance with temperature under a contact force of 50 g.

Due to the increase in temperature, the elastomer expands; therefore, the apparent contact deformation increases in the positive direction. During the decrease in temperature, the elastomer contracts, and the apparent contact deformation increases in the negative direction. Although a constant force was applied, a disturbance of contact force (around 10%) was observed

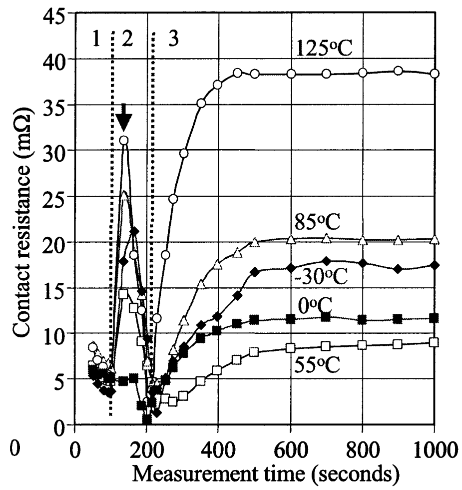

Fig. 7. Contact resistance as a function of temperature. The temperature is divided in three zones: zone 1, initial temperature; zone 2, temperature ramp; zone 3, final temperature.

during the ramp-up of temperature, possibly because the transducer could not respond quickly enough to the ramp of temperature, which usually takes about two minutes.

With the start of temperature ramp-up, the contact resistance shows an initial sharp increase and then falls dramatically; when the temperature reaches stabilization, the contact resistance increases again and eventually stabilizes. This fluctuation in contact resistance occurs at the same time as the fluctuation in z-axis deformation. Temperature changes to 55 °C and 0 °C show the smallest fluctuation in contact resistance.

The observed fluctuation in contact force and a change in the secondary contact interfaces (interfaces between metal particles inside the bulk interconnect) may be responsible for the dramatic change of contact resistance, since they outnumber the major contact interfaces (interfaces between metal particles and contact probe and substrate). With a temperature increase, the elastomer interconnect starts to expand. However, the testing probe may have the inertia to remain in the same position; correspondingly, extra interface stress may be generated and cause further radial expansion of the interconnects, resulting in an increase in the contact resistance. The extra interface stress is gradually relaxed, and a further increase in temperature will cause a reduction in the tunneling resistance. The temperature finally stabilizes; however, the interconnect continues to expand. The separation between metal particles eventually raises the contact resistance.

With a decrease in temperature, the interconnect begins to contract. The elastomer contraction keeps metal particles closer, causing a reduction in the contact resistance. When the temperature finally stabilizes, the deactivation of electrons and ice formation on the contact interfaces may be responsible for the increase in the contact resistance.

IV. Conclusion

In summary, a variety of mechanisms may be responsible for the observed contact behavior of the particle-in-elastomer interconnects, as its contact resistance is closely related to its mechanical, thermomechanical, and physical properties, due to the composite structure. The effect of temperature on the interconnect stiffness, lateral spreading, thermal expansion and contraction, and tunneling effect, among other things, may be factors affecting the contact behavior of the elastomer interconnects. These factors exhibit themselves as sensitivity of the contact resistance to external disturbances, such as force and temperature.

To successfully apply the elastomer sockets, a clear understanding of these factors and the influence of application conditions is necessary, their technology limits, such as the operating temperature range and the contact deflection range, must be established. The application conditions must be assessed before implementation to see if they fit in the operating window of the interconnect in order to keep the contact sensitivity under control and ensure a stable contact interface.

The composite structure of the particle-in-elastomer interconnect is believed to be responsible for its sensitivity to mechanical and thermal stresses. The effect of temperature on the interconnect stiffness and tunneling resistance, thermal expansion and contraction, and lateral spreading may contribute to the contact instability of the interconnects under applied stresses. It is crucial to understand the technology limit of this elastomer design before its application in order to keep the contact instability within preset limits.

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