

Temperature Rise Measurement due to Joule Heating in a Stamped Metal Land Grid Array Socket

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Abstract

Land grid array (LGA) sockets provide a solderless Printed Circuit Board (PCB) attachment method for microprocessors that require high interconnect densities. Stamped metal LGA sockets consist of metal contacts embedded in a plastic housing, that form the electrical and mechanical connection between the LGA component and PCB by means of compression.

The numbers of cores in a microprocessor has been increasing in recent years, placing demands for increased current-carrying capability on the interconnect. As greater currents pass through the interconnect, the temperature rise due to Joule heating is expected to accelerate failure mechanisms such as stress relaxation, cause melting of the surrounding polymer, or lead to a thermal runaway condition. The goal of this study is to determine the temperature rise due to Joule heating in stamped metal sockets, as close as possible to the powered contact. Measuring the temperature rise associated with current at a contact, allows failure models for appropriate thermally induced failure mechanisms to be applied and a risk assessment to be performed for the specific failure mechanism. In this study both temperature and resistance were monitored in a current induced aging test, which allowed detection of a thermal runaway condition at overstress currents. A temperature rise due to Joule heating was detected at an operating condition, but thermal equilibrium was quickly reached.

Keywords: *LGA socket, Stamped metal contact, Elevated current, Joule heating.*

Introduction

The number of cores in high-end microprocessors has been increasing in recent years, in an effort to meet increasing performance requirements. The International Roadmap for Semiconductors (ITRS) projects the number of cores to increase 1.4 times per year for networking applications [1]. The required processing power is expected to increase 300 times in the next 15 years, and power consumption is expected to increase five fold by 2015 for the non-portable electronics segment. Voltage has been scaling downward in an effort to cap power consumption, but there is a limit to how low voltage can scale. Low threshold voltages can make the gate turn on due to noise. Therefore, as performance requirements increase in the coming

years, the amount of current passing through the component interconnect is expected to rise.

Land Grid Array (LGA) packaging is commonly used in high-end microprocessors that require high interconnect densities. An LGA socket is used as a solderless attachment method to connect an LGA component to a PCB. The traditional method of attaching a microprocessor to a Printed Circuit Board (PCB) is by soldering. As performance requirements increase, larger package footprints are required in order to accommodate the increased I/O requirements. The Coefficient of Thermal Expansion (CTE) mismatch between a component with a large footprint and the PCB may cause reliability issues such as solder ball cracking. The use of LGA sockets eliminates the limitations on package footprint by providing a separable interconnection method.

Furthermore, the microprocessor can now be easily upgraded, repaired or tested. The use of LGA sockets therefore, allows the microprocessor component to be easily upgraded or repaired and eliminates the reliability risks to the package associated with soldering [2][3][4].

Higher currents through smaller interconnects increase the risk of Joule heating and may cause stress relaxation, melting of the surrounding polymer, or lead to a thermal runaway condition [5]. The objective of this study is to measure the temperature rise due to Joule heating as close as physically possible to the contact. An approximation of the contact temperature may then be used in a failure model in order to assess reliability risks for thermally accelerated failure mechanisms such as stress relaxation, electro-migration or thermo-migration.

The socket under study (Figure 1A) is a stamped metal socket with C-shaped (Figure 1C) contacts housed in a Liquid Crystal Polymer (LCP) matrix that provides alignment features and physical protection during handling. The contacts are made of copper beryllium alloy and protected from environmental exposure by a gold finish that is typically 30 microinches thick [2]. A nickel barrier layer between the base metal and the gold plating has been shown to protect the contact alloy from pore corrosion and is typically at least 50 microinches thick [6]. During operation the LGA socket is compressed between an LGA component and a PCB using compression hardware [2][7].

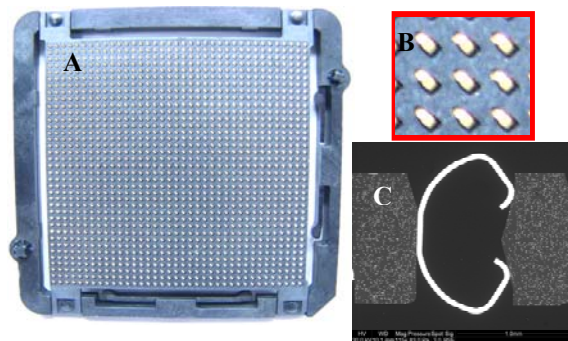


Figure 1 A: Stamped Metal Socket; B: Detail of contacts embedded in LCP housing; C : Cross section of a stamped metal contact.

Experimental Set-up

The experimental set-up is illustrated in Figure 2. The contacting plates were copper disks plated with 30 microinches of gold over 50 microinches of nickel in order to simulate the contact interfaces in a typical LGA socket assembly. A 10-A

power supply was used to force a specified amount of current through the contact. The resistance was measured using a milli-ohmmeter with a 4-wire method. The upper disk was attached to the loading plate of a compression tester and the applied force was measured using a force gauge. The lower disk was attached to a hot plate in order to simulate the presence of a powered die in an enterprise server application where operating temperatures can range from 70 to 100 °C. A piece of the socket with a single contact was placed on the lower copper disk and the upper copper disk was brought into contact with the sample using the loading lever on the compression tester. The wheel-based loading lever on the compression tester allowed the displacement to be controlled, which was maintained constant during the test. Double-sided Kapton tape attached to the non-contacting surfaces of the copper disks was used to electrically isolate the contact system from the rest of the set-up. A thermocouple was placed as close as possible to the contact. The location will be described for each test sample.

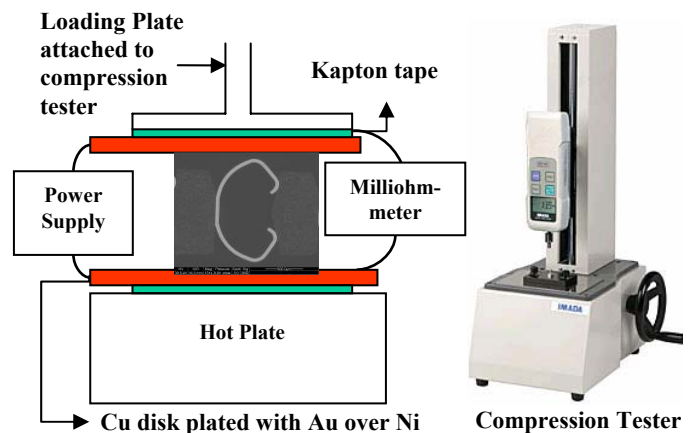


Figure 2: Experimental set-up consisting of a compression tester, power supply for applying the current and a milliohm-meter for measuring resistance

Experimental Procedure

The resistance measured by the milliohm-meter consists of two resistances in parallel, the power supply resistance and the resistance of the test sample. The resistance of the circuit was measured without the sample and with the plates apart. This was measured to be 300 mΩ and was subtracted out from the effective resistance using the law of parallel resistances, in order to obtain the resistance of the contact. Note that when contact is not sandwiched between the disks, there is still a closed path for the

current and this effective “open” circuit resistance is 300 m Ω .

Three samples, each with one contact, were tested using a compression force of 130 g, and current levels of 9, 7.5, and 3 A, respectively. The 9 and 7.5-A test conditions were chosen to represent accelerated conditions, while 3 A was chosen to represent an operating condition of 1-3 A in stamped metal LGA sockets [2]. Each sample was placed between the contacting copper disks and compressed to a specified force. The hot plate was turned on, and when thermal equilibrium was reached, the contact was powered on. The lower copper disk was maintained at a temperature of 80°C.

Experimental Results

For a current of 9 A, an open was detected after 2000 seconds (Figure 3). The effective resistance (of the contact and the power supply loop) measured by the milliohm-meter was approximately 300 m Ω at the end of the test, indicating an open at the contact surfaces. Such a large increase in resistance would be considered a failure in a functional circuit. The failure criterion for LGA sockets is an increase in contact resistance by 20 m Ω or greater [9].

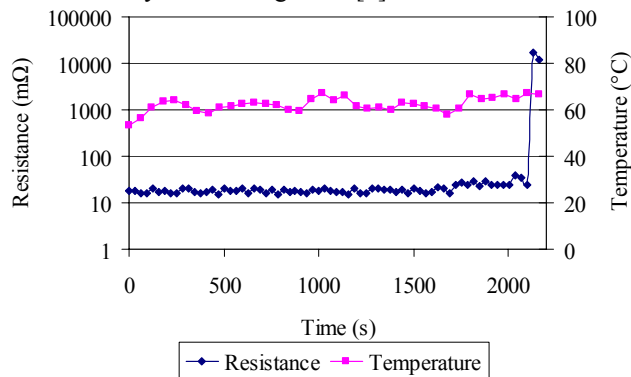


Figure 3: Resistance and Temperature vs. Time for test condition of 9A, 120-g force.

The temperature rise due to Joule heating for the 9-A test condition could not be captured using a 30 AWG (10-mil wire diameter) thermocouple placed in a cavity adjacent to the powered contact. Subsequent tests with a finer 40 AWG (3-mil wire diameter) thermocouple allowed closer placement to the contact, and the temperature rise could thus be captured. While both the 9 and 7.5-A tests were at overstress conditions that may not be representative of failures during operating conditions, they offer important clues on which regions of the contact may be experiencing the highest temperatures.

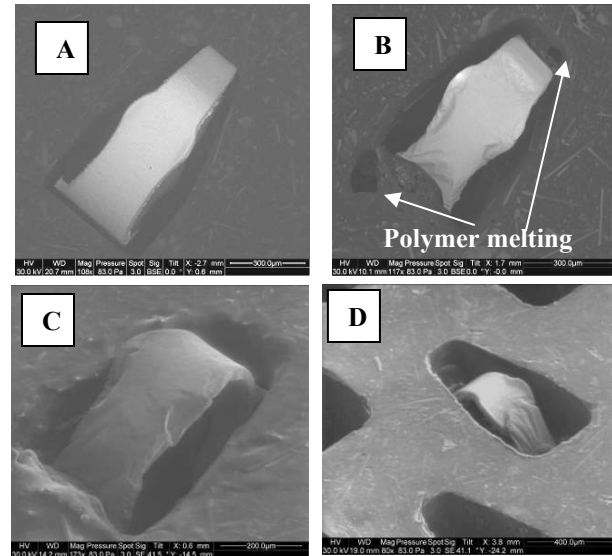


Figure 4 A: Pristine contact; B: Top view E-SEM image after failure at test current of 9 A; C: Tilted view of contact after failure illustrating contact deformation/softening; D: Tilted view of contact imaged from the back illustrating slumping of the contact as the cause of an “open”.

The failure analysis showed evidence of polymer melting and loss of contact shape and structure. Figure 4A illustrates a pristine contact where the contact and cavity structure are well defined. The two wing-shaped structures are the regions that make contact with the microprocessor component at the top and the PCB at the bottom. Figure 4B and Figure 4C show evidence of polymer melting as well as contact softening and deformation. A topographic image of the contact imaged from the back, with the socket sample flipped over, shows the contact slumping below the surface of the polymer (Figure 4D). Contact softening and deformation may have caused the contact to slump, leading to an open.

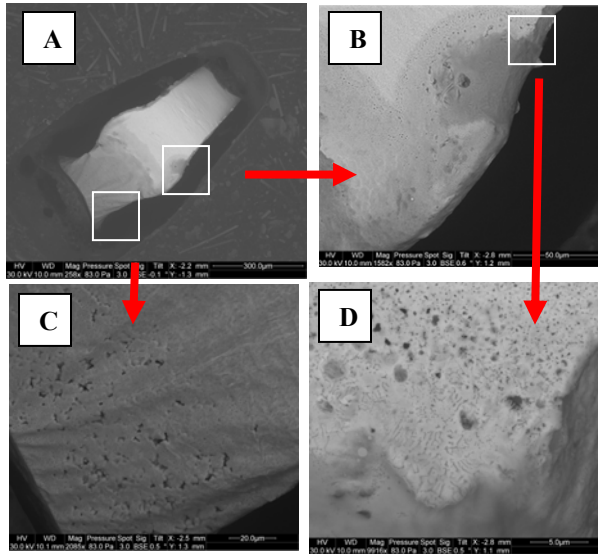


Figure 5 A: Backscatter image of failed sample at 9-A test condition imaged from the back; B: Detail of damage to wing structure. Darker regions are from exposed copper; C: Creep induced voiding at base of contact; D: Detail of creep induced voiding on wing structure.

A closer look at the backscatter images (Figure 5) of the back of the contact show significant damage to the contact structure at the base of the contact. While the two wing shaped structures are the source of the Joule heat, they are able to dissipate heat away since they are in contact with the copper disks. The regions of the contact that are adjacent to the polymer insulator are unable to effectively dissipate the heat and therefore show thermally induced damage. Figure 5A and Figure 5C show the most severe damage to the metal at the base of the contact, where wrinkle like features are observed. Creep induced voiding is evident in Figure 5C at the base of the contact and at the wing structure in Figure 5D.

The melting temperature for copper beryllium alloy is in the range of 1065 -1095 °C [8], and while contact melting is unlikely to have occurred, the temperature is high enough to induce severe plastic deformation and creep induced voiding. The softening temperature for copper is reported to be 190 °C [10]. Differential Scanning Calorimetry (DSC) measured the melting point of the polymer to be 320 °C. This value is in agreement with values reported in literature from 250 to 400 °C for Liquid Crystal Polymer (LCP) [6][8]. Since polymer melting was observed the temperature of the contact reached at least 320 °C.

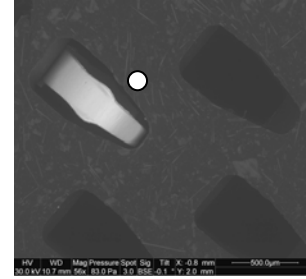


Figure 6: Approximate location of thermocouple

The second test condition was 7.5 A at 130 g compressive force. A finer thermocouple with a 3-mil wire diameter (40 AWG) was placed in the space between the powered contact and a neighboring cavity (Figure 6). A temperature rise of approximately 45 °C was observed as soon as the contact was powered on (Figure 7). Thermal equilibrium was not reached during the test, and both the resistance and temperature continued to increase until failure, in what appears to be a thermal runaway condition.

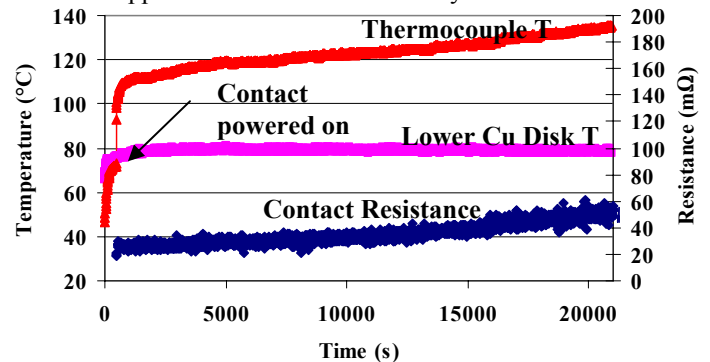


Figure 7: Resistance and Temperature vs. Time for 7.5-A test condition

Joule heating, I^2R causes a temperature rise in a connector. If the temperature rise is large enough to cause an appreciable increase in the electrical resistivity, then the resistance increases, producing more Joule heat. The associated temperature rise also causes the thermal conductivity of the metal to decrease. Less heat is now dissipated with more heat going into raising the temperature of the contact, leading to a thermal runaway condition as illustrated in Figure 8 [10].

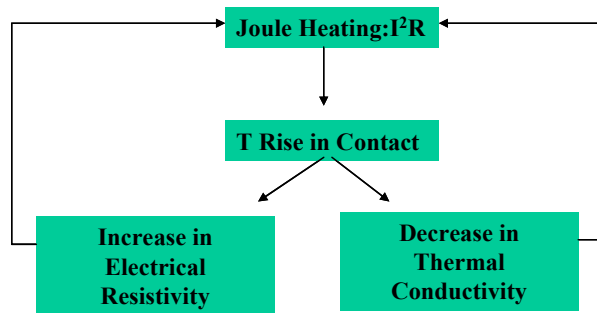


Figure 8: Illustration of a thermal runaway condition

Failure analysis of the contact structure showed evidence of creep induced voiding (Figure 9A) and what appears to be a thermo-migration effect. Figure 9A shows a sponge-like protruded feature on the wing shaped contact surface, while Figure 9C and Figure 9D show a similar feature when the contact was imaged from the backside. These protruded features may be from a thermo-migration effect. Energy Dispersive X-ray Spectroscopy (EDS) mapping showed the composition of the protruded features to be gold. An electro-migration effect would cause material to be transferred from the negatively charged surface to the positively charged surface and would involve deposition of material on one side of the contact and depletion on the other side. Since depletion of material was not observed from the underside of the contact, and both the top and bottom surfaces showed protruded surfaces it appears that the increased temperature at the contact interface was driving the material transfer. Electro-migration was therefore ruled out and thermo-migration hypothesized as the degradation mechanism responsible for the protruded features.

Figure 9B shows evidence of polymer residue at the base of the contact indicating that polymer melting occurred. Therefore at the 7.5-A test condition, the base of the contact reached a temperature of at least 320 °C.

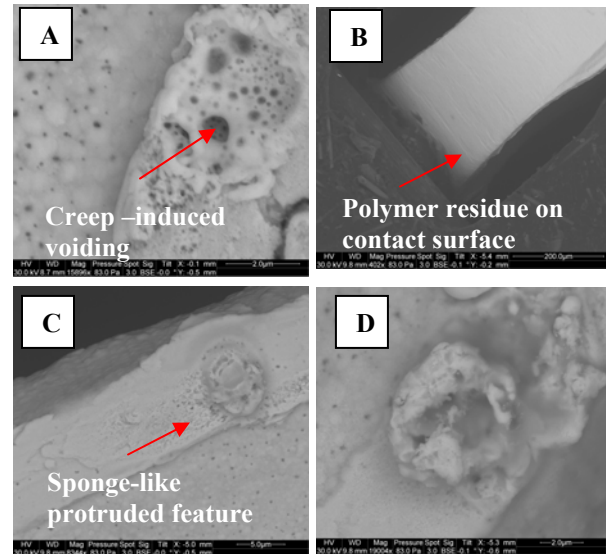


Figure 9 A: Illustration of creep induced voiding on contact structure; B: Evidence of polymer melting at the base of the contact; C: Sponge-like protrusion on contact surface, possibly from a thermo-migration effect; D: Close up illustrating thermo-migration effect.

For the 3-A test condition, while a temperature rise of approximately 30 °C was detected when the contact was powered on, thermal equilibrium was quickly reached (Figure 10). No appreciable change in resistance or temperature was detected after 20,000 seconds.

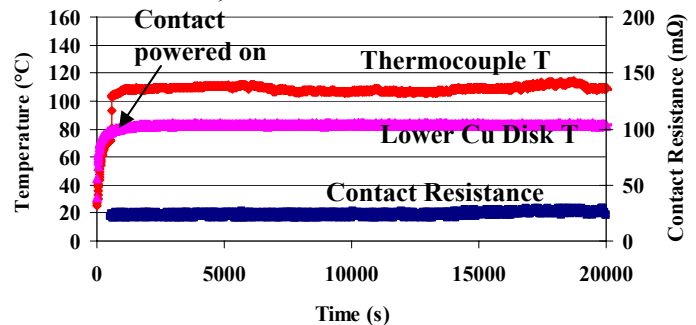


Figure 10 : Resistance and Temperature vs. Time for 3-A test condition.

Discussion

The results of the overstress tests at 9 A and 7.5 A show that the resistance increased continuously during the test, indicating a thermal runaway condition. While the temperature could not be captured in the 9 A test, the results of the 7.5 A showed increases in both the resistance and the temperature, till failure was eventually reached.

The temperature dependence of a material's electrical resistance is given by the expression

$$R = R_0 (1 + \alpha \Delta T) \quad (1)$$

where R_0 is the resistance at a reference temperature, α is the temperature coefficient of resistance, and ΔT the temperature rise above the reference temperature. Metals have a positive temperature coefficient of resistance, and therefore the resistance increases as a result of a temperature rise.

For the 7.5-A test case, both resistance and temperature were observed to increase until failure. Creep induced voiding and material transfer effects were observed on the contact surfaces. The increase in resistance may therefore be due to a combination of increase in resistance due to the material's temperature coefficient of resistance as well creep induced voiding /material transfer effects. At the overstress conditions, on powering up the contact, the temperature rise may have been large enough to cause the resistance to increase appreciably. The resistance increase further increases the Joule heat produced. The thermal conductivity of the metal decreases as the temperature rises, resulting in less heat dissipation and further increasing the temperature of the contact [10][11][12]. A failure mechanism acting in tandem would further increase the resistance and Joule heating, leading to an unstable contact and eventual failure. For the 3 A test case, after the initial temperature rise when the contact was powered on, thermal equilibrium was reached, and no further appreciable rise in temperature or resistance was detected.

In this study, the temperature rise was measured using a thermocouple which may have acted as a heatsink, and at a location on the polymer housing and not the actual contact. Nevertheless, a lower bound for the temperature of a powered LGA contact may be obtained using the test method described in this paper. Finite element modeling of the contact housed in the polymer may be able to predict the temperature rise at the contact, and will be the focus of a future study. Further temperature rise measurements will be conducted at operating currents of 1-3 A with a larger sample size.

Conclusions/Contribution

In this study, Joule heating was observed to cause a temperature rise in a powered stamped metal contact. Tests conducted at 7.5 A and 9 A resulted in unacceptable increases in contact resistance, while a test conducted at 3 A showed the resistance to be stable. A thermal runaway condition, observed as a continuous rise in temperature and resistance, was detected at overstress conditions of current. At operating conditions, a temperature rise due to Joule heating was observed, but thermal equilibrium was quickly reached.

The contribution from this study is a measurement technique, that allows an estimation of the contact temperature due to current, in stamped metal sockets. Estimating the temperature of a powered contact will allow a risk assessment from thermally accelerated failure mechanisms such as stress relaxation, electro-migration and thermo-migration.

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