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April 29, 2008

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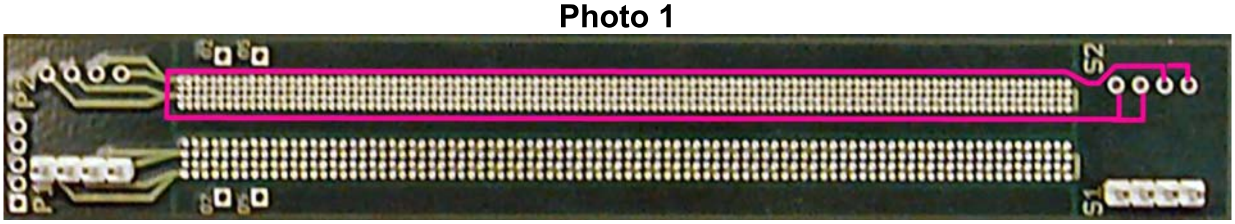
Thermal Distribution in an IST Coupon
NASA-DoD Lead-Free Electronics Project

This report reviews thermal distribution on the surface of an Internal Stress Test (IST) coupon. Specifically the report addresses the temperatures achieved in a silver printed trace on solder mask on an IST coupon. The goal is to determine if the IST heating method assured the trace achieve the temperature reported of 260°C. The data suggests the coupons achieved 270°C and the silver trace on the surface of the coupons achieved a mean of 265°C with a minimum of 255°C, not the 260°C that was previously stated.

The coupons reviewed in this study had test traces printed on the solder mask using an advanced metal deposition method. The deposition or prototyping technologies used for creating printable electronics emerged from a Defence Advanced Research Projects Agency (DARPA) program titled Mesoscale Integrated Conformal Electronics (MICE). The program ran from 1998 through 2003 and developed a number of advanced direct write technologies. The Center for Accelerated Applications at the Nanoscale (CAAN) at the South Dakota School of Mines and Radiance Technologies are working to further refine the technologies for DoD applications. The method, mesoscopic integrated electronics conformal deposition, uses a silver based ink, to create a conductive trace. The trace was applied directly on the solder mask as indicated in Photo 1. After application the coupon was subjected to a low temperature thermal excursion at 170°C to cure the ink.

Approximate Location of the Printed Trace
Photo 1



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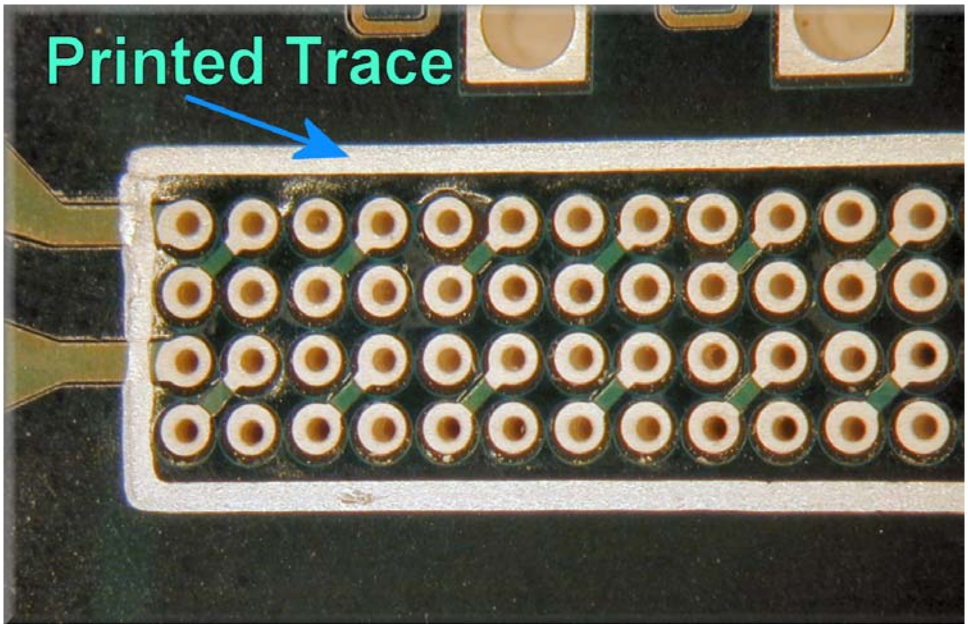
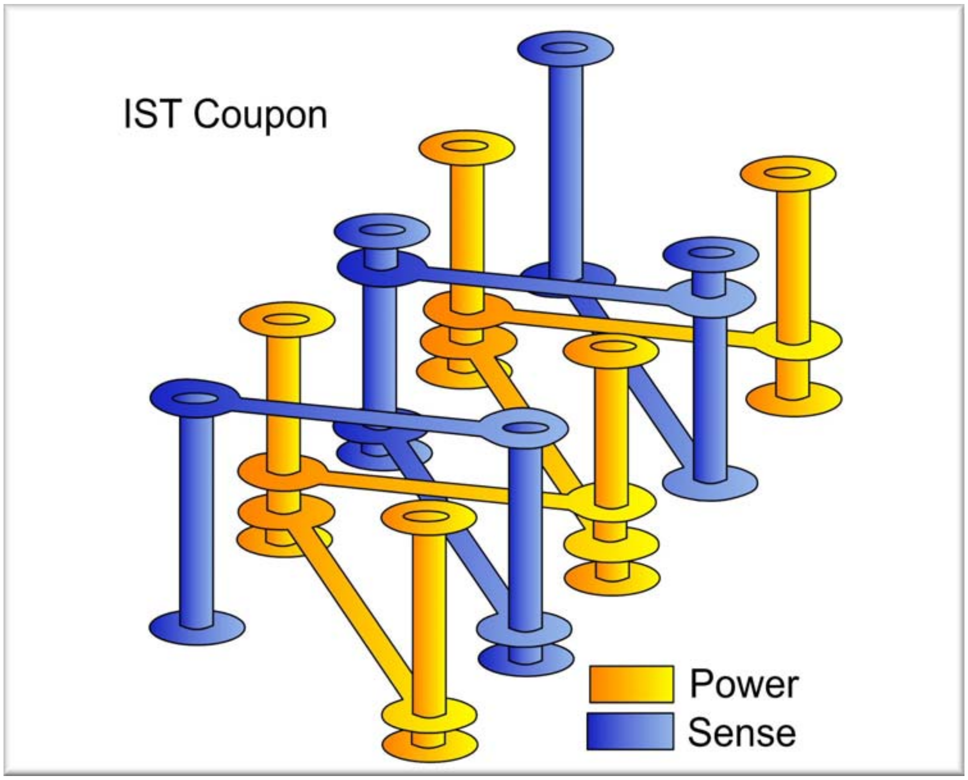
Printed Trace Around .032" Grid PTHs
Photo 2



IST Test Method – The IST test method is to induce internal heating on a representative coupon, by a direct current applied, in this case, on layers 2/3 and 4/5. The coupon is thermal cycled to failure (10% increase in resistance). The IST test method has been accepted by IPC in TM 650 2.6.26. DC Current Induced Thermal Cycling.

IST Coupon Logic and Construction – The IST coupons have two discreet and intertwining circuits commonly called the power and the sense circuit. The role of the power circuit is to actively heat the coupon and, at the same time, monitor damage accumulation during testing in the form of an increase in resistance. The sense circuit is passively monitored for damage accumulation during the duration of the test.

IST Coupon Design – PTH
Illustration 1

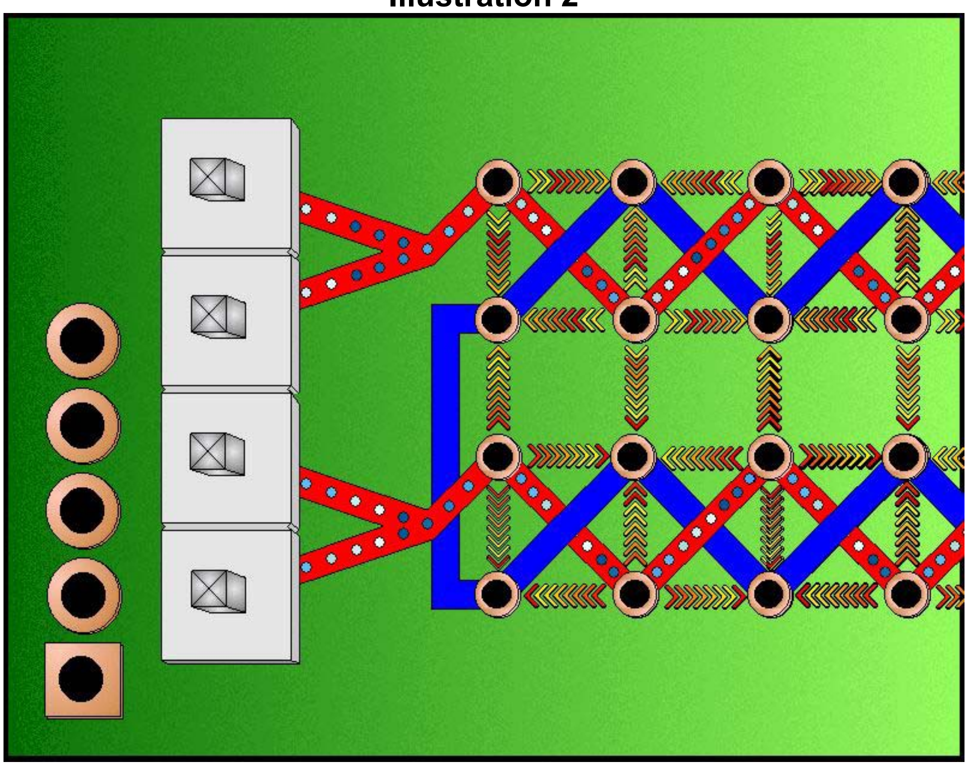


Power Circuit – The power circuit on layer 2/3 and 4/5 is designed within a specific resistance range and with a configuration that the traces between interconnect structure, typically a plated through hole (PTH) heat the circuit. In a typical design a power circuit includes 400 PTHs. The power circuit is designed to have the ability to heat the circuit effectively and measure damage in the internal interconnect (post) and to a lesser degree the barrel between adjacent layers on 2/3 and 4/5.

Sense Circuit – The sense circuit is designed to maximize the resistance in the barrel of the PTH thereby creating a circuit that is sensitive to damage, in the form of increased resistance. In a typical design a sense circuit includes 400 PTHs. A PTH sense circuit is sensitive to damage, in the form of copper cracks, in the barrel of the hole and to a lesser degree at interconnects.

Heating the IST Coupon – At the beginning of an IST test, coupons are precycled to determine the amount of current that is required to heat the coupon to a given test temperature in exactly three minutes plus or minus five seconds. The difference in temperature between a power and sense circuit is usually less than five degrees centigrade. Heat dissipates through a coupon very quickly. Finite element models (FEM) suggests that the different in temperature during heating in a power circuit PTH is less than 0.1C. Heat distribution in IST coupons appears to vary about +/- 10°C across a typical coupon. The average measured temperature difference between the power and the sense circuit is approximately 5°C. It should be noted that recent studies demonstrate a printed circuit board, loaded with components for soldering, in the thermal oven varies 20°C across the board.

Heat Distribution between Power and Sense Circuits
Illustration 2



Sensing Temperature – Algorithms have been developed for IST testing that allows the resistance change in circuits to be equated to temperature. In a typical application both the power and the sense circuits are monitored and the average temperature between the two circuits is used to control testing. Other applications will use either the

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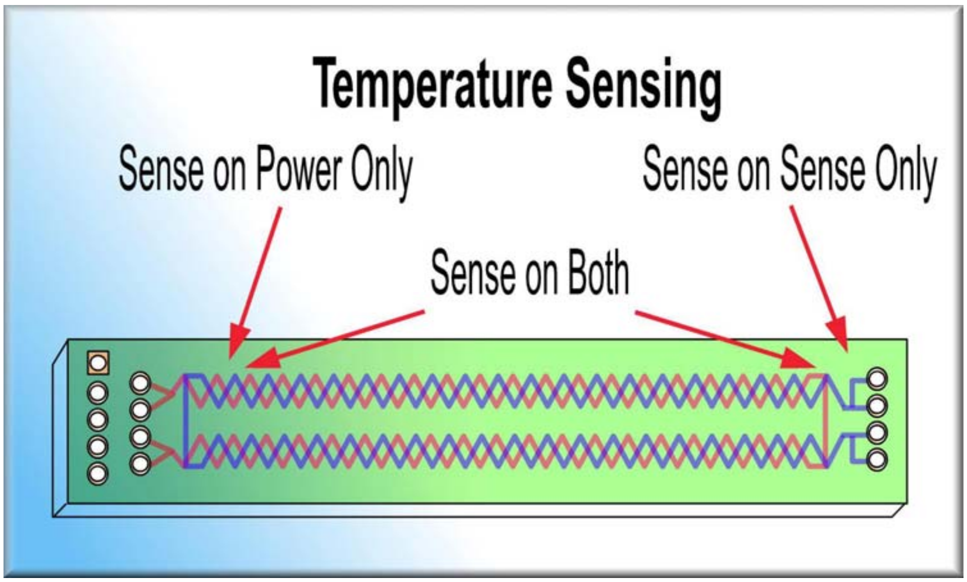
power or the sense circuit exclusively to monitor temperature during testing. In these test the power circuit temperature was used exclusively to determine the coupons temperature.

Temperature Sensing During IST Testing
Illustration 3



Confirming the Heat Distribution for the Lead-Free Applied Trace Study – In an attempt to measure the heat distribution in the IST coupon a thermal imaging camera was used. A constant current was applied to the coupon and temperatures were measured with the thermal imaging camera. There are a number of limitations imposed to measuring temperature accurately with this method including that normally the test coupon is being controlled and monitored with an IST tester. By heating the circuit with a DC power supply and monitoring temperature by means of thermography, heating control and accuracy could not be attained as well as on an IST testing machine. Also noted is a lag time between heating the coupon and temperature readings. A thermal camera is limited to measuring surface temperatures and effects like emissivity, surface reflection etc., can add to variations in readings. The thermal camera demonstrated that there was a minimal difference between the printed trace on the surface of the solder mask and the adjacent substrate. The variation in temperature of a coupon at 275°C was measured for the areas in the squares highlighted in photos 3 and 4 below.

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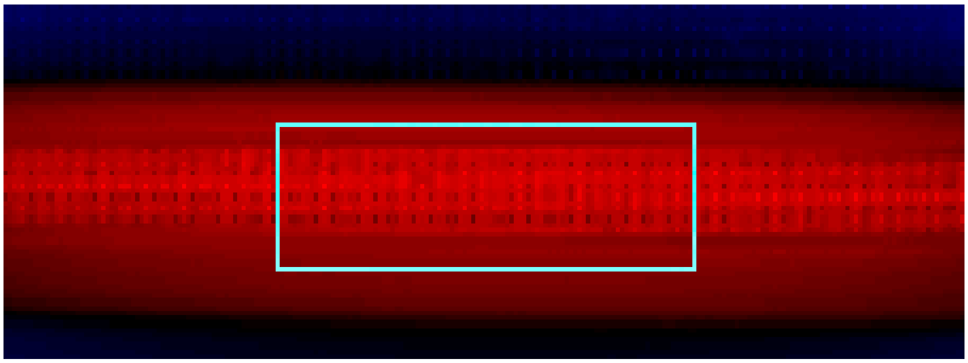
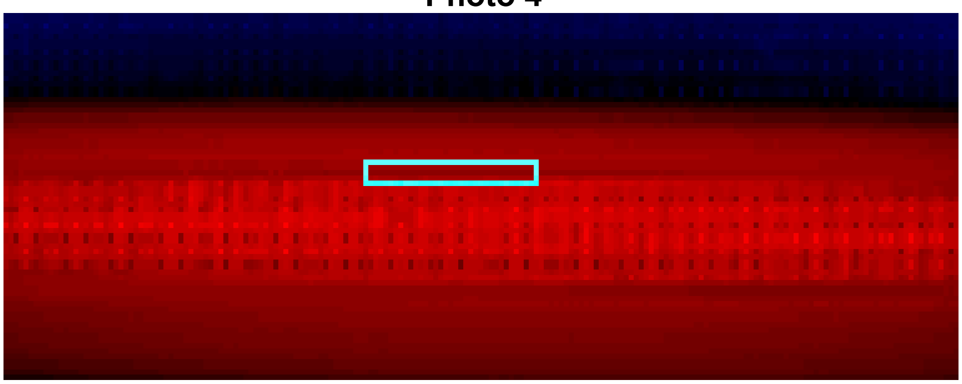
Thermal Image #1 – Heat Distribution of All Circuits @ 275°C
Photo 3



Thermal Image #2- Heat Distribution of Printed Trace @ 275°C
Photo 4



Observations of Thermal Imaging a Heating IST Coupon – The thermal camera demonstrated that the printed trace had a measurable difference between it and the surrounding material. The camera showed the difference to be approximately 30°C.

Temperature Variation Across and IST Coupon
Table 1

Temperature Data In Highlighted Square			
Image #	**Max**	**Ave**	**Min**
# 1	275	263	245
# 2	273	265	255

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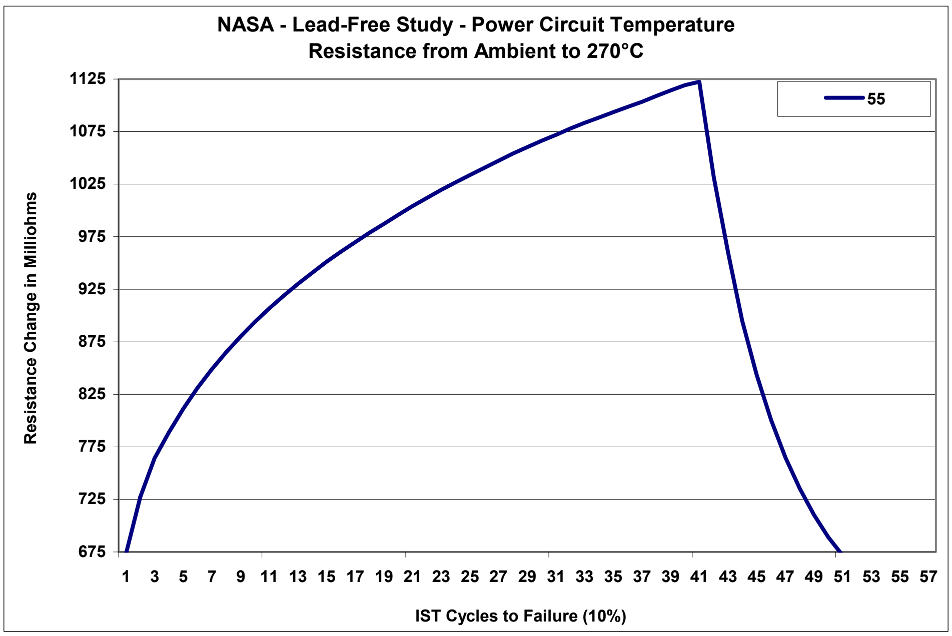
Measurement of Temperature in IST Testing – Graph 1 exhibits the thermal profile of the coupon measured on the power circuit during this test. For this evaluation there was a resistor added to the printed sense circuit in order to lower the resistance to be within the measurement range of the IST equipment. Because of this modification the printed trace of the sense circuit could not be monitored

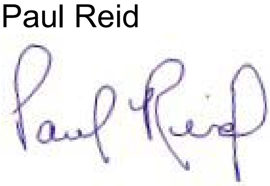
Thermal Cycle of Power Circuit – IST Testing
Graph 1



Conclusion – This investigation suggests that the trace on the surface of the coupons achieved between 273°C and 255°C based on surface measurements on an IST coupons with simulated heating.

Respectfully submitted,

Paul Reid



Program Coordinator