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Construction of a 3-D Current Path using Magnetic Current Imaging

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The need to miniaturize in the electronics industry is driving smaller form factors, and resulting in complex packaging innovations such as 3-D structures with multiple devices stacked inside a three dimensional package. But this innovation prohibits non-destructive fault isolation by conventional techniques. We present here, for the first time, non-destructive fault isolation of a power short in a 3-D packaged EEPROM module using magnetic current imaging of orthogonal sides to build a 3-D analysis of the current inside the device. Even at working distances of several millimeters, the location of the fault was isolated to a capacitor without any deprocessing of the module.

The 3-D device is a rectangular module consisting of eight, stacked EEPROM devices. During safe-to-mate testing at NASA Goddard Space Flight Center, this device was identified with a low-resistance short of less than 1 ohm between Vcc and Vss.

Precision radiography found that the internal construction of the module consisted of eight stacked mini circuit cards, each with a single chip capacitor and a plastic-encapsulated EEPROM device. The module was rectangular with dimensions: 10mm x 14mm x18mm. At each level in the stack, the circuit card connected a PEM and a capacitor to the exterior of the module, which was plated with gold and laser-scribed to create a circuit pattern. Thus, the Vcc pins provided power to each level of the stack through an external gold panel, and Vss pins were connected to a separate gold panel. Both Vcc and Vss panels were located on the one side of the device, but careful inspection ruled out the possibility of an external short connecting the two panels.

The dimensions of the device were deemed sufficiently small to allow the nondestructive, 3D internal examination of the EEPROM module using magnetic current imaging. Specifically, a superconducting quantum interference device (SQUID) sensor, known to have the capability of detecting 10mA of current at a range of 7mm, was capable of exploring the inside of the module, accessing opposite sides of the 14mm-thick device.

SQUID scanning with a 100-micron standoff distance was performed on three, orthogonal sides of the module. A current map of the side of the module exhibiting the Vcc and Vss panels showed that current flowed without loss to the top level of the eight EEPROM stack, and returned on the Vss panel. This fact isolated the failure to the top deck of the module. The module was rotated 90 degrees under the SQUID head to permit top-down mapping on the module. The top-down SQUID magnetic field map matched the entry and exit points of the current from the Vcc and Vss panels, previously seen in side view. The centerline of the magnetic field map followed a circuit card trace seen on the top-down radiographic view. The SQUID current map exhibited its greatest intensity at a location matching the x-ray position of the capacitor. Intensity in the SQUID current map can indicate either, or both a change in the proximity of the current flow to the SQUID sensor, or necking of the current flow.

The device was rotated another 90 degrees in the same plane, allowing the SQUID sensor to scan the side of the device opposite the Vcc and Vss panels. This view did not detect current on the opposite side of the device, 14mm distant. But it did show where current neared the surface of the device following the circuit board trace. This view also placed the current path on the top deck of the EEPROM stack, consistent with the magnetic current image from the opposite side.

The device was rotated 90 degrees orthogonal to the previous rotation plane, allowing a SQUID scan on the module end close to the capacitor, where previous scans had indicated current flow. The current map of this view also indicated current flow in the top deck of the EEPROM stack and clearly showed, at a depth around 2 millimeters, that current stepped up from the plane of the circuit card, traversing a short distance, then descending to the circuit board again. The current map was overlaid on the x-ray end view and found to exactly match the position and elevation of the capacitor.

All four scanning images were consistent with each other, showing current flowing to, and moving within the top deck of the EEPROM stack. The first side and top-down views matched the current entry and exit locations where the Vcc and Vss external panels interfaced with the circuit card. The magnetic current image on the opposite side of the module matched the location of the circuit card Vss trace where it neared the surface. Both the opposite side view and the end view matched together, and confirmed the current path in the top deck of the EEPROM.

Actual distance of the SQUID sensor from the current path inside the three-dimensional device varied depending on which side the scan was performed. On the side with Vcc and Vss panels, the distance of the SQUID probe from the current identical with the standoff distance, 100 microns. In the top-down MCI scan the current depth varied from about 1000 to 1600 microns from the SQUID sensor, as current passed through the circuit card and malfunctioning capacitor. The SQUID map from the side opposite Vcc and Vss panels, detected current to a depth of several millimeters. The current moving in the Vcc and Vss panels on the opposite side of the module, now at a depth of 14 mm, was not detected. SQUID mapping of the module from the end view produced a high-resolution image of the current path at a depth of approximately 2 millimeters.

Current was varied during MCI testing, but all sides of the module were re-scanned when it was determined that the short could sustain an indicated 2.7mArms current without drift.

Following location of the defect by MCI, the device was potted for cross-sectioning providing tubes for protection and stress relief of the fragile copper wires used during magnetic current imaging. Cross-sectioning of the device to examine the top-deck capacitor to confirm the failure location is currently underway. Cross section images and discussion of the failure mode will be presented.

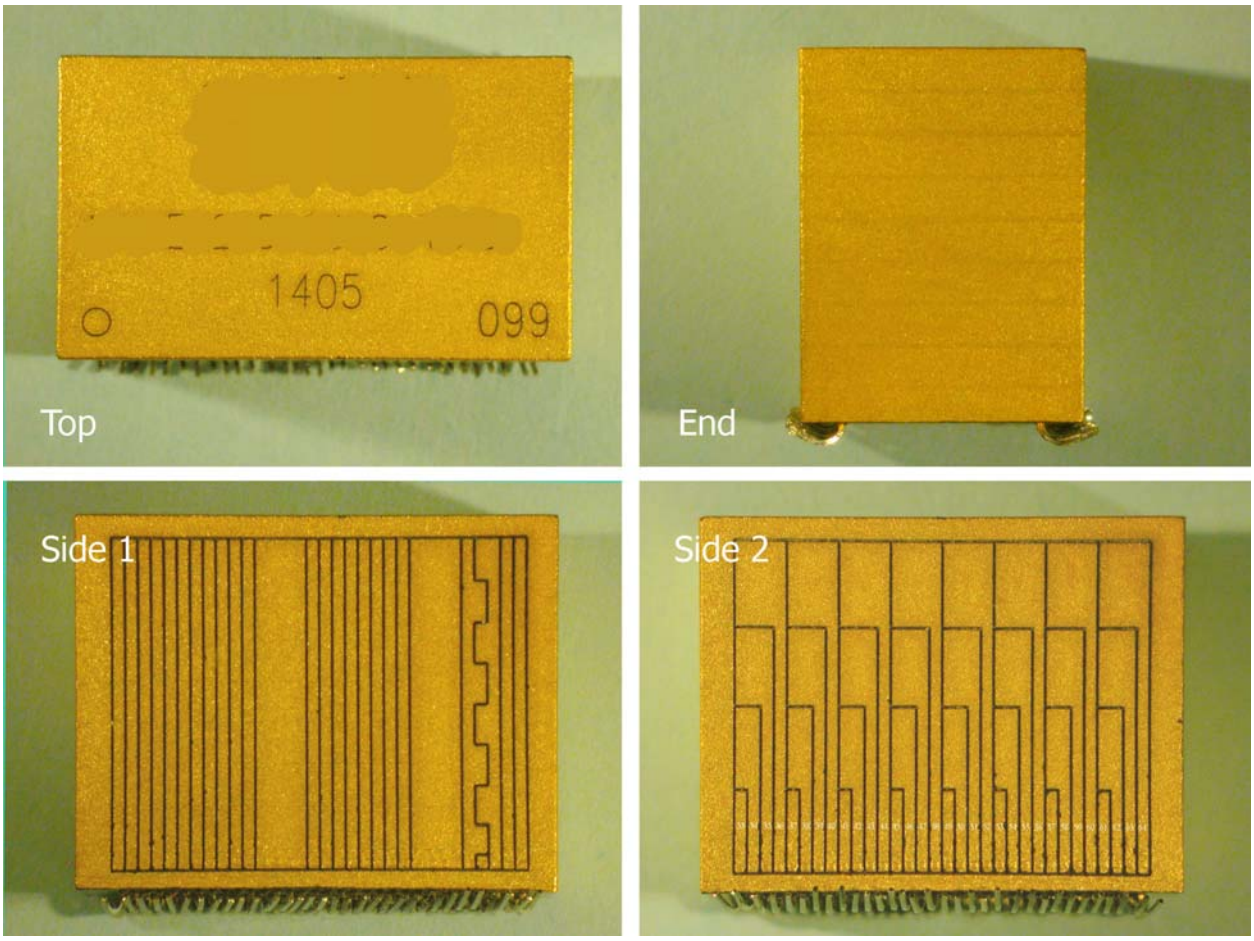

Figure 1. Four views of the EEPROM module show the sides that were scanned using magnetic current imaging. Markings have been rubbed out pending manufacturer concurrence.

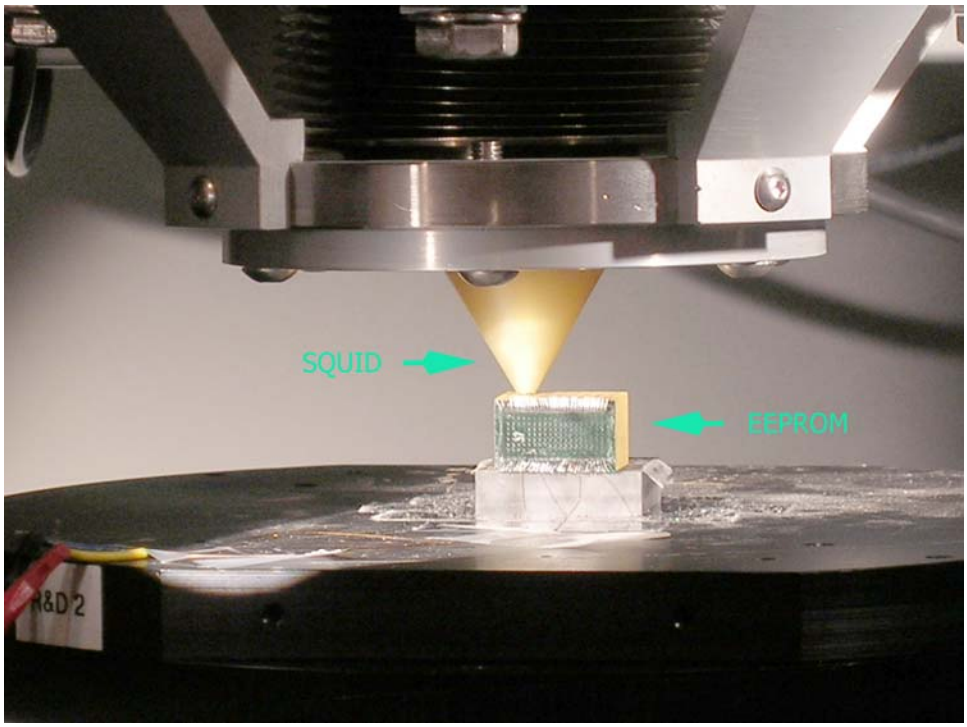

Figure 2. An image of the EEPROM and SQUID sensor. Scanning was performed with a nominal 100-micron standoff distance.

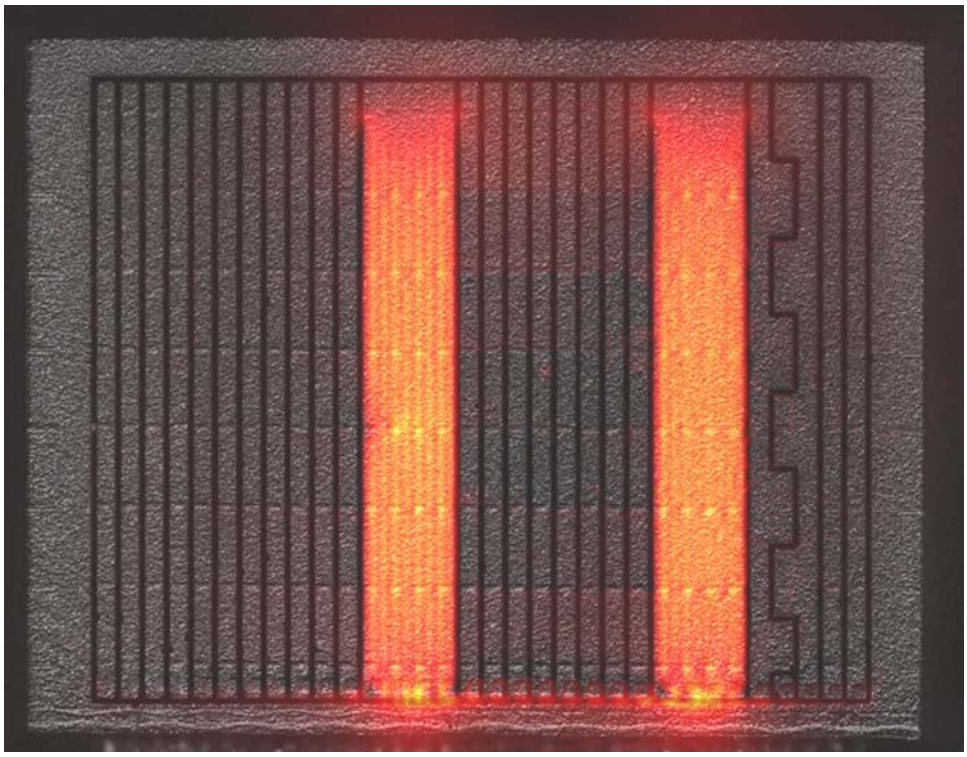

Figure 3. A SQUID-mapped current overlay shows current moving up the Vcc panel on Side 1 of the device to the top deck, then descending on the Vss panel on the right.

Figure 4. A SQUID-mapped overlay of the current path on the top-down image of the module shows a location of high-intensity at left.

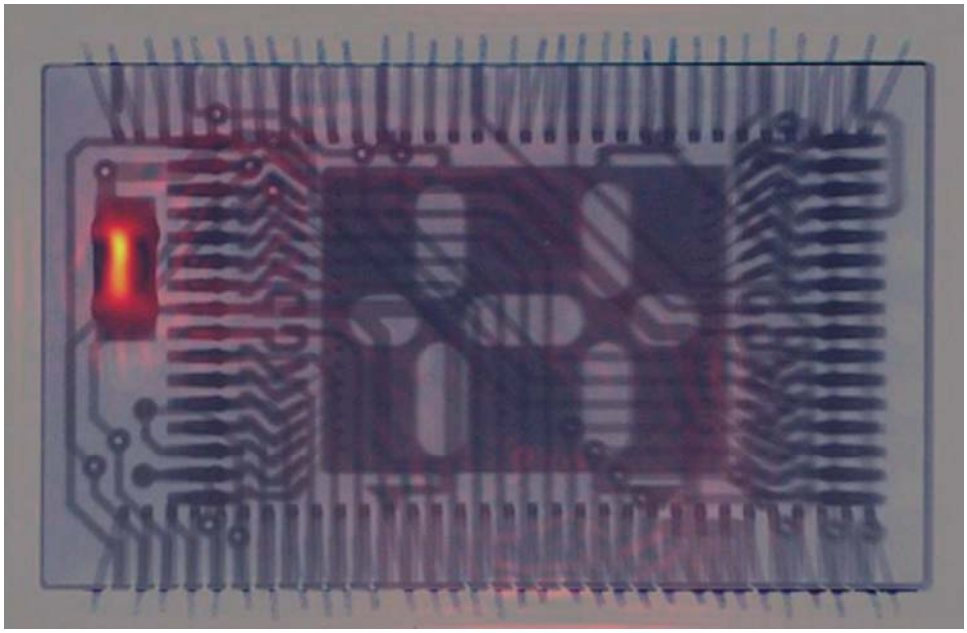

Figure 4. With current optimized for depth, a SQUID current overlay on the device x-ray shows current moving through the capacitor, the likely defect location.

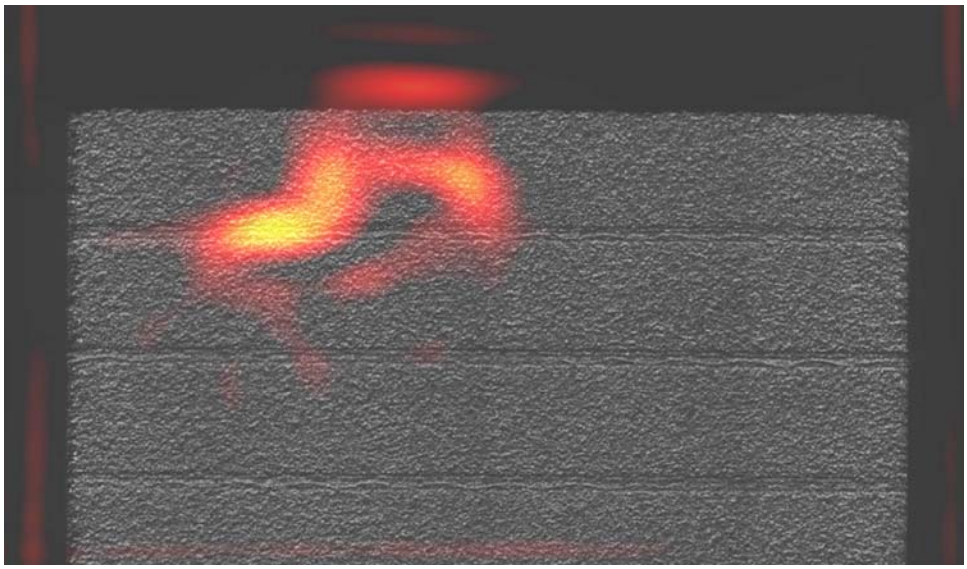

Figure 5. An overlay of the SQUID current map on the optical end view shows current rising from the circuit card, traversing a short distance, then descending again. The halo at top of the package is an artifact.

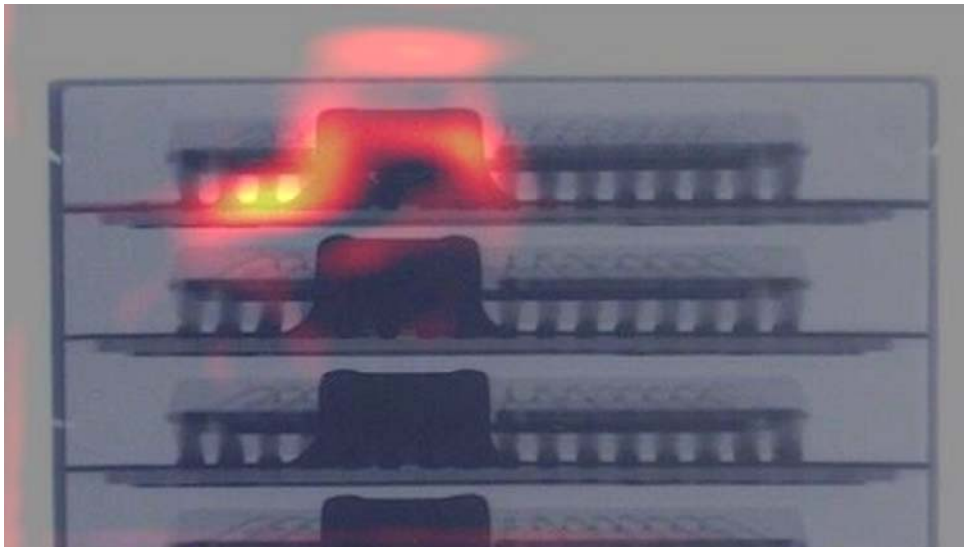

Figure 6. An overlay of the SQUID current map on the end view x-ray image shows the current rising from the circuit card and traversing through the capacitor before descending.

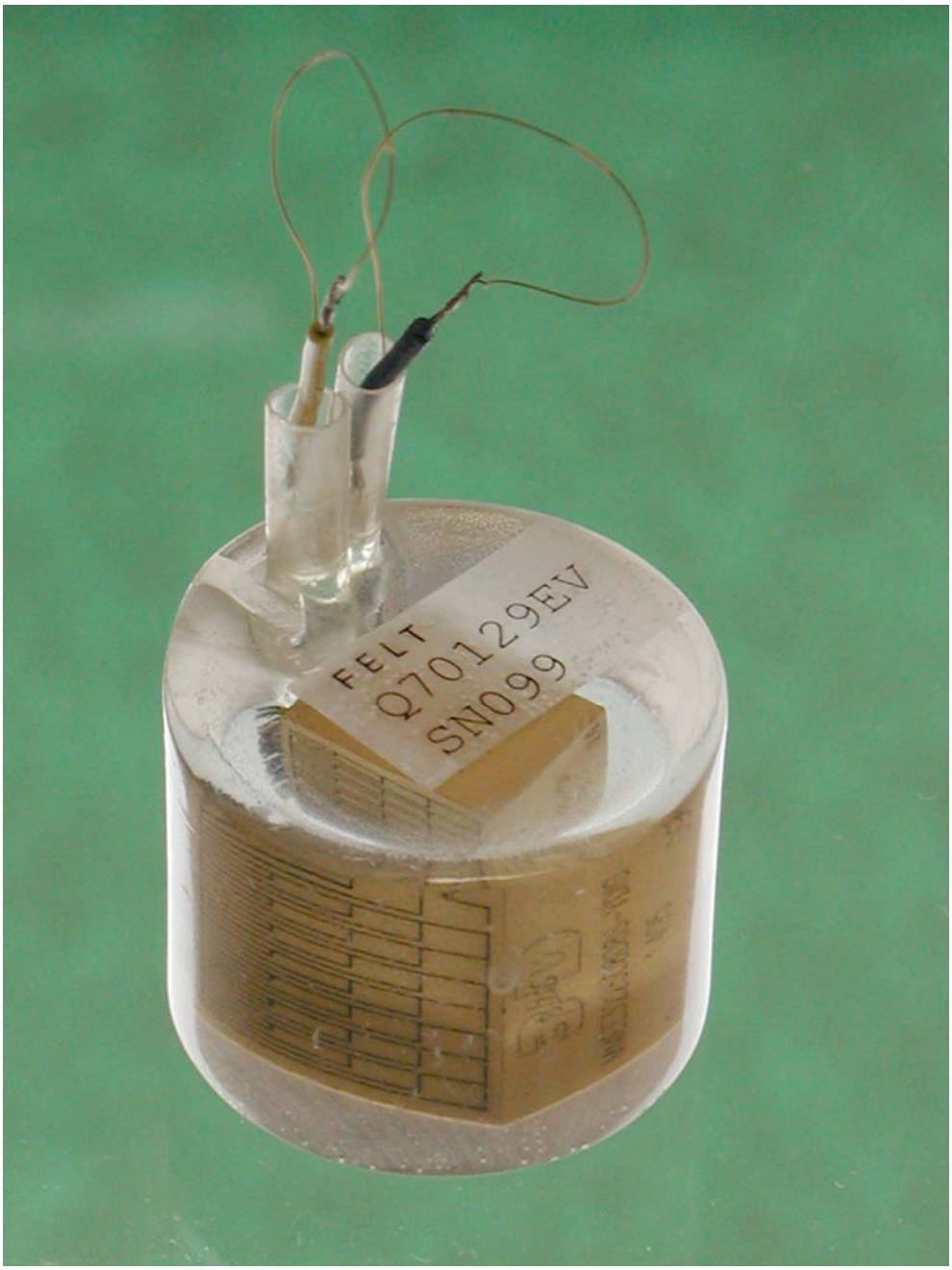

Figure 7. An optical view of the EEPROM module mounted in epoxy with raceways for the wires connected to Vcc and Vss pins. The resistance of the short will be monitored during cross-sectioning to verify failure location.

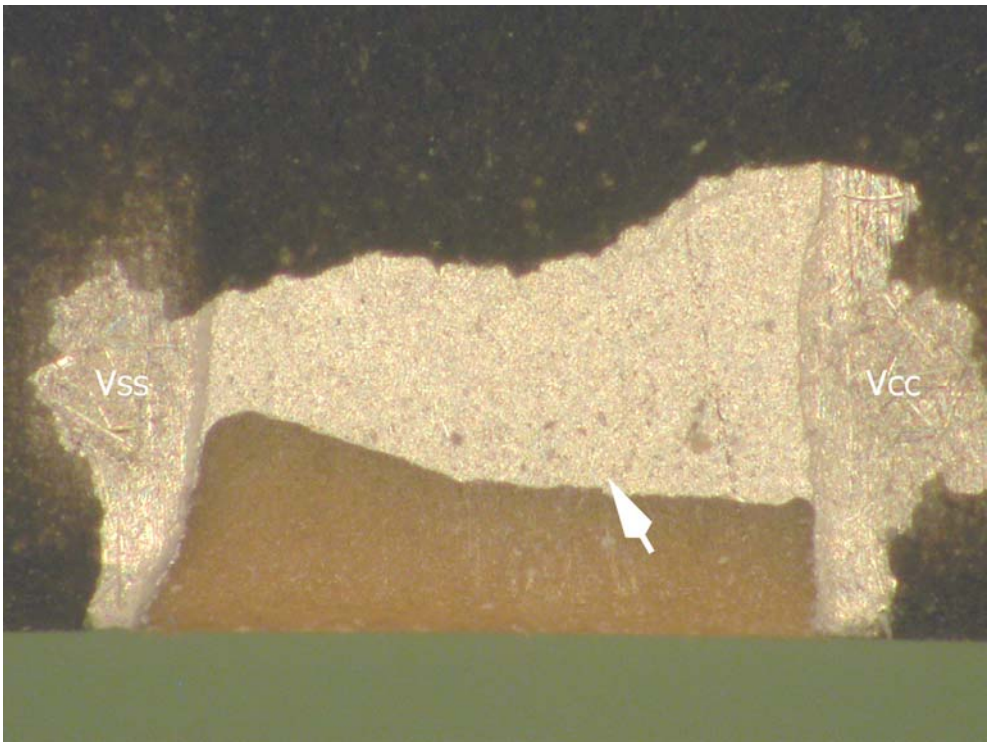

Figure 8. An arrow points to a metal sheet on the capacitor, shorting Vcc to Vss. This image was taken during the early stages of removal of the black encapsulant.

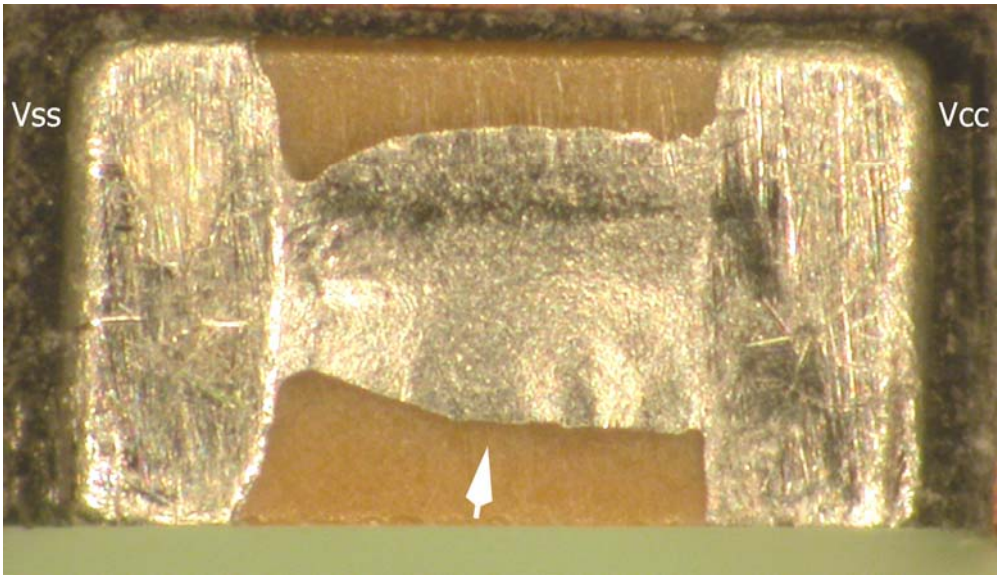

Figure 9. With encapsulant fully removed, a metal bridge is seen between terminals of the TSOP08 capacitor. The location and shape of the defect was correctly indicated by MCI.