Solder Reflow Failures in Electronic Components during Manual Soldering

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Purpose and Outline

Purpose:

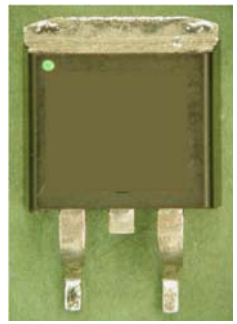
To discuss specifics of manual-soldering-induced failures in plastic devices with internal solder joints.

Outline:

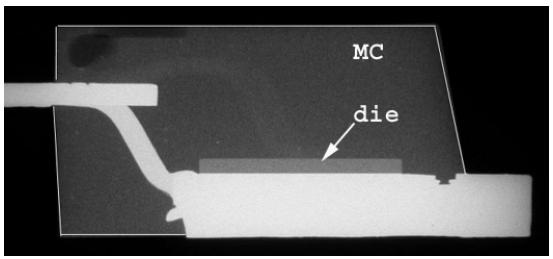
- ❑ Failures of power transistors
- ❑ Failures of temperature sensors
- ❑ Failures of 3D-Plus EEPROM
- ❑ Conclusion

Failures of Power FETs

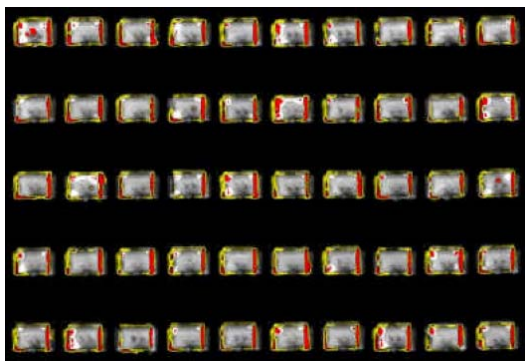
- Three power FETs in plastic surface mount packages (D2Pak) failed short circuit after manual soldering onto a board.
- The parts passed screening including 100% C-SAM inspection.
- Failed parts had top-of-die delaminations.



X-ray view



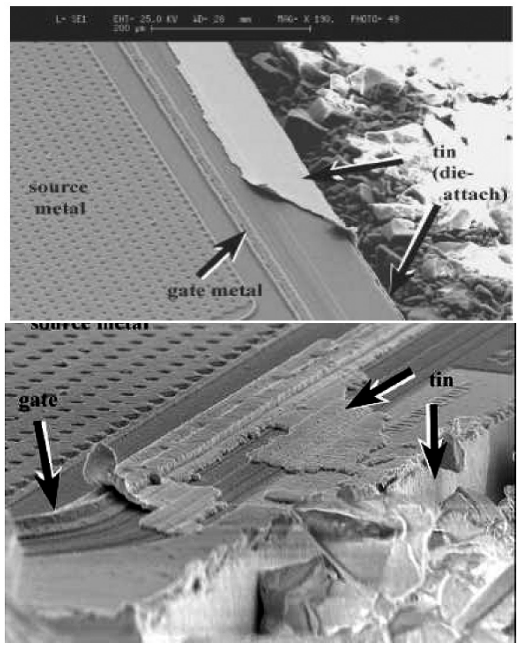
Typical CSAM images

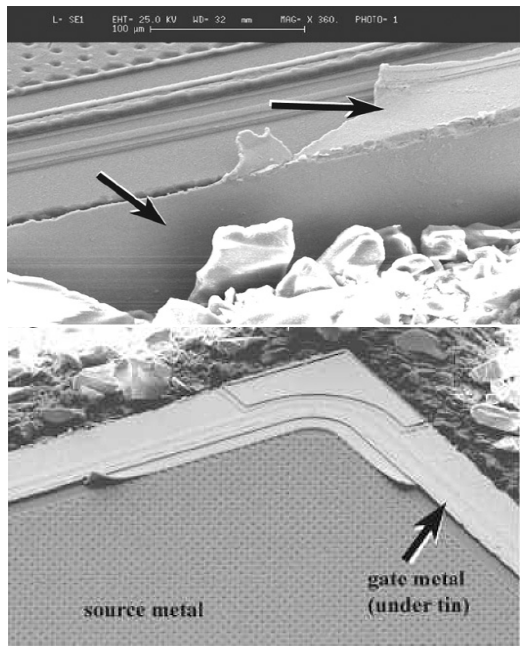


CSAM of failed part

Failure Analysis

- Molten solder squeezed up to the die surface along the die-molding compound interface.
- The dies were not protected with glassivation allowing solder to short gate and source to the drain contact.



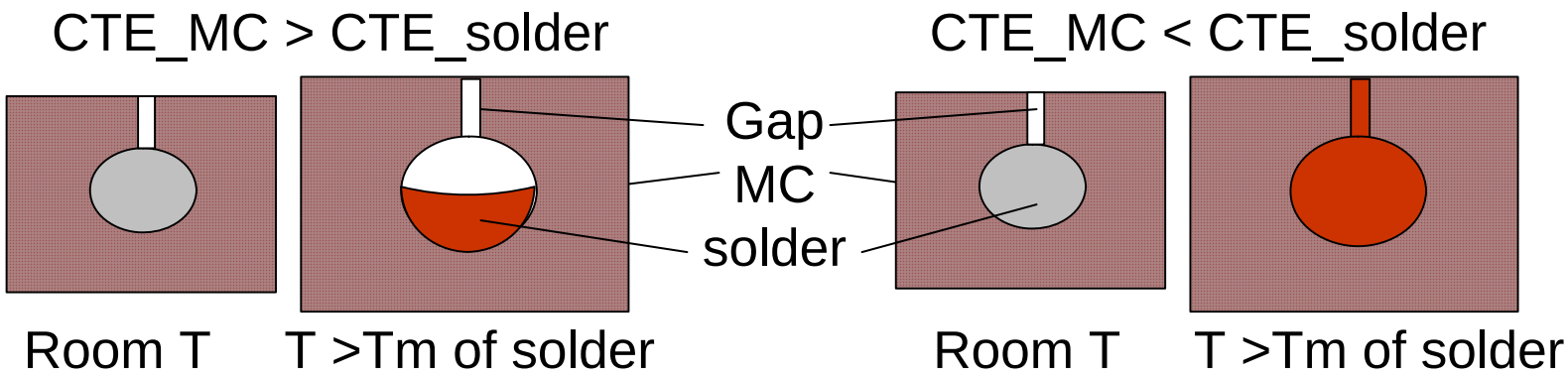


Conclusion: the parts failed due to overheating during manual soldering.

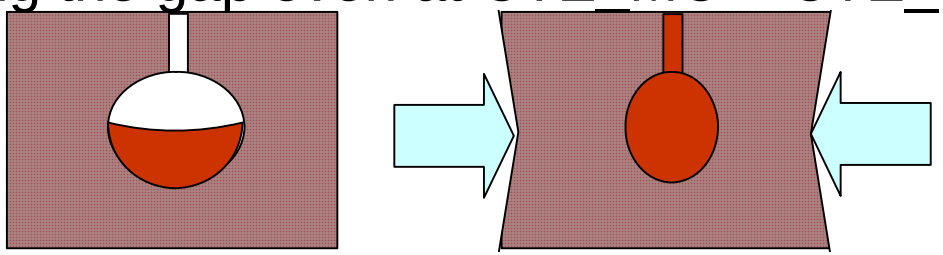
Possible Failure Mechanisms

Molten solder does not wet glass/ceramic/plastic and should be pressed to flow in a gap by internal or external forces.

- Internal force: compressive stresses develop if expansion of solder > expansion of MC.



- An external force during soldering might result in molten solder filling the gap even at CTE_MC > CTE_solder.

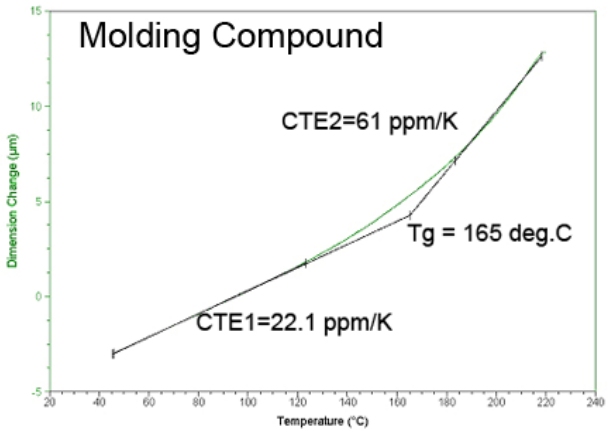


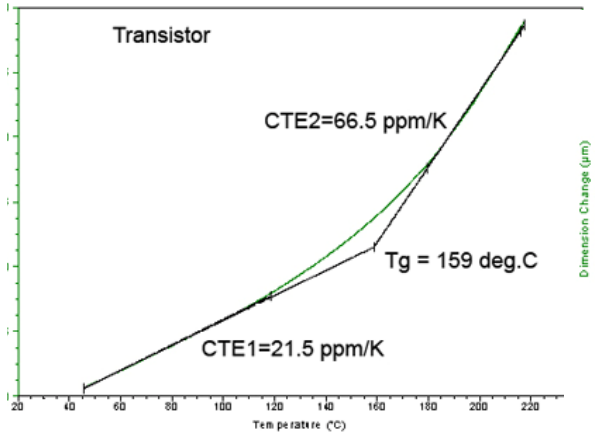
Thermo-Mechanical Characteristics of Package Materials

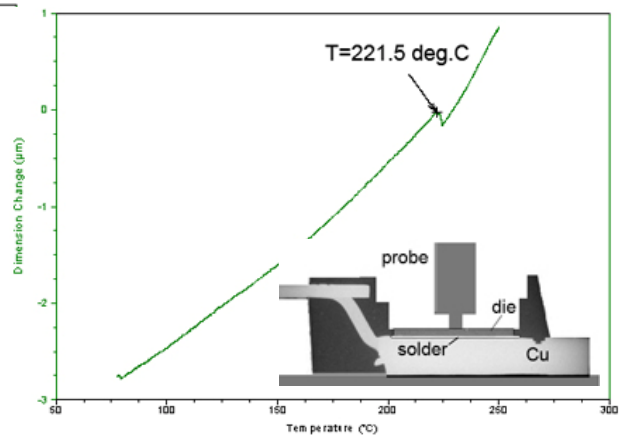
Deformation vs. temperature was measured on MC, transistors, and with a probe installed on a die (after decapsulation).

Average TMA characteristics

	Tg, oC	CTE1, ppm/K	CTE2, ppm/K
MC	163	21.5	65
Package	165	23	70



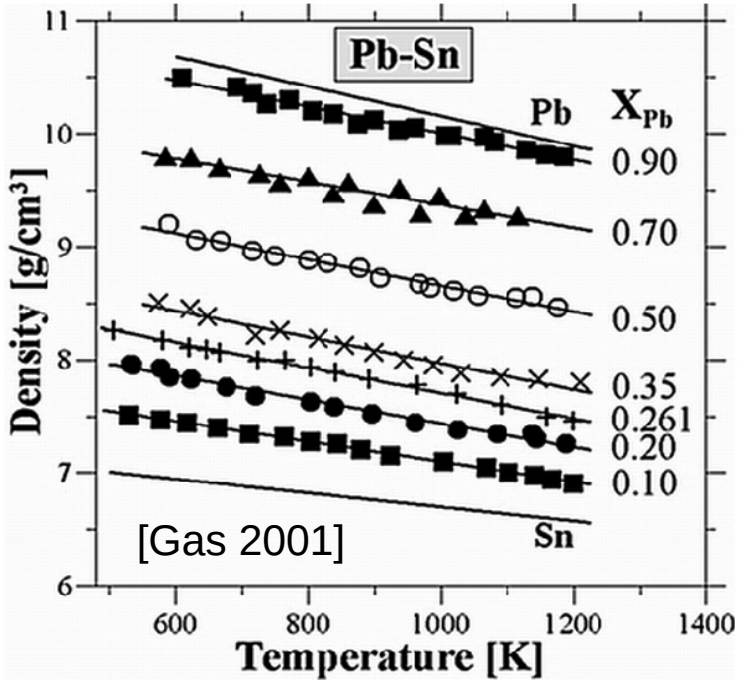




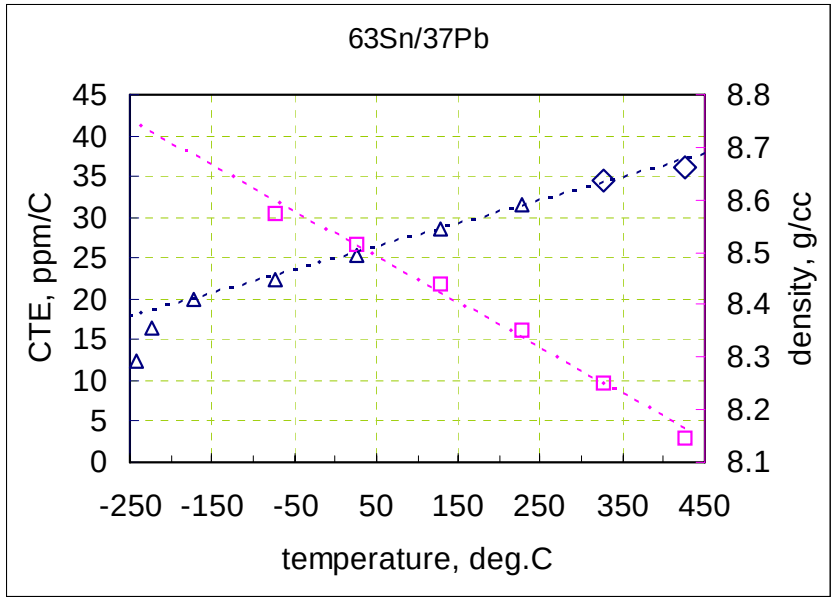
Probe-on-a-die measurements confirmed that a high-temperature tin-silver solder with a melting point of 221°C was used.

Temperature Deformations in Solder

Available literature data on solder expansion were used for best-fit estimations of CTE and density at -65< T< 450 °C.



Molten near-eutectic solder has CTE = 34.5 ppm/K.



$$CTE = 0.0285 \times T + 24.93$$

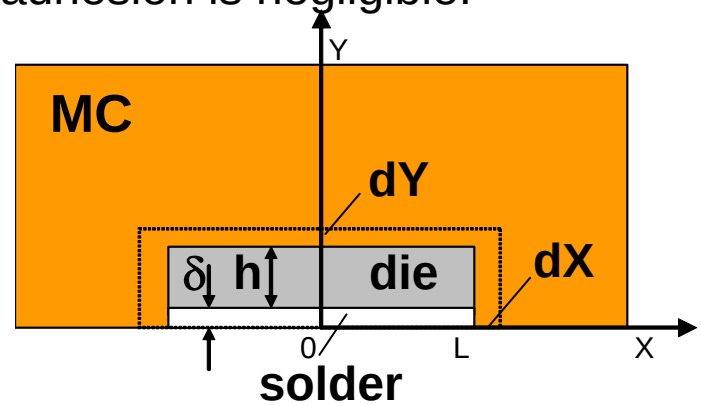
$$\rho = 9 \times 10^{-4} \times T + 8.53$$

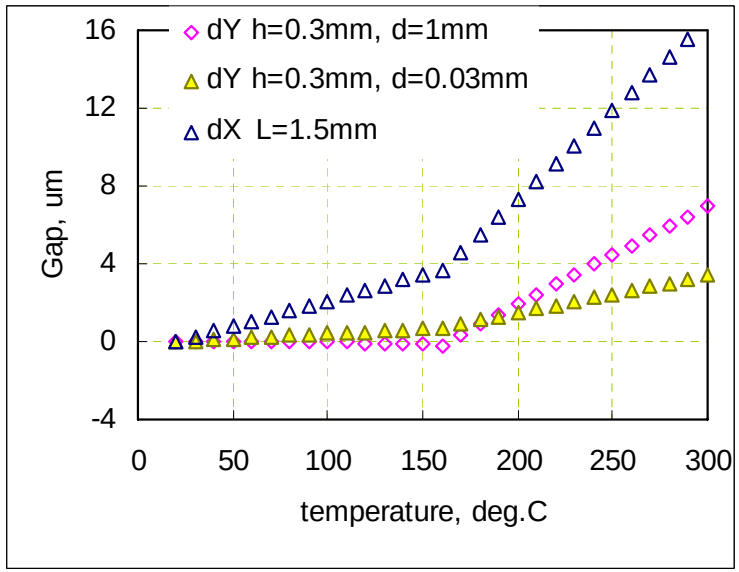
where CTE is in ppm/K, ρ in g/cc, T in °C

Delamination During Soldering

A size of MC/die gap, ΔY, was calculated assuming that at RT ΔY=0 and adhesion is negligible.

$$\Delta Y = \int_{T_0}^{T} [(h+\delta)\times CTE_{MC} - h\times CTE_{die} - \delta\times CTE_s]dT$$

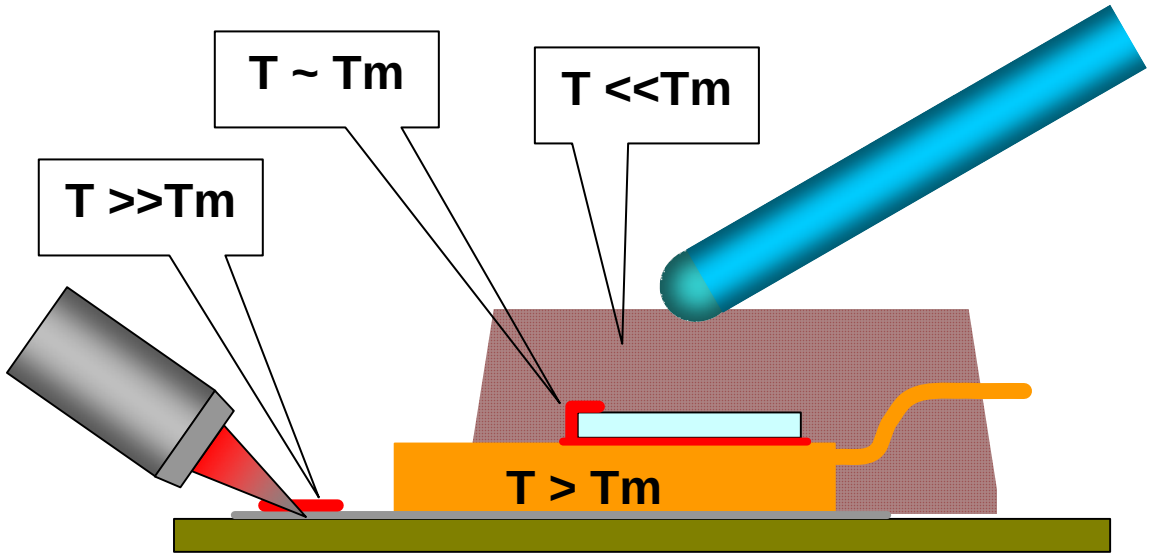




Compressive stresses (ΔY<0) might occur at very thick layers of solder (δ~1mm) only.

- Heating of the package uniformly creates enough room for solder expansion and no reflow failures should occur.
- Power FETs are designed for SMT for oven reflow soldering at T ~ 250 °C (up to 30 sec.), which exceeds Tm = 221 °C.
- Heating to melting temperature is a necessary by not a sufficient condition for reflow failures.

Most Probable Cause of Failure

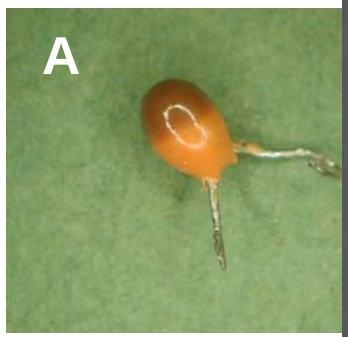


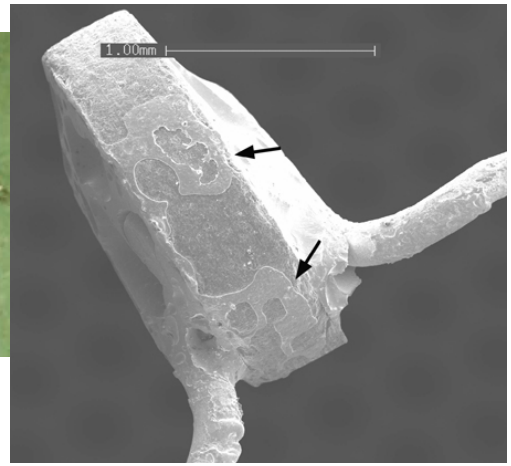
- Manual soldering caused fast heating of the copper heat sink while MC remained cool thus forcing molten solder to create and fill top-of-die delamination.
- Fixing a part on a board by applying a force to the package increases the probability of failure.

Solder Reflow Failures of Thermistors

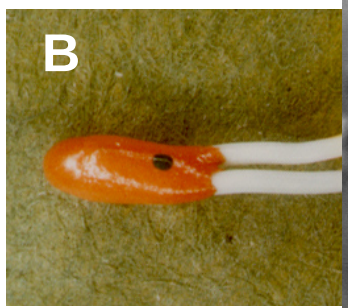
Thermistors per 311P18–02T-7R6 passed resistance to soldering heat test MIL-STD-202, TM210.

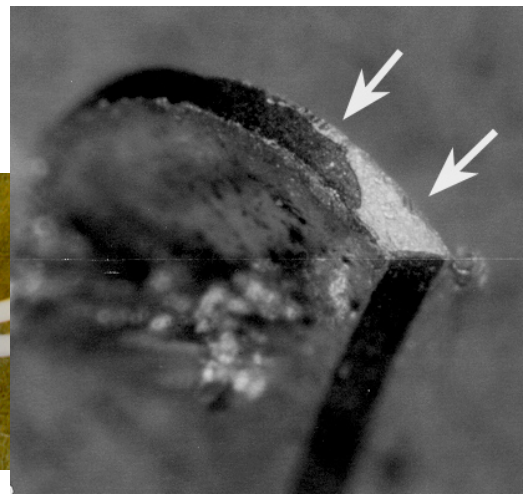
- Case A: failed during board-level testing.
- Case B: failed after rework on the adjacent microcircuit.
- FA: short is due to solder reflow caused by overheating.





Specified length of leads 7.6 cm





Effect of Wire Length

Temperature distribution along a wire of diameter d and length *l*

$$\frac{\partial^2 T}{\partial x^2} = \alpha^2 \times T \qquad \alpha = \sqrt{R_t \times G_t}$$

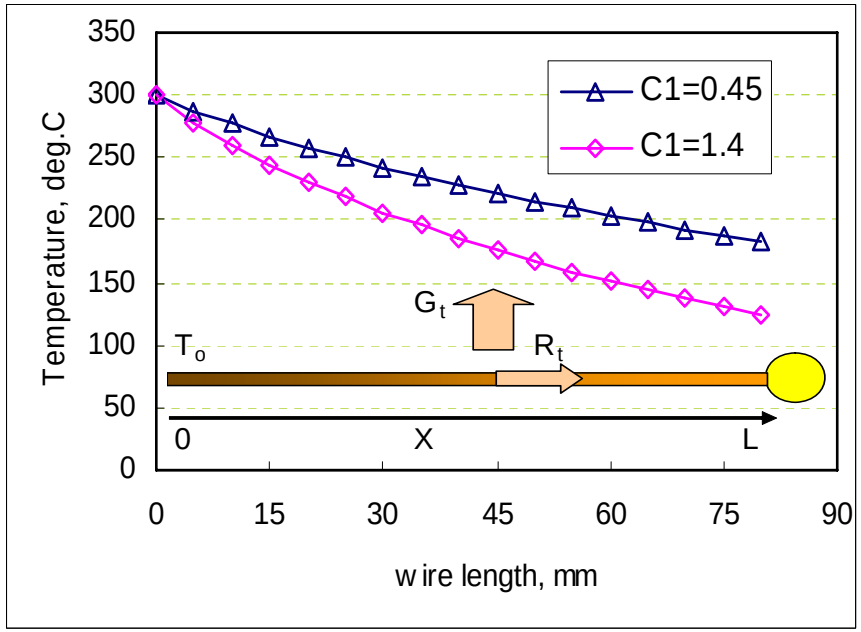
thermal resistance per unit length:

$$R_t = \frac{4}{\lambda \times \pi \times d^2}$$

thermal conductance per unit length:

$$G_t = d \times \frac{\lambda_{air}}{l} \times C_1 \times \left(a \times l^3 \times \Delta T\right)^n$$

Solution: $T(x) = T_o \times e^{-\alpha x}$



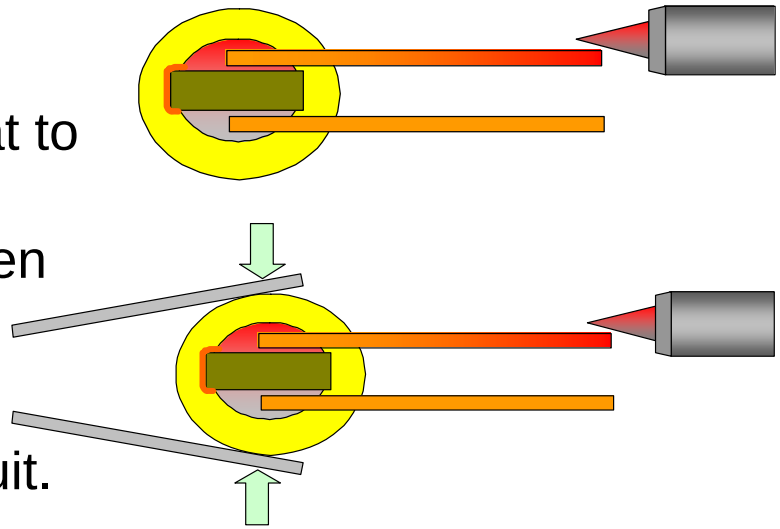
- At a specified conditions a soldering iron is set to T_o = 300 °C and at *L* = 76 mm T_{sensor} < 180 °C (no melting).
- Cutting leads to ~1" will increase T_{sensor} to 220 to 250 °C and might cause solder reflow failures.

Mechanism of Failure

Case A:

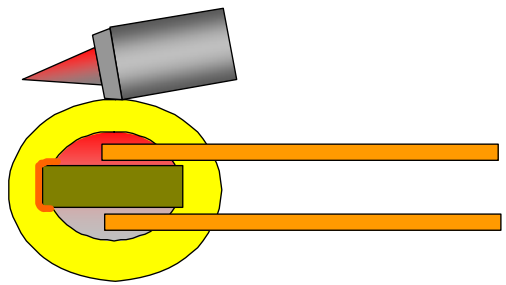
Short Cu wire transfer quickly the heat to one side of the sensor forcing melted solder to expand and squeeze between cold MC and die.

Holding a sensor with tweezers increases the probability of short circuit.



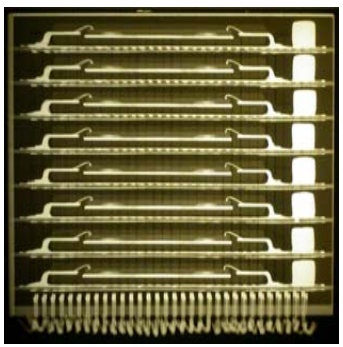
Case B:

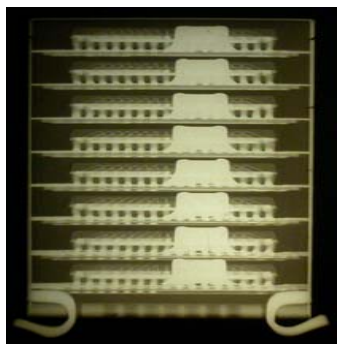
A touch with a soldering iron creates temperature gradient allowing solder melting on one side while another side remains cool.

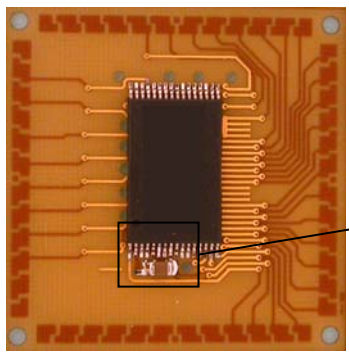


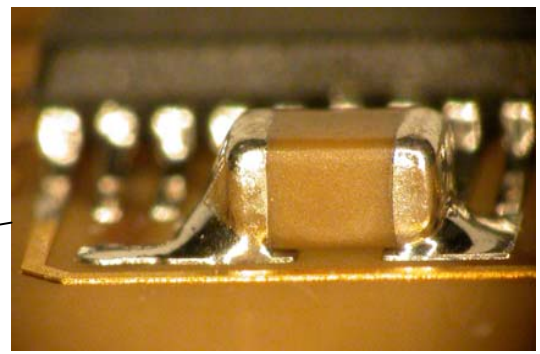
3D-plus Memory Failure

- The part passed all screening and qualification testing but failed with a short circuit in internal power supply lines after manual soldering onto a board with a soldering iron set to 700 F (371 ^{o}C).
- The part is comprised of 8 micro-boards with a TSOP memory microcircuit and ceramic capacitor in the power supply line. Interconnections are made on the boards and externally, via package metallization (8 μm Au/Cu/Ni).
- How to pinpoint location of the defect?



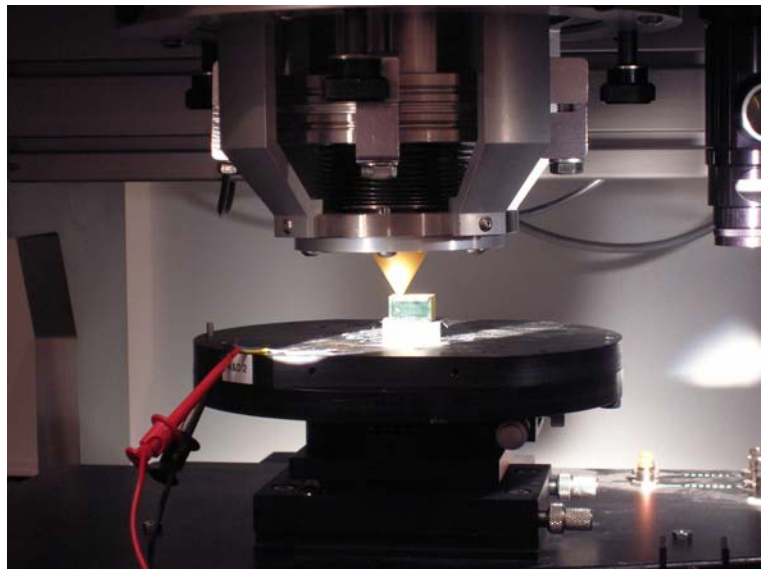






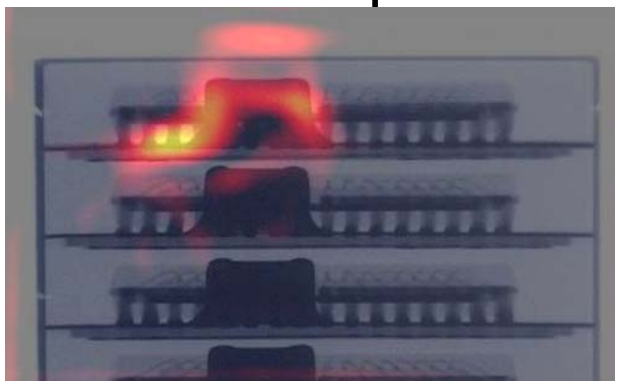
Magnetic Current Imaging with SQUID

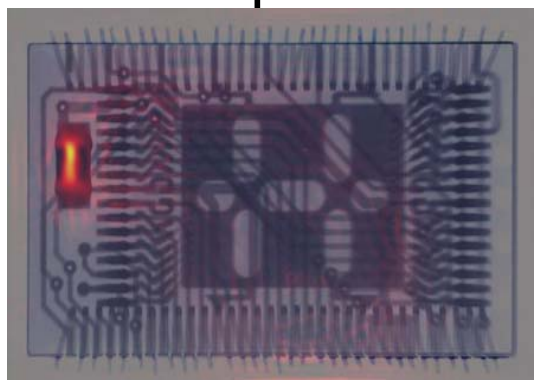
- MCI with a superconducting quantum interference device (SQUID) probe (NEOCERA) was used to locate the defect.
- Maximum current of 2.7 mA, 533 Hz, was applied to the sample.
- The technique allows for current density mapping by scanning magnetic field at a distance from the surface ~ 100 μm.
- SQUID is effective to depth of several millimeters.



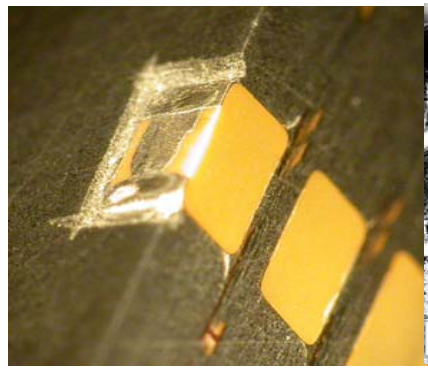
Location of Short Circuit

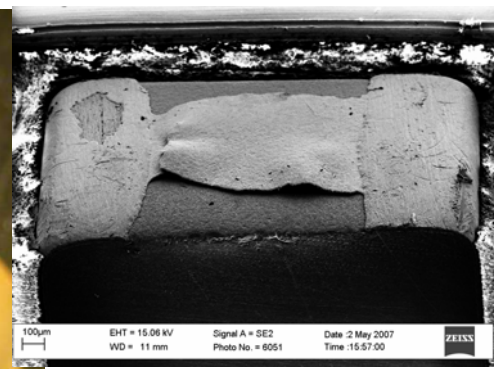
- Results of MCI indicated the short through a ceramic capacitor on the top board inside 3D-plus cube.





- Two plane X-section showed that the failure was due to reflowed solder short at the top surface of the capacitor.

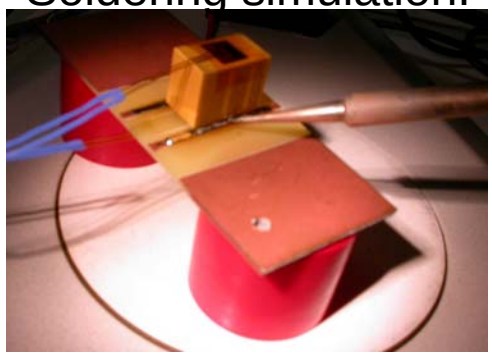


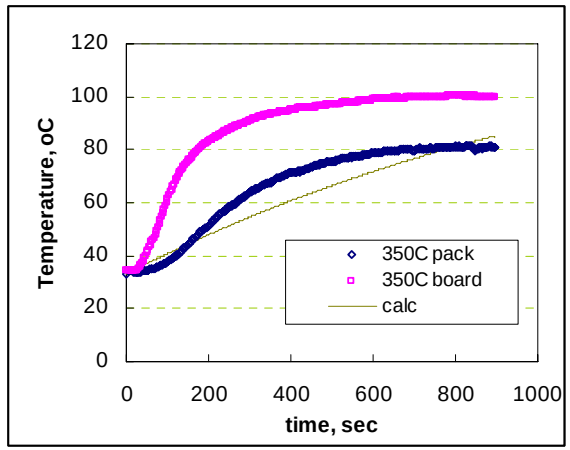


Conceivable Causes of Failure

- *Overheating during soldering (soldering iron was set to 371 °C).* Experiment showed that possible T rise do not exceed 80 °C.

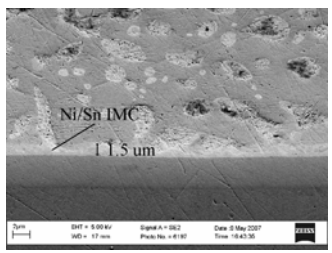
Soldering simulation.

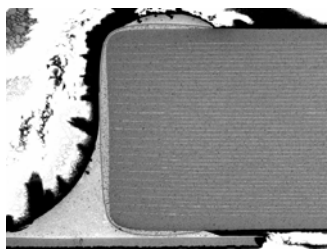


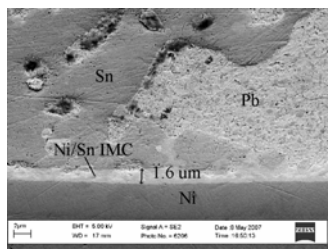


Experimental (marks) and calculated (line) temperature variations. The soldering iron was fixed at the middle of contact pads.

- *Overheating during baking in the oven.* Analysis did not reveal differences in microstructure of solder in 8 boards (no solder coarsening or variations in thickness of IMC layers).

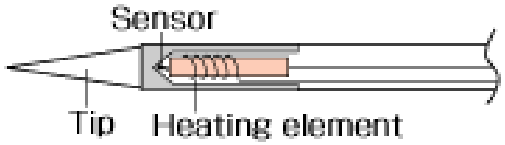




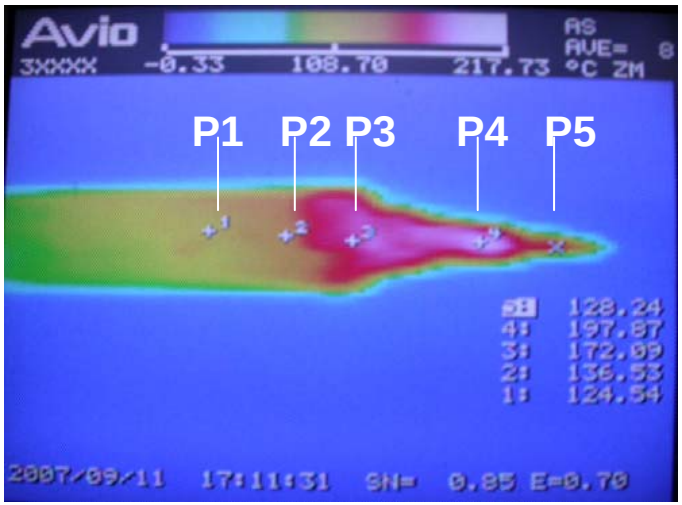


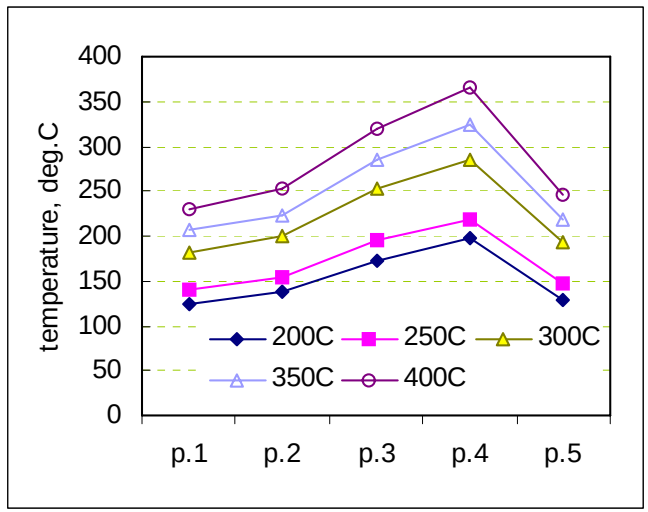
How Hot is a Soldering Iron?

- Temperatures of a soldering iron were set to 200, 250, 300, 350, and 400 °C.



- IR measurements in 5 points were used to get temperature distributions.





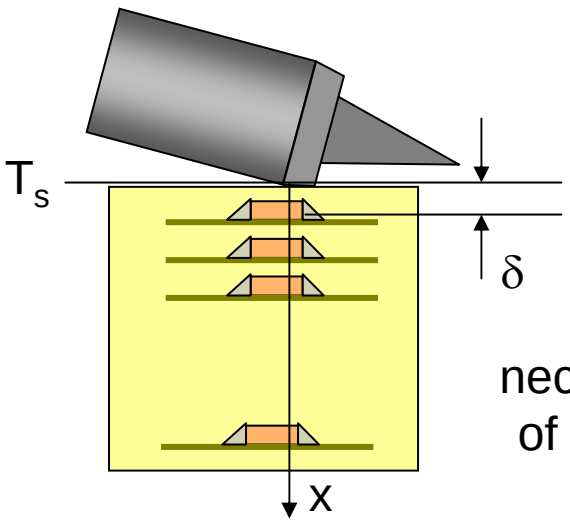
Temperature of the holder near the tip (P3) is only 10% to 13% lower than T_{max}.

Most Probable Cause of Failure

- The response of semi-infinite solid to surface temperature rise to Ts can be described with the Gaussian error function:

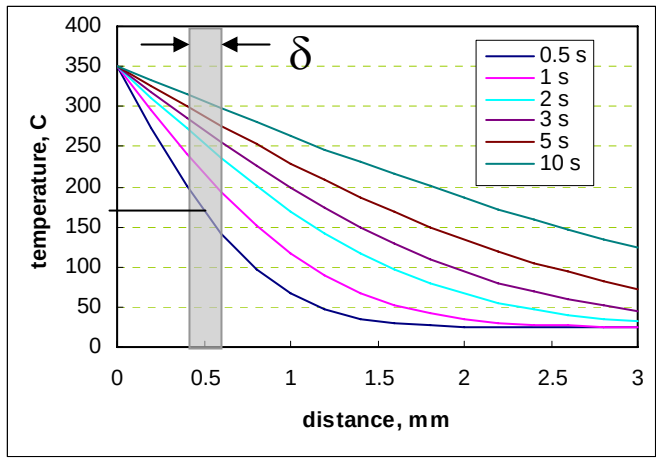
$$\frac{T - T_i}{T_s - T_i} = erfc\left(\frac{x}{(4\alpha t)^{0.5}}\right)$$

- Temperature distributions were calculated at T_s = 350 ^oC and thermal diffusivity, α = 4.3E-7 m/s^2.



Only ~0.5 sec is necessary to reach T_m of solder (~183 ^oC) at the top board

T distributions across 3D-plus package



The most probable cause of failure is inadvertent touch by a soldering iron.

Conclusion

- Reaching melting point of solder is a necessary, but not a sufficient condition for internal reflow failures in plastic encapsulated devices.
- Fast heating during manual soldering allows plastic encapsulation to remain at relatively low temperatures, so the die stays under compressive stresses. Expansion of solder might cause delamination and spreading of molten solder along the surface of the die resulting in short circuit failures.
- Preheating and equalizing temperature across the package might reduce the probability of failures.
- Temperature of soldering iron holder near the tip might be much higher than melting temperature of solder. Occasional touch to the surface of the package might cause failures.
- Reducing the length of wires increases die temperature. Special care (thermal shunts) should be taken to avoid solder reflow failures.
- Avoid holding or touching plastic packages during soldering.