Muanalysis Inc.
2301 St. Laurent Blvd, Suite 500
Ottawa, ON K1G 4J7
Canada
t. (613) 721-4664
f. (613) 721-4682
www.muanalysis.com

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Green LED Failure Analysis

Job No :

Customer :

Author:

Date :

Objective: Failure Analysis, Green LED

1.0 Objective

To determine the failure mode and, if possible, root cause of failure of a green LED.

2.0 Summary of Results

- Failed and intermittent LED's were found to have temperature-dependent intermittent open circuits but no apparent damage at the semiconductor device level.
- Optical examination and cross-section analysis indicated a delamination of the clear epoxy moulding compound from the inner surfaces, including the floor, of the metal reflector of the leadframe. Some force had lifted the die from the die attach glue line.
- No evidence of wirebond failure at the wedge bond to the lead frame was found.
- Electrical characterization confirmed that the operating voltage at a fixed current drops with temperature, suggesting that without active current regulation, these devices may run at higher currents and temperatures than intended or expected.

3.0 Analysis Methods

Optical Inspection: In this method parts are inspected with various low-power stereo zoom and high-power metallurgical microscopes for anomalies. Depth of field and resolution are limited, but colours and textures are represented in familiar ways.

Pin Test: The current-voltage characteristics of some or all device pins are recorded with the device unpowered. A known good reference part is normally tested in the same manner to determine what the undamaged part I-V characteristics should be.

Cross-section Analysis: The sample is encapasulated if and as required and then lapped and polished to reveal any internal plane for microscopic examination and/or physical analysis.

Scanning Electron Microscopy (SEM): This form of microscopy offers much better resolution and depth of field than optical microscopy. Contrast is by atomic density so normal colour information is lost.

4.0 Samples

Four through-hole LED's labeled "failed", six LED's labelled "intermittent", and five new parts were received. The parts carry no branding. A data sheet for XXXXXX super bright green LED's matching the parts was also received.

Figure 1a: Four failed LED's received.

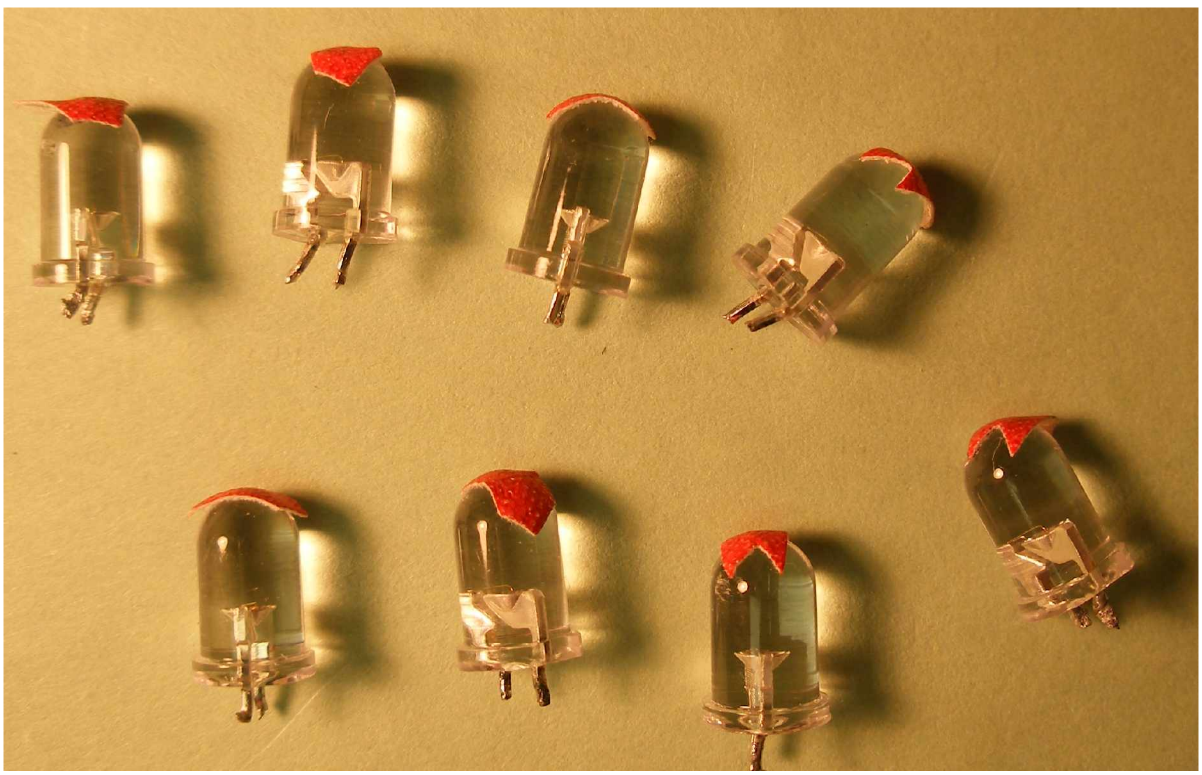

Figure 1b: Eight intermittent LED's received.

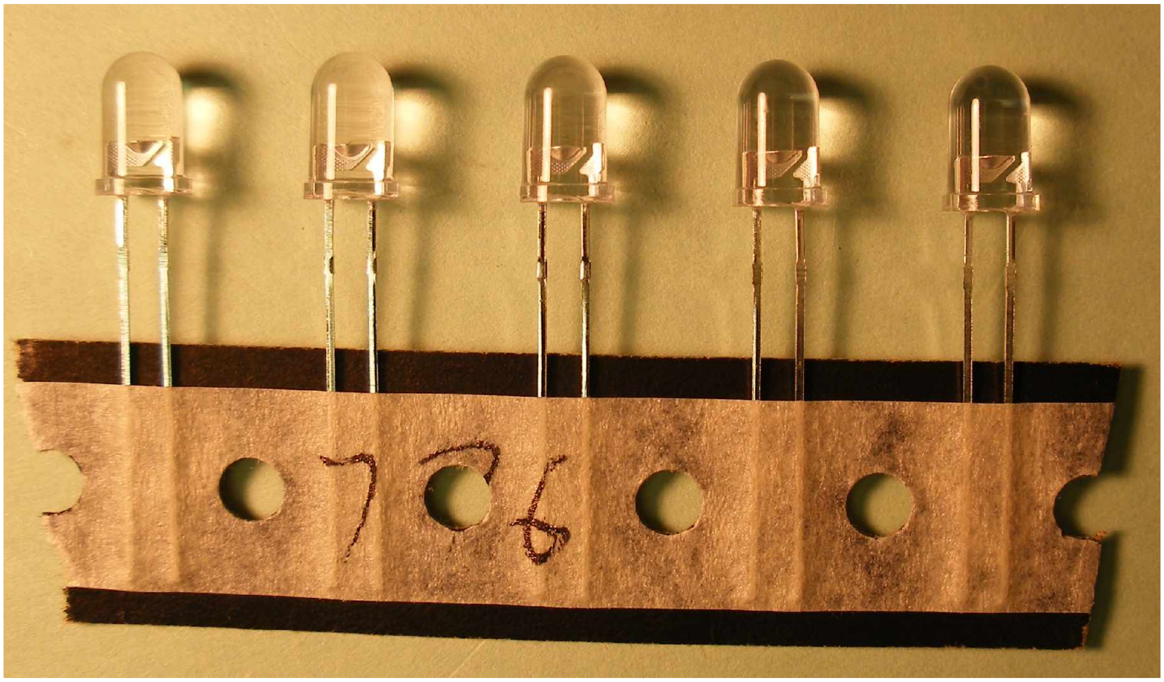

Figure 1c: Five new LED's received.

5.0 Electrical Test

The four reported failed samples were labeled D1 to D4 and three of the reported intermittent samples were randomly chosen and labeled I1 to I3.

Each of the four failed parts, the three selected intermittent parts, and one reference part were subjected to Current-Voltage (I-V) characterization, with warming with a hot air gun to verify stability.

The new part tested exhibited the expected diode characteristic, with a turn-on at about 3 volts and a green emission noted.

The failed and intermittent parts all showed a similar I-V curve and green emission to the reference part when first tested, but went open circuit suddenly after some seconds of warming with the hot air gun. Heating time to failure and recovery tine varied, with no clear distinction between the failed and intermittent sample sets. The new part tested was also subjected to warming and could not be made to fail.

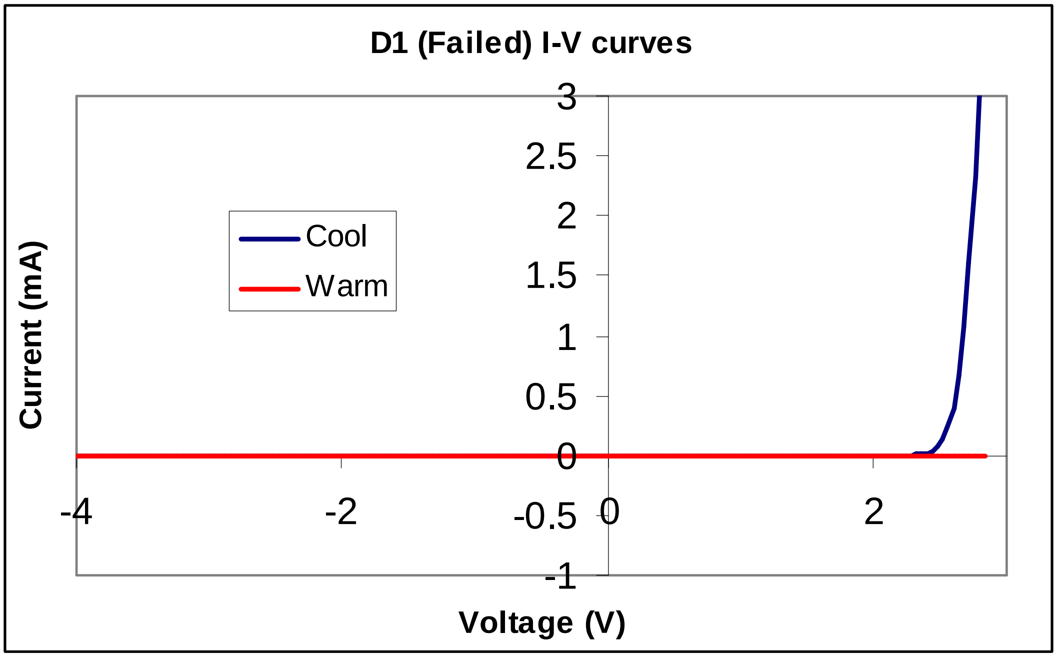

Figure 2: I-V curve of a failed part with and without warming. The part goes open circuit with warming.

Table 1: Summary of Electrical Test Results. Thermal Characteristics are subjectively described.

Part	I-V	Thermal Characteristics (OC = Open Circuit)
REF 1	3 volt diode turn-on	Stable
D1	3 volt diode turn-on	OC on warming, slow recovery
D2	3 volt diode turn-on	OC after persistent warming, recovers quickly
D3	3 volt diode turn-on	OC on gentle warming, recovers quickly
D4	OC	NA
I1	3 volt diode turn-on	OC after persistent warming, recovers quickly
I2	3 volt diode turn-on	OC after persistent warming, recovers quickly
I3	3 volt diode turn-on	OC on warming, slow recovery

6.0 Visual Inspection

Visual inspection of the wirebond and semiconductor die of the failed parts through the encapsulation was facilitated first by immersing the parts in index matching fluid and then by polishing the tops off the packages to give a flat, optically clear top surface to inspect though.

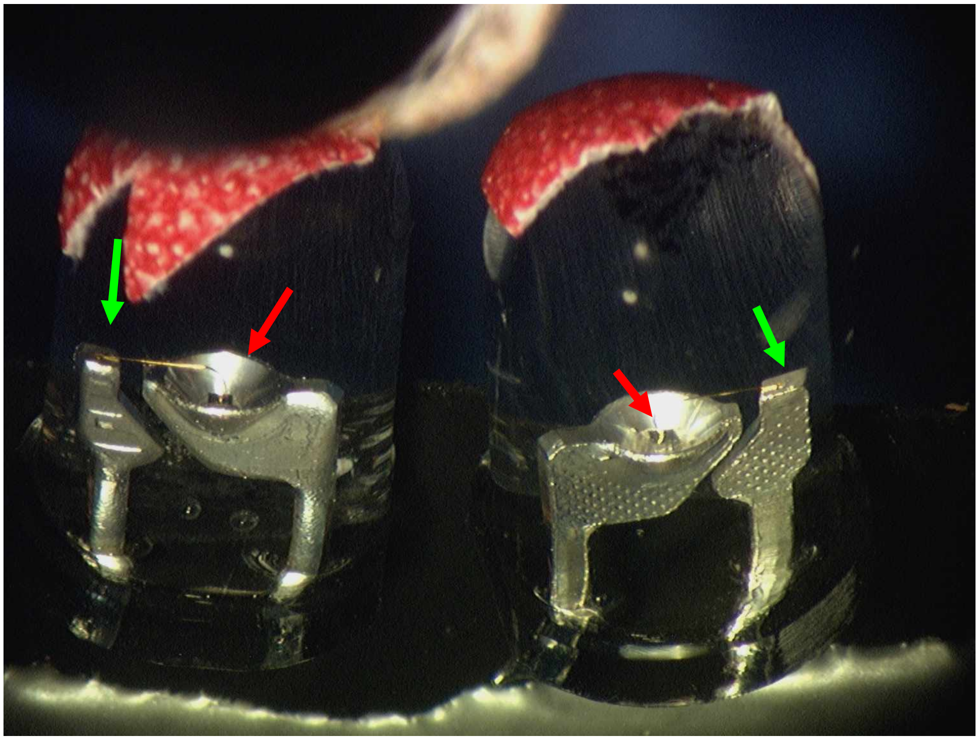

Figure 3: Two failed parts immersed in index matching fluid. The locations of the semiconductor die and the lead frame wedge bond are indicated with red and green arrows.

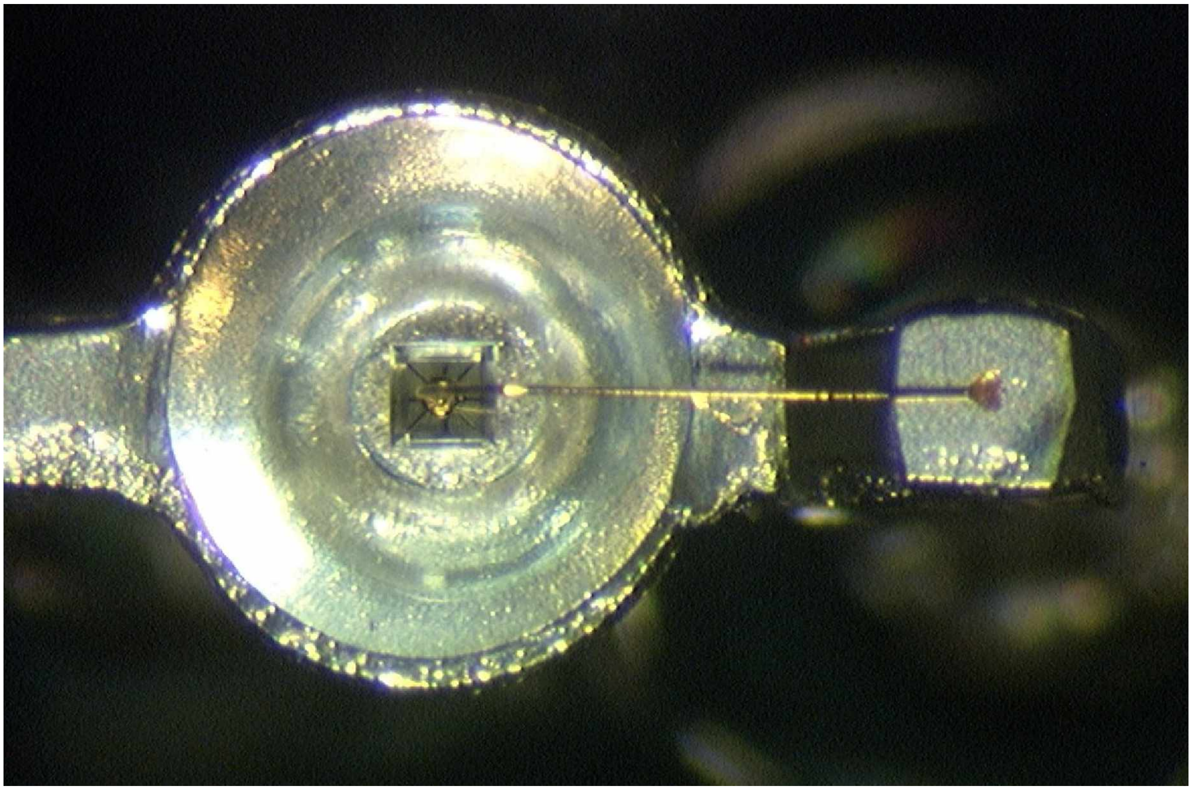

Figure 4a: Top view of die and wirebond of failed part D1, though an optically flat surface polished in the encapsulation. No damage is observed.

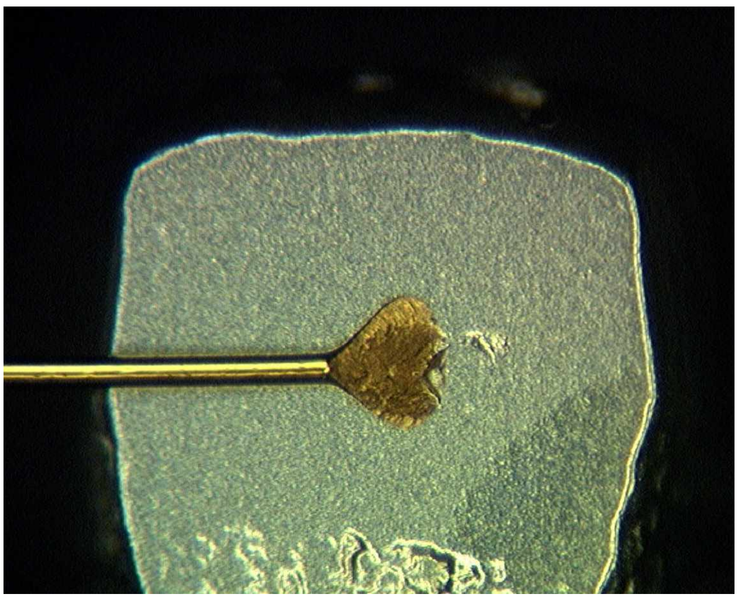

Figure 4b: Wedge bond of D1. No damage to the wire or voids in the encapsulation are observed.

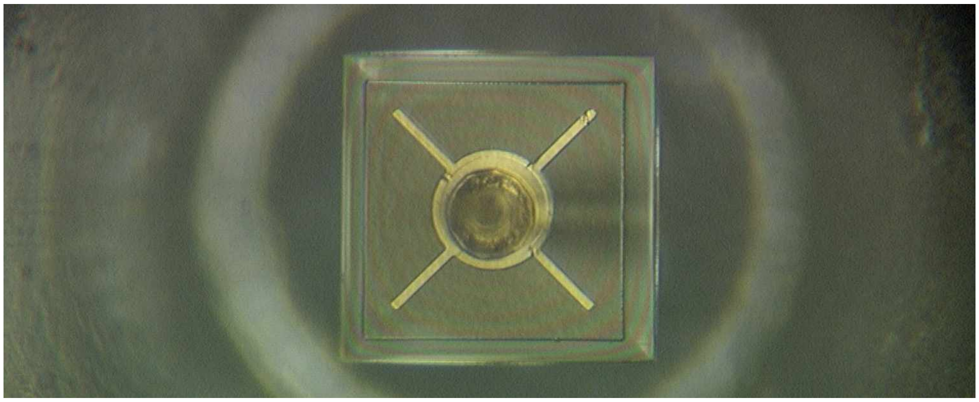

Figure 4c: Die of part D1. The faint circular pattern of fringes may indicate a delamination at the top of the die.

7.0 Thermal Analysis

The issue of current regulation in use may be of interest in this investigation. A reference part was immersed in an inert fluid at controlled temperatures, and I-V curves taken at various temperatures with a pulsed method to limit self-heating. In this way, curves of diode forward voltage vs. temperatures at fixed currents were collected.

The operating voltage at fixed currents of 20 ma and 35 ma were plotted. A distinct reduction in forward voltage with temperature is observed.

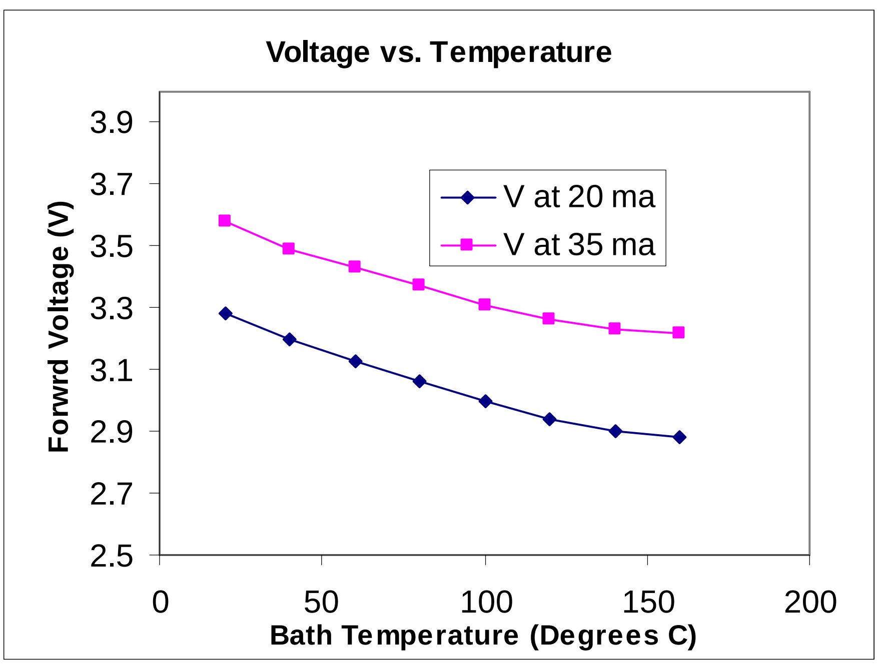

Figure 5: LED operating voltage at 20 and 35 ma as a function of temperature.

8.0 Cross-Section Analysis, Part D1

Failed part D1 was subjected to cross-section analysis by lapping and polishing from the side to reveal a cross-section of the semiconductor die.

Figure 6a: Low magnification optical image of cross-section of semiconductor die and lead frame.

Raman spectroscopy indicated that the semiconductor die substrate is AAA. The die is almost certainly a BBBBBBB, which is described in the CCCC documentation as an InGaN active layer on AAA substrate. These materials are extremely resistant to heat damage, and it is thought very unlikely that semiconductor or substrate damage could occur without serious bond-wire, die attach, or encapsulation damage also occurring.

The encapsulant is reported to be DDDD. It has a reported co-efficient of thermal expansion (CTE) of 65 ppm/C degree and a glass transition temperature of 110 degrees C. At any temperature above that value it can be expected to deform.

EDX analysis indicated that the lead frame is composed of iron (almost certainly mild steel) with copper, nickel, and silver platings. These are typical materials for a through-hole LED. Note that the CTE value for mild steel is found in several sources to be 11 to 13 ppm/C degree.

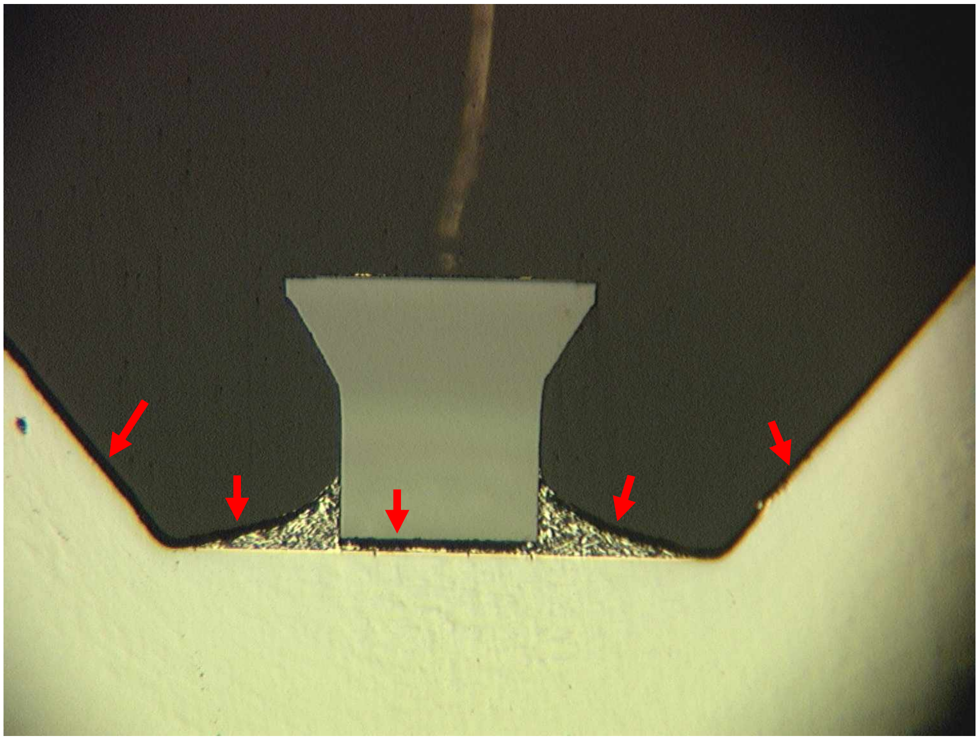

Figure 6b: Optical image showing delamination of the encapsulant from the lead frame and separation of the die from the die attach.

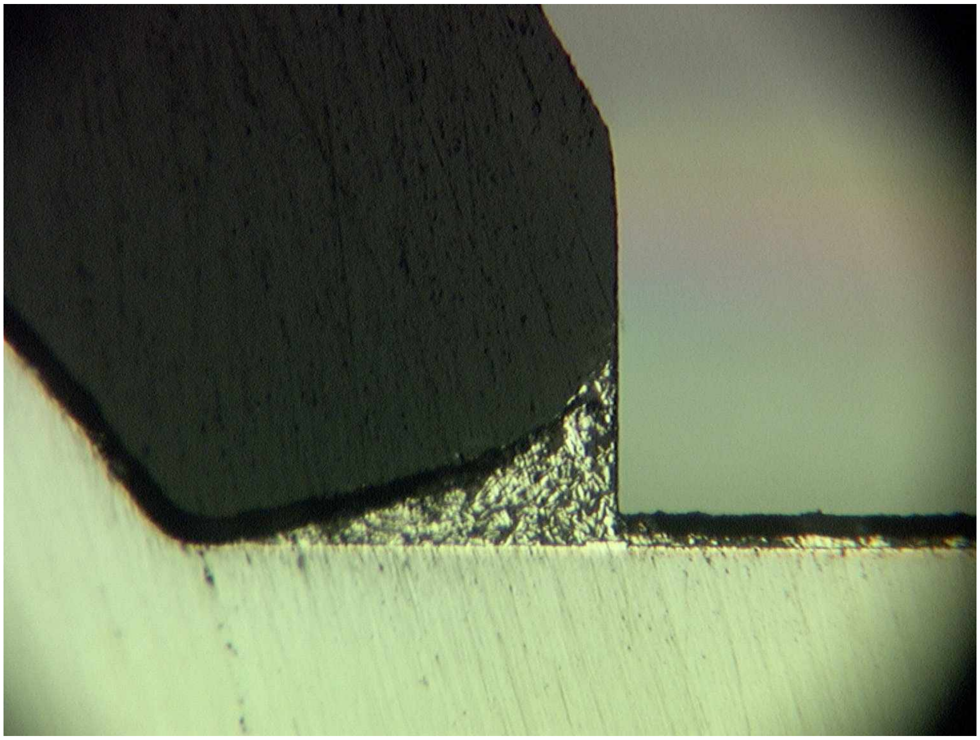

Figure 6c: Higher magnification.

Inspection of the cross-section indicated no sign of delamination at the location of the wedge bond on the lead frame, and imaging of the wedge bond through the polished face showed no damage or lifting.

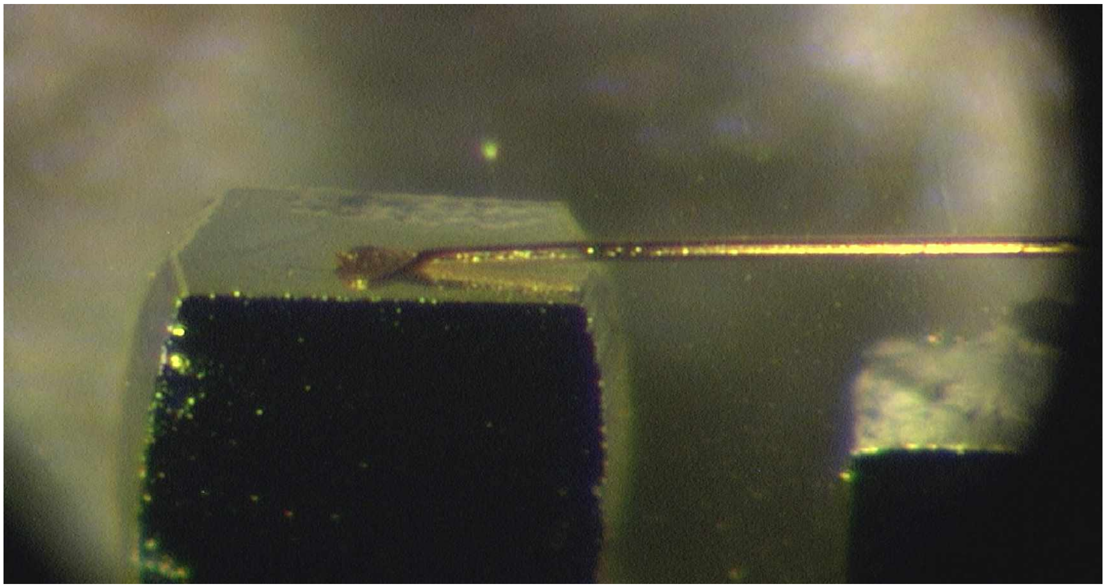

Figure 6d: Wedge bond of D1 observed in a stereo-zoom microscope through the polished surface of the encapsulant. No damage to the encapsulant or bond is noted.

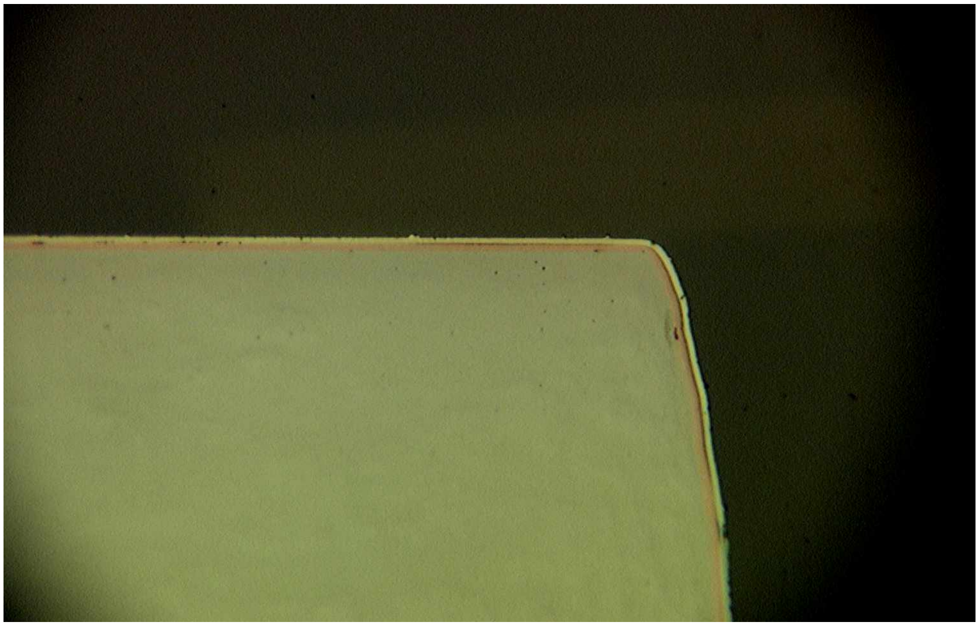

Figure 6e: High-magnification metallurgical microscope image of the Interface between the lead frame and the encapsulant near the wedge bond in the D1 cross-section. The metal platings are clearly resolved but no evidence of delamination is seen.

SEM imaging of the failed part confirmed the location of the gaps over the die attach material and directly under the die.

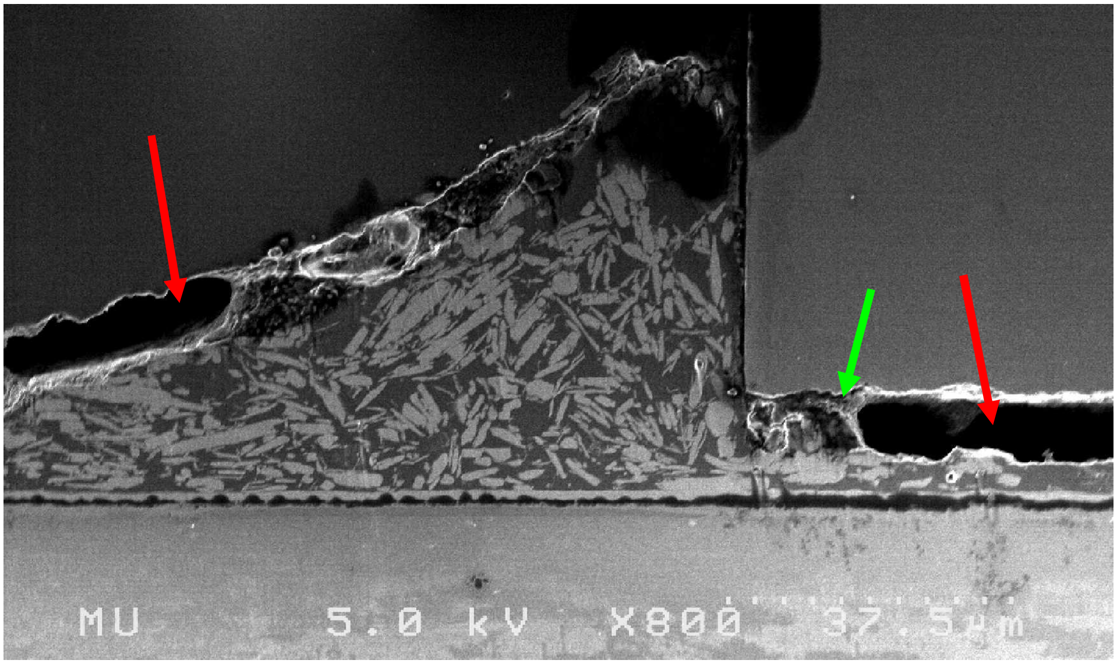

Figure 7a: SEM image of die attach fillet at right side of the die. Gaps (red arrows) are confirmed. There may be some re-melted epoxy (green arrows) but this is not conclusive proof of overheating. At least some of the material in the gaps is polishing residue.

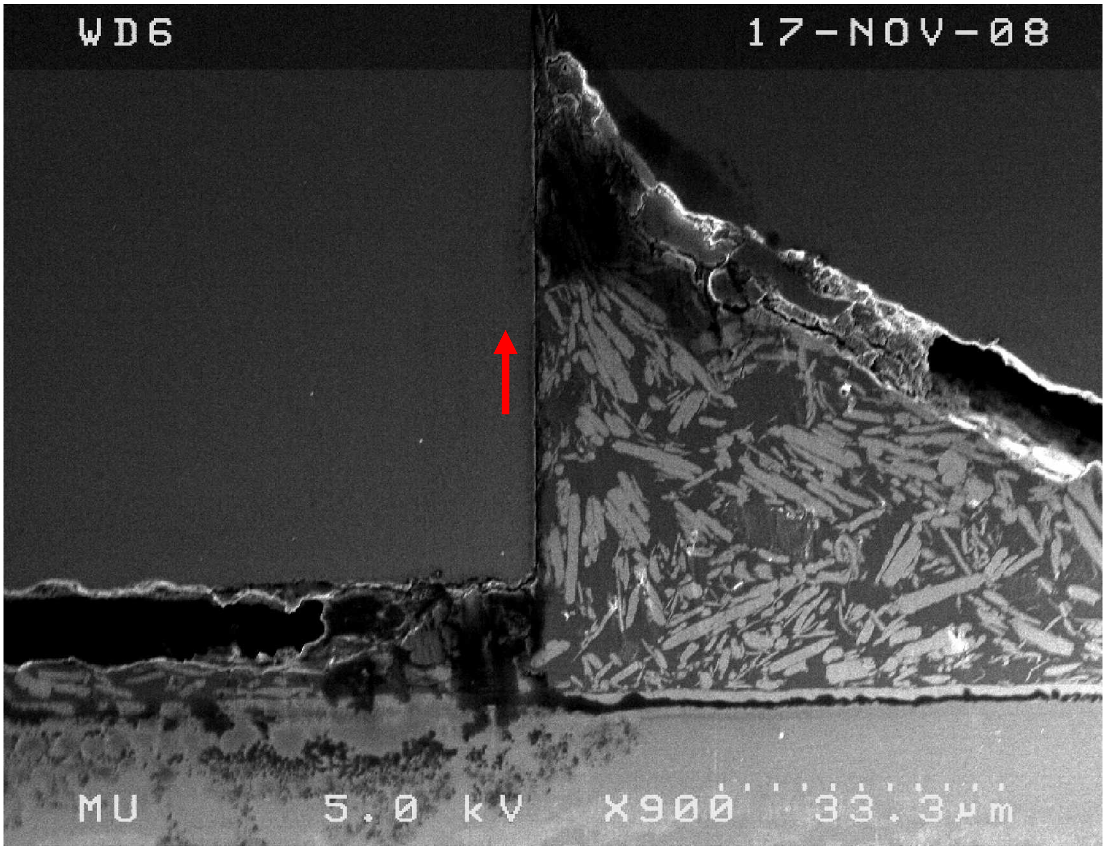

Figure 7b: SEM image of die attach at right side of die. The die has clearly been displaced upward (see arrow) by some force. Note that residues bleeding out of the gaps in the vacuum of the SEM cause dark stains at low beam energy.

9.0 Cross-Section Analysis, Part I2

A similar cross-section analysis of an intermittent part produced an almost identical result, lifting of the die in the die attach due to what appears to be shrinking of the encapsulant in the “cup” region of the leadframe. Inspection of both cross-sections indicated some delamination of encapsulant from the legs near the part bottom as well as the delamination in the cup, but also a large undelaminated region separating the two delamination locations. This indicates that the damage in the cup area was not due to original assembly by wave soldering or desoldering of the failed parts.

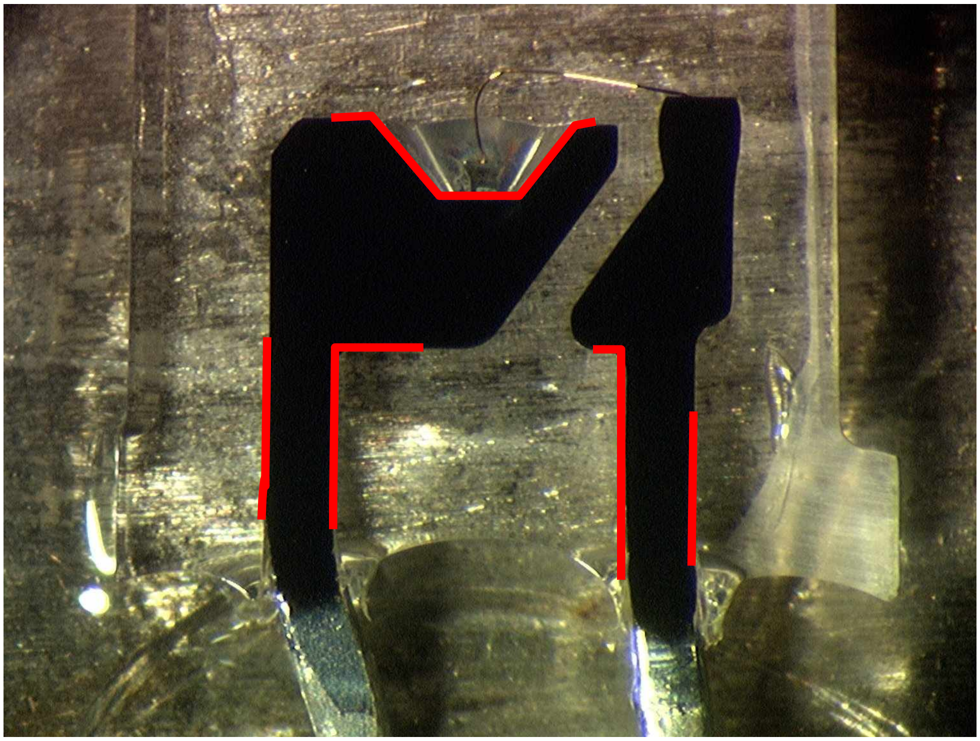

Figure 8a: Cross-section of part I2 with locations of observed delaminations marked in red. Part D1 was similar.

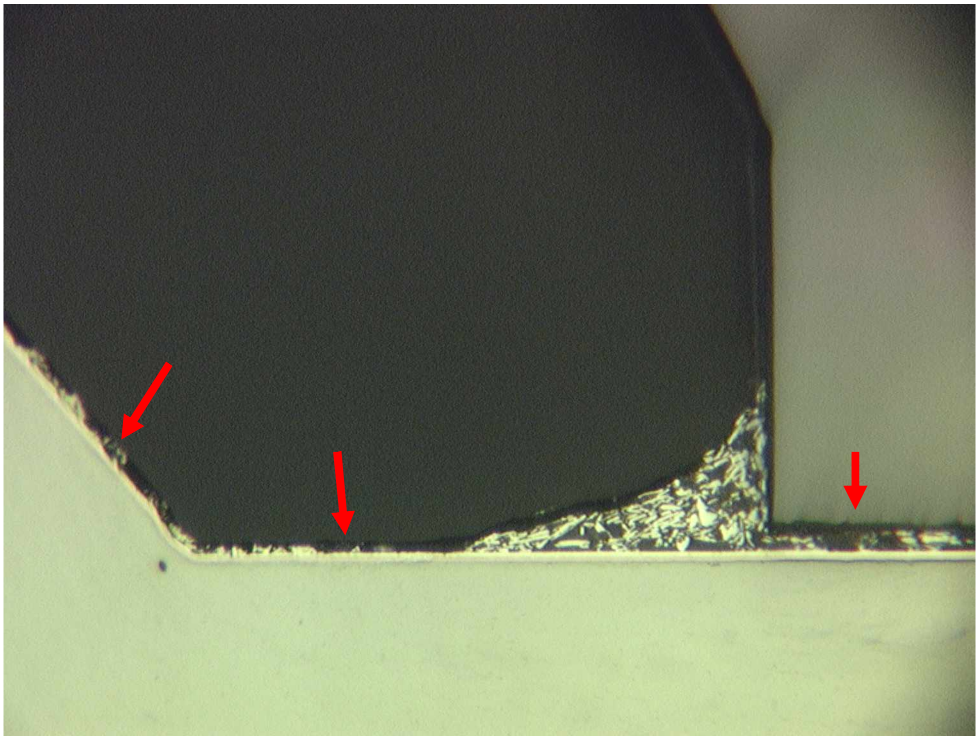

Figure 8b: Delamination of encapsulant from cup and die from die attach in part I2.

In this cross-section, the wedge bond to the lead frame was in the cut plane. There was no evidence of delamination of encapsulant at this location, and no damage to the bond wire or wedge bond seen.

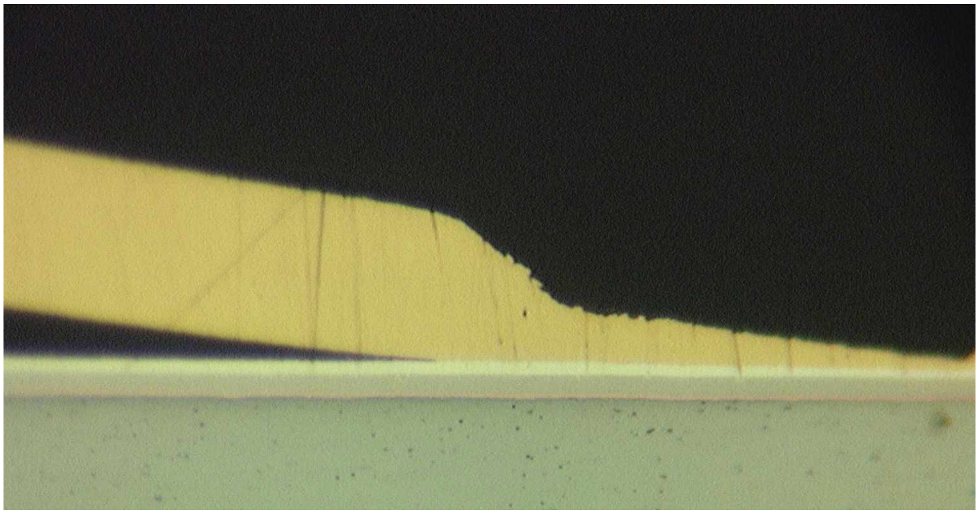

Figure 8: Lead frame wedge bond in cross-section of Part I2.

10.0 Conclusions:

The failed and intermittent parts subjected to electrical test were either open circuit or intermittent, with a clear temperature dependence. Whenever contact was present, a normal I-V characteristic was observed. This behaviour is characteristic of interconnect and packaging issues, and not of semiconductor material failure.

Optical inspection and cross-section analysis showed that the single wedge bond to the lead frame was undamaged in both cases investigated.

Cross-section analysis indicated an extensive delamination of the encapsulant from the optical "cup" of the lead frame which had the effect of lifting the semiconductor die from the die attach material in both cases. This is believed to be the location of the intermittent open circuits.

A thermal analysis of a reference device showed that operating voltage drops with increasing temperature. This would make it difficult to control the device operating current without active current regulation. As an aside, it is noted that high-power LED's based on InGaN anad AlGaN are typically supplied with a silicon device in parallel that acts as a current shunt should temperature rise.

The clear encapsulant has a listed CTE value of 65 ppm/k degree, which is more than five times that of the steel lead frame. Up to the glass transition temperature of 110 degrees, substantial forces may be generated in the leadframe cup. At the glass transition temperature, these forces may relax by strain in the encapsulant. Upon cooling, the resulting tension would extert a lifting force on the die. The "T-shaped" configuration and extreme strength of the AAA die substrate would force the inevitable delamination to be at the die attach level, not at the die top where the ductility of the gold ball bond may delaminate from the device or possibly allow contact to be maintained.