STEREO IMPACT

PROBLEM REPORT
PR-6001
HVPS_thermal
2003-09-15

PR Numbers: 1xxx=UCB, 2xxx=Caltech/JPL, 3xxx=UMd, 4xxx=GSFC/SEP, 5xxx=GSFC/Mag, 6xxx=CESR, 7xxx=Keil, 8xxx=ESTEC, 9xxx=MPAe

Assembly : SWEA FM2	**SubAssembly : HVPS board**
Component/Part Number:	**Serial Number: FM2**
Originator: Claude Aoustin	**Organization: CESR Toulouse France**
Phone : + 33 5 61 55 88 69	**Email : claude.aoustin@cesr.fr**

Failure Occurred During (Check one √)

☐ Functional test √ Qualification test ☐ S/C Integration ☐ Launch operations

Environment when failure occurred:

☐ Ambient ☐ Vibration ☐ Shock ☐ Acoustic
√ Thermal ☐ Vacuum ☐ Thermal-Vacuum ☐ EMI/EMC

Problem Description

During the Thermal test of the HVPS board at -70°C the Non Regulated HV was not synchronized.

Analyses Performed to Determine Cause

At -70°C the output of the HM 402 P 10 voltage multiplier from VMI used to create the non regulated HV used by deflectors HV and the analyzer sweeping HV, was not working properly. Nominally it should be at 1800V but it was oscillating between 200V and 1200V. It should be noted that coming back at ambient temperature it was working properly.

The qualification test of the HV board was done at -70°C to take into account a 20°C margin. The lowest foreseen temperature in flight should be -50°C. The HV prototype has been tested at -80°C. The ETU and FM1 have been tested at -70°C without any problem. The HM 402 P 10 is qualified down to -55°C.

Corrective Action/ Resolution

☐ Rework √ Repair ☐ Use As Is ☐ Scrap

The HM 402 P 10 has been replaced and a new qualification test has been performed successfully down to -70°C.

Date Action Taken: 2003-09-18 **Retest Results**: 2003-09-19 Success
Corrective Action Required/Performed on other Units ☐ Serial Number(s): None

Closure Approvals

Subsystem Lead: ________________________ Date:____________
IMPACT Project Manager: ________________________ Date ____________
IMPACT QA: ________________________ Date:____________
NASA IMPACT Instrument Manager: ________________________ Date:____________

PFR- 6001 HVPS VMI Multiplier Failure

PROBLEM DESCRIPTION

An intermittent high voltage output from the HM402P10 voltage multiplier was observed during low temperature (-70C) qualification testing. It was also noted that the output recovered while coming back to ambient temperature. The HM402P10 device was replaced and qualification testing was repeated down to –70C with no anomalies.

Additional investigation revealed that the assembly with the voltage multiplier was temperature cycled several times down to –70C, and the intermittent failure was eventually present (intermittently) even at ambient temperature.

ANALYSIS PERFORMED TO DETERMINE CAUSE

It appears that the most likely cause of the intermittent failure of the HM402P10 voltage multiplier was the result of a poor wire bond at D9 that was lifted due to thermal expansion and contraction of the molding material. The fact that the part can sustain without failures 100 hours of high temperature storage at 200C and 100 temperature cycles from –70 to 100C indicates that the observed failure during the HVPS board testing is most likely an infant mortality failure, rather than a failure caused by any wear-out mechanism intrinsic to the part's design and used materials. Accelerated environmental stress testing performed on the two flight parts and 7 parts from a new lot, have shown that exposure of the parts to –70C did not compromise the reliability of the flight parts substantially, and their use will have most likely a low risk for the project.

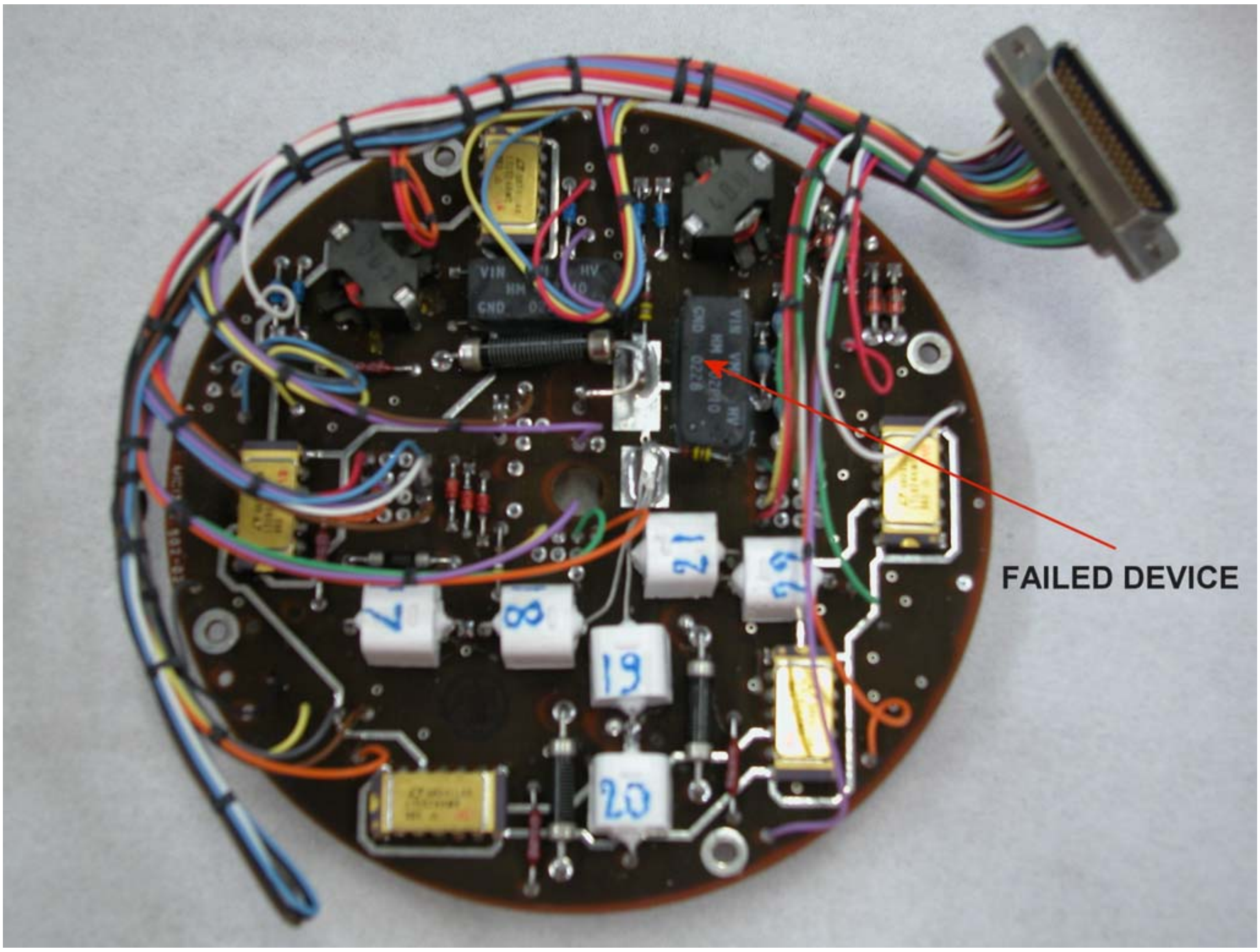
CORRECTIVE ACTION/RESOLUTION

The HM402P10 device LDC (0228) has been replaced with LDC (0402) and requalified. The boards were cycled in a thermal chamber that had a humidity trap and the transition rates were very slow (0.3 degrees/min). Therefore the risk of thermal shock is less. The Project recommended a close inspection, at a minimum of 10X, on the board to check for separation, cracks and fractured solder joints. An inspection of the SWEA FM1 HVPS board was completed at UCB, 4/30/2004. No separation, cracks and fractured solder joints were found. Inspections were made in particular under parts that used Scotchweld.

Failure Analysis :

During the test the HV board is installed in a thermal precinct. A wire is connected to the collectors of the transistors driving the transformer to verify if the HV is correctly synchronised. This is the first thing done at the different temperatures.
At -70°C it appeared that this frequency was unstable on the Non Regulated HV. This has been imputed at first to the synchronisation of the oscillator of the HV at low temperature because it was disappearing when the temperature was increased.
After several attempt to fix this problem, we understood that it was coming from something else.
Finally after several temperature cycling at -70°C the problem was existing at ambiant temperature as well. So it was becoming easy to study the problem on the bench. The output of the transformer (connected to the input of the VMI multiplier) was correct : 400 V peak to peak which should give 2000V at the output of the multiplier. But this output was oscillating between 300V and 1200V randomely.
It has not been possible to get some oscilloscope display of it because after some minutes it restarted to work correctly at ambiant temperature. The desynchronisation seen at the input of the transformer was due to the fact that the load on the secondary side was changing (explaining the first wrong behavior seen). It was resynchronising, loosing the synchronisation again ..and so on.
During this test the current at the output of the multiplier was equal to some µA much lower than the maximum current allowed equal to 200 µA.
This random failure can come only from the multiplier and we replaced it, repeated the test successfully. We can suspect some internal problem on the connections inside the chip.
It should be noted that we performed a test on standard parts at -80°C during 8 hours.
We have still the part which failed and we can ask for an inspection.

Part has been sent to Lillian Reichenthal on October 20, 2003


FAILED DEVICE

Appendix to STEREO IMPACT PFR 6001, VMI multiplier failure

2003-12-2 Dave Curtis, Claude Aoustin

There are 2 VMI multipliers in each SWEA unit (one for the MCP supply and one for the analyzer supply).

Test Performed on the different models:

- ETU1, at CESR:
    - Electrical test at ambiant temperature : 7 hours
    - Thermal test on the Hv board : - 80°C to 50°C
        - 3 cycles from ambiant to -80°C to adjust the gain of the HVs
        - Then step of 20°C up to +50°C
        - Total duration about 20 hours
    - Calibration tests :
        - Under vacuum
        - Ambiant temperature : 3 months
        - Full unit (SWEA CESR part only)

- ETU1, at UCB:
    - Bench Integration tests with the UCB parts of SWEA/STE
        - ~40 operational hours
        - MCP multiplier not powered
        - ~8 hours with power applied to the sweep multiplier.
    - Vacuum calibration/tests
        - ~100 operational hours, ~80 of which included both MCP and analyzer high voltage
        - Tests on-going, mostly to ring out test procedures for flight units.

- FM1 at CESR:
    - Electrical test at ambiant temperature : 7 hours
    - Thermal test on the Hv board : - 70°C to 50°C
        - 3 cycles from ambiant to -70°C to adjust the gain of the HVs
        - Then step of 20°C up to +50°C
        - Total duration about 20 hours
    - Calibration tests :
        - Under vacuum
        - Ambiant temperature : 4.5 months
        - Full unit (SWEA CESR part only)
    - Bake out 48 hours at 60°C : HV board, amplifiers board

- FM2 at CESR:
    - Electrical test at ambiant temperature : 7 hours
    - Thermal test on the Hv board : - 70°C to 50°C

        - 2 cycles from ambiant to -70°C to adjust the gain of the HVs (VMI failed and replaced)
        - 3 cycles from ambiant to -70°C to adjust the gain of the HVs
        - Then step of 20°C up to +50°C
        - Total duration about 23 hours
    - Calibration, Bake out yet to be performed

- FM1, FM2 at UCB (to be performed)
    - Bench Integration tests with the UCB parts of SWEA/STE,
        - ~40 operational hours
        - MCP multiplier not powered
        - ~8 hours with power applied to the sweep multiplier.
    - Vacuum calibration/tests
        - ~100 operational hours, of which ~80 of which included both MCP and analyzer high voltage.
    - Vibration tests (random, sine sweep)
    - Thermal vacuuum test
        - high voltage on;
        - 6 cycles -25 to +30
        - one survival cycle -30 to +50
    - Suite integration tests
        - high voltage off
        - ~8 hours
    - EMC tests
        - high voltage off
        - ~40 hours

We then have spacecraft integration and environments, mostly with HV off, though we will get ~100 hours of HV on operation during thermal vac. After spacecraft environments we will get the instrument back to verify the detectors survived environments, getting another ~16 hours of high voltage on operation time.

Flight Environment

STEREO goes to heliocentric orbit, so it does not see much thermal cycling. SWEA is normally in the shade, though it gets some warm excursions during off-pointing for delta-V maneuvers a few times early in the mission. Flight predicts are -20C to +16C (lower end is heater controlled).

Data on manufacturer bonding and encapsulation process

We (UCB) are attempting to get data from manufacturer on wire bond process for LDC or any statistical data on wire bonding process that can be obtained.

Flight Heritage with this part

Not to our knowledge

Impact if this parts fail on the board

The impact is very bad! We will loose the deflectors and analyser Hv and/or the MCP HV. So that means that we will not get anymore science.

Impact of replacing the HV multiplier on the board with the part procured to the Grade 2 specification - cost, schedule?

Availability of the components will take some months. During this time some more work (interface tests) could be performed on FM1 at UCB. But we cannot start environmental tests until after the replacement. We will also lose the many accumulated hours of trouble free operation.

To make the replacement, it is necessary to remove the electronic boards, unsolder the components, solder the new ones, have the electrical and thermal verification. Let's say one week minimum. This should be done in Berkeley by the French engineers. There will be a problem with French funding. Following that there needs to be at least one week of repeated functional tests and accumulated operational hours prior to the start of environments.

Impact of replacing both flight boards along with the HV multipler (procured to the Grade 2 specification) - cost, schedule?

This option is more critical in terms of planning and cost. We would need a new board fabrication and have enough components. We have spares to build one but not two replacement boards. Parts procurement would require several months, followed by ~2 months of fabrication and test. French funding could be a problem.

We feel that the FM1 board has not suffered at all for now. We have no reason to rebuild everything. Just the HV multiplier could be suspected but it worked in vacuum during 4.5 months.

Second Appendix to STEREO IMPACT PFR 6001, VMI multiplier failure

2004-4-30 Dave Curtis, Claude Aoustin

Thermal Stress:

Additional information provided by CESR was very helpful. The boards were cycled in a thermal chamber that had a humidity trap and the transition rates were very slow (0.3 degrees/min). Therefore the risk of thermal shock is less. The Project recommends a close inspection, at a minimum of 10X, on the board to check for separation, cracks and fractured solder joints. Pay special attention to the parts that use Scothweld between the device and the board.

An inspection of the SWEA FM1 HVPS board was completed by Ron Jackson, Berkeley QA. No separation, cracks and fractured solder joints were found, nor was there any problem with the Scotchweld.

GODDARD SPACE FLIGHT CENTER

Failure Analysis Report

Voltage Multiplier, Hybrid, Positive Output	Project STEREO
Mfr.: Voltage Multipliers, Inc (VMI)	
P/N: HM402P10	System IMPACT/SWEA
DC: 0228	
SN: None	Requester A. Reyes (562)
Investigator C. Greenwell (562)	Initiated Date 10/29/03

Background

STEREO/IMPACT Problem Report PR-6001 documented an intermittent high voltage output from the HM402P10 voltage multiplier. The failure was observed during low temperature (-70C) qualification testing. It was also noted that the output recovered while coming back to ambient temperature. The HM402P10 device was replaced and qualification testing down to –70C was repeated with no anomalies.

Additional investigation revealed that the assembly with the voltage multiplier was temperature-cycled several times down to –70C, and that the intermittent failure was eventually present even at ambient temperature, and that it was also intermittent at ambient temperature.

The device was submitted to the GSFC Parts Analysis Laboratory for failure investigation.

Part Description

The HM402P10 is a hybrid assembly, positive output, voltage multiplier that converts an AC voltage input into a DC voltage output. This particular device accepts up to 900V peak-to-peak at 20-100kHz input and produces up to 4000Vdc at 200uA output.

The device is constructed with an alumina substrate/base-plate, two monolithic, segmented capacitors and 10 discrete surface mount diodes interconnected with 1.5 mil (0.0015 inch) aluminum wires. The assembly is encapsulated with a glass-filled epoxy material similar to that of common plastic encapsulated microcircuit (PEM) devices. Three external leads, GND, VIN and HV(out) are soldered to pads on the alumina substrate.

Analysis and Discussion

External examination revealed a small round anomaly in the potting material near the VIN lead. This feature was not an artifact or cause of failure. The package had a hand-written “X” marked across the top surface, possibly identifying it as bad. Figures 1 and 2 show external views of the device.

Radiographic inspection revealed no anomalies but did reveal many construction features previously described. As expected, the aluminum interconnect wires were not visible in radiographic inspection. Figure 3 shows top and side view radiographic images of the device.

Electrical testing showed the device was non-functional. An input of up to 60Vp-p at 20 to 50 kHz produced only a 1Vp-p ripple voltage output at the input test frequency. Testing over a temperature range was not performed.

Due to the failure mode and the device construction it was decided to use oxygen plasma ashing to deprocess the device. This process is very slow but introduces no artifact. It does, however, remove organics, making the possibility of revealing foreign material and contamination unlikely. Alternatively, chemical deprocessing is likely to produce artifacts and destroy evidence of foreign material and any contamination present.

The potting material was removed until the tops of the diodes were visible. At this point, compressed air necessary to remove the ash inadvertently broke several wires bonded to the diodes. Figure 4 shows the device at this stage of deprocessing.

Importantly, optical inspection showed that the aluminum bond wire at diode D9 had lifted from the bonding surface instead of breaking at the neck-down region, as expected for adequately-bonded wires. Figures 5 and 6 show these results. The wire and diode were examined using energy dispersive spectroscopy (EDS). This technique revealed very little alloying of the aluminum and gold, indicating that a poor bond existed at this location. Figures 7 and 8 show the x-ray dot maps of gold and aluminum for these interface surfaces.

As previously mentioned, all the other wires that broke during deprocessing broke at the wire neck-down and left a bond wire “foot” present at the diode. Figures 9 through 11 show several examples of this expected result.

Conclusion

It appears most likely that the cause of intermittent failure of the HM402P10 voltage multiplier observed by the STEREO/IMPACT/SWEA team was the result of a poor wire bond at diode D9 that lifted due to thermal expansion and contraction of the molding material. The wire bond was defective at manufacture, and its subsequent fracture and failure was exacerbated by temperature stress.

Appended Images:

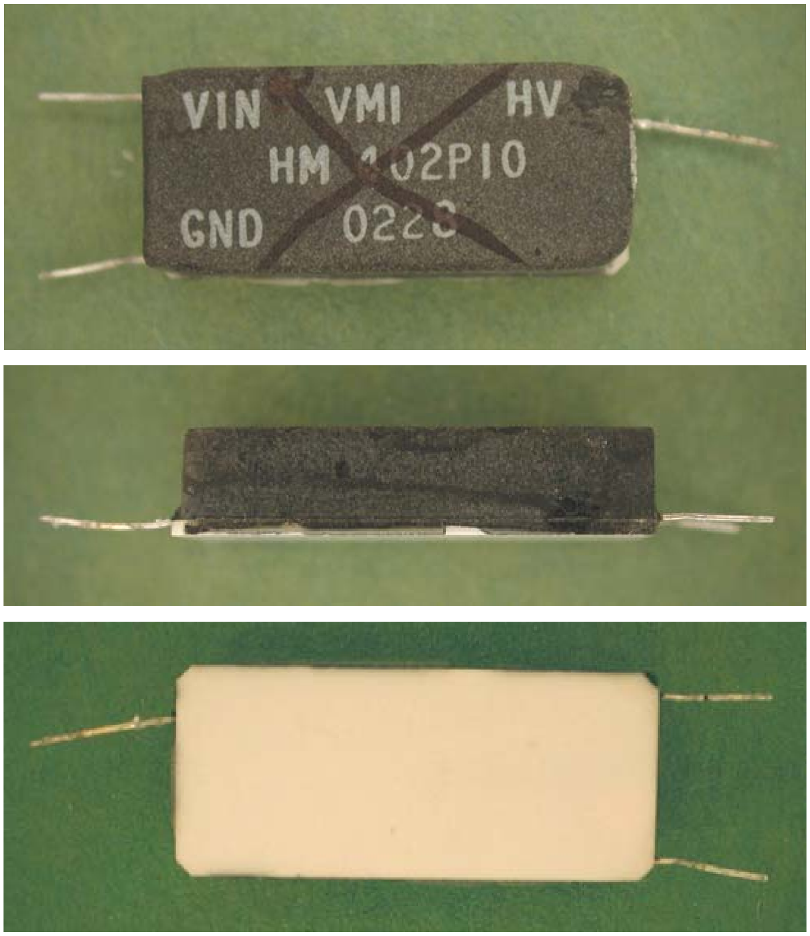


Figure 1. External views of the VMI HM402P10 hybrid voltage multiplier.

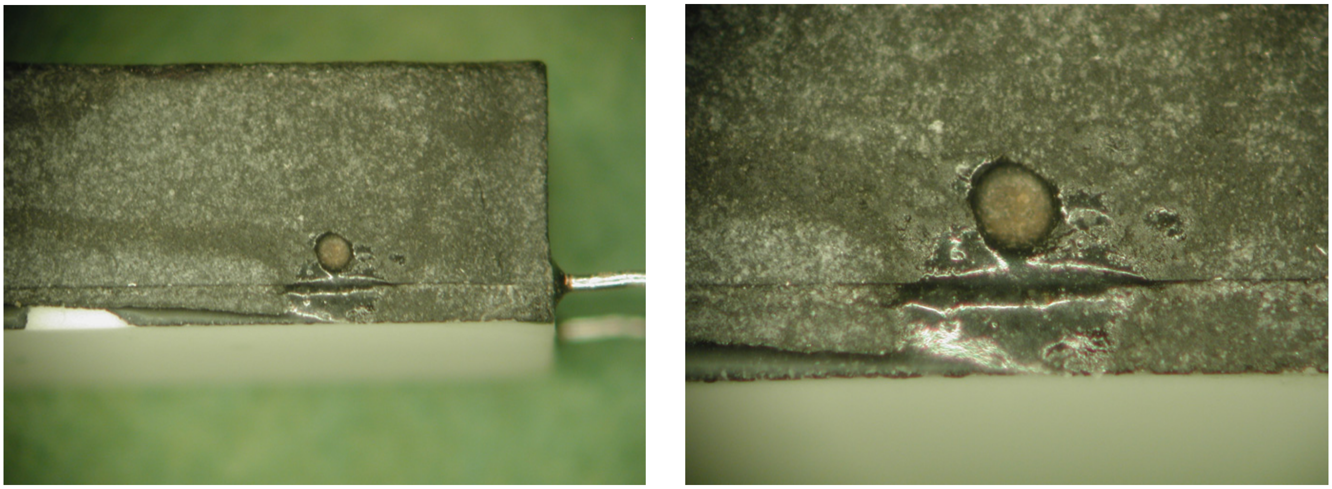


Figure 2. Anomaly in the potting material near the VIN lead.

Appended Images:

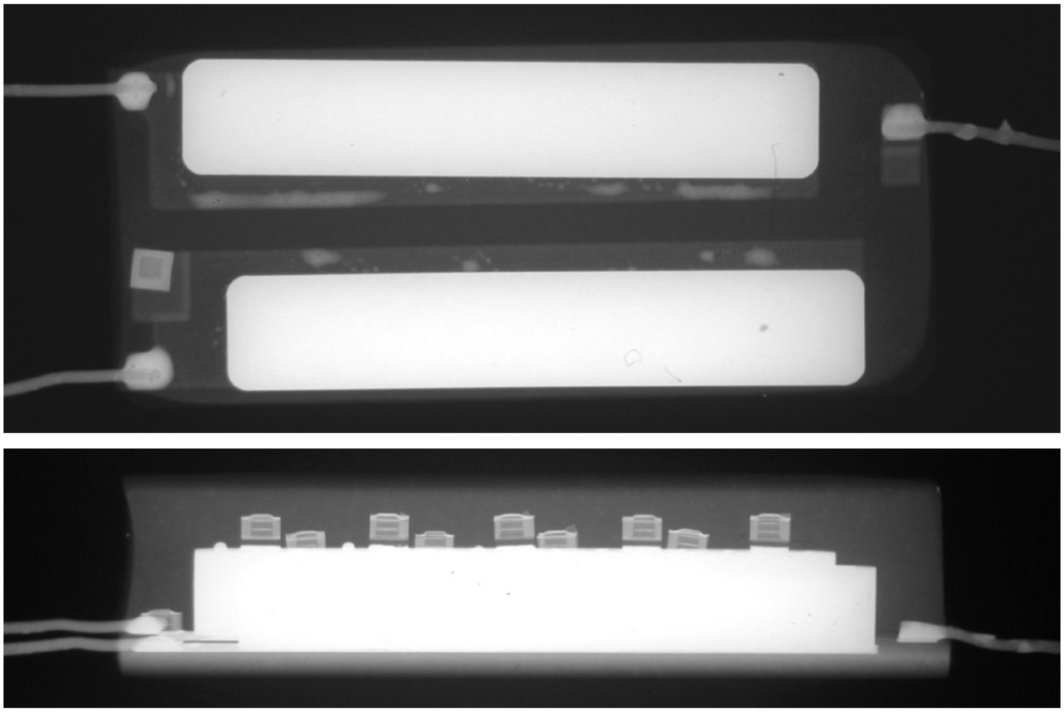


Figure 3. Radiographic images of the HM402P10 device. The large rectangular white objects are two monolithic segmented ceramic capacitors. Nine discrete surface mount diodes are mounted on the capacitors and one is mounted on the substrate near the GND lead.

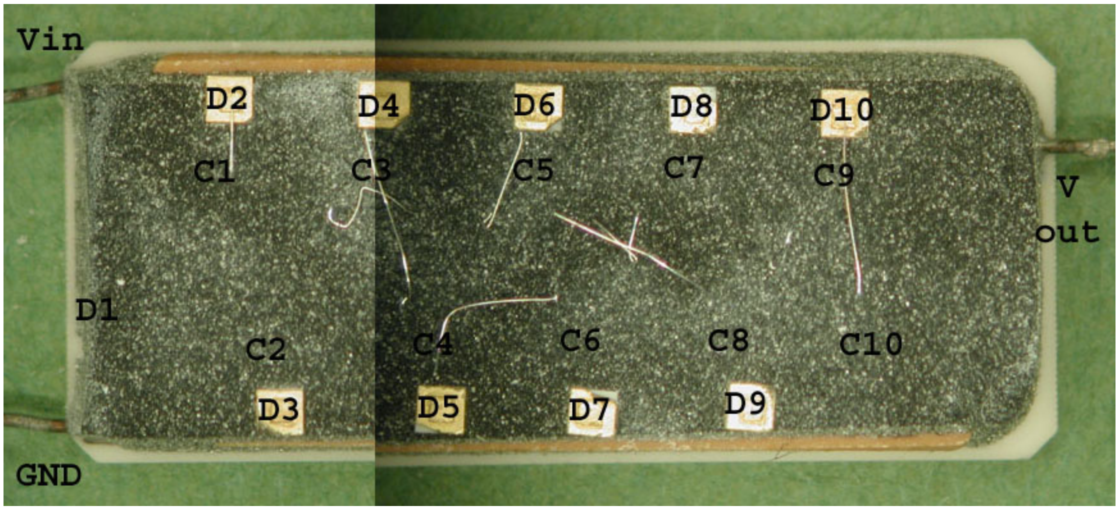


Figure 4. This view shows the device at an intermediate deprocessing stage. The tops of the diodes are revealed (except D1). The aluminum bond wires were inadvertently broken due to the blow-off process necessary for residue removal after oxygen plasma ashing.

Appended Images:

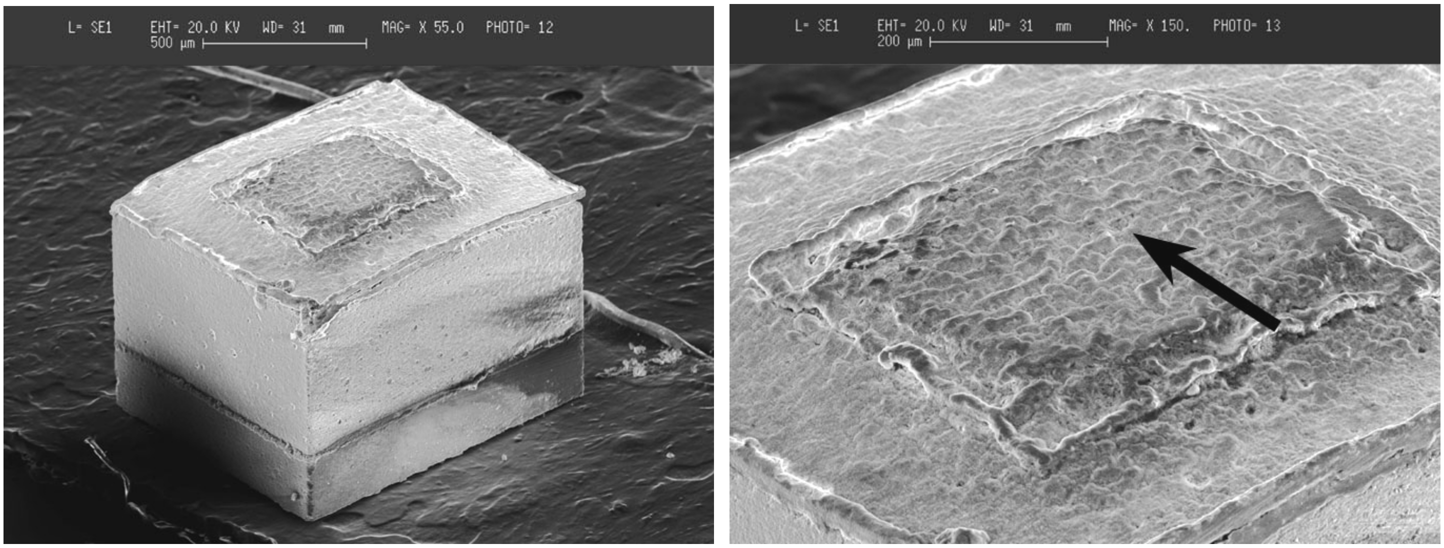


Figure 5. SEM views of diode D9 after removal from the assembly. The arrow in the right image points to where the aluminum bond wire was located on the diode.

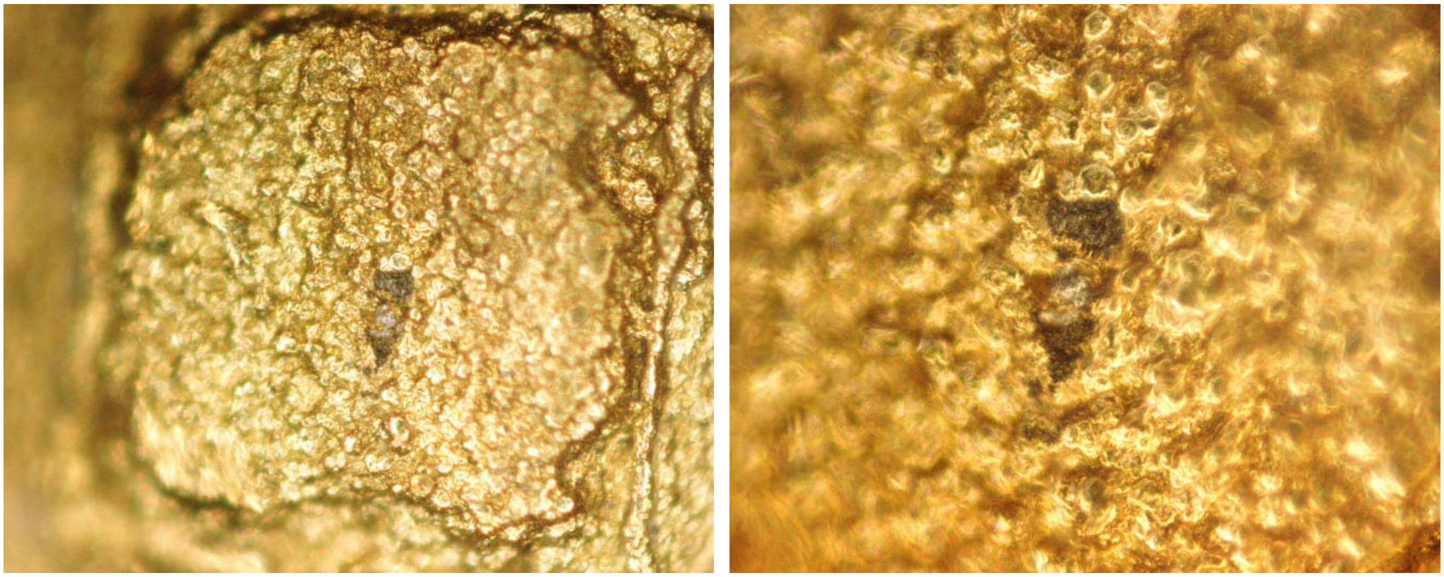


Figure 6. Optical images taken prior to removal of D9 from the assembly show the same area and the remaining wire bond foot-print on the gold plated surface.

Appended Images:

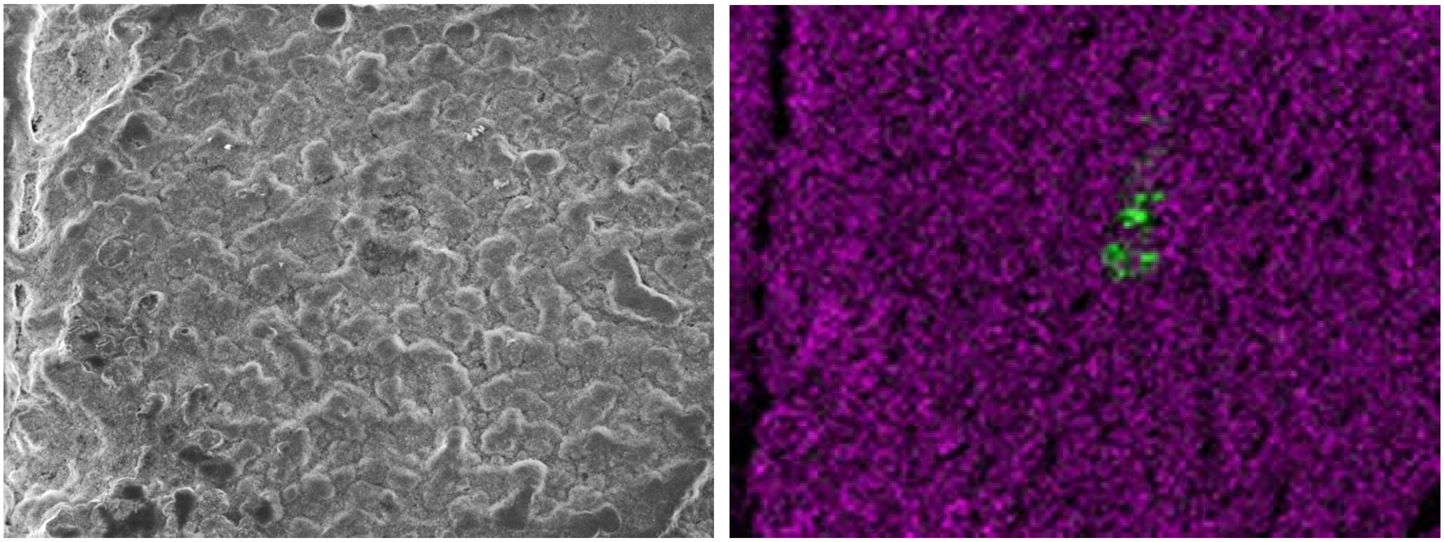


Figure 7. SEM and EDS x-ray dot map images of the diode surface where the aluminum bond wire was attached on D9. In the dot map at right, purple represents the element gold and green represents aluminum.

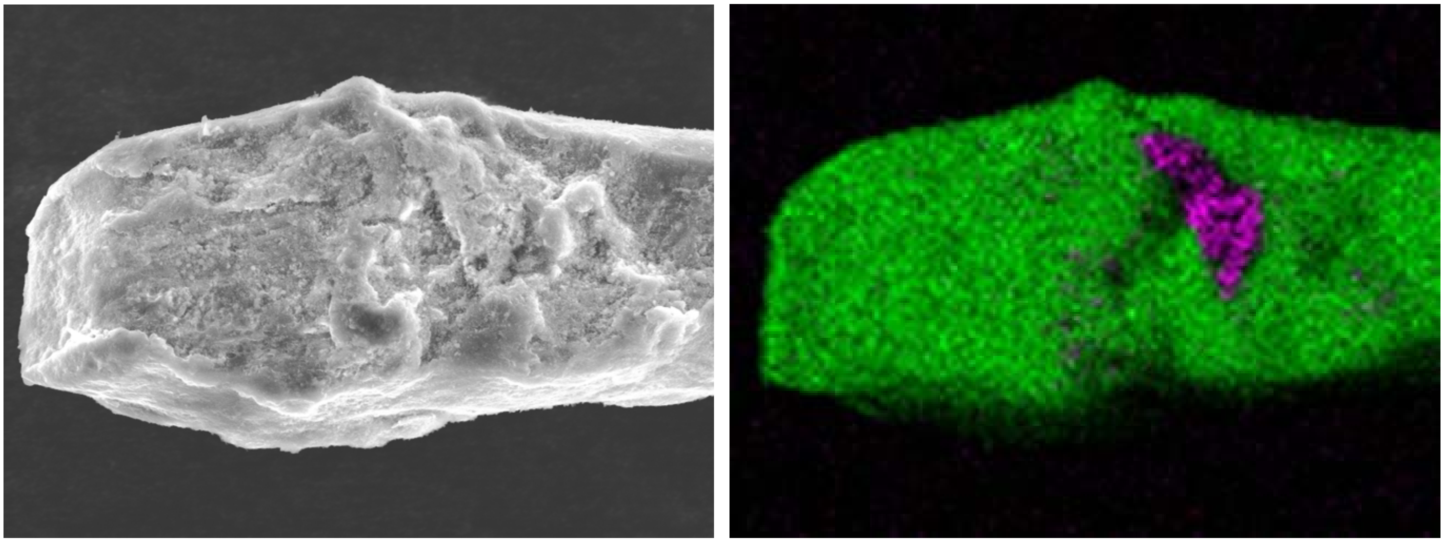


Figure 8. Images of the matching surface of the D9 aluminum bond wire. The surface shows insufficient alloying of aluminum-to-gold and gold-to-aluminum.

Appended Images:

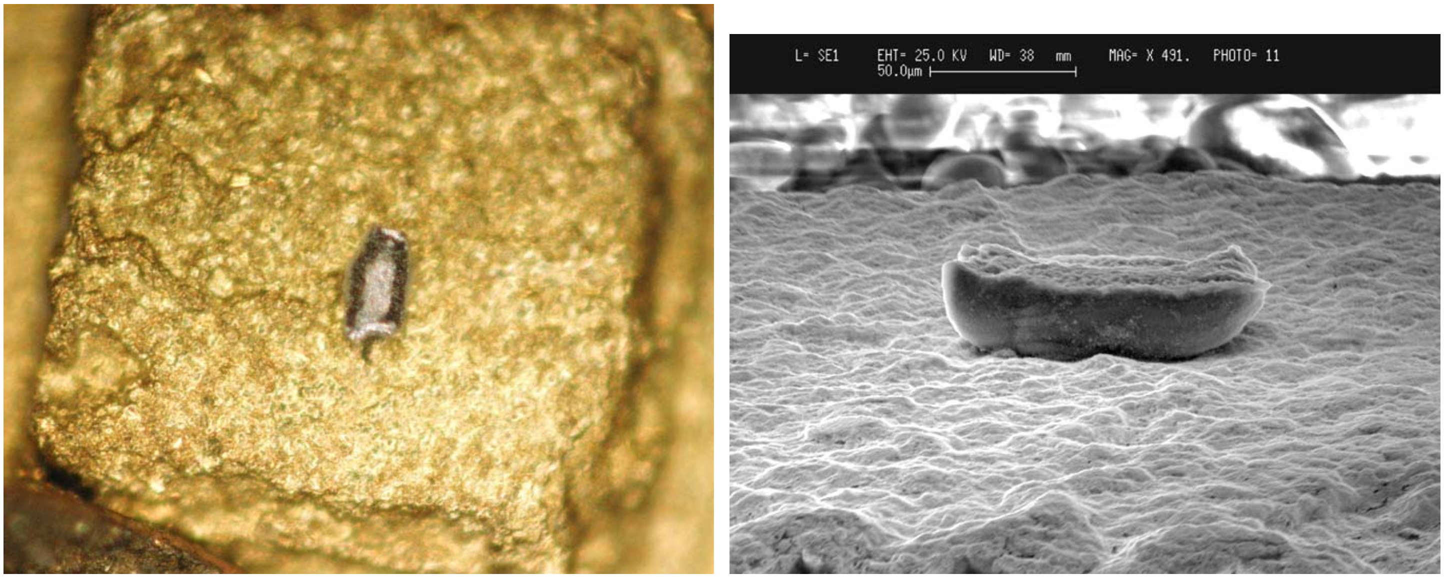


Figure 9. For comparison, optical and SEM images of the wire bond "foot" present on diode D7 are shown above.

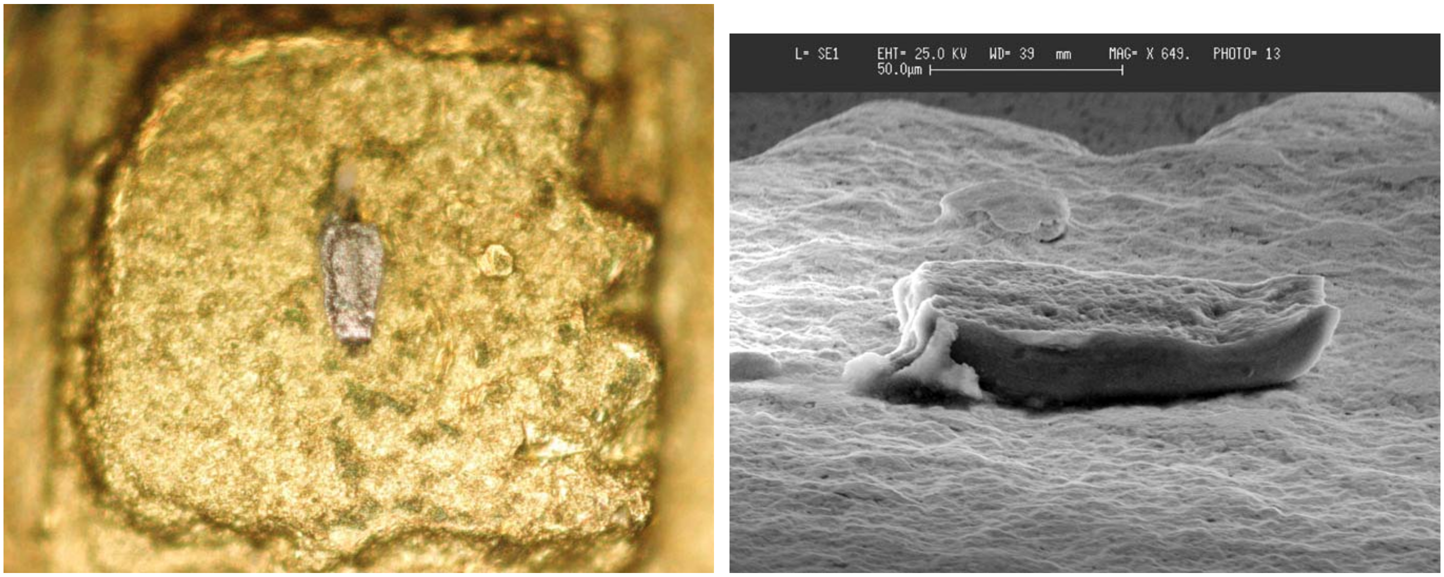


Figure 10. Optical and SEM images of the wire bond "foot" present on diode D8.

Appended Images:

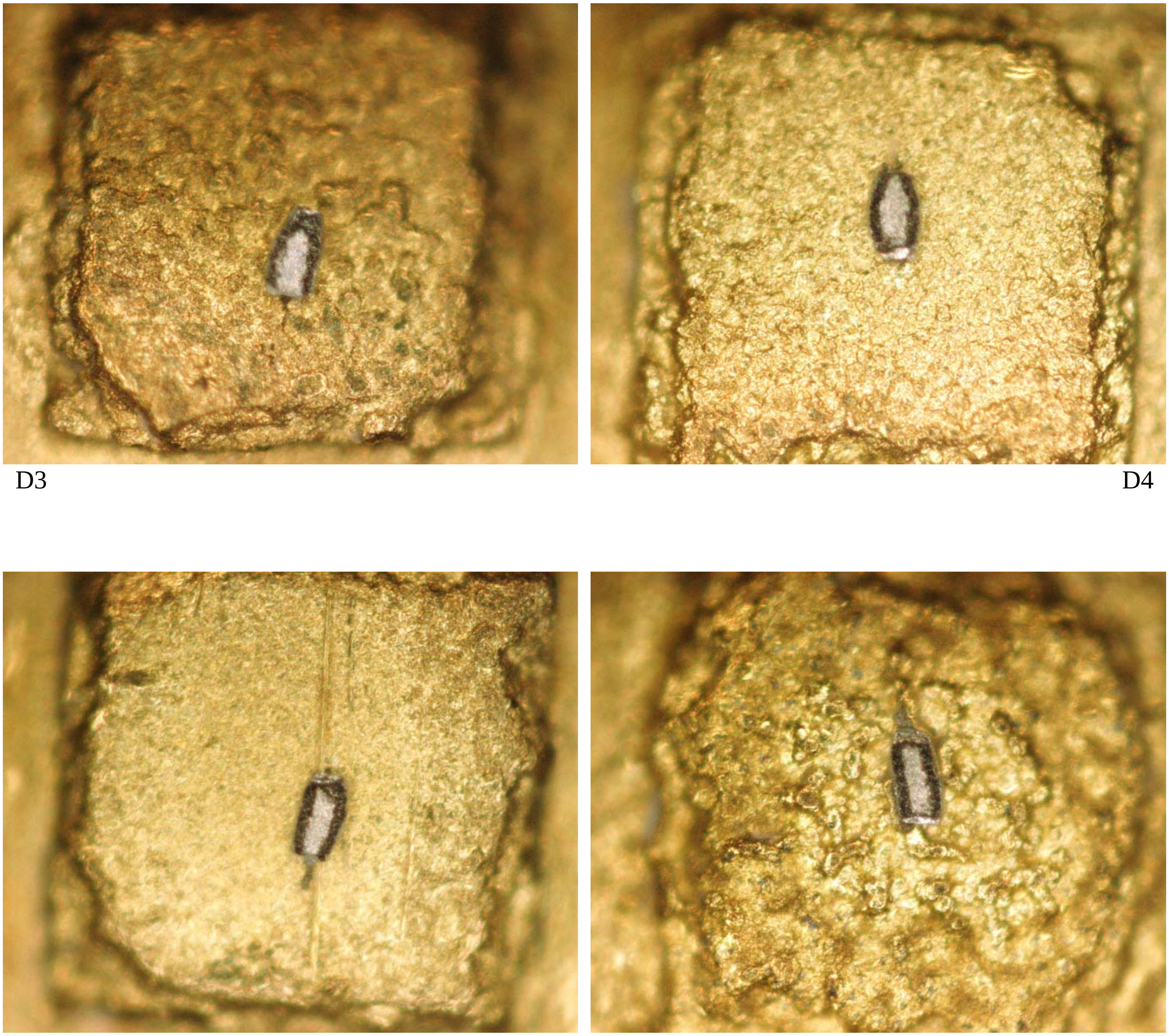

D3 D4
D5 D6

Figure 11. Optical images showing bond "foot" remnants on diodes D3, D4, D5 and D6.

Project: STEREO/IMPACT
EV Q30382_HM402P10

Investigator: A.Teverovsky (code 562)
March 16, 2004

Reliability evaluation of VMI HM402P10 hybrid voltage multipliers.

Background.

A high voltage multiplier (HVM) HM402P10 failed at low temperatures (-70 °C) during qualification testing of the HVPS board (see problem report PR-6001). The subsequent failure analysis (report Q3033FA) confirmed the failure and revealed a poor wire bonding between an aluminum wire and a gold-plated surface of one of the diodes used in the HVM assembly. This poor wire bonding was considered as a possible reason for the failure of the part.

Per manufacturer data sheet, the part is rated for storage and operational temperatures of –55 °C to +100 °C. This indicates that exposure of the part to –70 °C might have introduced defects in other HVM parts, which are still operational, but might have a compromised reliability.

This required further analysis of the parts and additional testing to evaluate the risk associated with the usage of conceivably compromised parts, which had been exposed to low temperatures, and to assess the overall thermo-mechanical robustness of the parts.

Details of the parts' design.

The performed failure analysis was limited to the observation of wire bonds to the top-side of the diodes only. For better understanding of design of hybrid design and construction, wire bonds to the bottom side of the diodes had also to be inspected.

Figures 1 to 3 show internal views of the hybrid and cross-section of the diodes used. X-ray microanalysis indicated that the capacitor pads, which were used also for wire bonding, were plated with silver, thus indicating that aluminum-to-silver wire bonds were used at the bottom of the diodes.

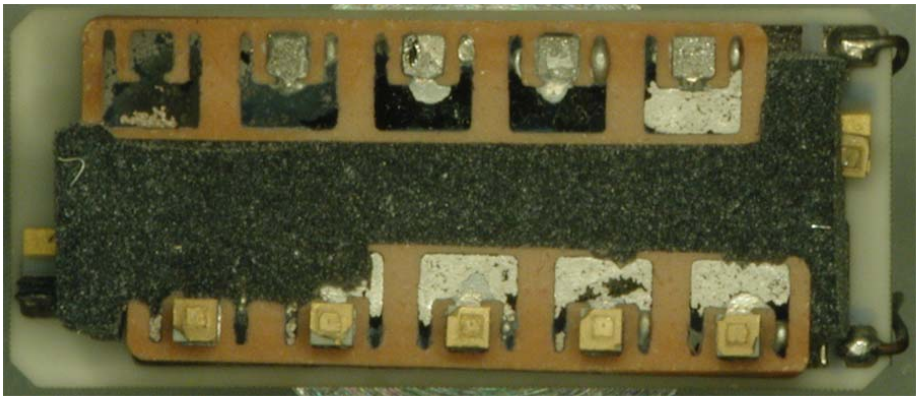


Figure 1 Overall view of the part showing silver plated capacitor pads. Wire bonds connected diodes and silver capacitor metallization.

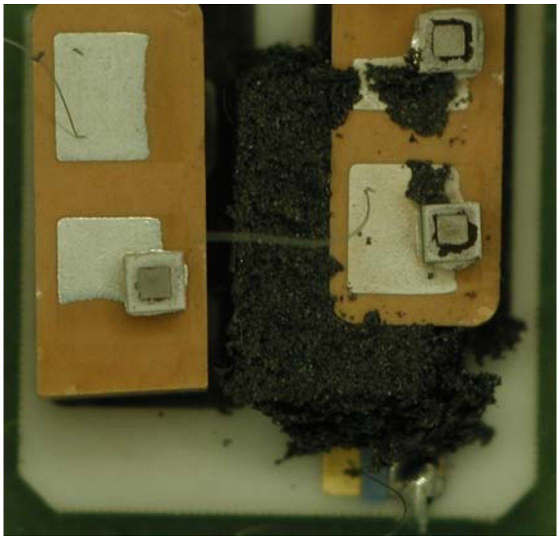
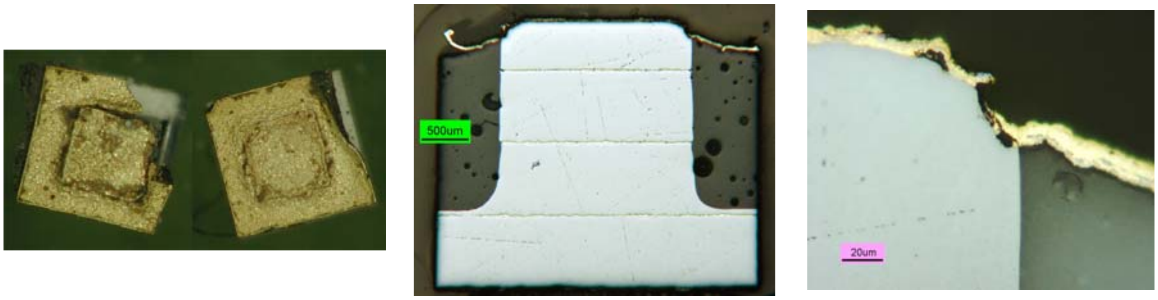


Figure 2. Aluminum wire bonds to silver plated electrodes. Note, that the capacitors had no internal electrodes.



a) b) c)

Figure 3. Overall view of the diodes (a), cross-section (b), and close-up of gold metallization (c). Note peeling of the gold plating which suggests poor process control and possible contamination in the gold layer.

The Ag/Al bonding is known to be less reliable compared to Au/Al bonding and should not be used without considerable reliability testing. The Ag/Al bonds are susceptible to fast degradation in humid environments, where the reliability of Ag/Al bonds is much worse then that of gold/aluminum bonds.

Data sheet specification.

The HM402P10 HVM has somewhat unusual specifications, according to which the operational and storage temperatures are the same and both are limited to –55 ^{o}C to +100 ^{o}C. Analysis of the design did not reveal any elements or materials, which would limit maximum temperature to 100 ^{o}C only.

As a result of discussions with the manufacturer representative, an error in the data sheet was recognized. The actual HM402P10 storage temperature range should be -65 to +150 C and the operating temperature should be -55 to +150 ^{o}C. Per manufacturer representative, the maximum operating and storage temperatures of the HM402P10 are limited mostly by the potting material used (HYSOL FP4450). The storage temperature of the multiplier is assumed to be the same as “the storage temperature of the potting material” (-65 to 150 ^{o}C).

However, the suggested manufacturer testing procedure for the HVM contains only 10 cycles from –55 ^{o}C to 105 ^{o}C and has no data on multiple temperature cycling in the –65 to +150 temperature range. So the claimed wider storage temperature range is not substantiated with experimental data.

Test plan.

It is known that degradation of poorly bonded wire bonds with time of aging occurs much faster and at lower temperatures compared to normal wire bonds. For this reason, and considering that only two flight parts were available, the hybrids were characterized after incrementally increasing stress test conditions: 100 hrs storage at 150 ^{o}C; 100 hrs storage at 175 ^{o}C; 100 hrs storage at 200 ^{o}C; 100 hrs storage in HAST chamber at 130 ^{o}C, 85 % RH. The characterization included measurements of transfer characteristics of the parts at different temperatures, input voltages, and frequencies.

A new lot of 20 HVM devices has been purchased to have back-up parts if a replacement of the existing lot for the project would be necessary and to carry out additional reliability evaluation of the devices. All 20 parts have been tested at three temperatures and seven parts have been subjected to the following stress testing:

a. Initial electrical measurements (EM) at –55, 25, and +100 ^{o}C.
b. Preconditioning: 10 TC from –70 ^{o}C to +70 ^{o}C.
c. TC from –70 to +100 ^{o}C with RT EM after 10, 30, and 100 cycles (total).

d. 100 hours storage at 200 ^{o}C followed by electrical measurements at temperatures cycling from -55 to a high temperature, which incrementally increased from 100 to 180 ^{o}C in 20 ^{o}C.

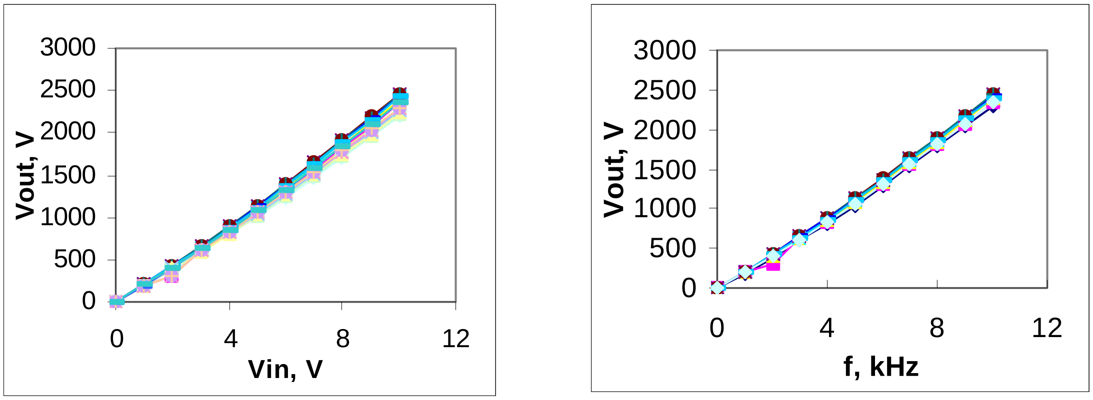
e. 100 hours storage in HAST chamber at 130 ^{o}C, 85 % RH followed by electrical measurements in the range from –55 to +100 ^{o}C;

f. Bake for 15 hours at 150 ^{o}C followed by electrical measurements at temperatures cycling from -55 to HT.

To evaluate quality of the potting compound used, thermo-mechanical characteristics and X-ray microanalysis of the encapsulating material was performed.

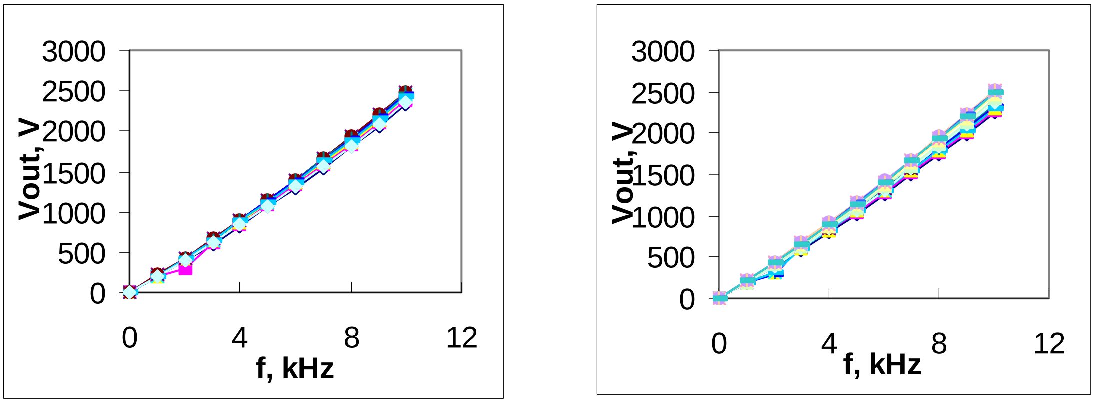
Test results for 2 samples from the flight lot.

Evolution of the transfer characteristics measured at –55, -40, -20, 0, 20, 40, 60, 80, and 100 during stress testing of the two flight parts are shown in Figure 4. Some degradation of characteristics was observed in SN2 only after HAST. Figure 5 shows an anomaly in the temperature dependence of the output voltage in SN2 after HAST, when the output voltage, which was initially ~400 V below normal recovered after the 80 ^{o}C measurement, thus indicating possibly intermittent contact in the part.



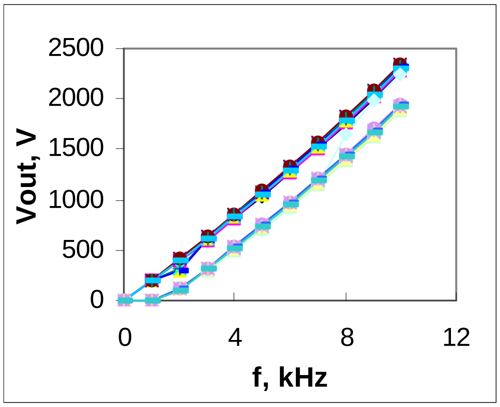
a) initial

b) after 100 hrs 150 oC



c) after 100 hrs 175 oC

d) after 100 hrs 200 oC



e) after 100 hrs HAST

Figure 4. Transfer characteristics of the two parts at 100 kHz and temperatures varying from –55 to +100 ^{o}C.

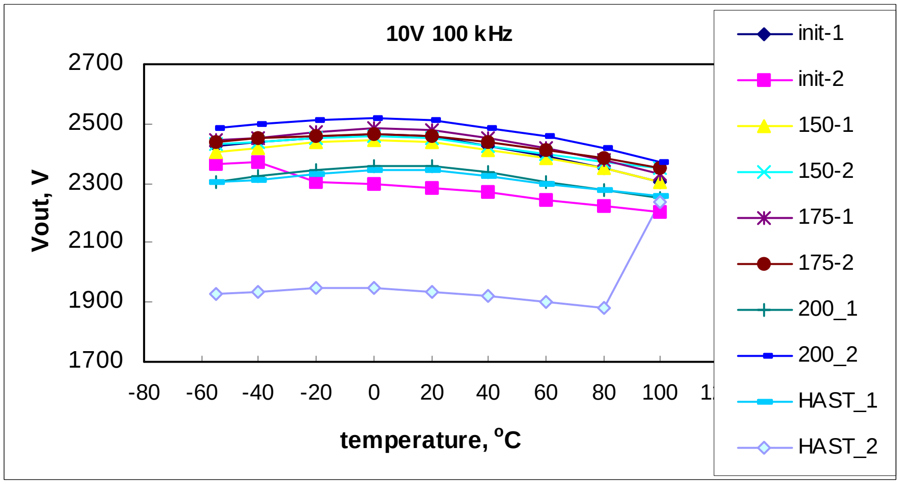


Figure 5. Temperature dependencies of the output voltage for the two samples after different stress testing.

After HAST the parts were baked for 15 hrs at 150 ^{o}C to remove moisture from the potting compound and then were subjected to five monitored temperature cycles from -55 to high temperatures, which incrementally increased from 100 to 180 ^{o}C in 20 ^{o}C increments. Results of these measurements are shown in Figure 6 and indicate a catastrophic failure of SN2 after the first cycle to – 55 ^{o}C and intermittent failure of SN1 when the output dropped to a few volts each time at –55 ^{o}C and then recovered at high temperatures.

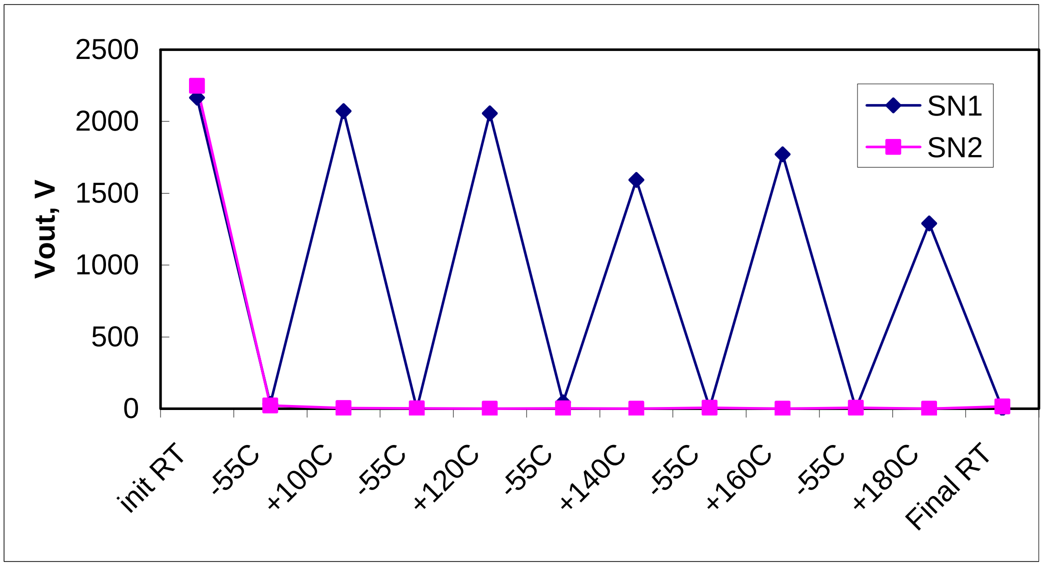
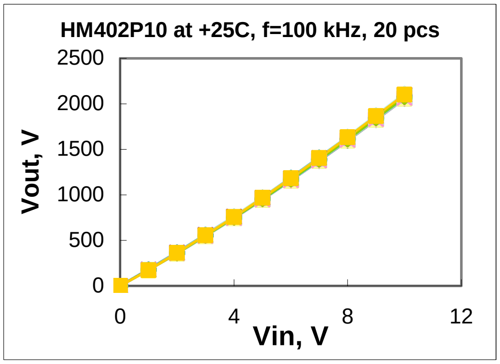
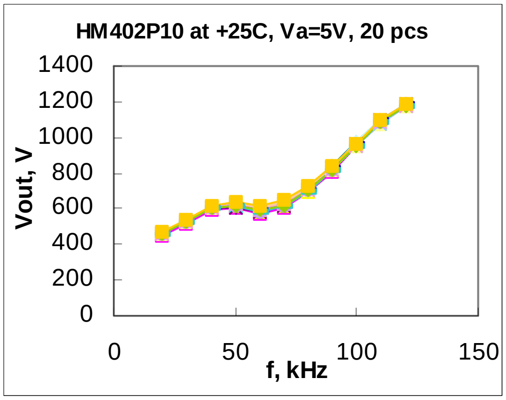


Figure 6. Monitored temperature cycle testing of the two flight parts after HAST followed by 15 hrs bake at 150 °C showing a catastrophic failure in SN2 and intermittent failure in SN1.

Test results for 20 samples from a new lot.

Results of electrical measurements at room temperature, +100 °C and –55 °C for 20 samples from a new lot are shown in Figure 7. The results indicate high reproducibility of the initial characteristics and only minor temperature variations.





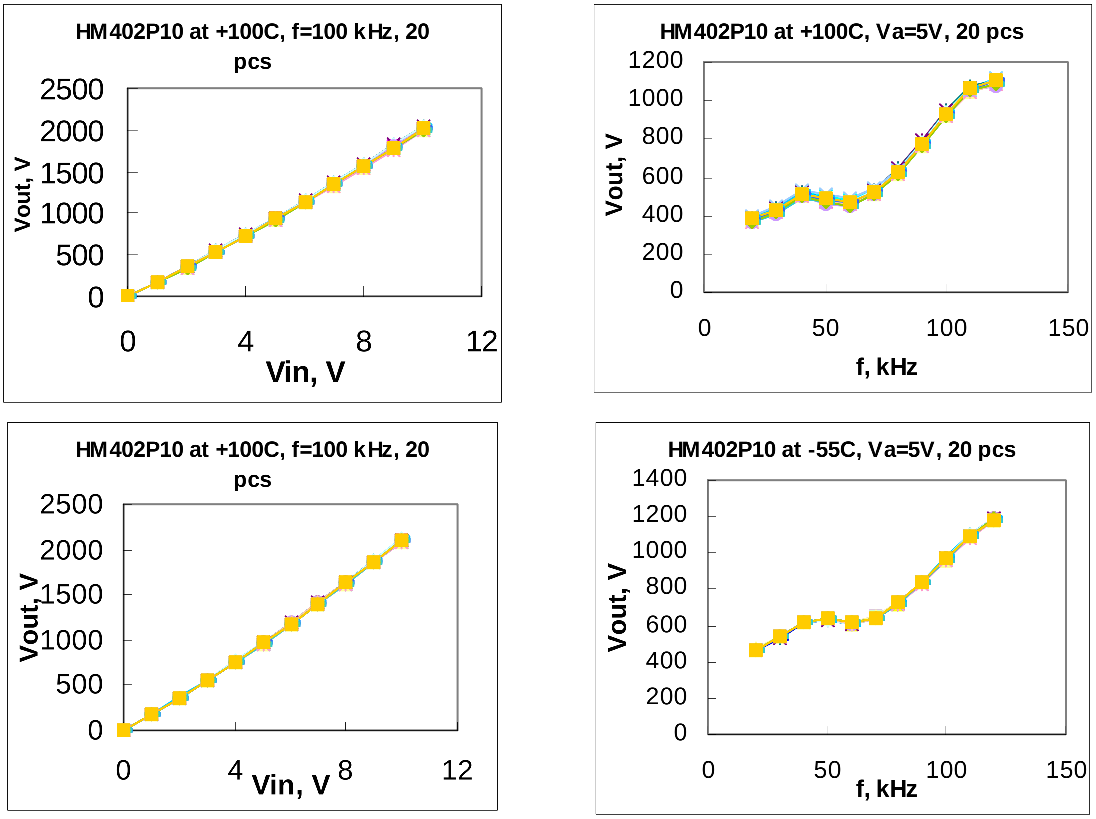


Figure 7. Initial characteristics of 20 samples from a new lot.

Figure 8 shows results of monitored temperature cycles carried out on two parts before stress testing.

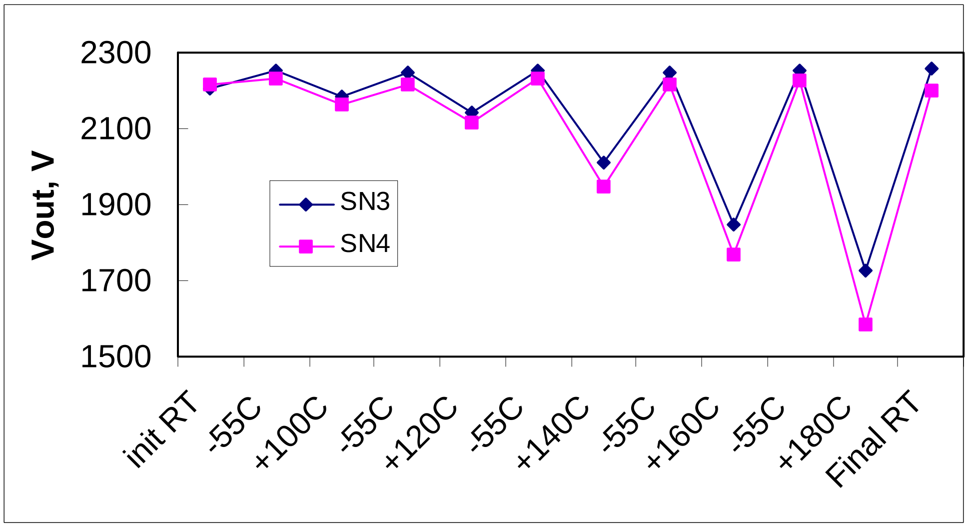


Figure 8. Initial monitored temperature cycling of two parts from a new lot.

No changes in electrical characteristics were observed after preconditioning temperature cycles (10 TC from –70 °C to +70 °C), after 100 cycles from –70 to +100 °C, and after storing the parts at 200 °C for 100 hours (see Figure 9).

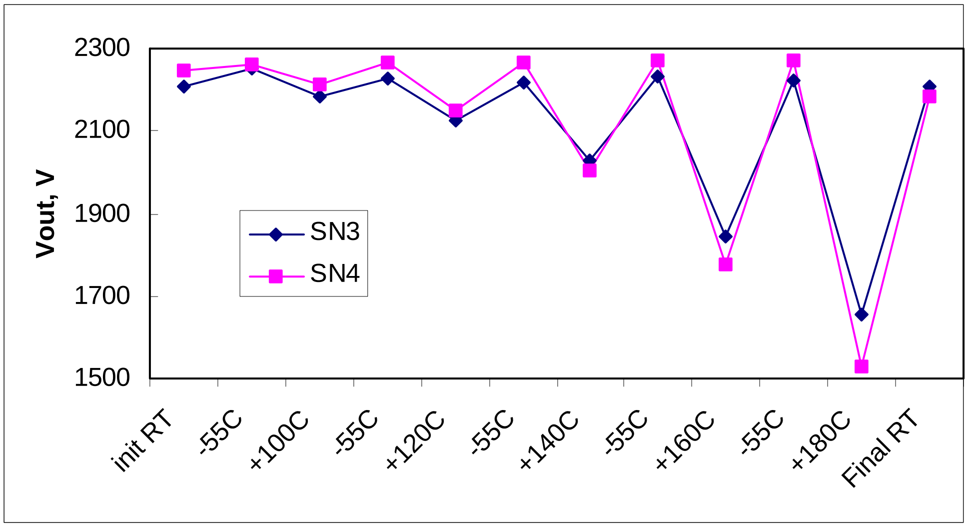


Figure 9. Results of monitored temperature cycles after storing for 100 hrs at 200 °C.

Similar to what was observed on the two flight samples, one part, SN4, failed at the first low temperature measurement after HAST (see Figure 10).

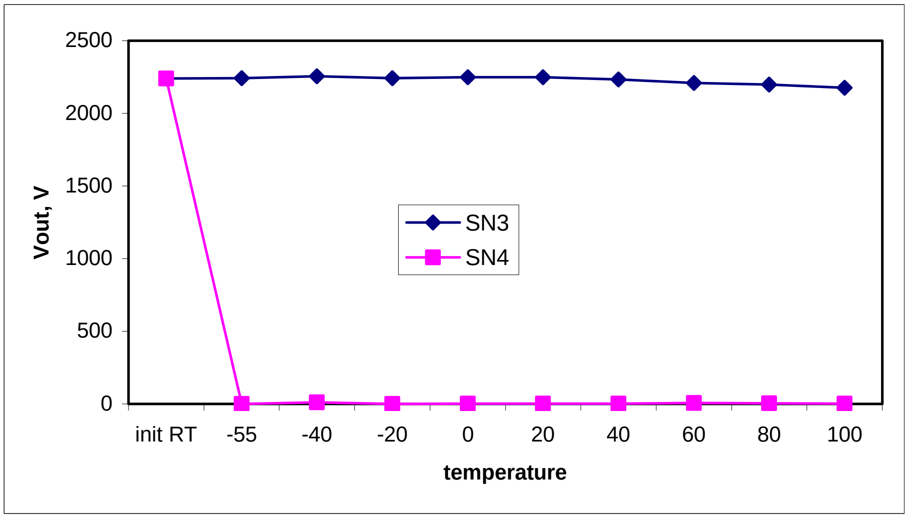


Figure 10. Temperature dependence of Vout after HAST for two samples.

Transfer characteristics for all seven parts measured after 15-hour bake at 150 ^{o}C (following HAST) are shown in Figure 11. In addition to SN4, which failed after HAST, two more samples, SN8 and SN9, exhibited degraded characteristics.

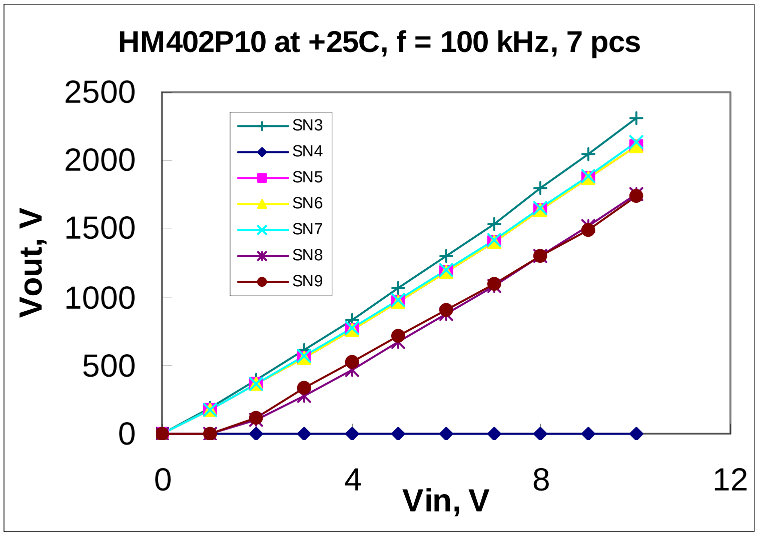


Figure 11. Transfer characteristics of the parts after stress testing.

Internal examination of failed parts.

Two deprocessing techniques have been used during this study: oxygen plasma and red fuming nitric acid. Unfortunately both techniques did not allow removing of the potting compound without disturbing the wires. As a result most of the wires were lifted or broken. Nevertheless, examination of areas on the top of the diodes and silver plates was useful to evaluate the quality of wire bonding.

In parts, which had not been stress-tested, the decapsulation revealed remnants of aluminaum wires still attached to the gold or silver-plated surfaces in most wire bond areas of the assembly. However, most of the diodes in the stress-tested parts had no evidence of wire bonding as shown in Figure 12. This indicates that the performed stress testing degraded the bonds to the point where they could be easily lifted from the surface. Typically, after lifting of the degraded bonds, gold/aluminum intermetallics can be observed. High power optical examination did not reveal similar intermetallics in our case. This is due most likely to a poor initial bonding, which resulted in few microwelding spots only.

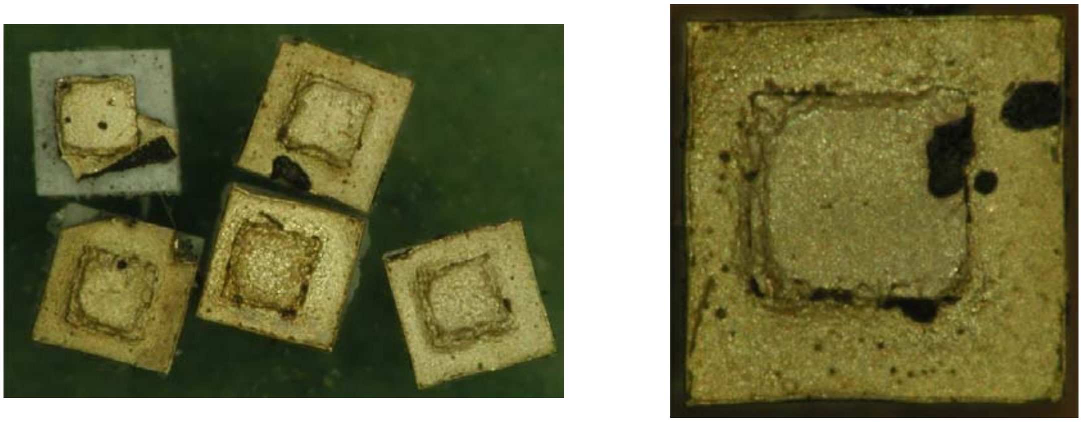

a) b)

Figure 12. Top gold plating on the diodes removed from the failed part, SN2 (a) and from the functional part, SN1 (b) after stress testing.

Cracking in the ceramic block used to form capacitors was found in the failed sample, SN2, (see Figure 13). These cracks are most likely not related to the observed failure and could possibly exist in the part before the stress-testing. Note, that no cracks were observed on the failed flight part.

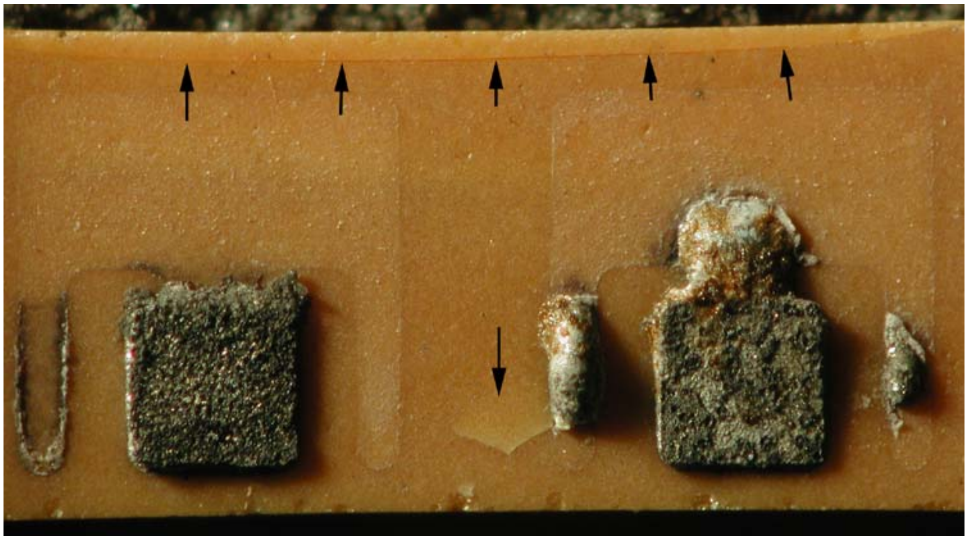


Figure 13. Cracks in ceramic in the failed part, SN2.

Characteristics of the potting compound.

Thermo-mechanical characteristics of the potting material were measured on a piece of epoxy cut from the device. The glass transition temperature and coefficients of thermal expansion are shown in Table 1. This table also shows characteristics specified in the

Loctite data sheet for HYSOL FP4450. Although the measured Tg is ~17 ^{o}C below the specified value, this was not likely related to the observed problems with the part.

Table 1. Thermo-mechanical characteristics of potting material

	Tg, ^{o}C	CTE1, ppm/^{o}C	CTE2, ppm/^{o}C
avrerage	143.1	14	62.7
Std.dev.	0.85	1.8	8.6
Data sheet	160	18	71

X-ray microanalysis indicated the presence of bromide in the composition of the potting material. Brominated epoxies are typically used as flame retardants to provide fire resistance to the encapsulating materials. Excessive concentration of bromide might degrade aluminum-to-gold bonds by a dry corrosion mechanism. However, estimations have shown that the concentration of Br was relatively small ~0.25 wt% and most likely is not a reliability concern.

Reliability estimations for flight conditions.

Considering that the CTE$_{C}$ of the titanate ceramic used for the capacitors is in the range from 7 to 10 ppm/^{o}C and is much less than the CTE$_{PC}$ for the potting compound, compressive mechanical stresses will be developed in the assembly. At a temperature T below Tg these stresses can be estimated using the following equation:

$$\sigma \approx A \times E \times \left[(CTE_{PC} - CTE_{C}) \times (T - Tg) \right] \ ,$$

where A is the size/shape coefficient.

According to this equation, when the part is under temperature cycling conditions, mechanical stresses will decrease at high temperatures and increase at low temperatures. At –70 ^{o}C the level of σ should be more than two times larger than at room temperature and approximately 3 times less at +100 ^{o}C. This significantly increases the probability of failures related to the formation of micro-cracks and/or delaminations between the assembly and epoxy, and in particular the probability of wire bond fracture. For his reason most likely, all observed failures occurred at low temperatures.

Normally bonded connections would most likely survive the formation of these micro-cracks. However, poor aluminum to gold and/or to silver connections, might be easily fractured resulting in failure of the part. Similar failure might be significantly accelerated by intermetallic degradation during high temperature and/or high humidity aging, which results in embrittlement of the bond.

Based on our data, the parts can survive 100-hour aging at 200 ^{o}C. Considering that the wire bon degradation follows Arrhenius law, we can estimate the equivalent “safe time” duration during normal operating conditions of the part:

$$t > 100 \times \exp\left[\frac{eU}{kT}\right]$$

A wide range of activation energies, U, (from 0.6 to 1.7 eV) has been reported in literature for wire bond degradation. Results of calculations using this range of U are shown in Figure 14 and indicate, that at 50 ^{o}C the equivalent time would be more than 13 years.

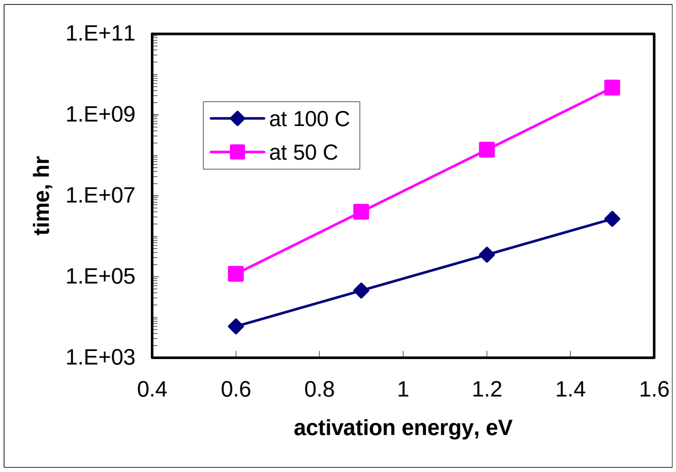


Figure 14. Calculation of the time equivalent to 100-hour aging at 200 ^{o}C for operating temperatures of 50 and 100 ^{o}C.

Our experiments have shown that the parts can endure 100 cycles from –70 to +100 ^{o}C. Considering that the Coffin-Manson exponent, m, for aluminum wire bonds varies from 3.5 to 4.2, the equivalent number of cycles, N_0, for operating conditions when temperature varies from –20 to +16 ^{o}C can be estimated using the following equation:

$$N_o = 100 \times \left[\frac{\Delta T_s}{\Delta T_u}\right]^m ,$$

where ΔT_s and ΔT_u are temperature swings at stress and use conditions. At $\Delta T_s = 170$ ^{o}C and $\Delta T_u = 36$ ^{o}C, N_o varies from 22,900 to 67,800 cycles. Assuming that the part will experience one cycle per day, these numbers correspond to 63 to 186 years of operation.

Conclusion.

1. Test results indicate that parts from the flight lot and parts from the new lot have similar quality and both are susceptible to degradation in humid environments. This degradation is probably due to corrosion of aluminum-to-silver wire bonds and will not pose a threat to the parts during operation in vacuum.

2. The fact that the part can sustain without failures 100 hours of high temperature storage at 200 ^{o}C and 100 temperature cycles from –70 to +100 ^{o}C indicates that the observed failure during the HVPS board testing is most likely an infant

mortality failure, rather than a failure caused by any wear-out mechanism intrinsic to the part's design and used materials.

3. Analysis of the part's design suggests that wire bonding used to interconnect diodes and capacitors is a reliability concern due to possible contamination in the gold plating on the die surface and poor reliability of the aluminum-to-silver bonds. However, these parts most likely will operate normally at relatively benign temperature conditions in vacuum.

4. The failures of the parts occurred at low temperatures and were most likely related to high mechanical stresses developed by the potting material. The probability of these failures significantly increases for poor quality wire bonds and/or after wire bond degradation at high temperature conditions.

5. Accelerated environmental stress testing performed on the two flight parts and 7 parts from a new lot, have shown that exposure of the parts to –70 ^{o}C did not compromise the reliability of the flight parts substantially, and their use will have most likely a low risk for the project.