Status Report
Characterization of
Polymer Tantalum Capacitors, FY12

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Jet Propulsion Laboratory
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NASA Electronic Parts and Packaging (NEPP) Program
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## TABLE OF CONTENTS

1.0 Introduction ................................................................................................................................. 1

2.0 Time-to-Failure Analysis ............................................................................................................... 2

3.0 Acceleration Models .................................................................................................................. 4

4.0 Preparation for Less Accelerated Testing ................................................................................ 6

5.0 Summary and Conclusions ....................................................................................................... 8

6.0 References ................................................................................................................................... 9
1.0 INTRODUCTION
The goal of this effort was to characterize tantalum polymer capacitors in order to determine whether the technology could be used in appropriate high-reliability space applications. Phase 1 included the history of tantalum capacitors, a discussion of different polymer types, and a summary of typical electrical characteristics. Phase 2 presented independent competitive data on electrical performance, dielectric robustness, and reliability. Phase 3 focused on highly accelerated time-to-failure testing in order to develop acceleration models to predict performance at rated conditions. Phase 1 and 2 were completed, while Phase 3 was partially completed.

The focus was to assess the lifetime of polymer tantalum capacitors at maximum rated conditions. Capacitors from two manufacturers, Manufacturer A and Manufacturer B, were tested at several temperatures and voltages chosen specifically to cause wear-out in a reasonable amount of time.

Data collected for Manufacturer B indicated that testing conditions were too harsh, exciting a new failure mechanism. It is also possible that the dominant failure mechanism for Manufacturer B’s capacitors was de-doping of the polymer rather than dielectric breakdown. Less accelerated testing conditions are required for further analysis.

The focus of FY12 was to prepare for less accelerated testing in FY13. This included expanding test capabilities and replacing outdated capacitor technology with current polymer technology. The capacitors used for the FY11 effort were procured in 2005 and 2006, and the technology may no longer be comparable to current tantalum polymer products.

Samples of data are provided to highlight key aspects in this status report. Full data are found in [1].
2.0 TIME-TO-FAILURE ANALYSIS

Tantalum polymer failures-in-time should produce a lognormal time-to-failure distribution with a very steep slope similar to the data for Manufacturer A in Figure 2.0-1. Figure 2.0-2 for Manufacturer B shows that the data do not always follow the expected trend.

Figure 2.0-2 identifies various distinct patterns in higher voltage time-to-failure distributions. The first region, A, consists of initial failures at the beginning of the test, and increase with increasing test voltage. Region B consists of failures occurring slowly over time. An overlap section of the flat region and pure wear-out, D, occurs in region C. The region considered to be pure wear-out is the region of interest. The next region, anti-wear-out is not yet well understood. It is believed that de-doping of the polymer material is occurring. As the polymer next to the dielectric becomes nonconductive, capacitance decreases and ESR increases. The final region is believed to be wear-out of the de-doped polymer material. Evidence of anti-wear-out de-doping of the conductive polymer appears in the subsequent discussion where capacitance loss and ESR increases demonstrate loss of conduction in the conductive polymer cathode.

An analysis of the capacitance and ESR values before and after time-to-failure testing clearly shows that anti-wear-out is present. The surviving capacitors from the 10.8 V distribution for Manufacturer B are in the anti-wear-out stage with decreasing capacitance (see Figure 2.0-3) and increasing ESR (see Figure 2.0-4). The shallow slope of the time-to-failure data in Figure 2.0-2 hints at this phenomenon where the rate of blown-out 1 A fuses slows as the normally conductive polymer becomes less conductive.

![Figure 2.0-1. Manufacturer A, 220 µF, 4 V tested at 85°C.](image)
Figure 2.0-2. Manufacturer B, 220 µF, 4 V tested at 85°C.

Figure 2.0-3. Manufacturer B, 220 µF, 4 V tested at 85°C, 10.8 V, pre- and post-TTF capacitance.

Figure 2.0-4. Manufacturer B, 220 µF, 4 V tested at 85°C, 10.8 V, pre- and post-TTF ESR.
3.0 ACCELERATION MODELS

Data collected for Manufacturer A resulted in a very promising acceleration model and predicts very long life at rated voltage and 85°C. The model produced for Manufacturer A shows that it is possible to use tantalum polymer technology in appropriate high-reliability space applications with suitable voltage derating.

Manufacturer A’s $t_{50}$ times at various temperatures and test voltages are plotted on a log-log scale in Figure 3.0-1 to linearize the power law form of the voltage acceleration in the equation proposed by Prokopowicz and Vaskas. The slopes of the lines generated by the data are similar and have a decreasing voltage ratio exponent ($\eta$) as temperature rises. The data for Manufacturer A are very well behaved and it is fairly easy to project back to rated voltage.

The $t_{50}$ times are plotted versus inverse absolute temperature for Manufacturer A in Figure 3.0-2. This linearizes the Arrhenius expression for temperature acceleration, allowing straight lines to be fit to the curves in order to estimate the activation energy at various test voltages. A least squares line was fit to those points and the activation energy was found to be 1.35 eV at 8.8 V, and 1.29 eV at 9.6 V. The higher activation energy at lower voltage is consistent with results published in [2].

In contrast, the data for Manufacturer B in Figure 3.0-3 are not as ideal and are not currently useful to establish an acceleration model. Manufacturer B exhibits evidence that test voltages were too close to the oxide formation voltage, which introduced a new failure mechanism, skewing the results. The dominant failure mechanism for Manufacturer B capacitors at application voltage may be de-doping of the polymer rather than dielectric breakdown. This possibility should be further investigated.

![Figure 3.0-1. Manufacturer A voltage acceleration.](image-url)
Figure 3.0-2. Manufacturer A temperature acceleration.

Figure 3.0-3. Manufacturer B voltage acceleration.
4.0 PREPARATION FOR LESS ACCELERATED TESTING

Additional test cards were procured and the product was replaced for both manufacturers. Table 4.0-1 outlines the procurements and associated cost.

Additional fixtures were built and test equipment procured to double testing capability. Each test card is specially designed to mount up to 20 capacitors, as shown in Figure 4.0-1. Each test fixture, shown in Figure 4.0-2, is capable of testing two groups with a sample size of 100 capacitors each. There are five plugs to support five test cards for each test group. The test fixtures are designed to sit inside an environmental chamber. Test cards act as an extension to connect the test fixtures to the fuse cards located outside of the chamber, shown in Figure 4.0-3. Two Agilent power supplies, one data acquisition unit, and six multiplexer cards were procured through the Electronic Parts Engineering Office to support the expanded test setup.

Mounting the capacitors on the test cards proved to be an issue this fiscal year. For past efforts, capacitors were mounted using the convection reflow oven in the solder surface mount training lab, as it is the most common solder reflow process used across industry. Reorganization of the division responsible for the convection reflow oven reopened negotiations for using the resource. The cost of using the reflow oven was estimated to be $720 per day. After much debate, the use of JPL resources had to be abandoned since the cost of using the oven over several days was too high. The test cards and capacitors would have to be mounted at an outside test house. Work was stopped prior to starting the estimation process with an outside test lab.

Table 4.0-1. Procurement details.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Part Number</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Cards</td>
<td>Type: JY07P904</td>
<td>750</td>
<td>$4,281.09</td>
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<tr>
<td>Capacitors</td>
<td>35TCQ10M</td>
<td>3000</td>
<td>$3,191.67</td>
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<tr>
<td></td>
<td>16TQC47M</td>
<td>3000</td>
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<td>10THB220M</td>
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<td>6THB220ML</td>
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</tr>
</tbody>
</table>

Figure 4.0-1. Capacitor test card.
Figure 4.0-2. Capacitor test fixture.

Holds capacitor test cards

Plugs into fuse cards

Figure 4.0-3. Fuse fixture.

Connections to scanner card for monitoring

Fuse cards
5.0 SUMMARY AND CONCLUSIONS

This report presents the current status of the accelerated life test data to date for the tantalum polymer capacitor research. Testing did not progress as far as expected; however, the testing limitations are now better understood.

The accelerated life tests are designed to test at high voltages in order to predict behavior at low voltages. The accelerated test conditions need to produce meaningful wear-out data in a short amount of time without introducing a new failure mechanism.

Additional tantalum polymer capacitors should be characterized. Recently procured capacitors for Manufacturer A and Manufacturer B have voltage ratings of 6 V, 10 V, 16 V, and 35 V. Tantalum polymer characterization results are published for capacitors rated at 6 V and 35 V [2,3]. The results highlight that low-voltage tantalum polymer capacitors behave differently from high-voltage devices. To date, no data exist for capacitors rated between 6 V and 25 V, and it is unclear whether they will follow the trend in behavior of low- or high-voltage capacitors.

The results for Manufacturer B demonstrate that caution must be taken when accelerating test conditions since the data currently obtained for Manufacturer B are not useful in establishing an acceleration model. Testing at less accelerated conditions is necessary to produce more meaningful time-to-failure results. It is possible that the dominant failure mechanism for Manufacturer B parts is de-doping of the polymer with resulting capacitance loss and increased ESR, as opposed to dielectric breakdown. This possibility should be further investigated.

The data collected for Manufacturer A resulted in a very promising acceleration model that predicts very long life at rated voltage and 85°C. With suitable voltage derating, tantalum polymer technology could easily be used in appropriate high-reliability space applications.
6.0 REFERENCES

