Quick Method for Determining the Reliability of a Thermoelectric Module via Pulse Testing

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Abstract

Users and manufacturers of thermoelectric modules (TEMs) are experiencing increasing demand for reliable products. As the volumes of manufactured TEMs increase, the need for a faster method of reliability testing is essential to minimize costs while ensuring the overall quality of the product.

The typical methods of reliability testing can take as many as 3-4 months to determine the projected operational life of a TEM. In many cases, there is not enough time or resources to qualify the growing manufactured quantities of TEMs, until now.

TE Technology has developed a pulse test method to quickly determine the integrity of the most crucial components within the TEM. This test process consists of applying a high magnitude, but very short duration, AC pulse through a TEM. This energy burst preferentially generates heat, pin-pointed wherever high contact resistance may be present throughout the TEM. These "Hot Spots" can be observed through thermal imaging methods applied to the exterior ceramics. Thus, every junction in the TEM is tested. Analyses of these thermal images are used to identify potential future failures.

Test data will be presented to correlate the results of the pulse tests with those obtained from longer term, conventional reliability testing.

Introduction

Several tests and measurement methods exist today to determine the performance and reliability of a Thermoelectric module (TEM). Testing for long term reliability usually involves some variation of a cycle test. This cycle test typically powers a TEM to some specified DC voltage to create the temperature differential and associated thermal stresses common to normal operation of the device. Then after some amount of time or temperature has been achieved, the power to the TEM is reversed. This reversal creates thermal expansion and contraction stresses primarily affecting the solder contacts. After hundreds, sometimes thousands, of these cycles the TEM begins to show signs of failure typically in the form of increased electrical resistance and decreased ZT. Although this type of test is usually dependable in determining TEM reliability, it can sometimes require 3-4 months of testing.

In addition, most users of this method can only test limited amounts of TEMs because of the test apparatus itself. As a result, most suppliers and consumers of TEMs are seriously limited when evaluating long term reliability to random lot samples and/or vendors.

This paper introduces a way to determine solder junction integrity without waiting several weeks for results.

Theory

Imperfect contacts between a TE pellet and its metal electrodes will result in added electrical resistance in the circuit as shown in figure 1. This extra resistance is referred to as "contact resistance". It is a common effect encountered at heterojunctions of dissimilar materials such as metal electrodes and TE material. The higher the contact resistance, the higher the extra, "waste" Joule heat will be at these specific heterojunctions when current is applied. This not only degrades cooling performance but also accelerates premature failure of the TEM.

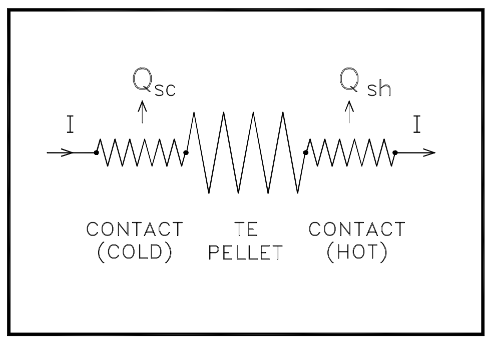

Figure 1. TEM Junction Circuit

One reason high contact resistance occurs at the junctions of a TEM could be the result of insufficient solder adhesion to the metal electrode. However, typically it is more difficult to achieve optimum solder adhesion to the unplated TE pellet. Another reason for high contact resistance at junctions may be poor plating adhesion to the metal electrode and/or the TE element when applied.

These conditions produce unusual thermal gradients in proportion to the contact resistance. The resulting thermal stresses fatigue the "weak link" in the heterojunction degrading junction integrity. When observing these "hot spots" of waste Joule heat during the instantaneous current pulse, junction deficiencies can be identified. A TEM exhibiting deficiencies of this nature will experience premature failure as a result.

Test Method

A simple variable AC voltage power supply with programmable timer pulse switch was used to apply power to the TEM. The power and pulse time had to be adjusted for each different type of imaging media and TEM. This usually required three to four trial tests to achieve optimum image clarity.

Thermally Sensitive paper was wrapped over both sides of the TEM to provide a thermal image or map for both the hot and cold sides during the electric pulse. A compression fixture was used to apply a slight pressure to the paper in order to keep the paper in position and make optimum contact with the TEM surfaces.

Cycle test comparison data was gathered as a result of applying approximately 12 VDC in the positive or “cooling direction” to TEMs mounted between aluminum heat sinks. The voltage was reversed after 5 minutes and lowered to a negative 5 VDC in the “heating” direction. After 5 more minutes in the “heating” direction the power was switched back to a positive 12 VDC, thus completing one cycle [1].

The transient test method [2] was used to measure and calculate the performance characteristics of the TEMs. These tests were performed periodically through out the analysis to evaluate changes in AC resistance (ACR) and heat pumping capacity (ZT).

Results

Photographs of thermal images, created from thermally sensitive paper, for 5 different sample TEMs are shown in Figure 2. The darker areas shown in Figures 2b and 2c represent “hot spots” caused by junction deficiencies (high contact resistance) in the TEMs where localized abnormal joule heat was generated.

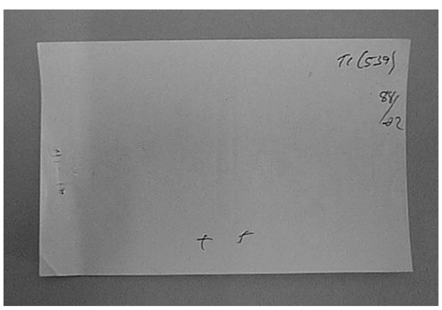

Figure 2a. Thermally Sensitive Paper Test #1

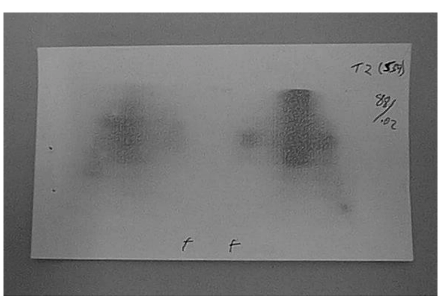

Figure 2b. Thermally Sensitive Paper Test #2

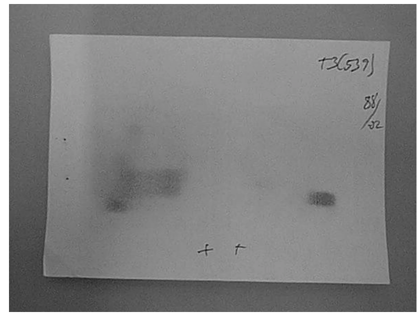

Figure 2c. Thermally Sensitive Paper Test #T3

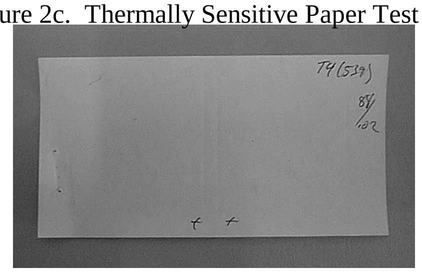

Figure 2d. Thermally Sensitive Paper Test #4

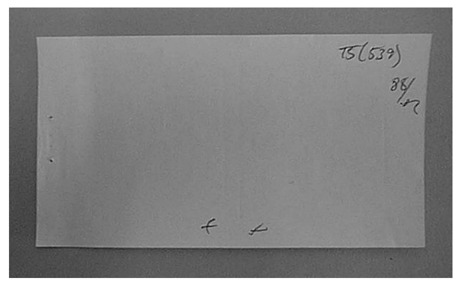

Figure 2e. Thermally Sensitive Paper Test #5

The voltage for this test was set to 100 VAC for all five TEMs. The pulse duration was set to 0.2 seconds on the timer. All five TEMs were produced by the same manufacture and came from the same lot. Serial numbers T1, T4 and T5 exhibit no known deficiencies in solder junction quality. This was evident by the uniform light gray exposure on the paper.

Figure 3a is a graph of corresponding cycle test data generated to verify the reliability of the 5 TEMs from the previous pulse test. The results of this cycle test indicated dramatic increases in AC resistance (ACR) and ZT for serial numbers #T2 and #T3. This directly corresponds to the thermal images identifying hot spots from the pulse tests.

The graph in Figure 3b indicates the shift in ZT as a result of power cycling. TEMs #T2 and #T3 have also experienced significant losses in heat pumping capability (ZT) as a result of poor junction quality.

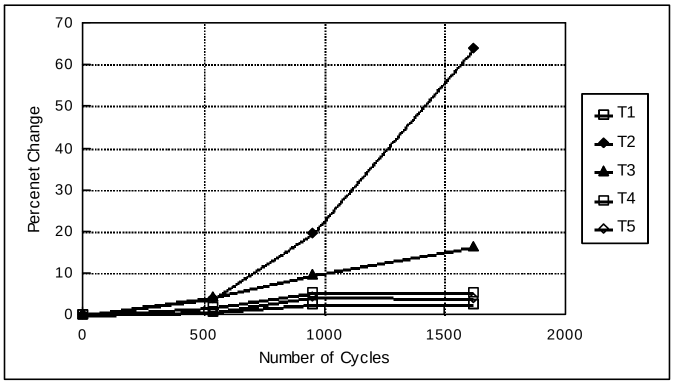

Figure 3a. Percent change in ACR due to temperature cycling

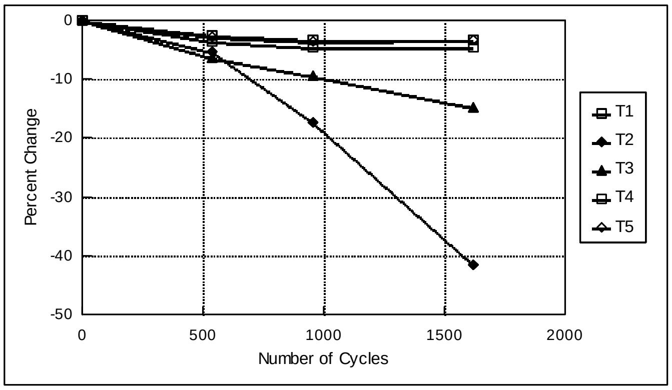

Figure 3b. Percent change in ZT due to temperature cycling

The graphs in figures 4a and 4b show the effect of multiple pulse tests performed on a new set of "good" modules. As indicated by the data presented in these graphs, the effect 100 pulses has on these TEMs for both ACR and ZT is negligible.

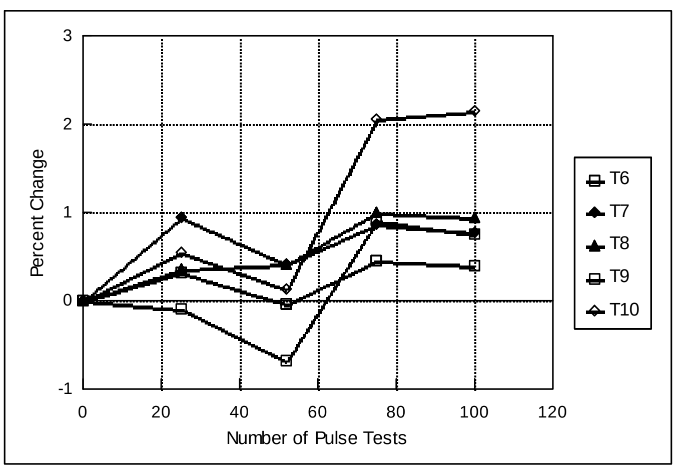

Figure 4a. Percent charge in ACR due to multiple pulse tests

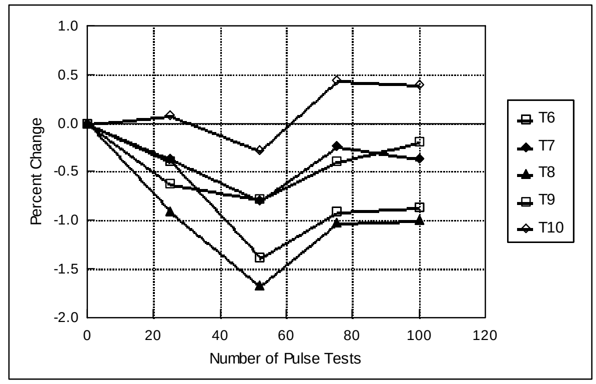

Figure 4b. Percent change in ZT due to multiple pulse tests

Discussion

The data presented in the previous sections represents how a manufacture or user can quickly and accurately evaluate long term reliability of TEMs. The basic test set-up is relatively inexpensive to manufacture and operate.

As illustrated by the thermal images in Figure 2, an accurate map of both sides of TEM can be produced and recorded.

Thermochromic Liquid Crystal Film or an Infrared (IR) Camera are two other methods available for identifying hot spots within a TEM. When using thermochromic liquid crystal film a lower pulse voltage can be applied to the TEM to produce a thermal map. However, the film begins to cool down after a few seconds loosing its image as it reaches room temperature. Another disadvantage when using the film is that only on side of the TEM can be mapped at a time. This, however, is not that great a problem when considering it only takes a few seconds to test the reliability of a TEM with this method.

The IR camera technique allows the image to be saved on a computer and will also give precise temperature measurements at each "hot spot". Again, like film, only one side of the TEM can be examined per pulse test.

Conclusions

The Thermal Pulse Test can be used on TEMs to evaluate long term reliability without several weeks of testing. This enables manufactures to continually monitor the quality of the products being produced during the actual assembly of the TEMs. Also, when problems arise due to inadequate TE junctions, they can be quickly identified so the manufacture is able to solve the situation before further products are fabricated.

This means that consumers of TEMs, can be assured of the highest quality and most reliable product on the market. In fact, users of TEMs can also benefit by incorporating this test method for product evaluation. It only takes a few moments to test with this method to verify that the quality and reliability of the TEM meet the high standards that the customer demands.

References

1. Ritzer, T. M, et al, A Critical Evaluation of Today's Thermoelectric Modules in proceeding of 16 Conference on thermoelectrics Dresden, Germany, (1997)
2. Buist, R. J., Methodology for Testing Thermoelectric Materials and Devices, CRC Handbook of thermoelectrics, CRC Press, Inc., 1995.

Acknowledgements
1. Steve Roman, TE Technology, Inc. for assisting in data collection.
2. Labelon Corporation, for technical assistance with Thermally Activated Paper.
3. Thermographic Measurements Inc., for technical assistance with Thermochromic Liquid Crystal Films.