Development of a Burst Voltage Measurement System for High-Resolution Contact Resistance Tests of Thermoelectric Heterojunctions

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Abstract

The recent enhanced search for high ZT thermoelectric (TE) materials has brought on new challenges to accurately characterize the contact resistance between the TE material and selected metallic bonds. Current technology for contact resistance measurements involve the sequential, physical placement of voltage probe or probes along the surface, curve-fitting the data and subsequent interpolation of voltage discontinuities at the heterojunction.

An improved technology has now been developed that utilizes a burst voltage measurement system which rapid tests and re-tests voltage with very high resolution and speed. This is done by starting a burst test and linearly dragging a voltage probe across the heterojunction. The resulting voltage profile yields accuracy, speed and resolution beyond that available with the "move and reset" technology currently employed.

Introduction

In 1992, Buist [1] introduced a new process for accurately testing the kinetic properties of thermoelectric materials and devices. The key to this test system was the use of a high speed, high resolution Analog-to-Digital (A/D) PC board. It was used to convert a personal computer to an exceptional digital voltmeter by simply plugging the board into an empty expansion slot. The unique characteristics of the PC board allowed full control over various functions of the voltmeter, including range control, electronic filtering, integrating measurement and rapid “burst” voltage measurement. All of these features have provided the means for obtaining accurate, fast-transient voltage measurement bursts with very high resolution, stability and repeatability.

This process has been used by Buist [1] to precisely define the characteristics of a thermoelectric material or device where power was applied until stability was achieved. Then, a burst voltage was initiated and the DC power was subsequently and abruptly turned off. The resulting waveform was digitally analyzed yielding the data needed to precisely measuring Seebeck coefficient, resistivity, thermal conductivity and Z.

This burst voltage test has now been applied to digitally measure the voltage profile along a “sandwich” of different materials by linearly dragging a flexible metallic probe across the various heterojunctions after quickly and abruptly applying a constant DC current through the sample. The resulting data consisted of more than 70 high-resolution voltage measurements per millimeter along the sample and its electrodes. Analysis of the voltage discontinuities in this voltage profile provided a value for the contact resistance at each heterojunction.

Test System and Process

The test system consisted of a TE Technology, Inc. test system, Model TS-205. It has the capability of quickly and automatically applying a constant DC current and measuring the burst voltage. One, fixed position voltage probe was attached to the copper electrode at one end of the sample and a moving probe dragged continuously and linearly from that copper electrode to the opposite copper electrode.

The system used to move the probe was a commercially available moving platform as shown in Figure 1.

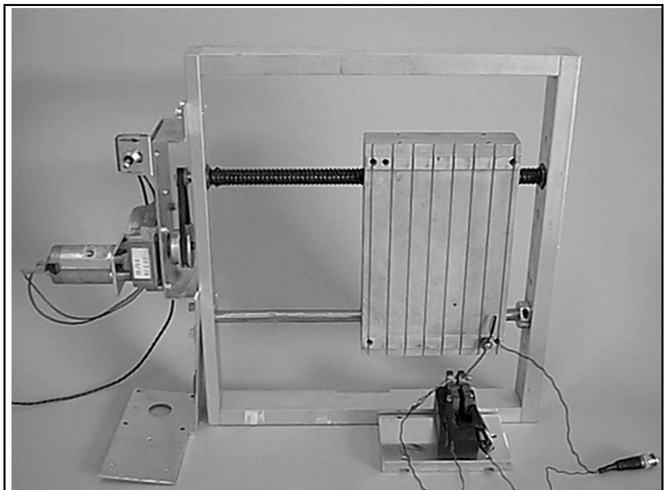

Figure 1. Movable platform and probe assembly.

The worm gear was driven by a DC motor assembly, moving the platform smoothly and linearly from left to right. The voltage probe was attached to the platform in such a way to apply the desired pressure to the sample surface at its sharpened point. A phosphor-bronze wire was used to fabricate this spring contact. The pair of current and voltage wires were attached to connectors to interface with the TS-205 test system.

The test sequence consisted of positioning the spring wire voltage probe onto the left copper electrode and measuring the (essentially zero) voltage to assure electrical connection with the electrode. Then, the platform power, sample current and voltage burst test sequence was simultaneously applied. The probe was allowed to travel the entire length of the sample from electrode to electrode, where the platform was stopped and the burst test terminated. The current was measured and then shut off. Finally, the burst test data was stored in a computer file for subsequent analysis.

Experimental

Initial tests were made to verify the proper operation of the test system. This “check-out” sample consisted of a parallelepiped of #304 stainless steel with electrically isolated copper electrodes applied at each end via compression. The stainless steel dimensions were 2.11 x 3.28 x 5.30mm long.

This configuration is shown in Figure 2. Note that the travelling probe is approximately half-way across the stainless steel sample. The special circular-shaped wire located near the upper left of this photograph was a spring-loaded clip used as the fixed voltage probe. The reason for this unusual shape was to facilitate connection to the appropriate copper tab within a TE module for TE pellet heterojunction tests subsequently performed. (See Figure 5).

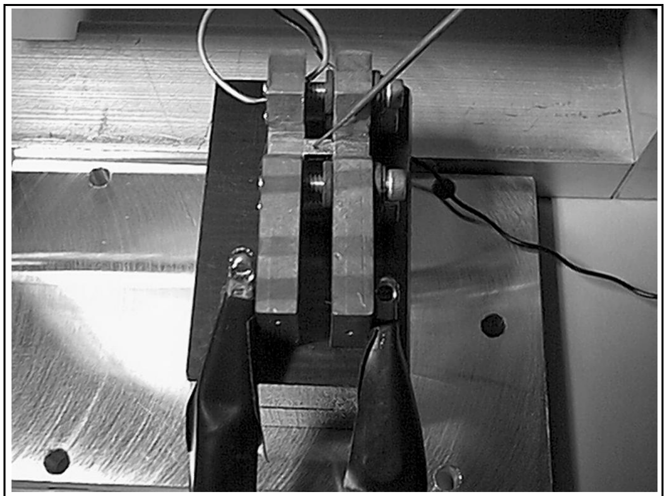

Figure 2. Test probe assembly with copper/304 stainless steel/copper sample.

The test data gathered from this "test" sample is shown in Figure 3. This is NOT a curve-fit! It is actually all of the 500 voltage test points connected together with line segments. The original X-axis data was actually time. The sample position for each voltage point was calculated from this time data and the probe velocity, calculated using the sample length over the elapsed time between discontinuities. This graph clearly indicates the resolution and repeatability the low voltage measurements as well as classic contact resistance.

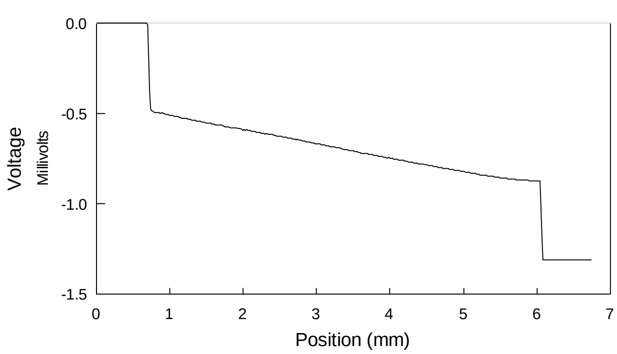

Figure 3. Voltage test data on a pressure-loaded copper + #304 stainless steel + copper sample.

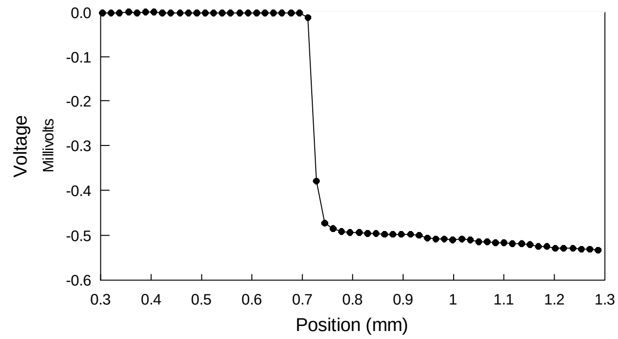

Figure 4. Detailed voltage test on copper/stainless steel junction.

Figure 4 is an expanded view of the initial portion of the full data shown in Figure 3. The constant and higher voltage region to the left is copper and the right region is the stainless steel. Note that 78 low voltage, high resolution test points, over only 1 millimeter, are evident in this graph. Also note the intermediate points in the region of the heterojunction. This is where the comparatively "blunt" probe was partially on both the copper electrode and the stainless steel sample.

To check out the accuracy of the test data, the slope of the data points within the stainless steel was used to calculate the electrical resistivity of the sample. It was 70.1 μOhm-cm. The published value for #304 stainless steel is almost precisely that value. The contact resistivity was also calculated from the discontinuities at both ends of the sample, its area and test current, 0.7491 amps. The values were: 43.4 and 40.3 μOhm-cm^2, respectively, for the left and right heterojunctions, respectively.

Thermoelectric Pellet Tests

The configuration for testing the contact resistance for TE pellets in a multi-couple module is shown in Figure 5. Note the circular-shaped probe for establishing a base-line voltage probe at one end of the pellet. Also note the travelling probe is approximately half way across the TE pellet sample. Four TE pellets were tested:

Figure 5. Test probe setup with TE module pellet sample.

1. Directly-soldered P-type sample
2. Directly-soldered N-type sample
3. Ni plated, “high temperature” P-type sample
4. Ni plated, “high temperature” N-type sample

Samples 1 and 2 were from the same TE module which was assembled using a Bi-Sn based, 138°C solder applied directly to the TE pellets, forming a shallow alloy region in the TE material at the contact point. Samples 3 and 4 were from the same TE module, but assembled by electroplating a Nickel barrier coating onto the TE pellets prior to applying a slightly higher temperature SnPb 183°C solder to the plated TE pellets.

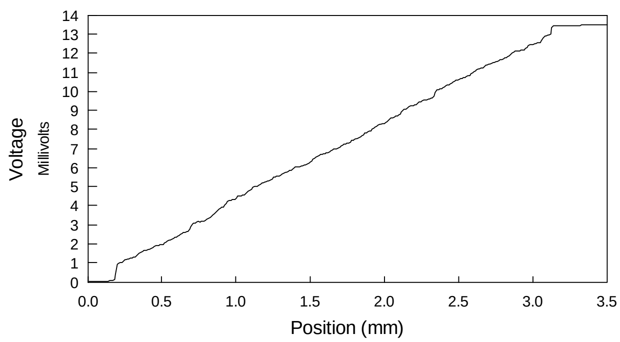

Figure 6. Standard TE Module, P-Type Pellet.

The test data on sample #1 is shown in Figure 6. Clearly, this data indicates some contact resistance evident by the small discontinuities at both heterojunctions. Also evident is the more imperfect voltage profiles within the TE material. This was presumed to be due to the unpolished TE material surfaces. That is, the TE modules were ground down so that the ceramics, copper tabs and TE pellets were all co-planar in order to facilitate the travelling probe. In fact, it was necessary to partially grind down the TE pellets.

The expanded first millimeter of sample #1 is shown in Figure 7. Because of the less sharp heterojunction, it was necessary to curve-fit the nearby region of the TE material.

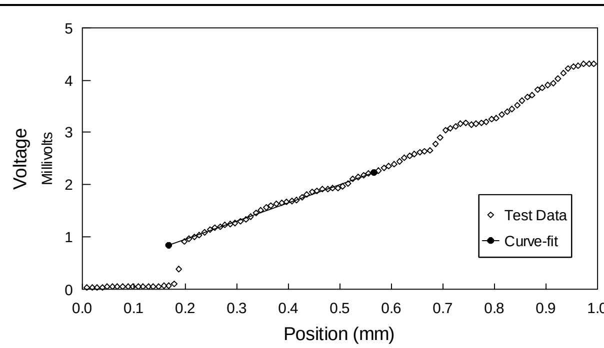

Figure 7. Standard TE Module, P-Type Pellet, expanded view.

The indicated left point of the curve-fit, minus the lower voltage of the copper tab was used to calculate the contact resistivity.

Figure 8 is the corresponding graph for the P-type pellet #3 for the Ni-plated TE pellet. Again, there is similar scatter in the TE material portion of this data, as was there for all TE material samples tested.

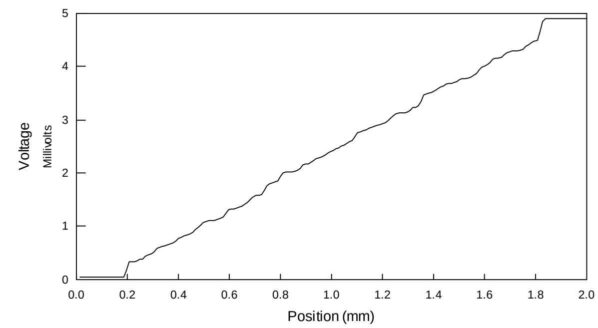

Figure 8. High Temperature TE Module, P-Type Pellet.

Results and Conclusions

Due to the similarity of all of the graphs, they were not all presented herein. However, their calculated contact resistivities are given in table 1 below:

Table 1. Contact Resistivity Test Results

Sample Number and Description	Cold side Contact Resistivity to Cu μOhm-cm^2	Hot side Contact Resistivity to Cu μOhm-cm^2
Stainless Stee1	43	40
1:Solder P-type	216	95
2:Solder N-type	105	153
3:Plated P-type	51	79
4:Plated N-type	57	102

It is not advisable to make any definite conclusions from only the 4 samples (8 contacts) tested at this point in time. However, these items are apparent at this time:

1. The tests of the stainless steel indicated excellent data and has qualified this test method.
2. The contact resistivity of Ni plated TE pellets was better (lower) than soldered TE pellets. This was a surprising result and suggests the need for more testing.
3. Hot side TE pellets have higher contact resistivity than Cold side TE pellets (with the exception of the soldered P-type TE pellet). This could be due to the fact that hot junctions are possibly re-melted in the assembly process.
4. More work on this test method should be performed, using cleaned and polished TE material surfaces.

References

1. Buist, R. J., “A New Method for Testing Thermoelectric Materials and Devices,” 11th International Conference on Thermoelectrics, Arlington, Texas, USA, October 7-9, 1992.