Variable Temperature Measurements in Cryogenic Probe Stations

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ABSTRACT

Electrical property measurements of nanoscale materials are important for the characterization and understanding of materials and devices. Equally important is measuring these properties at various temperatures. These measurements are facilitated with cryogenic probe stations that provide a variable temperature environment over a wide range of temperatures. However, until this time a major inconvenience was caused by the thermal expansion of the probe tips and probe station as the temperature changed. To prevent the tip movement from damaging the sample, the normal procedure is to lift the probe tips as the temperature changes. However, this interrupts the implementation of totally automated variable temperature measurements.

Keywords: thermal material characterization, cryogenic probe station

1 INTRODUCTION

We present results using a new probe design that allows the probe tips to remain in contact with the sample during temperature changes without scratching or drifting on the sample. Using optical microscopy, we show that this new design reduces total tip movement to less than 2 µm when the temperature of the sample changes from 4.2 K to 300 K. The same probes that eliminate the movement from thermal expansion also improve the isolation of the measurements to external vibrations. In standard cryogenic probe stations when the sample is in vacuum, the vacuum pump must be isolated from the probe station to eliminate vibrations, or the pump must be turned off while taking measurements. However, these probes allow measurements to be made with the pump on since there is no significant difference in the measurement with the pump on or off. Typical noise levels in well designed measurements are 10 parts per million (RMS) for resistance ranges from 1 Ω to 100 kΩ. Additionally, the forces on the probe are measured as the temperature changes. These measurements demonstrate that the probe design compensates for both movements of the probe arms, as well as movements of the sample stage during the temperature change.

To show the performance of this probe design, variable temperature resistance measurements were performed. Measurements were performed using tungsten probes as well as BeCu probes. Typical contact pads are gold or, in the case of measurements on metal samples, the sample itself served as a contact surface.

The variable temperature measurements were performed with two methods. In the first method, the set point of the temperature controller was ramped at a constant value, typically 5 K/min. This provided a relatively fast, although somewhat inaccurate measurement of the temperature characteristics. The second method was a stop and wait method. In this method, the setpoint was changed to a desired value and the temperature of the sample stage was monitored until a given settle criterion was reached. The resistance was measured and the setpoint was changed for the next measurement.

2 MEASUREMENT OF RESISTANCE

We measured the standard 10 Ω test resistor as a function of temperature in a TTPX. The resistance was measured with a Lake Shore Model 370 AC resistance bridge and Model 3708 scanner. Using a Lake Shore Model 331 temperature controller, the temperature was ramped continuously from 4.2 K to 300 K at a rate of 5 K/min. The I+ tip was 25 µm wide, the V+ tip was 10 µm wide, and the I- and V- connections were made to the probe station body (no connection through the arms). The measurement pads were gold covered copper on a standard PC board. The drive current was 100 µA. The Model 370 filter was off. The resistance noise was approximately 100 µΩ.

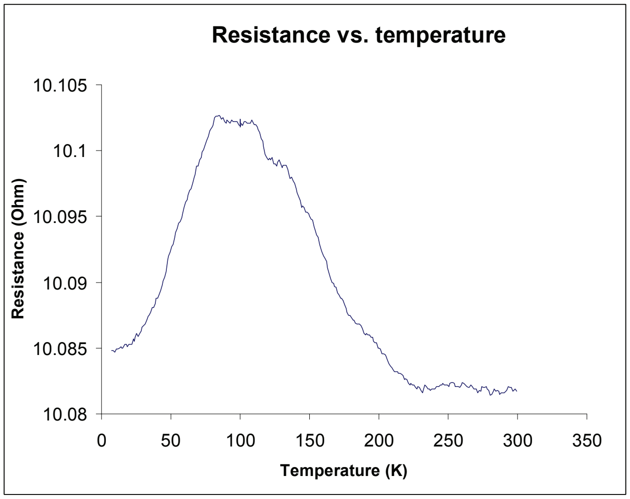

Figure 1 Variable temperature measurement of a 10 Ω resistor

Since the probe tips also provide mechanical stability, the vacuum pump was on during the measurement, with no isolation between the pump and the probe station. The probe station was floating on compressed air mounts.

Figure 2 is a picture of the probes positioned on the measurement pads. The temperature was 4.2 K, and the field of view was approximately 3 mm by 4 mm.

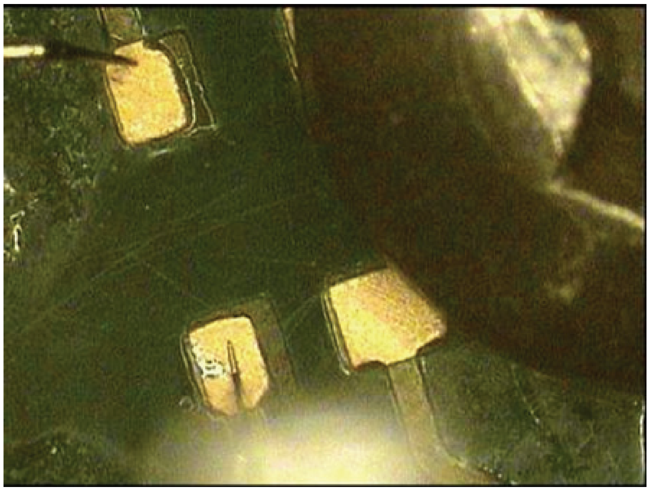

Figure 2 Probes positioned on measurement pads; sample temperature was 4.2 K

The temperature of the probe station was ramped continuously from 4.2 K to 300 K at a rate of 5K/min. The position of the probes at 275 K is shown in figure 3. There is no noticeable movement of the probes.

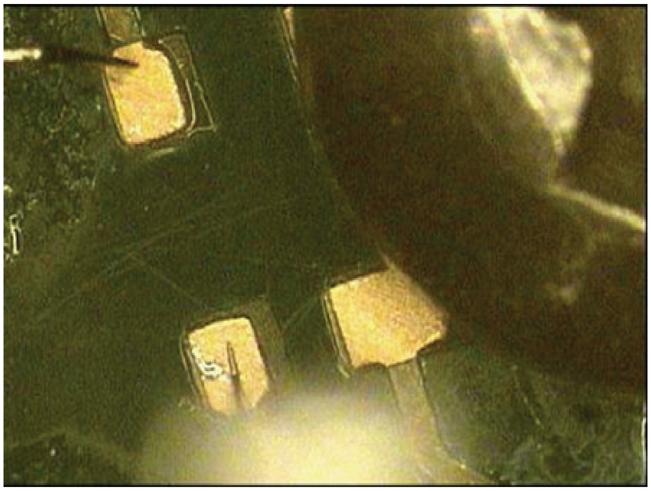

Figure 3 Probe position at system temperature of 275 K

Figure 4 shows a close up view of one of the probes while at a temperature of 300 K. The field of view is 500 µm square. The scratch visible on the contact is from a previous measurement. The scratch is about 50 µm long. This is typical of tip movement from probes currently used in probe stations.

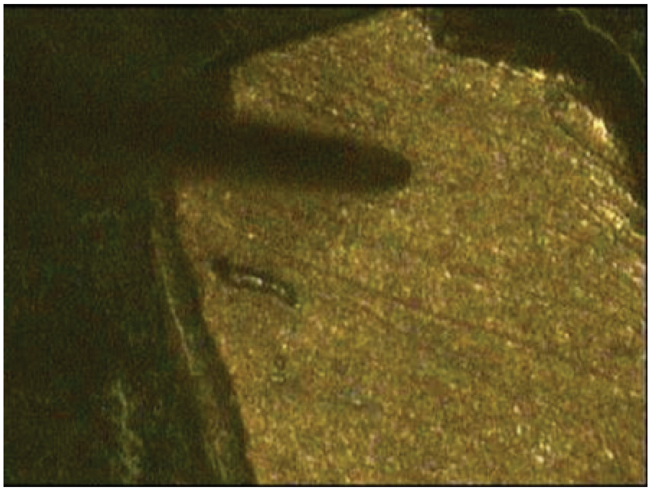

Figure 4 Picture of single probe enlarged to maximum magnification taken at 300 K

When the probe was lifted from the surface of the contact, there was no visible scratch on the gold contact pad. Figure 5 shows the contact after the probe was removed.

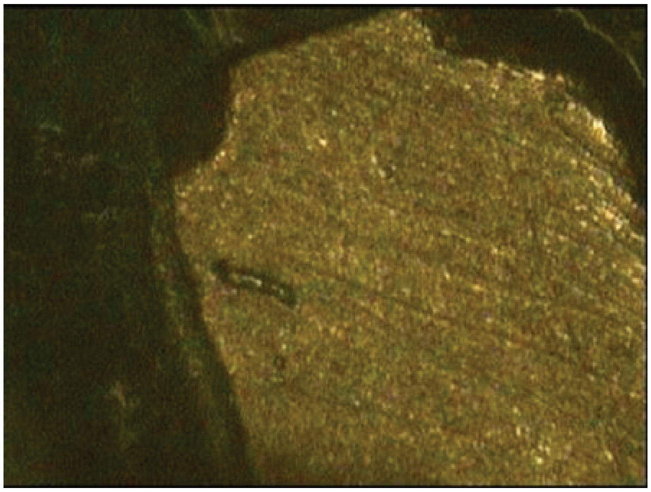

Figure 5 Contact pad after probe tip is removed

3 DISCUSSION

From these pictures we show that the drift absorbing probe design allows measurements of resistance vs. temperature with continuously changing temperatures. Additional measurements on different contact pad material and probe tip material are required to fully characterize this probe design.