INTRODUCTION

Accurate temperatures in gas environments are achieved through closed-loop temperature control, which is a standard feature on Atmosphere and Fusion systems. The temperature often depends on the electrical resistance of a given material, and MEMS technologies for *in situ* electron microscopy have heating elements that take advantage of the temperature versus resistance relationship.

Metals and ceramics are used to heat and actively control the temperature during *in situ* TEM experiments. Metals have a low resistance at room temperature, around 200 Ohms, and the resistance does not change much as one heats to high temperature. For instance, the resistance changes between 200–300 Ohms after reaching 800 °C. At resistances this low, the temperature measurement is prone to large error.

Why is this? The TEM holder itself has a known resistance, which is in the range of 10 Ohms, which makes up significant portion of the 200 Ohm metal resistance – around 5%. See Figure 1, left below. Since 10 Ohms significantly contributes to the overall resistance, a technique called **4-point probe is required for metals**. This measurement technique eliminates the holder resistance contribution so the Chip resistance measurement is more accurate.

The resistance of a ceramic is on the order of 9,500 Ohms, or **47x** larger than metal. At such a large resistance, the holder resistance of 10 Ohms does not play a role in the measurement, **so a 4-point probe measurement is not needed for ceramics**. For a temperature change from RT to 800 °C, the ceramic changes around 7,500 Ohms, roughly **25x** more than metal, around 200-300 Ohms, see Figure 2 for a comparison the resistance change for metal and ceramic heaters. To illustrate this further, a 2 and 4 point probe measurement of a ceramic MEMS heating device is shown in Figure 3. The difference in the measured resistance is less than 0.2% at its maximum over the entire range.

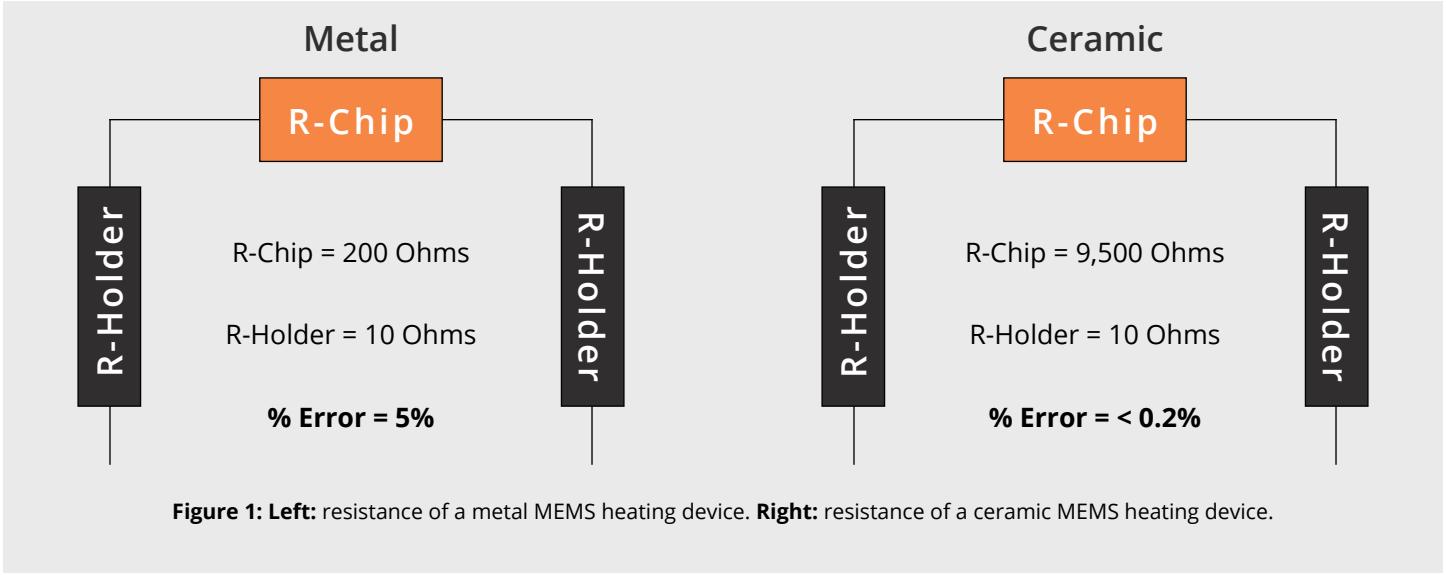

Figure 1: Left: resistance of a metal MEMS heating device. **Right:** resistance of a ceramic MEMS heating device.

Temperature	Ceramic	Metal
25 °C	9,500 Ohms	200 Ohms
800 °C	2,000 Ohms	500 Ohms
Ohms	7,500 Ohms	300 Ohms
Δ Ohms/°C	9.7 Ohms/°C	0.4 Ohms/°C
	No 4 pt needed	4 pt **required**

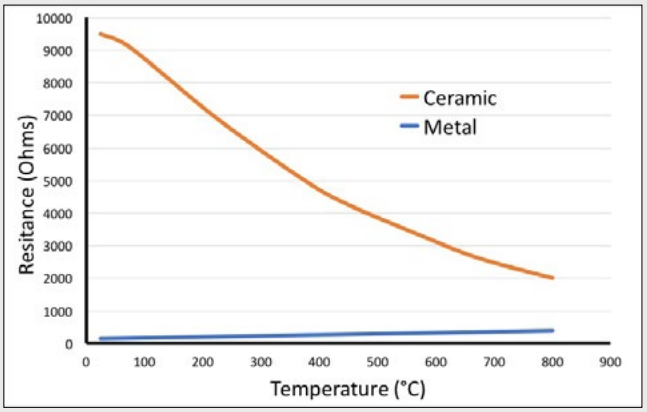

Figure 2: The change in resistance versus temperature. Comparison between metal and ceramic.

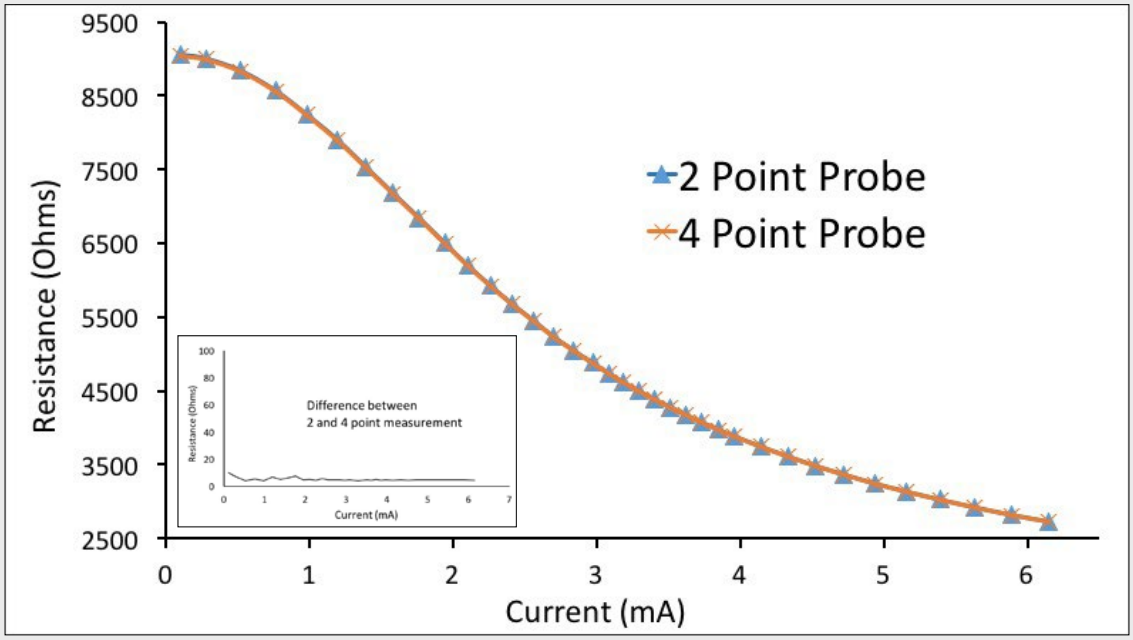

Figure 3: A comparison between 2 and 4-point probe measurements on a MEMS heating device with a ceramic heating membrane. The Electrical Current vs Resistance measurements are identical. The inset graph shows the magnitude of the difference between 2 and 4-point probe measurements. This corresponds to a maximum error of less than 0.2%

SUMMARY

In summary, Protochips uses the optimal technique for closed loop temperature control for ceramic thermal MEMS devices, the 2-point method, which delivers:

- Excellent temperature accuracy, < 5%, and uniformity, 99.5%
- Fast response and accurate closed loop temperature control
- Large change in resistance per °C for better accuracy and response