APPLICATION NOTE

Device Temperature in Cryogenic Probing Applications

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Introduction

Superconducting circuit evaluation[1] and device channel defect identification[2] are common applications for cryogenic measurements of electronic devices. Device characterization in conventional cryostats typically requires time-consuming and destructive wiring and packaging of an on-wafer device. Cryogenic probe stations enable visualization and electrical interrogation of multiple, wafer-level devices using positionable probes—accelerating development and device characterization efforts. The tradeoff for optical access to and flexible probing of the device under test lies in the heat loads from thermal radiation and heat conduction through the probe arms. Because of these heat loads, as well as the thermal resistance between the device and sample stage, the actual temperature of the device can deviate from the sample stage sensor. To minimize this effect, the cryogenic probe station should have radiation shields to reduce the thermal radiation on the sample, the thermal boundary between the sample and sample stage should be decreased, and the probes should be thermally anchored at or near the sample stage.

If the probing environment is not properly characterized, the deviation between actual sample temperature and sample stage temperature is often unknown and can lead to erroneous measurements. Here, we investigate the role of probe arm thermal anchoring on the device temperature in a cryogenic probing measurement. At the superconducting transition temperature of niobium (9.3 K), we demonstrate that with well-anchored arms the thermal gradient between the sample stage and a probed device can be less than 0.5 K.

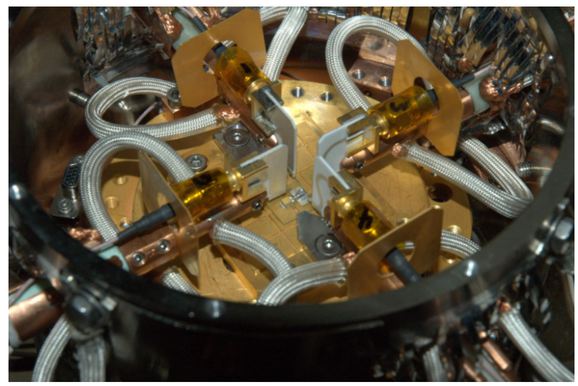

Figure 1—Four point probing of a Cernox reference device using a CRX-4K probe station.

Experimental setup

A Lake Shore CRX-4K probe station, with a fixed 1 W sample stage cooling capacity, was selected as a test platform. To simulate the device under test, a calibrated Cernox™ sensor was soldered onto a sapphire substrate. The underside of the sapphire substrate was coated with a thin layer of Apiezon® N grease and clamped to a 1.25 in grounded sample holder. Tungsten tips (25 µm diameter) mounted on four standard probe arms were landed on the contact pads of the Cernox sensor, and the Cernox device temperature was obtained with a Lake Shore Model 336 temperature controller using a four-point probing measurement of the sensor resistance (Figure 1). Additional temperature sensors embedded in each of the four probe arms and one bolted to the underside of the sample stage were used to monitor the probe arm and stage temperatures.

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Results

Table 1 summarizes the device, stage and arm temperatures for three common configurations of probe arm thermal anchoring. In the recommended configuration, the probe arm is anchored to the radiation shield, and the probe is anchored to the sample stage as shown in Figure 2. The second configuration relies solely on thermally anchoring both the probe arm and the probes to the radiation shield, and the final configuration consists of four unanchored probe arms and the radiation shielding removed.

Table 1—Configuration dependent device temperature

Probing configuration	Sample stage temp (K)	Mean arm temp (K)	Device temp (K)
Arms anchored to radiation shield, probes to sample stage	4.87	9.21	7.57
Arms anchored to radiation shield	3.80	34.94	12.13
Arms not anchored, no radiation shield	6.46	271.7	41.16

In the first configuration, the thermal load on the probe station cooling stage is increased by anchoring the probes to the sample stage and results in a higher sample stage temperature than in the second configuration with the probes anchored to the radiation shield. However, the lower sample stage temperature does not translate into a lower device temperature as the extra conductive heat load from the probes is not compensated by the additional cooling through the device substrate. Despite the relatively small impact on stage temperature by removing the radiation shield and probe/probe arm thermal anchors, the third configuration causes a substantial increase in heat load to the device and drives up the device temperature by more than 30 K.

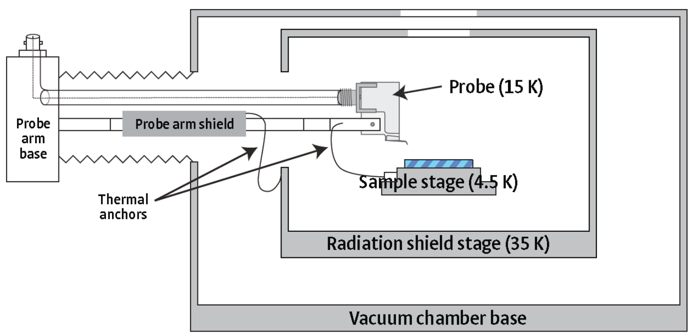

Figure 2—Recommended thermal anchoring configuration in a cryogenic probing environment.

Discussion

Using well-anchored probes and probe arms, we demonstrate the ability to rapidly evaluate superconducting circuits in a probing environment. For this measurement, a small wire was cut from a 99.8% pure niobium foil (Alfa-Aesar®) and affixed to a sapphire plate with a thin layer of cyanoacrylate adhesive. The wire was then thinned in order to increase the contrast in resistance between the normal and superconducting states; the thinned niobium wire has a 272 mΩ resistance at room temperature. The sapphire substrate was mounted in an identical fashion to the Cernox reference chip, then cooled to cryogenic temperatures in a Lake Shore CRX-4K probe station. After landing four probes directly on the niobium wire, the wire resistance was monitored as a function of stage temperature with a Lake Shore Model 370 AC resistance bridge (10 µA excitation, 60 s integration time) equipped with a Model 3708 pre-amplifier. At each stage temperature setpoint, the system was allowed to stabilize for 5 minutes prior to acquiring a device resistance.

Figure 3 shows the niobium wire resistance as a function of stage temperature. We observed a sharp decrease in the wire resistance at stage temperatures below 8.90 K, which we attribute to the onset of superconductivity in the probed wire. Below 8.75 K, the wire resistance drops below the measurement accuracy of the experimental set-up (<40 µΩ).

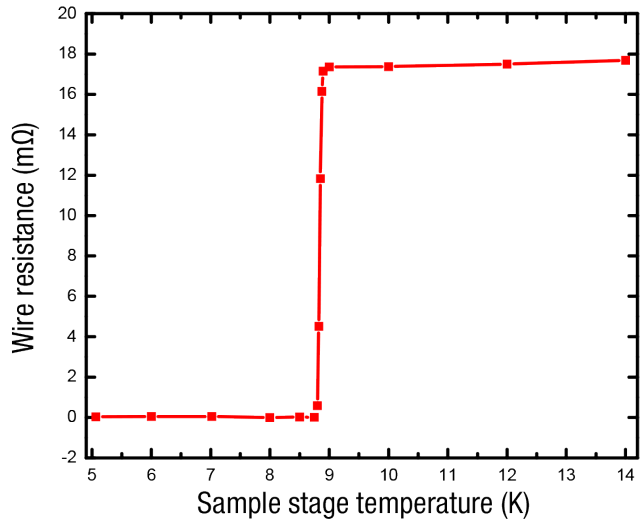

Figure 3—Superconducting transition in a probed niobium wire

Conclusion

Heat transfer to a device in a cryogenic probe station was studied by electrically probing a calibrated Cernox sensor as well as a niobium whisker. We found that conductive heat transfer from the probes can impart a significant thermal load on a device under test, and thermal anchoring is critical for effectively managing the heat transfer and achieving suitable device temperatures. We demonstrated that in a probe station configuration with properly thermally anchored probes and effective radiation shielding, the thermal gradient between device under test and the sample stage can be minimized.

References

[1] S. S. Attar and R. R. Mansour, "Low Temperature Superconducting RF MEMS Devices," IEEE Transactions on Applied Superconductivity, vol. 23, pp. 1800104–1800104, 2013.

[2] A. Motayed, S. Krylyuk, and A. V. Davydov, "Characterization of deep-levels in silicon nanowires by low-frequency noise spectroscopy," Applied Physics Letters, vol. 99, p. 113107, 2011.

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