RHK Technology Brief

APPLICATION • TUTORIAL • TECHNOLOGY

Ultra-High Vacuum Scanning Thermal Microscopy for Nanometer Resolution Quantitative Thermometry

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Introduction

Understanding energy dissipation at the nanoscale requires the ability to probe temperature fields with nanometer resolution. We have developed a novel ultra-high vacuum (UHV)-based scanning thermal microscope (SThM) technique that is capable of quantitatively mapping temperature fields with ~15 mK temperature resolution and ~10 nm spatial resolution. In this technique, a custom fabricated atomic force microscope (AFM) cantilever, with a nanoscale Au-Cr thermocouple integrated into the tip of the probe, is used in an RHK Customized UHV7500 STM/AFM along with a RHK Technology SPM1000 control system to measure temperature fields of surfaces. Operation in an UHV environment eliminates parasitic heat transport between the tip and the sample enabling quantitative measurement of temperature fields on metal and dielectric surfaces with nanoscale resolution.

Technique

Ultra-high vacuum (UHV)-based Scanning Thermal Microscope (SThM) technique enables a simultaneous measurement of the quantitative thermal map and topographic map. As shown in Figure 1(a), the custom fabricated atomic force microscope (AFM) cantilever with a nanoscale Au-Cr thermocouple integrated into the tip of the probe serves as a thermometer in addition to the conventional AFM probe. Scanning electron microscope images of the SThM probe with an integrated Au-Cr thermocouple is shown in Figure 1(b). The Au-Cr thermocouple junction is located near the apex of the tip.

Operating SThM in UHV environment overcomes limitations of SThM in an ambient condition. SThM in air condition has two main limitations: one is the spatial resolution due to the liquid film existing at the tip-sample interface and another is the difficulty of the quantitative measurement due to the parasitic air conduction between the sample and the SThM probe. However, operating SThM in UHV environment solves these two limitations, thus achieving the quantitative measurement of temperature fields with nanometer resolution.

With RHK based UHV-SThM technique, it is easy to obtain both the topography and the thermal map. Specifically the 200 nm wide Pt line (through which an electrical current is flowing) crossed with a 1µm wide Pt line (through which no electrical current is flowing) is scanned with SThM probe in UHV as shown in Fig 2(a) *(see page 3)*. The measured topographic image is shown in Fig 2(b), and the quantitatively measured thermal image is shown in Fig 2(c).

Figure 1(a)

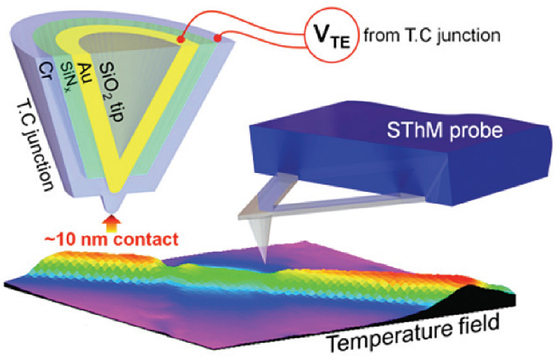


Figure 1(b)

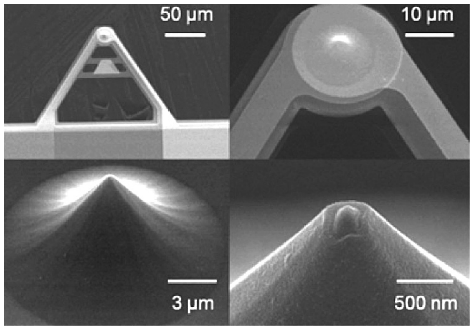


Figure 1(a) and (b): ***(a)*** *Schematic view of the scanning thermal microscopy (SThM) probe. The Au-Cr nano thermocouple junction is at the end of the tip. Heat transfer between the tip and the sample is dominated by solid tip-sample contact whose diameter is ~10 nm. The thermoelectric voltage generated output at the Au-Cr junction is directly proportional to the local temperature of the sample at the point contact and enables quantitative temperature measurements.* ***(b)*** *Scanning electron microscope images of the Au-Cr thermocouple probe for scanning thermal microscopy. The Au-Cr thermocouple junction is at the end of the tip. The diameter of the tip end is ~100 nm.*

Figure 2(a)

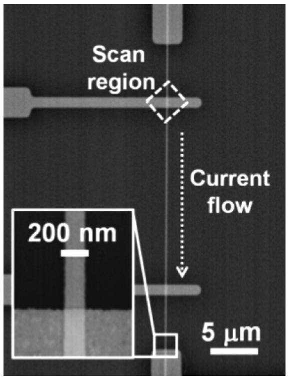
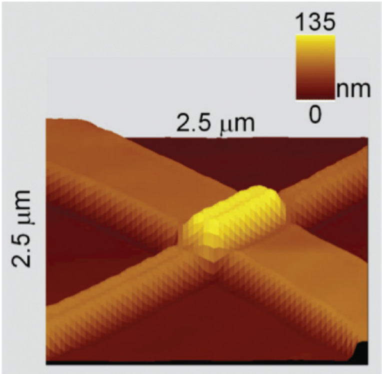


Figure 2(b and c)



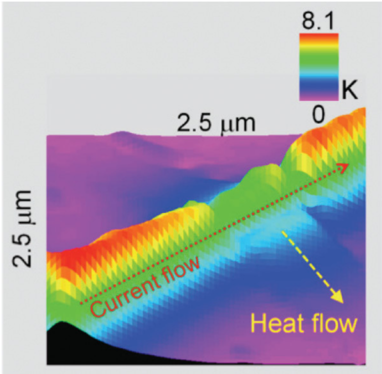


Figure 2 (a), (b) and (c): ***(a)*** *Scanning electron microscope image of a 200 nm wide Pt line.* ***(b, c)*** *show 3D topographic and thermal images in a 2.5 µm × 2.5 µm region where the 200 nm wide Pt line lies on top of a 1 µm wide Pt line. In the overlap region a rapid decay is observed in the temperature field on the 1 µm wide Pt line as it acts as a fin.*

References

1. A. Majumdar, "Scanning thermal microscopy," *Annual Review of Materials Science 29*, 505-85 (1999).
2. L. Shi, A. Majumdar, "Thermal Transport Mechanisms at Nanoscale Point Contacts," *Journal of Heat Transfer 124* (2), 329-37 (2002)
3. K. Kim, J. Chung, G. Hwang, O. Kwon, J. S. Lee, "Quantitative Measurement with Scanning Thermal Microscope by Preventing the Distortion Due to the Heat Transfer through the Air," *ACS Nano 5* (11), 8700-09 (2011).
4. K. Kim, W. Jeong, W. Lee, P. Reddy, "Ultra-High Vacuum Scanning Thermal Microscopy for Nanometer Resolution Quantitative Thermometry," *ACS Nano 6* (5), 4248-57 (2012).

How and why RHK

- Thermal imaging is very sensitive to the thermal contact resistance between the tip and the probe. The RHK AFM maintains a constant force during scanning, which greatly helps in controlling the contact diameter and the resultant contact thermal resistance. Hence, the RHK design greatly facilitates the implementation of quantitative scanning thermal microscopy.
- The customized RHK AFM enables incorporation of multiple (six) independent electrical connections to the scanning probe enabling easy electrical access to the thermocouple integrated into the probe, which is critical for successfully accomplishing UHV-SThM.

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