Prototype 6:

SThM Temperature Calibration Device

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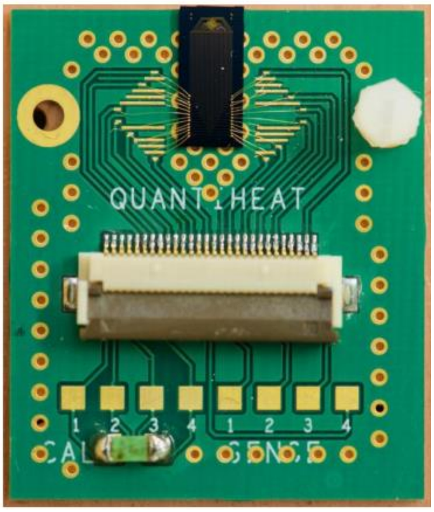
A considerable limitation of Scanning Thermal Microscopy (SThM) is that in most cases the temperature of the thermal sensor is only partially defined by the temperature of the sample at the tip contact. The SThM sensor is also affected by radiative and convective transfer of heat from the sample to the cantilever. Quantitatively knowing the spatial extend and temperature of the heated region is also a challenge.



This new membrane device provides two modes of spatially localised sample heating up to 100°C and an absolute noise thermometer for monitoring the sample temperature as it is interrogated by the SThM tip. By measuring the probe response in and out of contact, in different heating modes, and at different temperatures, one can quickly and accurately calibrate the SThM temperature sensor with a few mK accuracy.

Key Benefits

- *A temperature controlled calibration device for SThM probes*
- *Absolute measurement of temperature with 1mK accuracy*
- *Simple and direct way to establish a temperature calibration curve*
- *Simulate point source and long range sample heating*

Sample Specification

The calibration device, based on a Johnson noise thermometry (JN device), is fabricated as a bare metallic structure on the top of a 100nm thick Si_3N_4 membrane of size 560 x 560 µm² on the top of a 380 µm thick silicon wafer which acts as a mechanical support. As shown in Figure 1 the device consists of a thermometer surrounded by guarding and heater structures. The thermometer consists of a square Pt thin film resistor 5 µm on a side which is addressed using four leads in Kelvin Connection mode. The temperature sensing resistance surrounds a central gold "dot" of 2 µm diameter which is located at the exact centre of the temperature sensor. In this way the gold dot has the same temperature as the average temperature of the Pt resistor, regardless of the existence of any temperature gradients across the device. The combination of individually addressable 40 µm x 40 µm² and 400 µm x 400 µm² heated regions allow the device to be heated either uniformly or locally.

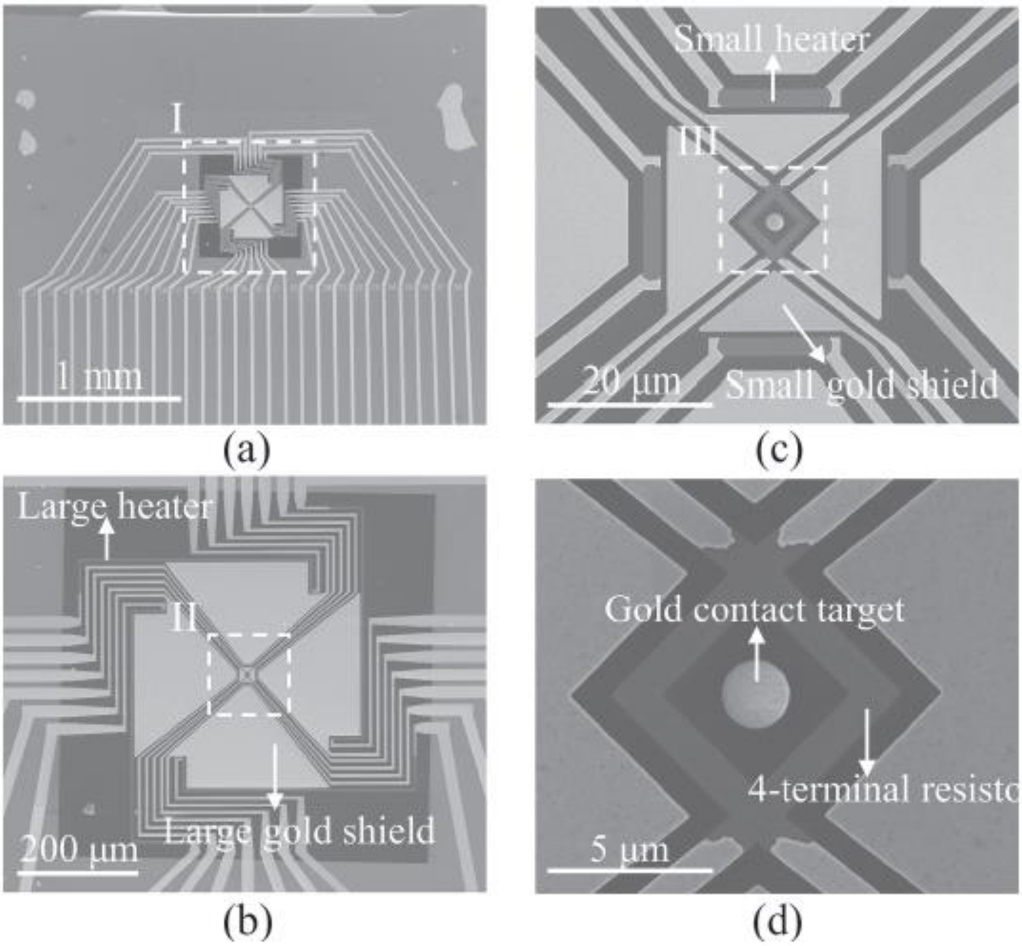


Figure 1: *SEM image of the JN device: (a) general view of the whole device including the membrane (dark grey area) and gold connecting wires (brightest wires), (b) details of features from the dashed square I in figure (a) showing four large heaters and four large gold shields on the membrane, (c) details of features in the dashed square II in figure (b) showing four small heaters and four small gold shields,and (d) details of features in the dashed square III in figure (c) showing the 2 µm diameter gold contact target with the NiCr 4-T split resistor surrounding it.*

Applications

Calibration of Temperature sensitivity of a passive SThM probe

Figure 2 shows the schematic of experimental setup for charactersation of a passive SThM probe. The probe was used in passive mode as a nano-thermometer allowing measurement of the temperature distribution on the membrane. As the JN device was heated using a DC voltage, care was taken to avoid an unintended direct electrical path between the device and probe instrumentation. Hence, the probe was connected in one leg of a Wheatstone bridge and driven by a 2.5 MHz 140 mV peak–peak sinusoid wave through a transformer. A more detailed description is mentioned in [1].

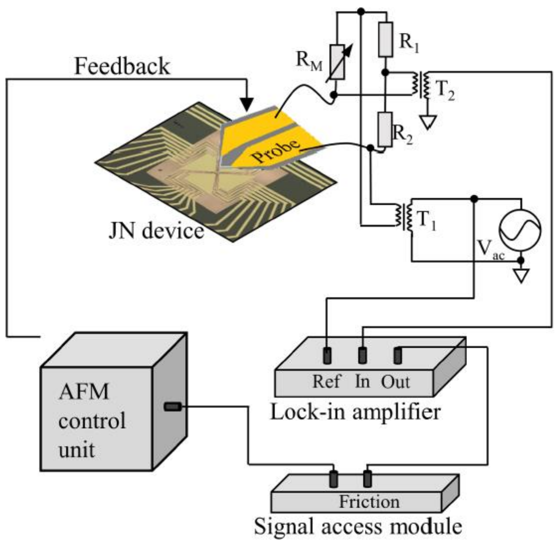


Figure 2 : Schematic representation of the experimental setup

A lumped circuit model has been developed in [1] to illustrates the different components of interaction between the sensor with the sample, like the tip-sample coupling, conduction through the Si3N4 cantilever and platinum tip and atmospheric conduction through air. Figure 3 shows the results of modelling and experiment on the measurement of temperature across JN device.

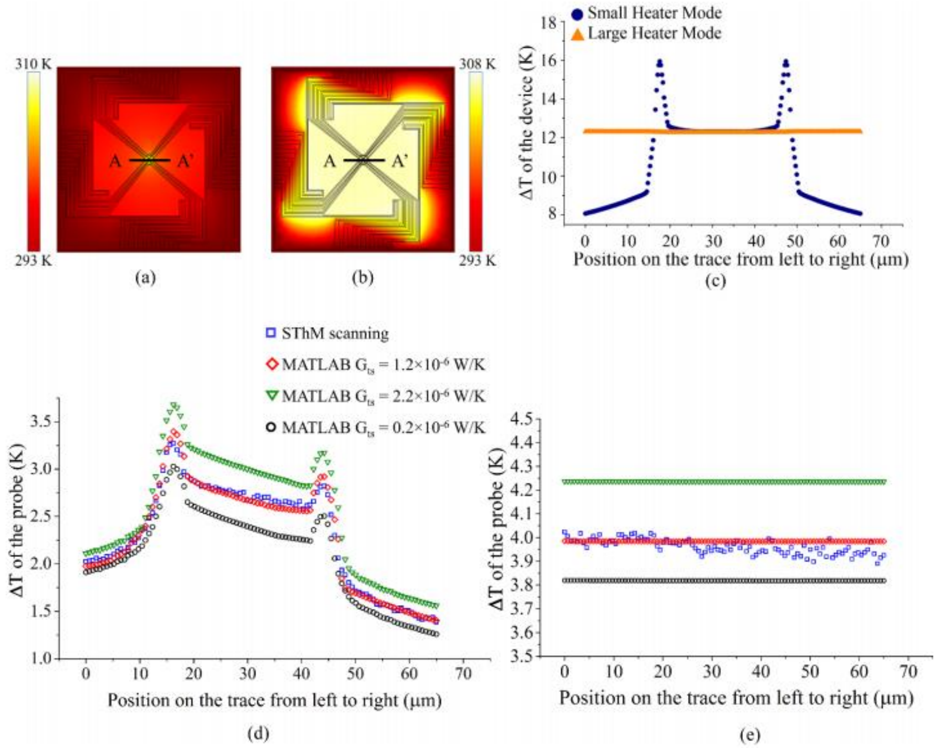


Figure 3: (a) and (b) show JN device temperature distribution from the FEA model. A 65 µm long trace A-A' across the centre of the membrane shows the section used for the data plotted in (c) showing the temperature difference from the ambient. (d) and (e) show a comparison, for the same region, between experimental data and modelled data corrected in using the heat transfer equation by different values of tip-sample thermal conductance, Gts.

Finally, the derived model may be used to characterise the temperature measured from a real sample with high accuracy. This is shown in Figure 4.

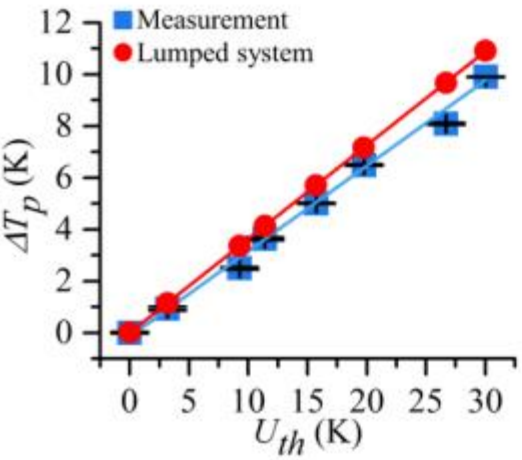


Figure 4: Probe temperature obtained from experiment (blue) and from the lumped system model (red).

Further information

[1] Yunfei Ge, Yuan Zhang, Jamie A Booth, Jonathan M R Weaver and Phillip S Dobson "Quantification of probe– sample interactions of a scanning thermal microscope using a nanofabricated calibration sample having programmable size" Nanotechnology 27 (2016) 325503

[2] Additional information on the sample can be obtained from the QUANTIHEAT website.

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