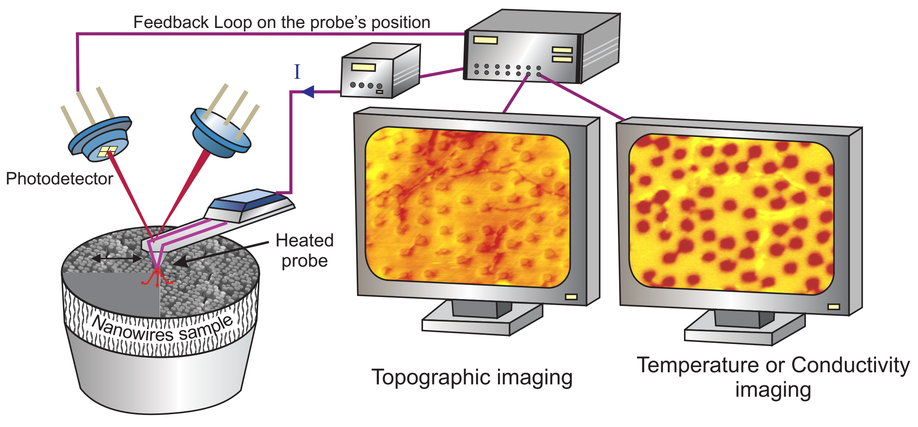
Thermal Imaging of Thermoelectric 1D nanowires of Bi_2Te_3 using Scanning Thermal Microscopy

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Introduction: Energy harvesting is certainly one of the most exciting challenge in modern physics. Theoretical calculations, material engineering and novel experimental characterization techniques have risen to fully explore the nanoscale limit and new materials with tailored properties. The purpose of this work is to present the current state-of-progress of the thermal metrology plateform developed at LEMTA and more specifically the scanning thermal microscope (SThM). We applied this SThM technique to the study of thermoelectric-based Bi_2Te_3 nanowires.

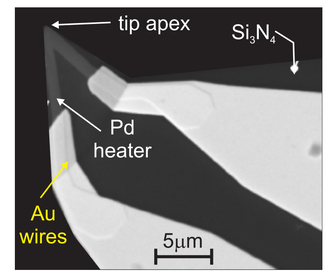
Scanning Thermal Microscopy principle



Principle

The nano-probe can be seen as an **electrical resistance** inside a Wheatstone bridge. When a current I is send, **Joule effect** takes place and heats up the nano-probe.
The knowledge in the variations of current send in the probe are related to its temperature changes and thus to the heat transferred to the nano-objects.

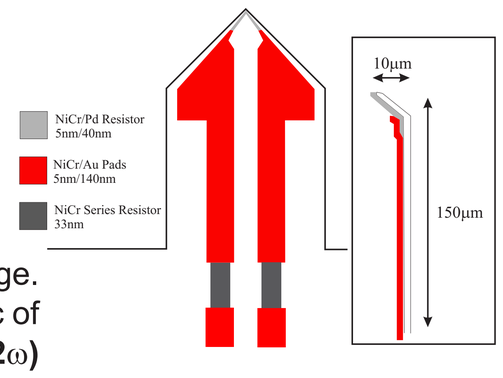
Thermoresistive Probe



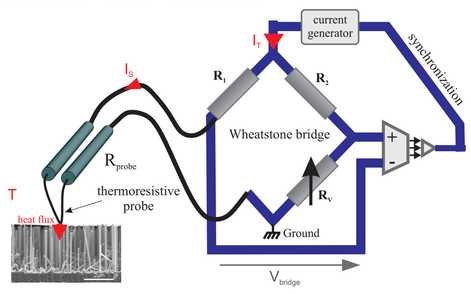
G. Wielgoszewski *et al*, Sensors and Actuators A: Physical 214 (2014)

Temperature imaging mode

Probe is kept at a constant temperature by keeping V_{Bridge} **= constant** inside a feedback loop.
The changes in the current are monitored to create an image



Inside the SThM

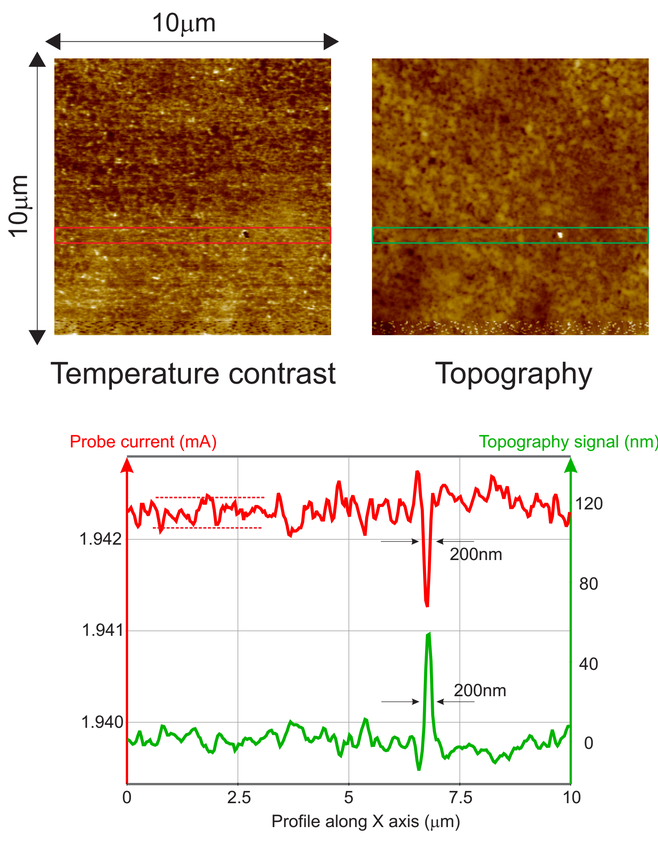


DC Conductivity imaging mode and 3-ω SThM

DC probe current is kept constant and the changes across the bridge are monitored to create an image. 3ω-SThM relies on the same principle except that the probe current is a AC-current. The third harmonic of the voltage, filtered by a lock-in amplifier, is proportional to the probe temperature: **$V(3\omega) \sim T(2\omega)$**

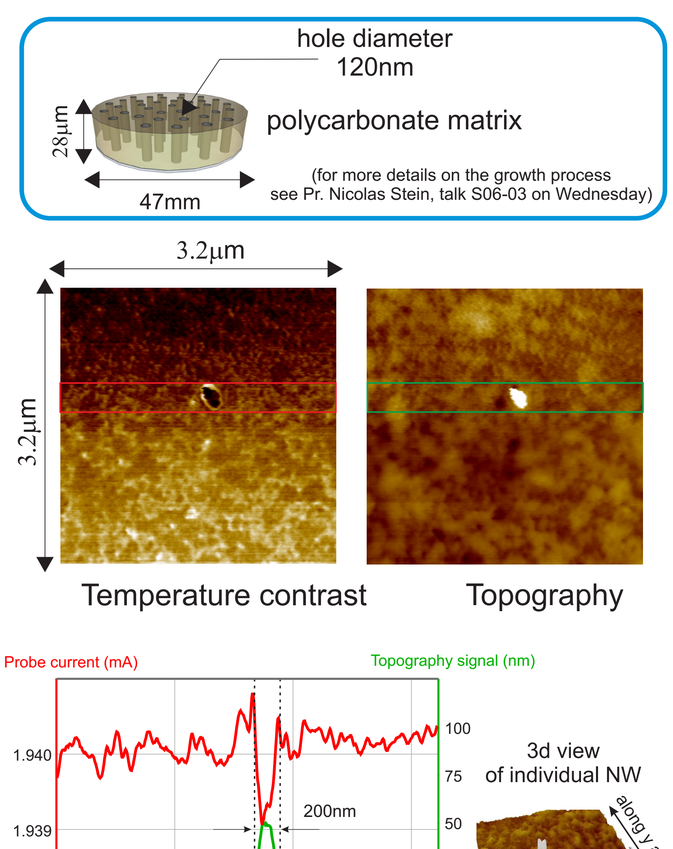
Imaging and thermal microscopy of nanowires

Electrochemically grown Bi_2Te_3 nanowires

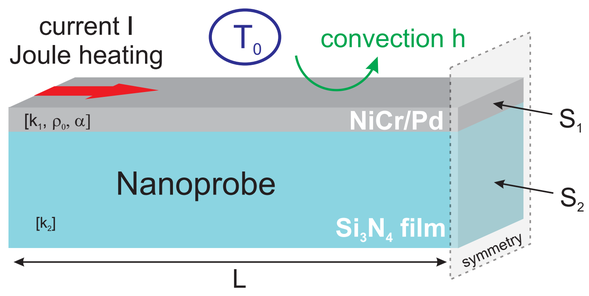


Probe current sensitivity contrast ~0.3µA

$$\text{Ratio} = \frac{\text{assumed conductivity NWs}}{\text{conductivity matrix}} \sim 5$$



Modelling heat transfer between nanoprobe and environment



solving balance equation with Joule heating source term

resistance of the tip changes with temperature

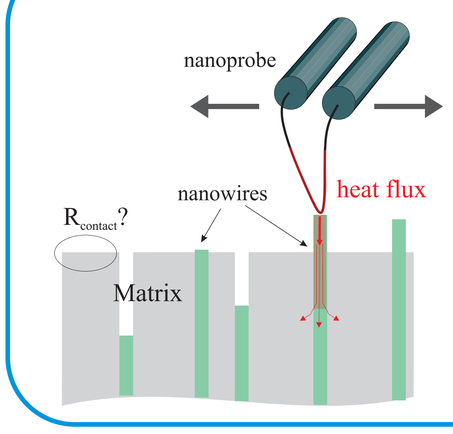
Out-of-contact Probe Temperature $\langle T_{Probe} \rangle = \frac{J}{m^2}\left[1 - \frac{\tanh(mL)}{mL}\right]$

Contact Probe Temperature $\langle T_{Probe} \rangle = \frac{J}{m^2}\left[1 - \frac{\sinh(mL)}{QmL} - 2\frac{W}{QmL}(\cosh(mL) - 1)\right]$

with $J = \frac{\rho_0 I^2}{S_1 S_2 k_2}(1+\alpha T_0)$ $m^2 = \frac{hp_2}{S_2 k_2} + \frac{\alpha \rho_0 I^2}{S_1 S_2 k_2}$ $Q = \cosh(mL) + \gamma \sinh(mL)$ $\gamma = (k_2 S_2 m R_{sample})^{-1}$

Modelling the contact with NWs

Puyoo *et al*, Scanning thermal microscopy of individual silicon nanowires, J. Appl. Phys. 109, 024302 (2011)



Association of thermal resistances in series

$$R_{NW} = \frac{L}{k_{NW} S}$$

$$R_{constriction} = \frac{1}{2 k_{Si} d_{NW}}$$

Future improvements

3ω-SThM

More sensitive than dc-method to energy transfer between tip and nano-objects. Better suited for thermal property metrology.

Controlled Environment

Install the SThM system in a vacuum chamber

Suppress artefacts like water meniscus between tip and sample, convection with external environment.

Conclusion: We have demonstrated the ability of SThM to perform images of individual Bi_2Te_3 nanowires.
Future improvements will allow to extract the thermal conductivity of individual NW.

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