Heat generation and dissipation in nanosystems

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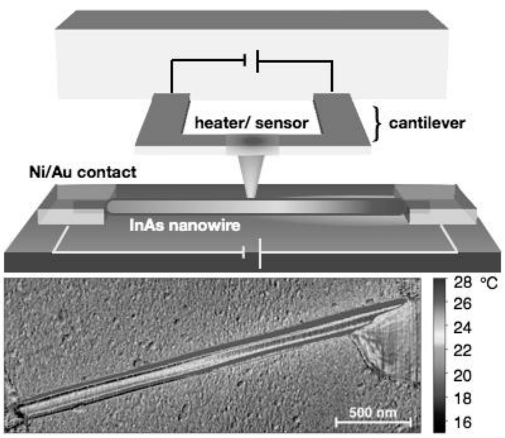
Self-heating degrades the performance of devices for logic, storage and energy conversion. Reduced thermal conductance in nano-structures has become a limiting factor towards increasing density, performance and reliability of many scaled CMOS devices. Other devices, however, may even benefit from the reduced thermal conductance, for example in thermoelectric energy converters or thermally assisted switching in various data storage schemes.

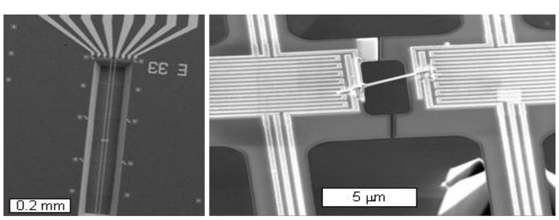
The technological need for characterization of scaled nano-devices is not paralleled with the availability of methods to measure heat flux and temperature on small scales. To measure local temperature and conductance variation we therefore focus on developing measurement tools. These are based on scanning a thermometer across the sample surface region of interest, so called scanning thermal microscopy (SThM), measuring thermal properties directly through self-heating, and measuring directly the heat-flux through molecular 1D-structures.

In SThM, a heater-sensor with a sharp tip is scanned across a sample surface to measure the spatial distribution of thermal conductance or temperature of a sample with a resolution down to ~10 nm. We discuss demonstrations of sensitivity and lateral resolution for both thermometry and conductance measurements using examples of graphene and organic layers and self-heated nanowires. It is shown that the surface roughness of tip and sample have critical influence on the measured thermal transport of the tip-surface contact.

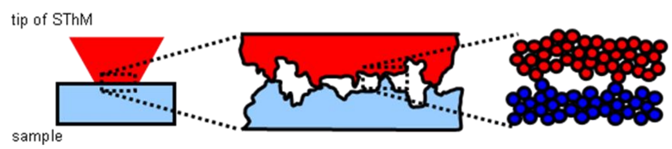
MEMS-based heater-sensors have been used since about a decade to measure thermal transport in nanowires, and tubes. A remaining challenge is the correlation of electrical and thermal transport properties of samples. We fabricated extremely sensitive MEMS devices to simultaneously measure thermal conductivity, electrical conductivity and thermopower. Results of a full thermoelectric characterization of single InAs nanowires are presented.



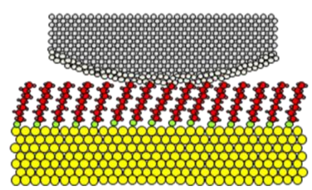
SThM setup with the tip in contact with a self-heated InAs nanowire (top). [1]



Electron micrographs of micro-heater device for the thermal trans-conductance measurement of single InAs nanowires. [2]



Schematic of a tip-surface contact of ultrasmooth surfaces leading to quantized transport over individual atomic contacts [3]



Measurement geometry to study heat flow along molecular systems using a scanning thermal microscope

[1] F. Menges, et al., Nano Letters 12 (2012) 596-601
[2] B. Gotsmann et al., IEEE Proc. DRC Conference (2013)
[3] B. Gotsmann and M. A. Lantz, Nature Materials 12 (2013) 59-65
[4] F. Menges et al., Phys. Rev. Lett. 111 (2013) 205901