# [1007] Characterisation of local thermal properties in nanoscale structures by scanning thermal microscopy

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Local characterisation of material thermal properties has become increasingly relevant, but also increasingly challenging, as the size of thermally-active components has been reduced from the micro- to the nano-scale [1] such as in devices based on semiconductor quantum dots and quantum wells, polymer nanocomposites, multilayer coatings, nanoelectronic and optoelectronic devices.

In this scenario, thermal management arises as one of the main issues to be treated as the proximity of interfaces and the extremely small volume of heat dissipation strongly modifies thermal transport and imposes a limit on the operation speed and the reliability of the new devices [2]. It therefore becomes critical to fully characterise the local nanoscale heat transport properties of different materials currently used in various industrial applications such as semiconductors, insulators, polymers etc, operating under different conditions and with varying doping levels [3]. Specifically, silicon is of interest due to its ubiquity in most sensors, electronic components or photovoltaic cells.

In the present study, we compare doped and intrinsic semiconductor to polymeric sample that have been characterised both topographically and thermally by means of scanning thermal microscopy (SThM). Thermal characterisation of the samples was performed with a modified AFM system (NT-MDT Solver) in ambient conditions using a commercial  probe with Pd microfabricated resistive heater and custom electronics allowing the measurement of local heat transport between the apex of the probe and the sample [4]. We demonstrate this approach on the set of the reference materials samples of sufficiently large size to be independently measured using standard thermal conductivity methods [5].

In order to improve the quality of the SThM measurements, sample temperature was stabilised via a combination of a Peltier heater mounted underneath the sample and thermistors monitoring the temperature of the sample in a closed loop setup, with the temperatures of the probe base and surrounding air continuously monitored. The setup allowed us to simultaneously acquire topographical and thermal measurements in the contact mode. During the measurements, approach-retraction curves (as shown in Figure 1), were taken at 16 different points of the sample's surface. The SThM electronics produced a voltage output ("thermal signal") due to the change of the probe resistance proportional to the change in the probe temperature. Probe response is best represented as , where  is the thermal signal of the probe when it is not in contact with the sample, and  is thermal signal when it establishes contact with the surface. This ratio is shown to be directly related to the thermal conductivity of the samples [4].

Our results for the 4 different materials – intrinsic, p++ and n++ doped Si, as well as the polymer are shown in Fig.2. In the measurement conditions of ambient pressure and temperature, single crystalline Si [100] is showing the highest value of the thermal conductivity, with the doped Si species showing lower thermal conductivity with smaller values *DV/V*, due to phonon-electron scattering that are dominating on the nanoscale [6].

Our measurements show that the SThM can reliably discriminate between group IV semiconductors presenting different doping concentrations based on the thermal conductivity, with a lateral resolution of about 20-50 nm. Further steps will focus on obtaining quantitative data from the DV/V measurements, using for this purpose, specially prepared reference samples of controlled geometry that can be characterised independently via large scale techniques such as flash thermoreflectance [5].

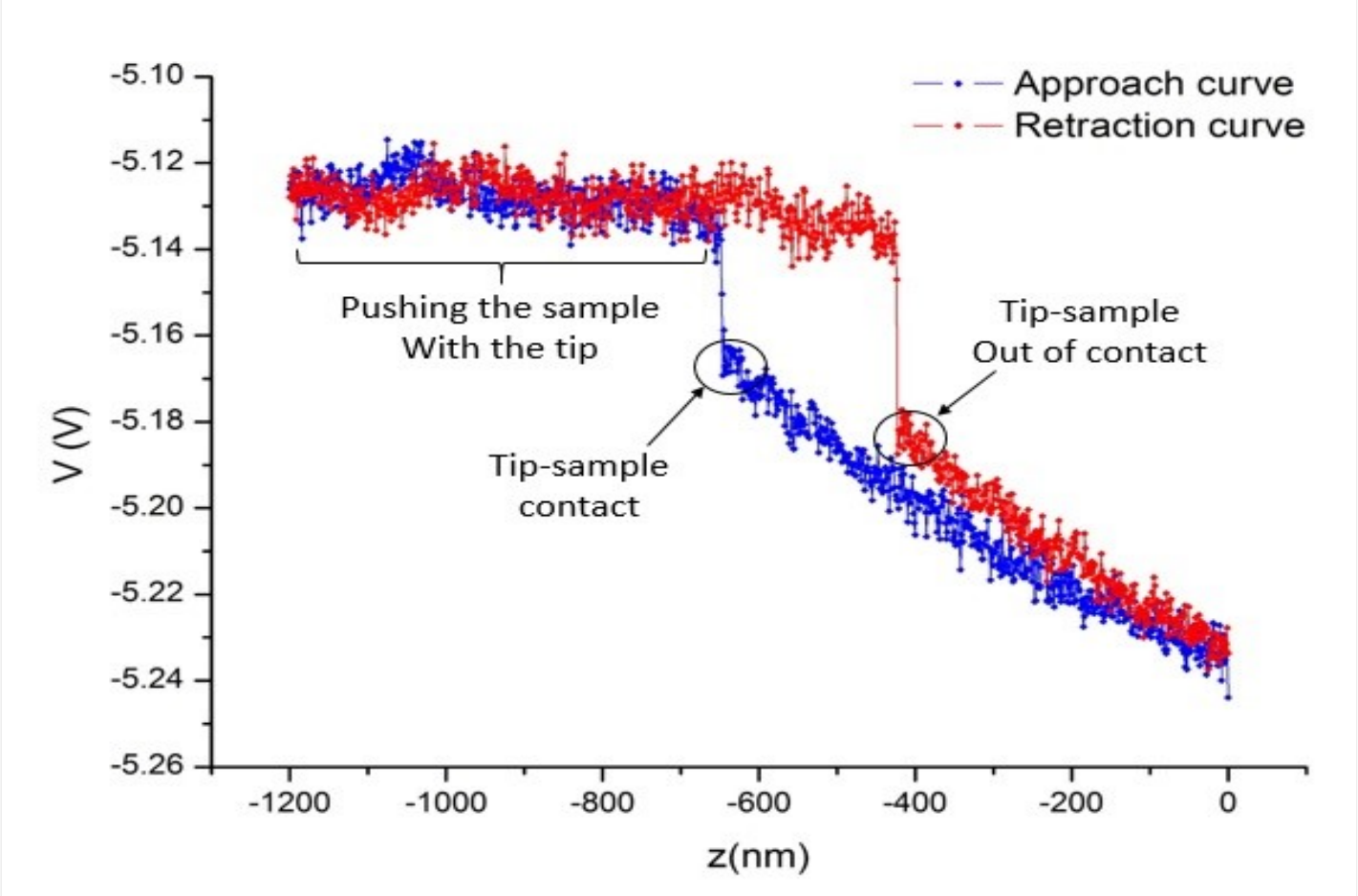


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**Figure 1.-** Thermal respon*s*e acquired during approach (blue curve) and retraction (red curve) of the tip to the surface of the sample. The change in voltage experienced by the probe is directly related with the thermal conductivity of the material under study.

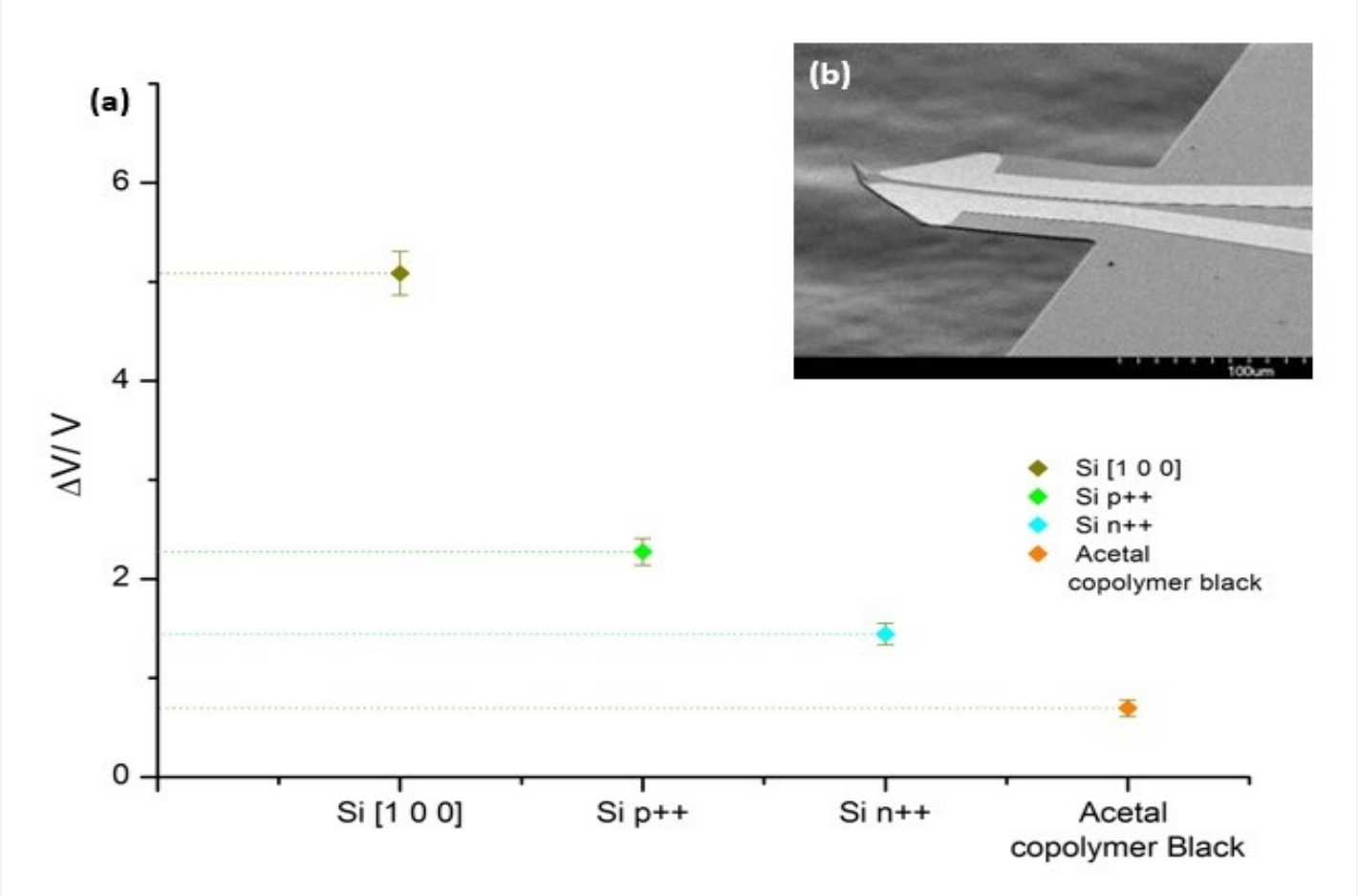


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**Figure 2.-** Thermal characterization of group IV semiconductors using SThM measurements. (a) Ratio of the voltages obtained for Si [1 0 0], Si p++, Si n++ and the acetal copolymer black. The measurements where performed in ambient pressure and temperature, using for the thermal characterlzation a modified AFM (NT-MDT solver) with a commercial probe coated with a Pd resistive heater. (b) SEM image of the probe, manufactured by Kelvin Nanotechnology (Image courtesy of ANASYS INSTRUMENTS)