Quantitative Nanothermal Study of 2D materials by SThM and Finite Elements Simulations

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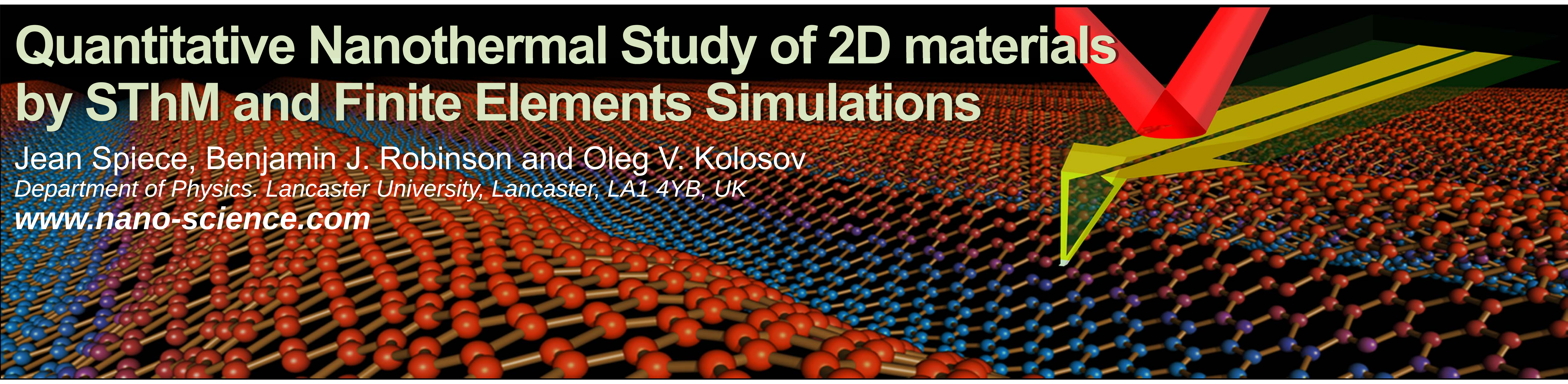
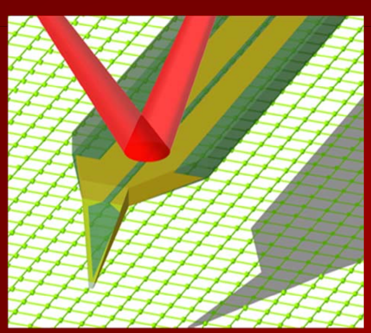


Introduction

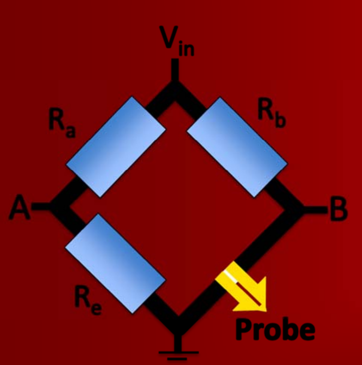
Measurement of thermal properties in nanoscale confined 2D materials are challenging our knowledge and techniques. We have investigated how these properties change as a function of sample number of layers for a range of 2D materials: graphene, MoS_2 and Bi_2Se_3. Using scanning thermal microscopy (SThM) and Finite Element method, we discuss the thermal conductivity dependence on multiple parameters.

Nanothermal conductance, 2D materials, interfacial properties, multiparametric studies.

Scanning thermal microscopy



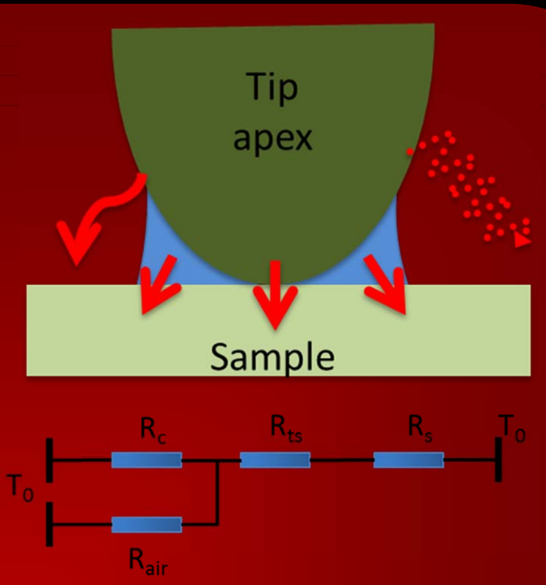
Scanning thermal microscopy (SThM) combines the nanoscale resolution of the AFM using a 50 nm Palladium (Pd) tip with local temperature measurements through resistance variations. The resistance of this Pd thin film is dependent upon temperature of the tip, $R(T) = R_0(1+\alpha(T-T_0))$, which in turn is related to the temperature of the sample.

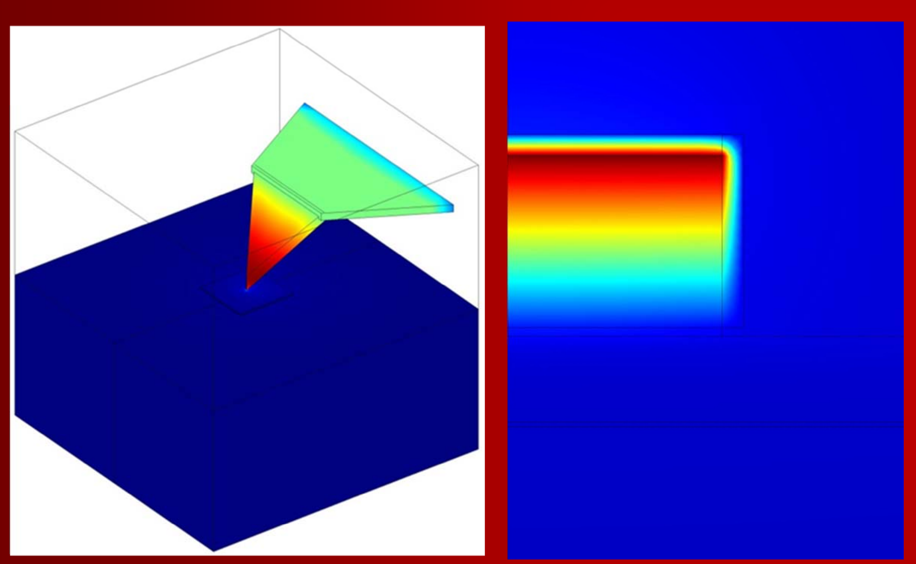


The tip resistance (and, correspondingly, its temperature) is measured with a modification of Maxwell bridge which is biased by a composite signal Vin = Vac + Vdc and balanced for both in-phase and out-phase components using resistors and capacitors.

Modelling heat transfer

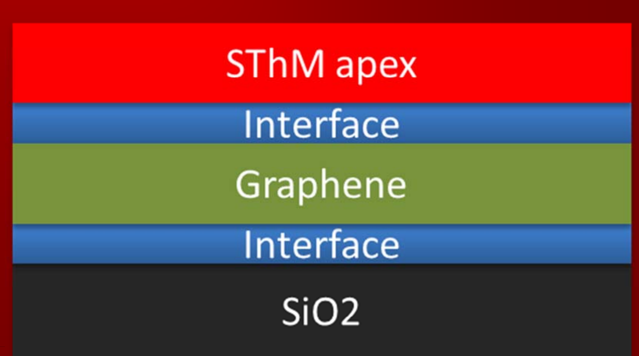
Understanding SThM requires the building of a heat transfer model between the tip and the sample. Several transfer channels need to be considered (radiation through air and air, liquid meniscus and mechanical contact conductions).



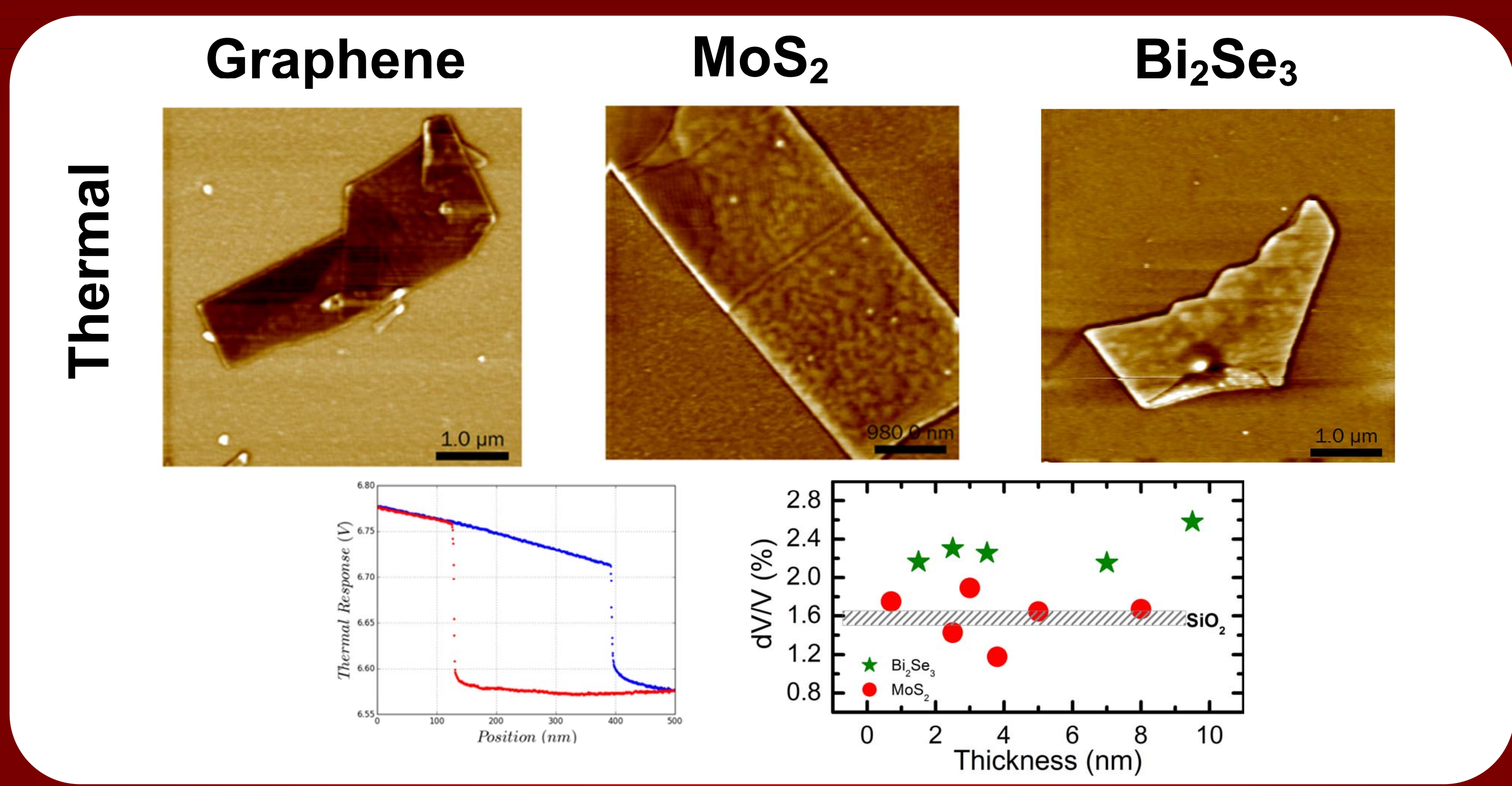


Finite element simulations of such a model were realized using a complete 3D geometry and a 2D axisymmetric one. COMSOL Multiphysics was used to compute Joule heating and heat transfer in a diffusive system created similar to our experimental set up. The temperature field as well as the electrical current were obtained and compared to experimental data.

An important feature of this model is to take into account the several interfaces that, as we show, governs the thermal response of the sample. Tip-sample interface and sample-substrate interface play a major role in thermal properties.



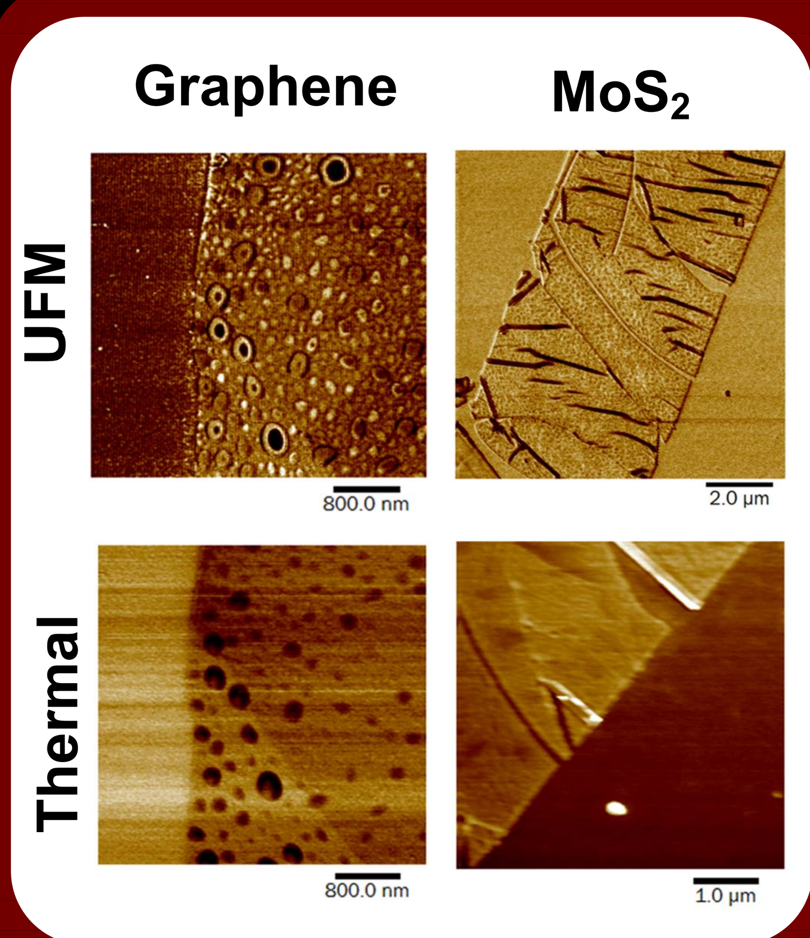
Mapping thermal conductivity of 2D materials



Graphene, MoS_2, Bi_2Se_3 were exfoliated onto 300 nm SiO_2 andflakes from monolayer to bulk identified by AFM topography measurements. Thermal probe was slowly bought into contact with the sample in the standard force spectroscopy way. A sharp snap-in to contact occurs when the gradient of attractive forces between sample and probe is greater than the spring constant of the cantilever. The gradient of the thermal response prior to snap-in is due to conduction through the narrowing probe-sample air gap.

Simultaneous thermal response of the SThM probe is monitored. For graphene we observe a lower thermal response than for the supporting wafer whereas MoS_2, and Bi_2Se_3 show a similar and an increased responses, respectively.

Interfacial challenges: multiparameters



With the help of Ultrasonic Force Microscopy (UFM), we performed multiparametric studies of our 2D materials. Probing the interfaces properties with UFM, that maps the surface stiffness and adherence, revealed the strong coupling between mechanical and thermal properties.

Nanoconfinement of 2D materials through ripples, bubbles or strain are strongly affecting the thermal conductivity at the nanoscale level and quantitative measurements are only coherent in this multiparametric vicinity.

Funding

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References

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2. Tovee, P. et al., Nanoscale spatial resolution probes for scanning thermal microscopy of solid state materials, Journal of Applied Physics, 2012, 112, 114317.