

Nanoscale mapping of elastic and thermal properties of graphene via scanning probe microscopy

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MOTIVATION

Exploration of **mechanical** and **thermal** properties of graphene with **nanoscale resolution**.

Why do we care about these properties?

Nano-mechanical and nano-thermal properties are vital for *functioning, preparation* and *stability* of any nanoscale device, *particularly* for graphene based ones

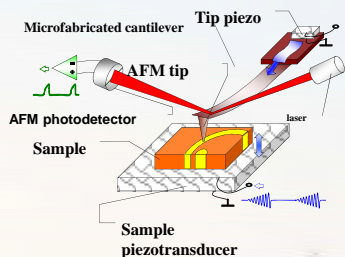
Poot, M. et al, *APL* (2008); Balandin, et al, *Nano Lett* (2008); Cai W et al, *Nano Lett.* (2010).

METHODOLOGY

Starting point is SPM (namely, AFM with a more universal feedback) combined with

NANO-MECHANICS

AFM + high frequency (ultrasonic, 2-100 MHz) vibrations = sensitivity to **nano-mechanics of solid state materials**:



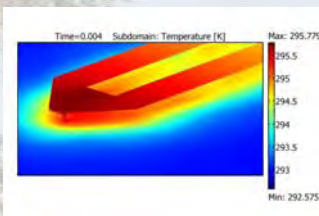
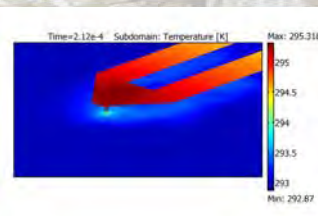
- Acoustic vibration at frequency $f \gg f_0$ cantilever resonance
- Cantilever becomes "infinitely" rigid at $f \Rightarrow$ ideal for indentation.

- Detect cantilever deflection at frequency $f_d \ll f_c$
- Cantilever then measures forces at low frequency where it is very soft \Rightarrow ideal for force sensing.

Kolosov and Yamanaka, *JJAP* (1993), Kolosov and Briggs, *Acoustic Microscopy*, (2010)

NANOSCALE THERMAL PROPERTIES

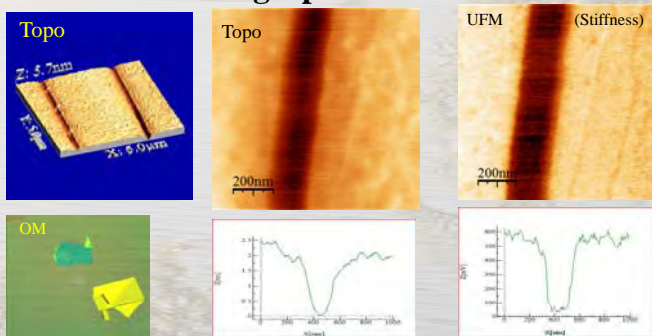
AFM + high thermal conductivity temperature sensitive nano-probes = SThM, thermal conductivity, self-heating of solid state nanostructures



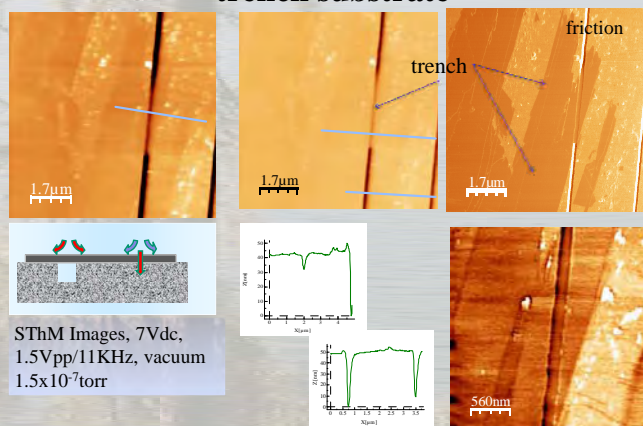
- In vacuum – predominantly end of the tip heats the material
- In ambient environment – heat transfer from the whole cantilever leads to significantly distorted results and decreased spatial resolution

Pumarol, Tovee and Kolosov Fall MRS (2010)

Graphene layer on trench – mapping local stiffness of graphene membrane



Single/bilayer suspended Graphene on ELITH trench substrate



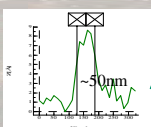
SThM Images, 7Vdc, 1.5Vpp/11KHz, vacuum 1.5×10^{-7} torr

Conclusions

- AFM + ultrasound (UFM) provided "ideal" nanomechanical probe for stiff materials exploring elasticity of suspended graphene (lateral resolution better than ~ 10 nm).
- HV Scanning Thermal Microscopy (SThM) indicated that thicker graphene layers have lower thermal resistance (lateral resolution better than ~ 50 nm).
- Suspended graphene layers showed lower thermal resistance than layers on substrate.

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Lateral resolution of thermal SiO2/Pd probe

