

## **Combined AFM, Raman and Tip Enhanced Raman studies of graphene with different number of layers**

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Graphene flakes (1,2,3 and 4 layers) on gold substrate are investigated by different AFM and spectroscopy techniques. We study in details how the thickness (number of monolayers) in graphene affects its physical properties: surface potential (work function), local friction, elastic modulus, capacitance, conductivity, charge distribution, Raman and Rayleigh light scattering etc. Results for graphene flakes are qualitatively compared to those for carbon nanotubes of different diameters. We show how electrostatic charging of graphene flakes can be effectively measured and modified by AFM cantilever. Studies are performed both in ambient air conditions and in controlled atmosphere and humidity.

We also present graphene measurements by Tip Enhanced Raman Spectroscopy (TERS) or “nano-Raman” mapping realized using integrated AFM-Raman system. We demonstrate near field Raman enhancement effect due to resonant interaction of light with localized surface plasmon at the apex of a metal AFM probe. Plasmonic and near field nature of the Raman enhancement is proven by a number of ways: dependence of the enhancement on the excitation wavelength and polarization, enhancement versus tip-sample distance curves, observation of selective enhancement of Raman signal from thin surface layers of the sample etc. Finally, the ultimate performance of TERS is demonstrated by measuring Raman 2D maps with *subwavelength lateral resolution* – determined not by the wavelength of light, but by the localization area of the surface plasmon electromagnetic field.

## Figures

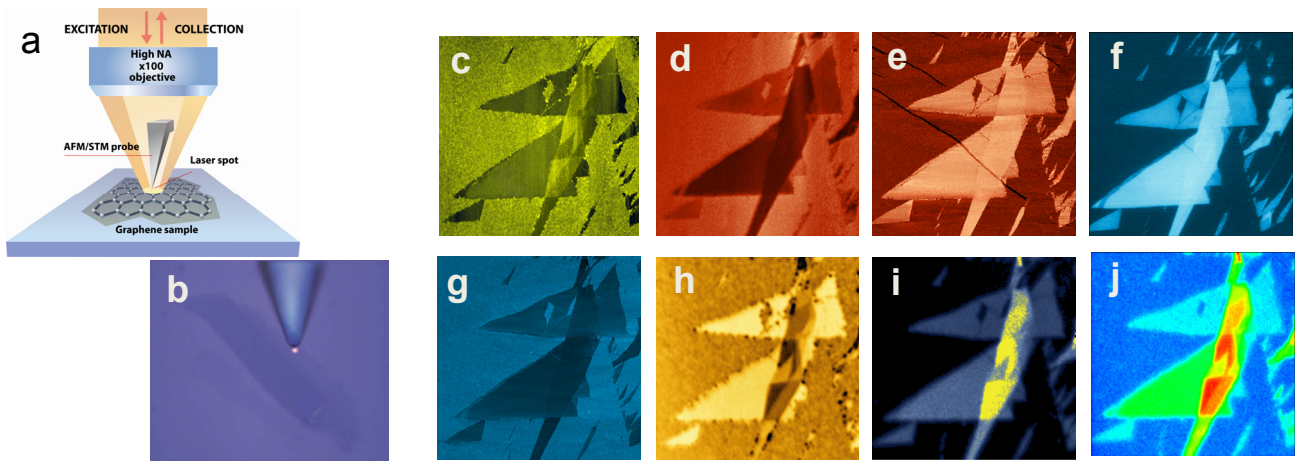


Figure Caption

a), b). AFM – Raman configuration: schematics (a) and white light image (b); Raman laser is tightly (400 nm spot diameter) focused onto the very end of a “nose”- shaped AFM cantilever using 100x objective; Graphene layer is positioned below the cantilever and under the laser spot; while scanning the sample, AFM and Raman data is obtained simultaneously.

c) – g). Various AFM images characterizing different physical properties of the sample - Topography (c), Electrostatic Force (d), Force Modulation (elastic properties) (e), Kelvin Probe (f), Lateral Force (g).

h) – j). Confocal optical images – Rayleigh light (h), Raman 2D band mass center (i), Raman G band intensity (j).