Probing electric polarization of nano-objects and biomolecules using scanning probe microscopy

Laura Fumagalli

laura.fumagalli28@gmail.com

Institut de Bioenginyeria de Catalunya (IBEC), c/ Baldiri i Reixac 15-21, Barcelona, Spain

Electric polarization, represented by the dielectric constant, ε_r, is an intrinsic property of matter that plays a crucial role in many fields, from materials science and information technology to biology. It is inherently linked to charge storage/transport, it influences light-matter interaction, and it allows for material identification. In biology, dielectric constant modulates the electrostatic interaction between biomolecules and it influences their shapes. In particular, it is key in DNA interaction with effector proteins, DNA bending, DNA packaging, etc. Yet, quantifying local dielectric properties at the nanoscale using scanning probe techniques has been a long-standing challenge because the dielectric signal of nano-objects is extremely weak, dominated by non-local contributions and tip/sample geometrical artefacts.

In this communication we will review our recent results using scanning probe techniques, namely, current-sensing atomic force microscopy (C-AFM) [1,2] and electrostatic force microscopy (EFM) [3,4,5]. By combining low-noise detection with quantitative numerical analysis of the tip-sample capacitance and capacitance gradient, respectively, we show that both techniques precisely measure the local dielectric constant with nanoscale lateral resolution.

By probing the dielectric constants of 10 nm-radius nanoparticles with *ultraweak* polarization forces (sub-picoNewton resolution) and using them as the fingerprints of the materials, we were able to recognize nano-objects of identical shape but different chemical composition [3], which would be impossible to distinguish from topography.

The long-range nature of polarization forces enabled us to identify the sub-surface material composition [3] and to experimentally resolve the dielectric constant of DNA [4] - remained unknown so far owing to the lack of experimental tools able to access it - in a natural condensed state inside single viruses. In contrast to the common assumption of low-polarizable behavior like proteins (ε_r r ~ 2–4), we found that the DNA dielectric constant is ε_r r ~ 8, considerably higher than the value of ε_r r ~ 3 found for capsid proteins. State-of-the-art molecular dynamic simulations confirmed our experimental findings, which result in sensibly decreased DNA interaction free energy than normally predicted by Poisson–Boltzmann methods [4].

Finally, dielectric quantification can also be extended to liquid environment [5], which will allow for the study of electrochemical and biological systems in liquid media.

References

[1] Fumagalli, L., Ferrari, G., Sampietro, M., Gomila, G. Appl. Phys. Lett. 2007, 91, 243110.
[2] Fumagalli, L., Ferrari, G., Sampietro, M., Gomila, G. Nano Lett. 2009, 9, 1604.
[3] Fumagalli, L., Esteban, D. Cuervo, A, Carrascosa, J.L., Gomila,G. Nature Mater. 2012, 11, 808.
[4] Cuervo, A., Dans, P.D., Carrascosa, J.L., Orozco, M., Gomila, G., Fumagalli, L. PNAS 2014, 3624
[5] Gramse, G.; Edwards, M. A.; Fumagalli, L, Gomila, G. Appl. Phys. Lett. 2012, 101, 213108.