Electro-mechanical Surface Properties by Force Microscopy

Neus Domingo[1]
[1]Institut Català de Nanociencia i Nanotecnologia, CSIC and The Barcelona Institute of Science and Technology, Campus UAB, Bellaterra, Barcelona 08193, Spain
Neus Domingo: neus.domingo@icn2.cat

There is a wide range of electromechanical phenomena that give rise to mechanical oscillation of an electrically biased AFM tip in contact with a surface as top electrode after *ac* electric excitation of the sample: from inverse piezoelectric effect in Piezoresponse Force Microscopy (PFM), to different chemo-electromechanical responses in the so-called Electrochemical Strain Microscopy (ESM). Their counterparts, that is, the generation of electrical signals after the application of mechanical strains and strain gradients with an AFM tip have also been proved, and it has been shown that it is possible to write ferroelectric domains [1] or to move oxygen vacancies and charges by applying strain gradients with and AFM tip.

PFM, born more than 20 years ago [2] as an indispensable imaging tool for nanoscale ferroelectric domains, has evolved to a wide set of advanced modes crucial for the discovery of new phenomena in polar materials, but beyond them, the same operating principles of PFM applied in a wider range of materials led to the appearance of new modes such ESM [3]. In this tutorial I will first discuss the technical aspects of PFM that remain common for most of the applications, along with the influence of electrostatic effects or mechanical tip-sample coupling among others, and then I will cover some advanced operation modes including resonance-enhanced imaging, spectroscopic and dynamic characterization modes. Then, I will overview all the fundamental electromechanical mechanisms present behind PFM and ESM image formation with their differential characteristics, embracing all possible intrinsic and extrinsic effects that need to be considered for a correct interpretation of the results. Finally, I will sketch recent applications to study emergent phenomena in nanoscale electromechanics, in which the AFM tip is complementary used to deliver strong mechanical strain and strain gradients.

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