Project no. NMP4-CT-2004-013684

FORCETOOL

Multipurpose Force Tool for Quantitative Nanoscale Analysis and Manipulation of Biomolecular, Polymeric and Heterogeneous Materials

Instrument:: **STREP**
Thematic priority: **NMP-3**

Publishable Executive Summary

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Project Organisation name: **Consejo Superior de Investigaciones Científicas (CSIC)**

Publishable Executive Summary

FORCETOOL (FT) proposes to develop a ***multipurpose tool*** for ***quantitative*** nanoscale analysis and ***manipulation*** of biomolecular, polymeric and heterogeneous surfaces. Key features of the proposed instrument are ***1 nm*** spatial resolution and ***1 pN*** force sensitivity; operation in ***technological*** relevant ***environments*** (air or liquids) and with ***no impact*** on the sample surface. The multifunctionality and flexibility of FT will enable characterization, control or manipulation of structures on a nanometer-scale, so it will open new approaches for manufacturing at molecular and nanoscale levels. This tool is based on two innovative concepts: (i) the bi-modal AFM and (ii) the multimaterial methodolody. The ***bi-modal AFM concept*** considers the cantilever as a three dimensional object with several resonance modes, in particular two. The concept ***departs radically*** from the ***established*** principles of ***dynamic force microscopy*** (only the fundamental mode is considered). The double excitation allows to separate topography from composition contributions in the experimental data. Furthermore, the ***bi-modal AFM*** is about ***two orders*** of ***magnitude*** more ***sensitive*** to force variations than state of the art ***tapping mode*** AFMs.

The ***multimaterial methodology*** will allow to transform the amplitude, frequency or phase shift changes measured by the instrument into quantitative information about the sample properties. The multimaterial methodology has both a ***general framework*** to describe dynamic force microscopy interactions and ***specific codes*** to be used with different materials such as inorganic materials, biomolecules, polymers or molecular architectures.

Specifically the key goals are:

Topography, composition analysis and manipulation of biomolecules, polymers and heterogeneous surfaces; operation in air or liquids so it will be compatible with industrial environments; 1 nm spatial resolution and 1 pN force sensitivity; compatible with existing atomic force microscopes, so an additional module could up-grade their capabilities.

Major Impacts: (1) FORCETOOL will develop a new multipurpose tool for quantitative nanoscale analysis and manipulation of heterogeneous surfaces in relevant technological environments (2). It will improve European competitiveness by establishing the technological and scientific foundations of the next generation of advanced scanning probe microscopes.

Consortium

The consortium brings together ***leading research*** groups in advanced dynamic force methods, synthesis of nanostructured materials, nanopatterning and manipulation methods, simulation and modelling of nano and meso-scale systems with *the world leader company* (an SME) in cantilever fabrication and a established SME in electronics and software design. The wide range of skills and competences needed to design and prototype the bi-modal AFM as well as to develop the multimaterial methodology explains the size of the FORCETOOL consortium (9 participants). The ***academic/research members*** of the consortium have a consolidated experience in transforming ***basic research results*** into ***technological implications*** (***six patents*** submitted in 2000-2004 period).

Two SMEs are involved in FORCETOOL. Nanoworld is the world leader on cantilever fabrication. It has a key role in FT: design and fabrication of tailored cantilevers for bi-modal excitation. Eldisa is a established company in electronics and software design. Its role is to design and fabricate the bi-modal control unit.

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Achievements

Progress has been made in the two pillars of ForceTool, the development the **bi-modal AFM** operation and the development of a flexible, robust and **multimaterial methodology**.

Bimodal AFM. We have designed, manufactured and tested several bi-modal AFM excitation/detection prototypes. The new AFM have successfully imaged proteins (antibodies) in air and liquid environments. We have extensively characterized the performance of the instrument under different excitation forces (mechanical and electrostatic), cantilever types, and different samples, such as biomolecules, polymers and layered nmaterials. The force sensitivity of the instrument is about 0.2 pN, i.e., a factor 10 better than conventional tapping mode AFM.. We have demonstrated that the bimodal AFM concept is compatible with existing AFMs and with nanotomography methods. A multiscale theoretical approach have been applied to understand bimodal AFM operation. This approach has involved continuous modeling, finite element simulations and analytical approaches. The analytical model identifies the virial and the energy dissipated by the tip-surface forces as the parameters responsible for the material contrast. The agreement obtained among the theory, experiments and numerical simulations validates the model.

We have also demonstrated that monomodal operation at higher modes and/or harmonics renders high resolution images of biological membranes and virus capsids in liquids. We have also shown that higher harmonics imaging is also compatible with molecular recognition process.

Multimaterial Methodology. We have developed a method to identify the mechanism of energy dissipation at the nanoscale. The method requires the determination of the energy dissipated on the sample surface as a function of the oscillation amplitude while the tip approaches the surface. The representation of the dissipated energy and, in particular, its derivative with respect to the amplitude, dynamic-dissipation curves hereafter, characterizes the dissipation process. Three different nonconservative processes were studied: surface energy hysteresis, viscoelasticity and long-range dissipative interfacial interactions. The method is being applied to characterize the organization of thin polymer films.

Multiscale theoretical simulations have also provided insight into the relationship between forces, molecular re-orientations and energy dissipation processes. We have performed a combined experimental and multiscale theoretical approach to establish the atomistic origins and hence the contrast, of the dissipative processes occurring in phase-imaging. First-principle simulations show that the configuration space sampled by the tip depends on whether the tip approaches or withdraws from the surface. The quantitative agreement obtained between simulations and experiments demonstrates that the above asymmetry is the origin of the observed contrast. The asymmetry arises because the presence of energy barriers among different bonding configurations.

Expected Impact

FORCETOOL has developed a *multipurpose tool* for *quantitative* nanoscale analysis, *manipulation* and *morphological characterisation* of polymers, biomolecules and heterogeneous surfaces in general. The instrument requires both a new concept in advanced scanning probe microscopy methods (the bi-modal AFM) and a new methodology to transform dynamic force microscopy measurements into material properties (multimaterial methodology). Breakthroughs in FORCETOOL will primarily contribute to establish an European technological sector in the manufacturing of advanced tools for high resolution imaging and manipulation at the nanoscale. Furthermore, FT multidisciplinar approach will contribute to develop a general platform for addressing scientific and technological issues at the nanoscale in fields as diverse as coatings manufacturing, biosensors applications (health) or new manufacturing processes based on organics (organic electronics).