Nanometer Structures
Room 308 - Session NS-WeM

Nanomechanics
Moderator: N.A. Burnham, Worcester Polytechnic Institute

8:20am **NS-WeM1 Dissipation in Few Atom Systems**, ***J. Pethica,*** University of Oxford, UK **INVITED**

9:00am **NS-WeM3 Quantitative Imaging of Local Electromechanical Properties of Ferroelectric Surfaces by Piezoresponse Force Microscopy**, ***S.V. Kalinin,*** Oak Ridge National Laboratory*; J. Shin,* University of Tennessee*; A.P. Baddorf, J.F. Wendelken,* Oak Ridge National Laboratory*; M. Kachanov, E. Karapetian,* Tufts University

Piezoresponse Force Microscopy has become the primary tool for the characterization of ferroelectric materials at nanoscale dimensions. Application of a periodic bias to the AFM tip in contact with the surface results in surface oscillations due to an inverse piezoelectric effect. These are detected with a lock-in amplifier to produce PFM amplitude and phase images. Special attention has been attracted to the potential of this technique for local spectroscopic measurements, i.e. the local electromechanical hysteresis loop of the material. Application of a dc bias or force to the tip can switch the local polarization, opening possibilities of PFM as a nanolithographic tool. Despite extensive effort, a detailed understanding of PFM imaging, including tip induced mechanical and electrostatic phenomena inside the ferroelectric, has not previously been achieved. Here, the analytical solution of the coupled electromechanical problem for piezoelectric indentation is used to derive the electric field and strain distribution inside the ferroelectric material, providing a complete continuum mechanical description of the PFM imaging mechanism. These solutions are used to quantitatively interpret PFM spectroscopic measurements and bias- and stress-induced domain behavior. It is shown that the dielectric gap formation at the tip surface junction due to surface contamination significantly affects the PFM imaging mechanism. Preliminary results of PFM imaging under controlled atmosphere and UHV conditions are presented.

9:20am **NS-WeM4 Evaluating Nanocomposite Strength at Individual Nanotube-Polymer Interfaces**, ***S.R. Cohen,*** *A.H. Barber, C.A. Cooper, H.D. Wagner,* Weizmann Institute of Science, Israel

Nanocomposites formed from carbon nanotubes have been proposed as an ultra-high strength material. Although bulk measurements of the properties of such nanocomposites support these claims, until this work the only direct microscopic investigation of the nanotube/polymer interfacial strength has been by theoretical predictions. We have developed two novel SPM-based techniques which measure, for the first time, the direct pull-out forces of individual nanotubes in a polymer matrix.@footnote 1@ In one approach, the nanotubes are mixed into an epoxy resin using a procedure which results in a porous structure with nanotubes bridging the pores and embedded into the polymer matrix. The SPM tip is used to drag these nanotubes out of a film formed by microtoming this structure. The force exerted is extracted from the SPM measurement, whereas embedded length is measured with the aid of TEM. In the second approach, a nanotube attached to an SPM probe is pushed into a polymer melt, and pulled out from the hardened polymer after cooling. Here, the SPM measurement is used to evaluate both the forces and embedded length. Our results verify the predicted high nanotube-polymer interfacial strength, and reveal trends correlated to fiber diameter and embedded length. @FootnoteText@ @footnote 1@ (a) Carole A. Cooper, Sidney R. Cohen, Asa H. Barber, and H. Daniel Wagner Appl. Phys. Lett. 81, 3873-75 (2002); (b) Asa H. Barber, Sidney R. Cohen, and H. Daniel Wagner Appl. Phys. Lett. (June, 2003) .

9:40am **NS-WeM5 Mechanics at the Nanoscale**, *T. Uchihashi, M. Higgins,* Trinity College, Ireland*; J.E. Sader,* E.T.S. Walton Visitor, Trinity College, Ireland, Australia*;* ***S.P. Jarvis,*** Trinity College, Ireland **INVITED**

Atomic force microscopy (AFM) evolved from the observation of the effects of mechanical contact in the scanning tunnelling microscope. Thus, even from its first inception, nanomechanics and atomic force microscopy have been inextricably linked. Whilst not all mechanical phenomena have been intentional or welcomed in AFM measurements there has also been a concerted effort to apply AFM to the investigation of mechanics at the nanoscale. Due to its highly localised measurement ability, the microscope can be applied to characterise the mechanical response of materials too laterally specific to be investigated by Surface Forces Apparatus or nano-indentation devices. For example, measuring mechanical responses with a probe of lateral dimensions comparable to that of a single molecule provides an invaluable insight into the processes controlling if and how a molecule approaches another molecule or a membrane and how mechanical property variations in any intervening fluid can modify that interaction. We introduce a significantly modified AFM which includes the ability to control the force sensor directly via a magnetic field in order to make sensitive dynamic measurements and direct stiffness measurements. In addition, to isolate the measured interaction to the tip apex we have used a multiwalled carbon nanotube attached to the tip. For the extension of the method to include lateral activation, and hence open up the possibility of measuring local viscosity, a new shape of cantilever has been used. To understand the mechanics of our new force sensors we have employed finite element analysis (FEA) to assess and improve the design and for calibration.

10:20am **NS-WeM7 Nanomechanics of Cytoskeletal Proteins**, ***J.G. Forbes,*** NIAMS, NIH, DHHS*; K. Wang,* LMB, NIAMS, NIH, DHHS

Striated muscle is the primary source of biomechanical force in organisms from worms to man, and can be thought of as a composite material that is organized on several length scales. The motor protein in all muscles is myosin, which generates piconewtons force through its interaction with actin and the hydrolysis of ATP. The tiny force generated by a single myosin is amplified by aggregating large numbers of myosin heads into an ordered structure called the thick filaments. The thick and thin filaments are then assembled into the basic contractile machinery called the sarcomere that link serially from one end of the muscle cell to the other. Striated muscle shortens by the sliding of actin filaments as they are dragged towards the center of the myosin filaments. When muscle relaxes, its original length is restored elastically. An array of cytoskeletal proteins are required to regulate the size, assembly and function of the sarcomere, as well as transmit force and provide elasticity for restoring the structure. One such protein is the giant protein titin (3-4E6 g/mol), which spans half of the muscle sarcomere length. The passive elasticity of muscle at a physiological range of stretch arises primarily from the extension of titin. Nebulin serves as a ruler for the actin filaments and may alter their compliance and tensile strength. Other proteins such as dystrophin help transmit force out of the muscle and desmin forms intermediate filaments, which help to stabilize the sarcomere organization. We have studied the elastic properties of these motor and cytoskeletal proteins via force spectroscopy with the AFM. We have found that the elasticity of proteins can arise from mechanisms other than simple entropic elasticity. These mechanisms work at the nanoscale and may allow for their properties to be fine tuned to fit the need of muscle to work under a variety of conditions. These insights from biology may allow for the engineering of more effective elastic materials.

10:40am **NS-WeM8 Effect of the Ionic Strength on a Natural Lipid Bilayer Assembling and Stability: A Force Spectroscopy(nanomechanical) Study**, ***S. Garcia-Manyes,*** *M.J. Kogan, F. Sanz,* University of Barcelona, Spain*; D. Ludevid,* CSIC, Spain*; E. Giralt,* University of Barcelona, Spain

Lipid bilayers have been widely studied on account of their biological interest regarding cell characterization, membrane protein transport, etc. In the last recent years many studies have been focused on the study of such membranes using Atomic Force Microscopy, since it gives chemical and topographic information in the nanometer scale. Some of these studies dealt with lipid deposition on flat substrates such as mica, silica or graphite either in the form of Langmuir-Blodget films or after bilayer self-assembling. Some of these lipid surfaces have been used to support proteins in order to study lipid-protein interaction or to test new drugs. Most of these studies used synthetized bilayers for the a priori sake of reproducibility and simplicity in their chemical composition. In these work we present novel results concerning the study of a natural plant bilayer membrane formation under physiological conditions. By using force spectroscopy we demonstrate that solution ionic strength is crucial in the self-assembling process and that small variations in ionic strength give rise to huge variations in bilayer compactness. There is a threshold ionic strength under which bilayers are not self-assembled, connected with the charge repulsion between the hydrophilic charged heads of the molecule. As the ionic strength is increased the charge repulsion seems screened out and the assembling process achieved, and this is reflected in a discrete jump in the force plot. The force at which this break takes place (the so-called yield point) is highly influenced by the own magnitude of the ionic strength, and ranges from ~ 1.5 nN at 10 mM to ~ 9 nN at 1 M. A nanomechanical study concerning the elasticity of the bilayer, as well as an

evaluation of the forces that take place (double layer, hydration forces, Van der Waals, etc.) is also included.

Author Index

Bold page numbers indicate presenter

— B —
Baddorf, A.P.: NS-WeM3, 1
Barber, A.H.: NS-WeM4, 1
— C —
Cohen, S.R.: NS-WeM4, **1**
Cooper, C.A.: NS-WeM4, 1
— F —
Forbes, J.G.: NS-WeM7, **1**
— G —
Garcia-Manyes, S.: NS-WeM8, **1**
Giralt, E.: NS-WeM8, 1
— H —
Higgins, M.: NS-WeM5, 1
— J —
Jarvis, S.P.: NS-WeM5, **1**
— K —
Kachanov, M.: NS-WeM3, 1
Kalinin, S.V.: NS-WeM3, **1**
Karapetian, E.: NS-WeM3, 1
Kogan, M.J.: NS-WeM8, 1
— L —
Ludevid, D.: NS-WeM8, 1
— P —
Pethica, J.: NS-WeM1, **1**
— S —
Sader, J.E.: NS-WeM5, 1
Sanz, F.: NS-WeM8, 1
Shin, J.: NS-WeM3, 1
— U —
Uchihashi, T.: NS-WeM5, 1
— W —
Wagner, H.D.: NS-WeM4, 1
Wang, K.: NS-WeM7, 1
Wendelken, J.F.: NS-WeM3, 1