Mechanical Properties and Thermodynamics of a Nanometric Column of Water Molecules

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Water is one of the most important substances of life and has been studied extensively for hundreds of years. Nonetheless, it is still quite a unique material that keeps surprising us and exhibits peculiarities, in particular, when confined in a nanometric configuration. For example, water and simple organic liquids exhibit solidlike orderedness in molecularly thin films [1]. Water molecules inside hydrophobic nanotubes manifest phases of ice that are not found under bulk conditions [2]. However, since bulk water possesses only short-range order and water molecules move incessantly, it is usually difficult to experimentally investigate novel features of confined water structures other than thin films.

To overcome this problem, we have employed an atomic-resolution amplitude-modulation atomic force microscope (AFM) in air [3], Fig. 1, and achieved the spontaneous formation of a nanometric liquid column consisting of thousands of water molecules. We also have performed the sensitive measurement of the elastic property (or the force gradient) of the thin water column during its mechanical stretch [4]. We have thereby demonstrated several novel phenomena (Fig. 2): (i) unusual stepwise decrease of the force gradient, associated with the atomic-scale stick slip on the AFM-tip surface, (ii) abrupt rupture of the thin water meniscus due to the thermodynamic instability of the liquid-vapor interface, and (iii) mechanical manipulation of the thin aqueous column by repeated stretch-relaxation cycles, revealing the atomic scale contact angle hysteresis.

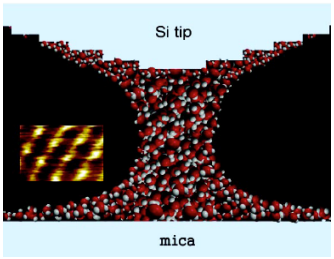

FIG. 1. Experimental schematics of a high sensitivity AFM setup operating in ambient conditions. The inset shows an atomic-resolution AFM image of a dry and clean mica substrate, obtain--ned at a modulation-amplitude change of 5% (scan area: 1.5nm×1nm) [3].

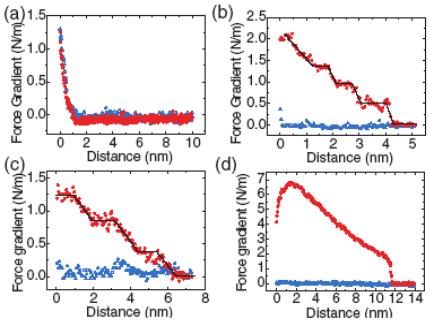

FIG. 2. Measured values of the force gradient of the water meniscus as a function of its elongation at a given RH of (a) 2%, (b) 15%, (c) 31%, and (d) 45%. The approach and retraction speed is 0.15 nm/s. The black solid line in (b) and (c) is a guide to the eye.

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