Theory of Amplitude-Modulation Dynamic Force Spectroscopy

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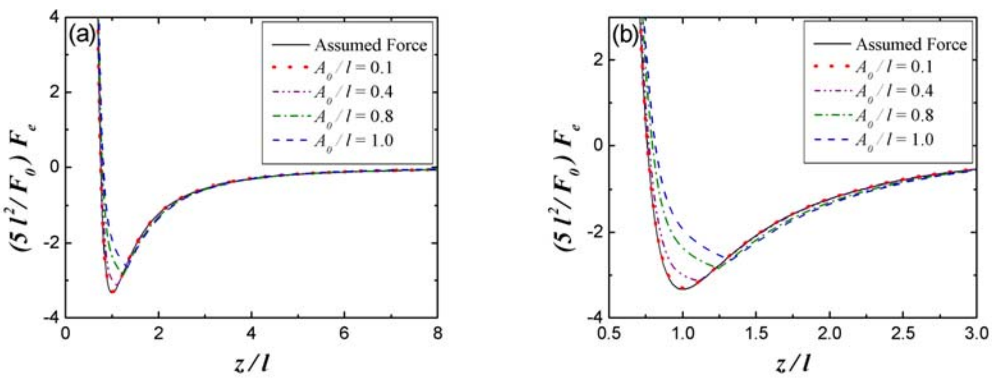
Atomic force microscopy (AFM) is usually operated in two different modes; amplitude-modulation mode (AM-mode) and frequency-modulation mode (FM-mode). While both of them have proved to be powerful imaging tools, they also can be used in measuring interaction forces between tip and sample. In FM-mode the methods to determine tip-sample interaction are well developed. Sader and Dürig proposed the force formulae for FM-mode [1, 2], which are used in imaging inter-atomic structures of a single tungsten atom [3]. In AM-mode, on the other hand, there was only average tip-sample force formula presented by San Paulo and García [4]. They obtained just average interaction force for given amplitude without getting the force itself. The absolute determination of the interaction force in AM-mode, widely used in air or liquid environments, can have many applications to quantitative analysis of interfacial surface phenomena such as nano-scale friction, adhesion hysteresis, capillary meniscus, etc.
We derived force formulae to determine absolute value of force for AM-mode under the small oscillation amplitude condition, which is indeed necessary for stability of a sample body to be measured including soft materials, biological systems, and capillary meniscus. For obtaining necessary amplitude condition to give exact force we examined our force formulae according to the method that Sader et al. used [1]. We first assume a tip-sample interaction force, evaluate the resulting amplitude change and phase shift from the equation of motion analytically, and then reconstruct tip-sample force using our force formulae. Frame (a) and (b) (close-up plot of the (a) near z/l=1) show the assumed force and reconstructed forces as a function of tip-sample distance z for various free oscillation amplitudes A_0's. For the case of A_0/l=0.1, good agreement is found between the reconstructed and assumed interaction forces. This shows that the tip-sample interaction force can be obtained precisely from our force formulae if the magnitude of free oscillation amplitude is smaller than the characteristic length scale l for the interaction by one order of magnitude.



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