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QUANTITATIVE MEASUREMENT OF TIP-SAMPLE INTERACTION FORCES IN TAPPING MODE ATOMIC FORCE MICROSCOPY

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In Tapping Mode Atomic Force Microscopy (TM AFM), the cantilever oscillates around its resonance frequency and the tip interacts with the sample surface intermittently during each cycle. It is important to know the tip sample interaction forces to both prevent sample damage (Fig. 1a) and determine the true height of the sample surface (Fig. 1b). However, in TM AFM the nonlinear tip sample interaction cannot be estimated from harmonic motion of the cantilever [1].

There are analytical and numerical studies to predict tip-sample interaction forces during TM AFM imaging [2]. The experimental studies on measuring tip-sample interactions are done by modifying the cantilever shape to extract the tip sample interactions during imaging [1]. However, an experimental study for measuring the tip sample interactions using conventional AFM cantilevers in TM AFM is missing.

In this paper, we introduce a new and rather simple experimental method for measuring the tip sample interaction during imaging in TM AFM (patent pending [3]). In this method, the tip sample interaction forces are measured directly from the surface, using a micro cantilever as a force sensor which acts as a sample surface at the same time. The proposed method can handle all types of AFM cantilever.

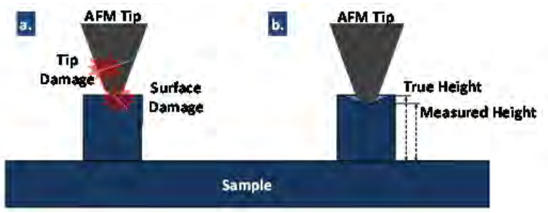

Fig. 1: Surface and/or tip damage during imaging (a) or hindering the true height measurement of sample structures (b).

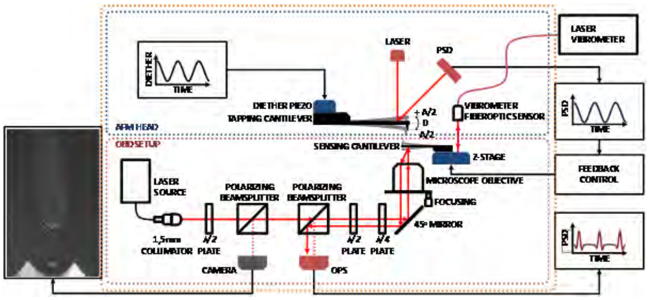

Fig. 2: Schematic representation of the experimental setup for measuring the tip-sample interaction forces in TM AFM.

Thus, in the proposed method, imaging cantilever engages the sensing cantilever's surface instead of a sample surface. The sensing cantilever is chosen to have a much higher first eigen frequency as compared to the imaging cantilever. The sensing cantilever will deflect due to the tip sample interaction forces during each tap and restore its initial position after each tap. The effective spring constant of the sensing cantilever, at the point where the imaging cantilever is engaged, is calibrated. It is easy to extract the tip sample interaction forces from the sensing cantilever by measuring the deflection of the sensing cantilever.

The experimental setup is designed and realized as shown schematically in Fig. 2. An Optical Beam Deflection (OBD) is designed to measure the deflection of the sensing cantilever with high sensitivity. The AFM head can be positioned independently from the OBD setup so that the imaging cantilever can be positioned on top of the sensing cantilever as depicted in Fig. 2. A z-stage is designed to position the sensing cantilever vertically and the motion of the z-stage is calibrated using a vibrometer. The z-stage is controlled by the AFM feedback electronics and the imaging cantilever is kept engaged with sensing cantilever's surface.

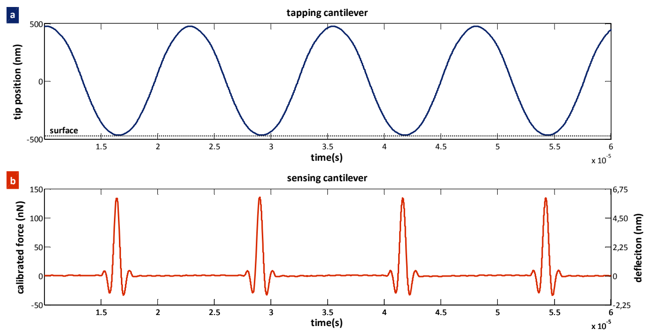

Fig. 3: The motion of the imaging cantilever is recorded simultaneously (a) with motion of the sensing cantilever (b). The time varying nanomechanical forces acting on the sample surface (b) is measured when the imaging cantilever is engaged with the sensing cantilever in tapping mode.

The motion of the imaging cantilever and the sensing cantilever is recorded simultaneously when the imaging cantilever and sensing cantilever are engaged in TM as shown in Fig. 3a and Fig. 3b respectively. The sensing cantilever deflects due to the tip sample interaction forces. In TM AFM, measured tip-sample interaction forces are impulse like functions with a periodicity equal to the excitation frequency.

There are two important parameters set by the operator in TM AFM imaging, amplitude ratio and excitation frequency. The amplitude ratio is the ratio between the oscillation amplitude in free air and oscillation amplitude when the imaging cantilever is engaged with sample surface. The maximum repulsive force between the tip and the sample surface is known as the reason for surface or tip damage. We have theoretically (Fig. 4a) and experimentally (Fig. 4b) investigated the trend of the maximum repulsive force with respect to amplitude ratio and drive frequency.

The experimental results on the trend in maximum repulsive force show a good match with the theoretical expectations. The maximum repulsive force changes a lot with respect to the change in the drive frequency. The maximum repulsive force gets almost 10 times higher when the excitation frequency is changed from 99% of the first eigen frequency to 101%.

In conclusion, The present method can be used for measuring the tapping forces with respect to different imaging parameters such as excitation frequency, oscillation amplitude, or cantilever shape. The experimental results on trend in the forces can be used to prevent surface damage, to increase the tip lifetime and to determine the true height of surface structures.

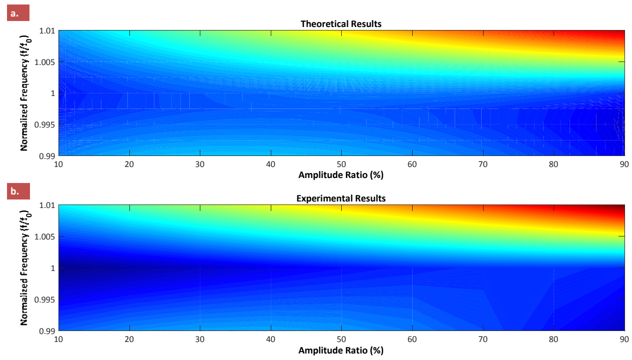

Fig. 4: The trend in the maximum tip sample interaction force is calculated (a) and measured (b) with respect to amplitude ratio and frequency ratio. Using this information from the results, we can tune the force and do lithography (d) on SiO_2 surface (c) using diamond tip.

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