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INTERACTIONS OF QUARTZ TUNING FORK OF ATOMIC FORCE MICROSCOPE OPERATING UNDER SHEAR-FORCE AND TAPING MODES

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Quartz tuning forks have been in recent years successfully implemented in force detection schemes for scanning probe microscopy applications. When properly operated, the shear and friction force sensor allows detecting a sample surface at distances of few nanometers away from it. Research of contact and frictional interaction of surface is very important in micro electromechanical systems. We present an experimental investigation of normal and shear force interactions at the nanometer scale using quartz-crystal tuning fork operating in shear-force and tapping modes in atomic force microscope. Measurements made with different material groups showed that the force affects in two scan modes of the system on quartz tuning fork under dynamic operation mode.

Introductions

Since the mid-1990s, a variety of non-optical tip–sample distance control methods have been developed for improving the sensing sensitivity, true atomic resolution images or for increasing the scanning rate. Most of these schemes are based on a shear force detection mechanism [1, 2]. The main advantage of the shear force sensor is directly applicable to straight optical fibers, simplifying the light coupling. And one of the successful schemes uses crystal quartz tuning fork as a shear force sensor [2], allowing a remarkably high sensitivity in air due to its high mechanical quality factor *Q*. Other approaches are based on vertical force detection [3, 4] similar to the tapping mode in atomic force microscopy. In these force detection schemes, the fiber tip oscillates vertically above the sample with amplitude of a few nanometers, touching the sample intermittently. In this way, the destructive lateral forces are practically eliminated, allowing imaging of softer biological samples in liquid.

In addition, the use of quartz tuning forks in atomic force microscopy (AFM) [5] has been gaining favor as a means for achieving ultrahigh resolution images at room temperature. Like piezo resistive cantilevers, quartz tuning forks are self sensing and do not require the use of optical detection methods. These quartz crystals have been successfully used under various conditions.

In this paper, however, we only report on the preparation, setup and research on shear force sensor in shear-mode and force interactions in taping-mode of a quartz tuning fork for atomic force microscopy (AFM). Its specific features, measurement results and their effects on stability and sensitivity are discussed in correlative force curves of

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a commercial quartz tuning fork driven in tapping mode and shear mode with an AFM tip. In order to improving, several test samples were investigated in amplitude, in phase signal feedback and in dynamic force spectroscopy.

Experimental setup

A standard operational amplifier circuit is used to convert the net current to a voltage (Fig. 1) [6]. The current to voltage (*I –V*) gain of the circuit has been calibrated from dc to 400 kHz. Sweeping the driving frequency f and simultaneously recording the corresponding induced voltage V, we can obtain the relationship between the frequency (f) and the output voltage (V). Under the resonant condition, the tuning fork arm has the biggest displacement that corresponds to the maximum or peak output voltage amplitude in f–V curve. Thus, the resonant frequency can be determined. The lower op-amp in Fig. 1 is not always necessary. However, it is present in order to cancel currents from stray capacitance (Co and other capacitance from wires). The upper current-to-voltage converter will sense both the piezoelectric currents from the tuning fork oscillation and these additional stray currents. The lower op-amp *(I- V)* converter allows us to subtract stray currents by adjusting the variable capacitor away from the resonance.

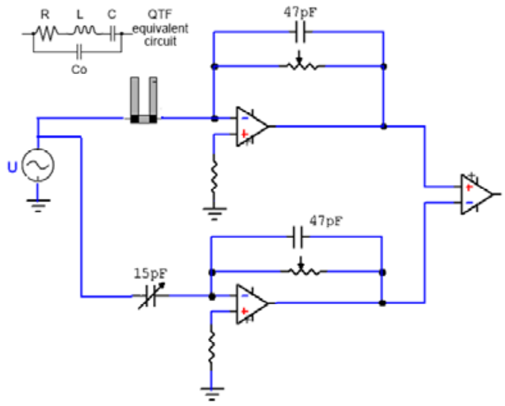

Fig. 1. Essential features of tuning fork sensing system and the equivalent circuit. Current through the tuning fork is converted to a voltage by an op-amp (OA). When the tip is attached to the tuning fork, the admittance due to Co can become a significant fraction compared to the RLC branch of the equivalent circuit

The commercial quartz tuning forks (QTF) used in our experiment have a nominal resonant frequency of 32768 (~ 2^{15}) Hz. As supplied in a small vacuum can, we have measured their quality factor to be Q ~ 90000. In air the Q drops to about 10000, and the resonant frequency is about 32768Hz-32900Hz. A commercial cantilever AFM tip was glued to the end of the side surface (Fig. 2 b) of the tuning fork prong for tapping-mode operation or the AFM tip was attached to the end of the prong (Fig. 2 a) for shear-mode operation. The tips used were commercial Contact silicon cantilever CSC21/15 chips produced by MicroMasch company [7] that have six straight cantilevers of different lengths. The mass of the AFM cantilever tip was so small that the reduction in the quality factor, amplitude resonant curve as well as the resonance-frequency shift of the fork was very small (both changes were less than 1 %).(Fig. 3)

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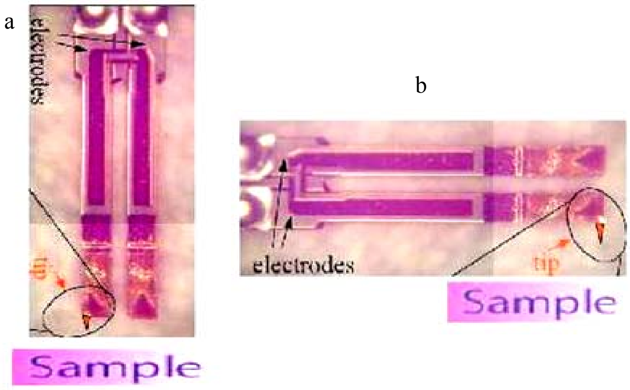

Fig. 2. Schematic principle of taping mode and shear-mode with quartz tuning fork in AFM

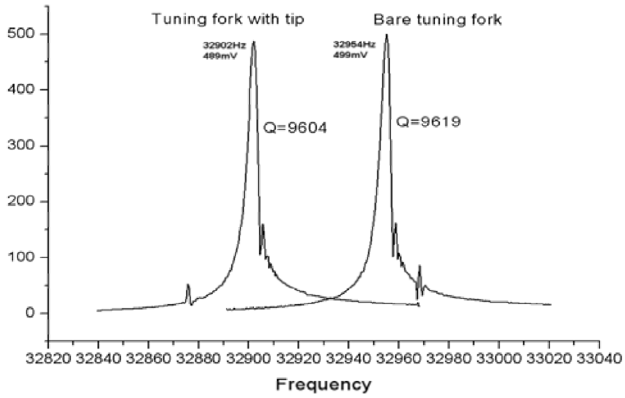

Fig. 3. Spectrum resonant frequency of quartz tuning fork before and after mounting commercial AFM tip

And the file was formed of the target data. For the three-dimensional image: amplitude-frequency-distance, a DFS-Spectrum (Fig. 4).

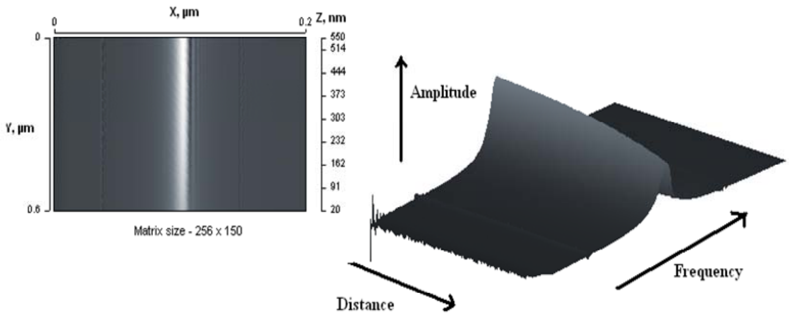

Fig. 4. The 2D, 3D-image of the measured data of dynamic force microscopy

Results and conclusions

In the taping and shear-force mode experiments, the distance separation between the tip and the surface is decreased until an interaction is detected. At this moment, the sensor controller and the frequency detector are replaced by a Lock-in amplifier. The

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Lock-in is then used to give a constant amplitude stimulation to the tuning fork and at the same time to record the amplitude *A(ω)* out of the tuning fork while the stimulation frequency is being swept around the resonance frequency.

Figure 5 a shows the resonance curves for different interaction in taping-mode. First, as reference, a resonance curve is recorded when the tip is still far from the surface i.e., some micrometer. At this distance there are no interactions between the tip and the surface, thus, the resonance curve for free oscillation is obtained. As expected, a frequency shift is observed. The frequency decreases corresponding to an attractive force due to the capacitive coupling between the tip and the sample. When approaching and have contact between the tip and sample, the resonant frequency and amplitude are changed suddenly. The broadening of the curve is surely due to an increase of the dissipation.

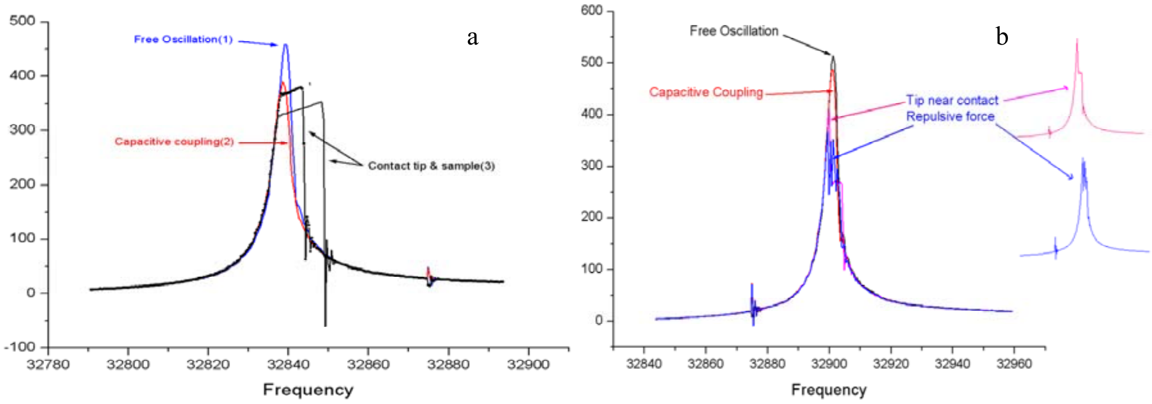

Fig. 5. Spectrum resonant curves for force interactions (a) Taping mode (b) Shear mode

In shear-mode, when the distance between the tip and sample decrease, the resonant frequency and amplitude reduce, but the shape of the resonant curve not change suddenly as taping-mode (Fig. 5 b). However, when the tip near the sample (not contact), the peak resonance is not sharp, and appears a row of peaks overlap another. It is evidence that in the shear-mode, the AFM tip in the prong of tuning fork is easily broken in scanning for photograph.

In all the resonance curves, an asymmetry is present. This asymmetry is due to the fact that a tip and the glue are stickled in one prong of the tuning fork, thus, breaking its symmetry. This asymmetry causes a coupling between different modes of the tuning fork, thus changing the resonance curve.

For researching dynamic force spectroscopy, three types of samples were considered: surface of silicon, plastic fibre, and sample of hologram. The results of account of force taping-mode and shear-mode are given in Fig. 6.

We have investigated the shear force and interaction force occurring at the interface between a probe tip and surface in dynamic mode operation of tuning fork on two scan modes. For the tip-surface combinations chosen, from the data and modeling presented, one can choose active regimes as: input signal, resonant frequency, or set point for scanning topography, for comparable results.

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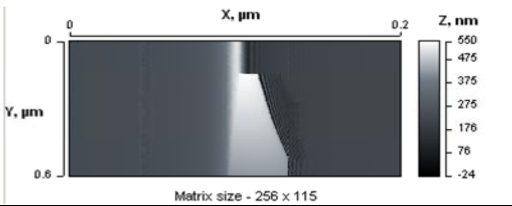
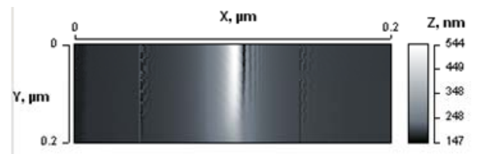
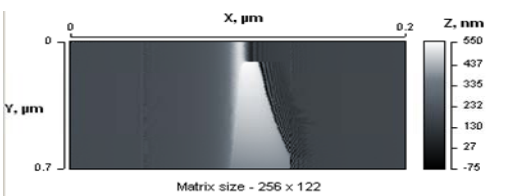
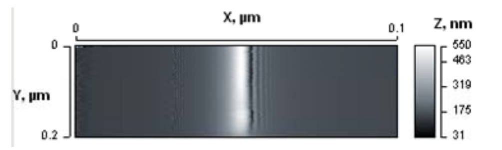
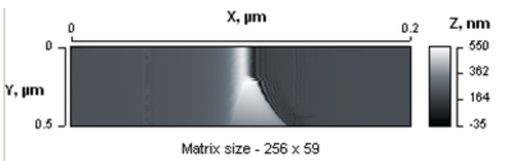
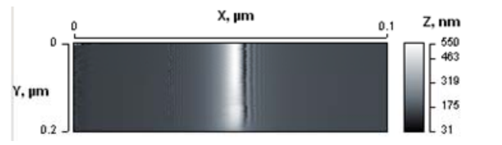
Sample	DFS spectrum (Taping-mode)	DFS spectrum (Shear-mode)
Silicon		
Plastic fibre		
Hologram		

Fig. 6. Results of force interactions of quartz tuning fork of atomic force microscope operating under taping and shear-force modes

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