Solution to homework No. 4 (Based on week 4 lectures)

1. When approaching the sample in FM-AFM, the frequency shift at a gap of $Z$ can be described by the following relationship described in weeks 2 and 4:

$$\omega'_0(Z) = \omega_0 - \omega_0 \frac{V_{ts}(Z,A)}{kA^2}$$

Or

$$\frac{V\omega'_0(Z)}{\omega_0} = -\frac{V_{ts}(Z,A)}{kA^2} = -\frac{1}{k\pi A} \int_{-A}^{+A} k_{ts}(Z+q) \sqrt{1-\left(\frac{q}{A}\right)^2} \, dq \quad (*)$$

where $k_{ts}(d) = -\frac{\partial F_{ts}}{\partial d}$

and $q = A \sin \theta$

One graphical interpretation of the integrand is shown below as the area swept under the conservative tip-sample interaction force gradient curve swept out by the oscillating tip but weighted but a semi-circular shape (shaded) representing the function $\sqrt{1-\left(\frac{q}{A}\right)^2}$ centered at $Z$.

We are interested in measured the frequency shift vs $Z$ in an FM-AFM approach curve to a surface. By examining the equation (*) and using the geometric interpretation of the integrand shown above, how would the measured frequency shift vs $Z$ curve depend on the constant oscillation amplitude at which the data are acquired?

a. At a given $Z$ separation, a frequency shift is larger for larger oscillation amplitude and smaller for smaller oscillation amplitude, as a result large oscillation amplitudes are necessary for improving the sensitivity of topography scans in FM-AFM.

b. At a given $Z$ separation, a frequency shift is larger for smaller oscillation amplitude and larger for smaller oscillation amplitude, as a result small oscillation amplitudes are necessary for improving the sensitivity of topography scans in FM-AFM.
c. At a given Z separation, a frequency shift is larger for smaller oscillation amplitude and larger for smaller oscillation amplitude, as a result large oscillation amplitudes are necessary for improving the sensitivity of topography scans in FM-AFM.

d. The frequency of an oscillator does not depend on oscillation amplitude so that the resonance frequency shift at a given Z should be independent of the oscillation amplitude.

Answer:

It helps to think of this problem in the following manner. Imagine that the oscillation amplitude A is extremely small, nearly 0. In this case the weighting function is basically like a Dirac Delta function centered at Z and the integral term is effectively equal to the local force gradient $k_{ts}$ at Z. As the oscillation amplitude increases the weighting function would make it so that the integral is a weighted average of $k_{ts}$ encountered in the oscillation cycle. The integral would then integrate over some gradients larger than the one at Z and some gradients smaller than the one at Z, and on the whole the integral would change little as the amplitude increases. On the other hand the term outside the integral is inversely proportional to the amplitude A and thus the frequency shift is largest when the oscillation amplitude is as small as possible. Since the topography feedback uses the frequency shift, the larger the frequency shift at a given Z, the more sensitive the topography measurement. Hence the correct answer is (b).
2. Which of the following is false about a Quartz tuning fork AFM probe?
   I. It can be excited electrically or mechanically
   II. Its deflection can be measured electrically or optically with a laser
   III. It can be used with both tines free to vibrate or by anchoring one tine as in the Q-plus sensor
   IV. A wide range of tuning fork stiffness is commercially available comparable with the stiffness range of commercial Silicon cantilevers
   V. It natural frequency is very stable with respect to temperature

Answer:

Quartz tuning forks are usually orders of magnitude stiffer (1000-10,000 N/m) compared to commercial Silicon cantilevers (10-100N/m). The correct answer is (d).
3. Consider the following statements

I. In FM-AFM the property contrast channel is the dissipation or drive amplitude channel while in AM-AFM the phase contrast shows material property contrast

II. In FM-AFM the property contrast channel is the frequency shift channel while in AM-AFM the phase contrast shows material property contrast

III. In FM-AFM the topography is identical to that acquired using AM-AFM

IV. Many more true atomic resolution images have been taking in vacuum conditions using FM-AFM than with AM-AFM

Which of the above are true?

a. I only
b. II and III only
c. III only
d. IV only
e. II and IV only
f. I and IV only

**Answer:**

The answer should be fairly clear based on the discussion of these modes in the lectures.