Probes and Forces in Amplitude Modulation (aka Tapping) Mode

In most popular oscillatory mode - amplitude modulation with phase imaging (AM-PI) the instantaneous tip-force is related to the probe spring constant in a complicated way that requires a solution of integral equations describing the probe interactions with the sample in the frame of Euler-Bernoulli approach. In this mode, the probe is driven in oscillation at the first flexural mode and the drop of the amplitude from initial level (A_0) to set-point level (A_{sp}) caused by tip-sample interaction is used as a measure of tip-sample forces, which is applied to the Z-servo for imaging procedure.

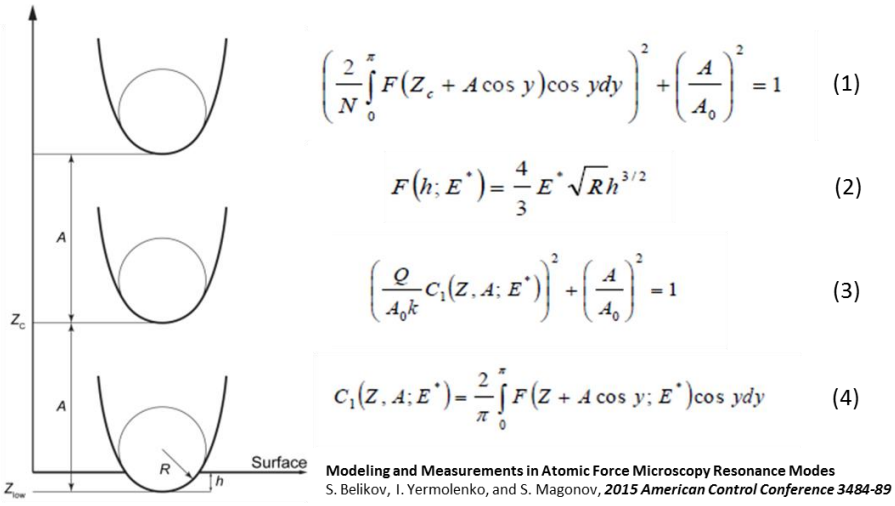

Figure 3. A sketch of the tip-sample contact in AM-PI mode and equations applied for calculation of maximal force and maximal deformation in tapping cycle. A – the probe amplitude; Z_c – central position of the tip apex; Z_{low} – low position of the tip apex; h – sample deformation, R – the tip radius; F – tip-force, E^* - elastic modulus of a sample.

In the simplified conservative case the solution of Euler-Bernoulli equation is represented by Eq. (1) in **Figure 3**. Using Hertz model in Eq. (2), the expression will change to Eq. (3) with C_1 defined by Eq. (4). The equation (3) was applied to find A for given $Z_C = Z$ and E^*. This was followed by calculating $Z_{low} = Z - A$, $h_{max} = \max\{0, -Z_{low}\}$ and F_{max} using Eq. (2). The results of such calculations for the probe interacting with samples having elastic modulus 0.1 GPa, 0.5 GPa, 2 GPa and 10 GPa are presented in **Figure 4**.

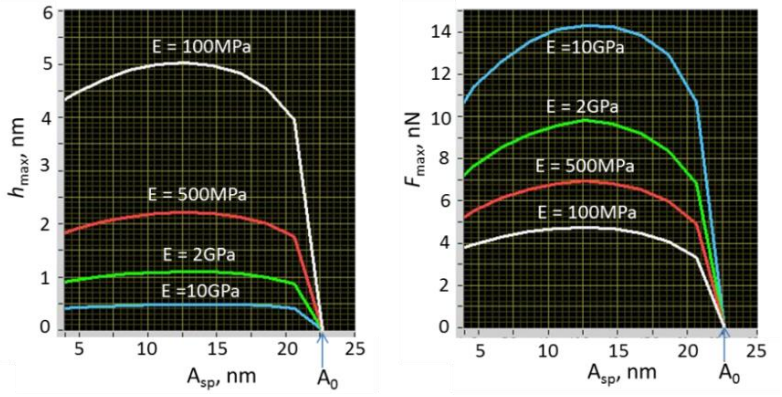

Figure 4. Graphs of maximal deformation and force at different A_{sp} in AM mode for samples with various moduli.

These calculations show that maximal force at sample deformation depend not only on the spring constant and A_0 and A_{sp}, but also on elastic modulus of the sample. Similar estimates of tip-sample forces, which can be achieved using the probes with various spring constants, are presented in **Figure 5**.

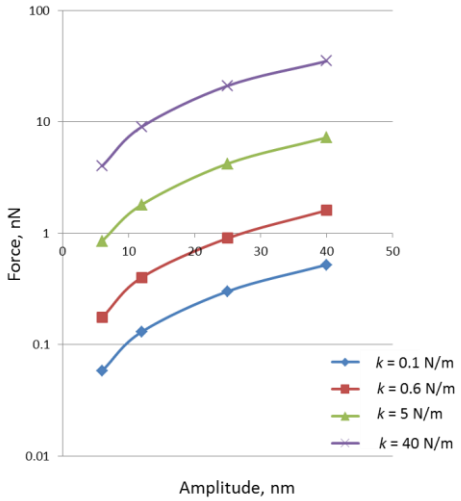

Figure 5. Dependence of tip-force at different set-point amplitudes for probes with spring constants 0.1 N/m, 0.6 N/m, 5 N/m and 40 N/m.

The presented graphs illustrate that the chosen probes complement each other and cover the 0.06 – 35 nN force range that is broad enough for AFM imaging in AM-PI mode. **Table 2** (see below) presents the relevant Si probes that can satisfy the needs of the users of this mode.