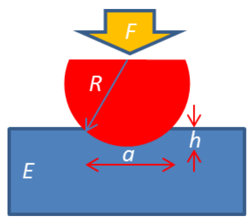
Probes and Forces in Contact Mode and Related Techniques

A cantilever deflection is a measure of the force experienced by the tip and the sample in contact mode during permanent tip-sample contact and also in dynamic contact (non-resonant) modes (Pulsed Force, PeakForce, Hybrid, etc). The same parameter is used for topography profiling in techniques associated with contact mode: contact resonance, force modulation, conducting AFM and piezo-response force microscopy - PFM. In these modes, the cantilever deflection (Δx) that changes the angle of the reflected laser beam in the optical beam deflection scheme, which is used in most AFM instruments, is a direct measure of the tip-force (F) defined as $F = k \times \Delta x$, where k - spring constant of the probe. So, the probe spring constant is vital for finding the tip-force, which is sensed by the cantilever bending from the initial rest level - Δ_0 to the set-point level Δ_{sp}. A simple analysis of the tip-sample indent in contact mode is shown in **Figure 1**. A deformation (h) and contact radius (a) characterize an interaction between a probe with radius R and sample with elastic modulus E caused by force F.



$$a = \left(3RF/2E\right)^{1/3}$$
$$h = \left(2F^2/E^2R\right)^{1/3}$$

Figure 1. A sketch describing the tip-sample interaction in contact mode.

The estimates using the relationships in **Figure 1** show how the sample deformation and contact radius are changing at forces of 1 nN, 10 nN and 30 nN on samples with elastic moduli of 0.1 GPa, 3GPa, 10GPa, and 30GPa, **Figure 2a-b**.

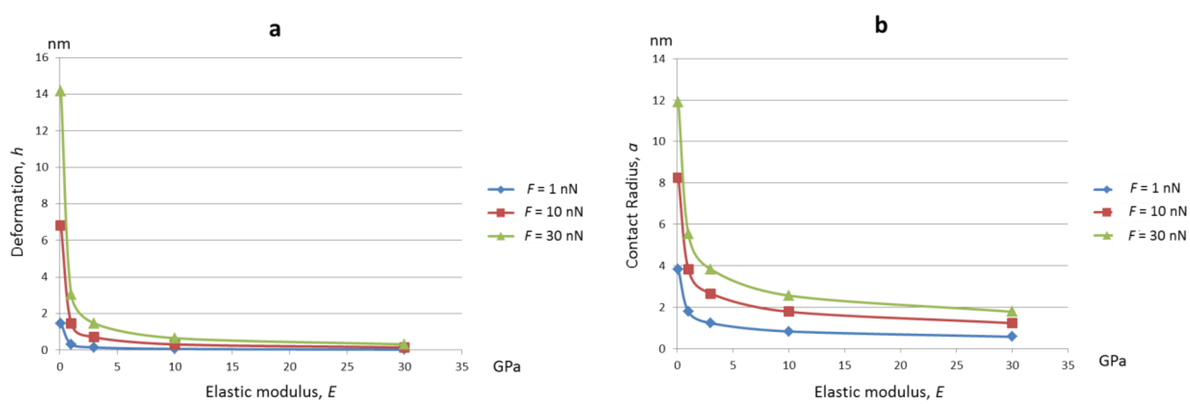


Figure 2a-b. Deformation-versus-elastic modulus (**a**) and contact radius –versus- elastic modulus (**b**) curves calculated for forces of 1 nN, 10 nN and 30 nN.

It is natural that the use of 1 nN force for AFM studies of polystyrene (E = 3 GPa) provides a minimal deformation (below 1 nm) and small contact radius (~1 nm) – both factors leading to the gentle and high-resolution imaging. Much smaller forces should be applied to examine soft samples with modulus less than 100 MPa. These requirements can be achieved using the probes with spring constants < 1 N/m.

For studies of soft samples in contact mode we suggest to use either Si 450/50/1 probes or rectangular Si_3N_4/Si probes: 100/35/0.6; 200/35/0.6 and 100/35/0.2. These probes, whose nominal characteristics are listed in **Table 1** (see below), cover a broad range of tip-sample forces in contact mode as their spring constant gradually changing from 0.01 to 0.7 N/m. By clicking the tabs in the "Calibration; Images" column you can get examples of the probe calibration and AFM images recorded with these probes. The calibration is made using thermal tune data obtained with the DCC accessory. The data include a power spectra density plot of the probe Brownian motion, which shows several Eigen modes; the enhanced view on the 1st Eigen mode curve showing its resonant frequency, Q-factor and calculated spring constant *k* (Sader model) and inverse optical sensitivity - IOS. The latter is estimated in the non-contact way - a useful alternative for getting the same characteristics by measuring it with force curves (deflection-versus-distance) on a hard substrate. In contact mode the force can be adjusted by setting Δ_{sp} close to Δ_0 (low force) or larger than Δ_0 (high force). A conversion of the cantilever deflection to the force can be complicated by adhesive and long range attractive interactions of electromagnetic origin. The total cantilever deflection from its rest level is caused by additive resultant of the attractive and repulsive forces. This should be taken into account in the quantitative estimate of the tip force and tip-induced deformation of an examined sample. Additional force minimization is often reached by imaging in water where meniscus force is eliminated.