How Non-Contact AFM Works

Cantilever characteristic resonant frequency
A cantilever vibrates naturally at this resonant frequency
Non-contact AFM uses detection of a cantilever's resonant frequency as an indirect measure of sample topography.

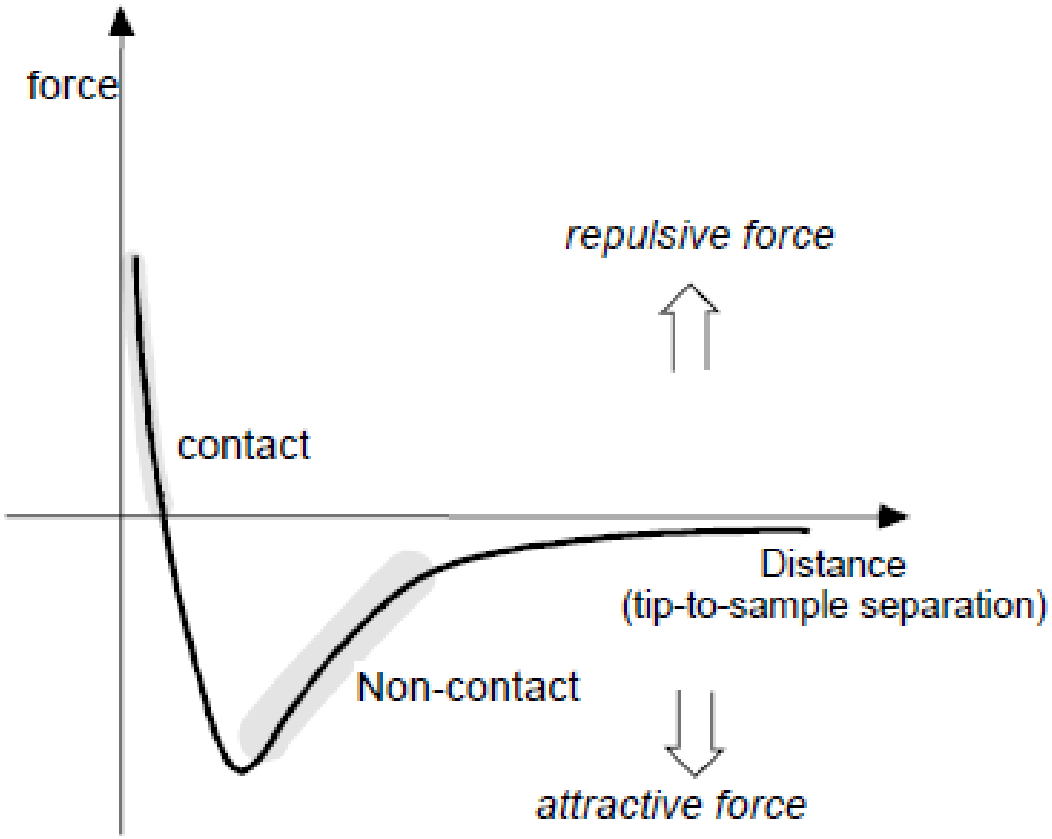

Figure: An interatomic force vs. distance curve, which illustrates the force between atoms on a cantilever tip and atoms on a sample surface vs. the separation distance between the tip and the sample.

- the “contact” regime:

  - less than a few angstroms, which represents the tip-to-sample spacing for contact AFM
  - the interatomic forces are repulsive

- the “noncontact” regime:

  - ranging from tens of angstroms to hundreds of angstroms, which represents the tip-to-sample spacing for NC-AFM
  - the interatomic forces are attractive

The total force between the tip and the sample in the non-contact regime is very low, generally about 10^{-12} N. Advantageous for studying soft or elastic samples.

Contact regime is several orders of magnitude greater. Cantilevers used for NC-AFM must be stiffer than those used for contact AFM.

NC-AFM signal small, and therefore difficult to measure. AC detection scheme is used for NC-AFM operation.

Resonant frequency of the cantilever and variations in sample topography. The resonant frequency of a cantilever is the square root of its spring constant, k, divided by its mass, m:

$$\omega = \sqrt{\frac{k_{eff}}{m}}. \qquad (1)$$

The spring constant is written as k_{eff}, the effective spring constant, because the spring constant of the cantilever changes as the cantilever moves into close proximity (within a few hundred angstroms) of the sample surface and interatomic forces affect its behavior.

The spring constant changes when the force between the tip and the sample has a spatial gradient. For a force gradient f', the effective spring constant is given by the following expression:

$$k_{eff} = k - f' \qquad (2)$$

An oscillating cantilever is brought near a sample surface, the force gradient experienced by the cantilever increases, and its resonant frequency decreases.

If the resonant frequency of a cantilever shifts, then the amplitude of cantilever vibration at a given frequency changes. Near a cantilever's resonant frequency, this change is large.

If the curve shifts to the left, for example, then there is a change (in this case, a decrease) in the amplitude of cantilever vibration at a given frequency (f*).

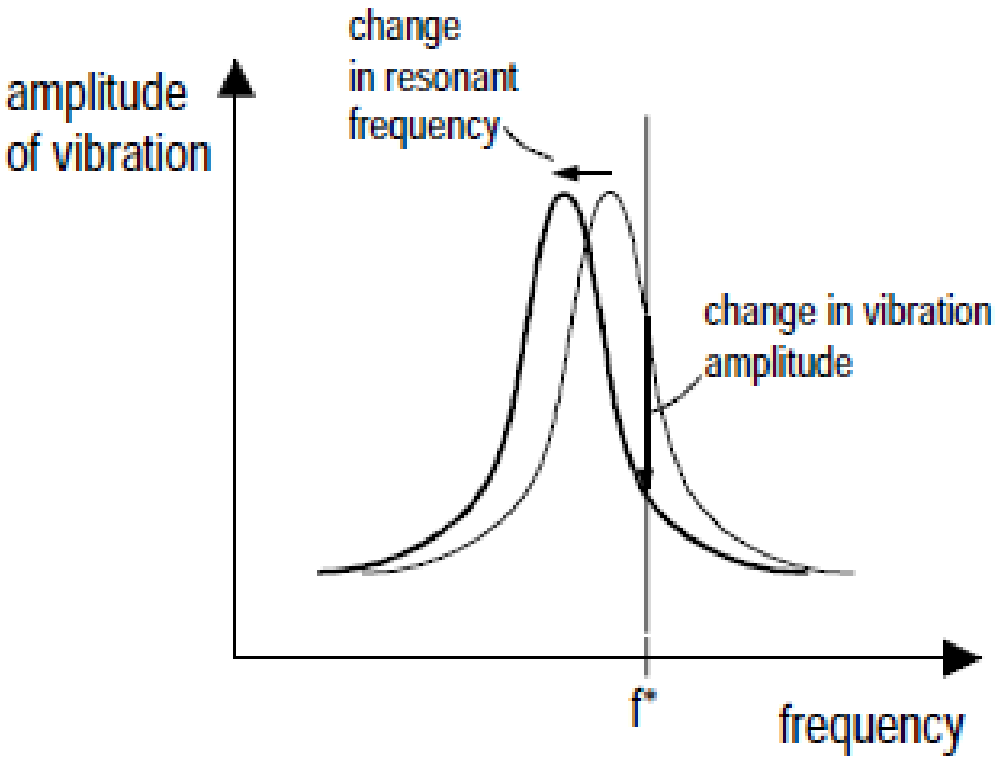

Figure: Response curves for a cantilever, showing a decrease in vibrational amplitude at f = f* for a decrease in cantilever resonant frequency.

This shift in amplitude, associated with a shift in resonant frequency, is the basis for the amplitude modulation (AM) measurement technique to detect changes in a cantilever’s resonant frequency.

Non-contact AFM mode, a drive frequency close to, but greater than, the free-space resonant frequency of the cantilever is selected so that the vibration amplitude decreases significantly as the cantilever is brought closer to the sample surface. These amplitude changes reflect the change in the force gradient acting on the cantilever, which in turn reflects changes in the tip-to-sample spacing. A feedback mechanism operates to maintain constant cantilever vibration amplitude by adjusting and restoring the tip-to-sample spacing during a scan. The amount of scanner z movement necessary to maintain the tip-to-sample spacing (i.e., to maintain a constant force gradient, for the case of NC-AFM) is used to generate an image of topography.

How Intermittent-Contact AFM Works

The underlying principles for intermittent-contact AFM are the same as those for noncontact AFM. The difference is that for IC-AFM the cantilever is driven (forced to vibrate) at a fixed frequency close to, but less than, its free-space resonant frequency, as shown in Figure below.

Because the drive frequency is just below the free-space resonant frequency, the vibration amplitude of the cantilever increases as the cantilever is brought closer to the sample surface, and intermittent contact is consequently achieved.

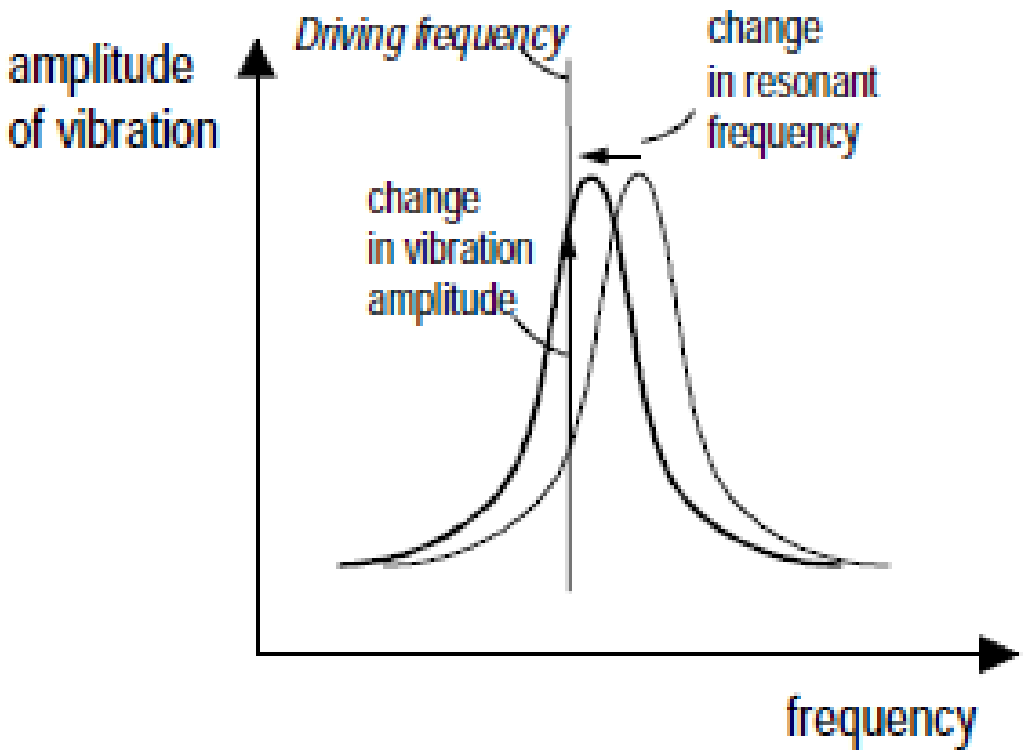

Figure: Response curve for a cantilever for IC-AFM mode, showing an increase in vibration amplitude at the drive frequency for a decrease in cantilever resonant frequency.

Hardware Components for Non-Contact Imaging

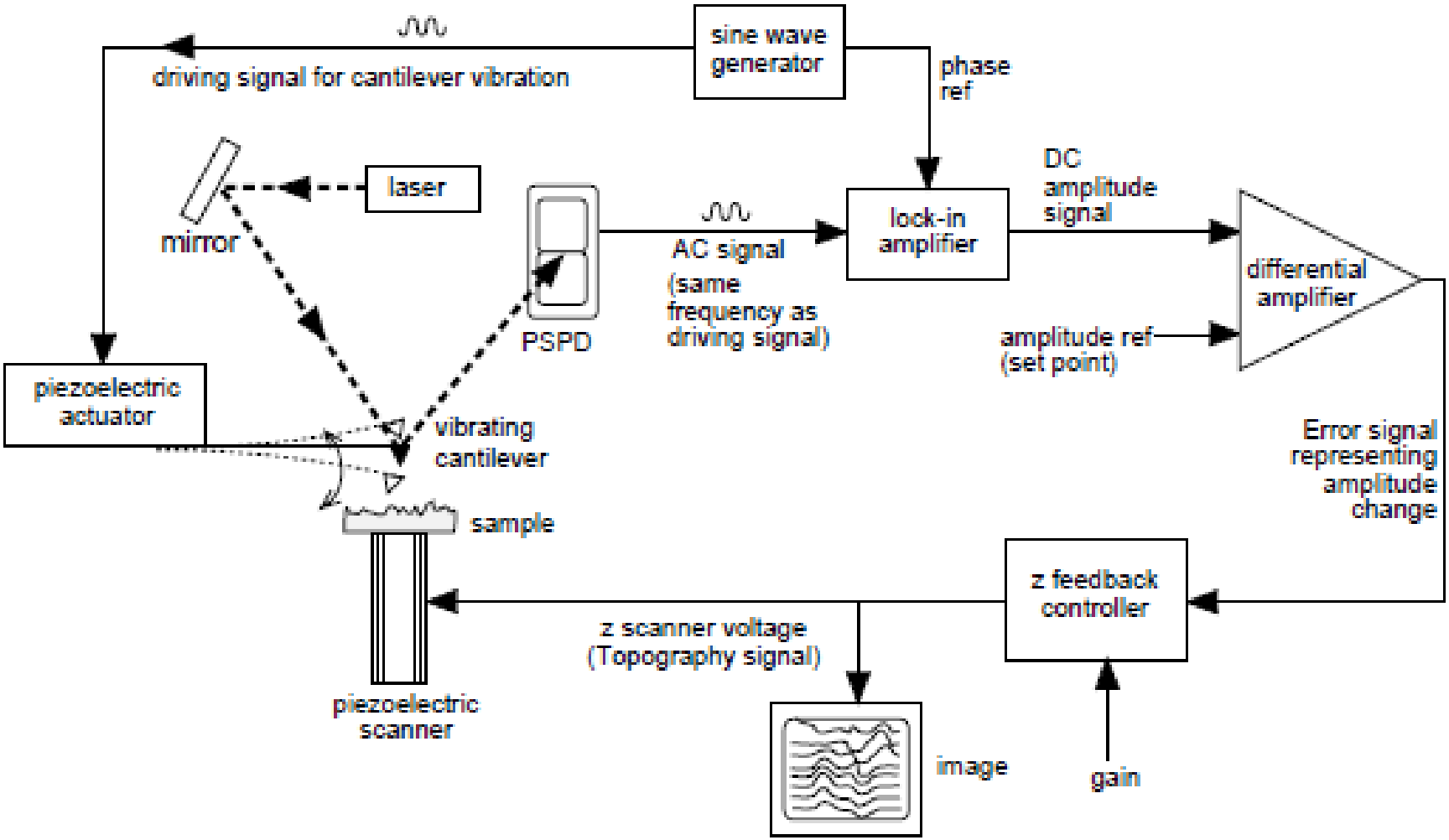

Figure: Simplified diagram of the non-contact system which applies to NC-AFM, IC-AFM, and MFM.