Chapter 8
Artifacts in SPM

The ideal tip is a sharp needle which can image surface features with high aspect ratios. If the tip has a broader shape artifacts occur due to a convolution of the tip shape with the surface features. Other kinds of artifacts in scanning probe microscopy include thermal drift, feedback overshoot, piezo creep, and electrical noise.

8.1 Tip-Related Artifacts

The most common artifacts in scanning probe microscopy occur due to the tip shape. Topographic features which have a larger aspect ratio than the tip are not imaged correctly. The acquired image is a convolution of the probing tip shape and the sample topography. Due to this effect, topographic features are broadened and measured corrugation amplitudes can be reduced. In extreme cases, if sharp asperities are present on the surface the tip shape is imaged by the surface asperities. The principle of how the tip shape influences the image of a sharp surface feature is shown in Fig. 8.1a. A sharp asperity on the surface is only imaged properly with an equally sharp (or sharper) tip.

An example of this is shown in Fig. 8.1b, where carbide clusters with a high aspect ratio are imaged on a Si surface. Each carbide cluster is imaged as a small high protrusion surrounded by a much larger "halo". All clusters appear with the same shape, which is the shape of the tip. In the image in Fig. 8.1c, we can see that the tip form changes during the image acquisition. In the upper part of the image the carbide clusters appear larger due to a blunt tip, while the tip changes to a somewhat sharper shape in the middle of the image. This occurred during a tip-sample contact. Traces of this are visible in the left part of the image. However, the tip shape is still not ideal in the lower part of the image, as higher clusters are imaged as three protrusions, due to the tip shape, as indicated by arrows in Fig. 8.1c. Generally, if all (or many) features on the sample have the same shape, or if all the features have an elongated shape in the same direction this is an indication of a blunt tip which is "imaged" by the surface.

B. Voigtländer, *Scanning Probe Microscopy*,
NanoScience and Technology, DOI 10.1007/978-3-662-45240-0_8

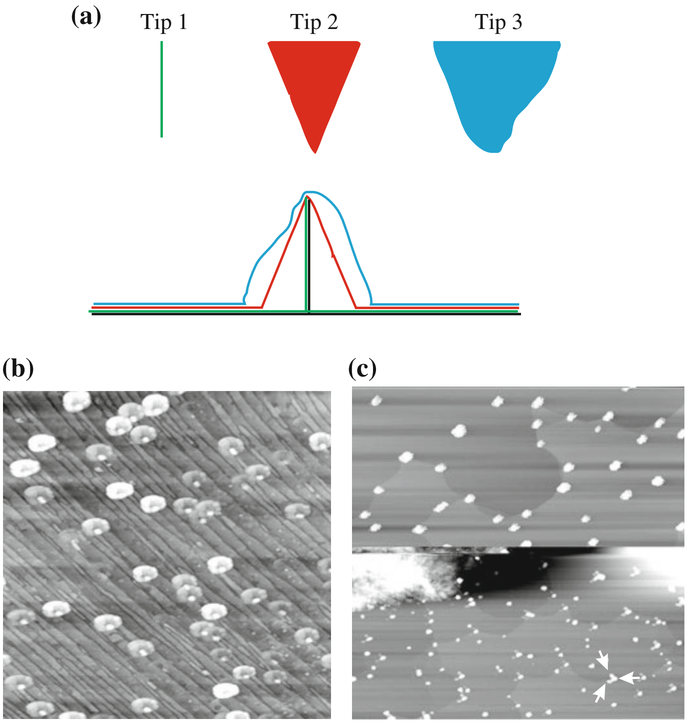

Fig. 8.1 **a** Sketch of the principle of how the tip shape influences the image of a sharp asperity present on the surface. **b** Example in which high aspect ratio carbide clusters are imaged by a blunt tip. All imaged clusters have a similar apparent shape: the tip shape. **c** Image of carbide clusters showing a change of the tip shape in the middle of the image

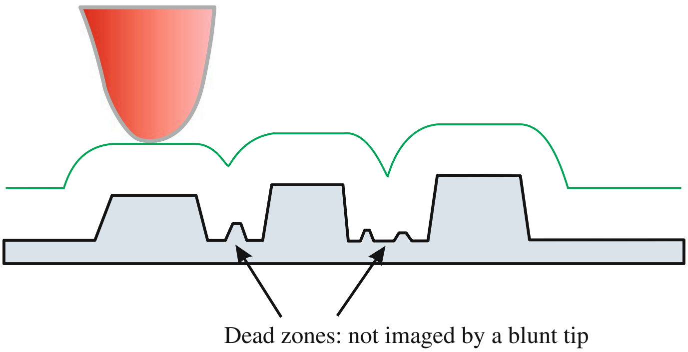

Fig. 8.2 Schematic showing the occurrence of "dead zones" due to the blunt shape of the tip

As a rule of thumb, all topographic features which have a radius of curvature smaller than the radius of curvature of the scanning tip, are not imaged properly. Many attempts have been made to use a mathematical deconvolution to recover the real surface topography. However, such attempts are often not very useful for three reasons: (a) Even for a known tip shape a full recovery of the true topography by deconvolution is not completely possible at sharp trenches or close to sharp asperities, because there are "dead zones", i.e. parts of the surface topography which are never reached by the tip as shown schematically in Fig. 8.2. (b) Most importantly the tip shape is generally unknown and a "measurement" of the tip shape at sharp

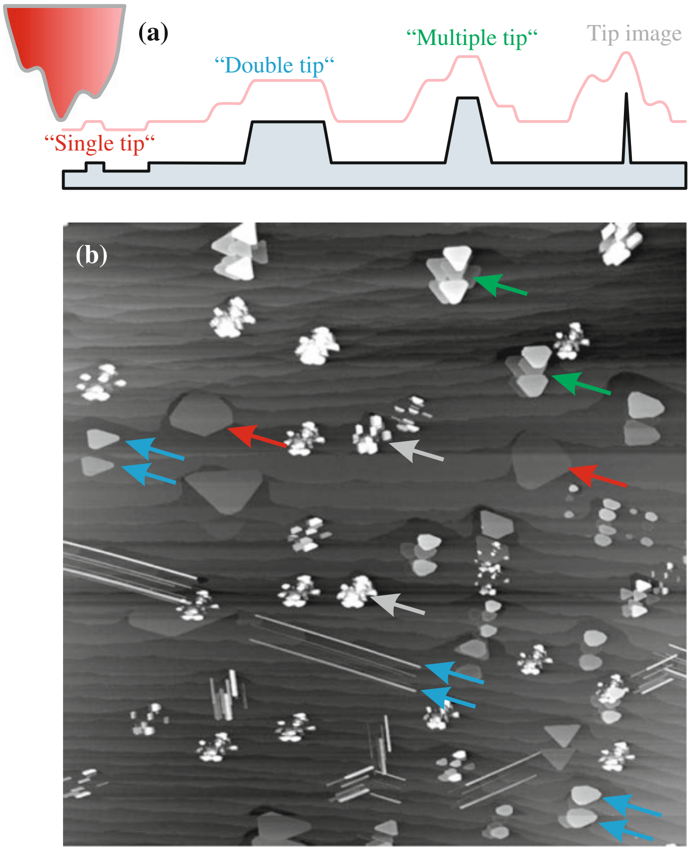

Fig. 8.3 **a** Sketch of a double (multiple) tip giving rise to doubled (multiple) imaging of surface features. The *light red line* shows the trace of the tip above the surface. **b** Example of silicide nano islands and nano wires imaged. The higher the structures imaged, the stronger is the tendency towards double (multiple images). For structures of one atomic height a single tip apex images (*red arrows*), somewhat higher structures are imaged by a double tip apex (*blue arrows*). Even higher structures are imaged by even more micro tips (*green arrows*). Narrow and high structures result in an image if the tip structure instead of the surface feature (*gray arrows*)

needle-like structures on the surface is not practicable. (c) The tip shape changes quite often. Therefore, any tedious measurement of the tip shape does not last for long. Probably not until deconvolution is attempted.

One particular case of a blunt tip is a double tip, as shown schematically in Fig. 8.3a. Such a double tip gives rise to double imaging of features on the surface as the islands and nanowires. These double images always occur at the same mutual distance and orientation as indicated by blue arrows in Fig. 8.3b. Depending on the height of the imaged features, the tip acts as a single tip for features of a single atomic height (indicated by red arrows in Fig. 8.3b), as a double tip for somewhat higher features (indicated by blue arrows in Fig. 8.3b), or as five or sixfold tip for even higher features (indicated by green arrows in Fig. 8.3b). Narrow and high structures present on the surface result in an image of the tip structure instead of the surface feature (gray arrows).

The STM images in Fig. 8.4 show that a blunt tip can give rise to a completely wrong estimate of the deposited coverage in thin film growth experiments. In Fig. 8.4a, a Si(110) surface is imaged on which 5 Å yttrium was deposited, which can be seen as elongated silicide wires on the surface. The *same* surface (however, not exactly the same area) was also imaged in Fig. 8.4b, with a different blunt tip. Here the silicide coverage *appears* to be much higher. This is not real, but an effect of a blunt tip where the silicide nanowires appear to be multiply imaged by several micotips forming the blunt tip.

This does not mean that you should not believe any SPM images, but rather you should always critically reflect on your SPM measurements and to reproduce measurements with different tips in order to exclude tip artifacts as carefully as possible.

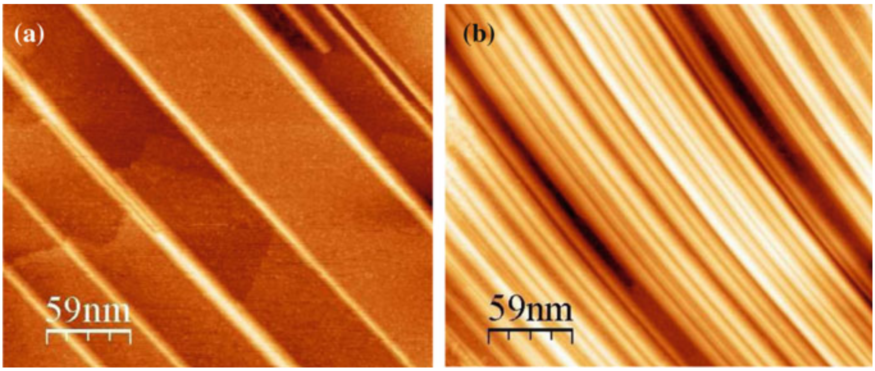

Fig. 8.4 STM image of 5 Å yttrium deposited on Si(110). **a** Silicide nanowires imaged with a sharp tip. **b** The same surface imaged with a blunt tip leads to much higher apparent coverage due to multiple images of the silicide nanowires

8.2 Other Artifacts

An artifact often appearing at the beginning of an image is a bending of all image structures, as seen in Fig. 8.5. This results due to piezo creep. Specifically if one moves to a new lateral position away from the previous one this effect is strong.

In discussing problems of piezo actuators Sect. 3.6, we have seen that the new position is not reached instantaneously after the corresponding voltage change, but is only reached asymptotically. If this creep is not yet finished this leads to an image distortion in the SPM images. An example of image distortion due to creep or a non-linearity in the piezo extension is shown in Fig. 8.6. A silicide nanowire, which is known to be straight due to its crystallographic structure, is imaged as bent.

If the feedback parameters are not optimized this can lead to image artifacts. If the feedback is too slow this will lead to blurred images; if the feedback is too fast this may lead to a feedback overshoot when the tip encounters sudden height changes such as a monoatomic step height or an other structure with high aspect ratio. In Fig. 8.7 the real signal (e.g. topography) changes from zero to one at $x = 50$ and back to zero at $x = 250$. The reaction of the AFM feedback signal to this is shown for too slow feedback settings (black line), too fast feedback settings (red line), and appropriate feedback settings (blue line). A scan in the reverse direction will show the opposite signatures.

Different kinds of artifacts are induced by noise. Noise with a high amplitude at a specific frequency will show up as stripes superimposed onto the true topography of the surface. Electrical noise from the power line is 50 Hz (or 60 Hz) noise, which can be recognized as stripes in the images, as shown in Fig. 8.8. Changing the scan speed will change the ratio of the 50 Hz noise to the frequency at which the scan lines are acquired. This has a massive influence on the angle of the observed stripe patterns.

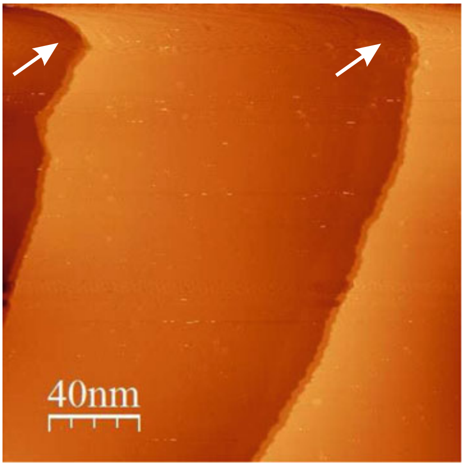

Fig. 8.5 Bending of atomic steps in the beginning of an image of a Si surface highlighted by *arrows*. Additionally to this artifact also an artifact due to a double tip is present in this image

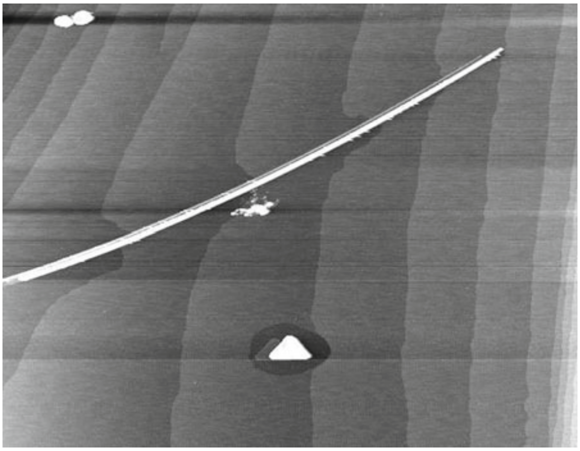

Fig. 8.6 Image of a straight silicide nano-wire, which appears bent in the STM image due to non-linearities in the piezoelectric actuators

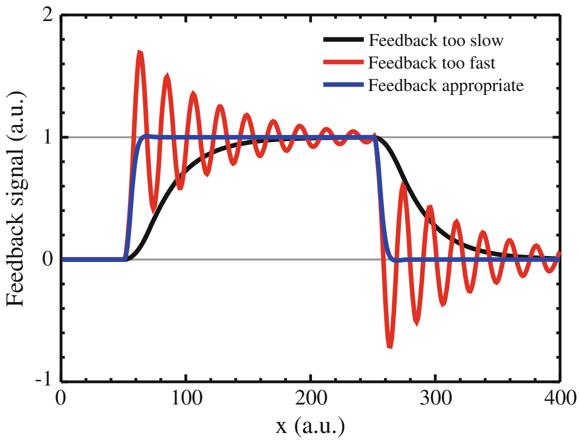

Fig. 8.7 Reaction of the AFM feedback signal to an abrupt change in the topography for too slow feedback settings (*black line*), too fast feedback settings (*red line*), and appropriate feedback settings (*blue line*)

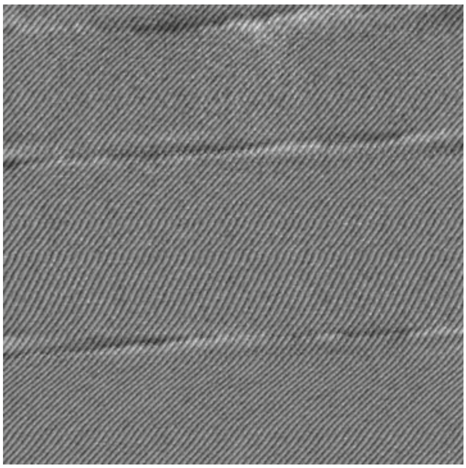

Fig. 8.8 Example of an image which is strongly influenced by 50 Hz noise. The three horizontal atomic step edges are hardly visible due to the strong 50 Hz noise

To remove electrical noise, careful debugging of the electronics has to be performed, including the removal of ground loops. Vibrational noise can be acoustic noise or vibrational noise due to building vibrations. In the section on vibration isolation, we discussed how to combat this kind of noise.

8.3 Summary

- The shape of the tip influences the SPM images, resulting in multiple images. The combination of sharp surface features with a blunt tip leads to the tip shape being imaged.
- When imaging with a blunt tip, parts of the features at the surface are not imaged: “dead zone”.
- Piezo creep and non-linearity leads to distorted images.
- Power line noise and feedback overshoot are further sources of image artifacts.