The problem of tip characterization

How can one determine the shape of a nanoscale AFM tip?

Atomic Force Microscope (AFM)

Size and shape of the tip influences:
- Surface interactions, such as friction and adhesion.
- Accuracy of surface imaging.

AFM tip manufacturers provide their customers with pristine images of tips, but sometimes tips directly from the manufacturer can be contaminated or broken on arrival.

Tip reconstruction overview

• One in-situ technique for determining tip shape is blind reconstruction (BR).
• Commercial software packages, such as Scanning Probe Image Processor (SPIP) and Gwydion, are available, but proprietary algorithms cannot easily be evaluated or adapted.

We have adapted a set of MatLab-based BR algorithms, with the goal of improving the versatility and capabilities of the programs.

• Algorithms were implemented in MatLab by Brian Todd (also at NIST).
• Adaptations and additional analytical algorithms coded by I. White, B. Dumba, and E. Flater at Luther College.

The MatLab-based reconstruction algorithm process:

1. Import the AFM image into MatLab.
2. Pick the reconstructed tip size and a range of threshold values.
3. Generate the tip reconstruction for each threshold value.
   - Profile x-coordinate (nm)
   - Profile y-coordinate (nm)
   - Tip height (nm)
   - Threshold number (Arb. unit)
   - RMS difference (nm)
4. Choose an additional set of threshold values to evaluate, if desired.
5. Choose the best reconstruction among the different threshold values.

To do this we plot the RMS deviation between the zero threshold tip and each successive reconstruction.

Comparison of MatLab and SPIP reconstructions

• Our goal is a proof-of-concept investigation to compare the effectiveness of our MatLab BR to SPIP BR.
• We pursue this goal through the use of simulated images, with full knowledge of actual tip geometry.

A simulated AFM tip and simulated sample surface are convoluted mathematically to produce a single simulated image with a variable amount of noise.

Artificial noise was added to some of the simulated images to investigate the influence of image noise on the ability of the each algorithm to ignore artificially sharp image features. Signal to noise (S/N) for each image is indicated below.

- Noisy image produces overestimation of tips shape, while a small amount of image noise (S/N = 160) produces very reasonable reconstructions not yet understood at this point.
- For moderately noisy images (S/N = 80), optimal tip reconstructions are readily identifiable.
- For severely noisy images (S/N = 40, 20), optimal tip reconstructions are not identifiable.
- For MatLab reconstructions, noise swamps the shape features in profiles that are close to true profile shape BR algorithms.
- For SPIP reconstructions, the apex of the tip is dominated by unphysically sharp features, regardless of detection count.

Summary

- We demonstrate the capacity of these MatLab-based BR algorithms to produce quantitatively similar tip reconstructions to those of SPIP.
- As expected, a sharp-featured sample produces close to ideal tip reconstructions.
- Ideal reconstructions can be readily identified within the MatLab algorithms using the RMS deviation from the zero threshold graph.
- Severely noisy images mask surface details necessary for an accurate tip reconstruction, while small amount of image noise may improve reconstruction accuracy.