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Comparison of two AFM probe inspection techniques for three-dimensional tip characterisation

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Abstract

The utilisation of an accurate and practical method for characterising the three dimensional (3D) geometry of tips used in Atomic Force Microscopy (AFM) is essential to support reliable AFM-based applications. Indeed, knowledge of the tip condition is important not only when employing AFM for imaging the surface topography of samples on the nanoscale, but also when implementing AFM-based nanofabrication techniques. In this context, this paper reports a study carried out to compare the performance and practical suitability of two different 3D tip characterisation techniques, which can be realised on AFM instruments. The first technique consists in obtaining an inverted 3D image of the tip as a result of using it to scan sharp pin-like asperities in non-contact mode. The second technique relies on obtaining a direct AFM scan of the tip under investigation, again in non-contact mode, but this time by scanning its apex with an ultra-sharp tip employed as the AFM probe. Systematic comparative studies were conducted on different types of diamond coated AFM probes. In particular, tip profile data obtained with Scanning Electron Microscopy (SEM) were used as a reference against the cross sectional profiles extracted from the acquired 3D measurements with both techniques under evaluation. Between both 3D characterisation methods investigated, the utilisation of sharp pin-like asperities to obtain an inverted scan of the tip was judged to be superior as it is 1) less time-consuming to implement, 2) less prone to result in tip damage and 3) more accurate with respect to the geometric information extracted within a distance of 100 nm below the tip apex.

Keywords: Atomic force microscope, Tip geometric characterisation

1. Introduction

Atomic force microscopy (AFM) is a powerful technique for applications such as the dimensional characterisation of surfaces with high-resolution, nano-tribology investigations and nanoscale manufacturing [1]. The resolution of such AFM-based applications is critically dependent on the tip geometry of the probe utilised. At the same time, the quality of the tip is strongly affected by the degradation of its apex through processes such as wear. Therefore, it is important to implement reliable and practical methods for the qualitative as well as the quantitative characterisation of the tip apex. To date, a number of research studies have investigated different techniques for this purpose such as those reported in [2-7]. Two of them present interesting characteristics as they can be implemented directly on an AFM instrument, while also being able to output three dimensional (3D) geometric data of the tip apex.

The first of these techniques relies on scanning a sample made of sharp pin-like asperities with the particular tip under investigation. In this way, an inverted 3D image of the tip can be obtained when imaging an asperity. With the second technique, the tip itself is used as the inspected sample. In this case, the AFM probe is positioned on the stage with its tip facing up so that its apex can then be scanned by a sharper tip. Despite the existing literature, it is not yet clear how reliable and consistent both techniques are in comparison with each other. Thus, this study reports a comparative investigation in an attempt to answer this question.

2. Methodology

The experiments were conducted on the XE-100 AFM model from Park Systems in ambient conditions. For both of the 3D tip characterisation techniques considered, the scan direction was parallel to the long axis of the probe cantilever. A XB1540 Scanning Electron Microscope (SEM) from Carl Zeiss was also utilised to obtain a 2D image of the tip profile for all the AFM probes inspected. These SEM micrographs were employed as references to evaluate the quality of the cross sectional profiles extracted from the 3D measurements methods. Following the inspection of the different probes with the AFM and SEM instruments, image processing programmes, namely the XEI and ImageJ software, respectively, were used to extract geometric data of the tips.

2.1 Scan of sharp pin-like asperities

Three different types of commercially available AFM probes made of single crystal silicon with diamond-coated tips were used to scan a sample with sharp pin-like asperities (TGT1 specimen from NT-MDT). These different types are referred to as “DCP-10”, “DCP-20” (from NT-MDT) and “DT-NCHR” (from NanoWorld). For each of them, three probes were selected and the scans were performed in non-contact mode.

2.2 Ultra sharp tip scan

For this second technique, non-contact AFM scans of the tips of six DCP-20 probes were realised using ultra sharp conical probes (Team Nanotech Improved Super Cone ISC300). Such ultra sharp tips had a nominal radius less than 10 nm and a cone angle less than 10˚.

3. Analysis of the results

Figure 1 shows examples of tip profiles extracted for the four types of probes considered. Each graph in this figure combines the SEM profile of a given tip aligned with its corresponding cross section, obtained with a 3D characterisation technique. It should be noted that for the results extracted from the sharp pin-like asperities scans, the data shown represent the average profile based on the scan of two asperities. It is observed with Figure 1(a) that the ultra-sharp tip scan tends to provide reliable data only on a small portion of the tip geometry at its apex. In contrast, the results displayed with Figures 1(b), 1(c) and 1(d) indicate a better qualitative agreement for the tip apex geometry between the SEM profile and that extracted from the sharp pin-like asperities scans. This observation could generally be made when considering the results from all other probes inspected.

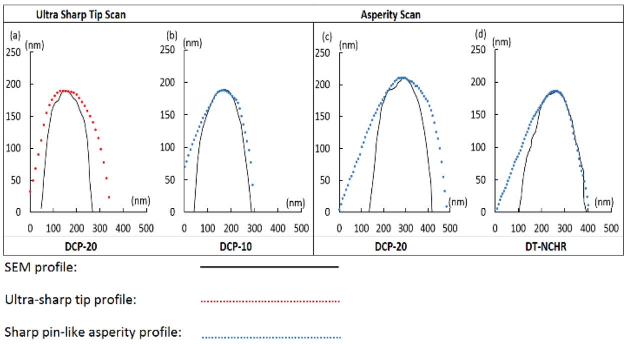

Figure 1. Qualitative profile comparisons between SEM data and the corresponding cross sections obtained with both 3D tip characterisation techniques.

In order to provide a more quantitative comparison, Figure 2 shows, for each type of probes utilised, the average difference in the tip radius extracted from the SEM profile and that obtained from the 3D techniques. When assessing each radius value, a polynomial was first fitted to the profile data. Next, the radius of curvature was calculated at the maximum point of the polynomial. From Figure 2, it can be said that the ultra-sharp tip technique exhibits the largest disagreement with the radius evaluated from the SEM data despite showing the smallest standard uncertainty.

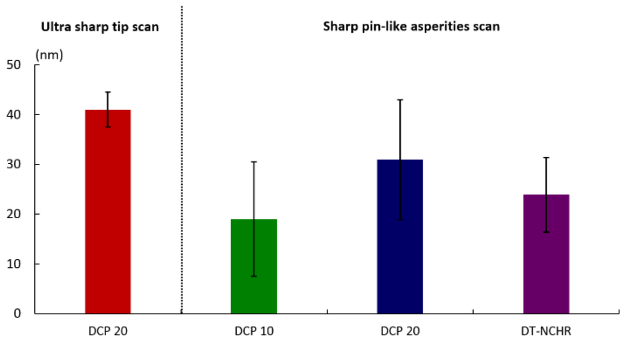

Figure 2. Average difference for radius measurements between SEM data and the 3D tip characterisation techniques. Error bars show the standard uncertainty.

In addition, Figure 3 compares the difference between the area for the different profiles when superimposing the SEM and cross section data as it was done in Figure 1. The vertical interval used to perform this evaluation was 100 nm from the tip apex in all cases. From the presented results, it is observed that tip profiles extracted from the sharp pin-like asperities scans provide a better agreement with those obtained from SEM micrographs. Thus, it could be argued that the tip convolution effect is less detrimental to the quality of the data obtained with this particular 3D characterisation technique. In addition, based the practical experience gained when conducting these experiments, it can be reported that the likelihood of potential damage to the ultra-sharp tip probe, via accidental contacts with the probe under investigation, was not negligible.

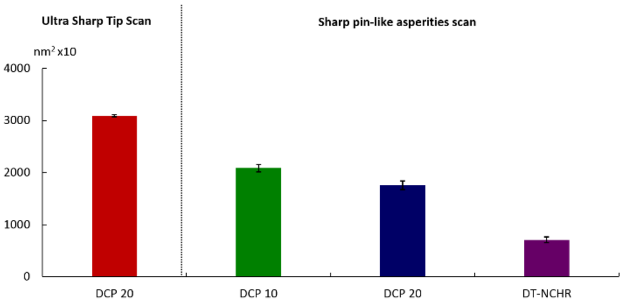

Figure 3. Profile area difference between SEM data and the 3D tip characterisation techniques. Error bars show the standard uncertainty.

4. Conclusions

In this study, experiments were conducted to compare the reliability and practicality of two different characterisation methods to assess the tip apex condition of AFM probes. All probes assessed in this work had diamond-coated tips and were available commercially. Both of the methods under investigation can be implemented on AFM systems and provide 3D information of the tip geometry. Thus, they are of potential interest for increasing the efficiency and data richness of tip monitoring operations in comparison with standard SEM inspections of tip profiles.

Based on the qualitative and the quantitative analyses conducted, it can be said that the utilisation of a sample with sharp pin-like asperities to obtain an inverted scan of the assessed tip is the preferred method. Indeed, it provided the closest agreement with reference profiles obtained from SEM data. From a practical point of view, it is also more straight-forward to implement compared to the ultra-sharp tip technique as there is no need to remove the tip under investigation from the AFM head. In addition, the process of precisely locating an ultra-sharp probe over the inspected tip apex proved to be a non-trivial operation, which could sometimes lead to damaging contacts between both tips.

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