SCANNING SIC 1.5 nm HEIGHT STANDARDS WITH THE AFM WORKSHOP TT-AFM AND TT2-AFM

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1. Introduction

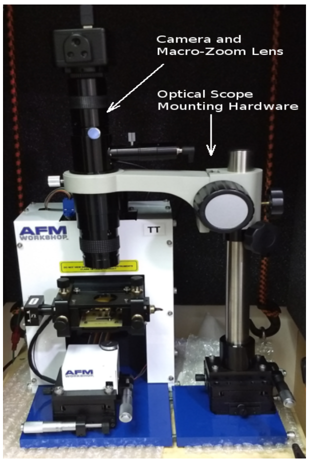
In this note, AFM images acquired using the AFM Workshop TT-AFM instruments are presented. The SiC test samples are specified as having terraces with a step height of 1.5 nm between adjacent terraces. In this document we address the following issues:

(1) Characterization and removal of periodic noise.
(2) Effect of the optical macroscope and its mounting hardware on the periodic noise.
(3) Methods for leveling the acquired AMF scan.
(4) Use of Gwydidon's build in capability to estimate terrace height and placement (Gwyddion v.2.55).

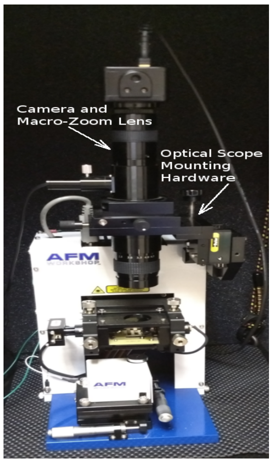
2. Materials and Methods

2.1. AFM Configuration. The Advanced Bio-Engineering Teaching Laboratory is equipped with two AFMWorkshop systems, one of which was purchase in 2013 and is designated TT-AFM, while the second was purchased in 2017 and is designated TT2-AFM. The specifications of these two instruments are very similar, and the latest specifications can be found here. Both units sit in the AFMWorkshop Acoustic Cabinet. They both have 50 µm XY-scanners.

A significant difference between the TT-AFM and the TT2-AFM concerns the mounting of the optical camera/macro-zoom lens combination. Figure 1 shows this difference.



(A)



(B)

FIGURE 1. (a) Original TT-AFM AND (b) TT2-AFM, with the camera, macro-zoom lens and mounting hardware indicated. The TT-AFM has a much more massive arrangement. The blue baseplate has been loosened to weaken the coupling to the scanner, and the AFM is placed on a layer of bubble pack.

The Z-HV was reduced to 5 V, in order to increase resolution at the expense of dynamic range.

2.2. Samples. The lab has four SiC 1.5 nm samples. Two are premounted Ted Pella 629-90AFM Silicon Carbide 1.5 nm step height standards. Two others were purchased unmounted from NT-MDT.

2.3. Image Processing. The open source Gwyddion software package was used to process the data. The image processing operations required for this study are leveling, denoising, and estimation of terrace height. The leveling method had to be applied to a single terrace, since the overall topology of the sample is a staircase. In some cases, the image was cropped to exclude obvious artifacts or edge distortion.

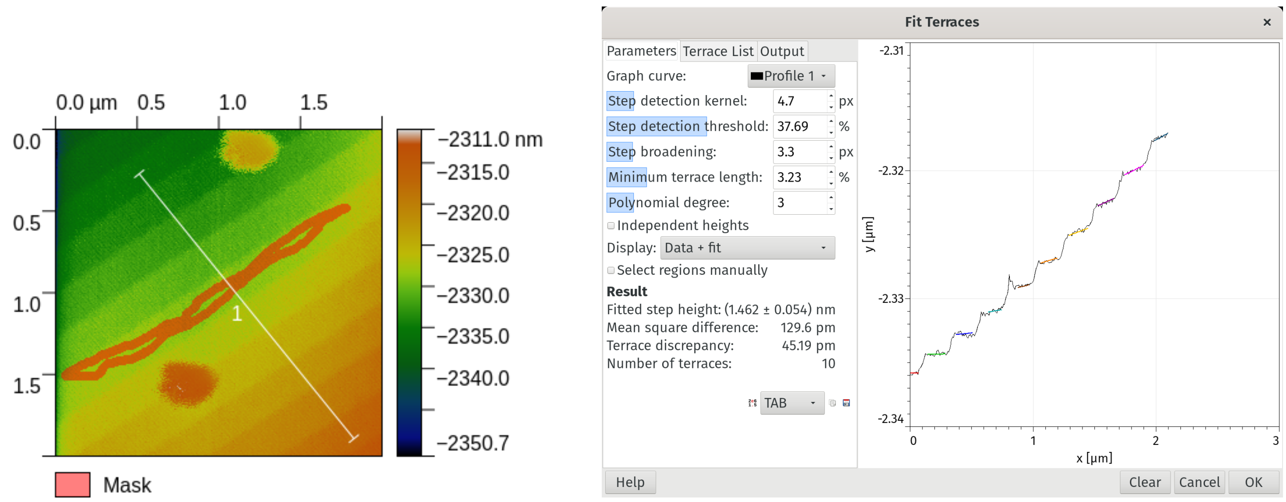
Denoising consisted of two operations. Periodic noise was reduced using Fourier filtering (Data Process>Correct Data>1D FFT Filtering... or Data Process>Correct Data>2D FFT Filtering...). Zero mean uncorrelated noise noise wsa reduced using the mean operation that is found in Gwyddion's "Basic filters:" tool.

The leveling strategy involved drawing a mask on a single terrace and doing a plane level.

Once an image was denoised and leveled, a like profile was acquired across the terraces. At least as of Gwyddion v2.55, the profile context menu includes a tool for estimating the location and height of terraces along a profile plot. This tool then shows the estimated polynomial fit to the terraces, and other statistics including average distance terrace height.

3. SiC Standards Height Measurements

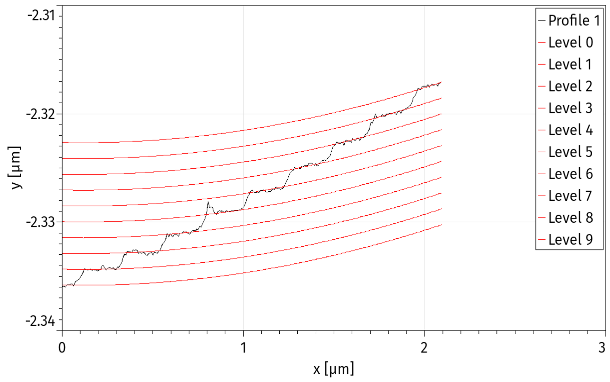
3.1. TT-AFM. Figure 2 shows images of the SiC test sample labeled NT-MDT#1 that were scanned using the TT-AFM.



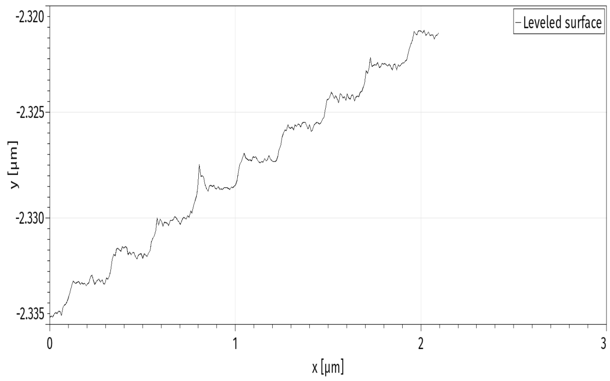
(A) (B)

FIGURE 2. (a) Image of SiC test target, after leveling. The mask that defined the area over which the plane level operation was applied appears as a red overlay (the round red circle is an artifact, probably a particle contaminating the surface). (b) A line profile across the terraces is shown. The profile was acquired along the white line shown on the image in (a). The lines at either end shown the width (10 pixels) over which the profile was averaged.The staircase is seen, but the leveling is not perfect.The terraces found by Gwyddion's Terrraces tool are shown superimposed on the plot. The plot is shown inside the Terraces tool window, which shows the parameters used to estimate terrace spacing. The average estimated terrace spacing is (1.462 ± 0.054) nm.

Figure 3 shows the polynomial fits that were used to estimate the terrace spacing, and the leveled terraces based on the polynomial fit.



(A)

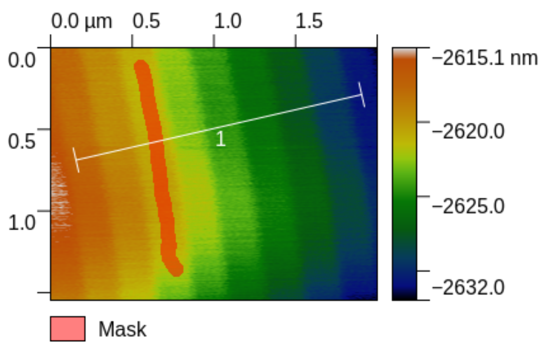


(B)

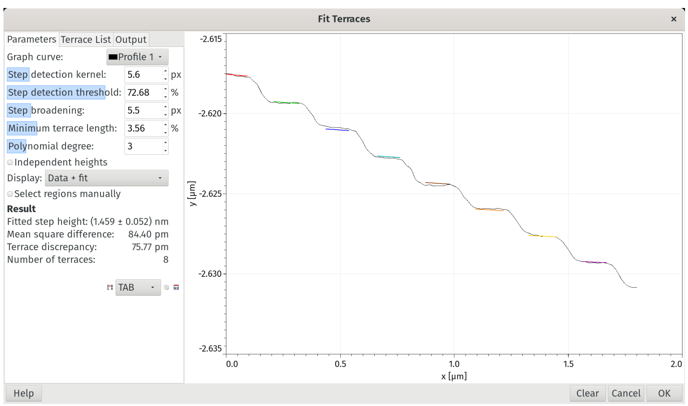
FIGURE 3. (a) Polynomial fit to the terraces. (b) Leveled terraces.

There is periodic noise in the image of Figure 2(a), but it is not readily seen in the image as displayed in this document. This will be discussed further on. The image of Figure 2(a) was analyzed without any noise reduction operations or Fourier filtering.

3.2. TT2-AFM. If this subsection, images acquired with the newer TT2-AFM are presented. Figure 4 shows images of a different SiC test sample, acquired from Ted Pella, Inc. and labeled as Lot#55369.



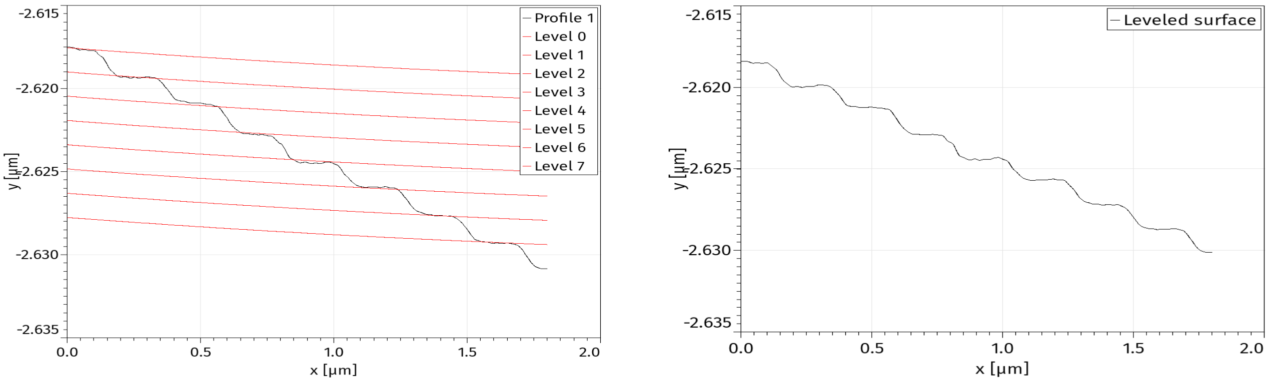
(A)



(B)

FIGURE 4. (a) Image of SiC test target (Lot#55369), after leveling. The mask that defined the area over which the plane level operation was applied appears as a red overlay (the round red circle is an artifact, probably a particle contaminating the surface). (b) A line profile across the terraces is shown. The profile was acquired along the white line shown on the image in (a). The lines at either end shown the width (20 pixels) over which the profile was averaged.The staircase is seen, but the leveling is not perfect.The terraces found by Gwyddion's Terrraces tool are shown superimposed on the plot. The plot is shown inside the Terraces tool window, which shows the parameters used to estimate terrace spacing. The average estimated terrace spacing is (1.459 ± 0.052) nm.

Figure 5 shows the polynomial fits that were used to estimate the terrace spacing, and the leveled terraces based on the polynomial fit. The parameters in the Fit Terraces tool have a large effect on the estimate,



(A) (B)

FIGURE 5. (a) Polynomial fit to the terraces. (b) Leveled terraces.

and must be found with some trial and error. Here are some considerations:

Polynomial degree This will determine how closely the estimate can follow the distortion of the terraces. A degree of 0 will produce flat terraces, and overestimate or underestimate the terrace spacing if there is any tilt (over or under depends on the orientation of the tilt). A third order polynomial appears to be sufficient.

Minimum terrace length If this parameter is too small, a single noisy terrace may be divided into two or more small terraces, which will obviously not be spaced as expected. If it is too large, then two or more real terraces may be combined into one terrace, with the step included.

Step broadening This parameter tell the tool that edge may not be sharp (as will happen when the tip is dull). In the TT2-AFM image shown here, that was the case. If the parameter is too large, then the edges encroach on the terraces and the terraces will be too narrow.

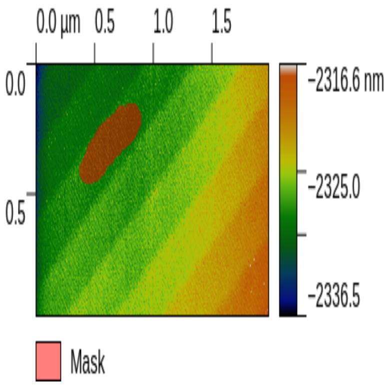
There are a number of other parameters that should be set. All of the parameters can be set interactively, and their effect on the fit is shown overlaid on the line profile. The Fit Terraces tool is described here.

4. NOISE

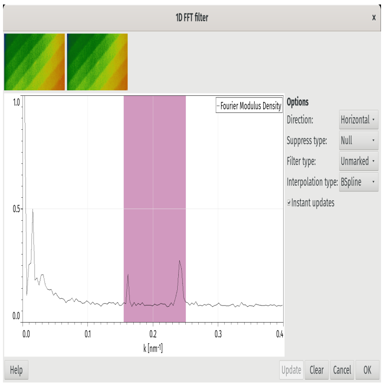
In this section, we consider the noise in our our scans of the SiC test targets. Figure 6(a) shows a scan of the SiC targetin the TT-AFM with the scope attached and no Fourier filtering. Figure 6(b) show the 1D FFT of this image along the horizontal axis. Figure 6(c) shows the image after suppressing the two rightmost peaks in the FFT spectrum. The noise in the image is estimated by measureing the mean roughness in the are marked by the red overlay. The Mean roughness (sq) of the image before Fourier filtering is 613.9 pm, while the Mean roughness (sq) in teh filtered image is 455.7 pm Figure 7(a) shows a scan of the same target with the scope removed from the TT-AFM. Figure 7(b) shows the 1DFFT of the image in Figure 7(a), and indeed the two rightmost peaks that are seen in Figure 6(b) are not present. However, the mean roughness of this image is 858.4 pm. It is noisier, although the noise is not periodic. I wonder if the scope reduces the mechanical noise, at the price of having a few Fourier components present at the mechanical resonance of the mounting hardware.

The same protocol, when done on the TT2-AFM, produced a Mean roughness (sq) of 170.2 pm. This cannot be directly compared to the TT-AFM scans, because the target may beof different quality, and the instruments are not situated in the exact same place. Never the less, we see that both instruments can measure to the nm level using only bungie cords for vibration isolation.

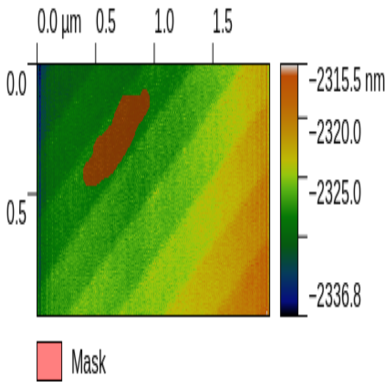
These roughness measurements are only relative indicators. The correct way to do this is the measure the noise with the AFM in feedback but set to not scan.



(A)

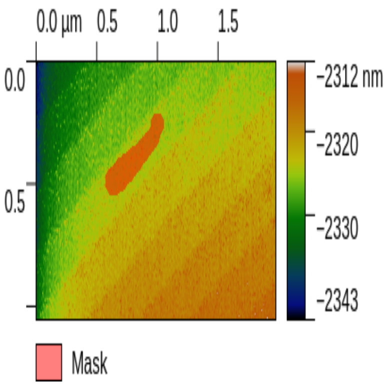


(B)

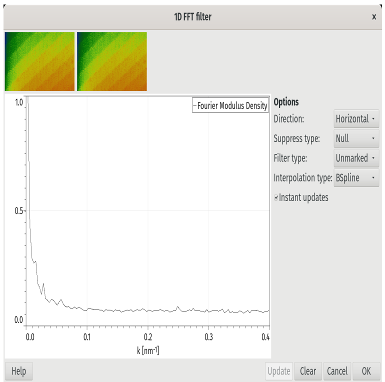


(C)

FIGURE 6. (a) SiC target scanned on TT-AFM; (b) 1DFFT of (a); (c) Image (a) after Fourier filtering, by suppression of peaks overlayed in red in the FFT spectrum.



(A)



(B)

FIGURE 7. (a) SiC target scanned on TT-AFM, with the scope removed; (b) 1DFFT of (a). The two rightmost peaks seen in Figure 6(b) are not present.