The origins of friction and the growth of graphene, investigated at the atomic scale

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Appendix C

Image-subtraction procedure

This appendix explains how the difference between two STM images was calculated. The result of this image-subtraction procedure is presented in Figures 6.2, 6.3 and 6.5 A special focus is put on the STM-image alignment. The kind of image alignment that was necessary to obtain a proper subtraction varied between sets of images. This variation was caused by conditions such as imaging stability, that were different in the various experiments.

The procedure was performed such that the pixel-values in the resulting image could be directly related to absolute distances in the z-direction.

C.1 Subtraction procedure used in Figures 6.2 and 6.5

The input for the subtraction procedure was the raw STM-data of two images from one image sequence. The z-values in this STM data were acquired from the 16-bit analog-to-digital converter of the z-channel of the STM.

The following steps were performed subsequently, the software used to perform these steps is indicated between parentheses.

1. Transform the STM data to a 16-bit tif-image. (Python script)

2. Blow-up the colour scale of the images to simplify the image alignment. The change in colour scale was identical for both STM images. (ImageJ)

3. Save the images as 8-bit tif-files. (ImageJ)

4. Align the images (Adobe Photoshop):

- Adjust image position (x,y) and rescale the y-size for Figure 6.2
- Adjust image position (x,y), rescale the x- and y-size and apply a horizontal stretch for Figure 6.5

5. Save the images as 8-bit tif-files. (Adobe Photoshop)

6. Crop the images to obtain images with similar dimensions. (ImageJ)

7. Subtract the images. (ImageJ)

8. Save the images as 32-bit tif-files. (ImageJ)

9. Set the colour scale to 255 and apply a blue-to-red colour table. (ImageJ)

10. Save the image as an 8-bit bmp-file. (ImageJ)

C.2   Subtraction procedure used in Figure 6.3

The image subtraction for Figure 6.3 was slightly different as the STM data contained some noise. This noise was characterised by a single, high frequency. For this reason, FFT-filtering was applied in the WSxM software. First, the STM data was exported to WSxM using the export function that is available in the STM software (LPM Camera software). After this export, the following steps were performed:

1. Apply a global plane subtraction. (WSxM)

2. Apply FFT-filtering of a small region in k-space to remove the noise. (WSxM)

3. Apply a greyscale colour table with proper z-scale. (WSxM)

4. Save the image as an 8-bit bmp. (WSxM)

5. Align the images by adjusting the image position. (Adobe Photoshop)

6. Crop the images to obtain images with similar dimensions. (Adobe Photoshop)

7. Save the images as 8-bit bmp-files

8. Subtract the images. (ImageJ)

9. Save the images as 32-bit tif-files. (ImageJ)

10. Set the colour scale to 156 and apply a blue-to-red colour table. (ImageJ)

11. Save the image as an 8-bit bmp-file. (ImageJ)

Appendix D

Island-extraction algorithm

Some of the analysis reported in this thesis was done using a routine to identify and extract graphene islands from STM data. This appendix describes this procedure.

In most of the images that were analysed, several iridium terraces were present. To optimise the island extraction, these images were anlyzed terrace by terrace. The following procedure was applied to every individual terrace, the software used to perform these steps is indicated between parentheses.

1. Export the STM data to WSxM using the export function that is available in the STM software. The image resolution is 1024×1024 pixels. (LPM Camera software)

2. Apply line-by-line flattening. (WSxM)

3. Perform a local plane correction on the iridium terrace. (WSxM)

4. Save the image as bitmap. (WSxM)

5. Blur the image with a blur radius of 2 pixels. (Adobe Photoshop)

6. Adjust the image levels to achieve maximum contrast between graphene islands and the iridium terraces. (Adobe Photoshop)

7. Select the graphene islands using the 'Magic Wand' tool with the non-contiguous-selection setting. (Adobe Photoshop)

8. Colour the selected islands white, colour other iridium terraces in the image black. (Adobe Photoshop)

9. Deselect the islands. (Adobe Photoshop)

10. Reselect the islands by a non-contiguous selection of the bright pixels. (Adobe Photoshop)

11. Invert the selection and colour all selected pixels black. (Adobe Photoshop)

12. Apply a colour threshold at level 128 to obtain a black-and-white image. (Adobe Photoshop)

13. Save image as bitmap. (Adobe Photoshop)

This procedure was repeated for every terrace in the image. The resulting images were added together, which resulted in a black-and-white image with all the graphene islands being white and all the uncovered iridium being black. This image was used as a mask for further graphene island analysis. For example, the graphene coverage and the average height of the islands were calculated via Python scripts that coupled the mask with the original STM data.