Experiment 9. Atomic Force Microscopy

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Abstract.
AFM is a scanning probe technique where the surface of a sample is scanned while the interaction forces with a sharp cantilever tip are recorded. Our objective is to learn imaging with an AFM as well as understanding its principles. Results include CD track pitch length of 1.6 µm which is extremely accurate according to that reported in the literature and CD manufacturing standards.

I. INTRODUCTION

The Atomic Force Microscope (AFM) is a system wherein the Scanning Tunnel Microscope (STM) is used to measure the motion of a cantilever beam with an ultra small mass and using this information to map or image a sample. The sensitivity of AFM is enough so that inter atomic forces between single atoms can be measured.[1]

STM is the predecessor of AFM and uses a similar technology. Tunneling current is achieved by establishing a bias voltage between a pair of electrodes which are the tip of the cantilever and the sample. STM's principle is to maintain the tunneling current, which is a sensitive function of the gap width, constant. This current changes by an order of magnitude for every angstrom change of the gap. Thus to fix the gap at a constant value (as well as the current) the tip is controlled by a piezoelectric motor.[2]

AFM is a scanning probe technique where the surface of a sample is scanned while the interaction forces with a sharp cantilever tip are recorded. In AFM as well the (x, y, z) positioning of the sample is adjusted by a piezoelectric scanner ensuring high-precision movements. A laser beam is reflected on top of a soft AFM cantilever and it is collected by a photodiode to record tip deflection. While the specimen is moved by the scanner, the deflection signal measures the forces resulting from the interaction between the AFM tip and the surface with piconewton sensitivity. [3]

Our objective is to learn imaging with an AFM as well as understanding its principles. Samples provided by the fabricator of the AFM will be analyzed as well as a section of a CD and results will be discussed with those reported. Measurment of CD-pits depth, width, and track pitch are expected.

II. EXPERIMENTAL PROCEDURE

During the experiment two sample materials were measured. The first was a SiO_2 layer on Si subtrate. This microstructure had approximately 113 nm depth (recommended size to perform AFM) and consisted either of square holes and pillars with a 10 µm pitch, arranged in a 1mm x 1 mm square or Circular pillars and holes, plus lines in the x- and y-direction, with 5 mum pitch arranged in a 500 µm x 500 µm square.

The other material consisted of a commercial CD. The sample was identified as polycarbonate with a repeated "track" structure. Based on industry standard a CD is 120 millimeters in diameter.

CD microstructure changes depending what kind of data is recorded on it. The recorded data on the CD takes the form of a continuous spiral starting from the inside and moving outward. This spiral or track consists of a series of indentations called pits, separated by sections called lands. A tiny laser beam moving along the track reflects light back to a photo sensor which interprets data, If no data is present, this spiral is free of pits.[5]

Samples were scanned using the "NaioAFM" AFM equipment from NanoSurf Company (See [4]). NaioAFM provide easy-to-use equipment and a straightforward interface to perform the the microscopy analysis [4]. These were later analyzed using Naio control software, provided by the same company.

III. RESULTS

Images obtained directly from "NaioAFM" equipment provided by lab instructor were analyzed in width and length and are shown next.

A. SiO_2 layer on Si substrate's microstructure

Figure 1 shows a 50 µm x 50 µm view of the sample were circular pillars and holes are included as well as vertical and horizontal valleys in micro structure.

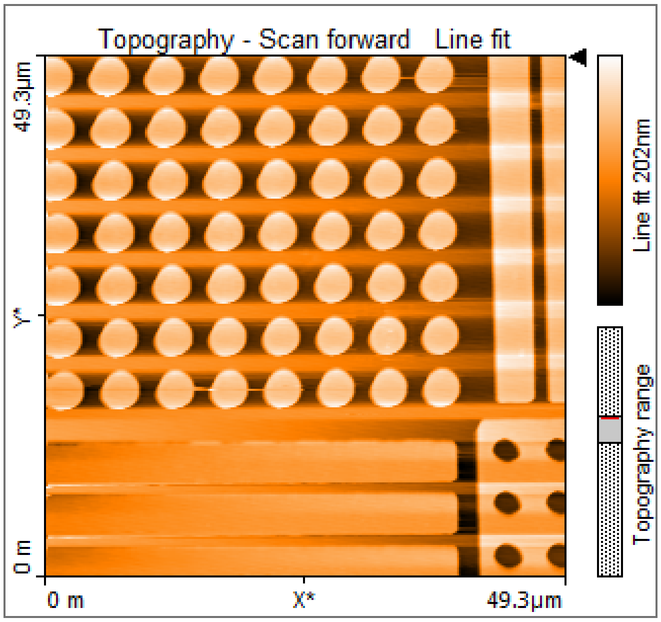

FIG. 1: 50 µm x 50 µm topographical scan showing circular pillars, circular holes, and ridges along the x and y-axes.

This section was then processed to better show circular pillars as in figure 2. In an approximate 10 µm by 10 µm image 2 pillars can be seen horizontally and 2 vertically which resemble information provided that will later be discussed.

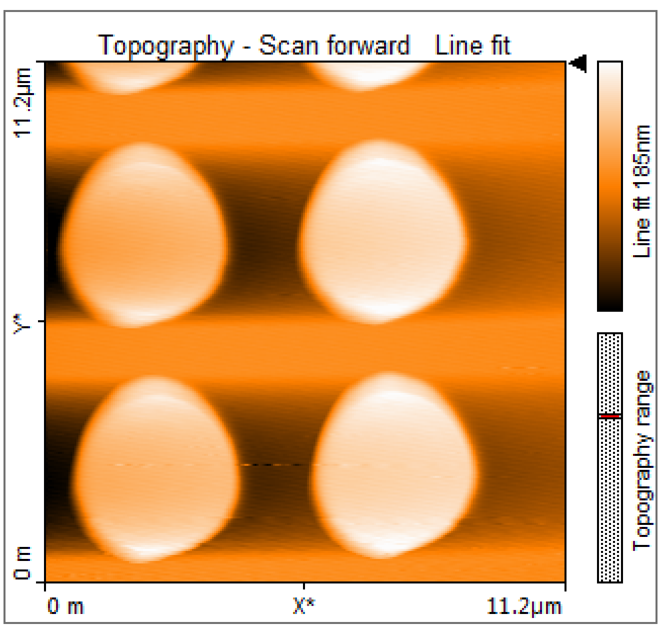

FIG. 2: Detail showing topography of circular pillars. Their diameter is around 3.5 µm.

Analysis was detailed as well for circular holes in the micro structure provided and are shown in figure 3.

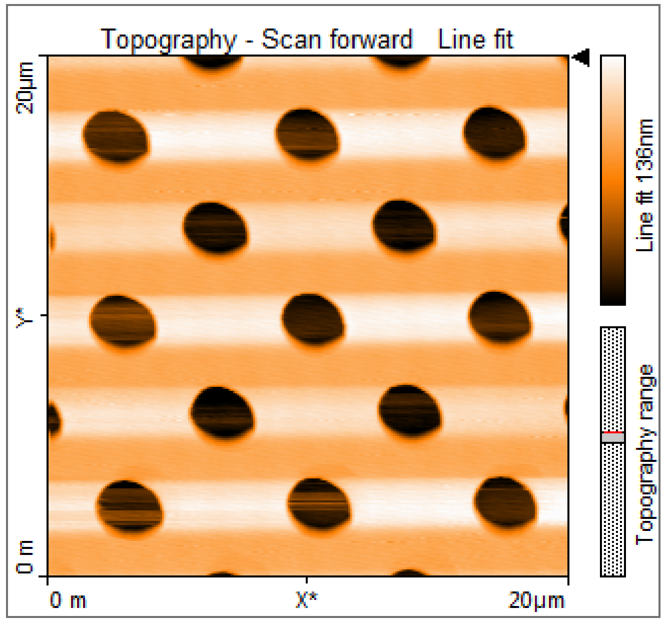

FIG. 3: Detail showing topography of circular holes. Their diameter is around 2.5 µm.

Figure 4 shows without much detail (50 µm by 50 µm measurement) the space between vertical regions and will later be discussed.

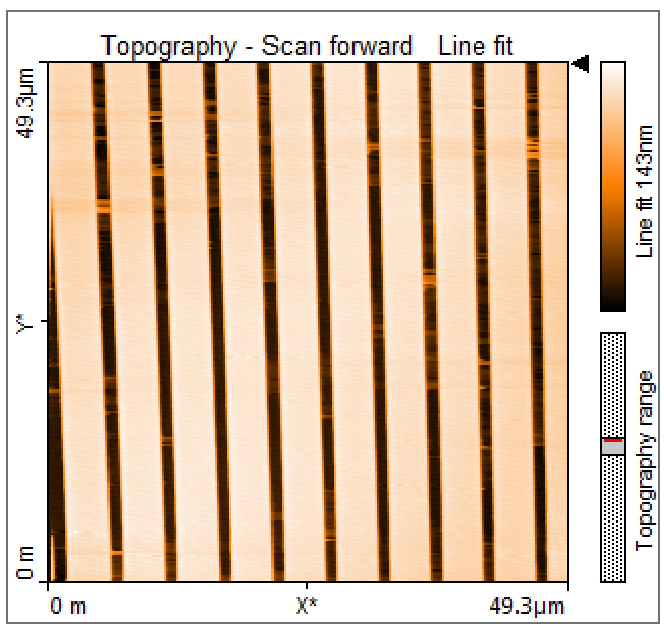

FIG. 4: Detail showing topography of the vertical bars. Their width was measured around 4.0 µm, while the valleys' were found to be around 1.0 µm.

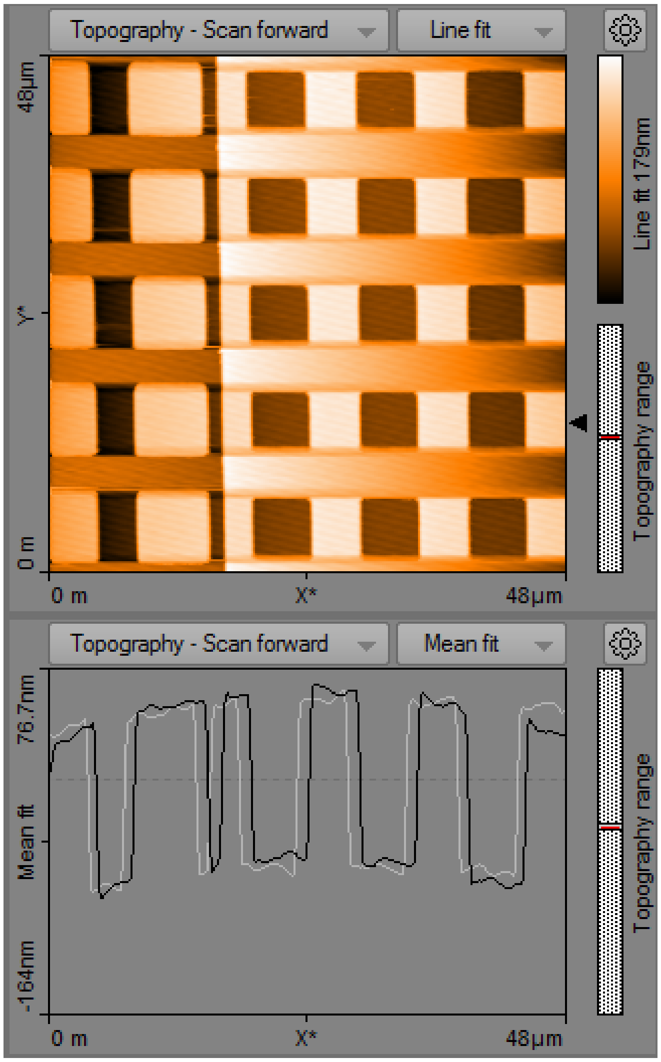

FIG. 5: Square pillars and square holes. Each pillar's edge has a length of about 7.0 µm. The square holes are no real squares. The side parallel to the x-axis shorter than that parallel to the y-axis. The former has a length of aprox. 4.8 µm, while the former is aprox. 5.4 µm. Also showing a feature of the Naio control software, which allows to see the relative distance between the square pillars and valleys (or square holes and ridges) of aprox. 110 to 120 nm.

A similar detail is shown in figure 5 for analysis of square holes and pillars. Here a topography scan specifying distance between holes and pillars is included as well. Relative distances are measured and are displayed in figure 5 description.

B. Compact disk's microstructure

CD sample images are shown in 20 µm by 20 µm format and 5 µm by 5 µm format. Detail of the structure is better appreciated in figure 6 as the complete pattern of data is visible, where valleys and standard depth areas represent different information (binary 1s and 0s where valleys correspond to 0s).

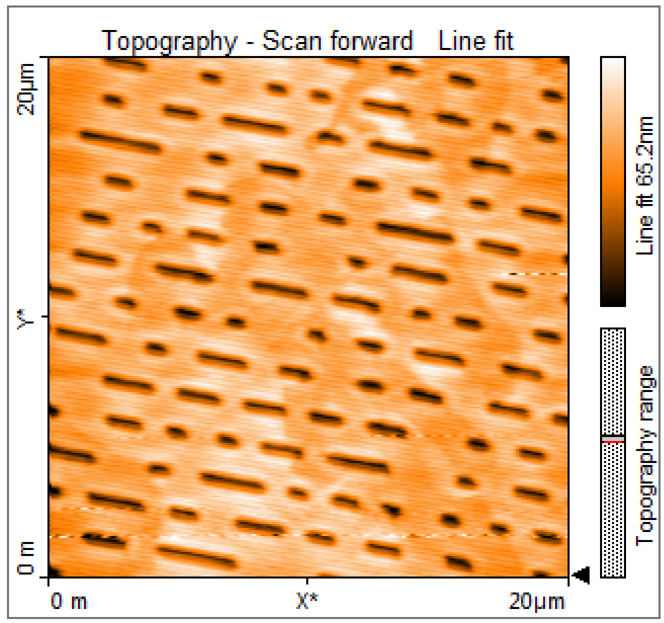

FIG. 6: 20 µm x 20 µm topographical scan of a CD. A relatively (unexpectedly)low resolution.

While resolution for better observation of CD pattern is present in figure 6, an important feature of CD structure such as track pitch is easier to observe in figure 7. Such track pitch measures were absolutely precise. Due to lack of proficiency in software management some important features are not detailed with markers to specify lengths. Nevertheless, that information is included in figure description.

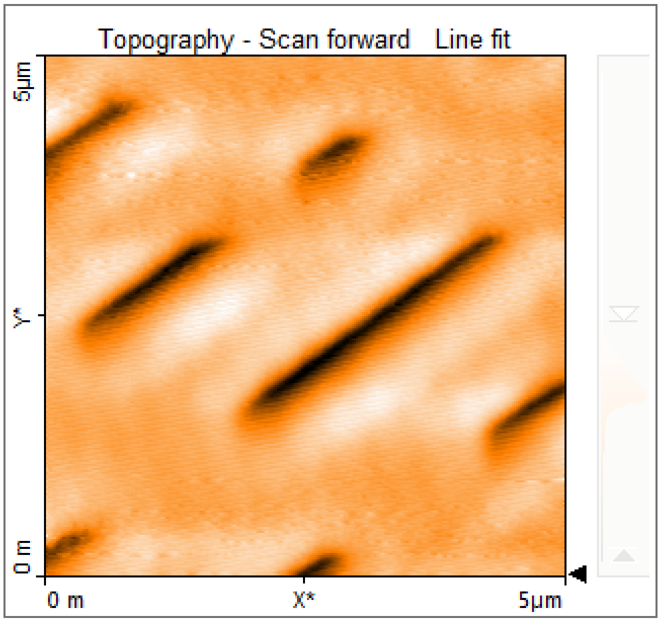

FIG. 7: 5 µm x 5 µm topographical scan of a CD. With this resolution, the distance between the tracks (the pitch) was measured to be 1.6 µm. The long pit in the middle was measured to be about 3.0 µm in length, a little more than 100 nm wide and close to 40 nm deep.

IV. DISCUSSION OF RESULTS

As explained in the experimental procedure section the first sample is a SiO_2 layer on Si subtrate with a pattern specially prepared to be able to measure pillars and holes in circular and square shapes. The samples and sample specifications were provided to our lab instructor by the fabricator of the "NaioAFM" AFM, this information was then provided to us.

A 113-114 nm depth was reported for the microstructure of the SiO_2 layer. Square holes and pillars were reported a 10 µm pitch arranged in a 1mm x 1mm square, while results show the pitch is around 7 µm m and arrangement space was not quantified. This accounts for a 70 % accuracy with a 30 % relative error, but this could also be expressed as a 3% error every 10 µm.

Circular pillars and holes, plus lines in the x- and y-direction, are reported with 5 µm pitch arranged in a 500 µm x 500 µm square, while results state pitch is 3.5 mum and arrangement space was not analyzed. The relative error is 30 % or 3 % every 10 µm exactly like in previous measures.

The CD sample that was analyzed shows pit width of 3 µm and depth of 40 nm while [7] reported a width of 0.8 µm for the smaller pits which coincide with our order of magnitude. Our results match within a range of values for pit lengths from 0.8 µm to 3 µm . As for the pitch track the reported length is of 1.6 µm and our results are exactly equal to those reported in [7]. Images reported in [7] for a AFM mapping resemble perfectly with ours taking into consideration scanning range.

V. CONCLUSION

In this paper we report in-lab micro structure pitch length measurements using "NaioAFM" Atomic Force Microscope. Measurements were made for 2 samples and analyzed using Nanosurf sotfware available online. Determination of pitch lengths were done using this equipment with 7 µm for square pillars and 3.5 µm for circular pillars. Measurements may have deviated from data provided due to user error when analyzing using Nanosurf software. Atomic Force Microscopy is one of the best, most accurate technologies for measuring micro structures and its relevance is on a high with current studies in nanotechnology. Use of AFM help characterizing highly detailed structures for data storage and other micro structures.[7]

VI. REFERENCES

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