Experiment AFM - preparation

Călin Mihai Ghizdaveț - S4659880, Blazej Rozmarynowicz - S4863852

1 Introduction

Atomic Force Microscopy (AFM), first used by Binning, Quate and Gerber in 1986 [1], is an experimental technique used to investigate the topography of different materials with incredibly high precision. In its most generalized form, the technique uses a cantilever-laser setup, where sample topography is calculated using the small differences in signals reflected from the cantilever that changes its vertical position upon encountering a noticeable "bump" in the moving sample. Operating on a sub-nano scale, AFM is described using the Lennard-Jones potential, which focuses on the attractive and repulsive contributions from the Pauli exclusion principle and van der Waals interactions, respectively, while ignoring electrostatic and magnetic forces [2]. This technique can be used for both measurement and modification purposes, allowing for both investigations of material properties of samples, as well as, for example, induction of nanoindentations or lithography.

2 Theory

2.1 Lennard-Jones potential

In order to determine the force caused by the Lennard-Jones potential one has to use the formula

$$\vec{F} = -\vec{\nabla} V. \quad [2] \tag{1}$$

However, due to the unidimensional nature of the problem, the gradient reduces itself to simply the derivative with respect to distance.

Therefore:

$$F = -\frac{d}{dr}V(r) = \frac{24\epsilon\sigma^6}{r^7}(\frac{2\sigma^6}{r^6} - 1), \tag{2}$$

which is a relationship that can also be used to determine the equilibrium distance (r_m) by setting the force to 0

$$r_m = 2^{1/6}\sigma. \tag{3}$$

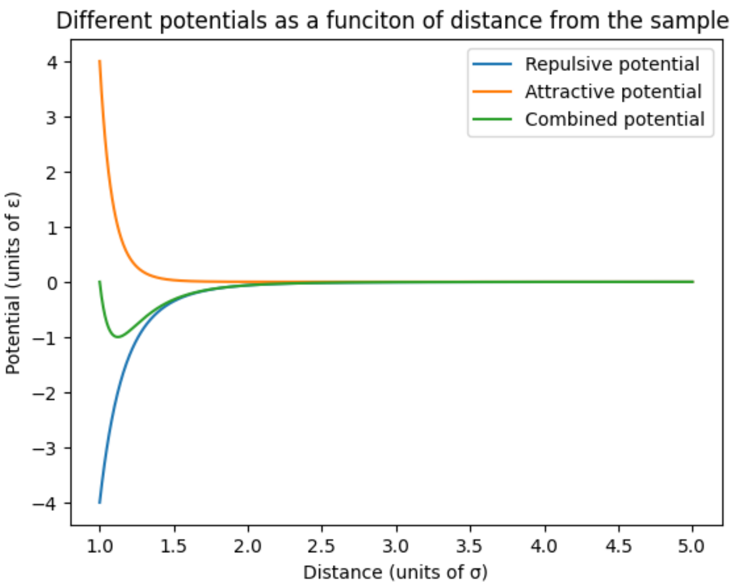

Figure 1: Comparison of the Lennard-Jones potential (total potential), Van der Waals potential (attractive potential), and Fermi potential (repulsive potential).

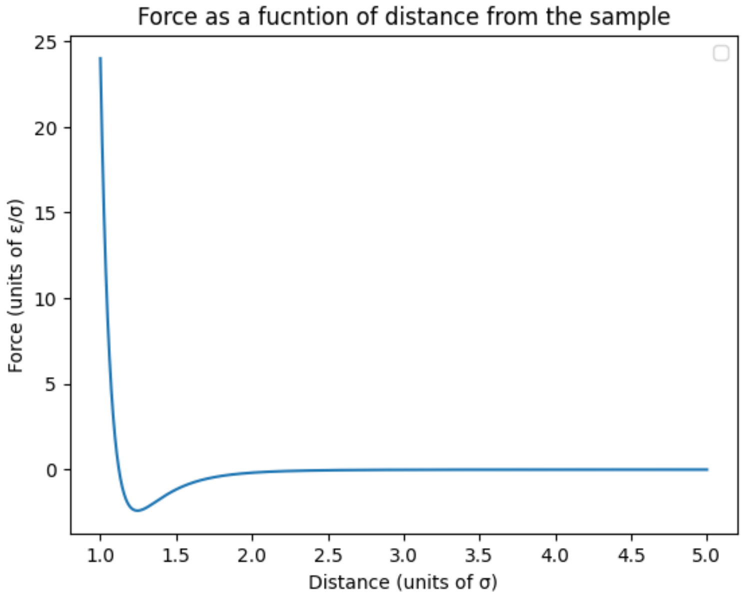

Figure 2: The force resulting from the Lennard-Jones potential as a function of distance from the sample.

2.2 Imaging modes

- Static mode: This mode of imaging keeps the tip of the cantilever in permanent contact with the sample while keeping force constant in order to determine topology.
- Dynamic mode: The cantilever oscillates near the equilibrium position (r_m); the equilibrium distance changes as a function of terrain topology, from which the latter can be determined.
- Force spectroscopy mode: Assuming that the distance for the sample does not increase past the point at which the behavior of the system becomes non-linear, the stiffness of the sample can be determined using the equation for two different springs in series

$$\frac{1}{k_{measured}} = \frac{1}{k_{cantilever}} + \frac{1}{k_{surface}}, \tag{4}$$

from where one can say that

$$k_{surface} = \frac{k_{cantilever} - k_{measured}}{k_{cantilever} k_{measured}}. \tag{5}$$

This mode of measurement allows for the construction of phase images which can be used to determine the mechanical properties of the material as a function of position.

3 Experimental Setup

The experiment is conducted with the use of the NatioAFM microscope. The setup mainly consists of a vibration isolation table and a scan head housing (see Figure 3), in which the sample and cantilever are positioned. The experiment can be viewed with a side view camera, positioned on top of the side view lens. The measurements are collected with NanosurfNaio software. The sample itself is stored on a sample stage with a magnetic holder, which can be adjusted using positioning screws. After properly adjusting the sample position, the positioning screws are half-turned in the opposite direction. Since a full turn is necessary for a change in position, a half-turn does not affect it. It does, however, decouple the screws from the setup, reducing their vibration contributions.

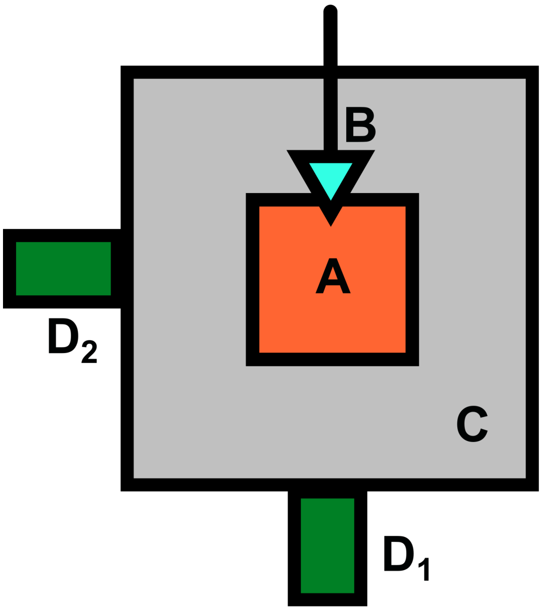

Figure 3: Experimental setup broken down by the relevant parts. (A) Magnetic holder with sample; (B) Cantilever, part of the scan head; (C) Vibration isolation table; (D) Positioning screws for the X and Y axes, respectively.

4 Safety considerations

- When working with a laser, always ensure that no one looks directly at it;
- Samples should not be used in a liquid due to the high voltages involved in the piezo drivers;
- Samples should be placed only using tweezers, neither they nor the surface are supposed to be touched by hand;
- A cantilever should always be kept installed on the scanner head, not doing so can damage the self-alignment structure;
- Do not change cantilevers before being taught how to do so.

5 Measurement plan

5.1 Preparation

Before the experiment, it is important to ensure the setup is prepared properly. For each measurement technique, a different cantilever is used, which is to be changed with tweezers. After correctly positioning the given sample and ensuring vibrational isolation, the setup can be calibrated.

For calibration, a microstructure grid of known dimensions, with 10μm periodicity, is used to perform both dynamic and static mode measurements. Other than calibration, the sample is also utilized to find whether the Gwyddion or ImageJ imagine mode is better suited for this type of measurement. It is crucial to consider the extrinsic, vibrational contributions to the measurement error, mitigated by ensuring no tools or people are in direct contact with the experimental setting in the immediate vicinity. Since the experiment is done with very high precision, loud conversations could also influence the results, and hence should be avoided during the experiment. The measurements are recorded with software, and retrieved data is analysed using Python algorithms.

5.2 Storage density of CD, DVD and Blu-ray

Using the AFM setup, we analyse the material properties of CD, DVD and Blu-ray discs. As the discs are used to record information with precise groove row, using dynamic imaging, we measure the grooves' dimensions, focusing on length, width, and depth. Using this data, we calculate and compare the information storage density for each disc using Python algorithms.

To investigate further, we propose a research question "investigating image artifacts in atomic force microscopy on sharp step boundaries"[3].

5.3 Nanoindentation

Using nanoindentation, described in Section X, we measure and compare the stiffness of each of the three given surfaces: two plastic-coated surfaces and silicon, as well as any other noticeable differences that can be used to distinguish between the three samples.

5.4 Material properties of various samples

We analyse the material properties of carbon nanotubes, staphylococcus aureus, and the chip structure of silicon, using the AFM setup in its static mode.

5.5 Lithography

If it is possible given the time constraints, we plan to use lithography to modify a CD ROM surface, ensuring to take images before and after the modification.

6 General lab schedule

The general lab schedule can be presented as follows:

- 07/06: 9am-11am;
- 07/06: 3pm-5pm;
- 08/06: 11am-3pm;
- 09/06: 9am-1pm;
- 09/06: 2pm-3pm;
- 12/06: 12pm-3pm;
- 12/06: 4pm-5pm,

where each time-slot will be attended by both students.

References

[1] G. Binnig, C. F. Quate **and** C. Gerber, "Atomic force microscope," *Physical review letters*, **jourvol** 56, **number** 9, **page** 930, 1986.

[2] B. Voigtländer, *Scanning probe microscopy: Atomic force microscopy and scanning tunneling microscopy.* Springer, 2015.

[3] F. Gołek, P. Mazur, Z. Ryszka **and** S. Zuber, "Afm image artifacts," *Applied Surface Science*, **jourvol** 304, **pages** 11–19, 2014. DOI: `10.1016/j.apsusc.2014.01.149`.