ISSN 1062-8738, Bulletin of the Russian Academy of Sciences. Physics, 2013, Vol. 77, No. 8, pp. 969–971. © Allerton Press, Inc., 2013.
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Development and Application of an AFM Probe Soft Approach Method

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Abstract—The soft approach of an AFM probe to a sample's surface is examined. Our method allows the approach of extremely fragile probes and differs advantageously from other known methods in its much lower degree of impact on the sample. At the same time, the proposed method is not much slower than the fastest available methods. Corresponding experimental results are presented.

DOI: 10.3103/S1062873813080236

INTRODUCTION

The tools of atomic force microscopy (AFM) are now widely used in biology, microelectronics and other fields of science and technology. The AFM probe is often the most easily damaged element of the whole measuring system. A mandatory condition that ensures successful (i.e., reliable and reproducible) AFM measurements is a soft approach of the probe tip to a sample's surface. The aim of this work is therefore to solve this problem.

KNOWN METHODS FOR THE APPROACH OF AN AFM PROBE TO A SURFACE

Various methods are known for the approach of an AFM probe to a surface [1–3]. The most common technique employed in many commercial devices is as follows: The feedback circuit of the device is preconfigured for a specific mode, with the vibration amplitude of flexible cantilever of AFM probe used as a feedback circuit input signal for the semi-contact mode. Mechanical excitation is applied to the probe with the fundamental resonant frequency of a flexible cantilever; the operating point of the feedback circuit is chosen to be less than the amplitude of free oscillations, and the feedback circuit is closed. The stepping motors then start bringing the probe to the surface. The scanner moving the sample or the probe sensor vertically and guided by a feedback loop is brought fully forward during the approach. The stepping motors then stop, and the approach is considered complete when the scanner is fixed in the middle of its range. Such an algorithm ensures a very rough approach because the stepping motors continue to work when the probe is already in contact with the surface.

The other known method of probe approach [2] is rarely used due to its slow operating rate and its more complex implementation. This technique is similar to the one above, but is characterized there being no continuous work of the stepping motors. Before several motor steps toward the surface are made, the feedback circuit is opened and the scanner is completely retracted. Once the motor steps are finished, the feedback circuit is closed and direct contact between the probe and the surface is determined by the position of the extended scanner. These stages are repeated until the scanner is in the middle (operating) position after the next circuit closing. This method ensures a softer probe approach than the above technique, but the approach time increases by as many as several tens of times.

A disadvantage of both techniques is that the operating point of the feedback circuit is chosen empirically before the approach begins. If the point value is close to the probe's free oscillations, a false alarm can sound because of amplitude drift, and the approach will stop before it is fully complete. The drift could be due to electrostatic interaction between the probe and the sample or by damping due to compressed air between the probe and the sample. If the value of the chosen operating point is too small, damage to the probe or the sample is possible during an approach.

The method proposed in this work is free of these disadvantages: the approach rate is high and the experimental results demonstrate the safety of the most fragile probes as they approach a surface.

IMPLEMENTING THE SOFT APPROACH METHOD

According to the proposed method, the approach process is divided into two stages to reduce the time required. In the first, stepping motors bring the probe to a surface at high speed with an amplitude drift of the resonant vibrations of the AFM probe flexible cantilever usually observed at a few micrometers above the

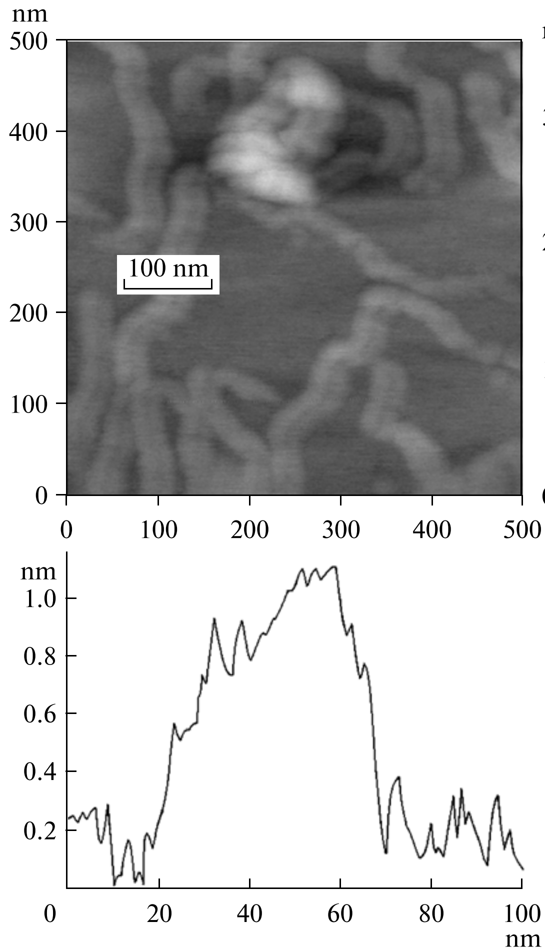

Fig. 1. DNA image obtained after AFM probe approach using the technique in [2].

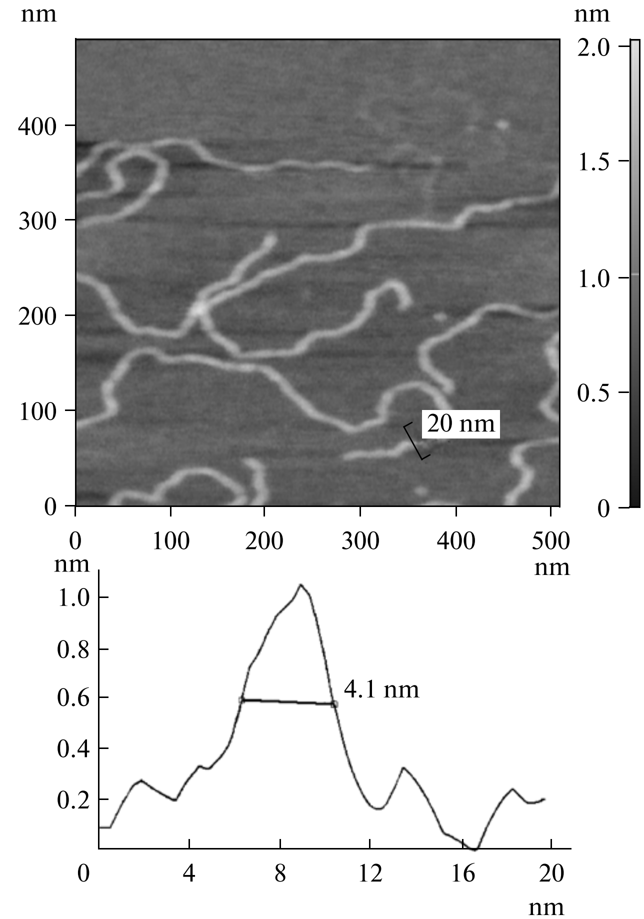

Fig. 2. DNA image obtained after AFM probe approach using our technique.

surface. If there is no amplitude drift under normal conditions, the conditions for the emergence of long range forces between the probe and the sample can be created artificially, e.g., by supplying the potential difference between them. After the vibration amplitude changes significantly (the change is usually 10–15% until the probe touches the surface), the second stage of the approach begins.

At the second stage, the approach proceeds step by step; it is very similar to the above approach algorithm [2]. In a similar way, before several motor steps toward the surface are completed, the feedback circuit is opened and the scanner is retracted; once the steps are complete, the feedback circuit is closed and contact between the probe and the surface is confirmed automatically by the position of the pushed scanner. The steps are performed until the scanner is in the middle (operating) position after the next closing of the feedback circuit. The originality of the technique proposed in the paper lies in the way of controlling the scanner at each step.

The main problem when we attempt to use the optimum approach is finding the moment when the probe is in contact with the surface. A good sign for determining this moment an abrupt change in the vibration phase [4] that corresponds to the optimum value of the feedback circuit's operating point. In the proposed approach method, the operating point value falls gradually (starting from the amplitude of free oscillations) after the feedback circuit closes in order to enable the feedback circuit to respond to these changes. As a result of reducing the operating point, either the scanner is advanced or there is an abrupt change in the vibration phase; the former means that the surface is beyond the reach of the probe at the current position of the stepping motors, while the latter indicates that the optimum operating point value has been achieved and the probe approaches the sample.

If at the stage of advancing the scanner the reduction of feedback circuit operating point produces an abrupt change in the vibration phase, the approach is complete. If the scanner is fully advanced but there is no abrupt change in the phase, the feedback circuit is opened and several steps toward the surface are made with the scanner being retracted. The feedback circuit is then closed and the selection an operating point is repeated. It is performed until an abrupt change in the phase occurs at a certain stage of scanner advance.

RESULTS AND DISCUSSION

Our method was practiced on an Ntegra Prima scanning probe microscope (ZAO NT–MDT, Russia) with the supplied software.

Each approach was entirely automatic. DLC Supersharp probe sensors (ZAO NT–MDT) were used to control the result of the algorithm with a typical tip size of 1 nm, that allows us to use these probes to achieve ultra-high lateral resolution. A DNA molecule fixed on mica was used as our test sample. In order to compare the techniques, scanning after each approach was performed both by the familiar method described above [2] (Fig. 1) and by our method (Fig. 2). Figure 1 shows the cross section of the DNA molecule to be ~40 nm, evidence of AFM probe damage during an approach. At the same time, we can see that the DNA cross section in Fig. 2 is ~4 nm, which approximately matches the molecule's expected width (allowing for the width of SPM probe).

CONCLUSIONS

Our experiments showed that the proposed soft approach methods makes it possible to bring fragile probes close to a surface and to obtain highly reproducible measurement results. The technique not only brings the probe to the surface, but also automatically tunes the optimum value of the feedback circuit's operating point. The way of choosing the optimum value of the operating point during an approach is universal and can be applied to the contact and other modes of microscope operation.

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Translated by D. Lonshakov