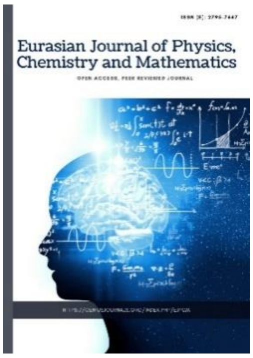


# Modes Of Atomic Force Microscopy In Investigation Of The Surface Topography Of Nickel-Doped Silicon Solar Cell.

**Adilbek Sayt-Muratovich Kulumbetov**
PhD student of the Department of Methods of teaching physics and astronomy
Chirchik State Pedagogical University.

ABSTRACT

This work describes the operating modes of atomic force microscopy (AFM), as well as its application in the study of various impurity silicon. The difference between using AFM in contact and semi-contact mode is shown. It is assumed that the combined use of these two modes in the study of impurity silicon is optimal.

**Keywords:** atomic force microscopy, silicon, nickel-doped silicon, solar cell, silicon solar cell

## Introduction

In recent decades, various methods have been developed to study the electrophysical properties and structure of materials. Scanning and transmission electron microscopy (SEM, TEM), which make it possible to study the surface and structure of materials with high resolution. However, the use of these methods requires additional preparation of materials and also has a destructive effect on samples. In this regard, this paper will consider the modes of operation of the atomic force microscopy (AFM) method, such as: contact mode, non-contact mode, semi-contact mode.

In contact mode [1], the AFM probe is in physical contact with the sample. During scanning, the force of the contact interaction bends the cantilever in accordance with the change in the topography of the sample surface. When the most common designs of AC microscopes operate in contact mode, the repulsive force usually compensates for two forces that press the probe against the surface of the sample. Firstly, it is the elastic force of the cantilever itself, which depends on the direction and degree of bending cantilever, its constant elasticity. In addition, when scanning for Due to the presence of a thin layer of water on the surface of the sample, a capillary force appears in the air.

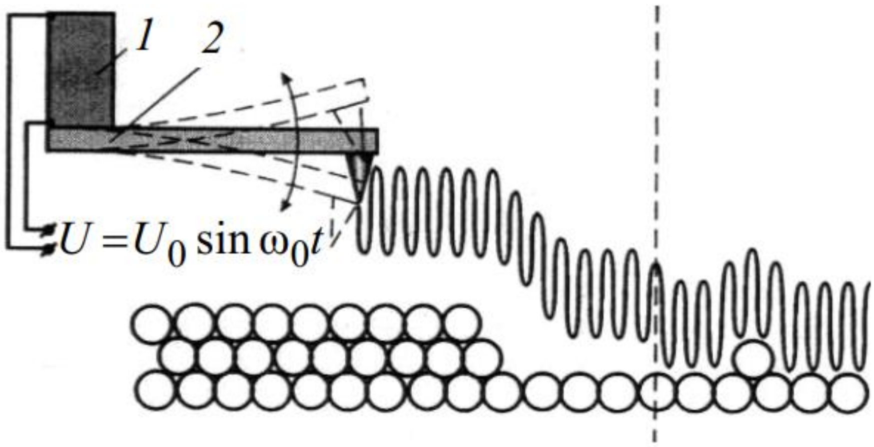


Figure 1. Two dynamic modes AFM: non–contact (a) and semi-contact (b): 1 - high-frequency piezoactuator of forced oscillations of the cantilever at its own frequency; 2 – cantilever [2]

The possibilities of atomic force microscopy significantly expand the dynamic methods of surface relief registration. In this mode, the probe is set in oscillatory motion at the natural resonant frequency $\omega_0$ of the cantilever 0 (Fig. 1). The parameters of forced oscillations (amplitude A, resonant frequency ω, phase shift between the oscillating force and the displacement of the probe), all other things being equal, depend on the average distance between the tip of the probe and the surface (Fig. 2).

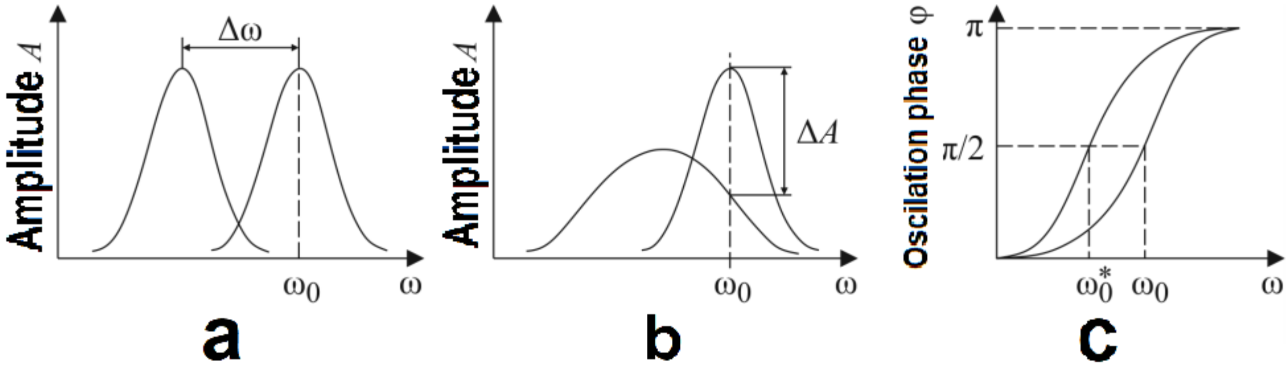


Figure 2. Three methods for recording the interaction of the probe with the sample surface:
a – by shifting the resonant frequency (in high–quality vacuum systems);
b - by reducing the amplitude of forced vibrations due to changes in Q–factor and resonant frequency (when working in air with damped cantilevers);
c - by shifting the phase of the cantilever vibrations due to interaction with the surface under study

Dynamic methods are also divided into the following 2 types (according to which parameter of the forced vibrations of the cantilever of the probe sensor is used as the OS signal)[3]:
– amplitude modulated atomic force microscopy (AM-AFM);
– frequency modulated atomic force microscopy (FM-AFM).

In AM-AFM mode (often called semi-contact) during registration The amplitude of the oscillations is used as a feedback parameter for the surface relief. For this purpose, rigid cantilevers with sharp probes at the end are used, in which vibrations are excited at a resonant frequency. Additionally, local changes in the properties of the surface material can be qualitatively visualized when registering the phase shift between the "rocking" signal and the vibration of the probe during the scanning process.

In FM-AFM mode, the probe of the AC microscope "swings" with a fixed amplitude at a resonant frequency, which depends on the forces of interaction between the probe and the sample surface. The spatial dependence of the

frequency shift, the difference between the actual resonant frequency and
the resonant frequency of the free cantilever are a source of topographic contrast. The surface image is formed by profiling the surface with a constant frequency shift.

The initial n-type silicon doped with phosphorus with a concentration of $N_P=1.5*10^{14}cm^{-3}$ was studied [4]. The concentration of zinc introduced by high-temperature diffusion was $N_{Zn}=1*10^{14}cm^{-3}$. To study the topography of the Si surface, MultiMode SPM (Veeco Instr., USA) was used in a semi-contact mode. The measurements were performed under environmental conditions using a silicon probe (cantilever) RTESP (Veeco Instr., USA) with the following characteristics: console length – 15mkm; tip radius – 10nm; stiffness – 40N/m; resonant frequency – 300 Hz.

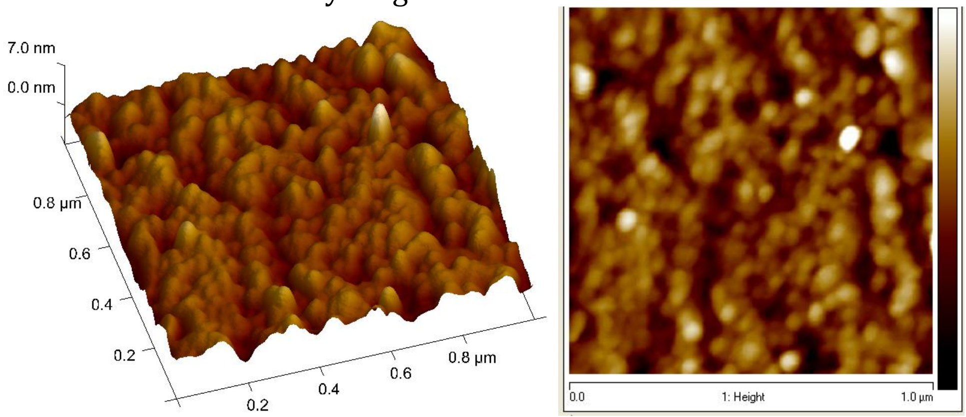


Figure 3. 3D image of the topography of the surface of the sample n-Si<Zn>.
The frame size is $1mkm^2$.

It is assumed that since zinc deposited on dislocations is etched faster than the defect–free part of silicon, the depressions on the silicon surface correspond to areas with increased zinc concentrations (precipitates), and the roughness to the rest of the silicon without these precipitates.
The morphology of the surface of porous silicon obtained by directional electrolytic etching by scanning atomic force microscopy has been studied [5]. A typical primary frame is shown in Fig.4. It shows a discontinuous film consisting of nanoparticles of various sizes. There is practically no interference on the frame, which indicates the absence of loose particles on the surface. Soft median filtering with a 1x3 matrix only slightly improved the frame (Fig.5).

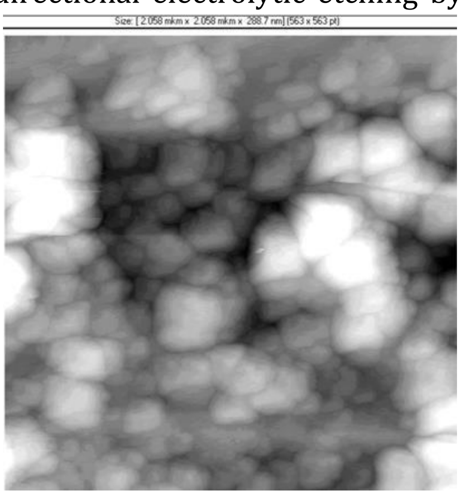

Fig. 4. The primary frame.

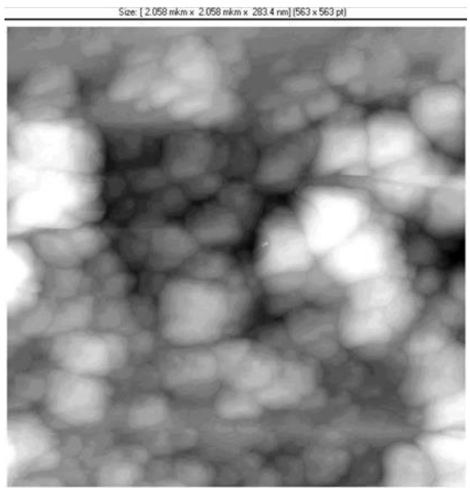

Fig.5. The frame after processing with 1x3 median filtering.

Work [6] presents the results of a study of the effect of temperature and annealing atmosphere on the properties of the near-surface Si layer doped with Zn ions at a dose exceeding the amorphization threshold.

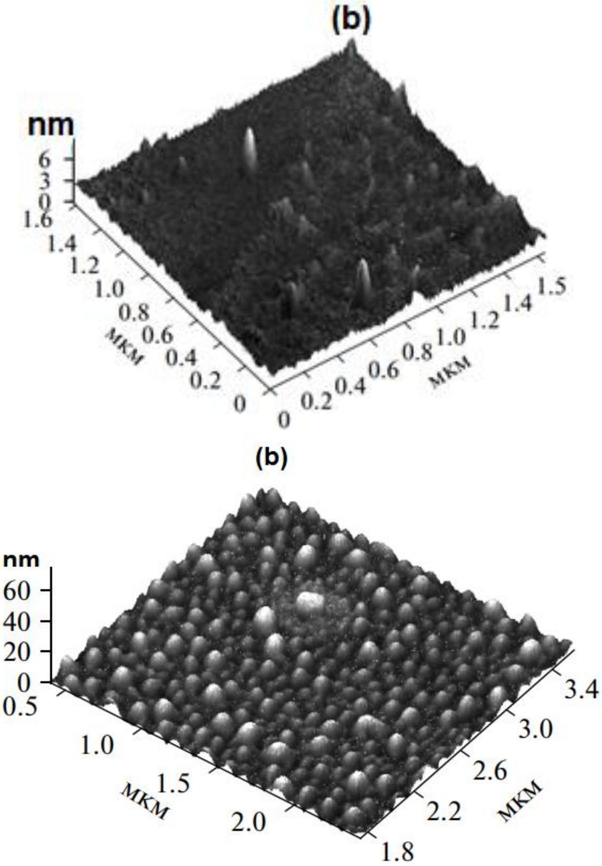


Fig. 6. AFM image of the surface of the Si sample implanted with Zn:1 ions – after the implant 2 – after annealing at 800 ° C in an inert medium (Ar) for 1 hour.

Figure 3 shows the 3D topology of the surface of the studied samples obtained in the AFM mode (a – after zinc implantation and b – after annealing at 800 °C). 3a shows no features on the implanted surface: it is fairly uniform with a roughness of no more than 10 nm. Figure 3b shows that the surface is clearly structured. It shows nanoparticles with a diameter of 10-20 nm and a height of up to 50 nm, representing zinc oxide formed during annealing at a temperature of 800 ° C.

## Methods

Experiments to study the topography of the surface of a nickel-doped silicon solar cell were carried out on an Agilent 5500 AFM atomic force microscopy. The design of this 5500 AFM microscope allows the use of many different scanning techniques and multi-purpose scanners, ensures high accuracy of measurement from the surface of the material at the nanoscale level and scale. In comparison with a scanning electron microscope, an atomic force microscope has a number of advantages, in particular, atomic force microscopy allows you to obtain a truly three-dimensional surface relief.

During the experiments, the samples are installed on a substrate, then (see Fig. 7). The substrate with the sample is installed under the cantelever, the AFM system automatically brings the substrate closer to the cantelever and scans the surface of the sample.

Fig. 7. AFM substrate for research samples.

The cantilever frequency is being pre-adjusted. In the AFM control program, Picoview1.10 (Fig. 8), select the scan mode.

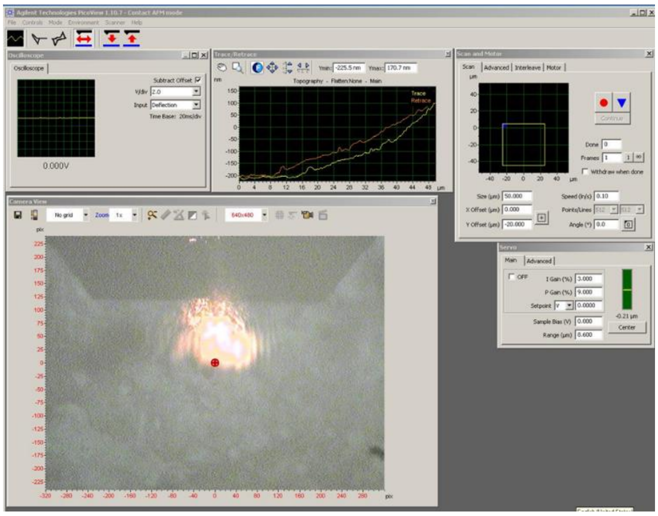

Fig. 8. AFM control program, Picoview1.10.

The processing of the results includes various image filters. First, the correction of the line is performed, which appear in the image due to the tilt of the sample, external vibrations. The image is filtered using the filter operator, where distortions caused by the presence of various post-root particles on the sample surface are removed.

## Results And Discussion

AFM studies have shown that a sample of nickel-doped silicon does not show particles during contact measurements and the surface is smooth (Fig. 9a).

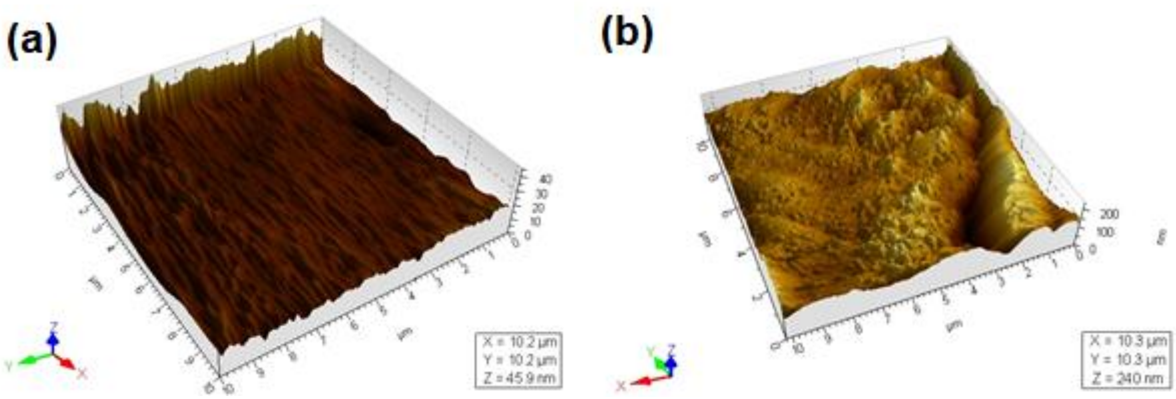

Fig. 9. AFM topography in semi-contact mode (a). AFM topography in semi-contact mode carried out after the preliminary contact mode.

We conducted the same sample in contact mode, then conducted it again in semi-contact mode (Fig. 9b). Presumably, the contact mode removes contaminated particles from the sample surface. Then, the semi-contact image allows to get a high-resolution image of the particles.

**REFERENCES:**


1. В. А. Мошников, Ю. М. Спивак, П. А. Алексеев, Н. В. Пермяков
2. Атомно-силовая микроскопия для исследования наноструктурированных материалов и приборных структур: учеб. пособие. СПб.: Изд-во СПбГЭТУ «ЛЭТИ», 2014. 144 с.
3. Головин Ю. И. Введение в нанотехнику. М.: Машиностроение, 2007.
4. Garcia R., Perez R. Dynamic atomic force microscopy methods // Surf. Science Reports. 2002. 47. P. 197–301.
5. О.Н.МАКЕЕВ., В.В.ПРИВЕЗЕНЦЕВ. МИКРОСТРУКТУРЫ В КРЕМНИИ С ПРИМЕСЬЮ ЦИНКА, ВЫЯВЛЕННЫЕ С ПОМОЩЬЮ АТОМНО-СИЛОВОЙ МИКРОСКОПИИ // https://www.rusnor.org/nanoworld/pro/7435.htm
6. Половинкина Ю. В. Исследование поверхности пористого кремния, полученного методом направленного электролитического травления, с помощью сканирующей атомно-силовой микроскопии. ГОУ Московский инженерно-физический институт (ГУ). https://megalektsii.ru/s41123t4.html?ysclid=lqrfxv4j2n894691467
7. В. В. Привезенцев, В. С. Куликаускас, В. В. Затекин, П. Н. Черных, Д. В. Петров, А. В. Макунин, К. Д. Щербачев ФОРМИРОВАНИЕ НАНОЧАСТИЦ В КРЕМНИИ МЕТОДОМ ИОННОГО ЛЕГИРОВАНИЯ ЦИНКОМ С ПОСЛЕДУЮЩИМ ТЕРМИЧЕСКИМ ОТЖИГОМ. Поверхность. Рентгеновские, синхротронные и нейтронные исследования. 2012, 30-34.