Project 3:

Surface roughness and sample coating (AFM and SEM)

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Abstract

Imaging tools such as scanning electron microscope (SEM) and atomic force microscope (AFM) can be used to produce high-resolution topographic images of specimens and hence are well suited for imaging surface roughness of investigated sample. We have studied the SEM and AFM technique for investigation of surface roughness and the effect of platinum and golden coating on roughness. It was seen that this types of coating are favourable for investigated sample.

1. Introduction

Surface texture is an important issue when the main interest is to understand the nature of material surfaces and it plays an important role in the functional performance of many engineering components. The American National Standards Institute’s B46.1 specification defines surface texture as the repetitive or random deviation from the normal surface that forms the three dimensional topography of a surface. Before 1990’s the measurement of sample surface was obtained by a contact stylus profiler (Whitehouse et al., 1975) that had limitations including a large stylus radius, a large force and low magnification in the plane and may have misrepresented the real surface topography owing to the finite dimension of the stylus tip (Vorburguer & Raja, 1990).

On the ultramicroscopic scale of surface, atomic force microscopy (AFM) has been developed to obtain a three-dimensional image of a material surface on a molecular scale. This method was invented by Binning, Quate, and Gerber, and has become an important tool for imaging surfaces.

In AFM, a sharp tip at the end of a cantilever is scanned over a surface. While scanning, surface features deflect the tip and thus the cantilever. By measuring the deflection of the cantilever, a topographic image of the surface can be obtained. With sufficient sensitivity in the spring deflection sensor, the tip can reveal surface profiles with subnanometer resolution. In other word, AFM uses a cantilever probe tip to detect weak forces on a specimen.

While the cantilever moves in the x-y direction, the pointed end of the cantilevered probe can either make contact with the specimen surface or function in a non-contact mode. In contact mode, the scanner moves along the x-y direction and detects the extremely small repulsion forces between the probe and the surface of the specimen and moves up and down vertically following the shape of the surface. All the data can be collected by using lasers, piezo electric sensors or photoelectric sensors. The piezo electric sensors send a voltage to a transducer whenever a movement from the cantilever is made. The photoelectric sensor is able to measure movements based on changes in the incident angle made by cantilever movements. The principle of the laser works in the same manner as the photoelectric sensor. Specimens can be observed in non-contact, tapping, and contact mode. Only in contact mode or in a state of strong repulsive forces, can the highest resolution be achieved (Bai 1999).

Also a Scanning Electron Microscopy (SEM) can be used for imaging surface roughness. Using this method it is possible to get some more realistic image about the surface roughness. A SEM is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The
electron beam is generally scanned in a raster scan pattern, and the beam’s position is combined with the detected signal to produce an image.

SEM can achieve resolution better than 1 nanometre. Specimens can be observed in high vacuum, low vacuum and in environmental SEM specimens can be observed in wet conditions. The most common mode of detection is by secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons is a function of the angle between the surface and the beam. On a flat surface, the plume of secondary electrons is mostly contained by the sample, but on a tilted surface, the plume is partially exposed and more electrons are emitted. By scanning the sample and detecting the secondary electrons, an image displaying the tilt of the surface is created.

Role of coating is also very important for studying the surface roughness. Different methods can sometimes destroy the sample and the coating can be made to prevent samples from damage. From the other side, the coating has a finite thickness and some roughness itself, which may sometimes cover the smallest details of the sample and lead to false interpretations.

In this project work, the surface roughness of a modern microcontroller was examined. Microcontrollers are small computers used in many different electrical devices, such as mobile phones, cars, measurement devices, and many others. The microcontroller examined was based on ARM-technology, which is nowadays used for example in mobile phones, tablet computers and cars. The smallest manufactured details in modern microcontrollers are as small as 22 nanometres. In this project we studied the surface roughness of Atmel SAM3-microcontroller, which is presented in Figure 1.

![Atmel SAM3-microcontroller](image)

Figure 1. An image of an Atmel SAM3 –microcontroller.

Because of the high density and small size of the details in the microcontroller, it is essential to know the surface roughness of the device. Semiconductor devices are manufactured in clean rooms and they are extremely sensitive to impurities, so everything inside the semiconductor device should be as smooth and clear as possible. To study the surface roughness of the sample, AFM and SEM techniques were used.

2. Experimental Details

The examined integrated circuit was packaged into a plastic pack. The encapsulation material around the silicon chip was removed using a hot air gun and wrenches. Hot air makes the plastic package fragile and thus easy to remove. The encapsulation removing process is presented in Figure 2.
2.1. Experimental setup

The imaging was done at the microscopy centre of the Aalto University. Two different imaging techniques and devices were used, a scanning electron microscope and an atomic force microscope. The type of the used AFM was Veeco Dimension 5000 Scanning Probe Microscope with a Nanoscope V controller (Digital Instruments, Inc.) and the type of the used SEM was Zeiss SIGMA VP. The images of the used devices are presented in Figure 3.

In the AFM imaging, the tapping mode was used to prevent the damage to the sample surface. The used tip was an Al-coated silicon AFM tip (NSC 15/AIBS, MicroMasch, Estonia) with a tip radius of 10 nm.

The imaging parameters for the SEM were 2 kV accelerating voltage, 30 μm aperture standard size, and 4.8 mm working distance. Secondary electron detector was used to produce the image.

The aim of the project was to study the surface roughness of the sample. Characterization was done in three main steps: first the samples were measured without coating with both AFM and SEM, after that the samples were coated and measured again with AFM and SEM.

2.2. Sample observation without coating

Samples were firstly located on top of a Silicon chip with using carbon tape. On this way samples without coating were ready for imaging by AFM.
To image samples with AFM, some high precision preparations had to be made. The small cantilever, which included the scanning tip, was installed to the cantilever holder. After that, the software was started and all the software preparations neatly made as described in the device user manual.

Imaging with SEM also required some preparations. The sample was positioned on special device specific sample holder. The electron gun and the vacuum pump were switched off to open the specimen chamber. The sample was inserted into the chamber and the door closed. After that a vacuum was pumped to the chamber and the gun switched on. The sample was moved inside the microscope using the motorized sample holder. When the interesting area of the sample was found the lenses were aligned to focus the image and a high quality image saved using the microscope user interface.

2.3. Coating the sample
Samples were coated by sputtering using EMITECH K100X. The used ion current for the sputtering was 30 mA and the sputtering time 1 minute. In sputtering, the samples were bombarded with high speed particles. The sample was placed on the bottom of the instrument making the anode. The platinum or gold target was placed on top of the sputtering chamber making the cathode for the system. Emitted atoms from the cathode were sputtered on the sample through the argon gas inside the sputtering chamber. On this way samples were prepared for next round of imaging.

2.4. Sample observation with coating
Samples were placed in sample holders and then imaged by SEM and AFM. Processes in this observation are the same as was described in 2.2.

3. Results and Discussion
As it was mentioned before, characterization with AFM and SEM were done during 2 main processes: measurement the surface roughness of samples without coating and measurement the surface roughness of sample with coating.

3.1. AFM characterization
In AFM, the tapping mode was used to prevent the damage to sample surface. The samples were first imaged without coating and after that coated with gold and platinum. Figures 4 and 5 show the 3D images produced from the AFM data using Gwyddion software.
From the figures 4 and 5 we can see that the coating makes the smooth silicon surface rougher. The z-scale in the figures is the same, so we can see the increase of the roughness due to the coating. It is hard to analyse the actual thickness of the coating from the 3D AFM images. However, it can be seen that the smoothness of the original silicon chip was covered with the metal particles of the coating.

### 3.2. SEM characterization

At first the SEM imaging was made for the samples without coating. Figure 6 shows the SEM images of the samples before coating.

During imaging the samples without coating, some charging was noticed. At some parts of the sample, charging even destroyed the sample a little. Also is noticed that on smooth surfaces are positioned bigger parts of microcontroller construction which make main roughness of sample surface.

After coating, it was possible to increase the magnification. Because no charging effect was detected, it was possible to increase the magnification up to 60 000. At the magnification levels of about 60 000 it was possible to detect the coating layer, which was not smooth but deposited in the form of small islands. Figures 8 and 7 show the SEM images of the coated sample.
Figure 7. SEM images of the sample with gold coating (left) and platinum coating (right).

Figure 8. SEM images of the sample with gold coating in higher magnification. Smooth surfaces become rough because of the presence of golden particles on the surface of the sample.

Because the imaged sample was very smooth, the coating did not cover the small details of the surface. Because the coating did not cover the details of the sample, coating suits very well for the samples like semiconductors.

4 Conclusions
From this work can be concluded that AFM technique is very nice technique for observation of surface roughness. It gives very nice 3D images of the surface of the sample and based on the height and phase images the height of the surface roughness can be observed. It was seen that SEM is also a very useful technique. Using SEM, it is possible to get realistic image of the surface roughness fast and easily.

During SEM observation some charging problems were noticed. This was very gently solved using platinum and gold coating. From SEM and AFM images can be concluded that the coating was very favourable for observation of surface roughness of the examined Atmel SAM3 -microcontroller.

The surface of the examined microcontroller was very smooth. The smallest details in the sample were about 500 nm size, so the coating did not cover the interesting structures and details of the
sample. Because the coating did not cover the details of the sample, coating suits very well for the samples like semiconductors.

Normally the thickness of the coating is 5 to 20 nanometers. The roughness of the coating also varies between coating materials, which can be seen from the Figure 7. However, because the examined sample was very smooth, in our case the roughness of the coating material did not have an effect to the imaging results.