AFM characterization of aerotaxy nanowires

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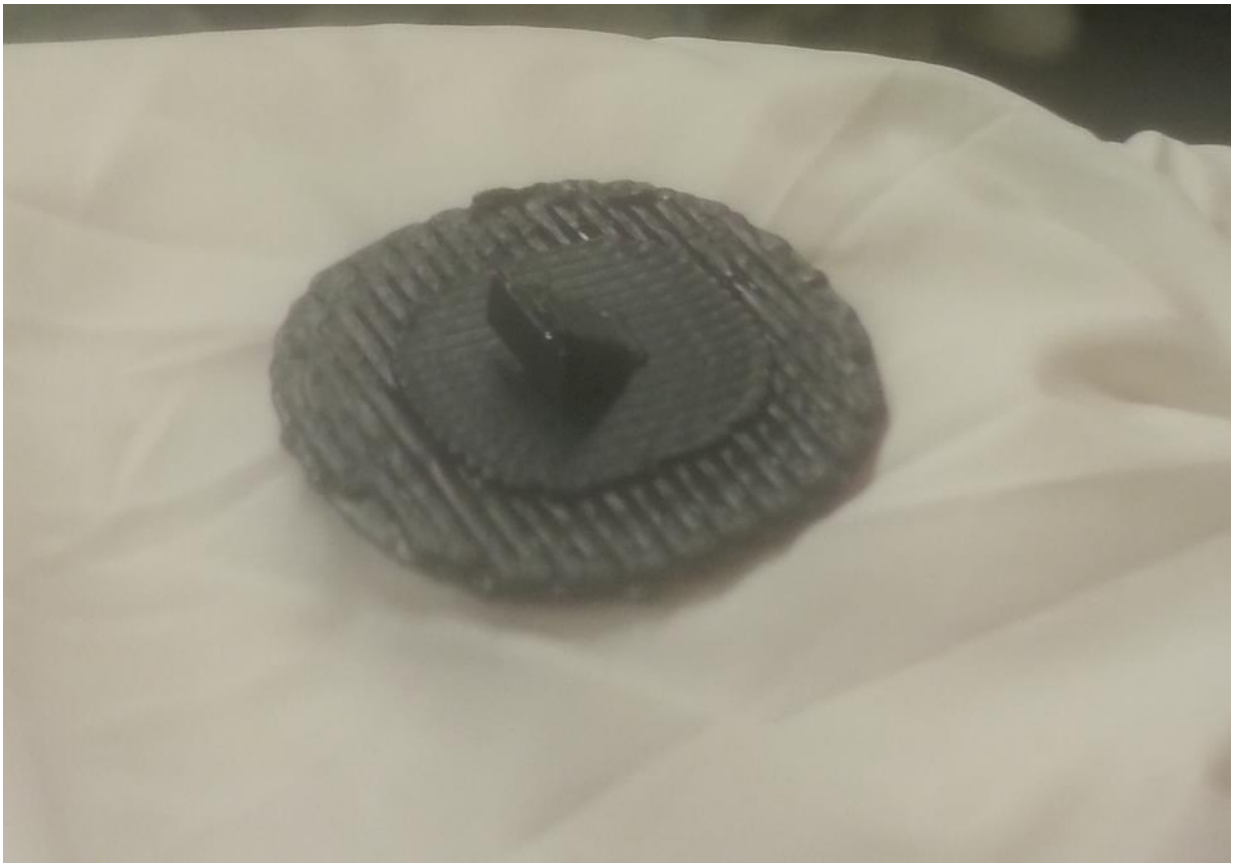

Figure 1: The sample mounted on a 3D-printed sample holder.

Introduction

Aerotaxy is a new method for growing semiconductor nanowires without having them grow on a substrate. It works by having seed particles in a tube furnace and then adding precursors which will cause nanowires to grow from the seed particles. The advantage is that the speed of the growth of the nanowires can be up to 1000 times faster than the method where the wires are grown on a substrate. When the growth is finished, the wires can be collected in a filter, deposited on a substrate or dispersed in a liquid [1]. Recently, p-doped aerotaxy nanowires have been sucessfully grown. However, there is not an effective method to characterize the doping profile in the doped nanowire.

A scanning tunneling microscope (STM) characterization is used to characterize the doping profile, but it requires a flat surface in order to work. If a cross section of a nanowire is going to be characterized with the STM, first the nanowires need to be cut and the flat cross sections of the wires need then to be localized. The purpose of this project was to localize these flat cross-sections with the help of an atomic-force microscope (AFM) so a STM characterization can be carried out. First, the aerotaxy grown nanowires were deposited on a substrate. Then, the substrate was spin coated with a polymer and cut to expose the cross-sections. These cross-sections were then analyzed with scanning electron microscope (SEM) and AFM.

Method

GaAsP aerotaxy nanowires (80 nm in diameter) were grown and deposited on a Si substrate previously. One drop of polymer PMMA (950 A5) was put on the nanowire sample. The sample was then put in a spin coater and spun at 3000 RPM for 45s to make the polymer as evenly distributed on the sample surface as possible. After that the sample was moved over to a hot plate at 95°C for 15 minutes to evaporate any excess polymer from the surface of the sample. Then the sample was cut with a pen with a small diamond tip. This was done to expose the cross-section of the sample and hopefully to see cross-sections of nanowires.

SEM is a technique where a focused electron beam scans a sample. The SEM is usually used to detect the secondary electrons which are the electrons emitted by the atoms that are excited by the electron beam. The detector detects the number of emitted electrons which depends on the surface material and the angle the beam hitting the surface of the sample which translates to the samples topography. [2] The sample was then put into a SEM where the cut cross-section was analyzed in in-lens mode. This was done to examine if there were any nanowire cross-sections present. The thickness of the polymer was measured and nanowires were localized.

A schematic view of an AFM setup is shown in figure 2. In an AFM, a sharp tip moves closely over a surface. The microscope uses the atomic forces to map the tip-sample interaction. A laser is shone at the cantilever (on which the tip is) and the light is reflected to a position detector. By measuring the deflection of the lever and knowing the stiffness of it the forces can be calculated using Hooke's law

$$F = -kz$$

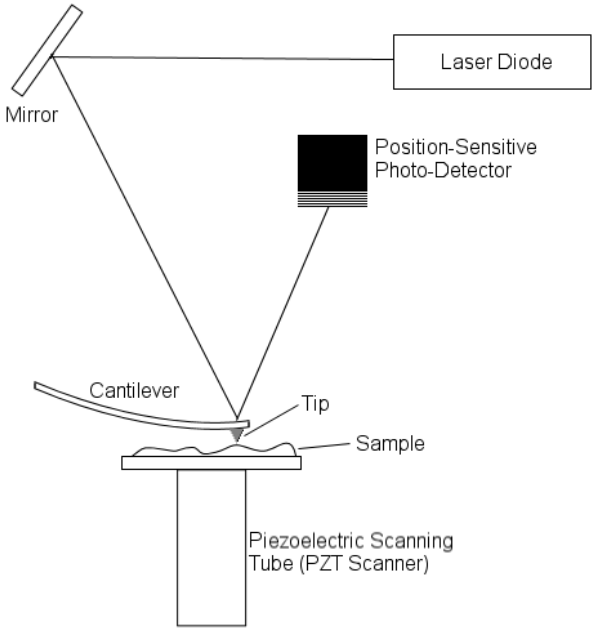

Figure 2: A schematic view of an AFM setup. The tip scans the surface and the laser deteflection from the cantilever is detected by the photo detector which will create an image of the surface. [4]

, where F is the atomic force between the tip and sample, k is the stiffness of the cantilever and z is the distance the lever is bent [3].

To be able to examine the sample in an AFM, a sample holder was needed. One was made by using 3D-printing. The sample would later be attached to the sample holder to be able to expose the cross-section in the AFM.

With the sample mounted on the sample holder, it was examined in the AFM. First the surface of the polymer part was studied and afterwards the cross-section. With help of the AFM images the roughness of the surface was analyzed.

Result

SEM Images

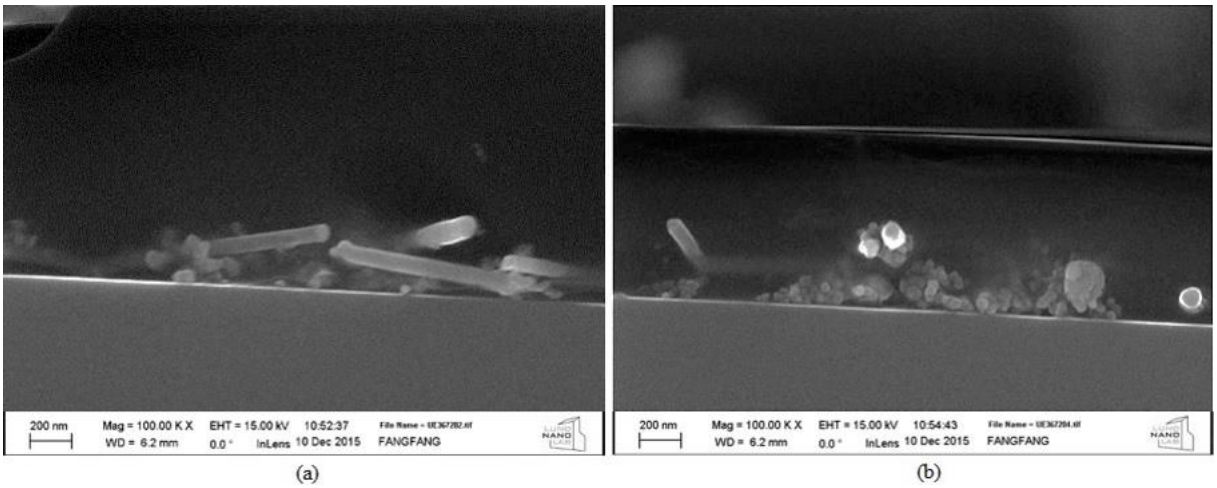

Figure 3: Here the cross-section of the sample is presented. In figure (a) nanowires in a lateral position is shown and in (b) cross-sections of nanowires are visible.

In figure 3(a) we can see the nanowires lying on the substrate inside the polymer. No cross-section of nanowires are present and it looks like some nanowires are sticking out of the polymer, creating a rough surface. The polymer appears dark in the picure because of it being non-conductive. A non-conductive material builds up a static charge on the surface and this is called the charging effect. The static charge reduces the number of electrons interacting with the sample thus detoriating the sample image. Because the nanowires are conductive, we can see them clearly in the SEM images.

In figure 3(b) we can see what appears to be cross-sections of nanowires. By looking at the bottom right nanowire we measured the diameter to be around 80 nm. This implies that this might be a cross-section of a nanowire.

From figure 3(b) the thickness of the polymer was also determined. We measured between the lateral lines in the image and got the thickness to be 1.5 µm. This couldn't be done using figure 3(a) because the polymer had been distorted by the electron beam.

AFM Images

In figure 4 the surface of the sample is shown and the maximum roughness measured to be 147 nm. In this figure the range in scale was between 0 to 100 nm. The width of the pink structure in the middle of figure 4 is about 1 µm which implies that it's not a nanowire. It could be an artifact, maybe from sample damage. The smaller green/yellow dots might be nanowires sticking out of the sample since it's size corresponds to be same as the nanowires.

Figure 5 shows the cross-sectional area with the range in roughness between 0 and 1000 nm. First we tried to scan using a range in scale between 0 and 500 nm, but the trace and retrace curve didn't match. Trace means the information the system registers when the tip scans in the forward direction and retrace is the corresponding information in the backward direction. This unmatching meant that the AFM tip didn't trace the surface information correctly, which wouldn't give an accurate value of the surface reoughness. For the measurement with range in roughness between 0 to 1000 nm we got a value around 200 nm which we think is not correct. If 200 nm was a correct value, this result should have been received in the 0 to 500 nm (roughness) measurement.

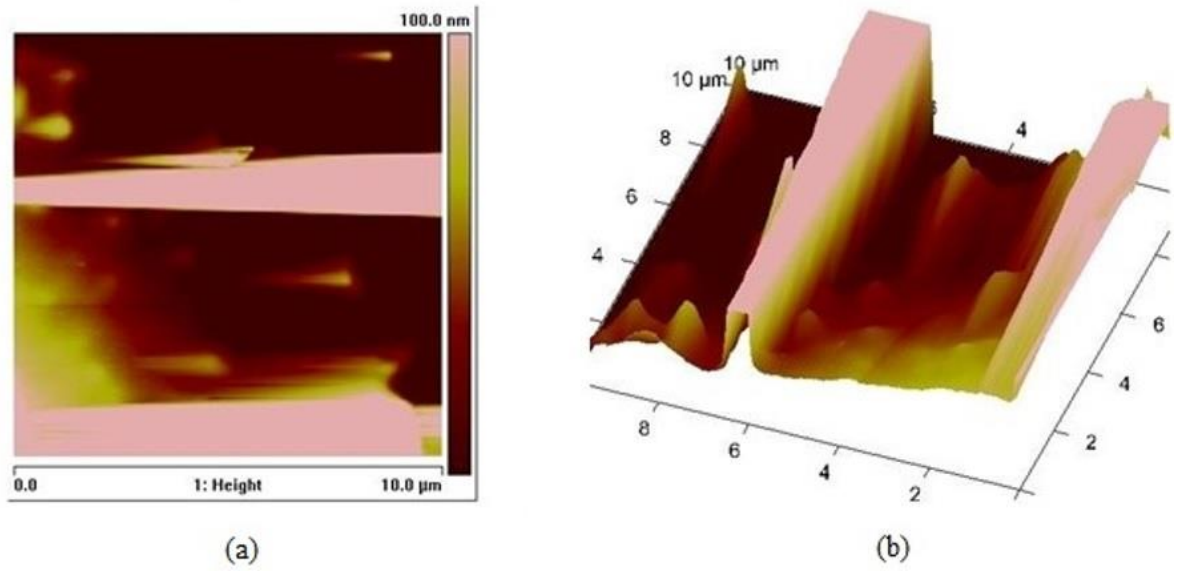

Figure 4: AFM images of 10×10 surface of the sample (a) 2-D image of the scanned area (b) 3-D view of the scanned area

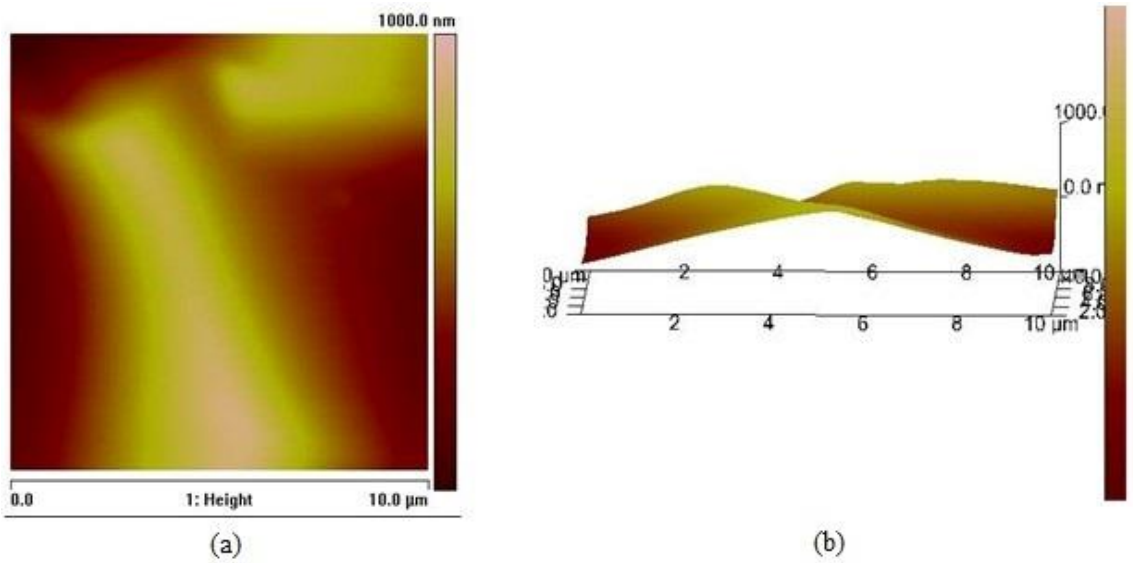

Figure 5: AFM image of the 10✕10 µm sample cross-section (a) 2-D image of the scanned area (b) 3-D image of the scanned area.

Conclusion

In this project, cross-sections of aerotaxy grown nanowires have been characterized with AFM. No flat surfaces of nanowires were found with the AFM. Even though some possible cross-sections were found using the SEM, the result from the SEM can't be used to carry out a STM characterization since it's not a surface method. To get the desirable result, more AFM measurements could be done on the sample to find a flat surface. Also a thicker polymer could have been deposited since the AFM used in the experiment creates images with the size 10✕10 µm and the polymer thickness were only 1.5 µm thick. The sample could also be polished in order to remove the roughness. Since the cutting method of the sample were primitive, other types of cutting methods could also be used to possibly get a better cut.

References

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[4] *An AFM system*, <http://www.tanos.co.uk/portfolio/applications/nanoprobe/>