Synthesis of silicon nanowires using plasma chemical etching process for solar cell applications

S. Juneja[1], V.S. Pavelyev[1], P.V. Mokshin[1]

[1]Samara National Research University, Moskovskoe Shosse 34A, Samara, Russia, 443086

Abstract. Recently, research on silicon nanowire solar cells has been developed rapidly and is one of the very young research field. The production of highly oriented long silicon nanowires is an challenging problem. Here, in this article we report the optimization of successful synthesis of highly oriented, long silicon nanowires on silicon substrates by plasma chemical etching process. The produced silicon structures were first examined using scanning electron microscopy (SEM). The SEM results clearly shows the highly oriented nanowires on the silicon substrate. The flowing carrier gas, temperature, pressure and voltage are main parameters responsible for the formation of the silicon nanowires. The successful synthesis of silicon nanowires shows bright perspectives for further research on silicon nanostructure properties.

1. Introduction

Silicon nanowires (SiNWs) are of the great interest nowdays because of their special properties and wide range of potential applications in different field of science. For example, they can be used in bio-sensing structures as well as in chemical-sensing, in photovoltaic, microelectronic and etc.

Properties and parameters of silicon nanowires must be taken into account for use in the manufacture of optical devices [1]. This article provides reader with some information on solar cell application. It should be mentioned that SiNWs-based solar cell have much shorter p-n junction that the other types of cell (thin film). Some researchers use the thin-film technology to present the use of grating structure for the enhancement of optical absorption [2-3].

Before charge carriers in nanowire structure (photo-excited electrons and holes) being collected by the electrodes they cover very short distance. In the result we have higher efficiency in the charge carrier collection process in the nanowire structure. It advantage allows to use lower quality silicon because of the higher tolerance of the material defects. The core-shell structure of the silicon nanowires solves the problem of charge carrier collection, this is one of the key factor that affects to the whole efficiency of the solar cell. There is another key factor – efficiency of the photon capture in the nanowire structure, but this parameter is not determined yet.

There are different ways to obtain cone or peak structure on the surface of the sample. Some groups have developed and used its own methods to get pillars with nanometer range [4-6]. A standard method is to use lithography techniques, but it limited by resolution of this optical method. It can be overcome by using the high-energy methods, shorter wavelength. Using electron beam lithography with the high energy coefficient and special resists, pillars and low-dimensional structures it possible to produce 10nm silicon pillar on the surface [4]. Another possible technique to produce nanowire structure on the surface is the plasma chemical etching, also known as bosch-process. It has its own advantages. Unlike liquid etching, etching is performed anisotropically, regardless of the crystallographic planes of the object being processed. But there are rough walls of the obtained figures [7].

Bosch process - a cyclical process consisting of two stages. The first stage is the etching stage in which plasma fluoride ions formed from SF6 gas react with silicon to form the SiF_4 gaseous compound, which is pumped out of the system by vacuum pumps. Etching occurs isotropic. The pickling stage is followed by a passivation stage. At this stage, the plasma is created from C_4F_8 gas. C_4F_8 ions form a polymer similar to Teflon, which is deposited on the sample surface. This polymer does not react with the etching plasma and provides protection against further etching for the silicon that is under it. Before the next stage of etching, this polymer must be removed from the bottom of the etched groove. For this purpose, ions are used that move under the action of an electric field practically along the normal to the bottom of the groove and knock the polymer from the surface. Thus, the polymer is removed only from the bottom, and the groove walls remain protected from etching. Further alternation of the processes of etching and passivation allows anisotropic etch silicon to the desired depth [8].

The purpose of the work is to obtain the necessary properties and parameters to get the silicon nanowires on the silicon surface using the plasma chemical etching (bosch-process).

2. Experiment

In this work, we used silicon substrates previously purified with HF acid. The next step was to fix the substrate on the stand. This should be done as carefully as possible in order to have a tight fit. Otherwise, the formation of the desired figures may not begin. After that, air was pumped out of the chamber. The state of vacuum was obtained by two pumps: air and liquid. After selecting the parameters, the process was started. The ratio of gases was equal to one to one, the time of etching was equal to 3.5 seconds, passivation - 2.1 seconds. During the experiment, to obtain the result, four cycles of 20 Bosch-process cycles were performed. Between each of the four cycles was a pause of 1 min. It should be noted that this process of obtaining structures is extremely unstable and depends on a large number of parameters. Having the same installation voltage, different results can be obtained in different experiments. It depends on the fact that in some cases there is an uncontrolled repassivation process with excessive cooling, which results in the presence of SiNWs. The diagram of plasma chemical etching system is shown on Figure 1.

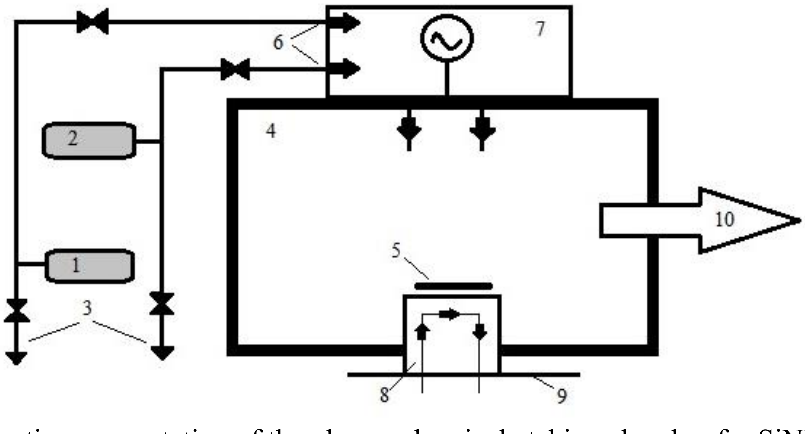

Figure 1. Schematic representation of the plasma chemical etching chamber for SiNWs growth: 1 – C_4F_8; 2 – SF_6; 3 – pumping system; 4 –chamber; 5 – sample; 6 – gas flows; 7 – ICP plasma source; 8 – cooling system; 9 – RF electrode; 10 – pumping chamber system.

After passing through all the cycles, the process stops. The supply of gases is stopped and the formation of plasma is also stopped. Air is pumped into the chamber to restore atmospheric pressure. As soon as pressure is restored, it becomes possible to remove the finished sample from the chamber. The presence of the desired SiNWs can be identified by the color of the mordant. The chance of positive result higher with the black color of the sample. After that, it is possible to analyze the obtained sample using a scanning electron microscope and other characterization techniques.

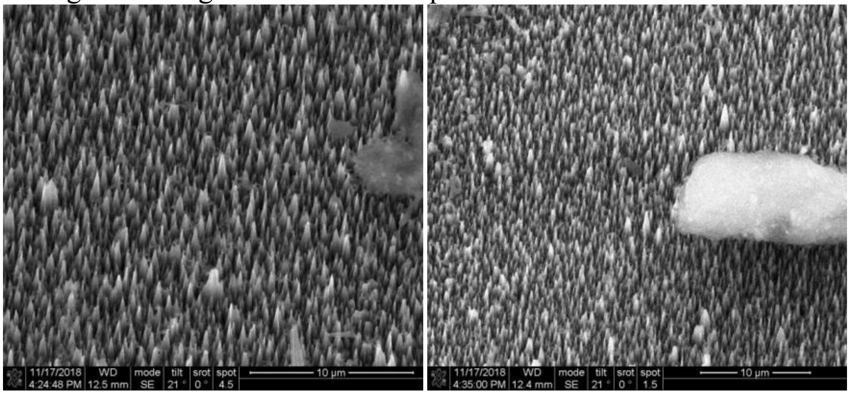

Figure 2. SEM resulting images of SiNWs on the sample surface. Different area is shown on the left and right image.

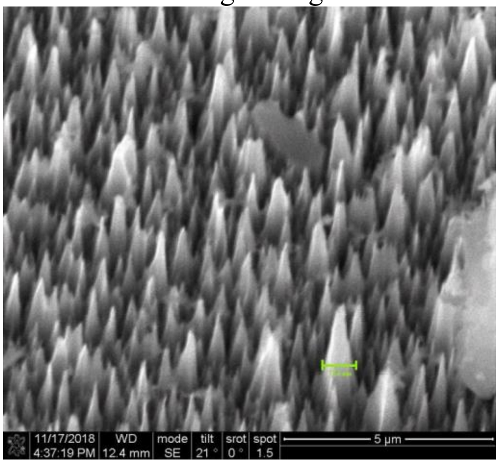

Figure 3. SEM resulting images of SiNWs on the sample surface. The thickness of the one average peak is shown. Average thickness is around 714 nm.

3. Results and discussion

Using this result we can conclude that our sample got the peak-like surface, but the process is unstable. If we want to get better structure with better characterization we should optimize our bosch-process techniques. Further experiments will be directed to find the optimal parameters of etching time, temperature and gas flow ration to obtain better structure. Also this sample will be characterized by some techniques like UV-characterization. We can lean on theoretical investigations in this field [9].

As a result in this article the sample with SiNWs structure is shown. Process should be optimized and when those parameter will be found, wide production of those cells will be possible.

4. References

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