Investigation of cryogenic dry etching of silicon on I-V curves of Schottky diodes

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Abstract. I-V characteristics of silicon wafer with Schottky contacts were investigated to find out influence of dry plasma etching on defects emerging in the structure. Wafer was divided into two pieces, one of them has affected to cryogenic etching using SF\textsubscript{6}/O\textsubscript{2} (in ratio 5:1) and a pressure 5 mTorr for two minutes. The second part of the wafer was used as a reference. It was founded, that for the same contact diameters, etched samples demonstrate higher slope of the I-V curve at the direct voltage. A similar effect was observed in the case of the existence of a defective near-surface region, where carrier recombination is enhanced, which results a significant increase in the direct current.

1. Introduction

Recently, there has been an increased interest in renewable energy sources due to global warming from emissions of hydrocarbon fuel combustion products. According to calculations, the Earth receives about 800 W/m\textsuperscript{2} from the Sun. To convert solar radiation into electricity, photovoltaic cells or solar cells are used as a special case. At the moment there are many types of solar cells, however, silicon solar cells are most prevalent. The achieved efficiency of a silicon-based solar cells with a heterojunction is 26.6\% and has not increased since 2016. To further improve the efficiency of solar cells, new approaches are required. One such approach is to form another transition on top of the silicon cell, which more effectively transforms the shortwave part of the spectrum of solar radiation. For its formation can be used amorphous hydrogenated silicon having a large band gap. However, due to the low conductivity of this material, it is impossible to increase its thickness over a wide range without an increase in resistance. Therefore, the approach involves the use of vertically oriented silicon nanostructures as a template for further deposition of the transition from amorphous hydrogenated silicon on it. In this way, the length of transmission of optical radiation in the material increases while maintaining its thickness. For the formation of vertically oriented silicon nanostructures, the method of low-temperature plasma chemical etching is used. However, plasma is a source of high-energy particles and hard ultraviolet radiation, which can potentially cause defects on the surface of a silicon substrate.

The purpose of this research is to study the effect of low-temperature plasma-chemical etching on the formation of point defects in silicon in the manufacture of a solar cell with vertically oriented nanostructures. This requires studying the characteristics of silicon before and after plasma exposure using the method of volt-amperometry.
2. Experiment details

The volt-amper characteristics of the n-Si structure with a Schottky barrier were investigated in order to reveal the effect of etching conditions on the formation of defects in the structure.

Samples were made on the silicon n-Si (100) wafer of the company TopSil double-sided polishing. The plates were processed using the Shiraki method, then a layer of amorphous hydrogenated silicon (n-a-Si:H) was deposited on one side with the method of plasma-chemical deposition. Then processed substrate in hydrofluoric acid (HF). Silicon dioxide SiO₂ was deposited on the layer of amorphous silicon to protect it from subsequent etching. Next, the substrate was divided into two parts, one of which was subjected to low-temperature (cryo) etching in SF₆ / O₂ in a ratio of 5:1 at a plasma pressure of 5 mTor for two minutes. Then both plates were again treated with hydrofluoric acid. After that, round gold contacts are applied on the front side, and a layer of silver is applied on the back side, and then gold is applied to protect silver from oxidation. Figure 1 presents a schematic representation of the final structure.

![Figure 1](image)

Figure 1. Schematic representation of the structure.

Figure 2 provides a photo of the front side of the control sample (a) - not subjected to cryogenic etching (b) - subjected one, taken with an optical microscope camera.

![Figure 2](image)

Figure 2(a,b). (a) Photo of the sample not subjected to cryogenic etching; (b) subjected one.
3. Results and discussion

When measuring current-voltage characteristics, an array of contacts with a number of about 35-50 is investigated, since a large sample is required for the statistical reliability of the experiment. Contacts are numbered for more convenient display of results.

Measurements of the I-V characteristics were carried out both before and after annealing at a temperature of 170 °C for 20 minutes.

The measured I-V characteristics of the sample for contacts of diameter 1mm before and after annealing are presented in Figure 3.

![Graphs showing I-V characteristics before and after annealing](image)

Figure 3(a,b). IV characteristics of the reference sample for d = 1 mm before(a) and after annealing(b)

From the general analysis of the graphs it can be seen that there is a certain discrepancy between the characteristics of the structures under study within one sample, which manifests itself in different amounts of reverse currents. This effect may be due to the presence on the original surface of traces of dirt or incomplete removal of the oxide layer (SiO₂).

The greatest divergence of reverse currents is observed in structures with the lowest and highest diameters of contact pads.

Annealing of structures at a temperature of 170 °C contributes to some averaging of the values of reverse currents. However, in some particular cases it leads to a sharp decrease in the currents on the straight branch, which indicates the appearance of a potential barrier.

The measured current-voltage characteristics of the control sample for contacts of diameter 1mm before and after annealing are presented in Figure 4.
Figure 4(a,b). IVC of the etched sample for d = 1 mm before(a) and after annealing(b)

From the general analysis of the graphs, it can be seen that, after low-temperature plasma-chemical etching, the direct branches of the I-V characteristics practically do not differ within the limits of one sample. For reverse currents, the spread of values also became smaller. Annealing of these samples practically did not lead to a change in the form of the I-V characteristic.

At the same contact sizes, the samples after etching show a sharper slope of the curve on the straight branch of the IVC. A similar effect is observed in the case of the existence of a defective near-surface region, where carrier recombination is enhanced, which results in a significant increase in the forward current. With a further increase in voltage, a slowdown in the current growth rate is observed.

Acknowledgments

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