Influence of dry etching condition to geometry of vertically aligned silicon nanostructures.

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Abstract. Recently, a new approach to the creation of solar cells based on a combination of silicon technology and III-V technology is gaining popularity. One of the interesting pairs to silicon is GaP. Unfortunately, GaP has a low absorption coefficient and using it as a second junction it is required to grow it sufficiently thick that affects its electrical characteristics. To reduce the thickness of GaP, proposed to use vertically aligned silicon nanostructures, which allow increasing the absorption of light by increasing the absorption length and quantum-size effects with decreasing layer thickness. In this paper we consider the influence of dry etching condition to the geometry of vertically aligned silicon nanostructures.

1. Introduction

Theoretical calculations showed that the use of advanced surface topography could increase by a factor of 1.5 the value of the short circuit current of the top junction of multijunction solar cells due to enhanced absorption [1]. This is a way to reach a currents match between the top and bottom junctions. However, technology of vertically aligned Si nanostructures formation with required geometry is a key issue for fabrication of such devices [2, 3]. Polystyrene spheres lithography followed by dry plasma etching are proposed as cost effective mass scale production technology. The aim of this study is to explore the influence of dry etching conditions to geometry of multijunction solar cells based on vertically aligned silicon nanostructures. Influence of chlorine and fluorine based chemistry as well as ICP and RIE [4] etching modes to Si nanostructure geometry was studied in this paper.

2. Experimental details.

Masks were prepared either using conventional photolithography process or using polystyrene spheres lithography with 2 micron size spheres. Etching was performed using Oxford Plasma Plasma Lab ICP 380 with two different etching mode ICP and RIE with different chemistry: Cl₂/BCl₃/SF₆/O₂. Etching temperature was -10 °C and the pressure was varied in the range of 2-7 mTorr. The RF and ICP power was varied in the range of 20-150 W and 0-2000 W, respectively. After the dry etching process the vertically aligned silicon nanostructures were cleaned in hot chloroform. Structures were studied by scanning electron microscopy (SEM).
2.1. Fluorine silicon etching

Fluorine etching is the main dry etching method for silicon. In most cases, it is performed using passivation gas. We did not use the passivation gas to reduce amount of process gasses. Etching parameters are shown in table 1.

**Table 1.** Etching parameters of fluorine process.

| SF<sub>6</sub> | O<sub>2</sub> | P (mTorr) | RF (W) | ICP (W) |
|------------|-------------|-----------|--------|---------|
| 36 sccm    | 2-6 sccm    | 5         | 20-200 | 0-1500  |

It was unable to obtain vertical walls using ICP mode with fluorine chemistry. ICP mode with fluorine chemistry without passivation is more isotropic compare to RIE mode as shown in Fig.1(a,b) for SF<sub>6</sub>=36 sccm, O<sub>2</sub>=4sccm, RF power = 200 W, P = 5 mTorr. Thus, RIE mode is preferred to reach the desired geometry. Variation of oxygen flow shown that increasing of flow to 6 sccm leads to more anisotropic etch of silicon but also leads to dramatical increase of etching rate of polystyrene spheres. O<sub>2</sub> flow of 4 sccm was chosen as an optimum between wall passivation and polystyrene etching in oxygen plasma. Etching rate for RIE mode four times lower compared to ICP mode however, vertical walls could be achieved. Variation of RF power shows linear dependence of etch rate on power but power should not be so high to melt spheres if the cooling conditions are not enough. Etching was performed with 1µm and 2µm polystyrene mask. An example of SEM images of silicon nanostructures formed using fluorine based chemistry is presented in Fig.1(b,c).

![SEM images of fluorine etching](image)

**Figure 1.** SEM images of fluorine etching in ICP mode without passivation (a) and of periodic vertically aligned silicon nanostructures obtained by fluorine RIE performed with 1µm (b), 2µm(c) polystyrene mask.

2.2. Chlorine silicon etching

To test the chlorine etching the samples with a chromium mask with strips of various thicknesses were prepared. This was done to reduce the effect of etching of polystyrene spheres from chlorine chemistry.

**Table 2.** Etching parameters of chlorine process.

| Cl<sub>2</sub> | BCl<sub>3</sub> | P (mTorr) | RF (W) | ICP (W) |
|-------------|--------------|-----------|--------|---------|
| 10-30 sccm  | 2-6 sccm     | 2-7       | 20-200 | 0-1500  |

Chlorine etching was performed in ICP mode because silicon etching rate in RIE mode 10 times lower. Variation of Cl<sub>2</sub>/BCl<sub>3</sub> ratio from 7/1 to 11/1 shows that increase of amount of BCl<sub>3</sub> leads to isotropic silicon etching but etching without BCl<sub>3</sub>show rough bottom surface. Increasing ICP power leads to increase of etching rate and increase of isotropy at the same time. Rise of RF power increases etching rate and anisotropy. First we start from Cl<sub>2</sub>/BCl<sub>3</sub>=7/1 and pressure of 25 mTorr (figure 2a). After some optimization steps, the most suitable etching conditions was found: P=5 mTorr, T=−28 °C, Cl<sub>2</sub>=22 sccm, BCl<sub>3</sub>=2 sccm, ICP=1500 W, RF=40 W. Etching profile shown in figure 2b. A sidewalls angle close to 80° and uniform bottom of etching were achieved, but a small trenching effect was observed.
Figure 2. SEM images for structures obtained by chlorine ICP etching with Cl$_2$/BCl$_3$=7/1 (a) and Cl$_2$/BCl$_3$=11/1 (b).

Geometry of vertically aligned silicon nanostructures obtained with polystyrene mask and chlorine ICP etching is shown in figure 3. On the right a trenching can be seen that affect to electrical characteristics of silicon heterojunction solar cells. Trenching causes leakage and short circuits in the structures. Thus, chlorine shows better sidewalls and etched profile compared to fluorine etching, but its usage for real structure is difficult because of the current leakage.

Figure 3. SEM image of vertically aligned silicon nanostructures obtained by chlorine ICP.

3. Conclusions

Vertically aligned silicon nanostructures using different etching conditions were prepared. Comparative analysis of different etching conditions was performed. Chlorine based chemistry shows better angles of side walls but have trenching effect. Trenching in vertically aligned silicon nanostructures leads to leakage current in multijunction solar cells. Fluorine based chemistry does not exhibit this trenching effects but side walls angles is worse compared to chlorine one. It is related to etching of polystyrene spheres mechanism. For chlorine based process the nanospheres are etched anisotropic, while for fluorine based process rather the isotropic etching in oxygen is observed.

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