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Influence of dielectric coverage on photovoltaic conversion of silicon solar cells obtained by epitaxial lateral overgrowth*

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This work presents an analysis of the influence of SiO_2 dielectric coverage of a Si substrate on the solar-cell efficiency of Si thin layers obtained by epitaxial lateral overgrowth (ELO). The layers were obtained by liquid phase epitaxy (LPE). All experiments were carried out under the following conditions: initial temperature of growth: 1193 K; temperature difference ΔT = 60 K; ambient gas: Ar; metallic solvent: Sn+Al; cooling rates: 0.5 K/min and 1 K/min. To compare the influence of the interior reflectivity of photons, we used two types of dielectric masks in a shape of a grid etched in SiO_2 along the <110> and <112> directions on a p+ boron-doped (111) silicon substrate, where silicon dioxide covered 70 % and 80 % of the silicon surface, respectively. The results obtained in this work depict the correlation between the interior efficiency and percentage of SiO_2 coverage of the substrate of the ELO solar cells.

Keywords: *liquid phase epitaxy, thin film solar cells, epitaxial lateral overgrowth*

1. Introduction

Nowadays, the world demand for energy increases very rapidly. The development of new technologies for energy acquisition and the improvement of the old ones are the main goals faced by contemporary scientists and engineers. Photovoltaics (PV) seems to be a very promising method for energy conversion, since the Sun is a very stable source of energy. Recent research reveals that the contribution of PV energy sources in the total energy production will increase. There are two main pathways in the development of PV: the first one concerns increasing the efficiency of PV cells, while the second one concerns decreasing the price of the modules. Both pathways aim on decreasing the price of a power unit obtained from PV modules. Research on epitaxial lateral overgrowth (ELO) [1] follows the latter pathway. Liquid phase epitaxy (LPE) [2] is a comparatively inexpensive method of obtaining thin silicon films, and it does not require large amounts of silicon. Applying this method in order to obtain the structures for photovoltaic applications seems to be a reasonable solution. Moreover, ELO makes possible to use low-quality silicon substrates, while its specific structure increases the distance the light beam travels inside silicon.

Thin-film technologies used in this work are based on the epitaxial lateral overgrowth of silicon obtained by liquid phase epitaxy. This method of obtaining silicon layers can be easily used in photovoltaic applications. The main advantage of this method is the possibility to apply a low-quality silicon substrate (which leads to a decrease in the production cost of solar cells). Moreover, an LPE apparatus does not require complicated systems, which makes it all the more economical. ELO is able to create a special design of active layers of photocells, which are placed between two dielectric films (SiO_2 mask and anti-reflection coating). This enables multi-reflection of the light beam from the SiO_2-Si surfaces and increases the distance traveled by light inside the layer, which in turn increases the probability of light absorption near

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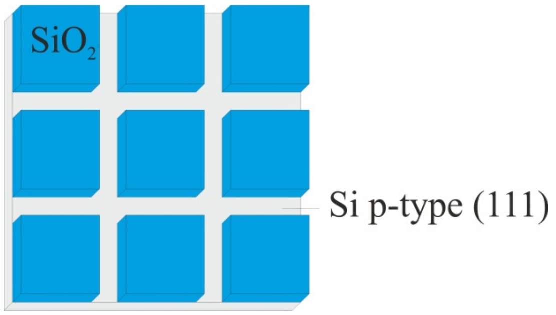


Fig. 1. Silicon substrate with SiO_2 pattern after photolithography.

the p-n junction and of the subsequent separation of generated electric charges.

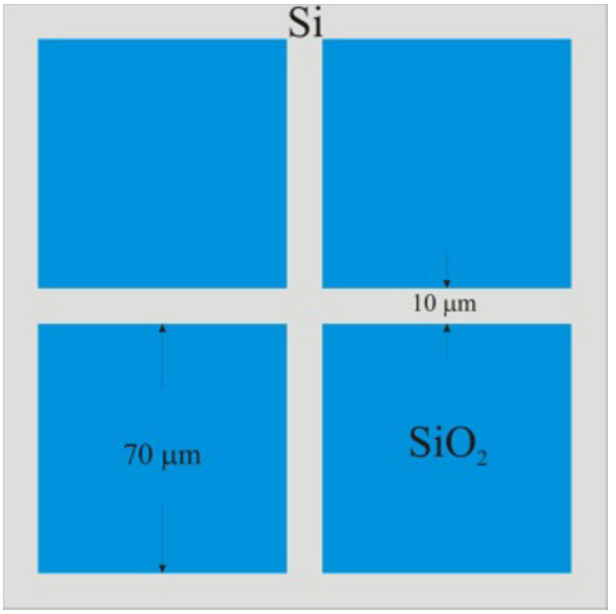
2. Experimental

A series of experiments was performed. The very first stage of the process consisted in obtaining a continuous p+ silicon layer on a silicon substrate by liquid phase epitaxy.

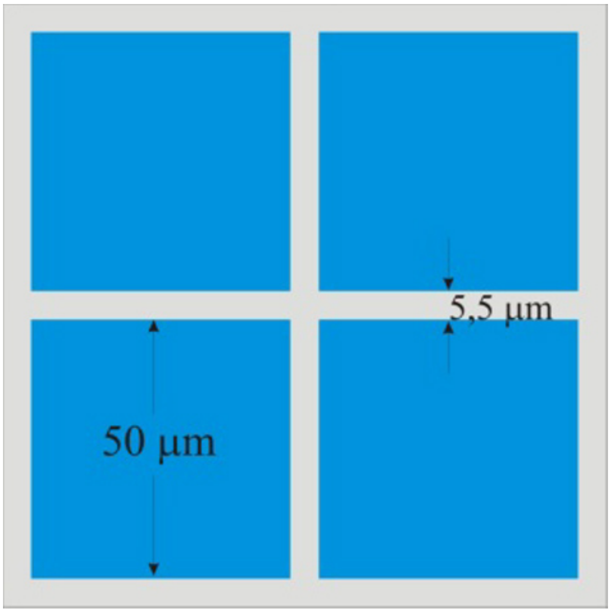
We used p+ silicon as the growth substrate (111). Prior to LPE, the silicon growth substrate was oxidized in order to obtain a 120 nm SiO_2 layer on its surface. The subsequent step was based on photolithography. Specially designed masks of silicon windows were opened in SiO_2 along the <110> and <112> perpendicular directions (Fig. 1).

Two different masks were used, each with a different level of coverage by SiO_2 – 70 % and 80 %, respectively. The dimensions of the masks are shown in Fig. 2.

Liquid phase epitaxy was carried out in a graphite slider boat system [2]. Working gas (argon) was used as an ambient. In order to establish the best conditions for LPE in photovoltaic applications, two cooling rates, 0.5 K/min and 1 K/min, respectively, were used. Sn with an addition of aluminum was used as a metallic solvent. During LPE, aluminum penetrates the crystallographic structure of the growing layer and changes the type of silicon conductivity to p-type, which is important when designing solar cells from ELO layers. Moreover, the addition of



(a)



(b)

Fig. 2. Dimensions of a) the mask with a 70 % SiO_2 coverage, b) the mask with an 80 % SiO_2 coverage.

Al enables silicon growth at 1193 K by changing the solvent surface tension [3].

In order to obtain the same amount of silicon crystallized on the surface of the samples, super-cooling was set to 60 K everywhere, which

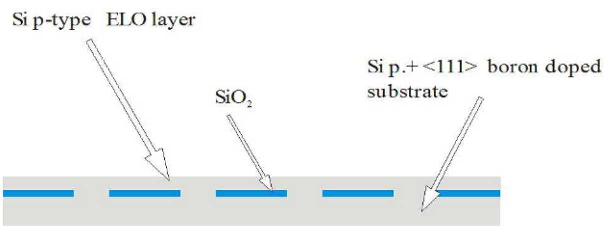


Fig. 3. Cross-section of the sample after ELO.

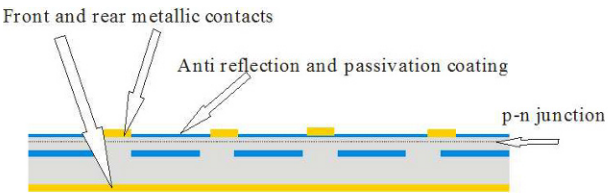


Fig. 4. Structure of the solar cells obtained from the ELO layer.

enabled a complete coverage of the sample surface with a silicon ELO layer. The initial temperature of growth was set to 1193 K. The samples prepared using this method exhibited the structure shown in Fig. 3.

The structures prepared in LPE were used to produce solar cells. The average surface area of an obtained solar cell was of 1 cm^2. The average thickness of the active epitaxial layer was of 21 µm. The standard process of producing solar cells was employed. In order to obtain the p-n junction, phosphorus diffusion was carried out. As an antireflection and passivation coating, 50-nm SiO_2 was deposited on the top surface of the sample. The reflectance of light is a function of layer thickness [4]. In our experiment, the difference between the thickness of the ELO layer and of the SiO_2 layer allowed us to obtain optical resonance.

Rear and front metallic contacts were deposited. The structure of the solar cell is shown schematically in Fig. 4.

The purpose of depositing silicon dioxide on the surface of the growing sample was twofold. Firstly, it prevents the defects of the growth substrate from propagating into the structure of the ELO layer during LPE [5]. Secondly, SiO_2 incorporated in the structure of the sample causes multi-reflection of the light inside the material (Fig. 5), which is beneficial to the performance of solar cells.

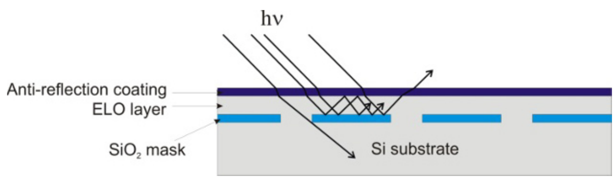


Fig. 5. Reflectance effect on silicon dioxide layer in silicon substrate.

Table 1. Normalized short-circuit current densities (N_{JSC}) for the samples with different percentages of SiO_2 coverage, obtained at the cooling rates of 0.5 K/min and 1 K/min.

Percentage of SiO_2 coverage	cooling rate [K/min]	N_{JSC}
70 %	0.5	0.92
	1	0.73
80 %	0.5	1.00
	1	0.80

3. Results and discussion

In order to assess the performance of the obtained solar cells, the I-V curve was measured under the same illumination conditions. A halogen lamp was used as a light source.

On the basis of I-V curves, the short-circuit current (I_{sc}) was determined for each cell. As the cells had slightly different dimensions, the short-circuit current density (J_{sc}) was chosen as a more reliable parameter for comparing performance [6]. J_{sc} was estimated according to:

$$J_{sc} = I_{sc}/S, \tag{1}$$

where S is the active surface of the solar cell.

The comparison of the cells was performed by normalizing the short-circuit current density. The results are shown in Table 1.

Significant differences between the short-circuit current densities of solar cells obtained under various conditions of crystallization of ELO layers were observed. The rate of silicon growth was higher for the cooling rate of 1 K/min compared to the cooling rate of 0.5 K/min. This had a strong influence on the quality of the silicon film, since faster growth leads to a higher number of crystallographic defects in the layer [7]. This is also reflected in the short-circuit current densities. Table 1 shows that the solar cells obtained from ELO layers grown at a cooling rate of 1 K/min exhibited an average short-circuit current density lower by 20 % than the layers grown at a cooling rate of 0.5 K/min. Higher density of crystallographic defects creates free energetic states, which increases recombination and decreases electron-hole generation.

We also examined the influence of SiO_2 coverage on J_{sc}. At a cooling rate of 0.5 K/min the difference between the solar cell obtained from the sample with a 70 % and 80 % SiO_2 coverage was 8 % in favor of the sample with the 80 % coverage. At a cooling rate of 1 K/min the corresponding difference was 7 %, also in favor of the sample with the 80 % coverage. This led us to the conclusion that a silicon dioxide layer incorporated inside the structure allows multi-reflection of a light beam (Fig. 5) inside the material, which increases the distance traveled by the light beam and in turn increases the probability of photon collection.

4. Conclusions

Four different samples were prepared by epitaxial lateral overgrowth. In order to compare ELO layers for photovoltaic applications, we produced the thin silicon films at two different cooling rates: 1 K/min and 0.5 K/min in LPE. We also used two different mask patterns (Fig. 2) with different geometries and with two different degrees of silicon dioxide coverage: 70 % and 80 %, respectively.

The analysis of the normalized short-circuit current clearly showed a correlation between the rate of silicon growth and the quality of the solar cells made of silicon thin films. J_{sc} of the cells made from the layers grown at a cooling rate of 0.5 K/min was about 20 % higher than that of the cells grown at a cooling rate of 1 K/min.

Moreover, the 80 % silicon dioxide coverage was more suitable for photovoltaic applications compared to the 70 % coverage, as, on average, an increase of 7.5 % in J_{sc} was observed (Fig. 4). Higher SiO_2 coverage increased the probability of electron-hole pair generation by increasing the distance traveled by the light beam inside the cell.

To conclude, for photovoltaic applications, it is advisable to use silicon samples with a higher silicon dioxide coverage and to grow thin silicon films at a cooling rate of 0.5 K/min during ELO.

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