Design of a Bifacial Si Solar Cell with Uniformly Doped B Implanted and P Thermal Diffused Layers

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INTRODUCTION

Si bifacial cells have been used extensively in space [1]. The ability to generate additional energy due to the earth's albedo illuminating the back of the cell made the bifacial cells promising for low earth orbit. Bifacial n^+-p-p^+ cells were produced by technology based on the combination of thermal P diffusion for n^+ emitter doping and B ion implantation with subsequent annealing for p^+ layer doping [2].

This design and basic elements of the fabrication technology can also have increasing terrestrial applications due to the development of high throughput ion implant tools [3]. p^+ layer doping using ion implantation procedure is a key component of cell fabrication technology. Parameters of this process such as ion dose and annealing conditions (time/temperature, gas atmosphere, cap layers etc.) are of significant interest for optimization of fabrication processing and improvement of solar cell performance. In addition to introducing electrically active doping atoms as well as defect formation in the doped layer, another effect can appear as a result of ion implantation – creation of a defect layer behind the implanted layer. Former as well as new data on conditions for minimization of, or avoiding defect layer formation in the base region will be analyzed.

Surface passivation of the p^+ layer is an important part of cell fabrication technology. The significance of the charges, trapped by the passivation layer for surface recombination suppressing, needs to be evaluated.

B implantation and its studying can be applied not only for p- but also for n-type starting Si. Superiority of the back junction compared to the front junction design ought to be estimated.

Effects of implantation dose, starting Si parameters and measurement conditions, on solar cell base recombination, surface recombination suppressing by thermal oxidation and comparative evaluation of back vs. front junction design are the subjects of this presentation.

EXPERIMENTAL

Wafers of single crystal FZ and Cz p-Si of 1 – 20 Ω.cm as well as n-Si of ~5 Ω.cm were used. Experimental bifacial solar cells 2x2 to 5x5 cm^2 were prepared. Their structures and the fabrication technology under investigation are based on the implantation of B ions with energy 30 keV and doses in the range $2.10^{15} – 1.3.10^{16}$ cm^{-2} for p^+ layer formation (using KVANT ILU-4 implanter). P thermal diffusion was used for emitter formation. Defect annealing was done at 910 to 1015 ^{o}C. Depth distribution of electrically active implanted B atoms was determined by sheet resistivity measurements with subsequent controllable anodic oxidation and oxide etch.

Passivation was prepared by thermally grown and forming gas annealed silicon oxide layers. The data on surface recombination were extracted from photo conductance measurements of the both sides implanted samples.

A study of recombination parameters of the cell base region and high-low barriers was made by analysis of front and back internal quantum efficiency, IQE. Comparison of calculated back spectral IQE values with the measured data allows for the determination of the recombination parameters of the base region and of the high-low barrier. The method was applied for solar cells with uniform and step-like distributions of recombination centers in the base. Qualitative detection of a defect layer adjacent to the doped p^+ layer was made by back IQE measurement at light biases of different spectral composition.

RESULTS

Measurements and analysis of back IQE of the n^+-p-p^+ cells leads to the conclusion on the possibility of defect introduction in the base region just behind the doped p^+ layer. Defect extension was significantly deeper than the ion range. The defects extend in the base region to an effective depth of 0.5 - 0.6 μm. The influence of this defect layer on recombination in the base region is due to the small effective diffusion length inside this layer and expressed by an effective surface recombination, S_{eff}, at the inner interface of the layer which can be relatively high even after annealing. The values of diffusion length and, S_{eff}, depend on the implanted dose, Si resistivity, as well as on the carrier injection level during the measurements.

The defect region behind of the B implanted p$^+$ layer can be detected by back IQE measurements at light biases of different spectral compositions. An example is shown in Fig.1, which compares the IQE measured with white bias (incandescent halogen lamp with approximate filament color temperature ~3900 K), red light source (~ 617 nm, narrow band monochromatic emitting diode) and without bias. A relatively small, but an obvious difference in spectral response measured with different bias light spectral composition reflects different effective S_{eff} velocities, 2450 and 2070 cm/s, respectively.

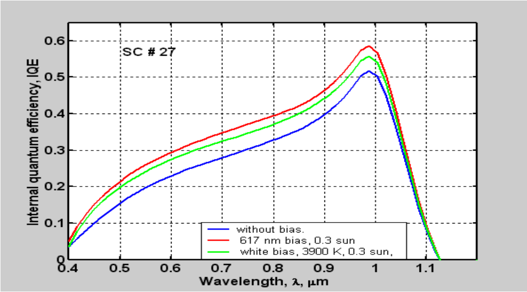

Fig.1. Effect of bias light spectrum on back spectral response of the cell with defect layer adjoining p$^+$ layer.

The same figure demonstrates the effect of injection level on recombination losses in the cell. Recombination decreases with injection level increase. This is a general effect, which is more significantly pronounced for the given type of defect, probably of group type. In some cases the influence of the defect layer on IQE of a sun light biased cell even cannot be seen due to injection effect.

Illustration of the Si resistivity effect is given in Fig. 2. Two back IQE curves are measured for solar cells fabricated using starting FZ Si of resistivity 1 and 20 Ω.cm. Both cells were implanted with the same boron ion dose, 5.6.10^{15} cm^{-2} and annealed at the same temperature 950 ^{o}C. The main reason for the difference in IQE is the influence of defect layers: in the 1 Ω.cm it is responsible for $S_{eff} \approx 1100$ cm/s, whereas in the 20 Ω.cm base the effect of defect layer is negligible. The same positive effect of using high resistivity Si was found for Cz Si.

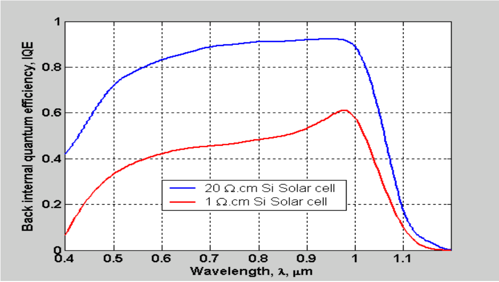

Fig.2 Back IQE for solar cell fabricated using FZ p-Si of different resistivity. Implantation dose was 5.6.10^{15} cm^2. Measurements under sun light bias.

According to experiments, decrease of implantation dose and increase of annealing temperature suppress the formation of the defect layer. Experiments with annealing temperature above 975 ^{o}C were carried out. Effect of a cup layer as a tool for decrese the implantation dose was tested. Use of SiN cap layer results in higher B concentration comparing to the not capped sample after the same implantation dose (see Fig.3).

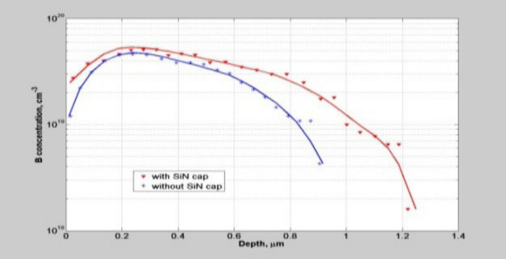

Fig.3 Effect of SiN cap on B distribution after ion implantation at E= 30 keV and dose 3.1.10^{15} cm^{-2}. Annealing temperature 1000 ^{o}C.

The measured profiles of electro active B atoms after annealing at high temperatures are quite deep, and back junction cell design was found as preferable. According to simulation the effective surface recombination at n$^+$-n barrier can be improved by using of high resistivity Si (above ~ 5 Ω.cm). The calculation results of IQE for one of the experimental n^+-n-p^+ cells are shown in Fig. 4. They are confirmed by measurement results.

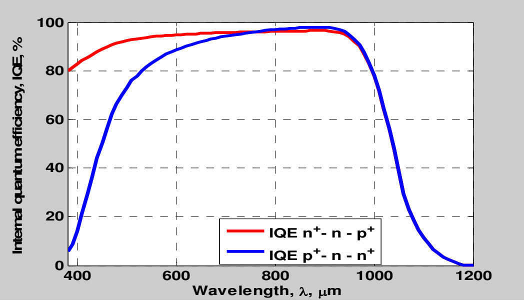

Fig.4 Front and back spectral response for solar cell fabricated using n-Si. Implantation dose was $5.6.10^{15}$ cm^{-2}.

Surface passivation of a p^+ layer is an important component of the cell fabrication technology. Thermal oxidation is a relative simple and controllable process of passivation layer growing. The drawback of such a layer is a positive charge which is typical for a silicon oxide film. According to simulation using PC1D program, the dominating parameter influencing the effective surface recombination is the surface doping concentration. The charge in the passivation layer isn't influencing significantly when surface doping concentration is relatively high. Fig. 5 illustrates the simulated effect of the charge in the film on passivation efficiency as it reflected by V_{oc} of the n^+-p-p^+ cell. Two groups of curves describe the structures with surface boron concentration, B_s, 10^{18} and 10^{20} cm^{-3} for 3 different charge cases: positive charge, no charge or negative charge. Charge density (when exist), $Q_\gamma$is 2.10^{12} cm^{-2}. As can be seen, at low B_s both factors associated with the film – decreasing the surface recombination and charge – have significant influence on the V_{oc} (i.e. reverse current). At high B_s the charge has minor effect, and improvement of surface recombination (due to decreasing the dangling bonds density) is controlling factor.

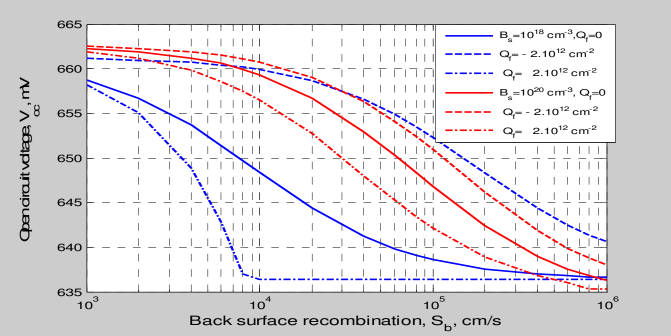

Fig.5 Effect of B surface concentration and surface charge density on passivation of the p^+ layer in the n^+-p-p^+ structure.

CONCLUSIONS

- The B ion implantation process can be effectively used for p^+ layer formation in a bifacial (and regular) Si solar cell with n^+-p-p^+ and p^+-n-n^+ structures.
- The drawback of B ion implantation as a doping process is formation of a defect layer behind the implanted layer that can result in additional recombination losses, characterized by S_{eff}.
- S_{eff} due to the defect layer is lower when the resistivity of the starting Si is higher; S_{eff} due to the defect layer decreases with increasing injection level up to a level corresponding to sun illumination.
- SiN cap layer allows to decrease the implantation dose
- Thermally grown SiO_2 is effective passivation layer for a p^+ layer.

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