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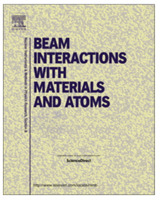

Homojunction silicon solar cells doping by ion implantation

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ABSTRACT

Production costs and energy efficiency are the main priorities for the photovoltaic (PV) industry (COP21 conclusions). To lower costs and increase efficiency, we are proposing to reduce the number of processing steps involved in the manufacture of N-type Passivated Rear Totally Diffused (PERT) silicon solar cells. Replacing the conventional thermal diffusion doping steps by ion implantation followed by thermal annealing allows reducing the number of steps from 7 to 3 while maintaining similar efficiency.

This alternative approach was investigated in the present work. Beamline and plasma immersion ion implantation (BLII and PIII) methods were used to insert n-(phosphorus) and p-type (boron) dopants into the Si substrate. With higher throughput and lower costs, PIII is a better candidate for the photovoltaic industry, compared to BL. However, the optimization of the plasma conditions is demanding and more complex than the beamline approach.

Subsequent annealing was performed on selected samples to activate the dopants on both sides of the solar cell. Two annealing methods were investigated: soak and spike thermal annealing. Best performing solar cells, showing a PV efficiency of about 20%, was obtained using spike annealing with adapted ion implantation conditions.

1. Introduction

In the PV industry, the main challenge is to increase the efficiency of the solar cells while reducing the manufacturing costs. For this, the process flow must be optimized with a simplification, or a decrease of the number of the process steps.

In this study, we propose to change the traditional gas diffusion doping process by an ion implantation doping process. The ion implantation allows to better control the doping profile inside the material with a better uniformity and reproducibility [1]. Also it allows to reduce significantly the number of process steps. In future, this doping process will reach the new cell technologies such as Interdigitated Back Contact (IBC) or selective emitter cells. The first tests on silicon solar cells using ion implantation date from 1980, where encouraging yields were reached [2]. Nevertheless, this doping technology is not very used in the PV industry, besides in microelectronic industry, because up to now, the ion implantation tools were relatively expensive and the throughput was not adapted to the PV industry. These last years, the development of the ion implantation technologies, such as Beam Line, Plasma Immersion or Shower, has consented to reduce the price of the ion implantation tools and to increase the throughput to become competitive for the PV industry.

In this paper we investigated the n-type and p-type doping for the fabrication of N-type homojunction silicon solar cells using ion implantation followed by an activation annealing. Our study consisted on comparing Beam Line Ion Implantation (BLII) versus plasma immersion ion implantation (PIII) techniques and also Soak annealing versus Spike annealing techniques. Firstly, we have separately optimized and electrically characterized the doping process of each type. Thus, these optimized doping processes were integrated on the total process flow for the fabrication of entire solar cells.

2. Experimental

In the PV industry, there are two cell technologies: Homojunction & Heterojunction, with different cell architectures. In our study, we used homojunction N-type implanted Passivated Rear Totally Diffused (PERT) silicon solar cells. N-type silicon has many

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advantages like the absence of light induced degradation (LID) [3,4], a low sensitivity to metallic impurities and a high lifetime potential [5]; and PERT architecture conciliates high efficiency and cost effective ($/W) processes [6].

A schematic cross-section view of this Si(n)-based cell is presented in Fig. 1. It is composed of an emitter in the front side doped with boron (B) and a back surface field (BSF) in the back side doped with phosphorus (P). Then the cell is passivated with SiO_2 and SiN_x layers. The last one is also used as antireflective coating. Finally, the front and rear contacts are fabricated using screen printing metallization.

Fig. 2 presents a simplified process flows for the fabrication of n-type cells using diffusion or ion implantation. In each flow, the steps corresponding to doping (ion implantation and thermal annealing) are highlighted in green boxes. In gaseous diffusion method, the cell is doped using the standard thermal diffusion process. However, such approach demands the deposition of a physical barrier to protect the rear side during front side diffusion and the front side during rear side diffusion. A last thermal oxidation step is needed for surface passivation. While in ion implantation method, the dopants are inserted into the cell by ion implantation and activated by subsequent thermal treatments. In these approaches, the number of process steps related to doping is reduced by 4 [7], in comparison to the 7 steps needed for doping by diffusion. Using ion implantation, the steps of barrier and dopant glass removal are eliminated and the oxidation is done during the activation annealing.

The substrates used in this study were 239 cm^2 Czochralski n-type pseudo-square silicon wafers with a thickness of 180 µm.

BLII were done using a VIISTA HCP of Applied Materials, and PIII were performed in Pulsion™ Nano from Ion Beam Services (IBS). Both tools are 300 mm micro-electronic ion implanters where we developed special silicon PV holders in order to process PV wafers as well as 300 mm wafers with no soft or hardware modifications. In BLII, the ion implantation parameters to define the dopant profile in the material are the specie, the energy (keV) and the dose (at/cm^2). While in PIII, in addition to the ion implantation parameters, the plasma parameters (gas precursor, RF power, chamber pressure, gas flow, time of pulse) have also an importance on the dopant profile. It is a technology more complex to apprehend, so first of all, we focused on the study of the influence of plasma parameters through some Design Of Experiments (DOE).

The post-ion implantation activation annealing was performed in a horizontal furnace for the Soak annealing, with some up/down ramps around 5 °C/min, and in a Rapid Thermal Annealing (RTA) lamp furnace for the Spike annealing with some up/down ramps around 10 °C/s. The annealing parameters we explored were the temperature and the time of the annealing.

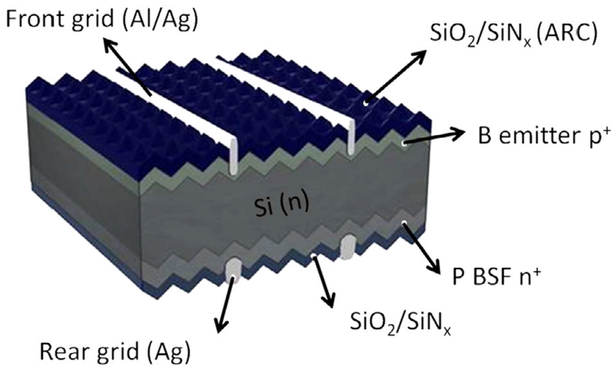

Fig. 1. Scheme in cross section view of a n-type PERT solar cell.

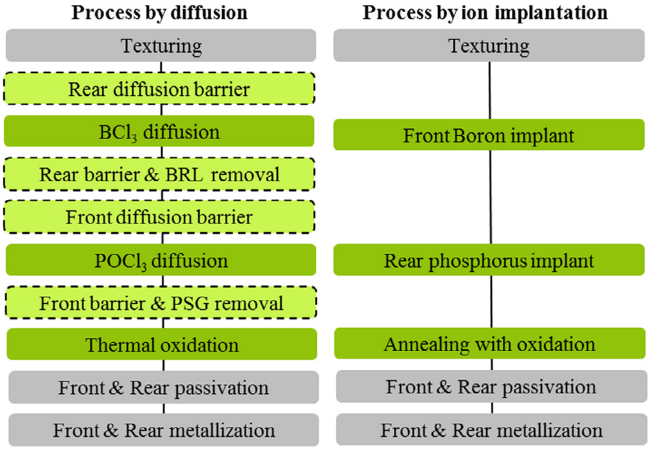

Fig. 2. Scheme of the process flows used to fabricate n-type Si solar cells: by diffusion or by ion implantation.

Firstly, we separately optimized the implantation and annealing conditions of the boron emitter and the phosphorus Back Surface Field (BSF), to obtain sheet resistance values similar from those of gas diffusion. Then, symmetrical cells with the same implantation and annealing conditions for both sides were fabricated. Finally, based on the results of the symmetrical cells, the best conditions of emitter and BSF were integrated in a solar cell.

In front side, an important dopant concentration in surface is necessary to have a good contact. However, a high doping concentration leads to the increase of Auger recombination rate, which limits the lifetime and the ultimate efficiency of the solar device. In rear side, the Back Surface Field (BSF) aims to repel the minority carriers in the bulk to minimize the impact of rear surface recombination. To fabricate the boron emitter in front side and the BSF in back side, ions were implanted with energies up to 10 keV and with a range dose from 10^{14} to 10^{15} at/cm^2. To activate both sides, annealing were performed at different temperatures, between 800 and 1050 °C during 1–60 min, with an included oxidation step for surface passivation.

All doped samples were characterized. Four probe method was used to measure sheet resistance after dopant activation. Secondary ion mass spectrometry (SIMS) analyses were done to obtain concentration-depth profiles of B emitter and P BSF. Electrocapacitance chemical voltage (ECV) was used to quantify the active amount of dopant as a function of depth.

To characterize symmetrical cells, lifetime measurement was done by quasi steady state photoconductance (QSSPC) where the implied open circuit voltage (iV_{OC}) and the saturation current density (J_{0e}) were determined. I/V measurements were performed to characterize the final cell and extract its efficiency.

3. Results and discussion

3.1. Diffusion

Since the beginning of the PV industry, the standard doping process is the diffusion on the both sides of the cell. It is a mature process where it is difficult to control the concentration and depth of the profile. Moreover, it is a technology that is not adapted to all cell architectures. The fact of tuning only diffusion parameters like temperature, time and gas flow, does not allow reaching cell efficiencies beyond 20% in production.

Fig. 3 shows SIMS profiles, which are the chemical profiles and ECV profiles, which are the activated profiles of the dopants for the

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