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Influence of nitride and nitridation on the doping properties of PECVD-deposited BSG layers

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Abstract

High efficiency p-type passivated emitter and rear (PERC) silicon (Si) solar cells are becoming industrial standard with demonstrated efficiencies above 22.6 %. Alternatively to the PERC design there is the possibility to apply a full-area boron back-surface-field (B-BSF) to the solar cell rear side for implementation of passivated emitter and rear totally diffused solar cells (PERT). In this work we investigate plasma enhanced chemical vapor deposited (PECVD) boron silicate glass (BSG) layers employing the precursor gases nitrous oxide (N_2O), silane (SiH_4) and diborane (B_2H_6). We experimentally demonstrate the impact of nitride (N) content in the BSG on the boron (B) doping efficiency within a thermal drive-in step, i.e. a subsequent high temperature diffusion step post BSG-deposition. It is found that the N content of the BSG which is mainly controlled by the $N_2O:SiH_4$ precursor gas flow ratio has to be kept as low as possible to achieve optimal B doping results of the Si bulk material. In addition an in-situ nitridation process has been developed to prevent build-up of a boron rich layer (BRL) on the highly doped Si surface. PERT and PERC solar cells were processed from material with different base resistivities and equal solar cell efficiencies were achieved.

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Keywords: PERC; PERT; BSG; PECVD; diborane; silane; nitrous oxide; boron doping; BRL

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1. Introduction

High efficiency p-type passivated emitter and rear (PERC) silicon (Si) solar cells are becoming industrial standard and efficiencies above 22.6 % have been demonstrated [1]. Alternatively to the p-type PERC design there is the possibility to apply a full-area boron back-surface-field (B-BSF) to the solar cell rear side for the implementation of passivated emitter and rear totally diffused (PERT) solar cells [2]. One advantage of the p-type PERT design is the possibility for the lighter doping of the boron (B) doped Si base material and thus a possible higher bulk lifetime and a reduced boron-oxygen related light induced degradation (BO-LID) [3,4]. In addition the increased conductance of the rear B-BSF has been shown to increase the fill factor (FF) of PERT solar cells on high resistivity substrates without significantly reducing the other cell parameters compared to PERC solar cells [5,6]. This increased rear conductance should also allow to reduce the contacted area on the rear side by reducing the rear contact spacing (pitch) without considerably reducing the FF of the resulting PERT solar cells and is therefore investigated in this work. The challenge is to achieve a high doping and consequently a low sheet resistance $R_{\text{sheet,B BSF}}$ of the B-BSF at a simultaneously low saturation current density $J_{0,\text{B-BSF}}$ of the passivated B-BSF. The rear additional p-type doping can be achieved either by an ion implantation process [7] or by a boron silicate glass (BSG) layer deposition followed by a high temperature thermal drive in process. This BSG layer deposition can be achieved either by a deposition step within a BBr_3-process [8] or a dedicated chemical vapor deposition process [8,9,10]. In the case of BSG-deposition via a CVD process the thermal drive-in of B from the BSG can be combined with the $POCl_3$-diffusion in a co-diffusion process for the implementation of a lean process flow [9,10]. Therefore, in this work a PECVD BSG process was used to achieve a high rear B doping. When utilizing a PECVD BSG process the B doping efficiency is significantly dependent on the BSG composition, mainly the total B content [11] and the gas flow ratios of the used precursor gases silane (SiH_4) and diborane (B_2H_6) [9], i.e. the resulting sheet resistivity $R_{\text{sheet,B-BSF}}$ increases with increasing SiH_4:B_2H_6 gas flow ratio. Up until now the influence of the nitrous oxide (N_2O) and the N_2O:SiH_4 gas flow ratio on the BSG composition and its doping capability has not been investigated in detail. In addition, during the high temperature diffusion step a boron rich layer (BRL) [12]can be formed on the B doped Si surface underneath the BSG layer depending on the B content of the BSG [11], the applied diffusion temperature and the applied diffusion time. The presence of a BRL will result in significantly increased surface recombination velocities due to its bad surface passivation behavior and its bulk lifetime degradation effect when the BRL thickness is increasing [12]. Prevention of BRL build-up is thus desired and after Yang et. al [13] it can be achieved by applying a thin Silicon Nitride (SiN_x) layer between the Si and the deposited BSG. In the first part of this work the doping efficiency from PECVD-deposited BSG layers is investigated with a special focus on the precursor gas flow ratio of N_2O:SiH_4. In the following part of this work prevention of BRL build-up via an in-situ nitridation of the wafer surface in the BSG process is experimentally demonstrated. Finally, this is utilized in processing PERT and PERC solar cells from p-type Si material with base resistivities of 2 Ωcm, 4 Ωcm and 6 Ωcm and two different rear contact pitches 1.0 mm and 1.3 mm.

2. Experimental details

The experiments performed in this work were realized in an industrial PECVD tube reactor at SolarWorld Innovations GmbH where a portfolio of many different precursor gases exists. For this work the precursor gases N_2O, SiH_4 and B_2H_6 were used for the PECVD BSG process at process temperatures below 400 °C. A PECVD SiN_x capping layer was deposited as a protection layer for the subsequent high temperature diffusion step in a tube furnace. The BSG layer composition was determined by X-ray photoelectron spectroscopy (XPS). The B content of the BSG layer was additionally determined by inductively coupled plasma mass spectrometry (ICP-MS) together with layer thickness determination by spectral ellipsometry. The B sheet resistances and the resulting doping profiles after the additional high temperature diffusion step were measured by four point probe (4PP) and electrochemical capacitance voltage (ECV) measurements after a wet chemical removal of the deposited layer stack of BSG and SiN_x. The B-BSF saturation current density $J_{0,\text{B-BSF}}$ is derived after the procedure of Kane and Swanson [14] from symmetrically coated samples with a stack of the BSG and a SiN_x protection layer which were diffused, the BSG and SiN_x layer stack etched back, passivated on both sides with PECVD-Aluminum Oxide (AlO_x) and finally fired in a belt furnace (see Fig.1).