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ScienceDirect

Energy Procedia 124 (2017) 313–320

Energy Procedia

www.elsevier.com/locate/procedia

7th International Conference on Silicon Photovoltaics, SiliconPV 2017

Advances in PassDop technology: recombination and optics

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Abstract

The *PassDop* technology is a promising approach to realize passivated emitter and rear locally diffused (PERL) silicon solar cells within a reasonable process sequence. In previous studies, the feasibility of this concept was evaluated, but two topics were only briefly discussed: the recombination at the locally diffused and contacted surface and the optical layer. In this study we present an analysis of the recombination at laser processed spots of local laser diffusion from a-SiN_x:P. We show that initially the local recombination prefactor $J_{0b,met}$ for the metallized area is very high (10^4 fA/cm^2) but a dedicated anneal can be used to reduce the recombination to a competitive level (600 fA/cm^2). The improvement was allocated to the inner area of the laser-processed spot by measuring µ-PL before and after annealing. To improve the optics we show that SiO_x can be used on the rear if an etch-back is applied after the laser diffusion. Applying SiO_x, results similar to the reference MgF_2 layer for J_{sc} and *FF* were achieved, while providing much improved adhesion. Finally, we show large area *n*-type silicon solar cells featuring a *PassDop* rear side as well as laser contact opening in combination with nickel- and copper-plating on the front. Combining these technologies, we were able to achieve an energy conversion efficiency of 22.2 %.

Peer review by the scientific conference committee of SiliconPV 2017 under responsibility of PSE AG.

Keywords: surface passivation; n-type; laser doping; nickel plating

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1. Introduction

n-Type passivated emitter and rear locally diffused (PERL) silicon solar cells have proven to offer a high-efficiency potential [1]. The *PassDop* approach (see Fig. 1) introduced by Suwito et al. demonstrated an industrially feasible realization of the rear side of such a PERL structure [2]. While the original *PassDop* layer was based on silicon carbide, we introduced an approach based on phosphorus doped amorphous silicon nitride with which we were able to reach 22 % on large area [3].

The main properties that such a *PassDop* scheme has to fulfill are a good surface passivation, good doping efficiency during the laser diffusion process, high internal reflectance and low recombination at the local back

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10.1016/j.egypro.2017.09.305

surface field (LBSF). While the first two were discussed in previous publications the other two topics were only discussed briefly.

In case of internal reflectance an MgF_2 layer was used to enhance light trapping at the rear. However, as shown later on, this layer is not compatible with module fabrication as the layer adhesion (both of the layer on the *PassDop* layer and of the aluminum on the MgF_2 layer) was low. Thus for the final step of the cell concept towards making modules, an alternative was required or one would have to make sacrifices in the optical efficiency of the device. Due to its low refractive index, SiO_x was thought of as a good candidate, but Suwito found that applying the laser process on this layer led to incomplete ablation preventing contact formation [4]. The focus on our work here is to test if the SiO_x layer can be made compatible with the laser diffusion process, meaning reliable contact formation without sacrificing the enhanced light trapping. In addition, we investigate if the layer adhesion is high enough for module fabrication.

The last topic to be discussed is the recombination at the *PassDop* LBSF. While most authors use the model of Fischer [5] to calculate the recombination at the LBSF, we decided to use the model proposed by Saint-Cast et al. mainly due to defining parameters which do not or only weakly depend on the LBSF size (a parameter with high uncertainty). In addition the simple structure of the model allows for proper propagation of uncertainties and thus to better judge the validity of the results.

With regard to cell fabrication, the *PassDop* rear side was combined with laser contact opening on the front followed by nickel- and copper-plating as an industrially feasible solution for the front side metallization. However, the cells featuring NiCu-plating were limited in V_{oc}, which was attributed to bulk degradation [3]. Hence in this work, we aimed at combining the above improvements with the removed bulk lifetime limitation to further explore the potential of the cell concept.

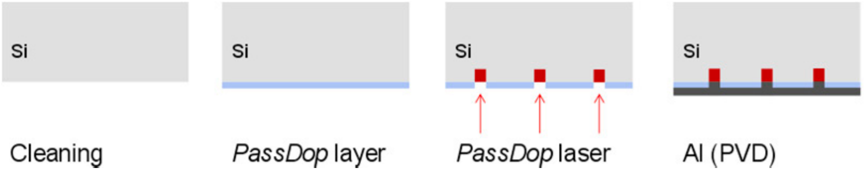

Fig. 1. Schematic of the *PassDop* process sequence for rear side passivation as well as LBSF and contact formation: 1. Cleaning of the silicon surface. 2. Deposition of the doped passivation layer. 3. Application of the laser process to open the layer and simultaneous diffusion of the dopants into the silicon to create the LBSF. 4. Contact formation, e.g. by evaporation of aluminum.

2. Recombination at the *PassDop* LBSF

2.1. The LPA model

The LPA model can be used to describe the recombination at a locally processed area (LPA), e.g. by a laser process. In detail, the model is described in [6] and [7]. Here, we only repeat the important aspects for the application of the model on *n*-type surfaces, as the original paper focussed on *p*-type silicon. The model proposes a linear relation between the effective surface recombination velocity S_{eff} and surface density of the LPA N_{LPA}:

$$S_{eff} = p_{eff} N_{LPA} + S_{pass}, \tag{1}$$

where S_{pass} is the effective surface recombination velocity at the passivated surface. p_{eff} is a proportionality factor and can be seen as a characteristic measure of the recombination at the surface due to the local processing. To determine the recombination at the actual LPA (e.g. a single laser spot) p_{LPA} can be calculated, which is the corresponding recombination parameter for a single LPA

$$\frac{1}{p_{eff}} = \frac{1}{p_{LPA}} + \frac{r_{diff}}{a}, \tag{2}$$

where r_{diff} is the diffusion resistance (see [6]) and a is the contact radius of a circular spot or the half width of a square-shaped contact. It should be noted that this relation is only valid for point contacts and not for lines. For the latter case see [7] or [8].

Before just calculating p_{LPA}, one should consider the case where p_{LPA} is very high, thus $p_{LPA}^{-1} \ll r_{diff}/a$. This