

6th International Conference on Silicon Photovoltaics, SiliconPV 2016

Plasma-free dry-chemical texturing process for high-efficiency multicrystalline silicon solar cells

Bishal Kafle^{a,*}, Timo Freund^a, Abdul Mannan^a, Laurent Clochard^b, Edward Duffy^b,
Sabrina Werner^a, Pierre Saint-Cast^a, Marc Hofmann^a, Jochen Rentsch^a, and Ralf Preu^a

^aFraunhofer ISE, Heidenhofstr. 2, Freiburg 79100, Germany

^bNines Photovoltaics, IT Tallaght, Dublin 24, Ireland

Abstract

In this paper, we study the influence of modifying the geometry of nanotexture on its electrical properties. Nanotexture is formed by an industrially feasible dry-chemical etching process performed entirely in atmospheric pressure conditions. A surface modification process is developed that allows low surface recombination velocities ($S_{\text{eff,min}} \leq 10 \text{ cm/s}$) on nanotextured surfaces. By simultaneously improving the surface passivation and the emitter diffusion processes, we achieve an equivalent passivation level ($V_{\text{OC,impl}} \geq 670 \text{ mV}$) for nanotextured surfaces to that of reference textured surfaces after applying either PECVD or ALD based deposition techniques.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer review by the scientific conference committee of SiliconPV 2016 under responsibility of PSE AG.

Keywords: black silicon; atmospheric pressure; dry texturing; silicon nitride; surface passivation; emitter recombination

1. Introduction

Higher surface reflection of multicrystalline silicon (mc-Si) wafers is one of the major reasons for an overall lower conversion efficiency of mc-Si based solar cells in comparison to monocrystalline silicon (mono-Si) based solar cells. Formation of submicron or nano-scale texture in mc-Si significantly enhances its light trapping properties [1–3] and promises a significant increase in conversion efficiencies of mc-Si based solar cells [4–8]. Nano-scale

* Corresponding author. Tel.: +49-761-4588-5499; fax: +49-761-4588-9051.
E-mail address: bishal.kafle@ise.fraunhofer.de

texturing has been achieved by using various texturing mechanisms and especially plasma-based texturing; metal-assisted wet-chemical etching and laser-based texturing are mainly reported by the contemporary works [4,5,9–11]. We proposed a novel texturing approach of applying a plasma-free dry-chemical etching of Si in atmospheric pressure conditions by applying spontaneous F_2 -Si etching process and using an inline etching tool that promises industrial throughputs. The proposed atmospheric pressure dry etching (ADE) process forms nanostructures in a single-step process and especially is of high interest to significantly reduce the surface reflection of mc-Si wafers to a value close to or below that of alkaline textured mono-Si surfaces. In past, we showed that a shallow single-step ADE process can lead to an improvement in the short circuit current density (J_{sc}) and the conversion efficiency (η) of mc-Si based solar cells in comparison to the reference acidic textured solar cells [6]. The parameters of the ADE process can be also adjusted to form deep nanostructures or ‘black silicon (B-Si)’ structures with very low surface reflection values ($R_w < 3\%$). Here, the weighted surface reflection (R_w) is calculated in the wavelength spectrum of 300–1200 nm and a weighing function is applied using the internal quantum efficiency of a standard silicon solar cell under AM 1.5G illumination conditions [12]. An enlarged surface of B-Si, however, poses major challenges in surface passivation and emitter formation process steps. Therefore, optimization of all these process steps is necessary in order to achieve the maximum current gain promised by the low surface reflection of nanotextured surfaces. Surface modification of B-Si structures either by alkaline [4,7,8] or acidic [5,13] wet-chemical solutions is one of the approaches that have been applied to relax the influence of surface topography on the electrical characteristics of the nanotextured solar cells. Recently, we also showed that a short alkaline surface modification of the nanostructures formed after ADE process is fully compatible with plasma enhanced chemical vapor deposition (PECVD) based deposition process by achieving a conversion efficiency of 18.0 % on the mc-Si based Al-BSF solar cell [14]. Improvement in the solar cell performance by performing nanotexturing on mc-Si substrate has paved the way to incorporate this approach with high efficiency solar cell concepts like passivated emitter and rear cell (PERC). In high-efficiency solar cells like PERC, however, the limit imposed on open circuit voltage ($V_{OC,max}$) due to the recombination channels activated in a solar cell becomes much more important. Therefore, the surface passivation and emitter diffusion processes on nanotextured substrates have to be further optimized in order to allow high V_{OC} values that are promised by the high-efficiency solar cell architectures.

In this paper, we will therefore discuss about the important technological milestones achieved by us in order to pave the path towards high-efficiency PERC solar cells on nanotextured mc-Si substrates. We first discuss about our surface texturing approach by explaining the process development of the modified nanotexture (mB-Si) structures on c-Si surfaces. Based on the lifetime measurements of the un-diffused and diffused surfaces, we would then discuss in detail about the electrical characteristics of the mB-Si structures.

2. Process development

For this work, we use the atmospheric pressure dry-chemical etching tool developed by Nines Photovoltaics and installed at Fraunhofer ISE facility. Fig. 1 i) shows a basic schematic of the etching system. The texturing of c-Si surfaces is performed by spontaneous etching of the Si surfaces with dilute F_2 gas (F_2/N_2) in atmospheric pressure conditions. The wafers are then dynamically transferred through the reactor with a set velocity (v_{wafer}) in an inline mode. The temperature of the etching gas (T_{GDP}) and the Si wafer (T_{wafer}); total gas flux, F_2 concentration and v_{wafer} are the major process parameters that are varied to form nanostructures of different morphologies and aspect ratios. More about the set-up of the etching tool and the process mechanism can be read elsewhere [6,15,16].

Fig. 1 ii) show the experimental plan followed during the development of mB-Si texture. p-type 15.6 x 15.6 cm² mono c-Si (CZ) wafers are first saw-damage etched and then textured by flowing F_2 gas over the heated wafer ($T_{wafer} \approx 170^\circ\text{C}$), which is moved through the reaction chamber. The etching process parameters are varied to obtain black silicon (B-Si) -like topography. In order to modify the surface topography, the B-Si wafers are then shortly dipped into the diluted alkaline solution using an industrial batch wet-chemical tool from Stangl. We chose alkaline solutions after considering their higher Si etching rate in comparison to the acidic solutions for an equivalent concentration. Typical alkaline solutions like KOH/TMAH react with Si in a redox reaction where the hydroxyl (OH) dissolve Si in the form of $Si_x(OH)_y$ [17]. Assuming homogeneous etching of Si along the wafer area, we estimate Si removal based upon the weight measurements performed before and after the surface modification process. The hemispherical surface reflections are measured by Varian Cary 5000 spectrophotometer and the

Download English Version:

<https://daneshyari.com/en/article/5446601>

Download Persian Version:

<https://daneshyari.com/article/5446601>

[Daneshyari.com](https://daneshyari.com)