Solar Energy Materials & Solar Cells 95 (2011) 3592–3595

Contents lists available at SciVerse ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Letter

Improved LDSE processing for the avoidance of overplating yielding 19.2% efficiency on commercial grade crystalline Si solar cell

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A R T I C L E I N F O

Article history:
Received 5 October 2010
Received in revised form
11 May 2011
Accepted 25 July 2011
Available online 3 September 2011

Keywords:
Silicon
Solar cell
Laser doping
Selective emitter
Plating

A B S T R A C T

A record in laser doped selective emitter (LDSE) solar cells with an efficiency $\eta = 19.2\%$ is reported. In this study, we investigate the effect of SiN_x films for laser doped selective emitter solar cells with plated front contacts. It is observed that the condition of processes such as silicon nitride and laser doping (LD) is of critical importance prior to light induced plating. If these processes are not performed optimally, localized shunts may form during the light induced plating (LIP) process that then inhibit plating in the surrounding areas. In the previous work an efficiency of 18.3% has been achieved, even though the fill factor was only 74.2% and the cell suffered from additional shunting and shading losses due to overplating. However, in this work, we demonstrate that with the optimization of the PECVD SiN_x and metallization processes, cells have reached efficiencies of more than 19% on commercial grade p-type CZ Si substrates.

1. Introduction

Currently, the crystalline silicon solar cell industry is focused on improving cell efficiencies and lowering the cost of production. Screen printing is a method widely used in photovoltaic industry to form the metal contact of silicon solar cells. One of the disadvantages of conventional screen printed technologies is the need of a heavily diffused emitter to create a high phosphorous surface concentration in order to obtain low metal–semiconductor contact resistance. High surface doping concentrations cause high surface recombination rates and a poor blue response. Consequently, the heavily doped layer acts as a dead layer for the generated minority carriers, reducing the short circuit current density. On the other hand, lightly doped emitters can also lead to low fill factor (FF) because of high contact resistance, low metal conductivity and junction shunting. Therefore, to improve cell performance, selective emitter technologies that allow good ohmic contact while avoiding a dead layer should be formed. Several approaches to industrially fabricate a selective emitter have been presented to date [1–3].

Selective emitters in crystalline silicon solar cell technologies provide a significant increase in solar cell efficiency. The application of LD has been studied widely from full surface area doping for emitter formation to selective area doping for highly doped region underneath electrodes or n^+ and p^+ regions at rear surface [4–7]. Using n-type wafers, Mai et al. demonstrated an efficiency of 18.6% on laser doped selective emitter (LDSE) cells [8] while on p-type substrates efficiencies of 18.5% have been reported [9] using the patented University of New South Wales (UNSW) LDSE process [10]. In this work, we also adopt the UNSW LDSE process under license from New South Innovations. The main advantage of the LD process is the ability to produce localized heavily doped regions, without any masking or exposing the entire wafers to high temperatures and the use of self-aligned LIP contacts as shown in Fig. 1. Such advantages make laser doping compatible for existing standard production lines and suitable for the use of commercial grade crystalline silicon wafers, which often degrade when exposed to high temperature.

Plasma enhanced chemical vapor deposition silicon nitride (PECVD SiN_x) films are the most commonly used anti-reflection coating (ARC) in the solar cell industry. The main advantage of SiN_x films is that the properties of films can be controlled by managing the deposition conditions, such as temperature, gas flow rates and pressure. However, SiN_x coated surfaces have countless defects and holes along the regions adjacent to the laser melted lines and this gives rise to overplating problems. There are two main causes of overplating on textured crystalline wafers with silicon nitride coated surfaces: the nature of PECVD SiN_x deposition itself and the topology of wafer surfaces.

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doi:10.1016/j.solmat.2011.07.030

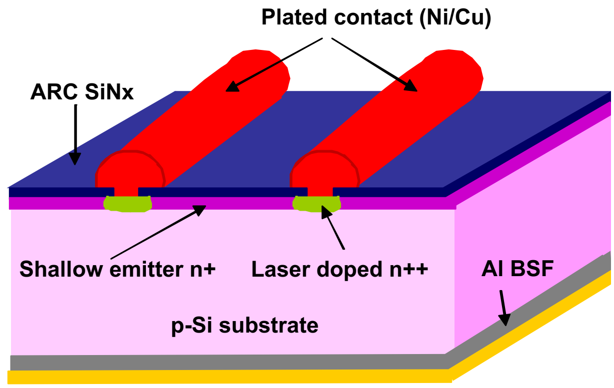

Fig. 1. Schematic of a laser doped p-type solar cell.

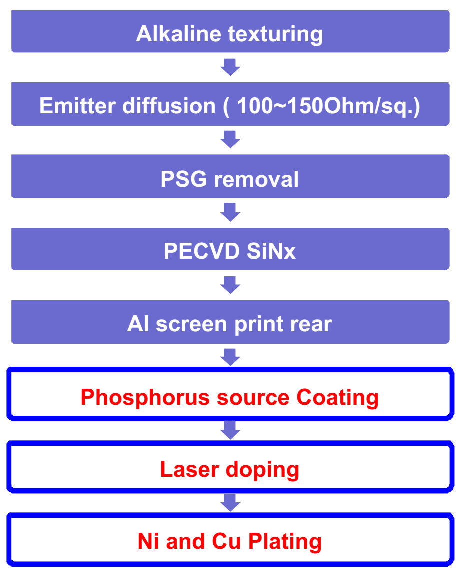

Fig. 2. Process sequence of the presented experiment.

In addition to increased shading losses, overplating can cause shunting mechanism or form Schottky contacts.

The unwanted Ni and Cu plating on the textured surfaces of the crystalline Si wafers results in increased shading losses, which lowers the short circuit current density of final devices. Overplating in the vicinity of the finger contacts can cause shunting when the metal contacts the p-type bulk material, or Schottky contact when the metal touches the lightly doped n-type regions [11]. The front anti-reflection coating must not only allow the hydrogenation effect to take place in passivating the bulk material but also protect the wafers against laser induced defects and be sufficiently dense to act as a plating mask. In our previous work, using commercial PECVD SiN_x for industrial screen printed solar cell, LDSE cells have been fabricated. The loss in FF of the LDSE cell mainly results from the overplating and shunts. As a result, efficiency of 18.3% has been reported [12]. This work presents improved condition of SiN_x film for the minimization of overplating on LDSE cells.

2. Experimental

Fig. 2 shows the process sequence used to obtain the selective emitter structure. The cells were fabricated using industrial p-type monocrystalline silicon wafers of 0.5–3 Ω cm resistivity and 200 ± 20 μm thickness. After novel chemical texturing, phosphorous diffused n-layer with sheet resistance of about 100 Ω/□ served as the front shallow emitter region. SiN_x passivation is deposited on the front side by direct PECVD (Centrotherm) for fabrication of the industrial screen printed solar cells. The SiN_x layers were deposited at 450 °C and different gas ratios. Table 1 shows the process condition of SiN_x film deposition. Processes up to the end of the aluminum back surface field formation were carried out on an industrial equipment at Shinsung, while the laser doping and plating processes were performed at UNSW.

Table 1
Process conditions of PECVD SiN_x deposition.

Sample	SiH_4/NH_3	Deposition time (s)	Deposition temp. (°C)	RF power (W)	Pressure (Mtorr)
(a)	0.09	660	450	3400	1700
(b)	0.14	900	450	3400	1400

Rear Al contacts were screen printed and fired at 900 °C. The front of cell process is based on the standard screen printing process widely used in industrial environment. Phosphorous spin on dopant (SOD) source was spun onto the front surface and samples were laser doped using a laser with 532 nm wavelength and 15 W power. The laser is a Diode-Pumped Solid State (DPSS) laser system with high-quality TEM00 mode beam output and good focusing ability ($M2 < 1.1$).

The metal seed layers for front contacts were formed by plating using LIP Ni, sintered at 370–400 °C and then the front metal contacts were formed by LIP Cu.

Photoluminescence (PL) imaging and 3D measuring laser microscope measurements were used to obtain the implied Voc (iVoc) and surface morphology of the SiN_x films. The iVoc was used for evaluation of the passivation quality since it has been shown that this parameter can predict the open circuit voltage of the finished solar cell very accurately [13].

2.1. The SiN_x layers deposition by PECVD

The SiN_x film was deposited using direct PECVD. To optimize the SiN_x ARC layer, SiH_4 to NH_3 gas ratio was varied in the PECVD SiN_x deposition process. The used gas ratios of SiH_4/NH_3 were (a) 0.09 and (b) 0.14. The refractive index and the thickness of the SiN_x layer were determined using a laser ellipsometer (SENTECH SE 400). Table 2 shows the characteristics of SiN_x films with different PECVD deposition conditions. The samples (a) and (b) gave almost the same lifetime and implied open circuit voltage (iVoc).

3. Characterization and disscussion

3.1. Structured properties of SiN_x layers deposited by PECVD at various deposition parameters

SiN_x is used for both chemical and electrical passivation of semiconductor surfaces as it can withstand the corrosive action of most reagents and prevents ion diffusion. In previous studies it was found that the mass density of the SiN_x layers is related to the Si–N bond density ([Si–N]): layers containing more Si–N bonds have a higher mass density ρ, while those with relatively more Si–Si bonds are less dense and have a more porous structure [14–16].

PL imaging can be applied to both unfinished and fully processed silicon solar cells of any practical size; it is contactless and non-destructive, it is applicable to both planar and textured samples and it measures the sample at room temperature [17]. The iVoc was used for evaluation of the passivation quality since it has been shown that this parameter can predict the open circuit