Applied Surface Science 305 (2014) 439–444

Contents lists available at ScienceDirect

Applied Surface Science

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

18.5% efficient AlO_x/SiN_y rear passivated industrial multicrystalline silicon solar cells

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ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form 10 March 2014
Accepted 17 March 2014
Available online 28 March 2014

Keywords:
Aluminum oxide
Silicon nitride
Passivation
Multicrystalline silicon
Solar cell

ABSTRACT

Due to the trend toward thinner and higher efficient crystalline silicon solar cells, excellent rear surface passivation and internal optical reflectance have become more and more important. Aluminum oxide (AlO_x) capped with silicon nitride (SiN_y), which is considered as one of the most promising candidates to achieve superior rear passivation and internal reflectance, has to date been mostly used for the rear side of p-type monocrystalline silicon (mono-Si) solar cells. In this paper, we have optimized rear AlO_x/SiN_y stacks deposited by industrial plasma enhanced chemical vapor deposition (PECVD) for multicrystalline silicon (mc-Si) passivated emitter and rear cells (PERC). Sufficient passivation activation effect from industrial fast-firing process and SiN_y deposition process have been demonstrated, so the samples were not subjected to additional thermal treatment process in the cell fabrication flow. For rear AlO_x/SiN_y stack, it is shown that when PECVD AlO_x is thicker than 40 nm, apparent blisters in fired AlO_x deteriorate the cell performance, and the appropriate SiN_y capping is N-rich SiN_y with thickness of at least 180 nm. After process optimization with the least additional process steps, independently confirmed efficiency of 18.5% for Pluto-PERC with PECVD AlO_x/SiN_y rear passivation on standard 156 mm × 156 mm p-type mc-Si wafers has been achieved.

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1. Introduction

In the past years, crystalline silicon (c-Si) solar cells have always been dominating the industrial solar cell production. Appropriate rear dielectric layer for passivated emitter and rear cells (PERC) can lead to not only outstanding rear surface passivation, but also excellent rear internal reflection, so it is one of the prerequisites to reach thinner and higher efficient c-Si solar cells. In previous studies aluminum oxide (AlO_x) has been proved as one of the appropriate passivation materials for the rear side of p-type mono-Si solar cells [1,2], because AlO_x can provide field effect passivation and chemical passivation through high fixed negative charges and low interface defect density [3], respectively. Several deposition methods, including atomic layer deposition (ALD) [4–7], plasma enhanced chemical vapor deposition (PECVD) [8,9], inductively coupled plasma (ICP) PECVD [10,11], atmospheric pressure chemical vapor deposition (APCVD) [12,13] and reactive sputtering [14–16] have been employed to deposit AlO_x films. Among these deposition technologies, PECVD is the most extensively used technology in the mass production of c-Si solar cells. The aim of this work is to demonstrate the effect of integration of AlO_x/SiN_y stacks fabricated by PECVD as rear passivation and internal reflection layers for industrial Pluto [17] mc-Si solar cells with the least additional process steps.

2. Experimental

The wafers used for cell fabrication in this work were 156 mm × 156 mm p-type mc-Si wafers with a resistivity of 0.5–3.0 Ω cm and a thickness of 200 μm. These mc-Si wafers were all neighboring wafers and randomly selected from Suntech mass production line. After standard processes of texturing, diffusion and etching with a final HF/HCl clean in the production line, AlO_x/SiN_y stacks were deposited by Roth&Rau inline micro-wave PECVD system at the rear side of wafers and SiN_y anti-reflection coatings were deposited by Centrotherm direct PECVD at the front side of wafers,

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http://dx.doi.org/10.1016/j.apsusc.2014.03.108
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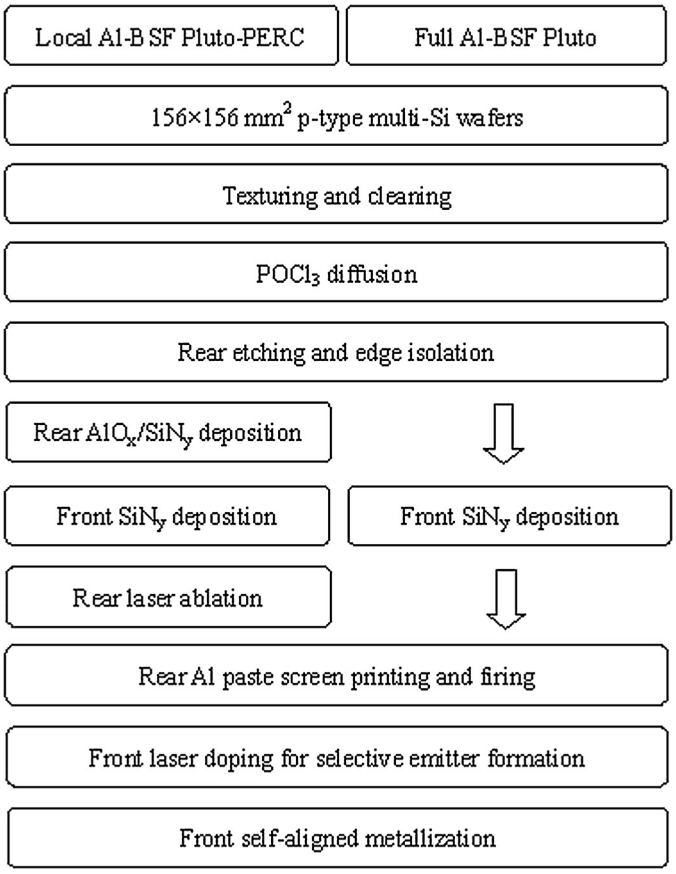

Fig. 1. Process flow of local Al-BSF Pluto PERC and conventional full Al-BSF Pluto cells.

respectively. For industrial purpose, there were no additional surface treatment such as wet chemical polishing and special cleaning prior to surface passivation mentioned in previous studies [18–21]. After deposition, line openings with a width of around 15 μm and a pitch of 1 mm were formed at the rear side by Coherent UV picosecond laser ablation. After printing of aluminum (Al) paste designed for local backside surface field (BSF) structures, a local Al-BSF was formed only in the openings of the passivating dielectric layers during the firing step in Centrotherm infrared conveyor-belt furnace. In parallel to the cells with local Al-BSF structure, a group of neighboring wafers was processed in conventional full Al-BSF for reference. All the front side processes were implemented based on Suntech owned Pluto technology. Since self-aligned plated front metallization comprising more than 90% copper is used in Pluto technology, there is no need to consider co-firing of front silver electrod and rear local Al-BSF, and therefore, Pluto technology provides a wider process window for rear local Al-BSF formation. The cell process flow is illustrated in Fig. 1.

After deposition of front SiN_y and rear AlO_x/SiN_y double-side passivation layers, effective minority carrier lifetime (τ_{eff}) samples were characterized by micro-wave photoconductance decay (MW-PCD) method (Semilab, WT-2000) before and after thermal treatment. In order to get a deep insight into the passivation effect, a contactless capacitance–voltage (*C–V*) measurement (Semilab, PV-2000) was performed. In the studies of deposition processes of AlO_x/SiN_y stacks, blistering was visualized and measured with optical microscope (Olympus, BX51M) and scanning electron microscope (SEM) (JEOL, JSM-6380LV), respectively. Thickness and refractive index (RI) of the dielectric layers were measured with spectroscopic ellipsometer (Sentech, SE400adv), and bond compositions of AlO_x and SiN_y were determined using Fourier transform infrared (FTIR) spectroscopy (Thermo Scientific, Nicolet 6700). Finally, the finished cells were analyzed through the measurement of light current density–voltage (*J–V*), spectral response, Suns-V_{oc} and light beam induced current (LBIC), respectively.

3. Results and discussion

3.1. Influence of thermal activation of passivation layers on the lifetime

For double-side passivated mc-Si samples, which were subjected to front SiN_y depositon followed by rear AlO_x/SiN_y deposition, average lifetime measured from mapping the whole wafer before and after thermal activation were 9.5 and 23.3 μs for fired in a conveyor-belt furnace at industrial fast-firing process, and 8.9 and 22.1 μs for annealed in a N_2-filled tube furnace at 425 °C for 30 min, respectively. To obtain a deep insight into the passivation effect before and after thermal activation, we applied non-contact *C–V* measurements with the samples of single-side AlO_x or AlO_x/SiN_y coating. Table 1 lists the extracted values of Q_{tot}, V_{fb} and D_{it}, which are defined as the charge density needed to move the surface from initial condition to the flatband, flat band voltage and interface trap density corresponding to the minimum value typically close to the midgap position, respectively.

From Table 1, it can be seen that little field effect passivation can be provided by as-deposited AlO_x single layer due to its very low Q_{tot} and V_{fb}. We can also observe that the absolute value of Q_{tot} in as-deposited AlO_x/SiN_y stack is one order of magnitude higher than that in as-deposited AlO_x single layer, because the deposition process of SiN_y capping could partly activate the passivation effect of AlO_x [22]. After firing in industrial fast-firing furnace with a set peak temperature ranging from 700 to 900 °C and belt velocities ranging from 4 to 6 m/min, which is the same firing condition used for local Al-BSF formation, the absolute values of Q_{tot} and V_{fb} increase substantially for both AlO_x single layer and AlO_x/SiN_y stack. However, D_{it} decreases a little for AlO_x single layer and increases a little for AlO_x/SiN_y stack. These small changes in D_{it} suggest that chemical passivation may not be dramatically affected by the firing treatment. Therefore, the significant increase in lifetime after firing mainly arises from the more negative charges activated by thermal treatment. Comparing *C–V* and lifetime measurement results between industrial fast-firing and annealing at lower temperature for longer duration, the industrial fast-firing process is sufficient for obtaining similar passivation effect like thermal annealing in a N_2 environment for 30 min at 425 °C, which was usually applied for thermal activation of ALD grown AlO_x films in previous work [23]. Additionally, with respect to the industrial application, fired at industrial fast-firing furnace with the same condition used for local Al-BSF formation would be preferable to thermal annealing for longer duration.

3.2. Influence of deposition sequence of passivation layers on the lifetime

Table 2 presents as-deposited and fired lifetime values of mc-Si samples, which were double-side passivated by front SiN_y and rear AlO_x/SiN_y with different depositon sequences of dielectric layers. Comparing with rear AlO_x depositon process, front SiN_y depositon process has higher temperature and longer duration, and therefore, Group 2 and Group 3 have higher as-deposited lifetime compared with Group 1 due to the partly activation effect of passivation induced by thermal treatment during the deposition process of front SiN_y. We can also see that in the as-deposited state, Group 3 with rear SiN_y capping prior to front SiN_y deposition exhibits the longest lifetime, and similar level of passivation can be achieved

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