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Full Length Article

Passivation properties of tunnel oxide layer in passivated contact silicon solar cells

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ABSTRACT

Passivated contact in advanced high-efficiency silicon solar cells based on the full back surface field (BSF) is reported here in based on the application of a tunnel oxide layer that is less than 2 nm thick. The open-circuit voltage (V_{oc}) was significantly improved via interface passivation due to insertion of the tunnel oxide layer. During oxide layer growth, a transition region, such as a sub-oxide, was observed at a depth of about 0.75 nm in the growth interface between the silicon oxide layer and silicon substrate. The properties of the less than 2 nm thick tunnel oxide layer were primarily affected by the characteristics of the transition region. The passivation characteristics of tunnel oxide layer should depend on the physical properties of the oxide. The interface trap density D_{it} is an important parameter in passivation and is influenced by the stoichiometry of the oxide which in turn strongly affected by the fabrication and the post annealing conditions. During heat treatment of a-Si:H thin films (for the purpose of crystallization to form doped layers), thin film blistering occurs due to hydrogen effusion on flat substrate surfaces. To minimize this behavior, we seek to control the surface morphology and annealing profile. Also, the passivation quality of passivataed contact structure declined for the sample annealed above 900 °C. This decline was attributed not only to local disruption of the tunnel oxide layer, but also to phosphorus diffusion. The resistivity of the tunnel oxide layer declined precipitously for the sample annealed above 900 °C. On the basis of these, implied V_{oc} over 740 mV was achieved in n-type Si wafer through the control of the oxide stoichiometry via optimizing the annealing conditions.

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1. Introduction

A high-efficiency silicon solar cell that acts as a 25% passivated emitter has been developed by using a rear locally diffuse (PERL) cell by applying a photolithography process [1]. Recently, a 25.1% tunnel oxide passivated contact (TOPCon) cell based on an n-type Si wafer was reported. The highlight of this cell is the excellent interface passivation quality achieved by applying a < 2 nm tunnel oxide layer. A passivation contact structure was inserted into the <2 nm tunnel oxide layer between the doped poly-Si and the silicon substrate. Transport through the oxide was reported by the tunneling mechanism. The TOPCon cell achieved an open-circuit voltage of 718 mV and saturation current density ($J_{0,rear}$) of <7 fA/cm^2, attributed to the tunnel oxide layer [2–4]. Also, 23.1% of silicon solar cell based on tunnel oxide junction was achieved to apply to replace the intrinsic a-Si:H thin films with tunnel oxide (<2 nm) based on heterojunction with intrinsic thin layer (HIT) solar cells [5]. The tunnel oxide layers that were less than 2 nm thick were formed by various methods such as thermal and wet-chemical and UV/O_3 photo-oxidation [6–8].

The initial steps of oxide growth on silicon substrates at the molecular level are well established [9–11]. Notably, the growth interface between the silicon oxide layer and silicon substrate exists as a chemically graded transition region. The features of the transition region differ from the characteristic features of silicon dioxide and the silicon substrate. This region contains silicon atoms in an intermediate state of oxidation, i.e., a sub-oxide (SiO_x, x < 2), and is about 0.75 nm thick. A disordered Si layer of about 0.3–0.6 nm is

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