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Firing Stability of Phosphorus Doped Polysilicon Passivation Layers

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Introduction

The application of passivating contacts with a structure of phosphorus doped polysilicon (polySi) and ultra-thin SiO_x layers can dramatically reduce carrier recombination at the metal/Si interface, which achieves an excellent J_0 below 5 fA/cm^2 [1, 2]. Mass production of solar cells with phosphorus doped polysilicon passivating contacts is already underway, with PV manufacturers such as Trina Solar reaching impressive 24.6% efficiency [3]. In mass production, high-temperature firing treatment is compulsory for the fabrication of screen printed solar cells. It has been found that the firing process can affect the passivation quality of the polySi contacts [4-6]. This work investigates the influence of firing on phosphorus doped polySi passivated n-type Cz-Si lifetime samples coated with various dielectric films, and explores the root causes of the performance loss.

Experiments

Planar n-type Cz-Si (~ 4 Ω·cm) wafers were used in this work. They were processed into lifetime testing samples featuring symmetric phosphorus doped polySi/SiO_x structure capped with either SiN_x/AlO_x stack or SiN_x. The fabrication process involved saw damage etch, thermal silicon oxide growth (1-2 nm), and intrinsic a-Si layer deposition (100 nm) in an industrial low-pressure chemical vapour deposition tool (LPCVD). This was followed by a $POCl_3$ diffusion to dope the polySi layer, a deposition of dielectric layers, firing, and removal of dielectric layers (for characterisation). Three groups of samples with different dielectric layers were tested in this work. They were either capped with PECVD SiN_x, a stack of AlO_x/SiN_x layers, or control samples without any capping layers. Effective carrier lifetime ,τ_{eff}, values were measured using photoconductance decay (PCD) [7], with their corresponding recombination current density parameters, J_0, extracted using Kane and Swanson method [8]. The J_0 values are used to monitor changes in the surface passivation quality of polysilicon passivation layers.

Results and Discussion

Figure 1 presents the τ_{eff} and J_0 of samples coated with SiN_x films measured before and after firing with different temperatures (actual temperature measured with thermocouple). It can be observed that all samples show some reductions on τ_{eff} and increase of J_0. When the samples are fired at 800℃, they exhibit very obvious degradation in τ_{eff} and J_0, with τ_{eff} dropping from 9 to 2 ms and J_0 increasing from 5 to 32 fA/cm^2. Interestingly, the magnitude of degradation in J_0 does not increase with peak firing temperature. Despite the absence of degradation on samples fired at 750℃, reductions on τ_{eff} and increases of J_0 are observed on samples fired at 600℃, suggesting the firing impacts could appear after any firing treatment with a peak firing temperature above 600℃.

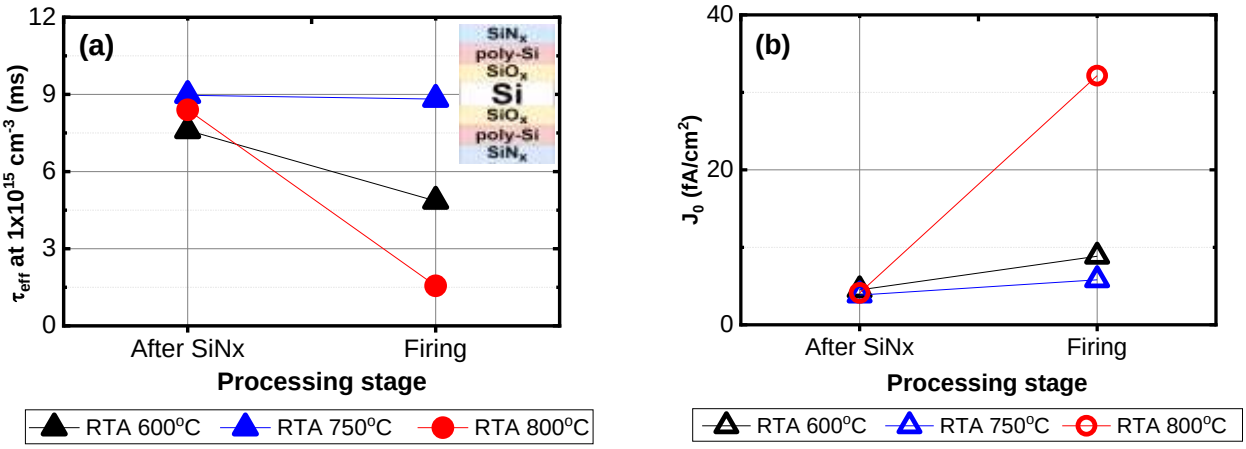

Figure 1. τ_{eff} (a) and single-side J_0 (b) values measured before and after RTA treatment at 600℃, 750℃ and 800℃.

Figure 2 summarises the GIXRD data measured on the non-fired control sample and the samples fired at 600℃, 750℃ and 800℃. The results indicate very minimum changes in the crystallinity of the polySi films after firing. This implies that the degradation of passivation quality observed from Figure 1 is unlikely due to the crystallinity change in polySi passivating contacts.

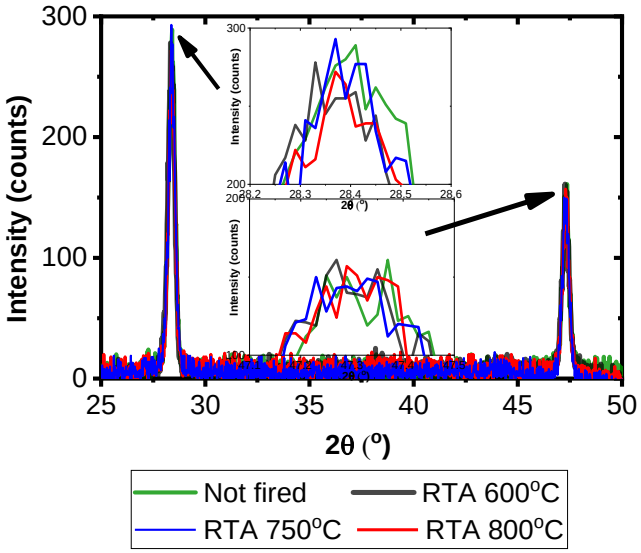

Figure 2. GIXRD results measured on the non-fired samples and the samples fired with RTA at 600℃, 750℃ and 800℃.

Figure 3 (a) depicts the evolution of J_0 values for the samples fired at 800℃ with various dielectric coatings. When comparing the samples before and after firing, all studied samples exhibit a reduction of passivation quality, but with different extents. It has been reported that the quality of the surface passivation of the polySi structures is potentially correlated to the presence of hydrogen [9], we therefore measured hydrogen concentration in the samples before and after firing treatment using Secondary-ion mass spectrometry (SIMS), with the results shown in Figure 3 (b). Samples without any dielectric coatings suffer a severe degradation in J_0 after firing, and reveal minimum hydrogen concentration among the tested samples. Regarding to samples capped with AlO_x/SiN_x stack, a small reduction of J_0 and a strong hydrogen signal are observed after firing, implying the injection of hydrogen into polySi passivation layers during the firing treatment. Sample capped with SiN_x films shows moderate increase in J_0. Surprisingly, the sample contains the highest hydrogen concentration compared with the other tested samples. Based on our results, it is suggested the

passivation quality does not necessarily increase with the hydrogen content in polySi films. Further work is required to investigate if there are any other factors affecting passivation quality of polySi layers or a proper amount of hydrogen in polySi films is required to achieve a good surface passivation.

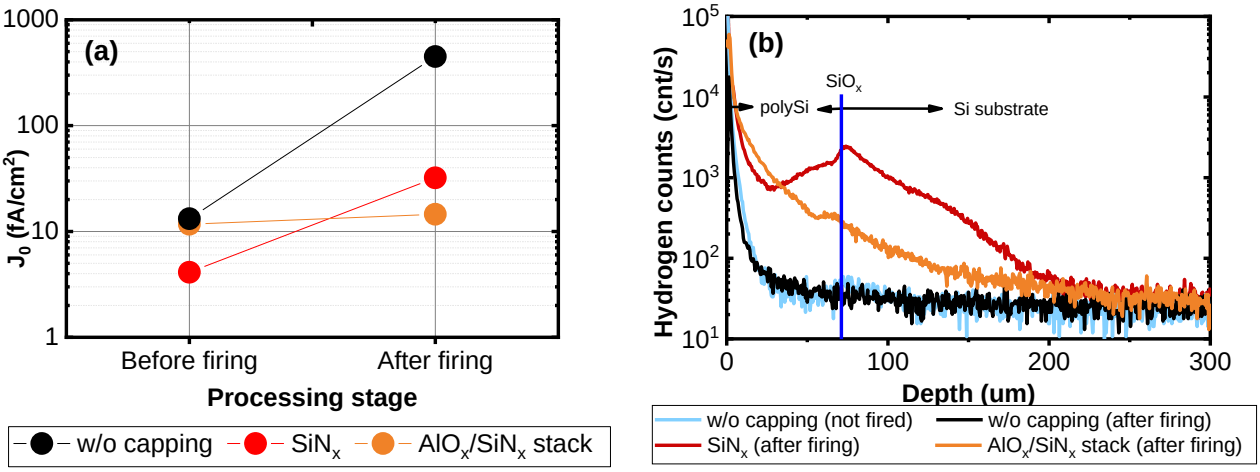

Figure 3. (a) Evolution of surface passivation quality of samples coated with various dielectric films, and (b) their H signals measured by SIMS.

Conclusions

We observed a degradation of surface passivation quality in polySi passivated wafers upon firing, dependent on peak firing temperature. Our results suggest that the degradation of J_0 is not related to the crystallinity of polySi films, assessed via GIXRD measurements, but could be potentially attributed to the changes of hydrogen concentration in polySi passivation layers measured by SIMS. Surprisingly, it was found that quality of surface passivation does not solely increase with higher concentration of hydrogen content in polySi films.

In the later work, we will extend our work to include samples coated with SiN_x films varying the deposition conditions and investigate their impact to the properties of the SiN_x capping layer and the fire stability of the polySi contact. Moreover, various advanced characterisation tools will be used to analyse different components in the polySi passivating structures. Transmission electron microscopy (TEM) will be employed to examine the change in the SiO_x tunnelling layer and in the interface between dielectric film and polySi upon firing.

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