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Controlling P and B Diffusion During Polysilicon Formation

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Abstract. High quality passivating contacts can be realized by using the combination of a thin interfacial oxide (SiOx) and doped polysilicon (polySi). Recombination losses are minimized by providing very good passivation between the thin hydrogenated oxide and the cSi, a high field effect by the highly doped polySi [1-2], combined with the low level penetration of dopants in the wafer [2-3]. To realize this low level in-diffusion of dopants, several interacting options are evaluated in this work: the quality of the thin oxide layer (growth method), combined with a diffusion blocking method (nitridation), doping concentration levels in the polySi and temperature of diffusion. It is shown that for Phosphorus (P)-doped polySi, in-diffusion can be reduced by adding an i-layer in between the oxide and the highly doped polySi, lowering the overall doping level in the system slightly. For Boron (B)-doped polySi, in-diffusion can be blocked by nitridation of the SiO2 layer.

INTRODUCTION

The continuous strife for higher solar cell efficiencies leads to the need to realize passivating contacts, where the metal contact is realized with very low resistance and recombination losses. One way to obtain this is by using the combination of a thin interfacial oxide (SiOx) and doped polysilicon (polySi) [4-6], where the latter can be contacted well by metal [7]. Recombination losses are minimized by providing very good passivation between the thin hydrogenated oxide and the cSi, a high field effect by the highly doped polySi [1-2], combined with the low level penetration of dopants in the wafer, result in excellent passivation [2-3]. In-diffusion of the dopants from the polySi in the crystalline (c)-Si depend on the doping level in the polySi and the temperature and time during the poly anneal. However, the diffusion mechanisms themselves differ from dopant to dopant and also the dominant diffusion mechanism is highly dependent on the doping level at which the dopant is diffusing. The focus in the paper is reducing the high doping level in-diffusion. The main diffusion mechanism at high doping levels for P is the substitutional diffusion mechanism, which depends on the presence of vacancies, which are non-occupied positions in the crystal lattice [8,9]. Reducing P-diffusion in highly doped regions can be obtained by reducing vacancies at the c-Si interface [10]. This can be realized by using an interstitial oxide with minimum amount of voids and pinholes at the interface with c-Si. For B, the high dopant diffusion depends on the interstitialcy diffusion mechanism and is dependent on the presence of self-interstitials (Si atoms in non-lattice positions) [8,9]. Reducing B-diffusion can be achieved by reducing the amount of self-interstitials at the c-Si interface, this can be realized by using a thermal oxide with minimum amount of voids and pinholes at the interface and by nitridation (insertion of nitrogen (N)) of the surface [9].

EXPERIMENTAL SETUP

The effects on in-diffusion are examined on textured 175 µm n-type Cz-Si 156·156 mm^2. During the processing, the pyramids are slightly rounded. Subsequently, the wafers are divided in the two groups, one received a thermal oxide (1.3 nm) while the other group obtained a chemical oxide via nitric acid oxidation of silicon (NAOS).

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Each group was split again and Boron-containing (p-a-Si) or Phosphorus-containing a-Si:H (n-a-Si) was deposited on both sides of the wafer using in-situ CVD. All samples were annealed in an inert environment to create respectively p-poly and n-poly. All samples received the same processing on both sides of the wafer.

Part of the p-poly samples was subjected to a nitridation process (using a NH3 plasma) prior to the deposition of the p-a-Si. The n-poly samples obtained intrinsic a-Si:H (i-a-Si) with varying thicknesses prior to the deposition of n-a-Si (also with varying thicknesses) to vary the concentration of doping in the final poly and effect on in-diffusion. The n-poly samples were annealed at 850˚C during 25 min, the p-poly samples were annealed at 850, 900 or 920˚C during 25 min. After the anneal, a-SiNx:H was deposited on both sides of the wafer and fired. Per parameter combination 2-3 wafers were used and measured on five spots on the wafer for lifetime using the Sinton WCT-120 instrument. ECV profiling was done after the anneal. For all ECV profiles shown, the interface with Si is positioned at 0 nm.

RESULTS AND DISCUSSION

Doping level of poly can be controlled by inserting an i-a-Si layer between the Si and the doped a-Si. This was done for n-poly. Total layer thickness (i-a-Si + n-a-Si) varied between 20 and 40nm and the ratio between (n/(n+i)) in thicknesses varied between 0 and 1. As can be seen in Fig. 1a, for NAOS, the lifetime is very poor when the ratio is very low, as the ratio increases slightly lifetime steeply increases to a maximum close to 3500 µs, corresponding to an iVoc of 730 mV, however this decreases significantly to poor values again for high doping levels. For the thermal oxide (Fig. 1b), lifetime is lowest for low doping levels of the poly, but this increases with incrementing doping levels, to a maximum of 7600 µs, corresponding to an iVoc of 736 mV.

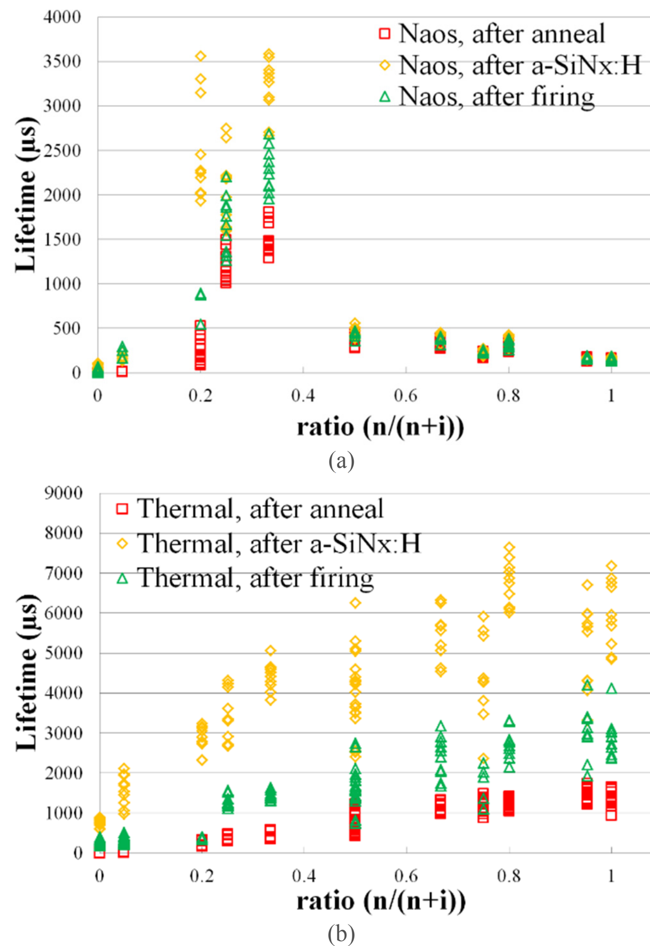
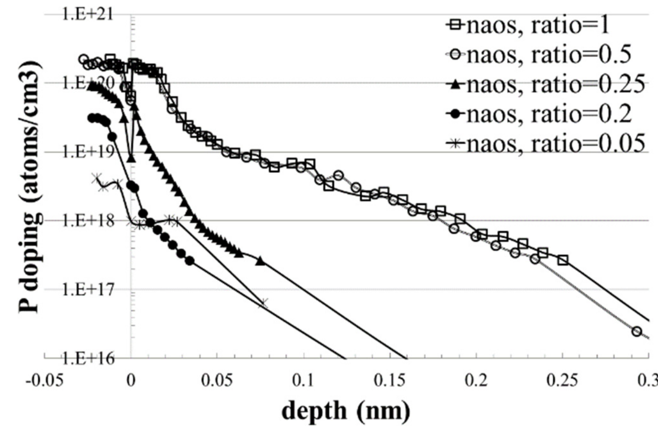
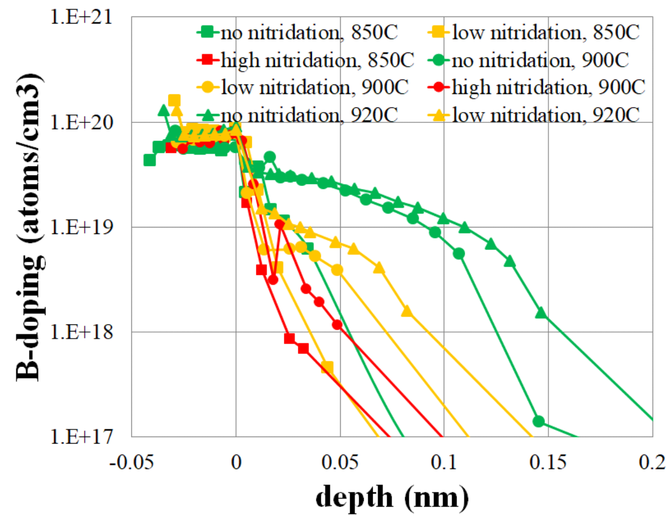


FIGURE 1. Minority carrier lifetime as function of the ratio (n/(n+i)) with NAOS (a) and thermal oxide (b) as interfacial layer, as measured after anneal, after a-SiNx:H deposition and after firing.

To fully understand this behavior the ECV profiles for the different stacks are examined and shown in Fig. 2a. For NAOS, starting at high doping levels, as the field effect passivation by the poly is good and recombination in the c-Si is lowered, lifetime increases. For lower doping levels, the field effect becomes less, while the lowering the in-diffusion further does not improve lifetime anymore. This is reflected in the corresponding drop in lifetime. A first conclusion based on this data can be drawn that doping in the poly needs to exceed $1\cdot10^{19}$ atoms/cm^3, while the doping in the c-Si should not exceed $3\cdot10^{18}$ atoms/cm^3. These results correspond to what can be expected from results by others [4] and what can theoretically be determined for the Auger recombination in the bulk. The results show that inserting an i-a-Si layer in between n-a-Si and NAOS, in-diffusion can be more controlled and high iVoc values up to 730 mV can be reached.



(a)



(b)

FIGURE 2. ECV profiles for (a) P doping for different ratios (n/(n+i)) using NAOS as interfacial layer, and (b) B-doping (40nm layers) on wafers with NAOS annealed at 850, 900 and 920˚C which received high, low or no amount of nitridation.

The ECV profiles for the thermal oxide (not shown) showed a low in-diffusion for all ratios and the lifetime was shown to correspond to the doping level and thus field effect of the polySi.

In-diffusion of B can be controlled by nitridation. This was achieved by subjecting the wafers with oxide to a remote-PECVD NH_3 plasma. Two different speeds with which the tray moved through the system were used, resulting in a factor 5 difference in time to which the wafers were exposed to the plasma. To study the effect related to the in-diffusion and passivation, two different oxides (chemical and thermal oxide). On the oxides, p-a-Si was deposited with two different thicknesses (20 and 40nm). In Fig. 3a and b the minority carrier lifetimes of the two samples per setting as measured after firing are shown for NAOS and for thermal oxide, respectively and for NAOS, the

corresponding ECV profiles are shown in Fig. 2b. For NAOS, it can be seen that nitridation significantly reduces the in-diffusion for all temperatures, and for higher temperatures this feature is more distinct. As expected, in-diffusion increases with increasing anneal temperatures. The blockage by nitridation of in-diffusion is highly effective in increasing minority carrier lifetime. However, damage to the interface with SiO2 and c-Si does occur, as the more exposed (high nitridation) wafers show a lower lifetime. In-diffusion is critical in determining the lifetime, as for no nitridation the low anneal temperatures result in the highest lifetime. As soon as the in-diffusion is more blocked, the application of higher temperature, resulting in higher crystalline and slightly higher doped poly, results in an increase in minority carrier lifetime. The thermal oxide itself showed to be a good diffusion barrier and the nitridation procedure yielded no effects on the in-diffusion, as no difference in the ECV profile was observed. However, the lifetime was effected due to the additional damage by the nitridation at the interface.

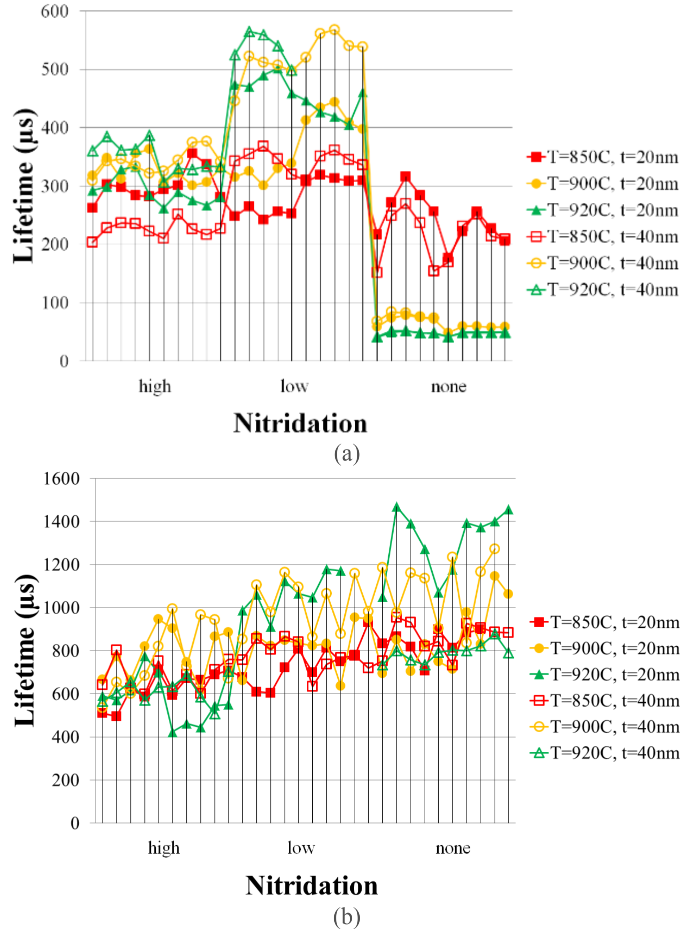


FIGURE 3. Minority carrier lifetime as function of nitridation for p-poly with (a) NAOS and (b) Thermal oxide.

CONCLUSIONS

To realize low level in-diffusion of dopants from the polySi layer in the c-Si during anneal, several interacting options are evaluated in this work: the quality of the thin oxide layer (growth method), combined with a diffusion blocking method (nitridation), doping concentration levels in the polySi and temperature of diffusion. It is shown that for Phosphorus (P)-doped polySi, in-diffusion can be reduced by adding an i-layer in between the oxide and the highly doped polySi, lowering the overall doping level in the system slightly. For Boron (B)-doped polySi, in-diffusion can be blocked by nitridation of the SiO2 layer.

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