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# Dissolution of electrically inactive phosphorus by low temperature annealing

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**Abstract**

In this study we investigate the dissolution of electrically inactive phosphorus complexes by low temperature annealing after the $POCl_3$ diffusion process. This has the immediate consequence that the existing near-surface emitter volume SRH recombination can be reduced. Thereby, a significant reduction of emitter saturation current density $j_{0E}$ is achieved without driving the emitter further into the silicon substrate. For short-term temperature treatments well below the $POCl_3$ diffusion temperature, a reduction of up to -60 fA/cm² has been achieved. This study increases our understanding of the formation and dissolution of electrically inactive phosphorus complexes during post-annealing processes.


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*Keywords:* low-temperature annealing; electrically inactive phosphorus; $POCl_3$ diffusion

## 1. Introduction

Today, most screen printed solar cells have highly doped emitters which include a non-negligible fraction of electrically inactive phosphorus on the emitter surface [1]. Here, one must distinguish between stable P-precipitates and less stable complex phosphorus-oxygen structures. Furthermore, it can be assumed that Shockley-Read-Hall (SRH) recombination in the near surface emitter region is strongly correlated with the density of these electrically inactive P complex structures [2].

The formation of the electrically inactive phosphorus depends on various process parameters such as $POCl_3$-$N_2$ gas flow, process temperature as well as the cooling-down phase. In a conventional diffusion process very high cooling ramps (>20 K/s) are usually used. Thereby, we assume that during the rapid cooling down phase P-


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complexes from the surface of the phosphorus silicate glass and the silicon surface transfer into a frozen state by the quenching effect [3]. In this study, we introduce an additional low temperature annealing (LTA) to reverse this effect and thereby dissolve a significant part of the electrically-inactive phosphorus on the emitter surface and in the near surface emitter region [4-10].

## 2. Experimental details

### *2.1. Interaction between the density of the electrically-inactive P and LTA*

In the first experiment 3 different $POCl_3$ diffusions have been processed to form 3 emitter structures with very high, medium and very low density of electrically inactive phosphorus. For this experiment, FZ silicon wafers of 200 µm thickness and a resistivity of 2 & 200 Ωcm were used. After the diffusion process, the wafers were divided into 2 groups, with and without PSG, followed by 3 LTA steps. After this process, all samples were cleaned by a conventional cleaning procedure ($H_2O$-HCl-HF) and symmetrically passivated by PECVD $SiN_x$ (including firing). The samples were finally characterized. We intend with this first experiment to show the temperature range in which LTA exerts the strongest influence on the inactive P-concentration. In the second experiment, the density of the inactive phosphorus was reduced by steps using a wet-chemical emitter etch-back procedure EEB [11]. Thereby we start with an emitter with a high density of electrically-inactive phosphorus. The wet chemical EEB allows to etch-back the emitter homogeneously in small nm steps. The focus is thereby on showing the extent to which the density of the inactive phosphorus can be influenced or respectively reduced by LTA in a defined temperature range.

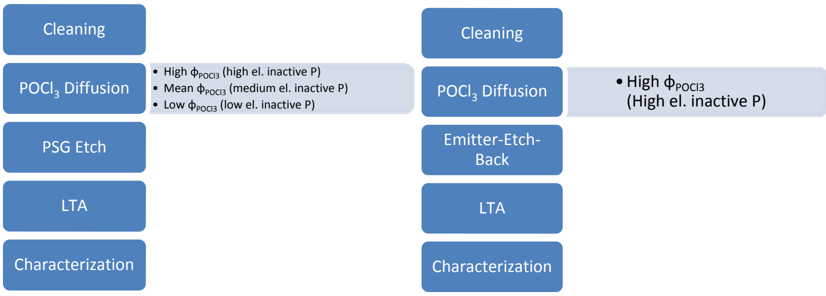


Fig. 1. Experimental details of the studies on the influence of LTA on the P-concentration and the recombination activity of the n-type emitter

## 3. Results and discussion

### *3.1. Temperature range of LTA*

In the first experiment, the influence of the temperature range on the change in electrically active and inactive P is shown. Measured sheet resistances as a function of LTA temperature is displayed in Fig. 2 (left). Since sheet resistance is determined by the density of electrically active P in the emitter, here we can analyze the influence of LTA on electrically active P in dependency on LTA temperature. Two emitter structures with lower and higher densities of electrically inactive phosphorus are studied. In Fig. 2 we see that LTA leads to a weak increase in emitter sheet resistance. The change of emitter sheet resistance appears here for both types of emitters. The absolute change in $R_{sheet}$ is <2.8 Ωcm and is therefore insignificant. Since LTA temperatures studied in this investigation lie far below the diffusion temperatures, we assume that LTA causes a restructuring of the P-O complexes on the emitter surface and in the emitter volume. Fig. 2 (left) shows furthermore that LTA temperature has only a small influence on sheet resistance of the emitter. Comparison of ECV profiles as a function of LTA temperature range in Fig. 2 (right) shows that LTA temperature far below 800°C has only a very weak influence on the change of the electrically active P.