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Microscopic homogeneity of emitters formed on textured silicon using in-line diffusion and phosphoric acid as the dopant source

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ABSTRACT

An important point of comparison between $POCl_3$ emitter diffusion in a quartz tube furnace and in-line diffusion using sprayed phosphoric acid is the microscopic homogeneity of the diffusion, i.e. the homogeneity along the texture of a silicon surface. Two characterization methods were used. In each case, the cross-section of cleaved mc-Si and Cz-Si textured samples was observed in a scanning electron microscope (SEM). First, the thickness of the phosphosilicate glass (PSG) was measured. Second, the emitter was observed on SEM images which showed the n-type silicon as a darker region. The results show comparable homogeneity for in-line and $POCl_3$ diffusion.

1. Introduction

Due to the trend toward thin and hence fragile wafers, and toward highly automated production lines, a well-proven in-line diffusion process is desired. This work investigates the microscopic homogeneity of a diffusion process, which consists of in-line spraying at room temperature of a dopant source (2.5 wt% aqueous solution of H_3PO_4 with a small quantity of surfactants [4]), followed by phosphosilicate glass (PSG) formation and emitter diffusion in a metal-contamination-free in-line furnace. Microscopic homogeneity refers to the lateral distribution of PSG thickness and emitter depth along a textured surface. Microscopic homogeneity of the emitter is particularly important to avoid shunt formation during front contact metallization.

2. Experimental

Microscopic homogeneity of both PSG thickness and emitter depth was characterized by means of scanning electron microscope (SEM) images of sample cross-sections. The samples were cut from $125 \times 125\,mm^2$ wafers using a diamond scribe, mounted on a sample holder and introduced in the SEM chamber. The PSG was etched from the samples intended for imaging of the emitter. Two in-line processes, named *D1* and *D2*, were examined. They differed in the flow rate of the dopant source to the spray nozzle: 3.5 and 5 ml/min, respectively. In addition, a $POCl_3$ process, called *D3*, was examined. The samples come from mc-Si and Cz-Si textured wafers with a resistivity range of 1–3 and 0.5–2 Ω cm, respectively. The doping profiles were measured using secondary ion mass spectrometry (SIMS) on polished FZ-Si wafers. Table 1 shows the approximate p–n junction depths X_j as well as the PSG thickness D_{PSG}, measured on polished FZ-Si using ellipsometry and averaged over the whole wafer.

The images of the PSG were taken with a Hitachi S-4700 SEM. The images of the emitter however, were taken with a newer model, the Hitachi S-4800 SEM, which makes in secondary electron images the n-type emitter region appear darker than the p-type base. The contrast formation is being attributed to the built-in voltage of the p–n junction, which results in local fields outside the silicon, which in turn influence the number of detected secondary electrons [1–3].

3. Results and discussion

3.1. Microscopic homogeneity of PSG thickness

The SEM images (see Figs. 1 and 2) show that the PSG mostly follows the surface texture. Fig. 1 shows the PSG on Cz-Si samples textured with random pyramids. On the pyramid flanks, no difference was found between *D1* and *D2*: PSG thickness D_{PSG} is equal to about 55–70 nm and is therefore thinner than on FZ-Si (see Table 1). In the valleys however, D_{PSG} is thicker than on FZ-Si. A similar liquid accumulation in the valleys was observed in [5], where photoresist was sprayed on a substrate with V-grooves. On the Cz-Si samples with *D1* and *D2*, D_{PSG} was measured in five and

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three valleys, respectively and was equal on average to 317 nm for *D1* and 403 nm for *D2*. A higher accumulation was therefore observed for the higher sprayer flow rate. On textured mc-Si (see Fig. 2), the PSG from the in-line diffusion is to some extent thicker in the valleys and gets progressively thinner toward the peaks. The PSG from the $POCl_3$ process is in general more homogeneous.

Table 1
Emitter junction depth X_j and PSG thickness D_{PSG} on polished FZ-Si.

Process	X_j (μm)	D_{PSG} (nm)
In-line diffusion *D1*	0.45	93
In-line diffusion *D2*	0.45	114
$POCl_3$ diffusion *D3*	0.37	50

3.2. Microscopic homogeneity of emitter thickness

Fig. 3 shows a comparison between the emitters on Cz-Si samples with *D1* and *D3*. In both cases, a deeper emitter is observed at the peak of the pyramid than on the flank. This can be explained by the higher ratio of Si surface to the Si volume at the peak: The phosphorus diffuses from a larger surface into a given volume of Si. The approximate depths of the transition from n- to p-type are indicated under the graphs. The difference between the

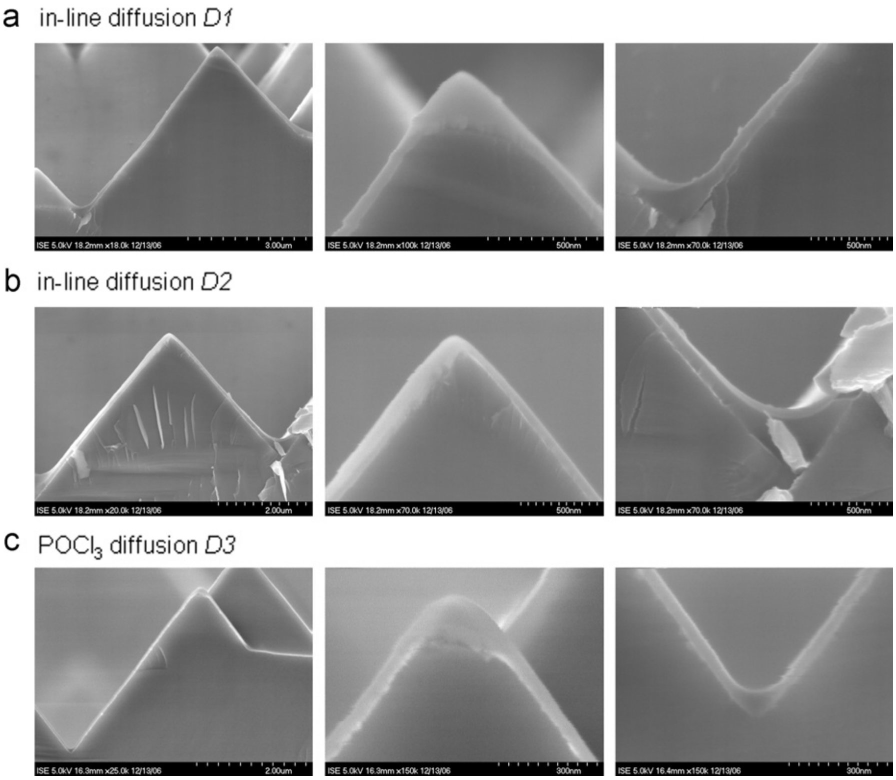

Fig. 1. SEM images of PSG on textured Cz-Si. For three diffusion processes (*D1*, *D2* and *D3*), three images of the same location are shown (whole pyramid, peak, valley).

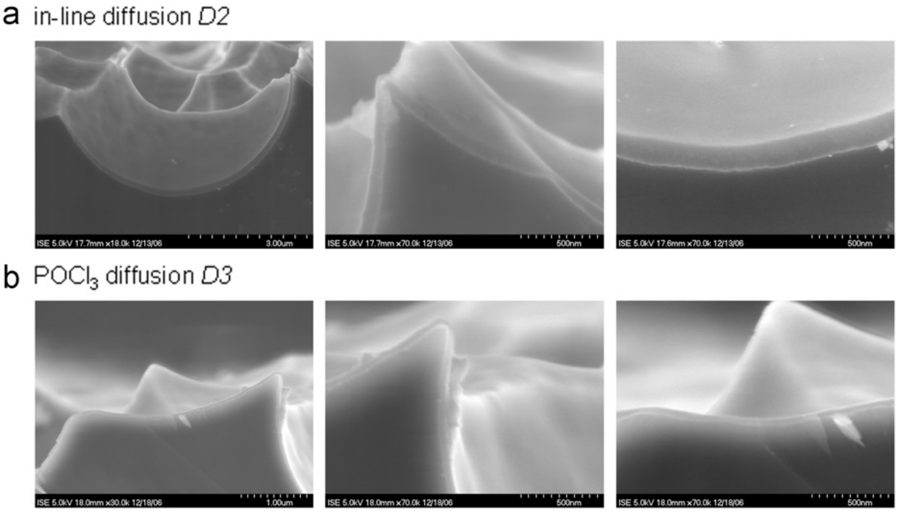

Fig. 2. SEM images of PSG on textured mc-Si. For two diffusion processes (*D2* and *D3*), three images of the same location are shown (whole structure, peak, flat).