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ENHANCEMENT OF INTERNAL GETTERING EFFICIENCY OF IRON BY LOW TEMPERATURE NUCLEATION

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Internal gettering (IG), *i.e.* gettering of metal impurities by oxygen precipitation related defects, is a common method used in the IC industry to improve device yields. However, further understanding of IG together with predictive computer modeling, is essential to improve the gettering process as current experimental optimization through device yield studies is unreasonably expensive and time consuming. There have been several publications[1-4] about the modeling of IG of transition metals in silicon, which are based on the assumption of diffusion-limited precipitation. These models, nevertheless, tend to overestimate the IG efficiency especially at low supersaturation[5]. Low supersaturation is the most significant region in real IC fabrication: iron concentration is reasonably low (less than 10^{13} cm^{-3}) and front-end-of-line processing temperatures are above 600°C.

Our experiments show that the gettering efficiency of iron can be drastically improved if the wafers are exposed to a short low temperature anneal to form iron nuclei before the actual gettering anneal. Traditionally, gettering is activated during a slow cooling at the end of the process. However, the time consuming slow ramp is often not good enough for effective gettering[6]. Figure 1 shows an example of the influence of iron nucleation at low temperature on the gettering efficiency.

In the experiments we used p-type CZ-silicon, in which about 10^9 cm^{-3} and 10^{10} cm^{-3} oxygen precipitates were grown in a 600°C/6h + 1100°C/16h thermal oxidation. To get a difference in the oxygen precipitate densities, we used two different initial oxygen concentrations: 14 ppma and 16 ppma. Iron was diffused into the wafers at 850°C for 55 minutes to get an initial iron concentration of 10^{13}cm^{-3}. The surfaces of the wafers were cleaned and the wafers were oxidized again at 900°C to guarantee homogeneous iron distribution. Two different kinds of gettering experiments were performed to study the effect of low temperature nucleation. The gettering anneal was the same for both series: annealing at 700°C for varying processing times (0h, 1h and 2h). In the first test, the wafers were slowly cooled (2°C/min) from the oxidation temperature at 900°C down to 700°C, which was directly followed by the above mentioned gettering anneal. In this series we did not observe any gettering to take place. In the second series, the only difference is that after the oxidation at 900°C, the wafers were quickly pulled out of the furnace to the room temperature before the gettering anneal at 700°C was performed. In the latter case the gettering is clearly observed. We did not notice much difference between samples with different oxygen precipitate densities. This implies that not all oxygen precipitates are active gettering sites for iron. In homogeneous reference wafers that experienced the same gettering anneal as the second series, we did not observe almost any iron precipitation to take place, which suggest that iron does not precipitate homogeneously.

The enhanced gettering efficiency can be explained by the formation of iron nuclei to some of the oxygen precipitation related defects at low temperature. After nucleation iron has low barrier for precipitation at higher temperature while its diffusivity is increased. This results in strong gettering and the dissolved iron concentration approaches the solubility value. The phenomenon is analogous to oxygen precipitation in silicon[7]. High enough supersaturation is needed before nucleation and precipitation take place. For iron the required supersaturation level is lower compared to oxygen as iron precipitates heterogeneously to the existing defects while oxygen may need to precipitate homogeneously.

In this paper we study the gettering efficiency of iron at different gettering temperatures. In addition, we study what the optimal nucleation temperature is for iron. We also create an empirical model that improves the predictability of the real gettering efficiency at low supersaturation. The results indicate that instead of concentrating on a slow cooling at the end of the device processing, one can improve the gettering efficiency by making a "low-high" anneal to activate the gettering. In order to optimize the furnace time consumed on gettering, the best option is most likely to pull the wafers out of the furnace (the pull-out temperature is insignificant) and then draw them back into the furnace at constant temperature. One has to keep in mind that competitive gettering[8] by the areas of heavily doped real devices probably reduces the overall gettering efficiency.

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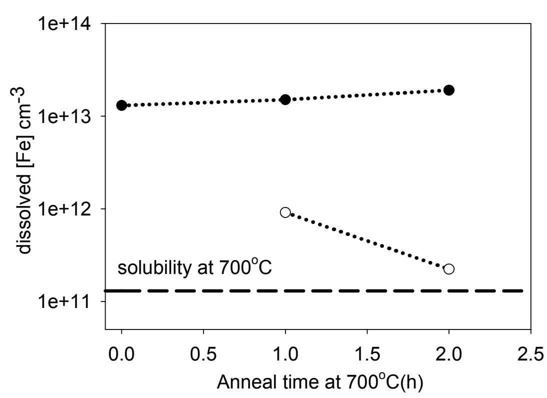

Fig. 1. Measured iron concentration after gettering anneal at 700°C: i) Wafers are slowly cooled down from 900°C (solid circles) ii) Wafers have been unloaded to room temperature after the oxidation and then loaded back to the 700°C gettering anneal (open circles).