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Some aspects of proton implantation and subsequent thermal annealing

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In contrast to the well known physics of conventional ion doping the situation for hydrogen seems to be quite different. The implantation of hydrogen induces crystal damage into the Si matrix. These defects are decorated by the hydrogen itself after a soft anneal and thereby a donator complex is build. We investigated those defects and complexes with the aim of acquiring a better physical understanding of them and their changes under certain variable parameters. In particular, the impact of implantation dose variations, annealing temperature and annealing time on crystal defects and doping concentration mainly in FZ material were examined.

A wide variation of techniques including Doppler broadening, the highly sensitive positron annihilation spectroscopy and low temperature lifetime spectroscopy measurements down to 10 K were used along with electrical methods like spreading resistance profiling. In order to de-couple crystal defects originating directly from proton implantation also experiments utilizing co-implantation with He followed by hydrogen treatment were carried out.

The proton irradiation induced defects perform a gettering function for impurities, strongly influence the diffusion of oxygen and hydrogen itself and serve as thermal donor formation-centers. A major finding is that different donor states are build predominantly as function of the annealing temperature. The complexes are stable within certain annealing temperature ranges and populate different energy levels in the Si band gap. Ultimately, about 10-4 donors are created for every radiation-induced Frenkel defect.

One main focus of the investigation is the dependency of the donor introduction efficiency on the ion dose and the annealing temperature. The position and shape of the damage profile will be discussed in view of the different preparation methods.

We were also able to detect shallow traps in Czochralski silicon after specific annealing processes, and its corresponding temperature dependence of the trapping rate. The latter was found to be positron de-trapping from extended Rydberg states.

Author: Dr SCHUSTEREDER, Werner (Infineon Austria)

Presenter: Dr SCHUSTEREDER, Werner (Infineon Austria)

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