Radiation-induced deep levels in Pb- and Sn-doped n-type Czochralski silicon

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Introduction. Although group IV impurities in silicon do not possess direct electrical activity, they can modify the properties of the material in a more subtle way. It is for example known that substitutional Ge or Sn atoms trap vacancies (V), thereby forming Ge-V or Sn-V defect centers, at the expense of A centers (V-O) and divacancies (V-V) [1]. This suggests the possibility of a material hardening effect by doping with Ge or Sn and triggered the study of radiation defects in Sn-doped silicon [2-3]. One of the main outcomes of these investigations was the identification of the four deep levels associated with the Sn-V complex, separating five charge states and shown in Fig. 1 [1-3]. Detailed studies of the optical and electrical recombination properties of Sn-doped Float-Zone (FZ) and Cz silicon have led to the conclusion that Sn-doping is not very effective in making the material more radiation tolerant [4-5]. Regarding the effect of Pb-doping, its precipitation behaviour has been investigated to some extent [6], while little is known about the interaction with radiation defects.

The aim of this paper is to investigate the impact of a high-energy electron or proton irradiation on Pb-doped Si in order to identify possible new radiation defects and to evaluate its hardening potential. In addition, samples co-doped with Sn and Sn+C will also be studied by Deep Level Transient Spectroscopy (DLTS).

Results and Discussion. N-type Cz Si doped with Pb in the range 1-5x10^{18} cm^{-3}, as derived from SIMS, has been irradiated by 3.8x10^{11} cm^{-2} 60 MeV protons and by 10^{15} and 10^{16} cm^{-2} 1 MeV electrons. Before irradiation, DLTS on Au Schottky barriers indicates the presence of at least two grown-in electron traps, occurring below 80 K and having an activation energy in the range 0.11 and 0.15 eV. The latter is believed to correspond to the C-H donor.

After electron irradiation, radiation-induced deep levels can be identified in Fig. 2 for temperatures above 70 K, the dominant one being the V-O center, while the as-grown peaks appear to be unaffected in the first instance. It should be remarked, however, that the Pb-doped material has been co-doped with C, in order to keep the Pb atoms at substitutional sites. This means that we expect a non-negligible contribution of the C_i-C_s center to the V-O peak. Measurements as a function of the pulse duration are currently undertaken to discriminate the two peaks.

In the temperature range above 100 K, beside the well-known levels related to the acceptor states of the divacancy V_2 and the phosphorous-vacancy (P-V), one can also discern some unidentified deep levels in Fig. 2, both in the Pb-doped and standard Si material. Further in-depth analysis of the trap parameters is on-going to identify these radiation defects. However, at the moment, there is no clear evidence for specific Pb-related centers.

In the case of Pb and 2x10^{17} cm^{-3} Sn co-doping one observes the two acceptors states of the Sn-V complex, already shown in the upper spectrum of Fig. 1. It will also be shown that the 60 MeV proton irradiation introduces much smaller densities of radiation defects, due to the lower Non Ionizing Energy Loss (NIEL), going into atomic displacements.

Conclusions. DLTS studies reveal the presence of so far unidentified electron traps in both proton and electron irradiated n-type Cz silicon doped with Pb, co-existing with the standard radiation defects (V-O and V_2). A further in-depth study of the deep level parameters should reveal whether Pb doping may yield more radiation tolerant material.

References

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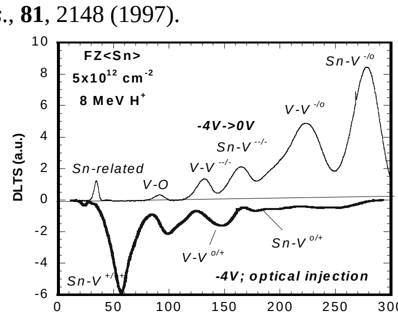

Fig. 1. DLT-spectrum corresponding to an 8 MeV proton irradiated Sn-doped n-type FZ sample, using an electrical pulse from –4 to 0 V (upper spectrum) and an optical injection pulse at a reverse bias of –4 V (lower spectrum).

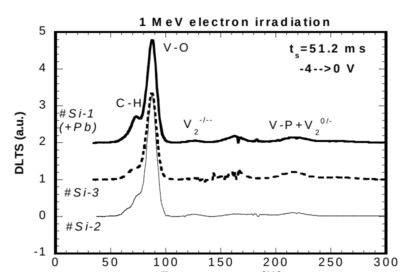

Fig. 2. DLT-spectra of 1 MeV, 1x$10^{15}$$e^-$/$cm^2$ irradiated n-Cz Si, doped with Pb (#Si-1) and two reference samples without Pb (#Si-2 and 3).