

Oxygen Precipitation and Thermal Donor Formation in Pb and C 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 material properties during heat treatments. It is for example known that substitutional C, Ge or Sn have an effect on oxygen precipitation and on thermal donor (TD) formation processes. This effect is related to the presence of additional precipitation centres and their influence on the oxygen solubility in silicon, whereby intrinsic elastic strain associated with the difference in covalent radius between the impurity atoms and silicon can play an important role. Therefore, the various covalent impurities have a different influence on oxygen precipitation in silicon. However, the interaction may be complex as illustrated for C- and Ge- or Sn-doping.

It is well established that the reduction of the silicon lattice period by C-doping ($R_C=0,077$ nm, $R_{Si}=0,117$ nm), results on the one hand in a decrease of the oxygen-related thermal donor (OTD) generation rate in the 300-500°C temperature range [1,2], but on the other hand increases the dissolution of the oxygen solid solution and the new donor (NTD) generation rate (at 600-800°C) [1, 3-4]. While Ge- or Sn-doping increases the silicon lattice period ($R_{Ge}=0,122$ nm, $R_{Sn}=0,140$ nm), a decrease of both the OTD and NTD generation rates and the dissolution of the oxygen solid solution have been reported [5-8]. For the same doping concentration, the effect of Sn is more pronounced than for Ge.

Of all covalent impurities, Pb has the highest radius ($R_{Pb}=0,146$ nm), suggesting the possibility of a more intense thermal stabilisation effect by Pb-doping. As there are some technological problems for the direct Pb-doping of Si in the melt, a solution is to perform simultaneously a C- and Pb-doping. The aim of this paper is to investigate the oxygen precipitation and thermal donor creation in (Pb+C)-doped Si in order to evaluate its thermal hardening potential.

Results and Discussion. N-type Cz silicon doped with Pb+C, with C or non-doped standard material were used. The interstitial oxygen concentration was $6.5\cdot 7 \times 10^{17}$ cm⁻³ (Pb+C), $7.5\cdot 8 \times 10^{17}$ cm⁻³ (C-doped) and $8\cdot 9 \times 10^{17}$ cm⁻³ (non-doped Si). The initial doping concentration was in the range $1\cdot 2 \times 10^{15}$ cm⁻³, as determined from Hall effect. Thermal annealings have been performed at 450, 510 and 650°C for different times. Figure 1 represents the change in the free electron concentration (Δn) after a 450°C anneal, caused by the creation of OTDs. One can notice that the OTD generation in Si<Pb+C> is suppressed in comparison with the reference n-Cz material (curve 3), but less than in Si<C> (curve 1).

It will be shown that after a 650°C anneal just the opposite trend is observed in Δn . In this case, the increase

in electron concentration is due to the creation of NTDs, whereby the highest concentration is found in Si<C>, followed by Si<Pb+C>. As will be demonstrated, the difference in NTD generation can be eliminated by a preliminary heat treatment at 510°C. There is a similar effect of Pb-doping on the precipitation at 650°C of the optically active (dispersed) interstitial oxygen atoms, as derived from infrared absorption. From this, it is concluded that the effect of Pb-doping is to partially compensate the impact of C on the oxygen precipitation kinetics.

Conclusions. The effect of Pb-doping on TD-generation and oxygen precipitation in Si is opposite to C-doping. C-doping leads to a reduction of the OTD generation, and an increase of both the NTD generation and the oxygen precipitation. A further in-depth study of the Pb distribution in the Si crystals may reveal the exact role of Pb-doping on the oxygen behavior during thermal treatments.

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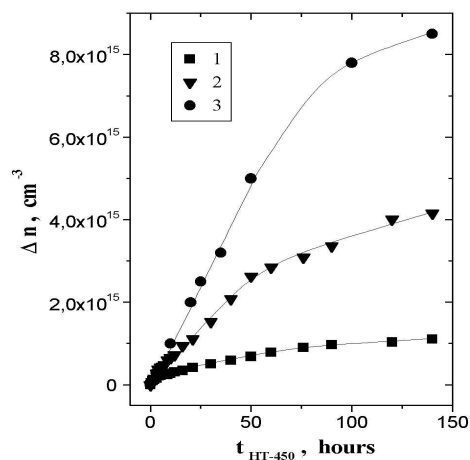


Fig. 1. Change of the free electron concentration versus anneal time at 450°C: 1 – Si<C> ($7\cdot 8 \times 10^{16}$ cm⁻³), 2 – Si<Pb+C> ($1\cdot 5 \times 10^{18}$ cm⁻³+ $7\cdot 8 \times 10^{16}$ cm⁻³); 3 – Si<undoped>.