TSC analysis of g-irradiated Si standard and oxygenated diodes in a wide temperature range

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Motivations

1. INTRODUCTION

- n type Standard FZ inverted above 200 Mrad. Considerable improvements (ROSE coll.) could be achieved using DOFZ. The effect is maximum for gamma irradiation: inversion is not observed up to 1.76 GRad, even if polarization effects arise.

Z. Li et al., “Paradoxes of steady-state and pulse operational mode characteristics of silicon detectors irradiated by ultra-high doses of g-rays,” NIM A, in press.

- Only point defects are introduced by *gamma*-rays - Oxygen atoms can prevent formation of vacancy related acceptor like complexes (V_2O)

Open problem: Thermal donors in irradiated oxygenated silicon

-Thermal donor clusters are known to generate two lines in I-DLTS spectra, related to the transitions $TD^{0/+}$ and $TD^{+/++}$. Kimerling and Benton (1981) measured the zero-field energies (including Poole-Frenkel correction) 7 meV and 150 meV.

Kimerling L. C., Benton J. L, **1981**, Appl. Phys. Lett. 39, 410.

- Energies deduced simply from peak position, without PF correction, are 45 meV and 120 meV respectively.

Keller W., Wunstel K., **1983**, Appl. Phys. A 31, 9-12.
Wada K., Inoue N., **1985**, J. Appl. Phys. 57, 5145.

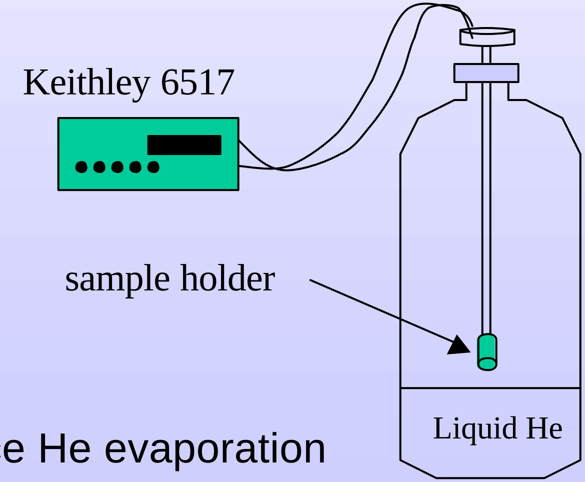
- Thermal donors should not appear in standard float zone silicon.

2. SAMPLES AND EXPERIMENTAL PROCEDURES

Samples: standard and oxygen enriched FZ (DOFZ) Si diodes irradiated with a ^{60}Co g-source up to a dose of 300 Mrad (from Ioana Pintilie, Hamburg)

Experimental technique

-Thermally Stimulated Currents (TSC)
-Temperature range: **8-300K** (spanned energy range ~0.05-0.50eV)
-Cooling by immersion in liquid He vapors
-Heating (by a resistance) with rates 0.07-0.20K/s.
-Reverse bias: 10 V.
-Excitation:forward bias up to current saturation (3.8 mA).
-Reverse bias V_{rev}=10 V.
-Filling Temperature varied by changing distance from the Liquid He surface



- Several measurements in different T intervals to reduce He evaporation (10-25 K, 20-80 K, 80-220 K).

3. EXPERIMENTAL RESULTS AND DISCUSSION

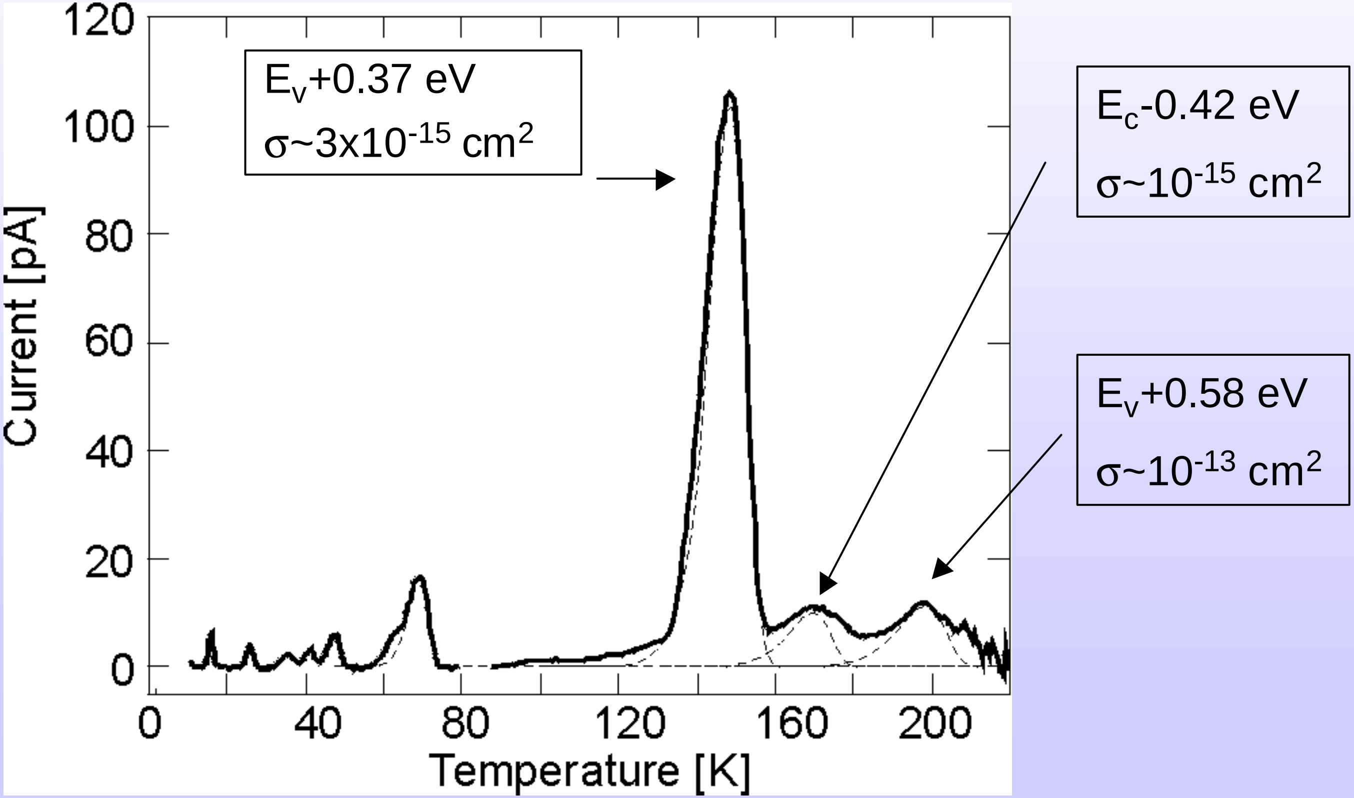
Standard Float Zone Si sample - Overview

Above 100 K:

a) 140K: $\sigma \cong 3\times10^{-15}$ cm^2, $E \cong 0.37$ eV, probably C_iO_i

b) 170K: $\sigma \cong 1\times10^{-15}$ cm^2, $E \cong 0.42$ eV, $V_2^{-/0}$

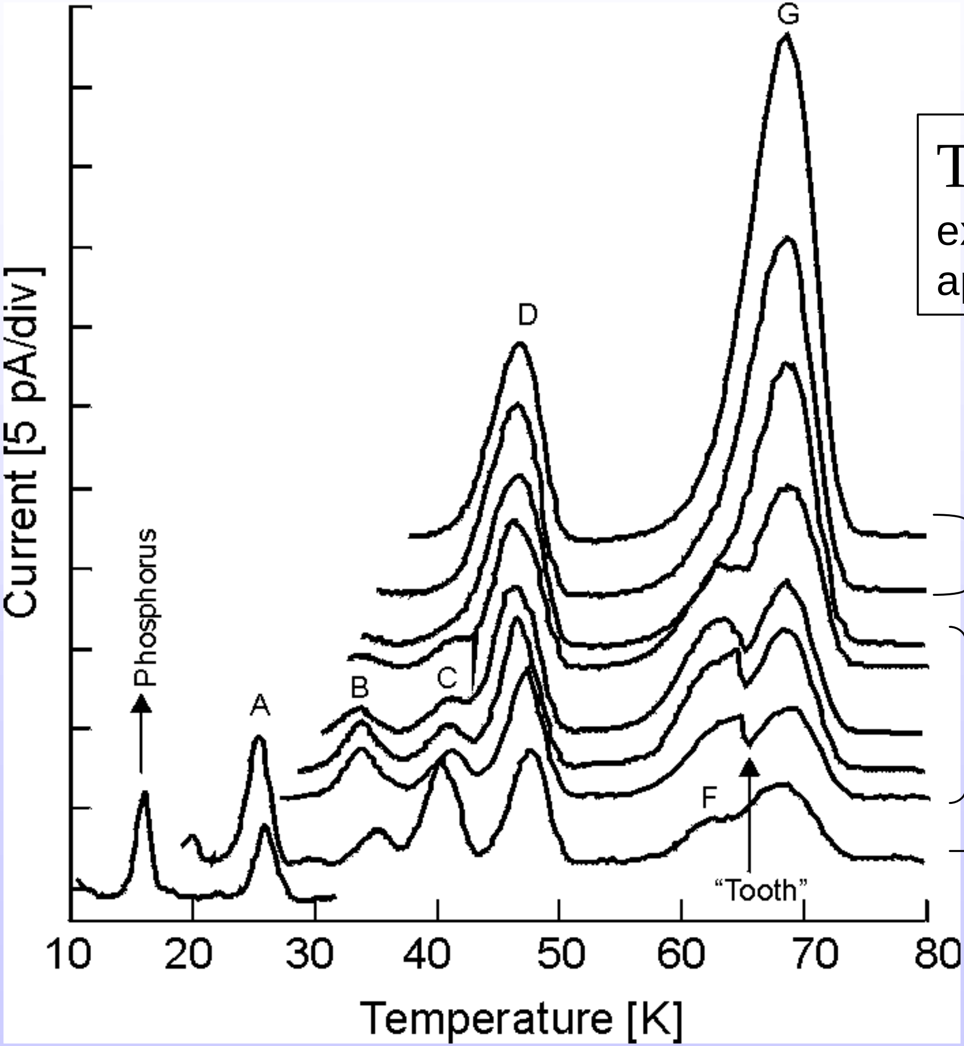
c) 200K: can be fitted with $E \cong E_v + 0.58$ eV, $\sigma \sim 10^{-13}$ cm^2 (Pintilie 2003).



Standard Float Zone Si sample. Low T region

spectrum strongly depends on the filling temperature T_i

Obs.: The amplitude of (B, C, D) and (F, G) rise with T_i .



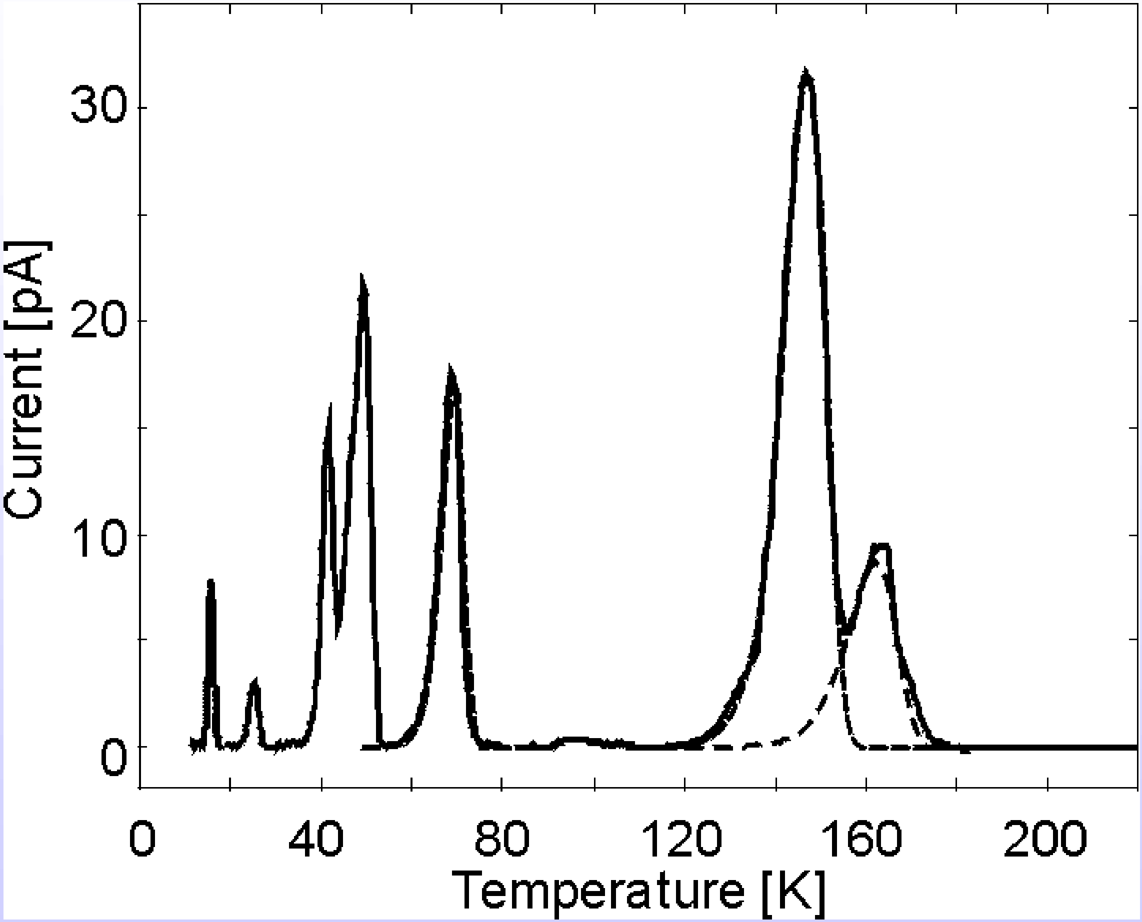
T_i > 35 K (A and B are not excited). Only a single peak G appears above 55 K.

T_i ~30 K (A is not excited, B is excited). 55-75 K feature exhibit a "tooth" (abrupt decay). After the decay the signal can be fitted by a single peak G (0.16 eV).

T_i is small enough (both A and B are excited): a structured peak (F+G) is observed at 55-75 K.

M. Bruzzi et al., 2nd RD50 Workshop - CERN - May 18-20 2003

DOFZ Si sample : Overview

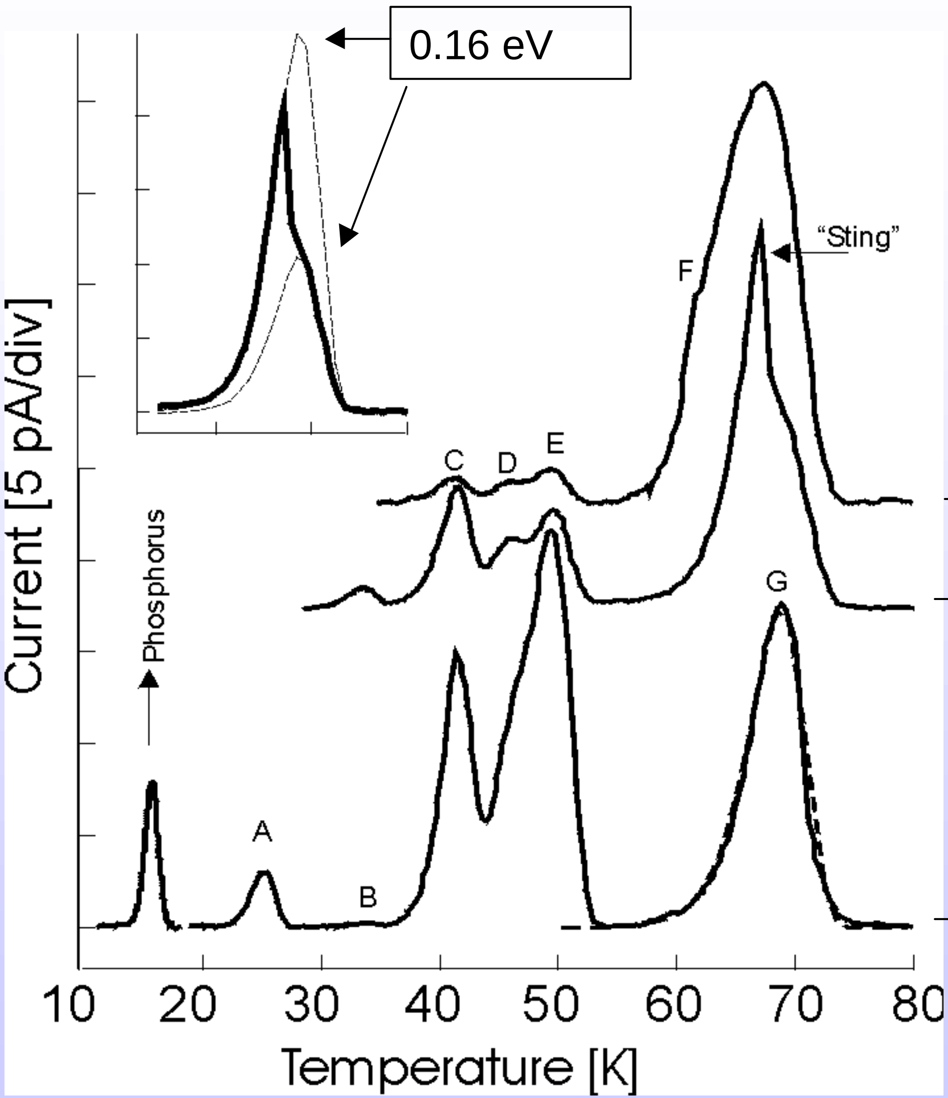


Above 80 K the spectra are similar to those of FZ samples, but

a) The 200 K (0.58 eV) signal is suppressed, in agreement with (Pintilie03).

b) The 140 K (C_iO_i) peak is three times higher in FZ. However this may be due simply to changes in the depletion depth or type inversion related effects

DOFZ Si sample. Low T range



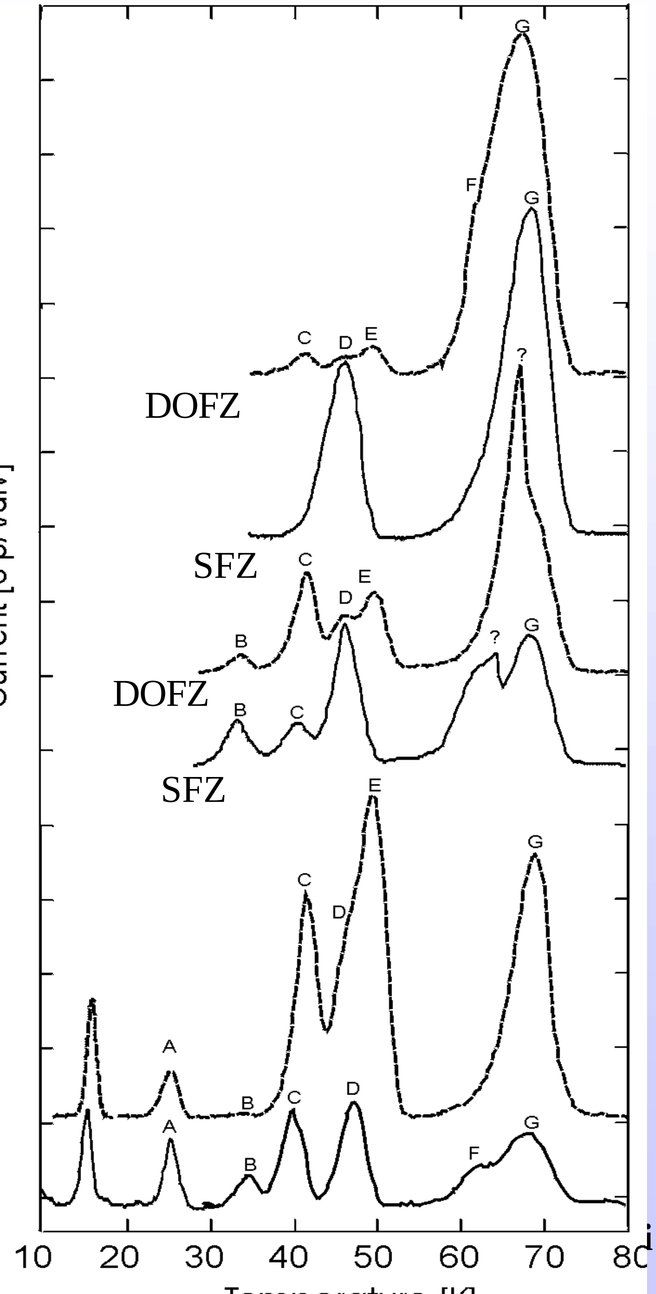
T_i > 35 K (B is not excited). In the 55-75 K region a broad peak appears. It should be fitted by at least two deep levels (possibly F and G).

T_i = 25-35 K (A is not excited, B is excited). A "sting" (abrupt decrease) in the current shape is observed near 65 K. Both the rising and falling edge of the peak are fitted by the same deep level (E~0.16 eV). See inset.

T_i is lower enough (A is excited). In the region 55-75 K a single peak is observed. It is well fitted by a single deep level near 0.16 eV, as shown in the plot.

Obs.: As T_i is raised: the amplitude of the peaks (C, D, E) decreases, while (F, G) rises.

Comparison between samples in the low T rang



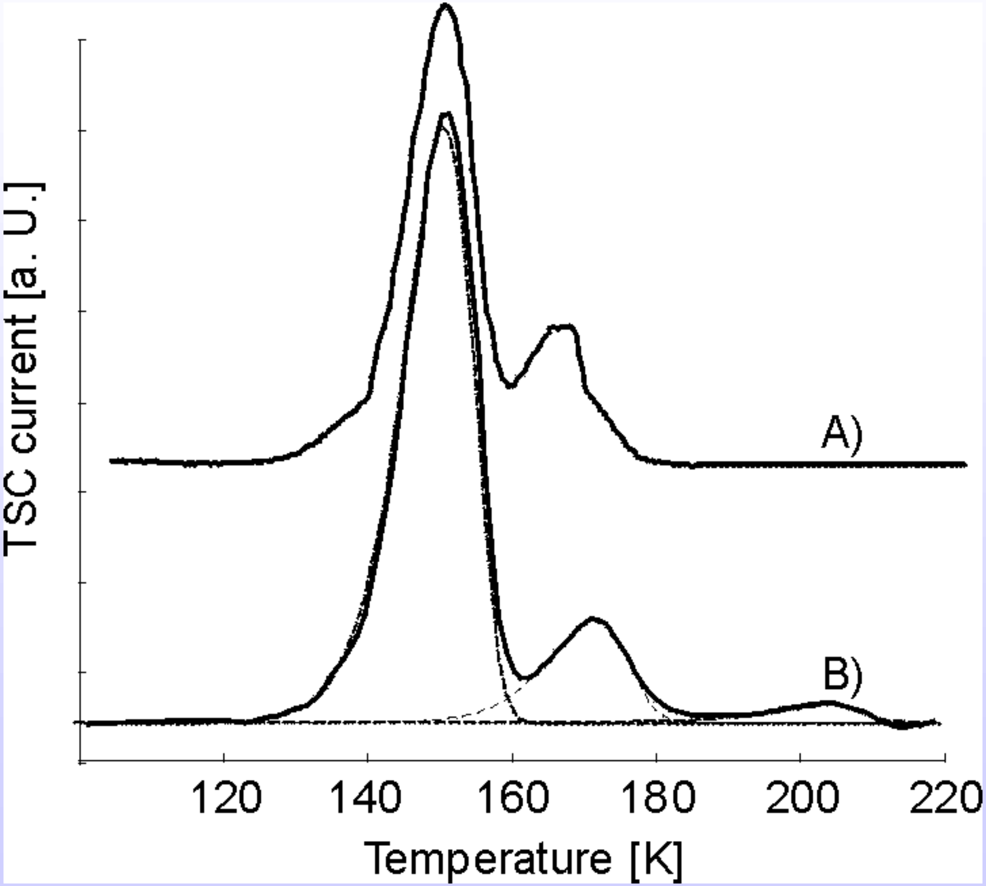
Similar spectral features BUT:

1) E peak is observed only in DOFZ.

2) The evolution of 55-75 K group follows opposite ways. In the SFZ, the group contains the emission of a single deep level (G) if T_i >35 K. In DOFZ the group consists of a single standard deep level emission if T_i <25 K. In every case, irregularities are observed if B is excited while A is not. These can be explained in terms of space charge sign inversion and junction side shift, due to emission from an electron trap.

4) When T_i is raised: in DOFZ amplitude of 30-50K peaks decreases, the amplitude of the 55-75 K group rises. In standard FZ, all the amplitudes grows with T_i.

Spectral shape dependence on V_{rev} in the high T range



Signal irregularities are observed in the high T peaks too.

Signal profile becomes regular as V_{rev} is increased from 10 V (A) to 100 (B). The irregularities are probably related to space charge sign inversion occurring during trap discharge.

This is supported by I-DLTS experiments currently under way in Florence.

Amplitude of curve A is multiplied by a factor 3 for a better comparison. Temperature shift is due to a faster heating rate.

Conclusions

Low T range

We observed changes of amplitude/shape probably due to changes in the depletion depth during trap discharge. Collective transformation of peaks indicate that various energy levels seem to involve the same kind of defects.

- Peak amplitude and shape are strongly related to T_i, even if it is distant from the peak maximum. A temperature dependent capture cross section $\sigma(T)$ appears unlikely to explain this as the change in T_i can be very small

- The 55-75 K feature exhibits a non-standard behavior (abrupt change of amplitude). The dependence of F and G shapes on T_i suggest a strong correlation between the peaks A, B and F and G. The temperature peaks of A and B are consistent with $TD^{0/+}$, E and F may correlate with $TD^{+/++}$, G is related to V-O (0.16eV). Nevertheless A, B, F are observed also in SFZ.

- The E peak observed at 50K, only in DOFZ, is in agreement with level E(50) reported in (Pintilie 03), it may be also associated with the interstitial oxygen dimer IO_2.

Pintilie et al. Appl. Phis. Lett. 82 (2003) 2169.

High T range

The peak at 200 K observed in FZ can be accounted for a very deep level at 0.58 and very large σ ($\sim 10^{-13}$ cm^2): it is not found in DOFZ sample. It corresponds to the emission of holes from the “I” defect, a candidate that has been associated with the V_2O complex (Pintilie 03).