DLTS Measurements of Energetic Levels in the Temperature Range 10 K < T < 350 K

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Summary

From DLTS (Deep Levels Transient Spectroscopy) spectra measured in the temperature range 90 < T < 350K, we detected four energy levels for electrons (E₁, E₂, E₃, and E₄) and two energy levels for holes (H₁ and H₂) [1-3]. For the six levels, the activation energies, with respect to the conduction and valence bands, were determined. In the last years, we upgraded our DLTS system, with a helium cryostat and investigated also the levels at lower temperatures. In this paper the results of measured DLTS spectra in the temperature range 10 < T < 350K, where new energy levels were detected, are discussed. The new detected energy levels are numbered in agreement with those given in previous papers [1-3].

The samples were silicon detectors, used in high-energy physics. The structure of the devices was an unsymmetrical, p'–n–n' junction, made on FZ n-type, phosphorus doped silicon. The bulk resistivity was between 4 to 6 kΩ cm, corresponding to a carrier concentration of about 7 x 10¹⁷ cm⁻³. The devices were made by ST-Microelectronics, using a standard microelectronics technology.

The detectors were neutrons and Krypton-ions irradiated. The neutron irradiation was made at the Triga reactor RC:1 of the National Organization of Alternative Energy (ENEA) at Casaccia, Rome, at a fluence of 1.0 x 10¹ⁱ n/cm². The Kr-ions irradiation was made at the Grand Accelerateur National d’Ions Lourds (GANIL), at a 60MeV/a beam of ⁸⁶Kr (ionized +34). The analyzed samples were irradiated at 5.3 x 10⁷, 7.5 x 10⁸ and 1.0 x 10⁹ Kr/cm².

The analysis of silicon detectors was carried out using a DL4600 – DLTS system, employing a Boonton C(V) meter of 1 MHz (manufactured by Bio-Rad, UK). The very low temperatures (~10K) were reached with a helium cryostat of APD-Cryogenics (temperature range 10 ≤ T ≤ 350 K).

The DLTS spectrum, after Kr-ions irradiation at 5.3 x 10⁷ Kr/cm², is presented in Fig. 1. The junction was reverse biased at -35 V, the filling pulses were 2 ms long, with amplitude V_{fill} = -0.5 V and V_{fill} = +1.5 V, for majority (electrons) and minority (holes) scan, respectively. The time window used for sampling the capacitance transient was 1ms. Eight electron levels and two hole levels, some of those present also in non-irradiated samples, were detected. Two levels, never observed before, one for electrons (E₅) and the other for holes (H₅), appeared at T about 20K. The DLTS spectrum, measured at the same conditions of polarization and filling pulses, for a neutron irradiation at 1.0 x 10¹ⁱ n/cm², showed the same levels observed for Kr-ions irradiated sample, except for peak E₅, since larger peaks obscure its small signal. E₅ was detected also in non-irradiated sample and its interpretation is not yet clear.

DLTS peaks in the temperature range 90 < T < 350 K, for neutrons and ions irradiated samples, were previously detected [1-7], but only few data concerning measurements in the range 10 < T < 90 K were published [5,8,9]. In this range of temperatures, both non-irradiated and irradiated samples show two peaks (E₆ and E₇), with activation energies E = E₆ − 0.12 eV and E = E₇ − 0.04 eV, respectively. They are associated to oxygen related thermal donors [10] and their amplitudes were not changed by irradiation. In particular, E₆ was identified as oxygen-carbon pairing [8, 9]. E₅ was detected only in irradiated samples and its signal is larger for neutrons than for Kr-ions irradiation. The amplitudes of E₅, E₆, E₇, and E₈ are strongly correlated: for larger applied filling pulses, E₁ decreases and the other three peaks increase, for both neutrons and Kr-ions irradiated samples. This can indicate that E₅ is also an oxygen-related level. A new hole level (H₅), observed only in irradiated devices, was detected at T about 20K.

Similar amplitudes of DLTS peaks, which are proportional to traps concentration, are observed for Kr-ions fluences about three orders of magnitude smaller than the neutron fluences. This confirms the behavior observed in resistivity and Hall coefficient measurements, done on silicon bulk irradiated with the same particles [11,12]. Moreover, the ratios between the amplitudes of DLTS peaks in each spectrum are different for the two kinds of irradiations.

In our previous paper [1], it was shown that the concentration of the E₅ level, as measured by DLTS, is proportional to the neutron fluence, up to 2.7 x 10¹¹ n/cm². Similar to the results obtained for neutrons, a linear dependence is seen also for Kr-ions irradiation, up to 1.0 x 10⁹ Kr/cm².
References


Fig. 1. DLTS spectrum for Krypton ions irradiated sample with fluence $5.3 \times 10^7$ Kr/cm$^2$. The full line is the spectrum obtained for negative fill-pulse, where only the majority carrier traps give signal. The dotted peaks have been seen only for positive fill-pulse and they represents minority carriers traps.