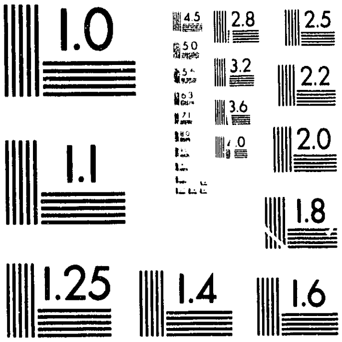
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STUDIES OF DEEP LEVELS IN HIGH RESISTIVITY SILICON DETECTORS IRRADIATED BY HIGH FLUENCE FAST NEUTRONS USING A THERMALLY STIMULATED CURRENT SPECTROMETER*

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Studies of Deep Levels in High Resistivity Silicon Dectectors Irradiated by High Fluence Fast Neutrons Using a Thermally Stimulated Current Spectrometer

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Measurements of deep level spectrum of high resistivity silicon detectors irradiated by high fluence fast neutrons (Φ_n:$2x10^{12}n/cm^2$ to $1x10^{14}n/cm^2$) have been made using a thermally stimulated current (TSC) spectrometer. It has been found that at least nine new defect levels, with peaking temperature of 19K, 27K, 36K, 44K, 49K, 83K, 93K, 105K, and 120K, begin to appear when $\Phi_n \geq 1x10^{13}n/cm^2$. All peaks have strong dependences on the filling voltage (V_{fill}, forward bias) or injection current especially for high fluence ($\Phi_n \geq 10^{13}n/cm^2$) situations. The defect concentration, energy level in the band gap, and cross section of each deep level, totaling at least 13, have been studied systematically and possible identifications of the levels have been discussed.

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SUMMARY

Physical parameters of displacement radiation induced defect levels in silicon, such as defect energy levels in the band gap E_t, carrier capture cross sections σ_t, and defect concentration N_t, have been traditiionally studies by the capacitive deept level transient spectroscopy (DLTS) for low resistivity silicon ($\rho \leq 10$ Ω-cm)or $N_d \geq$-$10^{14}/cm^3$), for which the requirements for valid DLTS results, $N_t/N_d << 1$, is readily satisfied [1-5]. Althoguh recently DLTS has also been applied to neutron radiation induced defact levels in high resistivity silicon ($\rho \geq 2K$ Ω-cm,. or $N_d < 1x10^{12}/cm^3$), its use has been largely limited to samples with low neutron fluences ($\Phi_n < 10^{12}/cm^2$) to keep the defect concentration low ($N_t \leq 10^{12}/cm^3$)[6-9]. Other techniques that use current or current transient instead of capacitance transient, such as laser-DLTS[10] and thermally stimulated current (TSC)[11-14], have been proven not limited by the ratio of N_t/N_d and good analytical tools for studying defect levels in high resistivity silicon (or other semiconductors) irradiated by high fluence fast neutrons or other particles that cause desplacement damage. In this paper, we will report new defect levels in heavily neutron irradiated high resistivity silicon detectors revealed by the TSC technique.

Silicon p^+-n^--n^+ junction detectors used in this study were made on n-type <111> wafers with resistivity of 4-6 KΩ-cm in Brookhaven National Laboratory's Silicon Detector Development and Processing Lab (SDDPL). Fast neutrons form 10 keV to 2.2 MeV, with an average energy of 1 MeV, were obtained from the ^{7}Li(p,n) reaction using 4 MeV protons from a Van de Graaff accelerator at the University of Lowell. Detectors from the same wafer, with the same processing conditions, were irradiated to various neutron fluences ranging from $2x10^{12}n/cm^2$ to about $1x10^{14}n/cm^2$, and were measured with the TSC set-up at the University of Florence, Italy.

The TSC spectrum of a detector without any radiation is shown in Fig. 1a. Only two peaks, T=17K and T=25K, have been found for this undamaged detector. The peaks at T=17K and t=25K are very shallow (E_t in the order of <100 meV), and are probably doping impurities phosphrous and boron, respectively. Fig. 1b shows the TSC spectrum of a detector irradiated to $4.79x10^{12}n/cm^2$. Note that the peak at 17K becomes much narrower and the peak at 25K smaller, indicating deactivation of both type of doping impurities or carrier removal. Also, two new peaks, one at 19k and one between 140 to 170 k, denoted as the "C" peak, begin to take shape. The broad peak between 140K to 170K was studied extensively by Bruzzi, et. al, and was attributed as a cluster[12].

Many new peaks between T=20K to 130K start to appear when the fluence is in the order of $1x10^{13}n/cm^2$, as shown in Fig. 2a. these new peaks take clear shapes when the fluence is about 3-4x10^{13}n/cm^2, while the borad "C" peak continues to grow wider and higher, as shown in Fig. 2b. The peaking temperatuires for the new peaks are 19K, 27K, 30K, 44K, 49K 83K, 93K, 105K, and 120K. The peak at T=70K, denoted as "A" peak, also appears at lower fluences and is the oxygen-vacancy (A-center) complex. With further radiation of neutrons, as it is shown in fig. 3, some of these new peaks simply become higher, others overlap and become broad peaks. We note that there are little changes for peaks at 17K and 25K when Φ_n>5x10^{12}n/cm^2, This fluence value is consistent with the one at which the type inversion in the space-charge-region (SCR) was observed[15-17].

We must note here that all peaks in Fig. 1a to Fig. 3 were obtained, or observable, only in conditions of high positive filling voltage V_{fill}, or more appropriate, the high injection currents (>μA's) during the filling process. Without high injection current, nothing could be seen. This is demonstrated in Fig. 4a (no peaks when I_{inj} was low) and Fig. 4b (all peaks when I_{inj} was high). The V_{fill} dependence of the "C" peak of a heavily damaged detector was shown in Fig. 5a and 5b, which agrees with the early work of Bruzzi, et. al,[12]. The V_{fill} dependence of the "A" peak of a lesser damaged detector was plotted in Fig. 6. As the defect concentration increases with neutron fluences, one needs to inject certain amounts of carriers into the detector to fill the levels. Since for a given injection current, the forward bias becomes larger as neutron fluence increases[18], the V_{fill} dependence of peaks other than the "C" peak (for which the V_{fill} dependence was explained as charge trapping of a cluster[12]) may be just a reflection of the I_{inj} requirement. More data and detailed modeling of V_{fill} dependence will be published elsewhere[19].

The physical paramerers (E_t,σ_t,N_t) of each peak can be obtained by analyzing the deexcitation data shown in Fig. 7. By waiting for various times (t_d) before the TSC run, one can get a decay data of each peak from which the parameters can be obtained. In the full paper, the physical parameters of each peak, and their dependence on the neutron fluence, will be reported.

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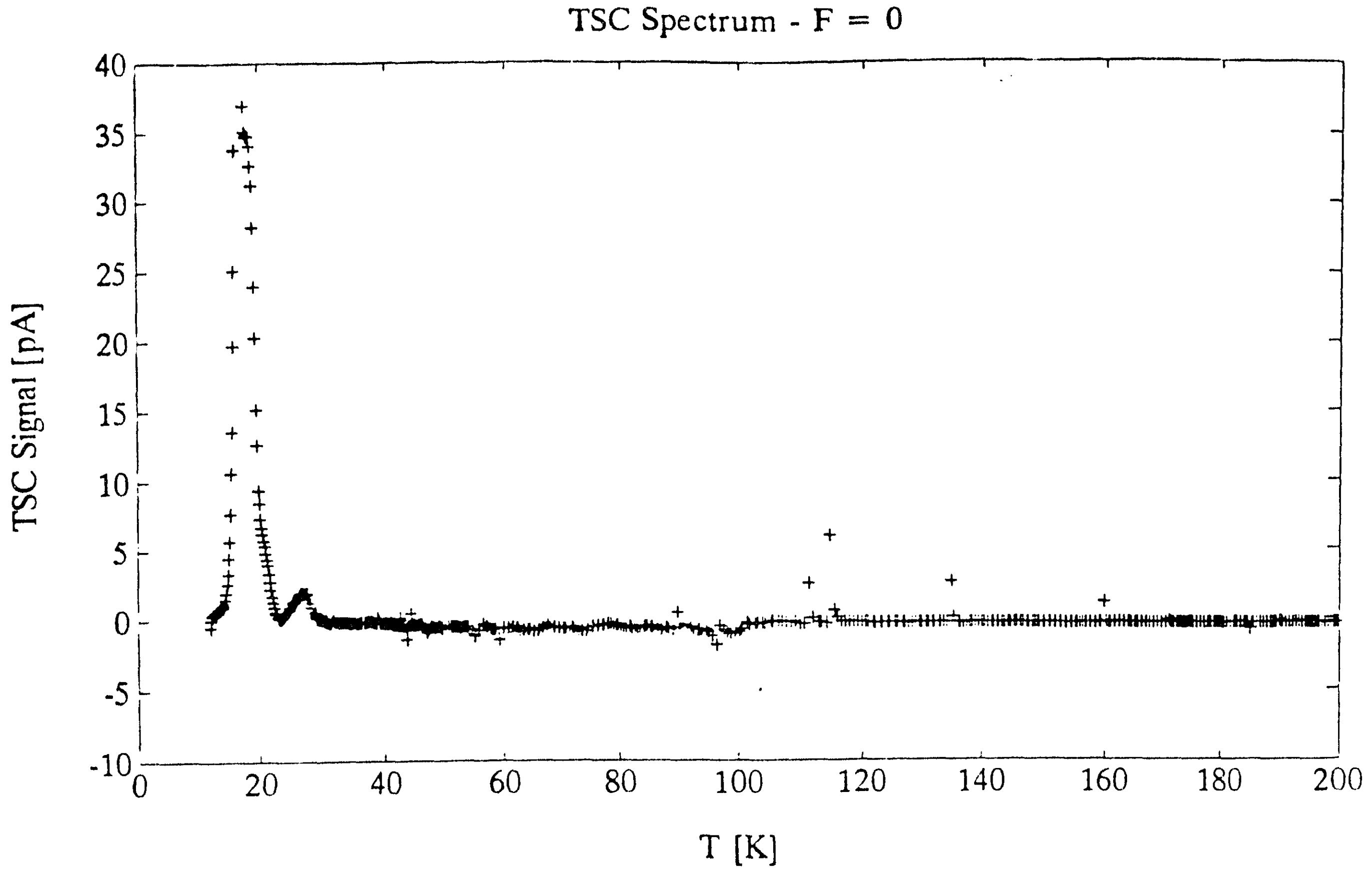
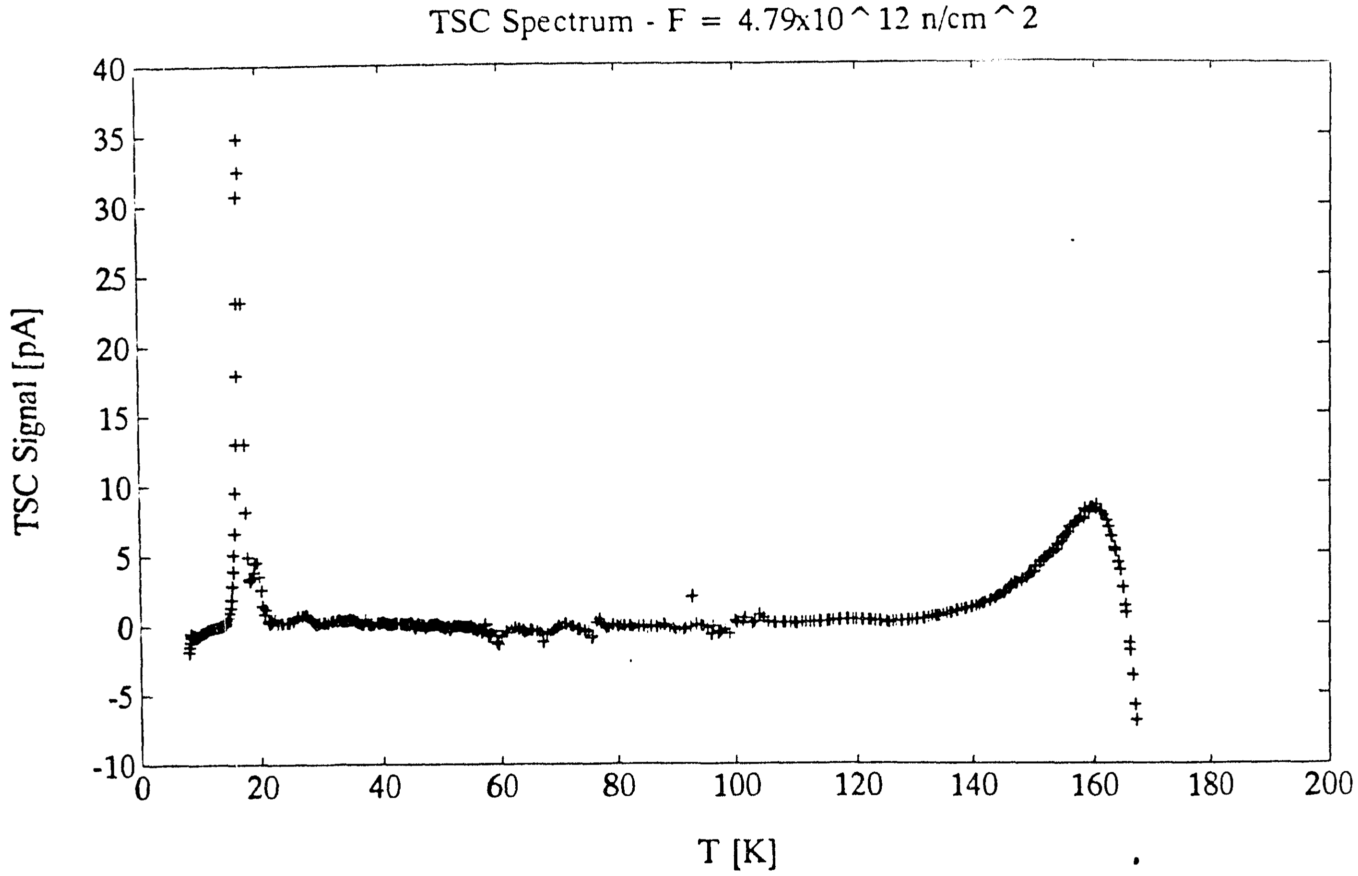
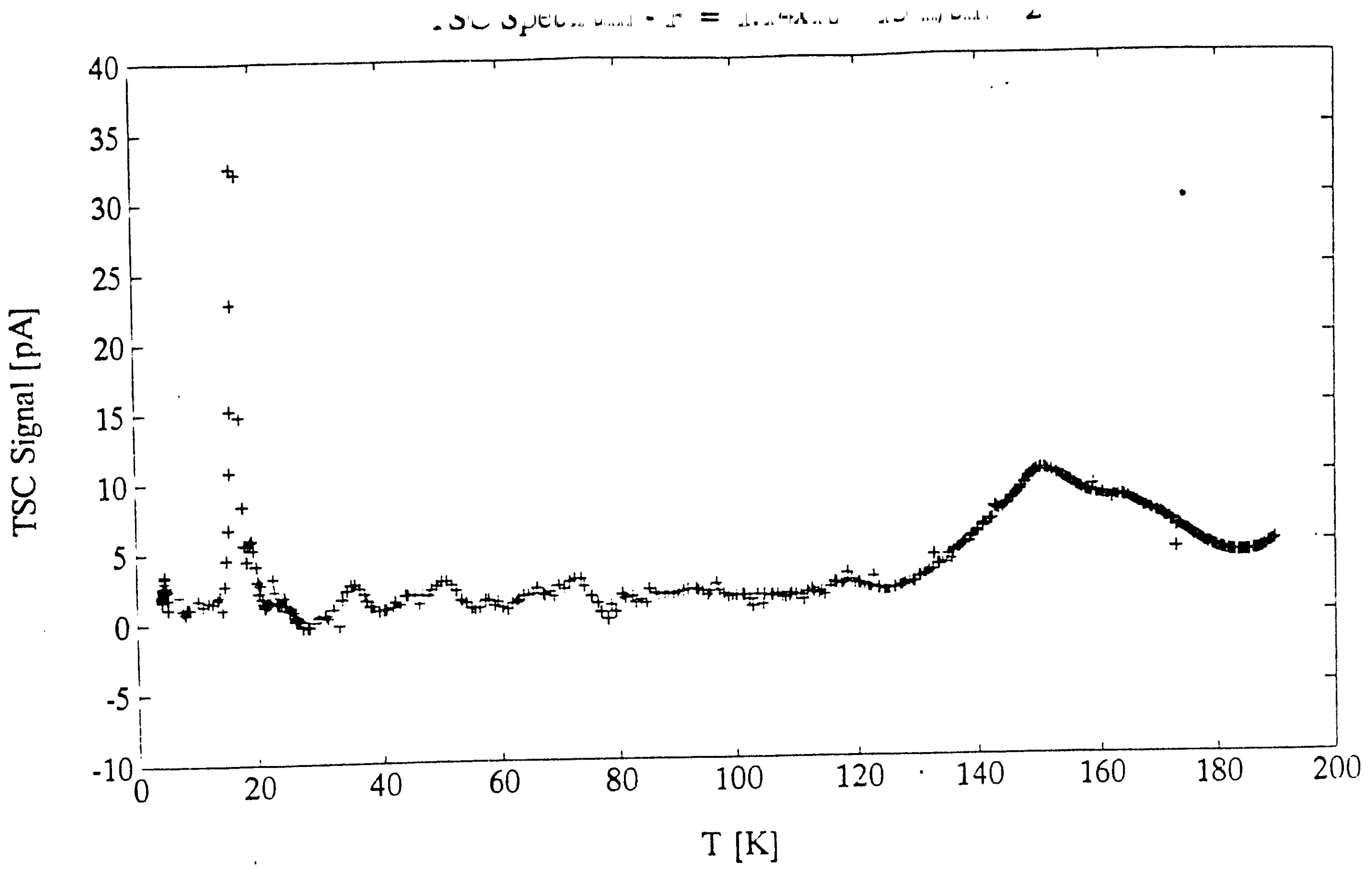

TSC Spectrum - F = 0

a) Not irradiated, Φ_n=0

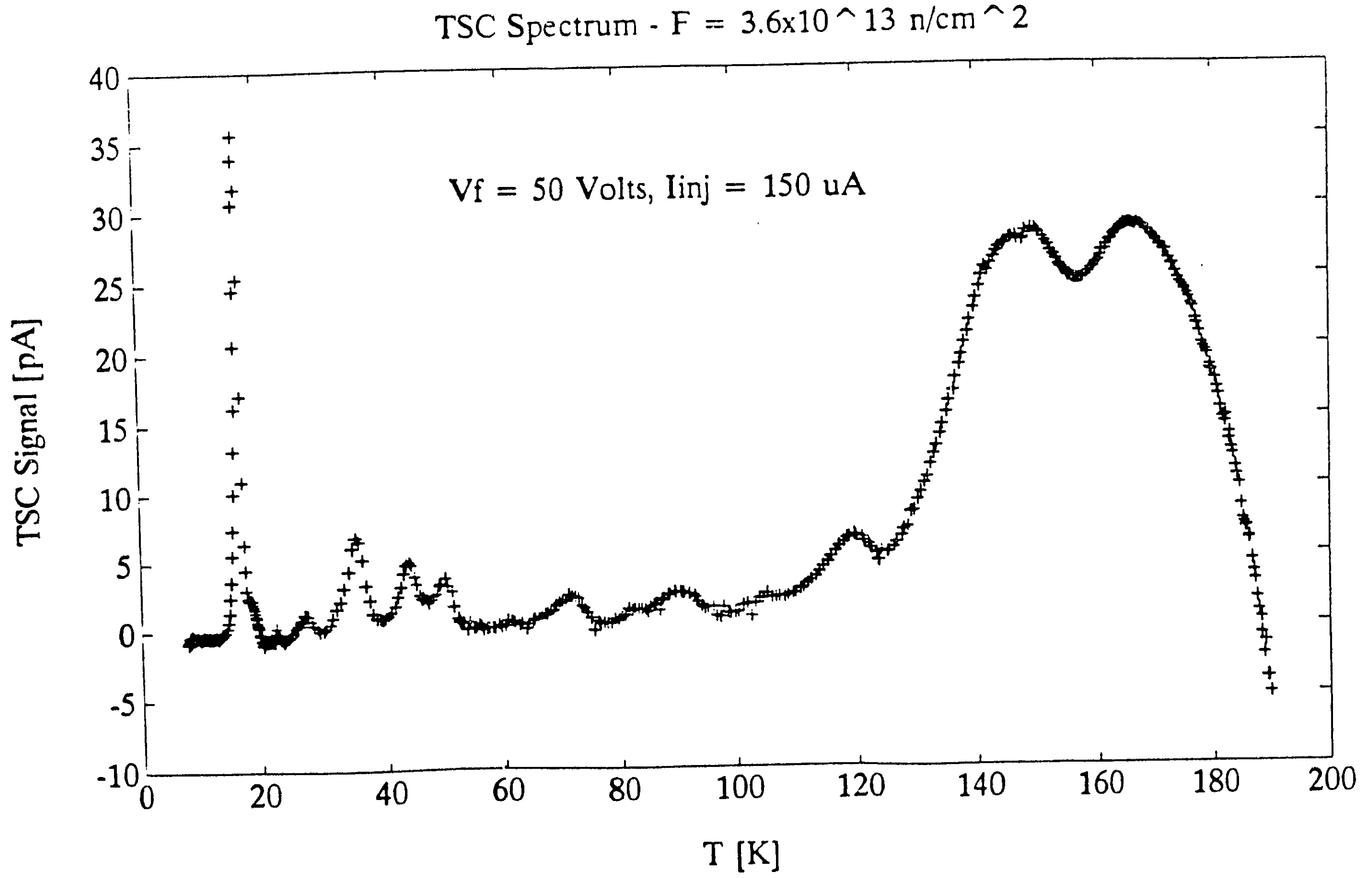

TSC Spectrum - F = 4.79x10^12 n/cm^2

b) Irradiated to a medium fluence, Φ_n=4.8x10^{12}n/cm^2

Fig. 1 TSC spectrum for a control detector and a detector irradiated to a medium fluence.



a) $\Phi_n=1.14\times10^{13} n/cm^2$



b) $\Phi_n=3.6\times10^{13} n/cm^2$

Fig. 2 TSC spectrum for heavily irradiated detectors.

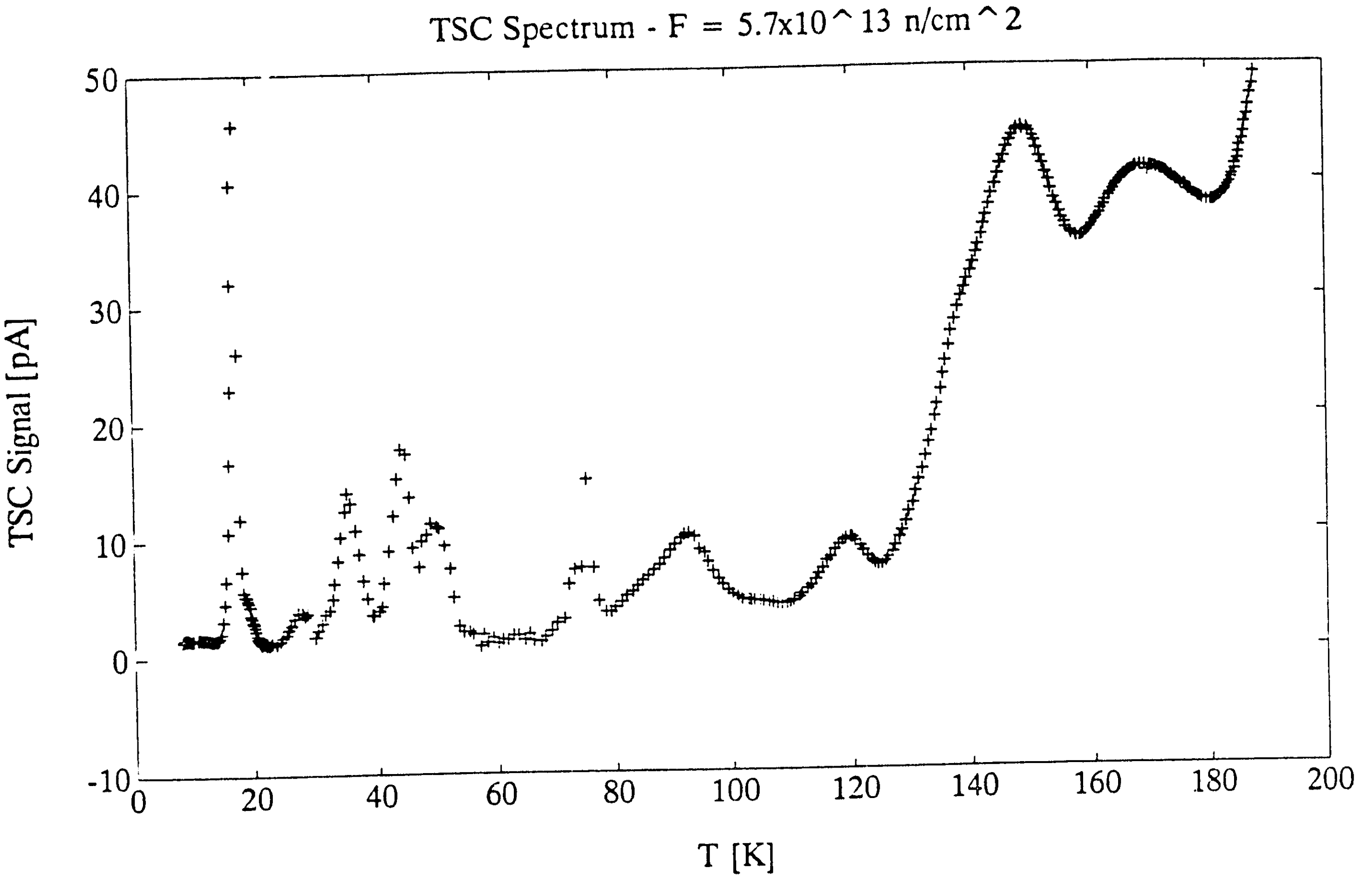
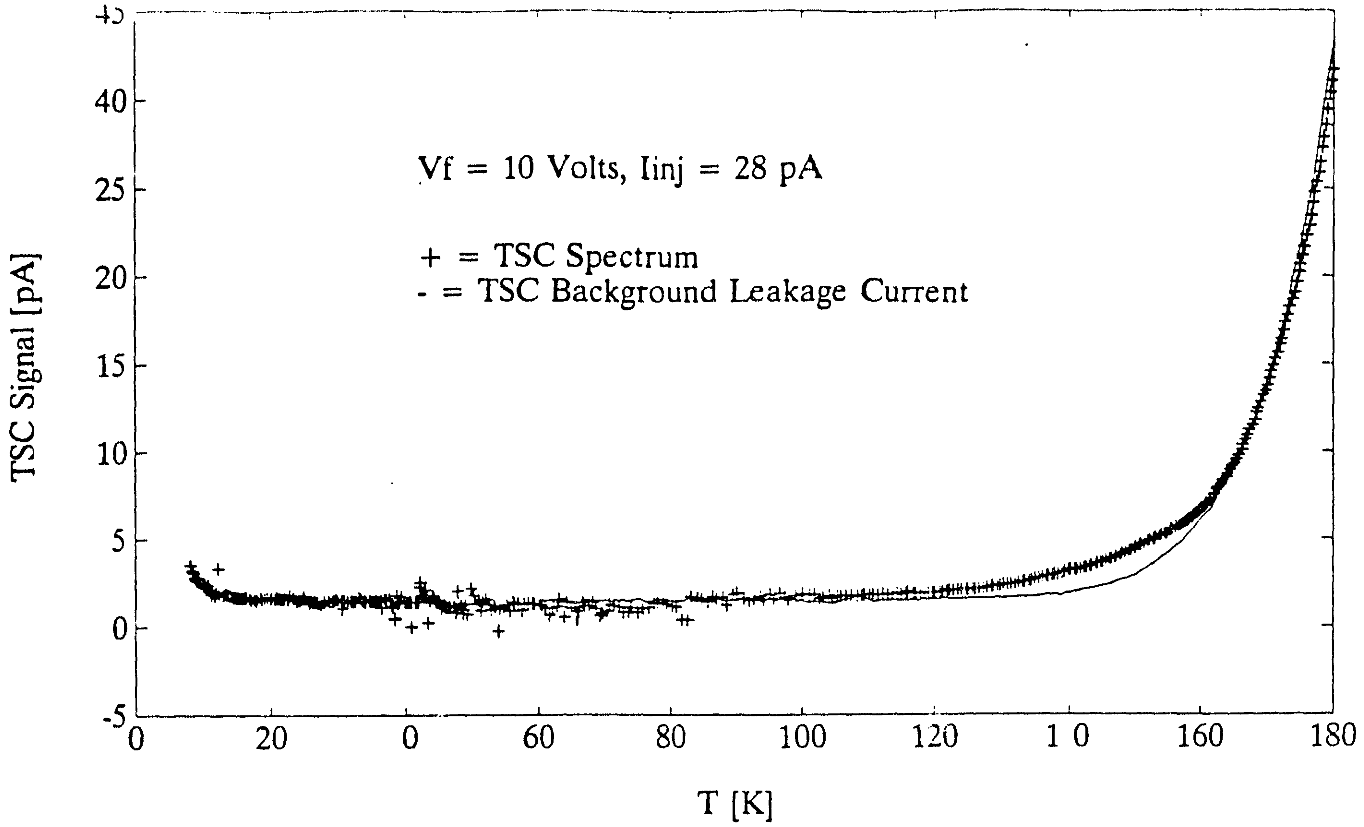
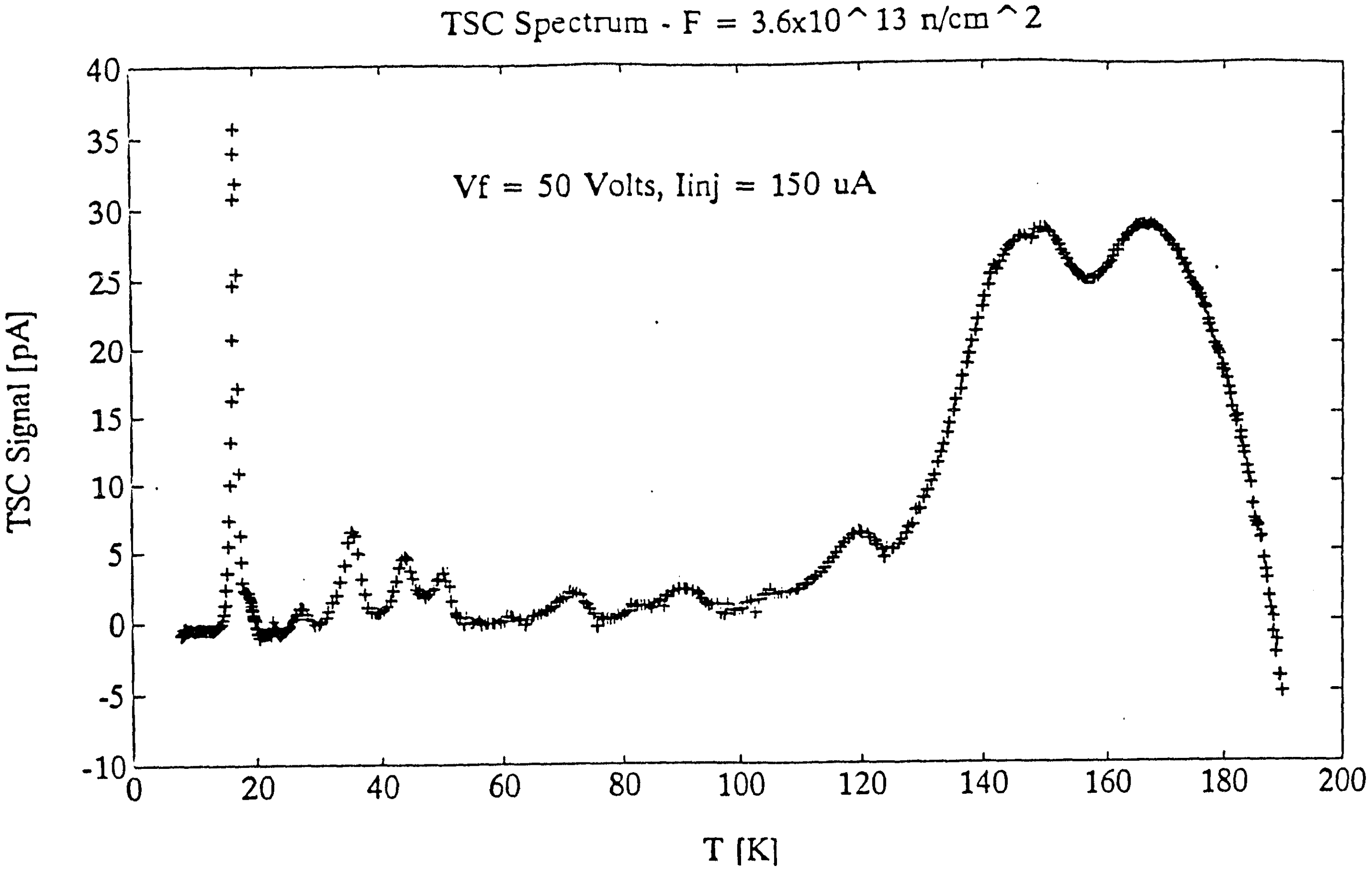


Fig. 3 TSC spectrum for a detector irradiated to 5.7×10^{13}n/cm^2

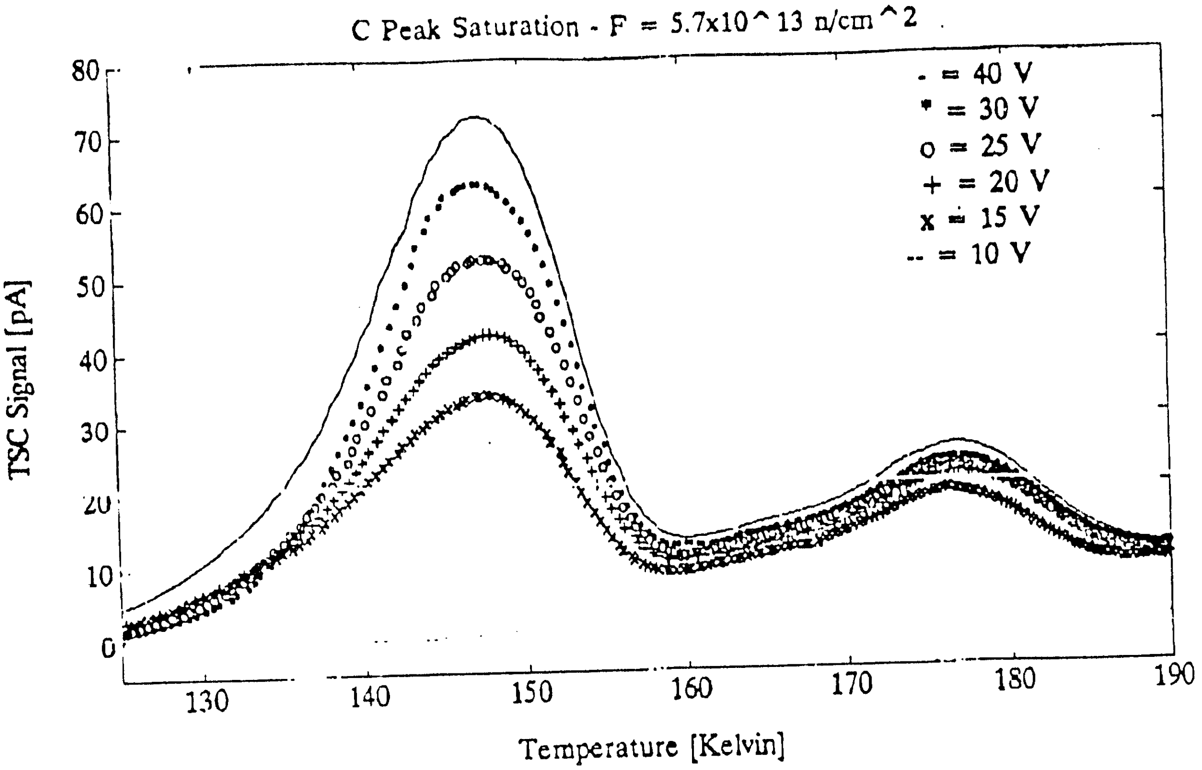


a) Low injection current.

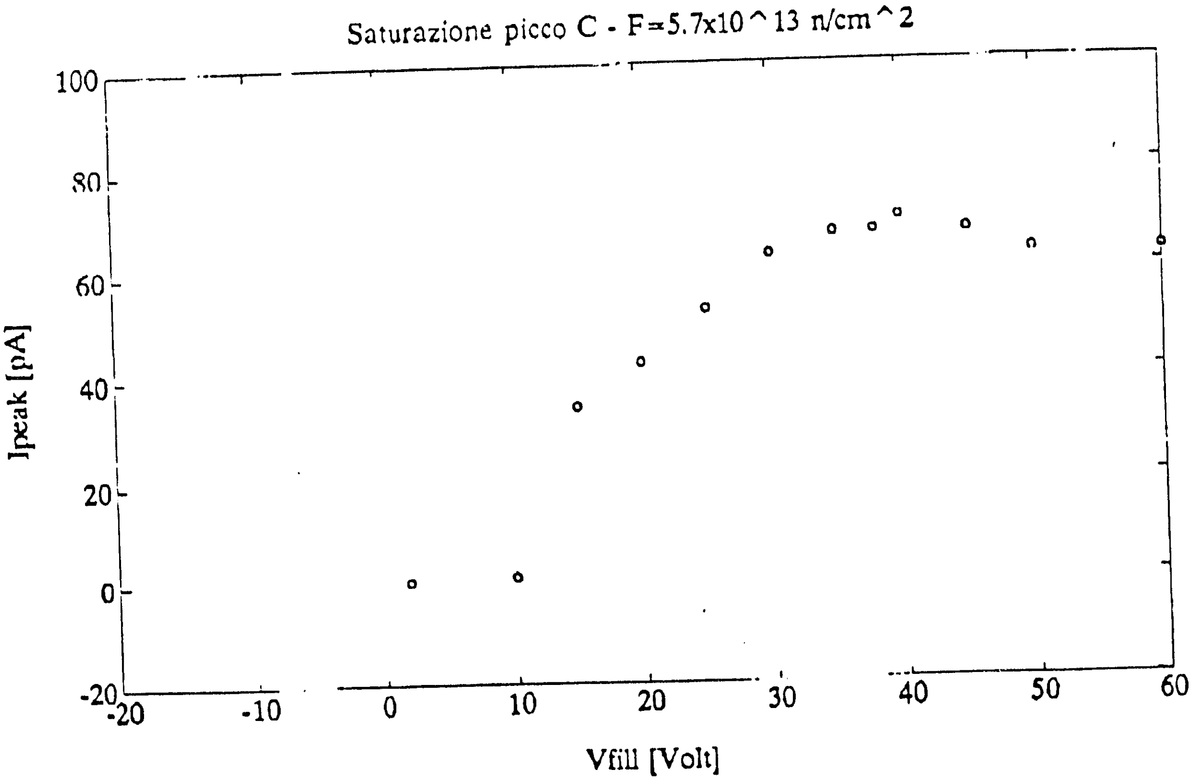


b) High injection current.

Fig. 4 Filling voltage or injection current dependence of TSC peaks.



a) TSC spectrum.



b) Peak high dependence.

Fig. 5 TSC "C" peak height dependence on the filling voltage.

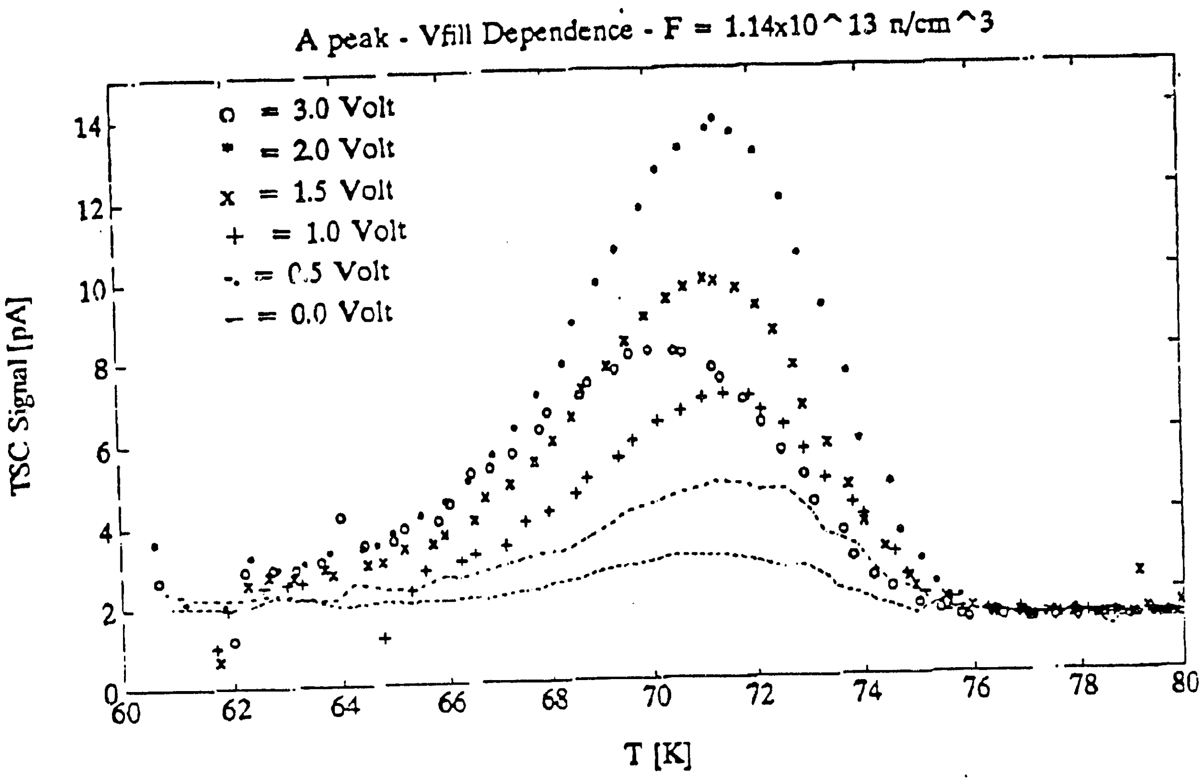


Fig. 6 TSC "A" peak height dkependence on the filling voltage.

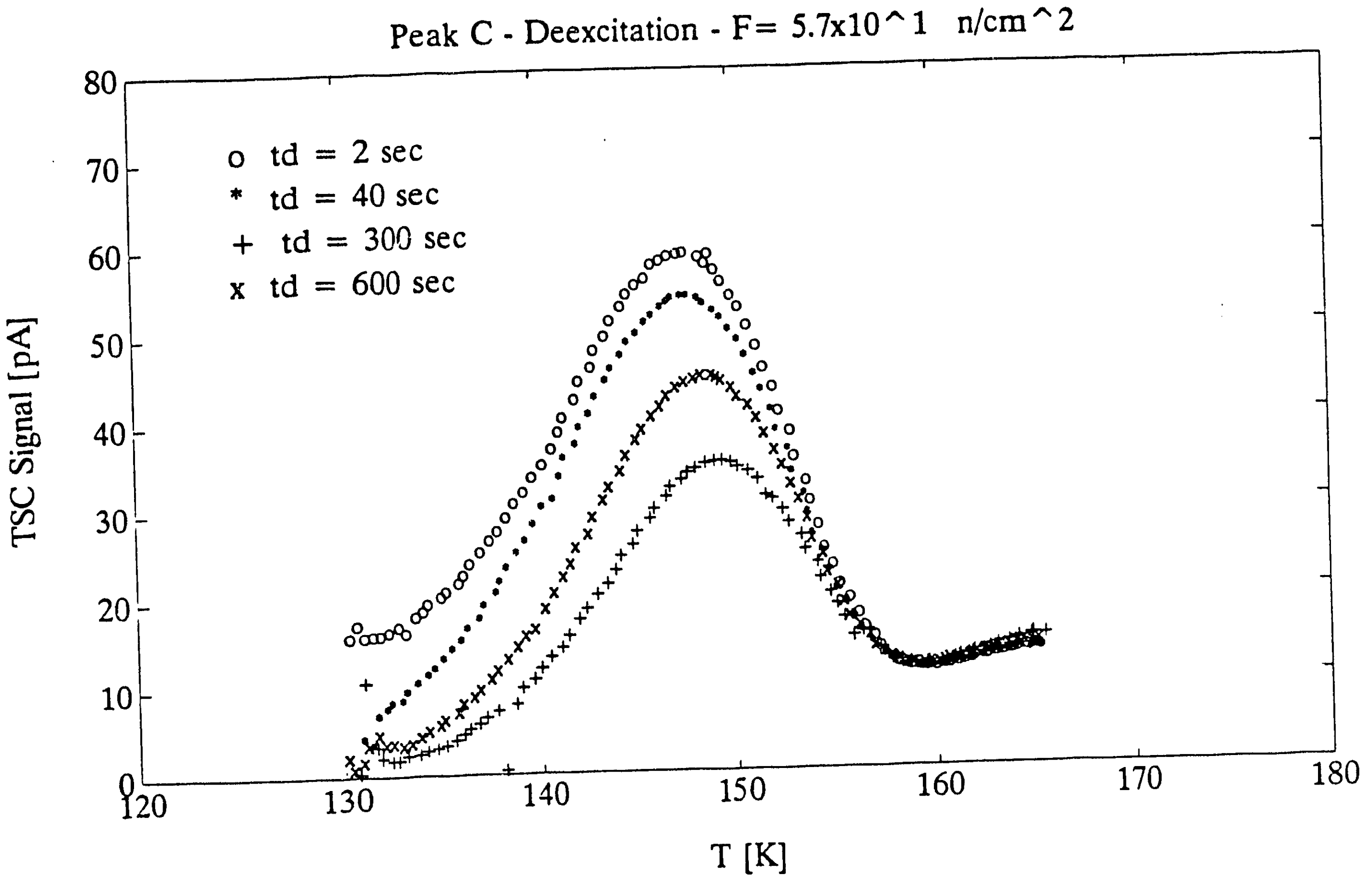


Fig. 7 TSC peak height dependence on the excitation time.

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