TSC measurements on n- and p-type MCz silicon diodes after irradiation with neutrons up to 10^{15}-10^{16} n/cm^2

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Samples and irradiation

-Material:n-type magnetic Czochralski silicon produced by Okmetic (Finland) with 900 Ωcm resistivity, <100> orientation and 280μm thickness.
-Devices: p-on-on planar diodes 0.5x0.5cm^2
-Procurement: WODEAN, Thanks to E. Fretwurst, G. Lindstroem
-Irradiation: reactor neutrons at the Jozef Stefan Institute, Ljubljana
-fluence: 10^{13}-10^{14}-10^{15} n_{eq}/cm^2 1MeV equivalent neutron
-Annealing: 1 year room temperature

-Material: p-type magnetic Czochralski silicon produced by Okmetic (Finland) with 2k Ωcm resistivity, <100> orientation and 280μm thickness
-devices: n-on-op square diodes 0.5x0.5cm^2
-Procurement: SMART, Thanks to D. Creanza, N. Pacifico
-Irradiation: reactor neutrons at the Jozef Stefan Institute, Ljubljana
-fluence: 10^{14}-10^{16} 1/cm^2 1MeV equivalent neutron
-Annealing: few days room temperature (+ 80min 80°C)

Measurement Techniques

1. Thermally Stimulated Currents with cryogenic equipments: measurements performed on Liquid He vapors, to ensure stable temperatures down to 4.2K minimize thermal inertia and mismatch.

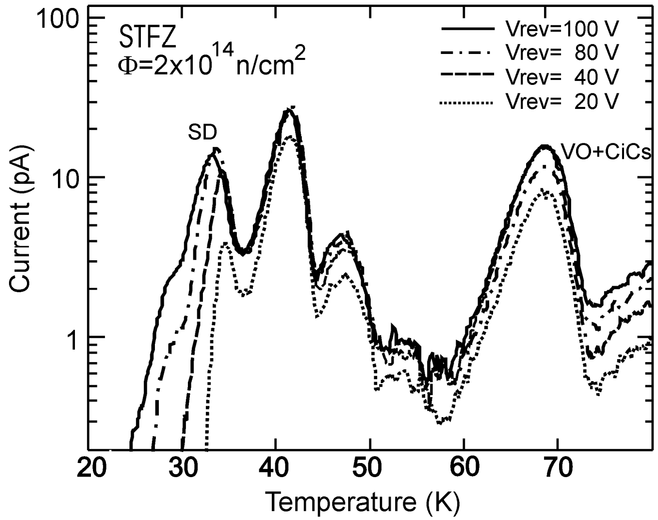
(a) To evidence presence of shallow donors/acceptors
(b) To study annealing effects (80min 80°C)

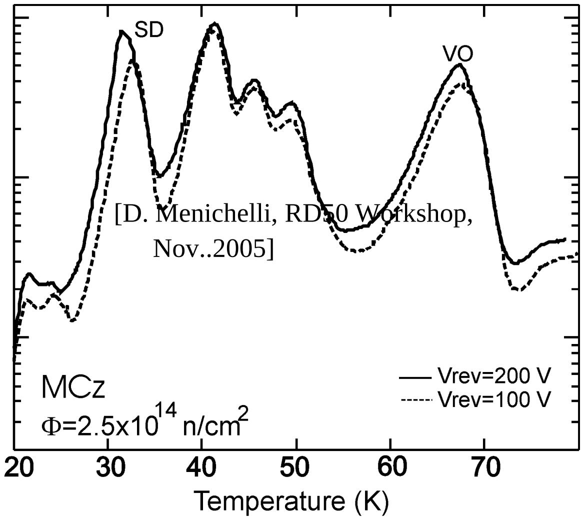
2. Zero Bias Thermally Stimulated Currents measured at high fluence in the high temperature range (100-200K),

(a) to avoid background current subtraction, and increase resolution in deep levels analysis.
(b) To get information about electric field distribution

1. (a) Low Temperature measurements - Standard TSC analysis

- 2005: Shallow donor generated by 24GeV proton irradiation in MCz ($4x10^{14} p/cm^2$)





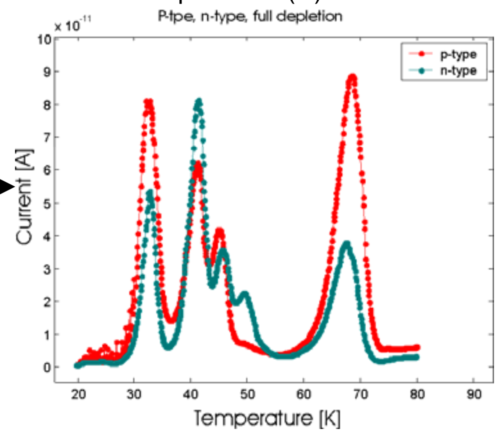
[D. Menichelli, RD50 Workshop, Nov..2005]

MCz n-type 26 MeV p irradiated, $\Phi=4\times10^{14}$ cm^{-2}

$[SD]_{MCz}/[SD]_{FZ} > 5$

M. Scaringella et al. NIM A 570 (2007) 322–329

Comparison between p- and n-type MCz Si in low T reveals presence of same shallow peak at 30K.



MCz n-type and p-type 24 GeV p irradiated, $\Phi=4\times10^{14}$ cm^{-2}

[M. Bruzzi, Trento Workshop, Feb. 2005]

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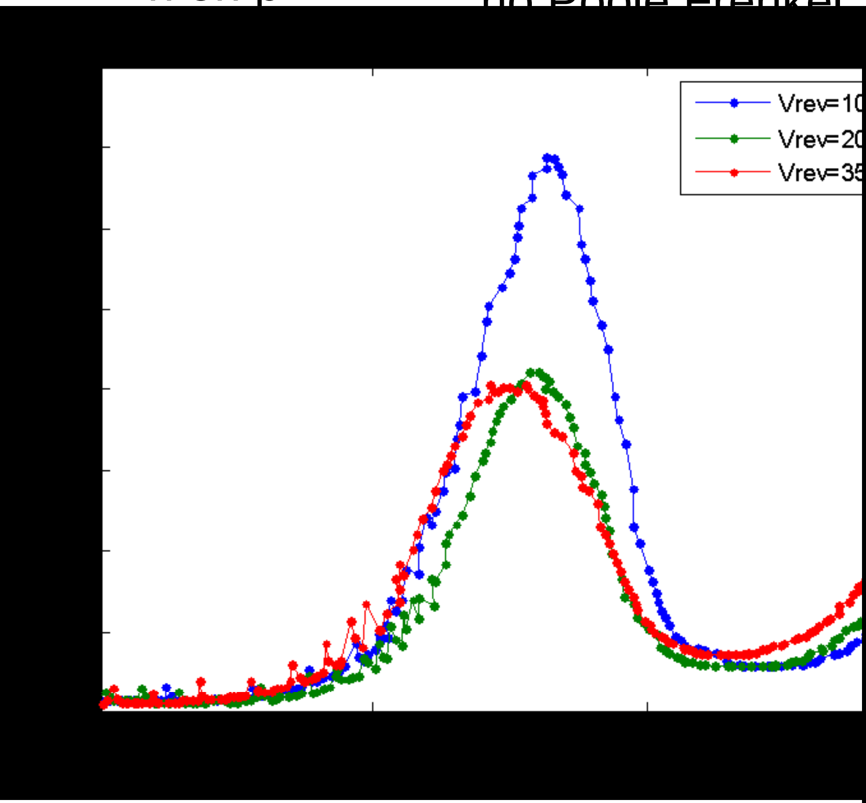
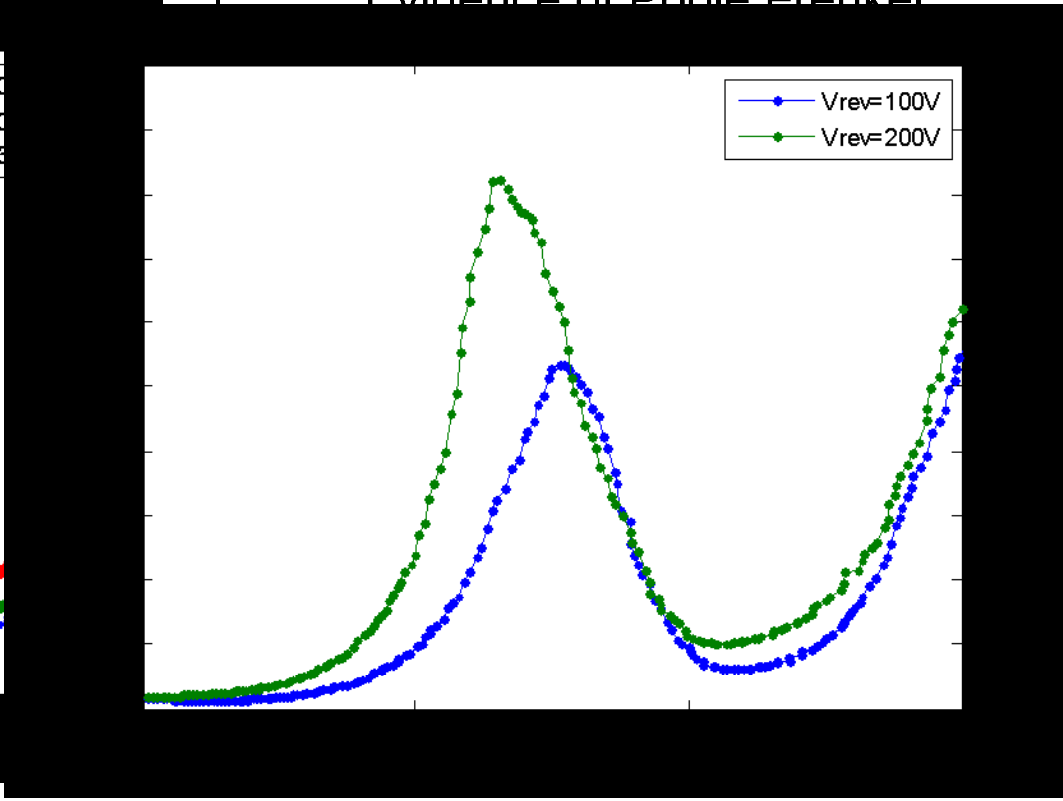
30 K peak - PF shift evidences its charged nature in n-type. No P-F shift observed in p-type MCz Si irradiated with same fluence.

n on p   no Poole Frenkel



p on n Evidence of Poole Frenkel



n- and p-MCz Si 24 GeV p irradiated $4x10^{14}cm^{-2}$ (Φ=$2.5*10^{14}$ n_{eq}/cm^2)

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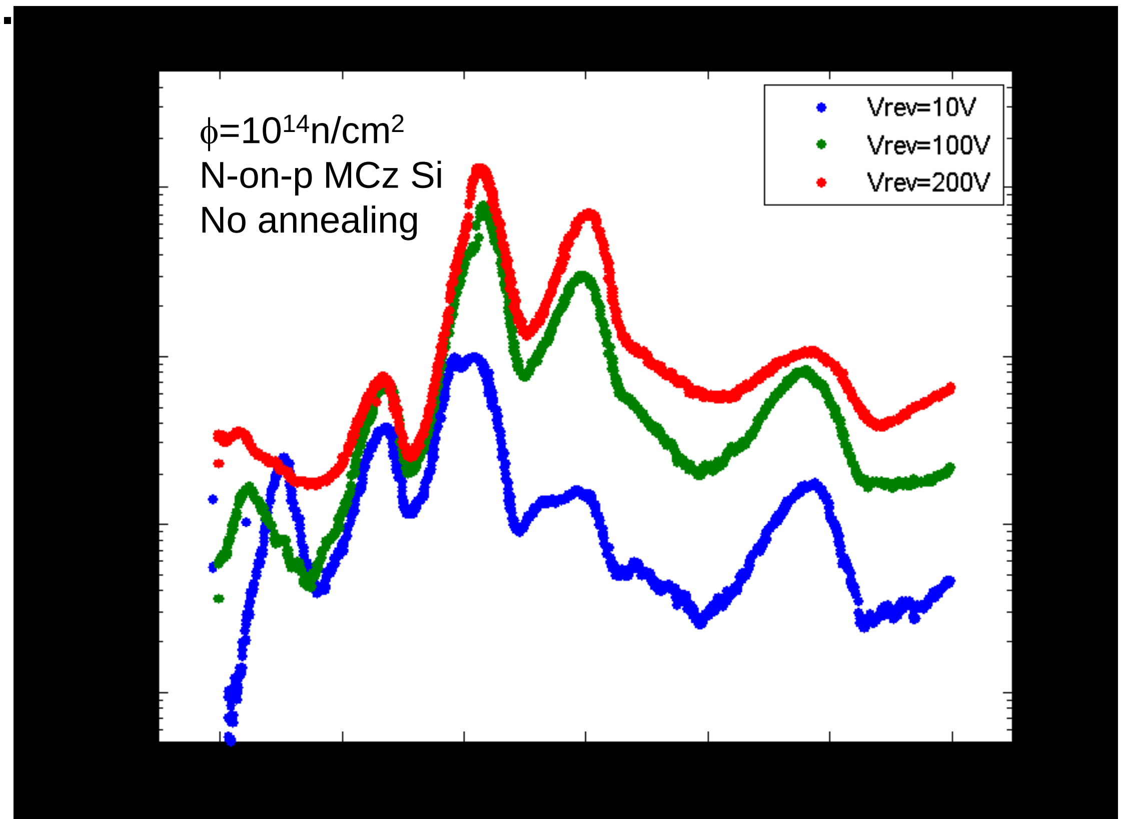
2009 measurements

p-type MCz Si after neutron irradiation. Different reverse voltages (10-300V) to evidence Pool Frenkel effects and thus visualize the existence of charged defects. Confirmed that peak at 30K has no appreciable Poole Frenkel shift.



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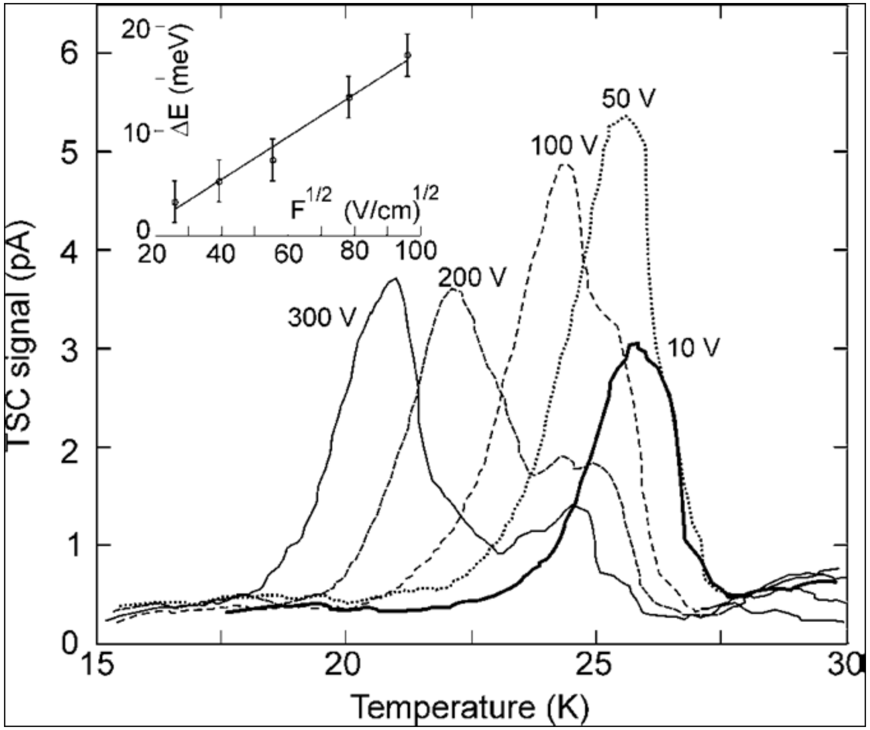
P-F on D(25K) peak

Only peak at 25K is observed to shift in temperature, but this peak always present (in irradiated and non-irradiated samples, independent of material type and kind, irradiation fluence and annealing time up to 110 min at 150 ◦C).



D.MENICHELLI et al. Appl. Phys. A 84, 449–453 (2006)

2. (b) Annealing studies: Standard TSC

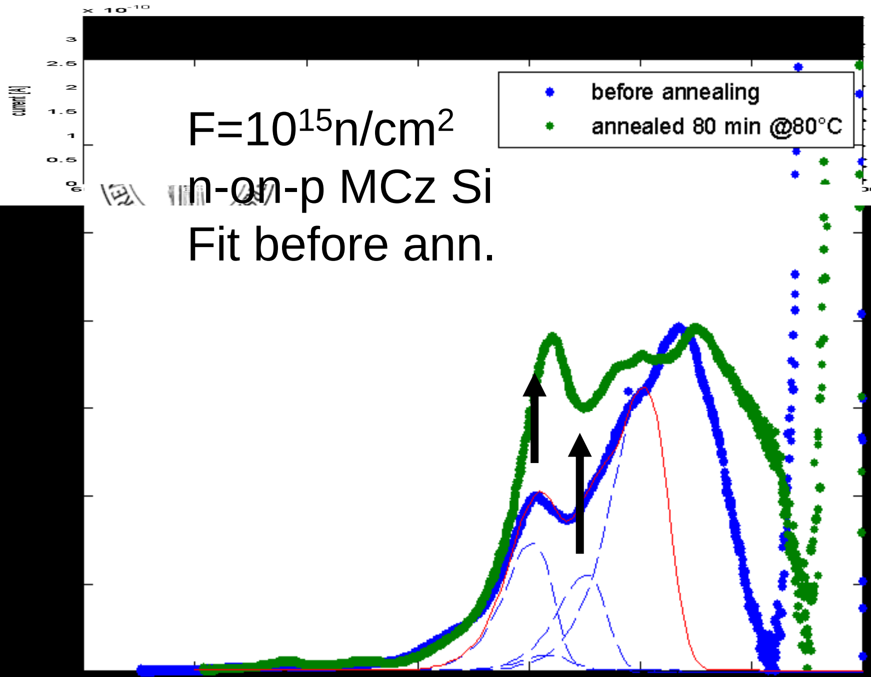
Up to now the study has been performed on p-type MCz Si

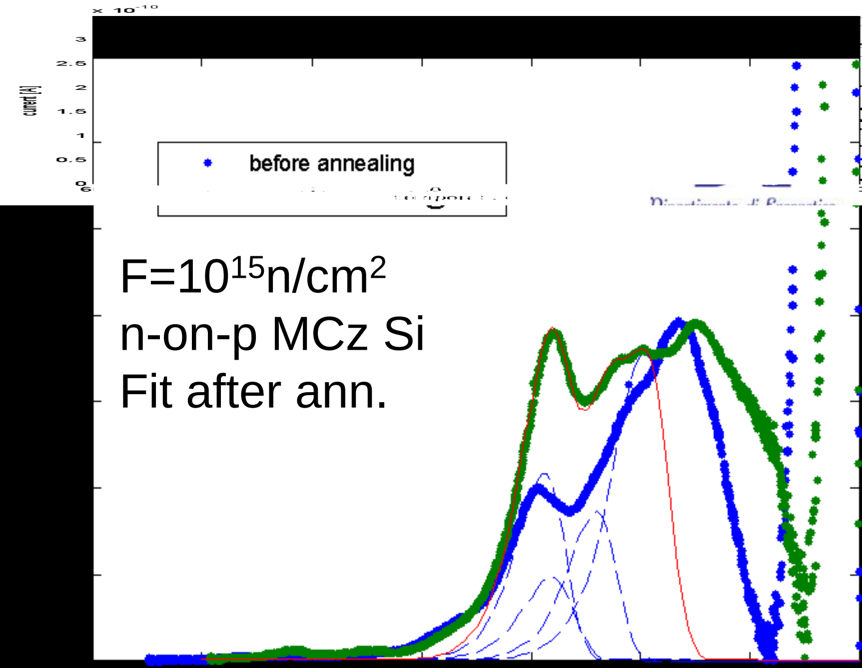
Irradiated with reactor neutrons up to $\phi = 10^{15} n/cm^2$

Annealing: 80min 80°C

Measurements carried out: Standard TSC

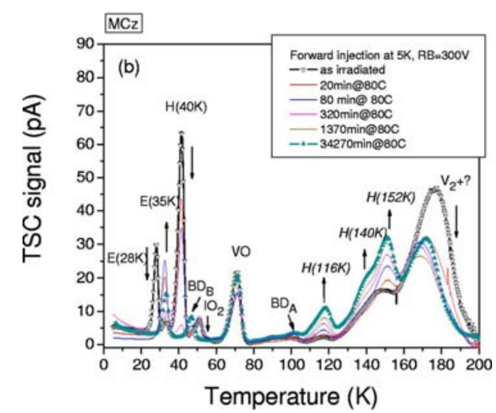
-Peaks studied for temperatures up to 170K because at higher T too low resolution due to background current subtraction





We evidence an increase of peak components at 140K and 150K, as found in MCz material n-type, ϕ (1MeVn)= 5×10^{13}cm^{-2} (I.Pintilie et al. Appl. Phys. Lett. **92**, 024101 2008)

E_a (eV)	σ (cm^2)	type
0.36	1.2×10^{-15}	H(Pintilie)
0.36	2.5×10^{-15}	H (C_iO_i)
0.41	1×10^{-15}	E (V_2)
0.42	23×10^{-15}	H(Pintilie)



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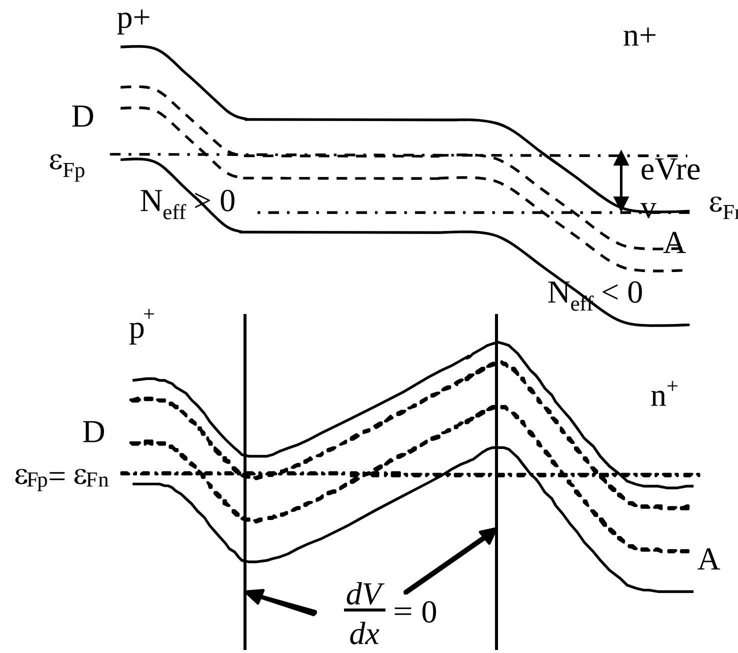
ZBTSC: Method and Experimental procedure

1. **Priming provide an injection of carriers which are trapped at energy levels, according to an asymmetrical distribution induced by external polarization (V_{rev}).**

2. **At low temperature electrodes are short-circuited: the carriers at electrodes and in bulk redistribute themselves in order to establish zero voltage and zero field boundary conditions. Charge frozen at low temperature → non-uniform electric field and non-monotonous potential distribution with minima and maxima corresponding to zero electric-field planes settle.**



Zero-field planes

Example: double junction in irradiated p-on-n Si (Voltages measured at n^+ respect to p^+). Charge distribution not shown.

3. ZBTSC scan (heating): system brought back to the fundamental equilibrium state. Charge redistribute into the volume and charge injection occurs at the electrodes, giving rise to current detected in the external circuit. Charge relaxation during heating scan can be discussed in terms of motion of the zero electric-field planes along the sample thickness.

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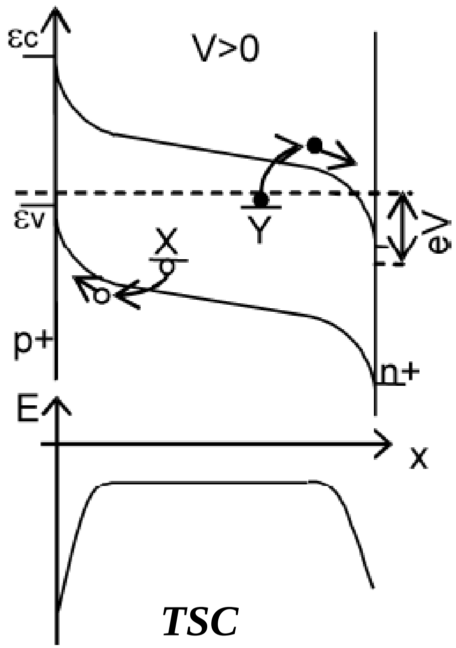
Why negative currents?

Example: double junction in irradiated p-on-n Si (Voltages measured at n^+ respect to p^+, currents positive when flowing from n^+ to p+) ; X hole trap Y electron trap.

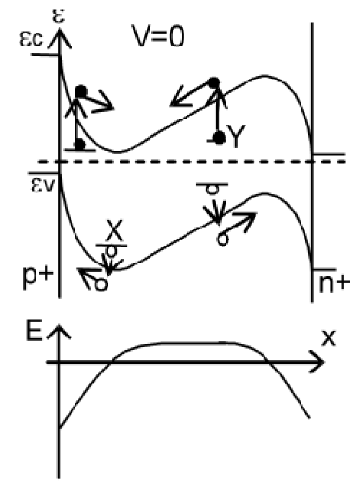
TSC



TSC

Sample reverse-biased: electric field always with same sign. As a consequence, emitted electrons and holes, regardless of the region from which they are emitted, produce always a positive current.

ZB-TSC



Electric field changes sign inside the bulk. Traps emitting close to p^+ or n^+ interfaces give rise to a positive current; those emitting in the bulk will produce a negative current. These two contributions, whose intensity is related to electric field rearrangement during emission, are summed up in the overall measured current. Current sign depends on which components dominate.

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Advantages of ZB-TSC

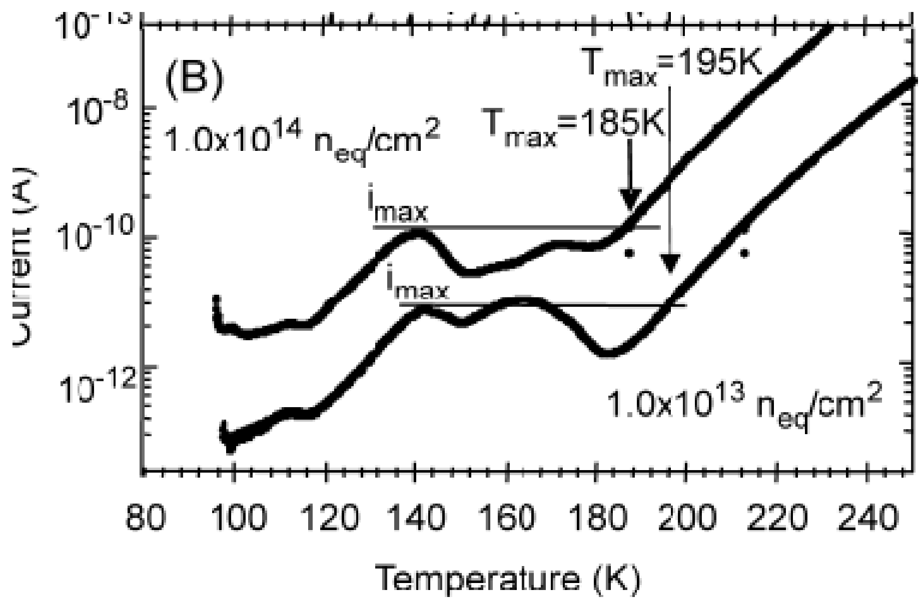
1. Better resolution and reliability in detecting deep traps. **In a standard TSC, deep level emissions can be analyzed as long as they are clearly distinguishable from the background current i_{rev}. This becomes a problem with heavily irradiated silicon. In fact i_{rev} increases linearly with fluence and exponentially with temperature.**

$$\frac{i_{rev}}{volume} \propto \Phi ,$$

$$i_{rev} \propto T^2 \exp(-\varepsilon_g / 2k_B T),$$

In our n-on-p samples:

10^{13}n/cm^2	**T_{max} ~ 195K**
10^{14}n/cm^2	**T_{max} ~ 185K**
10^{15}n/cm^2	**T_{max} ~ 150K**



Deep levels with activation energies close to midgap, important because are believed to be related to extended defects, give TSC signal in the range 180-220K → No reliable evidence for such defects, usually with energies >0.4eV, at high fluences.

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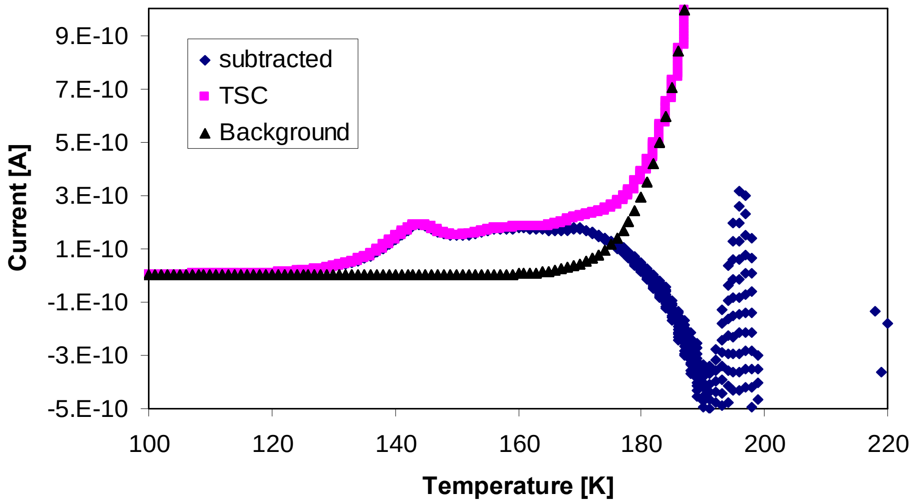
Advantages of ZB-TSC

Cumbersome subtractions of background current from TSC produces big uncertainties and can give rise to artifacts.



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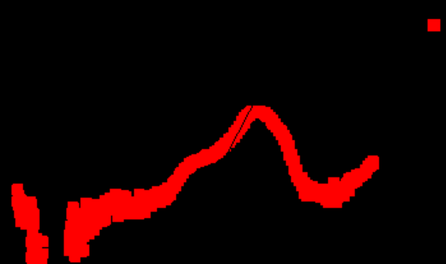


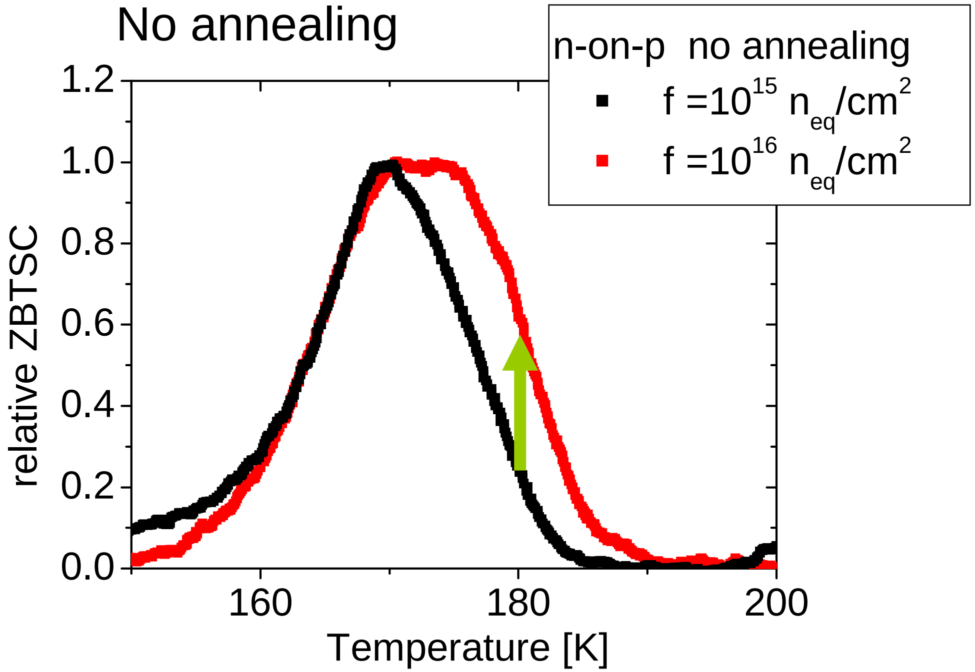
In ZBTSC background current is heavily suppressed and a wider temperature range can be explored.

[redacted]icon diodes after irradiation with neutrons up to 10^{15}-10^{16} n/cm^2
[redacted]009, Freiburg13

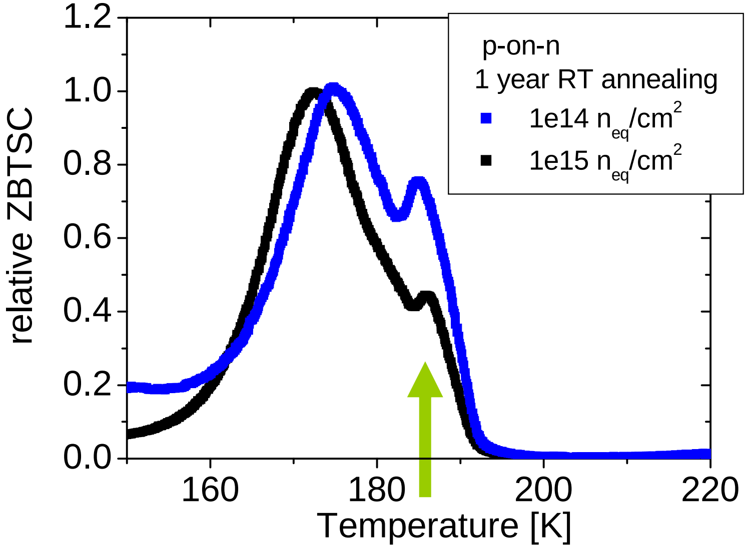
Preliminary measurements: Comparison with different fluences, same material, similar annealing

As ZB-TSC cannot give trap concentration, we compare directly the relative signals.

N-on-p MCz Si diode
No annealing



p-on-n MCz Si diode
1 year at Room Temperature



Tendency to increase the high T part of the spectrum rising the fluence

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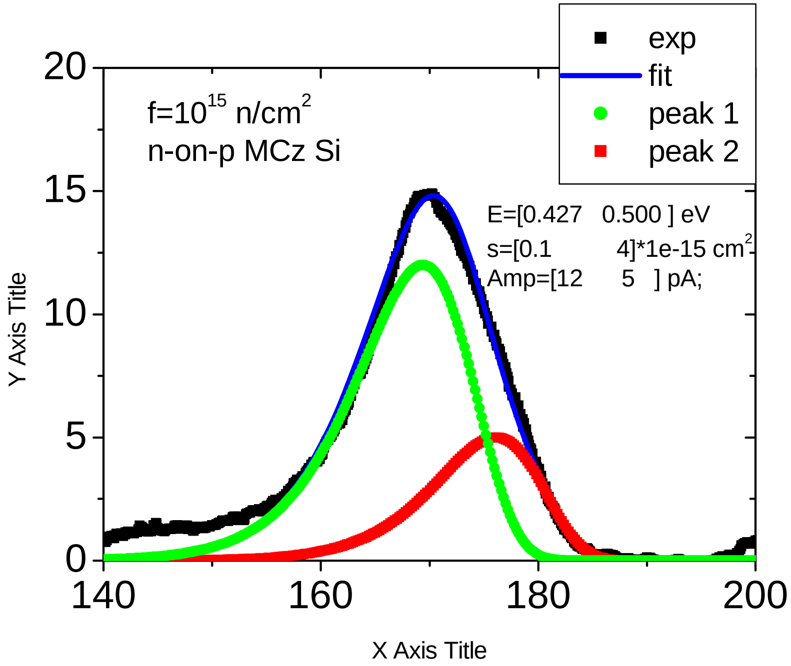
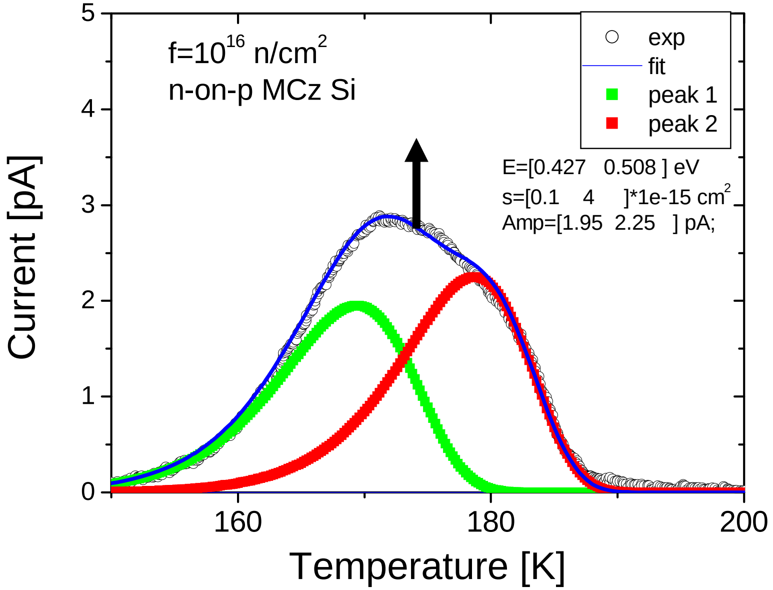
Preliminary: analysis on ZBTSC n-on-p MCz Si fluence = 10^{15} and 10^{16} n/cm^2

-Two components:
-T_{max}= 170K;176K; -E_t ~ 0.4;0.5eV
Deepest level increases relative amplitude with fluence.





Results must be confirmed with more investigations on priming procedure and electric field structure evaluation during measurements.

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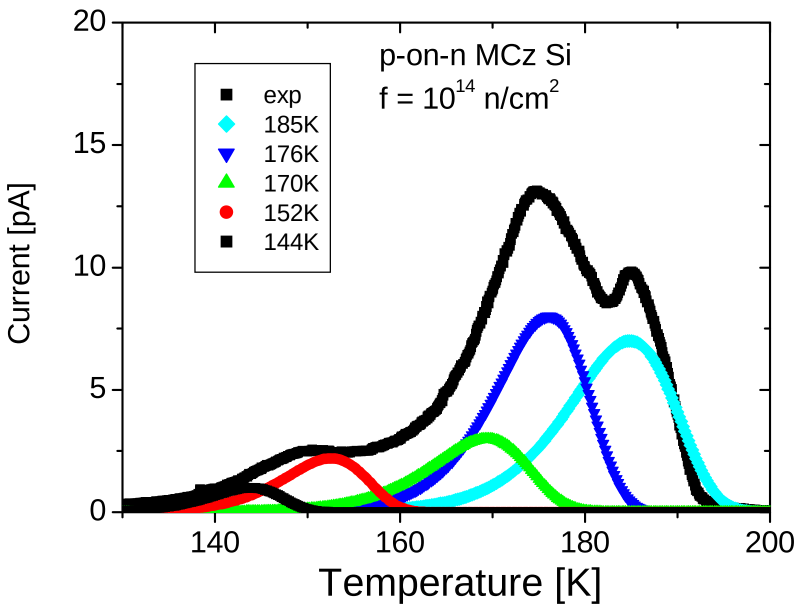
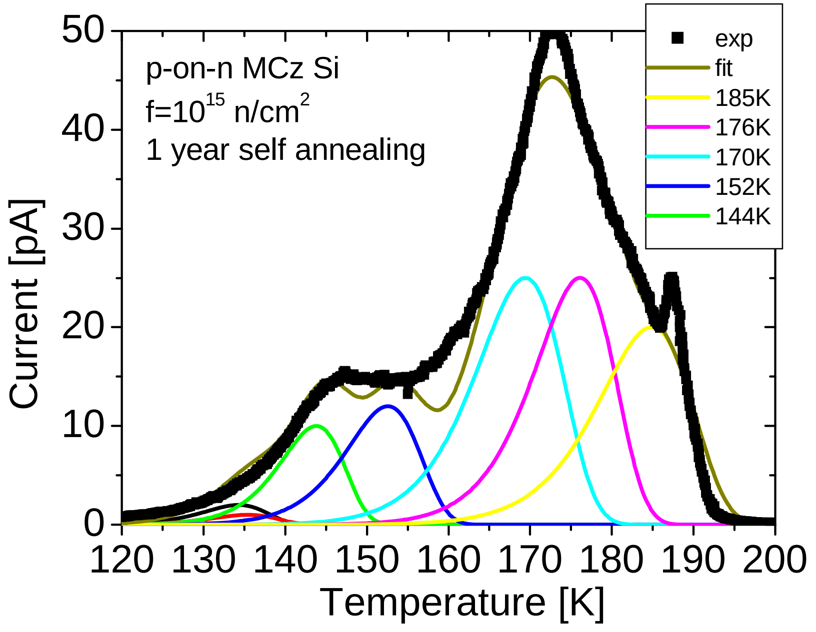
Preliminary: analysis on ZBTSC p-on-n MCz Si fluence = 10^{14} and 10^{15} n/cm^2

-Three components in the high T range (T>160K):
-T_{max}=170K, 176K,185K , E_t = 0.4-0.5eV





Results must be confirmed with more investigations on priming procedure and electric field structure evaluation during measurements.

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Summary

We performed an evaluation of radiation-induced defects in p- and n-type MCz Si after irradiation with reactor neutrons up to 10^{15}-10^{16}cm^{-2}.

-Low Temperature TSC was carried out to inspect shallow defects. No Poole Frenkel effect on 30K-peak in p-type MCz. Shallow peak at 30K does not contribute to space charge in p-type?

-After 10^{15}n/cm^{2} irradiation and annealing of 80min at 80°C two peaks at H(140K) and H(150K) increase amplitude in p-type MCz Si. Same effect as in n-type MCz (observed for lower fluence by Pintilie et al.).

-Defects analyses carried out up to 10^{15}-10^{16}cm^{-2} with ZB-TSC, to avoid background current. Preliminary analysis comparing relative amplitudes as a function of fluence and conductivity type: (a) increase of the high T components increasing the fuence (b) **presence of one more component peak in n-type at higher T with respect to p-type. Results must be confirmed with more investigations on priming procedure and electric field structure evaluation during measurements.**

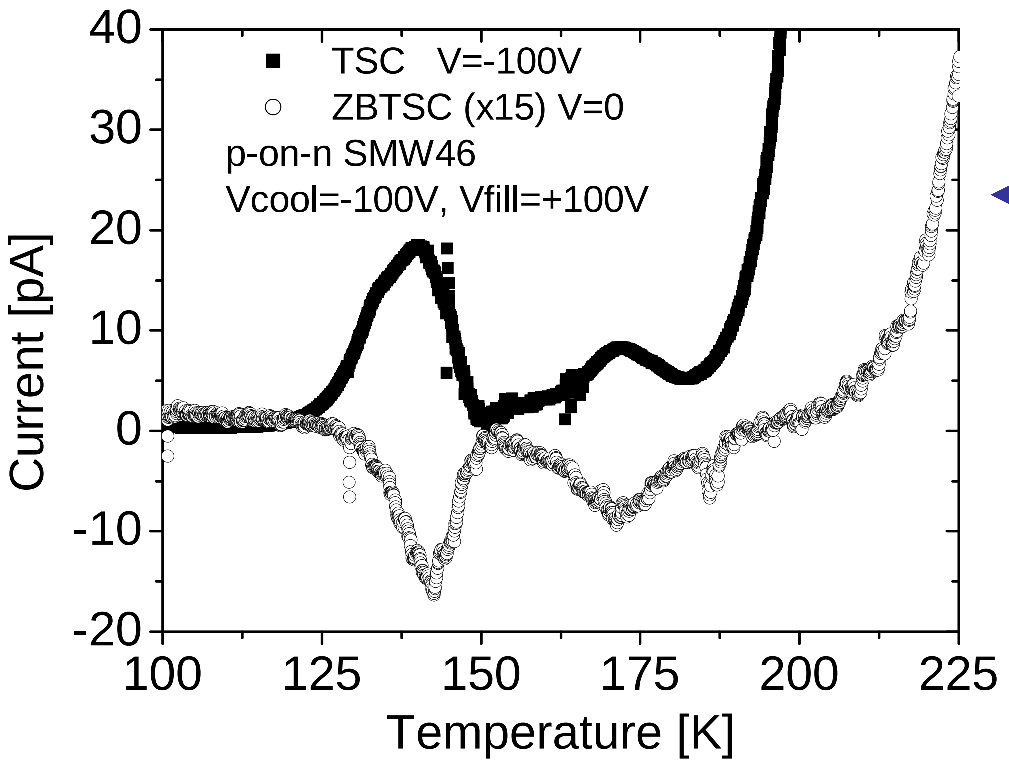
spares

Electric field contributions in ZBTSC:

a) **built-in** at electrodes;
b) **intrinsic** at traps ionized in the bulk;
c) **offset** due to faible potential differences remaining at electrodes during short-circuit.
d) **Intentional** offset applied to counteract or support emission (quasi-ZBTSC).

Best conditions to observe trap emission must be determined experimentally, by evaluating these components and evaluate their effect on trap emission.

Typically, but non-necessarily, the ZBTSC will flow in the opposite direction of the current that has established the charge distribution during the priming, but the initial direction can be reversed during the thermal scan.



Here signal due to trap emission change sign when changing from TSC to ZBTSC, while current background, due to offset voltage, is always positive.

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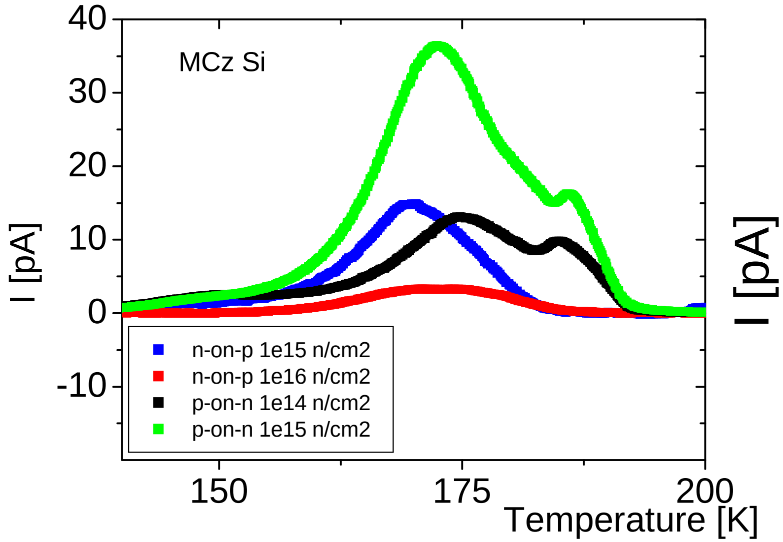
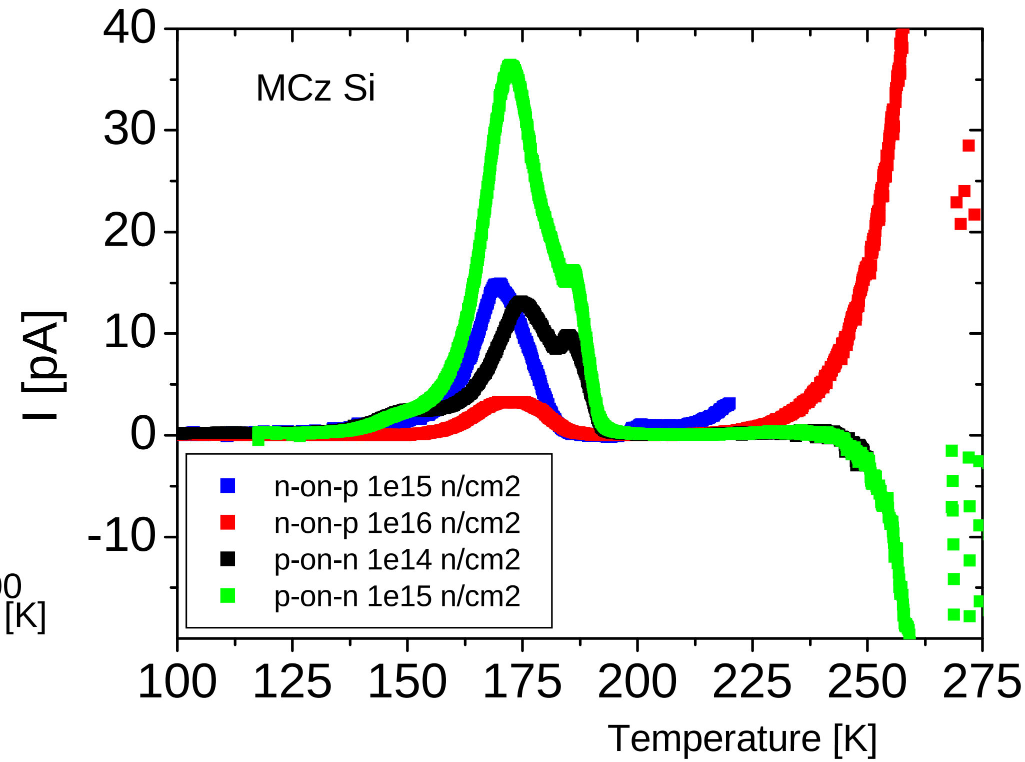
Offset effect on current





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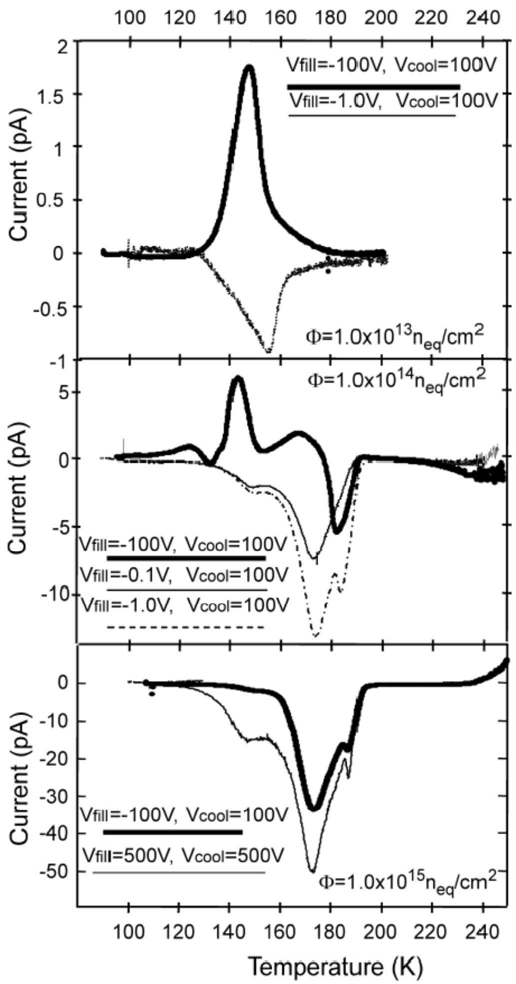
2. Inspection of intrinsic electric field due to charged defects



n-on-p irradiated Si

ZB-TSC measurements performed at different fluences. Thick lines indicate measurements carried out in the following reference conditions: $V=V_{cool}$=100V during the cooling from room temperature to T_0, V=Vfill=-100V to inject carriers at T_0.

At the lowest fluence a positive signal is observed in the range 130-160K. At the intermediate fluence the signal extends up to 190K and its zero-crossings reveal the presence of regions with opposite electric field. At the highest fluence the spectrum is completely dominated by negative components from the bulk.

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