Properties of a new series of Hamamatsu Si diodes

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A new series of diodes FZ-Si (Hamamatsu) investigated by:

1) a standard technique (I(V) and C(V));

2) by microwave photoconductivity decay measurement;

3) the response on the linear front bias pulse technique (BELIV);

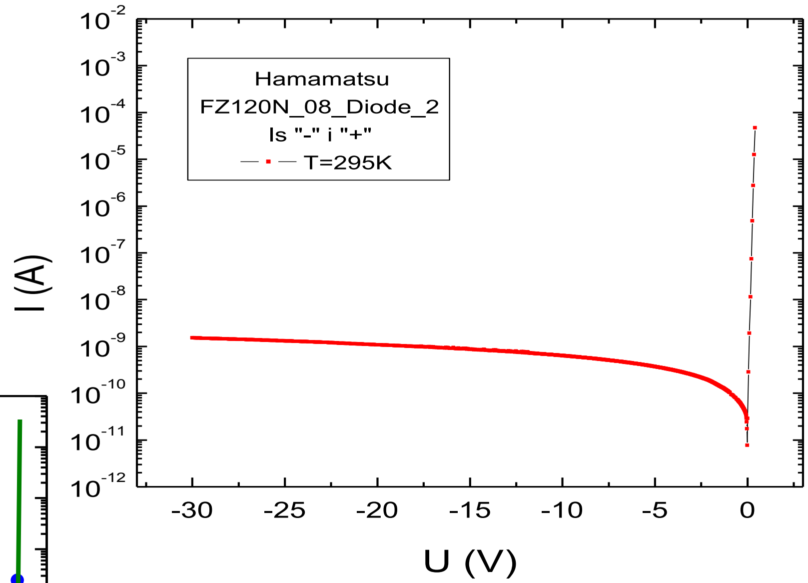
4) the photoconductivity spectra in the extrinsic region.

Measurements performed at room at a low temperature.

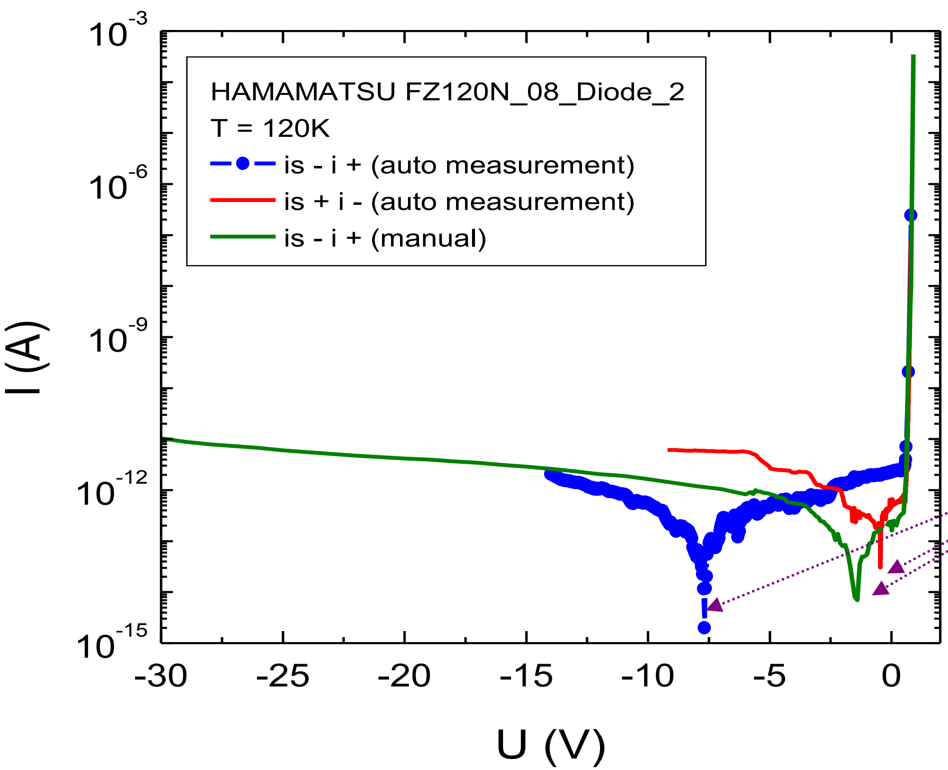
The results are compared with the similar measurements in other supplier and in irradiated samples.

I-V characteristics in non-irradiated diode

HAMAMATSU FZ120N-08-diode- **T=295 K**



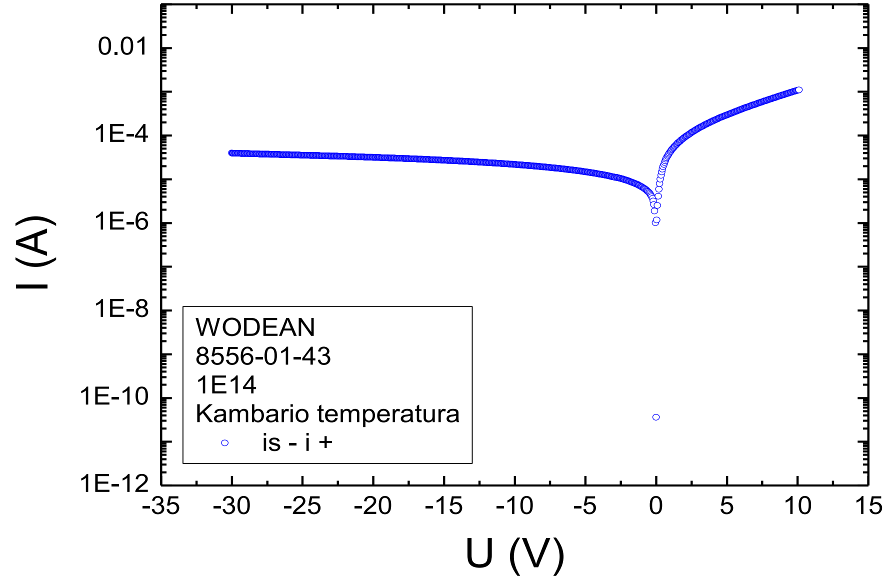
HAMAMATSU FZ120N-08-diode- **T=120K**



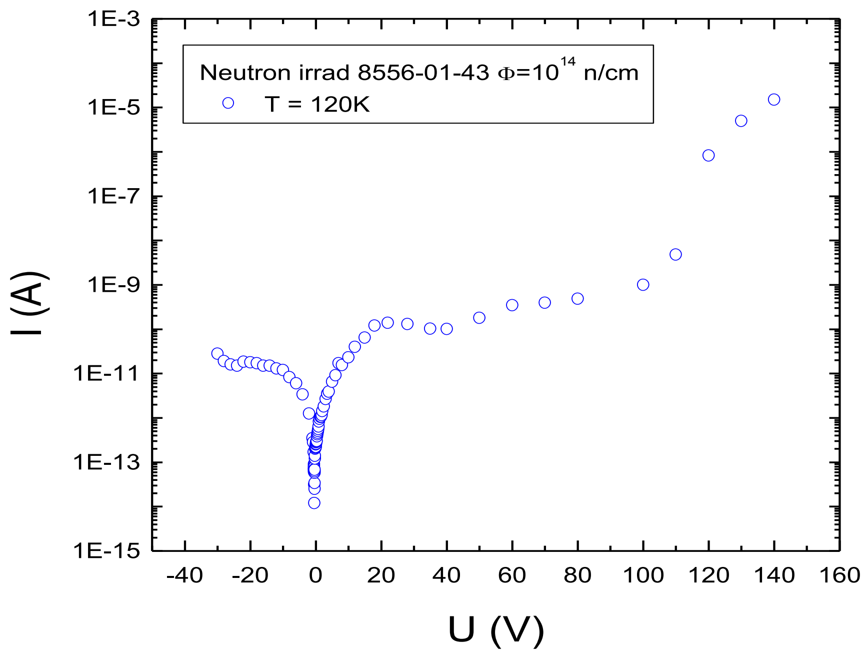
Surface charge on high resistivity/isolator ??? (non-metallized) material with very long (10^3 s) relaxation

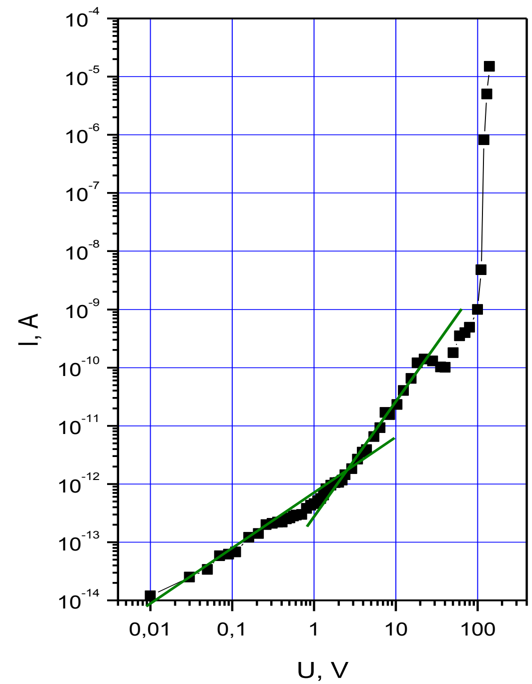
I-V characteristics in radiation damaged diode

WODEAN 8556-01-43 MCZ Si
neutrons 1014 cm-2 diode **T= 295 K**
still diode –like characteristic



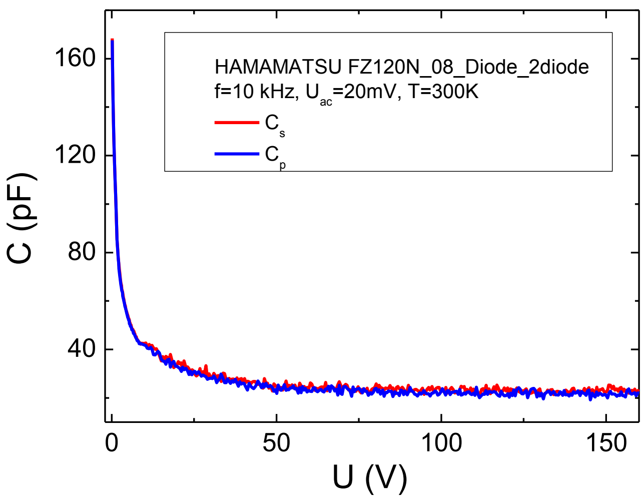
T= 120K
WODEAN 8556-01-43 MCZ Si neutrons
1014 cm-2 diode-?
Insulator like characteristic

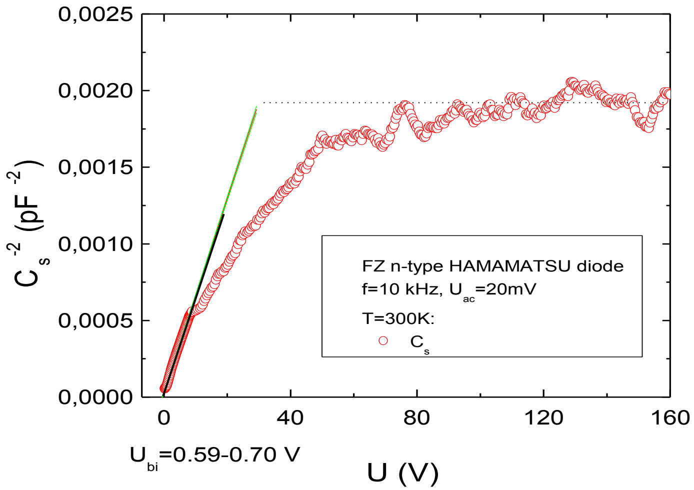




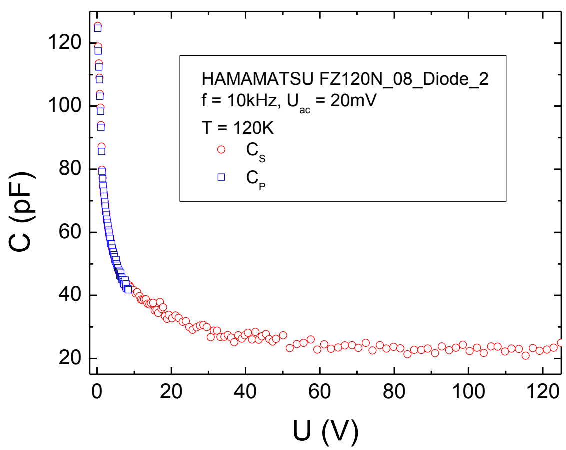
C-V-T characteristics in non-irradiated diode

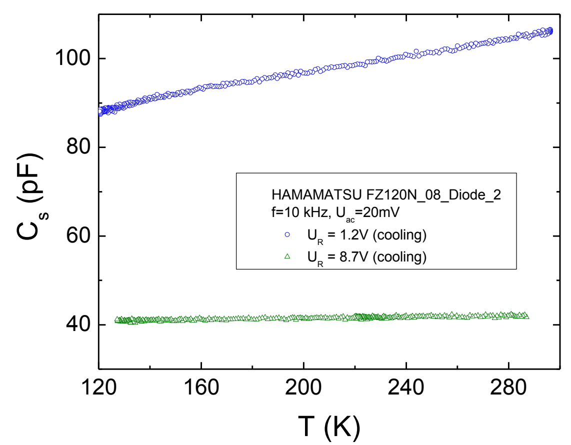
Non-irradiated Hamamatsu diode T=300K





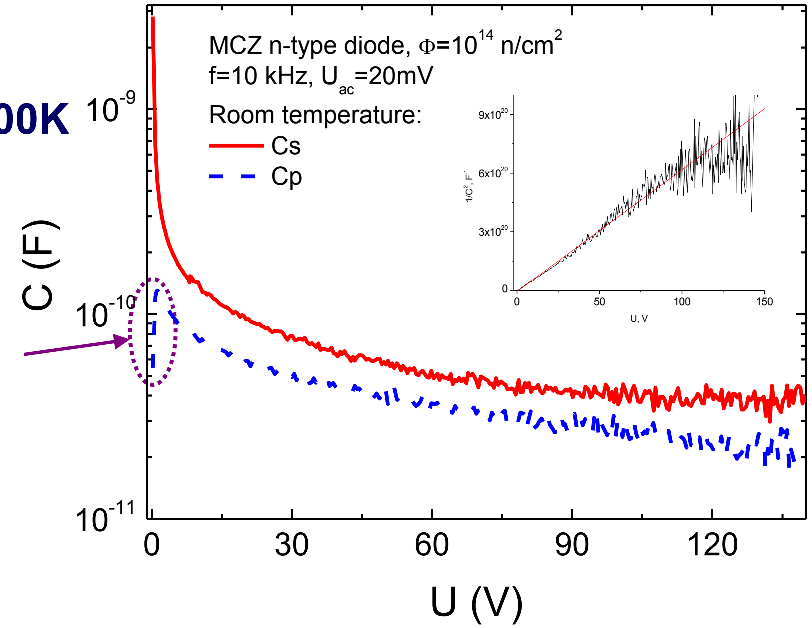
Non-irradiated Hamamatsu diode T=120K (diode barrier exists over all the range of T)





C-V-T characteristics in radiation damaged diode

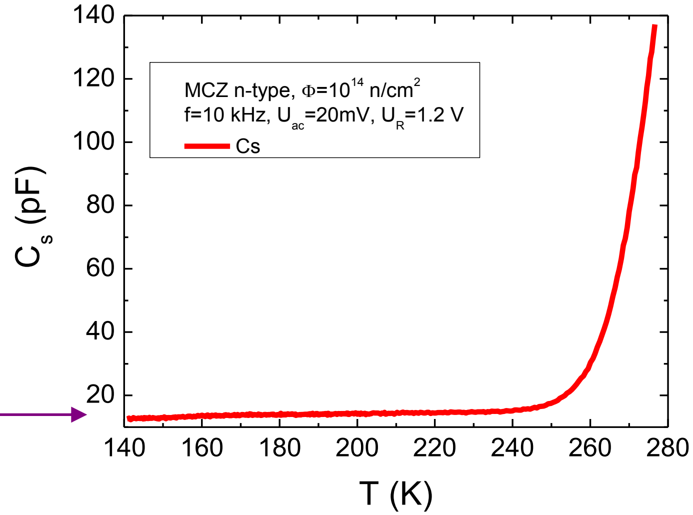
Neutron-irradiated 10^{14} cm^{-2} MCZ diode T=300K



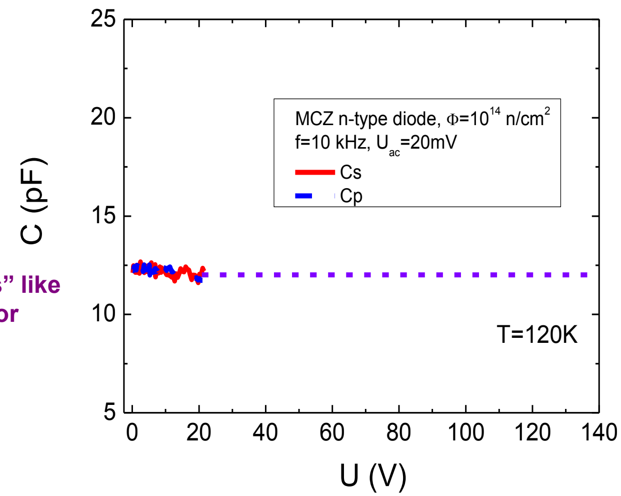
Caused by traps

Neutron-irradiated 10^{14} cm^{-2} MCZ diode T=120K

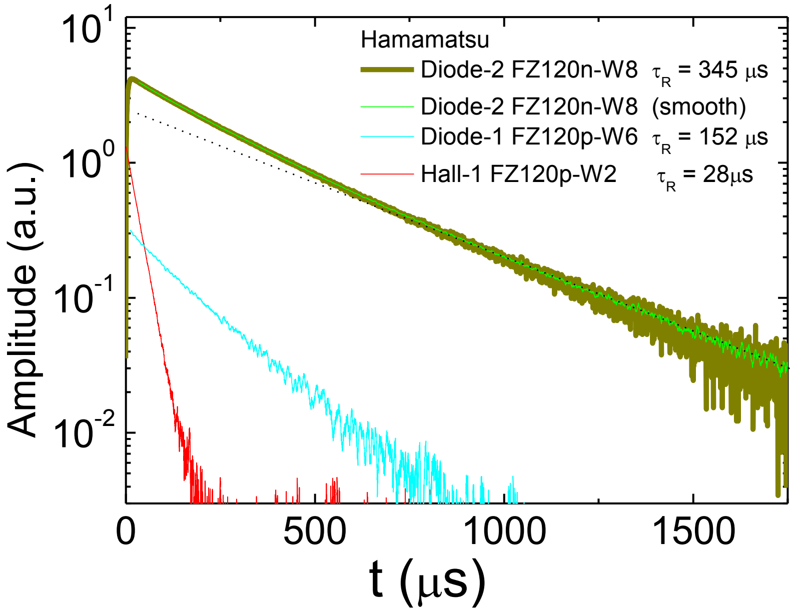
Reaches a geometrical C value even at low voltage

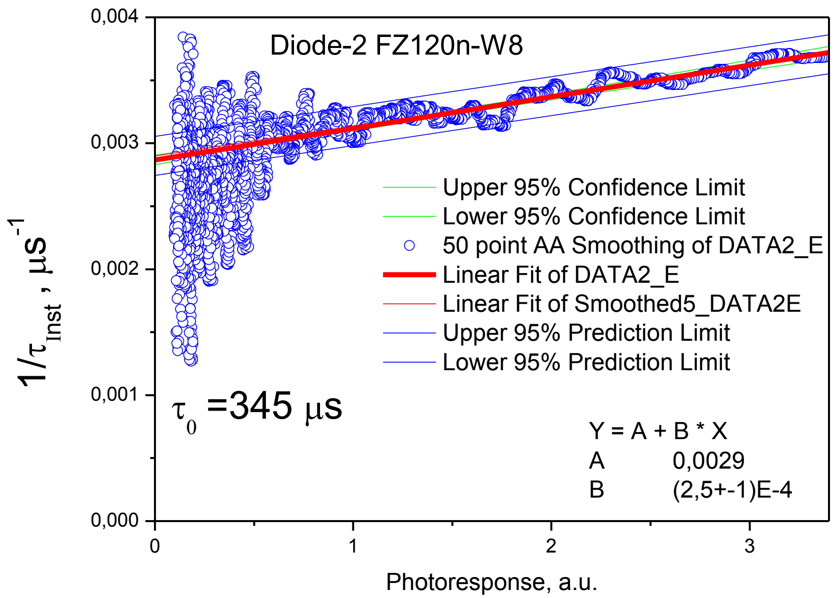


"Behaves" like a capacitor



Carrier recombination characteristics in the non-irradiated CMS CEC samples





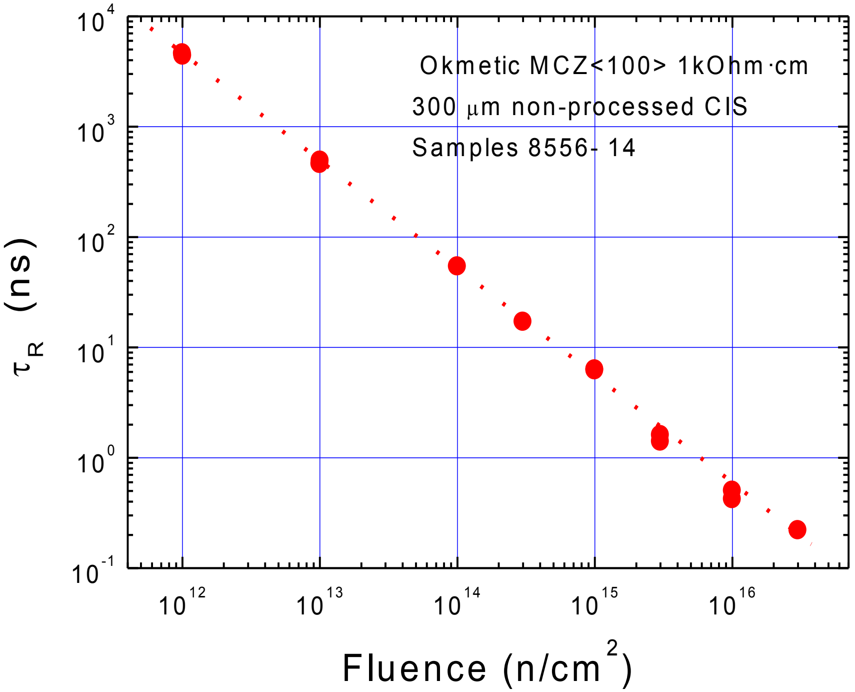
Carrier lifetime and MW-PCD transients at bulk(λ_{ex}=1062 nm) excitation

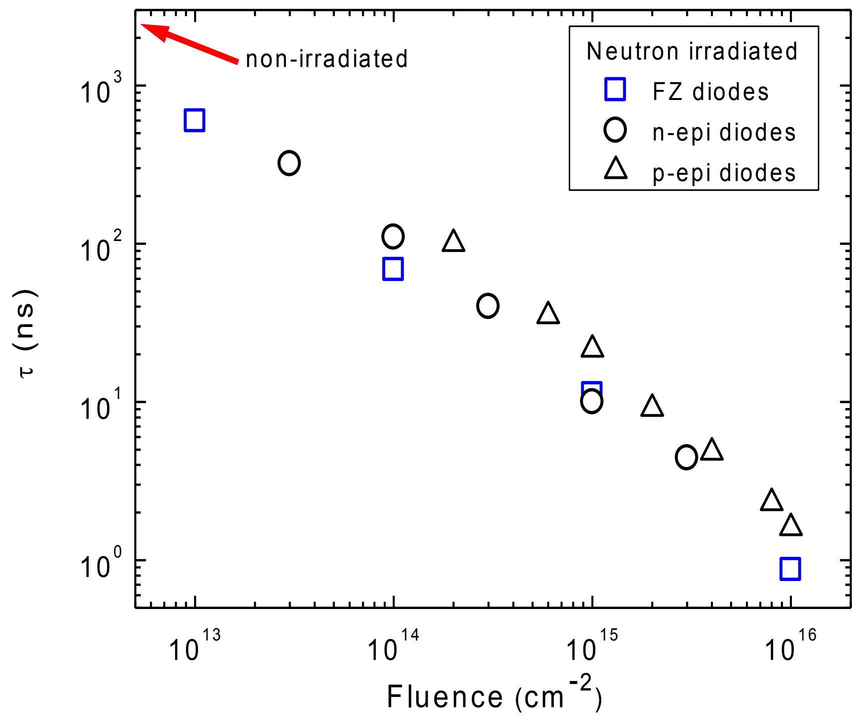
(n- and p-type base diodes and "Hall" samples). Δn=1.5e12 cm^{-3} (S= ~2,5 e-16 cm^2)

Conclusion: Recombination centers in n-diode base are near to filled up;

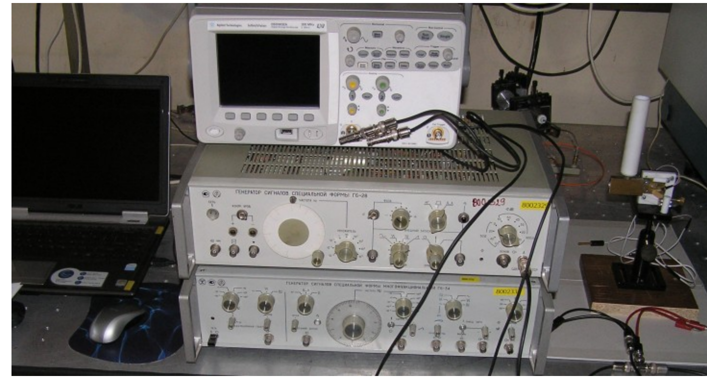
Recombination centers in p-diode base and in Hall sample are near to empty;

Neutron fluence dependent recombination lifetime in MCZ and epi- Si



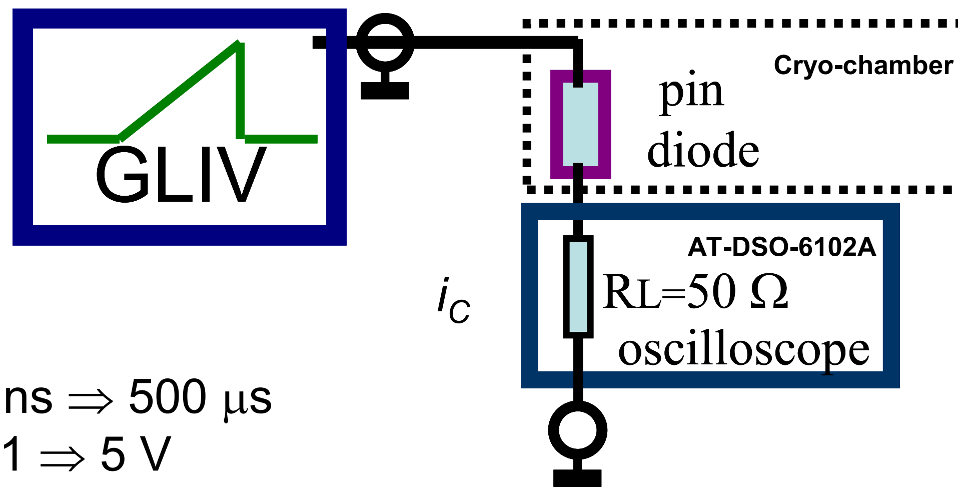


BELIV technique



$U(t)=U_P/\tau_{PL}t = At$

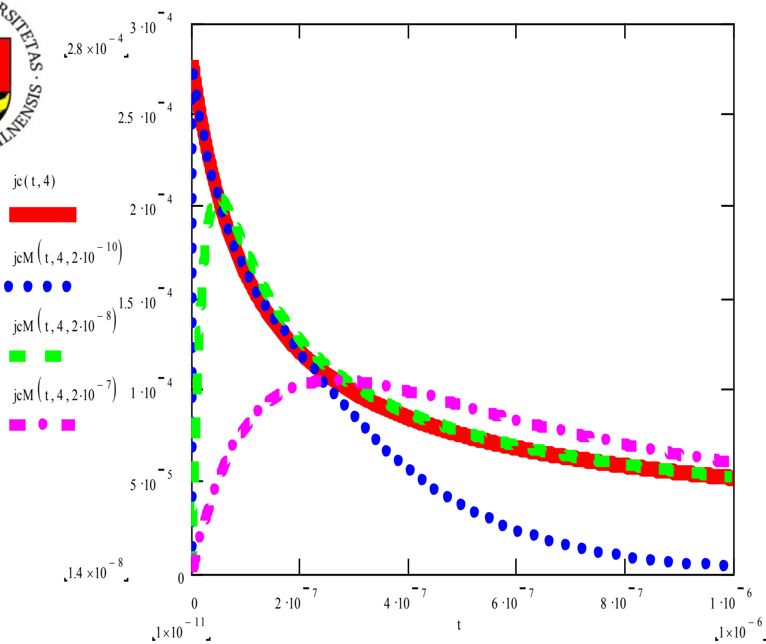
LIV ramp $A=U_P/\tau_{PL} = \partial U/\partial t$



τ_{PL}= 10 ns ⇒ 500 μs
U_P= 0.01 ⇒ 5 V

This method allows to avoid the displacement current change in time

BELIV model and simulations



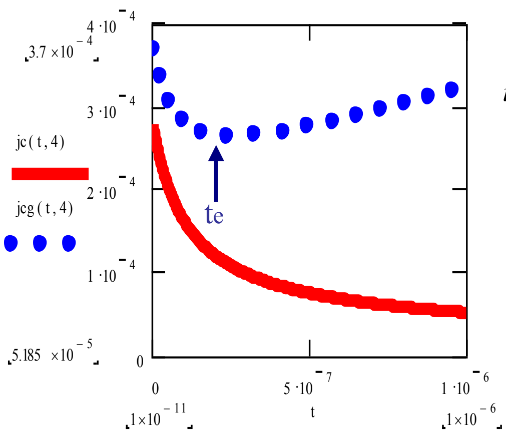
Reverse bias

<0

$$i_C(t) = \frac{dq}{dt} = \frac{\partial U}{\partial t}\left(C_b + U\frac{\partial C_b}{\partial U}\right) = AC_{b0}\frac{1+\frac{At}{2U_{bi}}}{\left(1+\frac{At}{U_{bi}}\right)^{3/2}}$$

$$i_{CM}(t) = \frac{1}{\tau_{RC}}\int_0^t i_C(x)\exp\left[-\frac{(t-x)}{\tau_{RC}}\right]dx$$

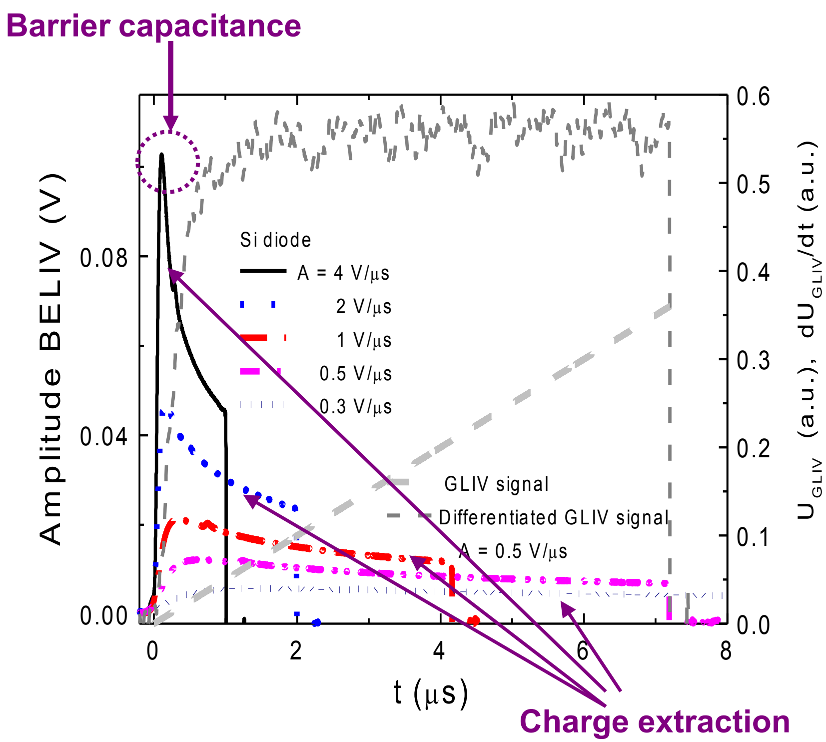
Short transient processes acting in series due to t_D, τ_{DR}, τ_{capt}, τ_{gen}, *etc* (to complete a circuit) determine a delay & a reduction of the initial displacement current step.
Similar effect perturbs the C-V characteristic at $U_R \to 0$ measured by impedance technique (LRC-meters).

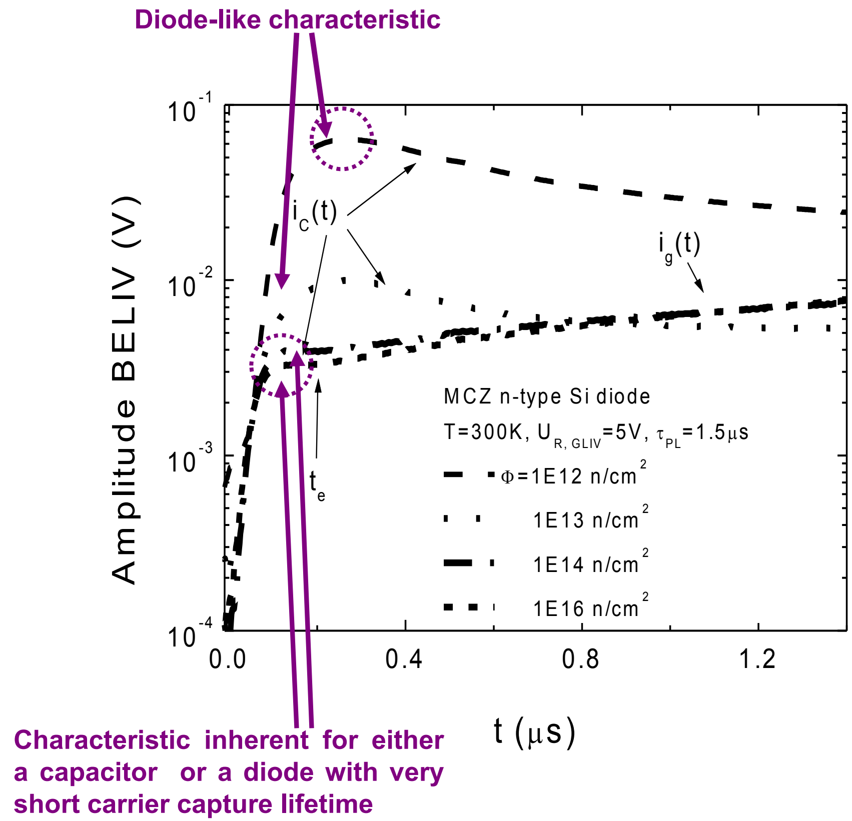


$$i_{R\Sigma}(t) = i_C(t) + i_{diff}(t) + i_g(t) = AC_{b0}\frac{1+\frac{At}{2U_{bi}}}{\left(1+\frac{At}{U_{bi}}\right)^{3/2}} + i_{diff\infty}\left(1-e^{-\frac{eAt}{k_BT}}\right) + \frac{en_iSw_0}{\tau_g}\left(1+\frac{At}{U_{bi}}\right)^{1/2}$$

$$t_e = \frac{U_{bi}}{Ai_g(0)}\left[\frac{i_C(0)}{4} - i_g(0) + \sqrt{\left(\frac{i_c(0)}{4}\right)^2 + \frac{3}{2}i_c(0)i_g(0)}\right]$$

BELIV transients – qualitative variations of the transient shape





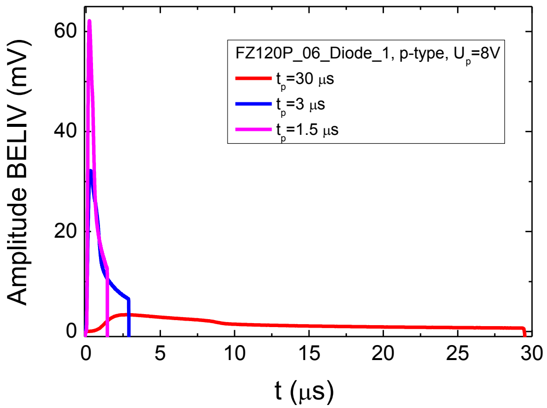
Barrier **e**valuation by **l**inearily **i**ncreasing **v**oltage (BELIV) technique based on charge extraction current transients measured in the non-irradiated and irradiated with small fluence pin diode at reverse (U_R) biasing by LIV pulses.

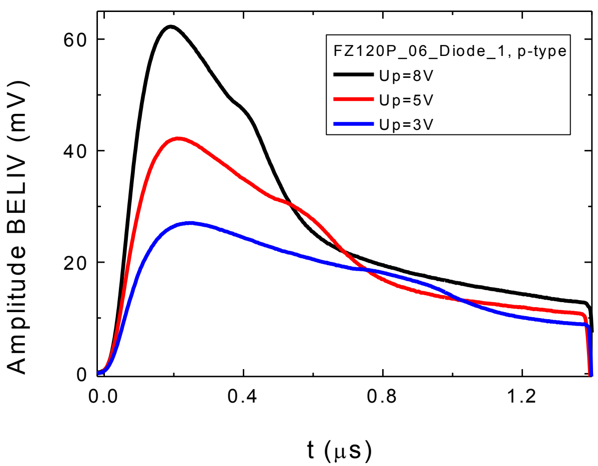
Variations of BELIV transients with irradiation fluence for reverse biased Si pin pad-detector at the same LIV parameters (A= 3 MV/s, τ_{PL} =1.5 μs).

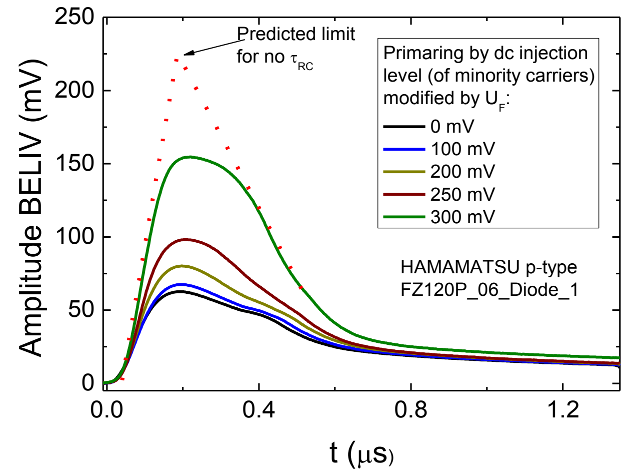
BELIV transients – non-irradiated Hamamatsu diodes (T=300 K)

in-dark

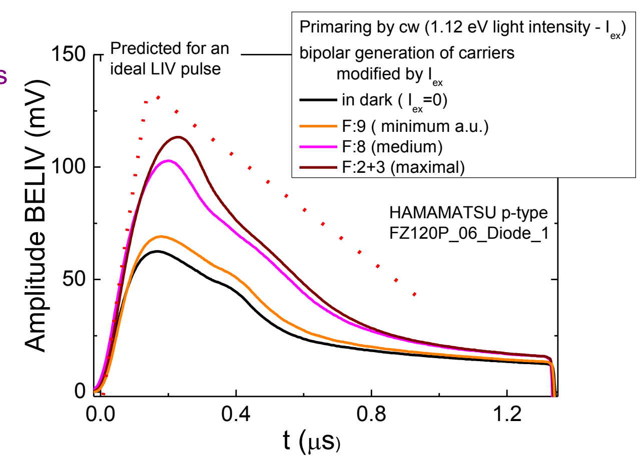
Primary steady-state filling of traps by dc injection (U_F) and cw bias-illumination







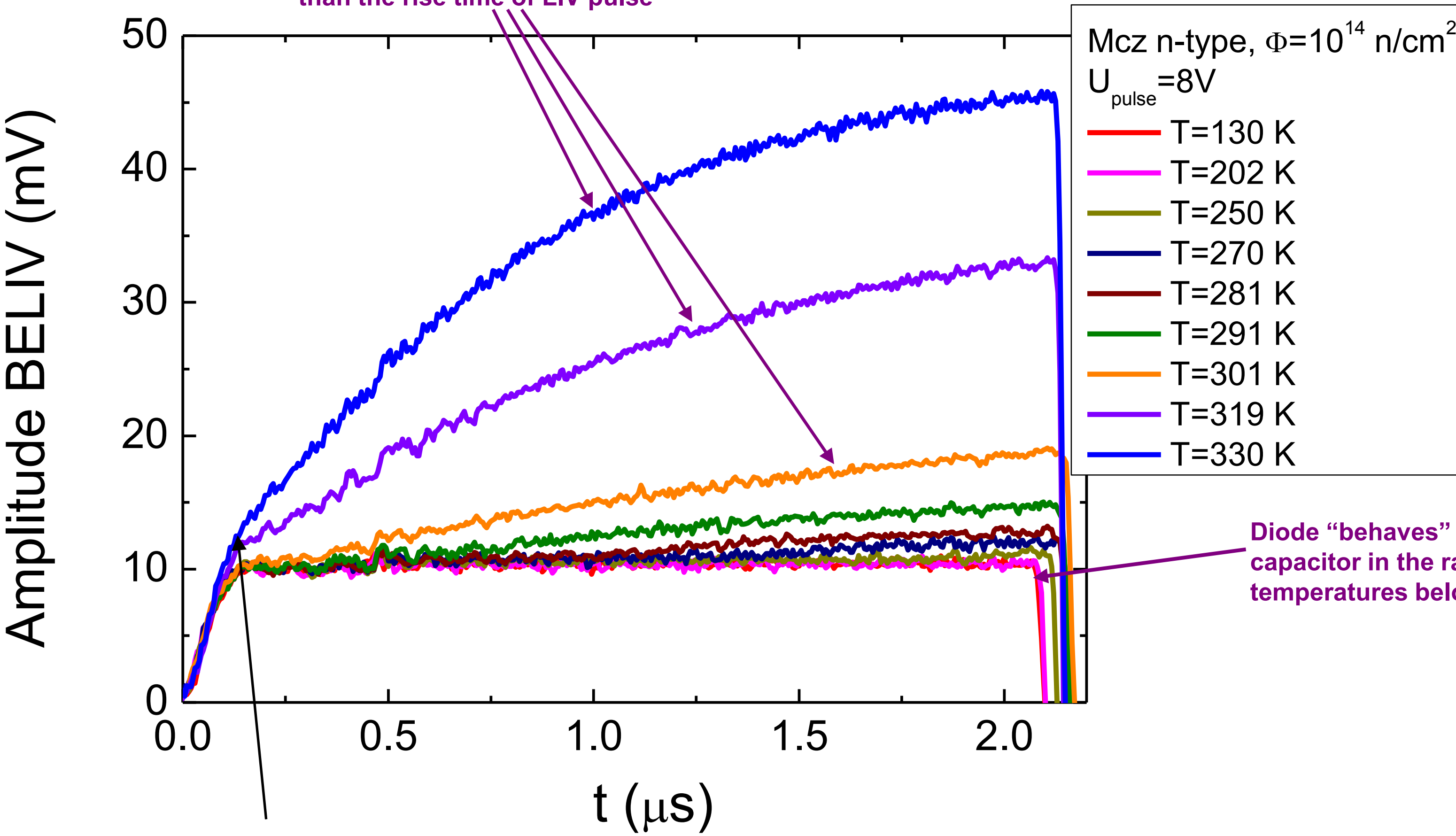
Improvement of barrier (relatively to a black transient on left Fig.) by steady-state filling of traps



Modification of BELIV transients caused by fast trap primary filling in pin diodes containing p-type base by exploiting either dc U_F injection of minority carriers or bipolar injection of carriers by cw IR light additional illumination

Temperature dependent BELIV transients – in neutron 10^{14} cm^{-2} irradiated MCZ diode

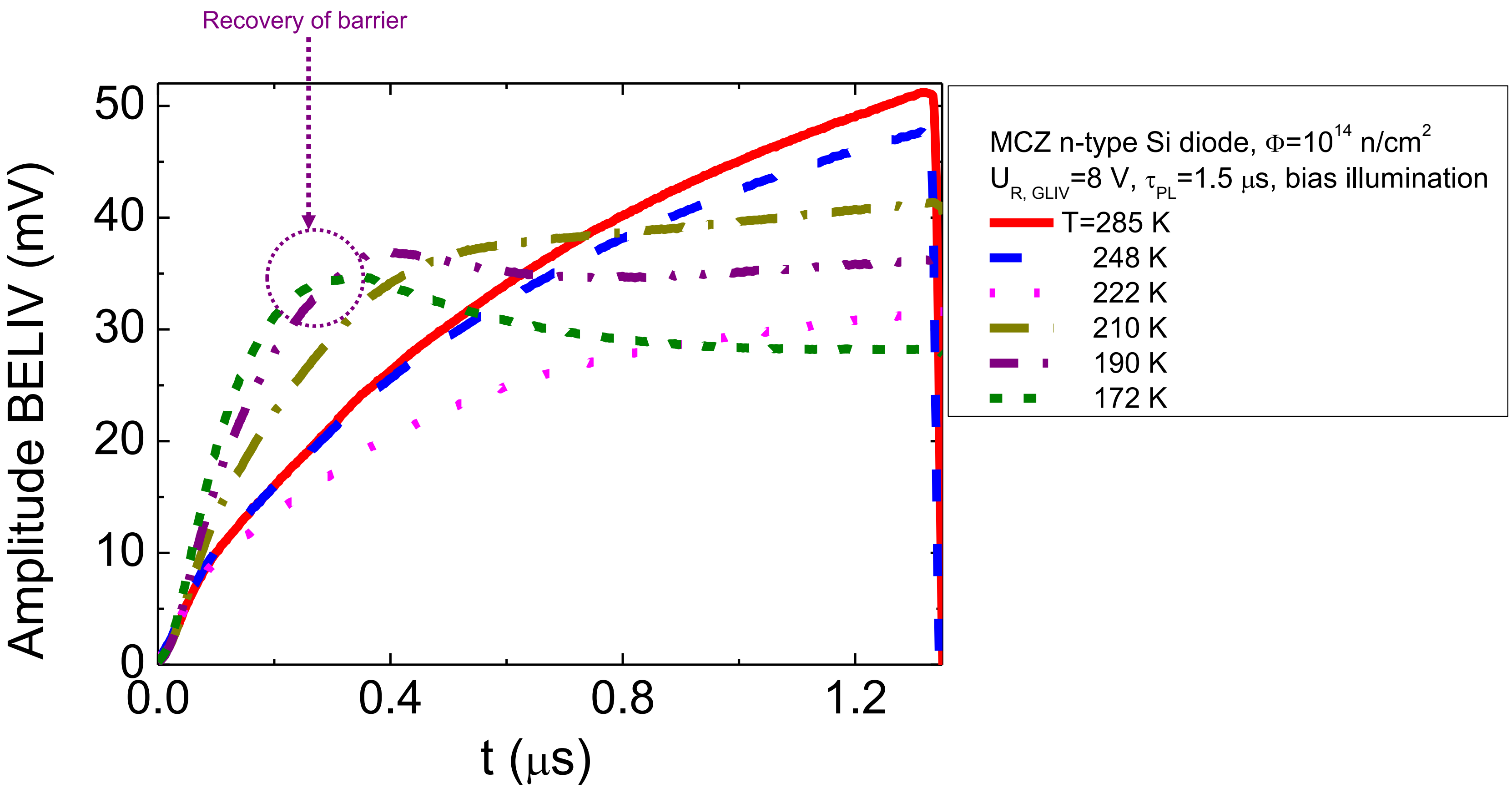
The generation current prevails in time scale >1 μs, while the carrier capture time is shorter than the rise time of LIV pulse



Diode "behaves" like a capacitor in the range of temperatures below 250 K

t_e

Temperature and IR biasing dependent BELIV transients in neutron 10^{14} cm^{-2} irradiated MCZ diode



Suppression of traps (by combined cooling and primary filling) and recovery of barrier can be implemented by varying the external factors of temperature and of fixed bias cw illumination

TCT (transient current technique)- ChCT(charge collection transient technique) -TOF (time of flight)

ChCT signal transforms to TCT signal with reduction of excitation I_{ex} density (when $n_{ex} \rightarrow$ to n_{tr}) in non-irradiated MCZ Si samples

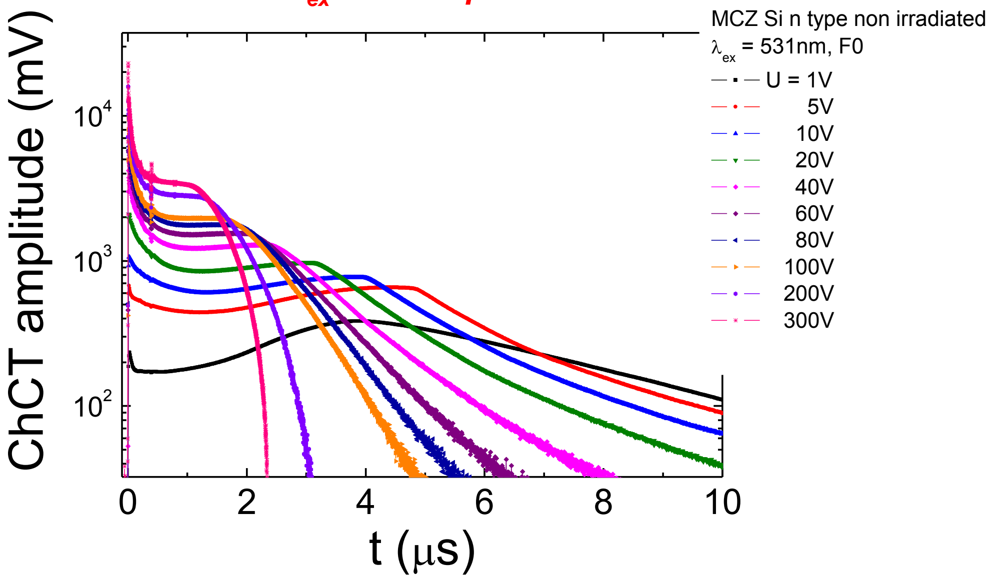
$n_{tr}=\varepsilon\varepsilon_0 U/ed^2$, w→d=f(U), $n_{ex}=(1-R)\alpha(1-e^{-\alpha d})I_{ex} \approx (1-R)\alpha I_{ex}|_{\alpha d>>1}$

TCT signal transforms to TOF signal with enhancement of fluence (when $t_{tr}<< \tau_M$, or $t_{tr} \rightarrow$ to τ_M, $\tau_R<<\tau_M$) in the irradiated ($\Phi>10^{13}$ cm^{-2}) samples

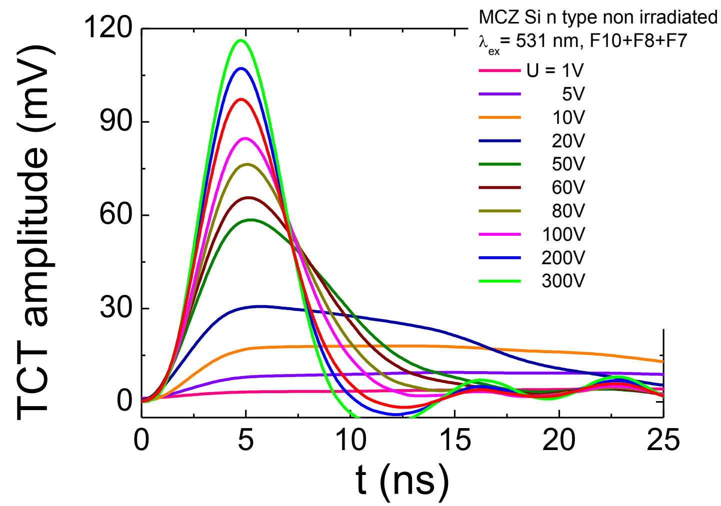
$\tau_{tr}= d^2/\mu U$, $\tau_M=\varepsilon\varepsilon_0/e\mu N_{eff}|_{Neff\rightarrow ni \text{ or } 0}$

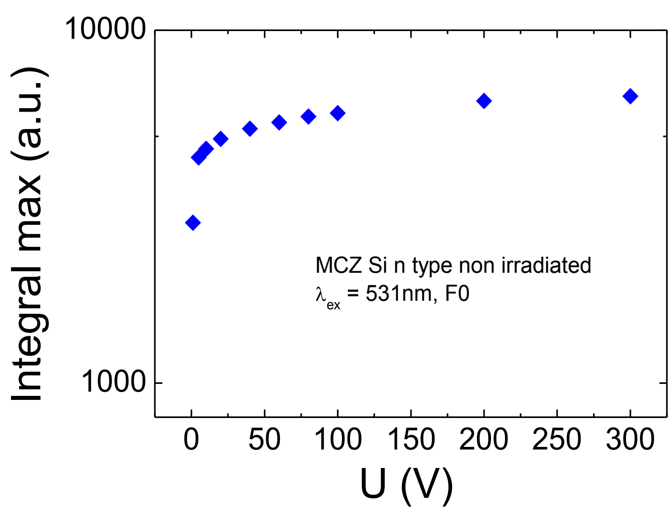
ChCT – TCT in the non-irradiated MCZ Si diode (d=300 μm), λ_{ex}=531 nm, drift of electrons to the back electrode, U_R

I_{ex}= 900 nJ/pulse

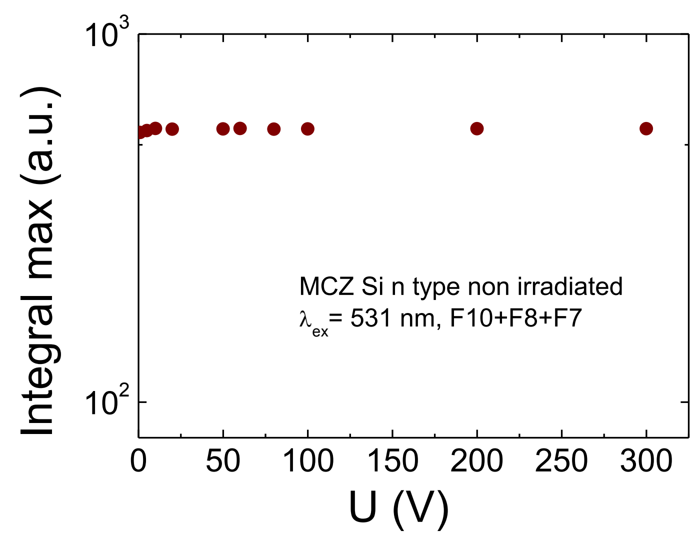


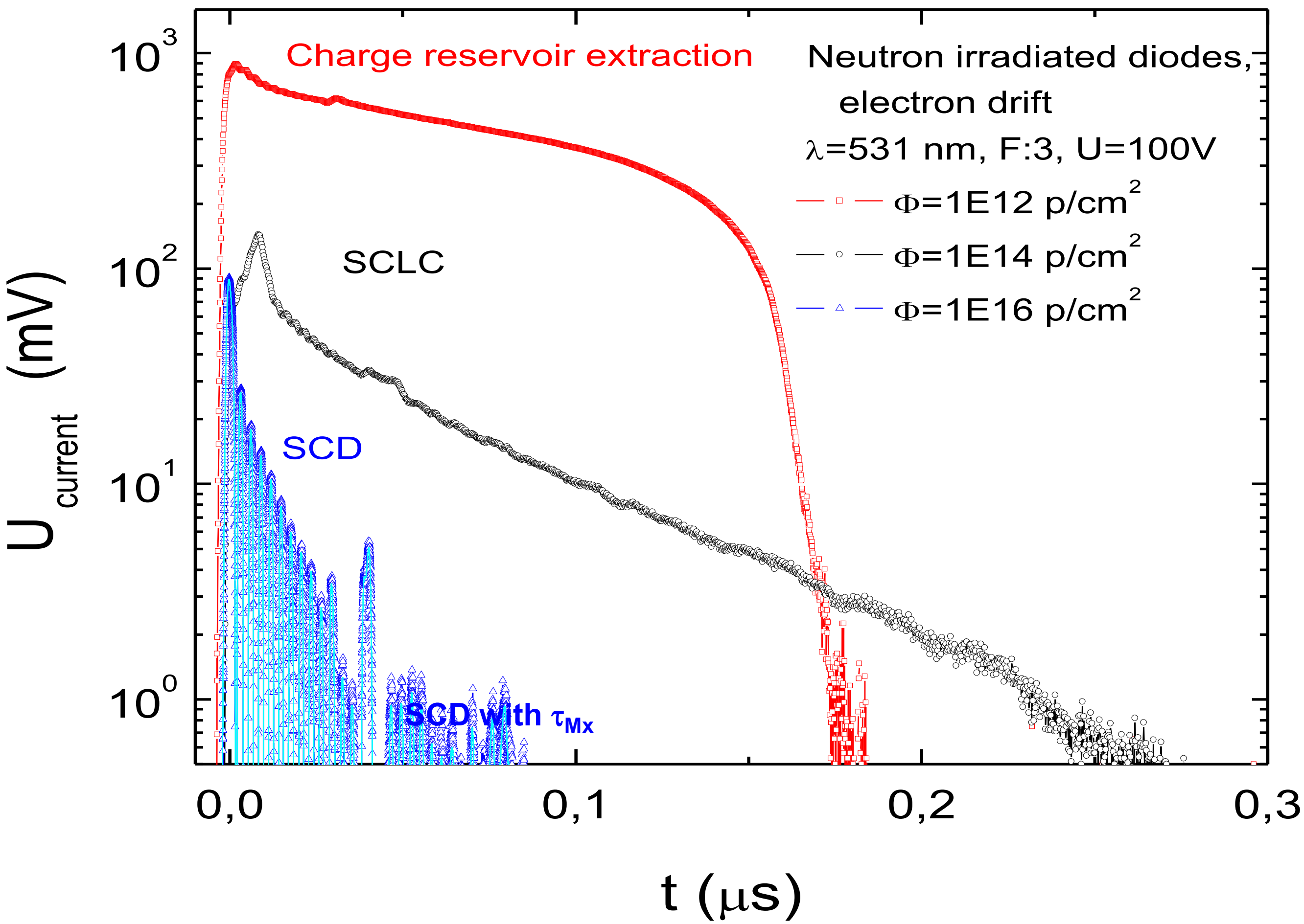
I_{ex}=2.5 pJ/pulse





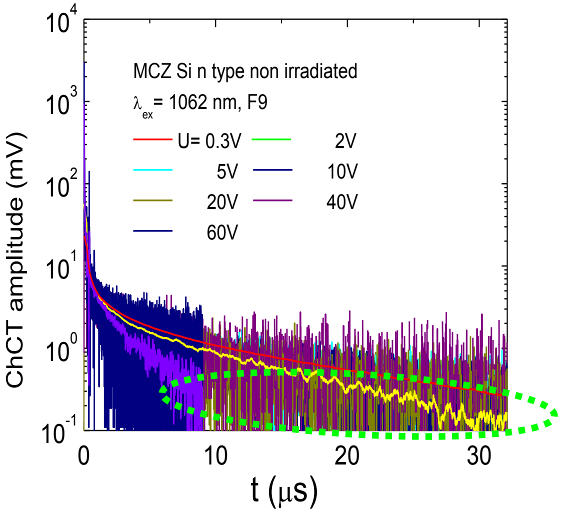
CCE

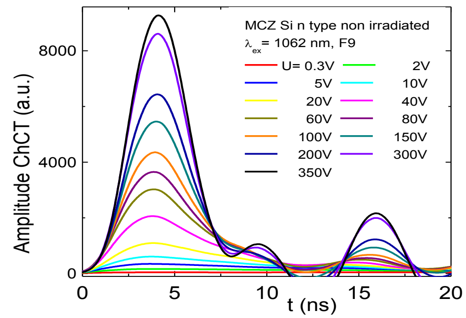


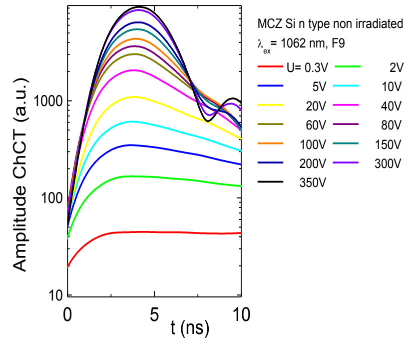

Charge reservoir extraction
Neutron irradiated diodes,
electron drift
λ=531 nm, F:3, U=100V
Φ=1E12 p/cm2
Φ=1E14 p/cm2
Φ=1E16 p/cm2
SCLC
SCD
SCD with τMx
Ucurrent (mV)
t (μs)
10^3
10^2
10^1
10^0
0,0
0,1
0,2
0,3

ChCT – TCT in the non-irradiated MCZ Si diode (d=300 μm), , λ_{ex}=1062 nm, drift of both type carriers to the opposite electrodes, U_R

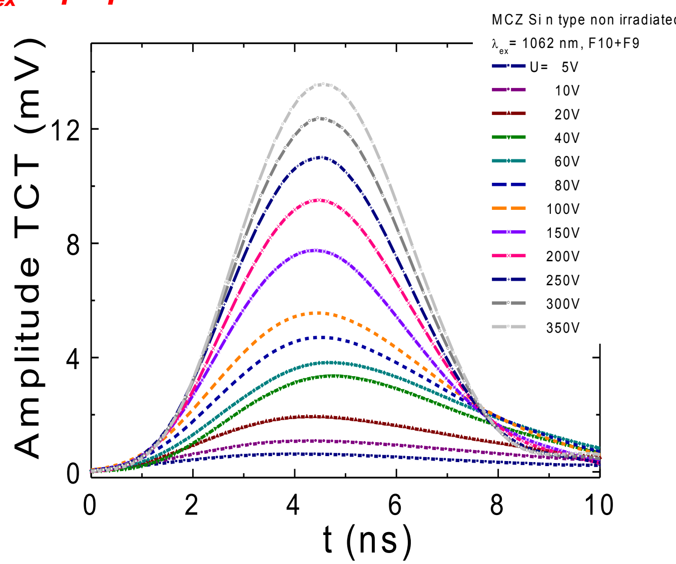
I_{ex}= 2 μJ/pulse

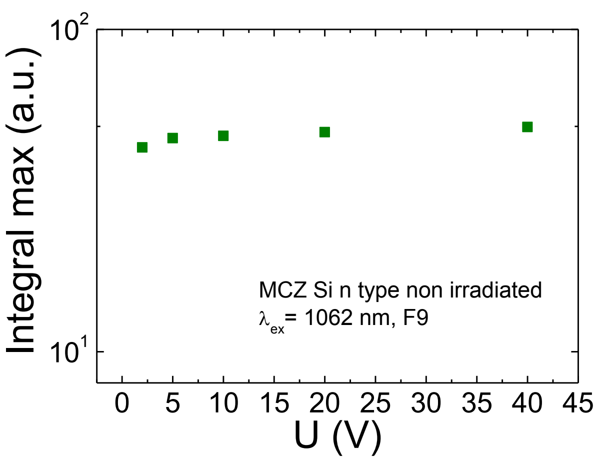






I_{ex}=5 pJ/pulse





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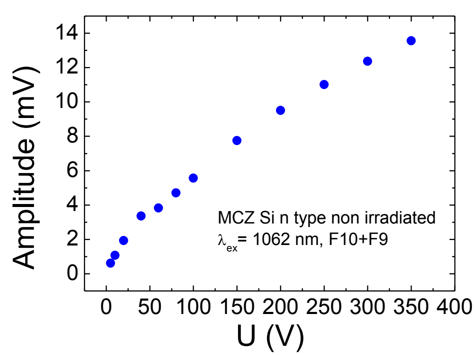
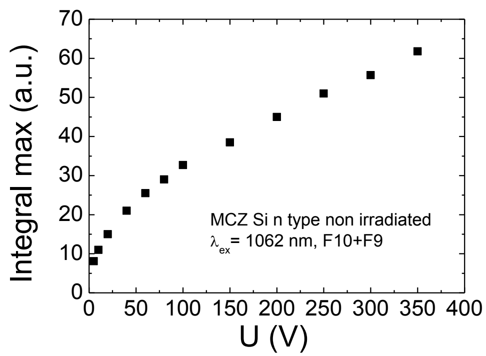
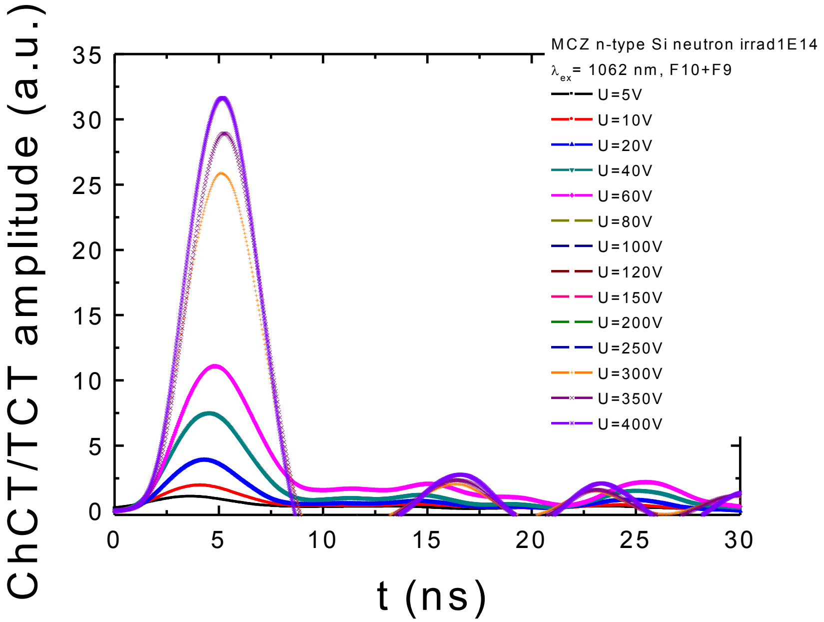




Integral nearly follows the amplitude of a drift signal, a difference due to hidden, long tail of the decay (non-recordable)

ChCT – TCT in the 10^{14} n/cm^2 irradiated MCZ Si diode, λ_{ex}=1062 nm, drift of both type carriers to the opposite electrodes, U_R

I_{ex}=5 pJ/pulse



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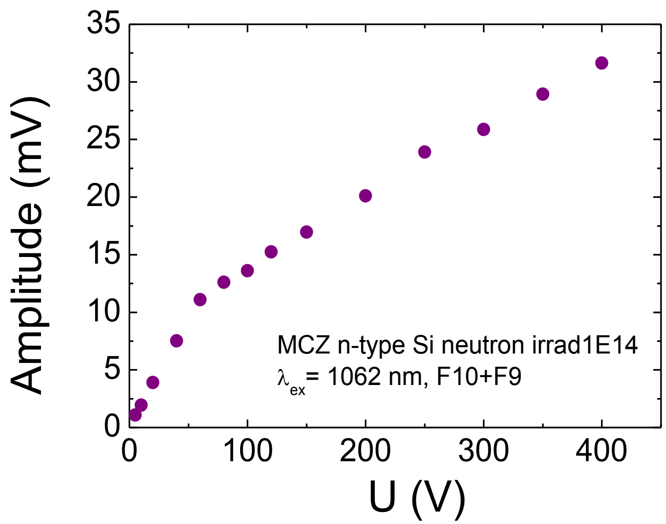
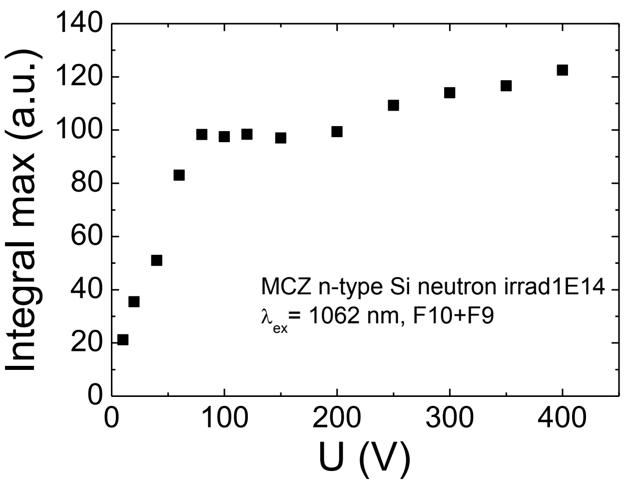


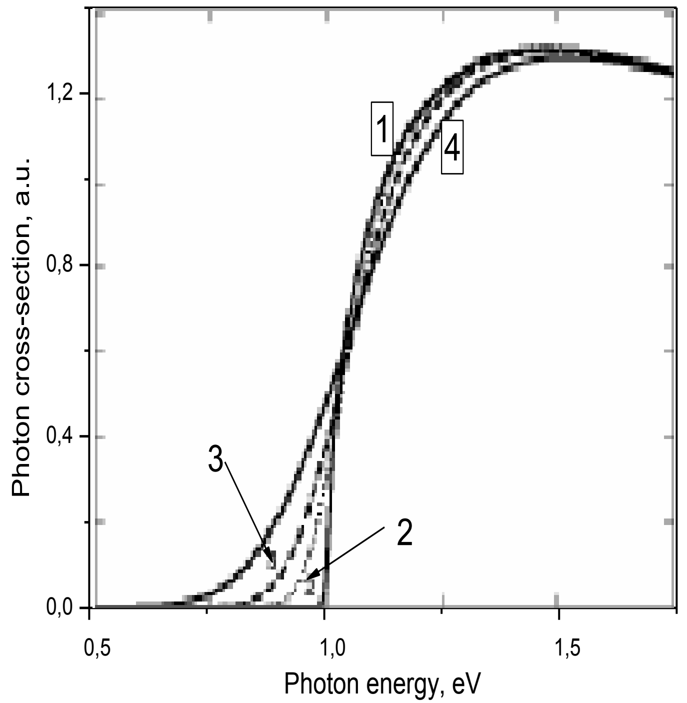


Extrinsic photoconductivity

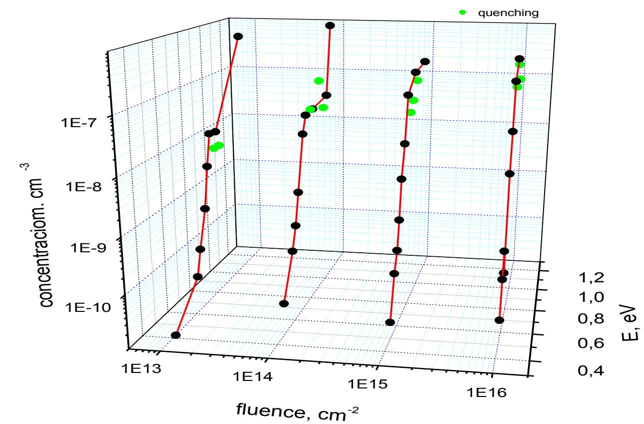
- Lukovsky model was used for the data analyze.

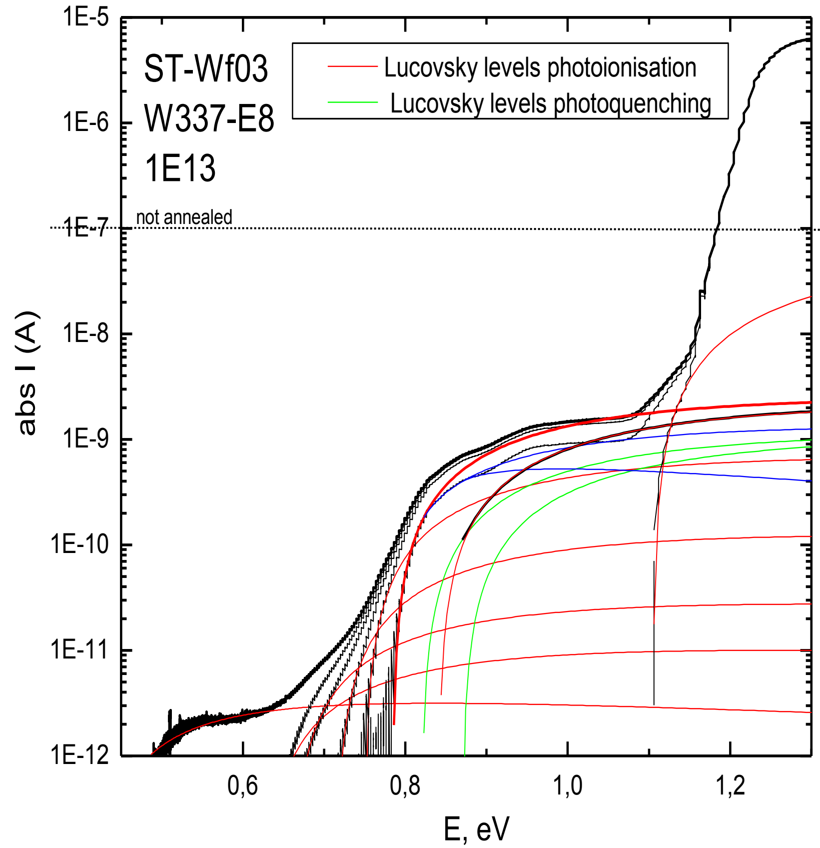
  $I \sim m \times \Delta E_M^{0,5}(h\nu - \Delta E_M)^{1,5}/(h\nu)^{\wedge 3})$

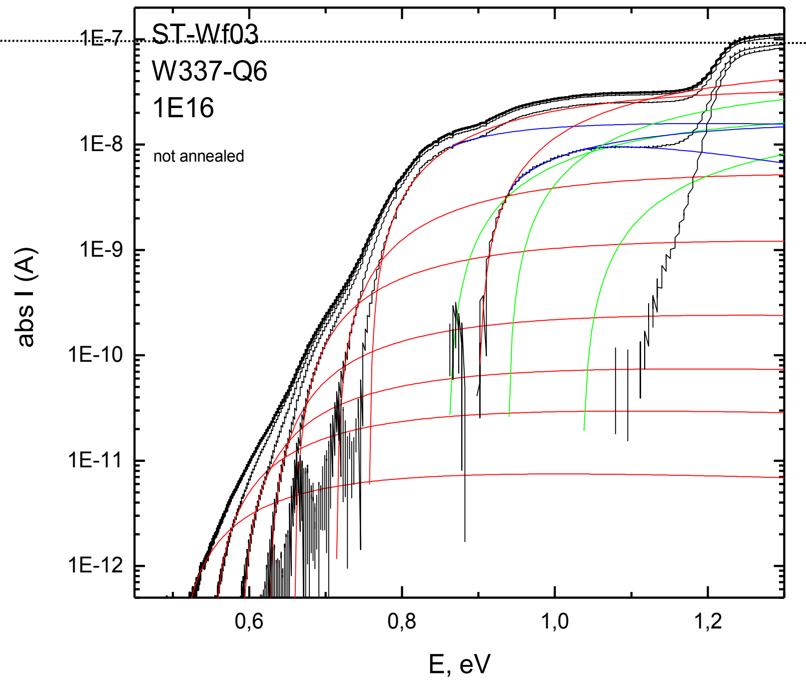
- This model (at low temperatures) does not valid:
  - for the hydrogen type defect and
  - for the inter-deep level state transitions
- Low temperature requires the attention on the filling of the traps and to avoid the influence of electron-phonon coupling



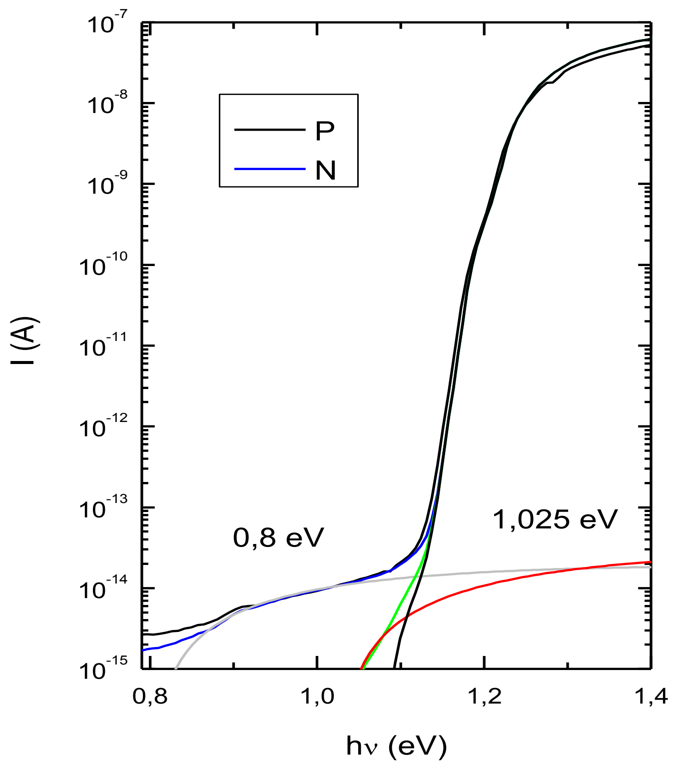
Irradiated Si (Wodean samples)

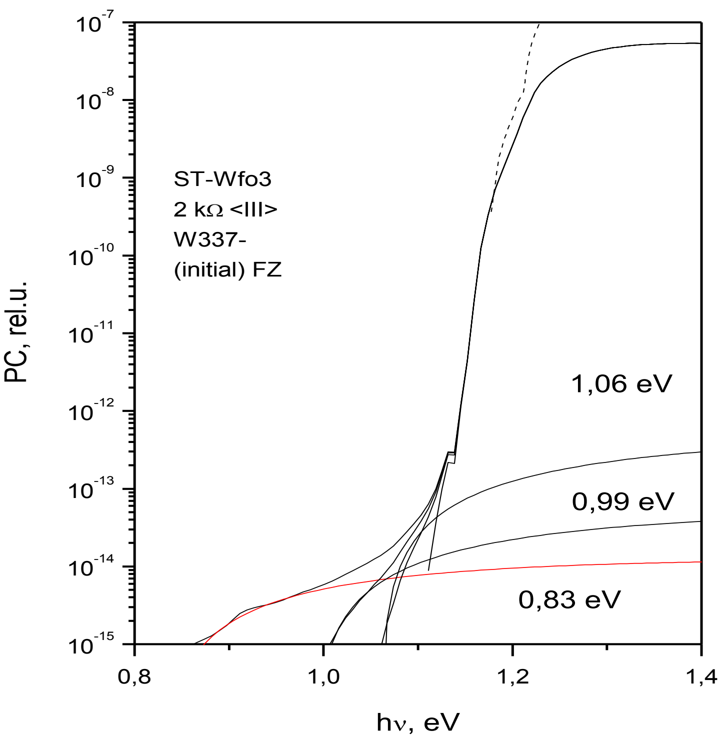






PC spectra in nonirradiated a new (Hamamtsu) and "old" (Wodean) samples





The deep levels in n- and p- base are lower the Fermi level, i.e., they are in the lower part of the bandgap

A summary:

The initial data of a new series of samples obtained.

The next step: a test of irradiated sample.

Some strange peculiarities observed.

Thank You for Your Attention!