Annealing of effective trapping times in irradiated silicon detectors

M. Batič, V. Cindro, G. Kramberger, I. Mandić, M. Mikuž, J. Pulko, M. Zavrtanik

Outline

- Introduction
- Samples and their time evolution
- CV measurements
- TCT measurements
- Results

Introduction

- CCE in Si-detectors is influenced by trapping of drifting carriers.
- Effective trapping times can be expressed as

$$\frac{1}{\tau_{eff,e,h}} = \Phi_{eq} \overbrace{\sum_t \left[g_t \left(1 - P_t^{e,h}\right) \sigma_{t,e,h}(T)\, v_{th,e,h}(T) \right]}^{\beta_{e,h}(T,t)}$$

equivalent fluence

introduction rate of defect type *t*

occupation probability

capture cross section

carrier thermal velocity

- β is independent of: resistivity, [O], [C], wafer production (float zone, Czochralski, epitaxial).
- Temperature dependence of β can be found in

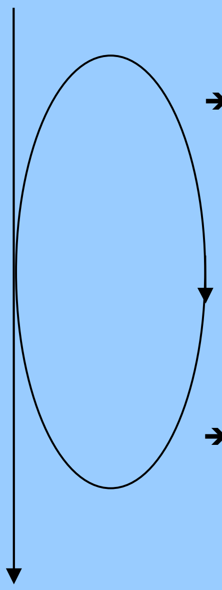
  G. Kramberger et al., Nucl. Instr. and Meth. A 481 (2002) 297.
- Systematic measurements of the dependence of $\beta_{e,h}$ on annealing time at different temperatures are presented in this talk.

Samples and their time evolution

Sample	Material	Φ_{eq} [cm^{-2}]
w339_a[01-06]	15kΩ, V_{fd}~15V, <111>, standard FZ	7.50E+013
w339_a[07-09]		1.50E+014

Samples were irradiated with reactor neutrons at Triga Research reactor in Ljubljana.

time line



- annealing (at 40°C, 60°C or 80°C)
- CV-IV measurements (at 24°C)
- TCT measurements (at 20°C)
- meantime samples kept in freezer at -17°C

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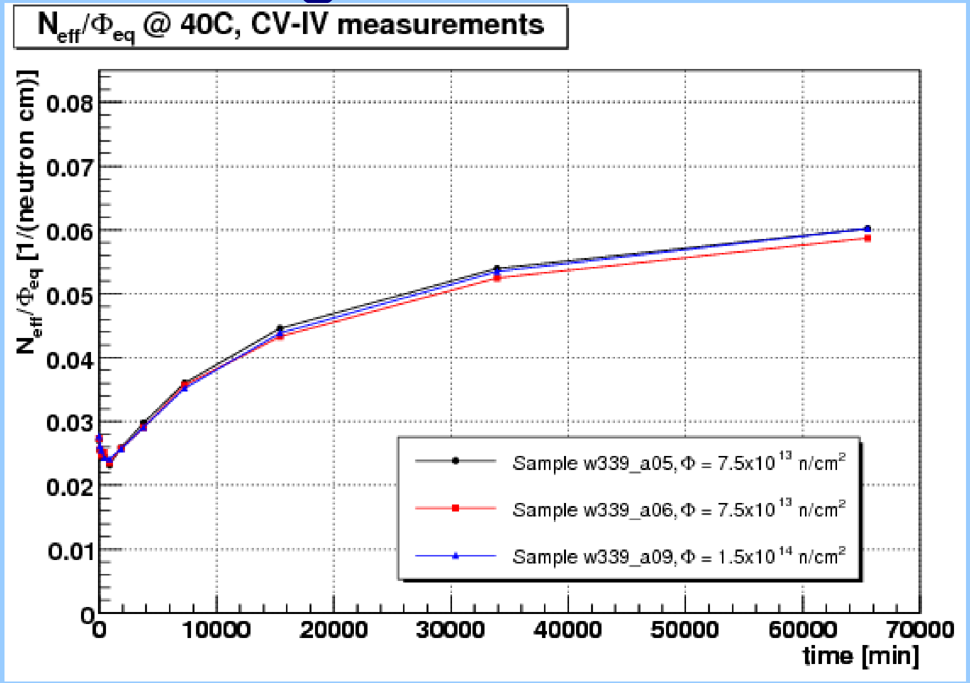
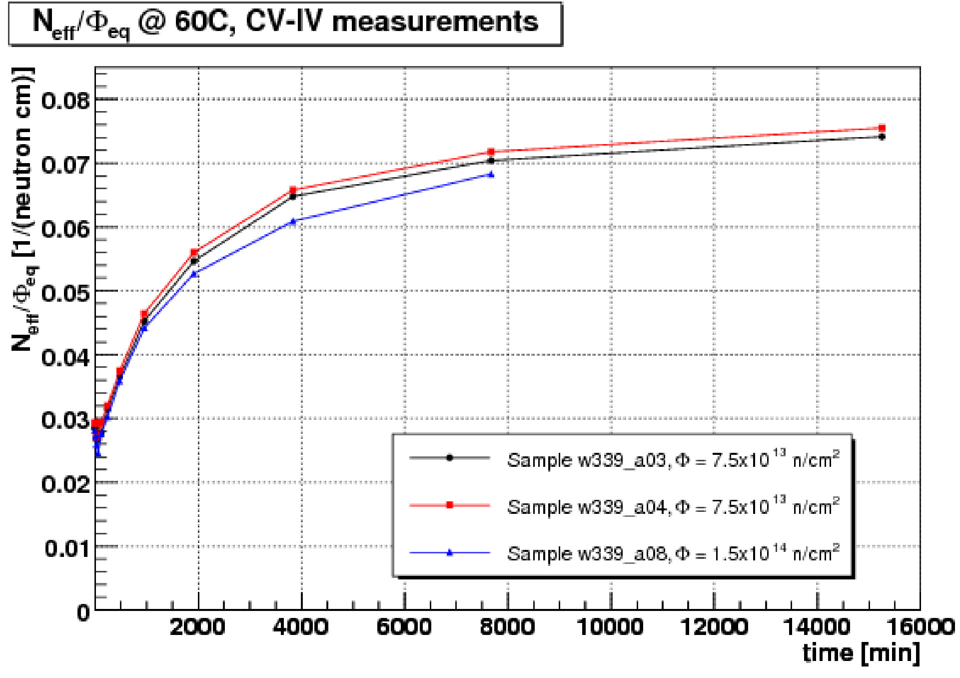
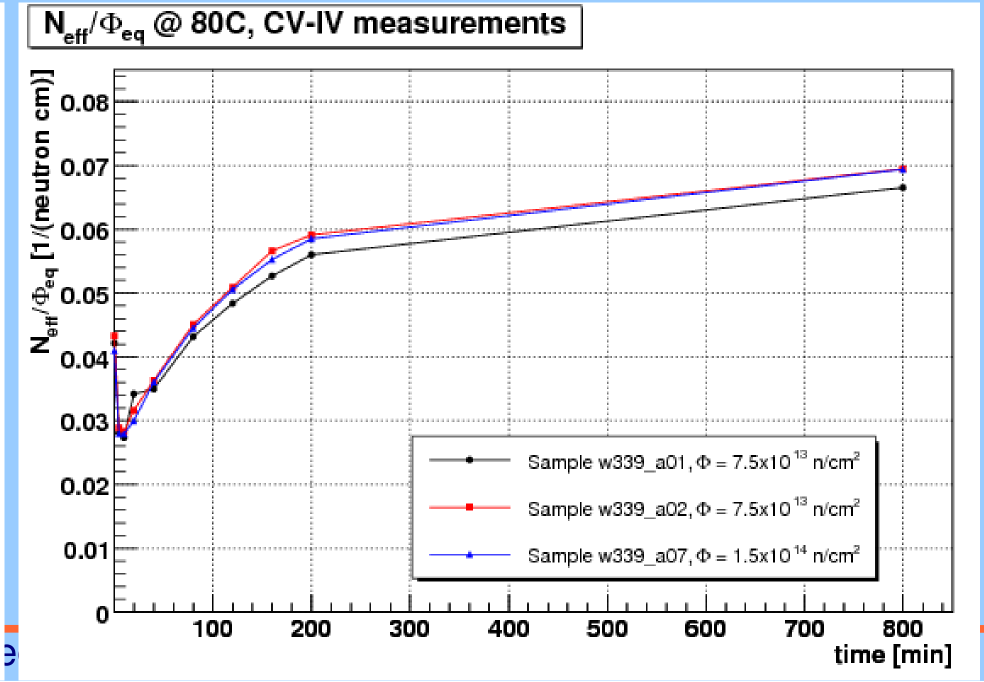
CV measurements: FDV vs annealing time



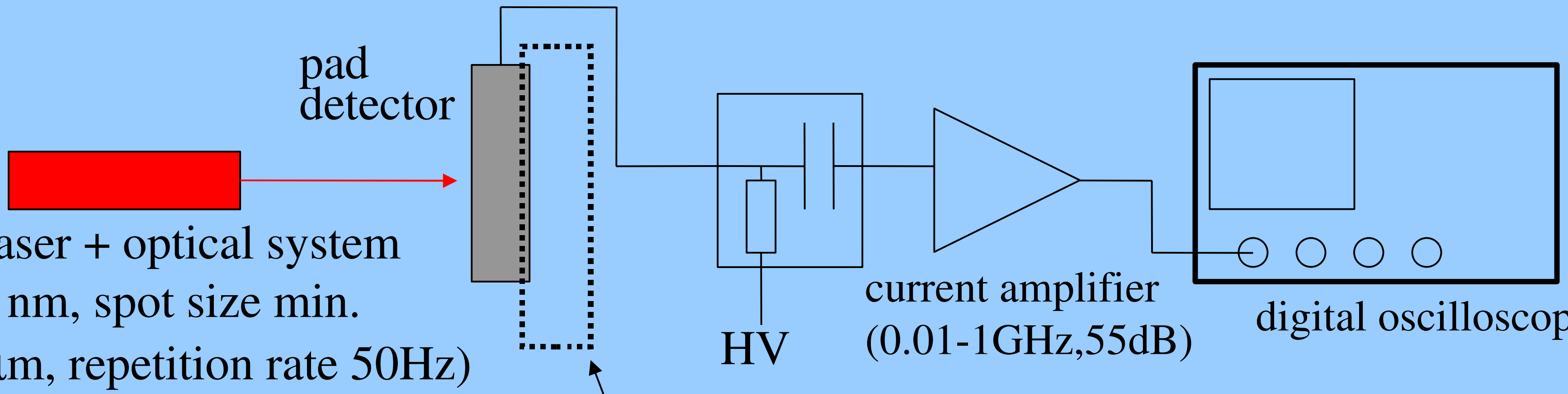
- Full depletion voltage determined with the position of kink in $1/C^2$ vs voltage curve.
- Effective dopant concentration calculated from

$$N_{eff}=2\frac{\epsilon_0\epsilon_{Si}}{e_0 D^2}V_{fd}$$





TCT setup



pad detector

red laser + optical system (670 nm, spot size min. 100μm, repetition rate 50Hz)

HV

current amplifier (0.01-1GHz,55dB)

digital oscilloscope

Peltier cooler

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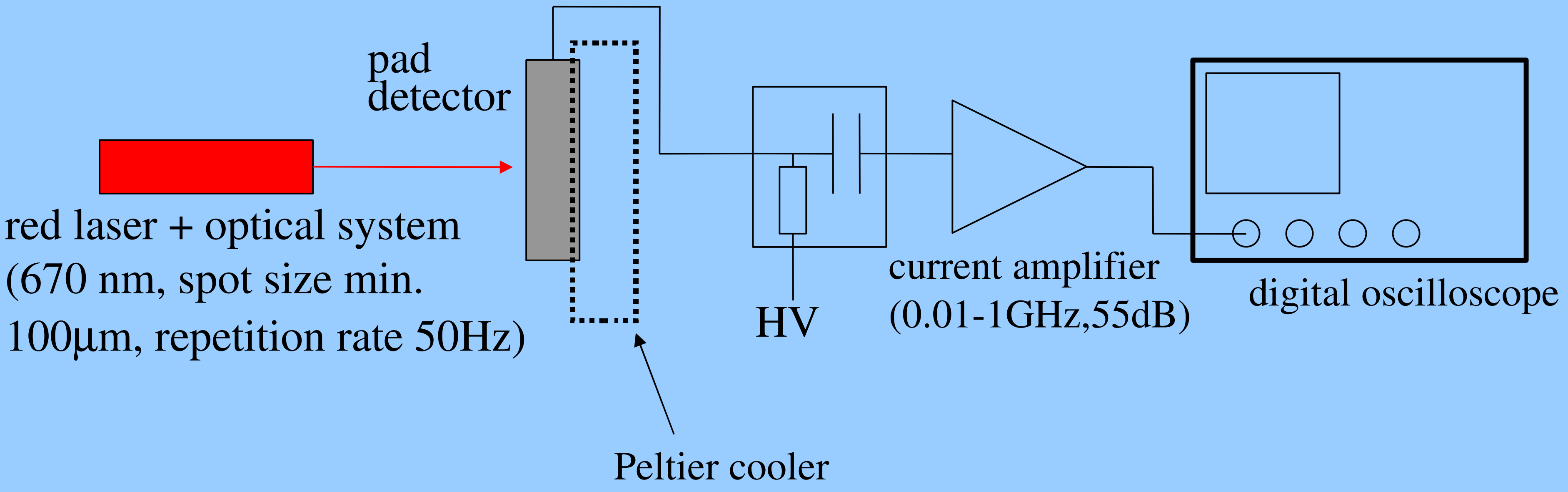
TCT setup



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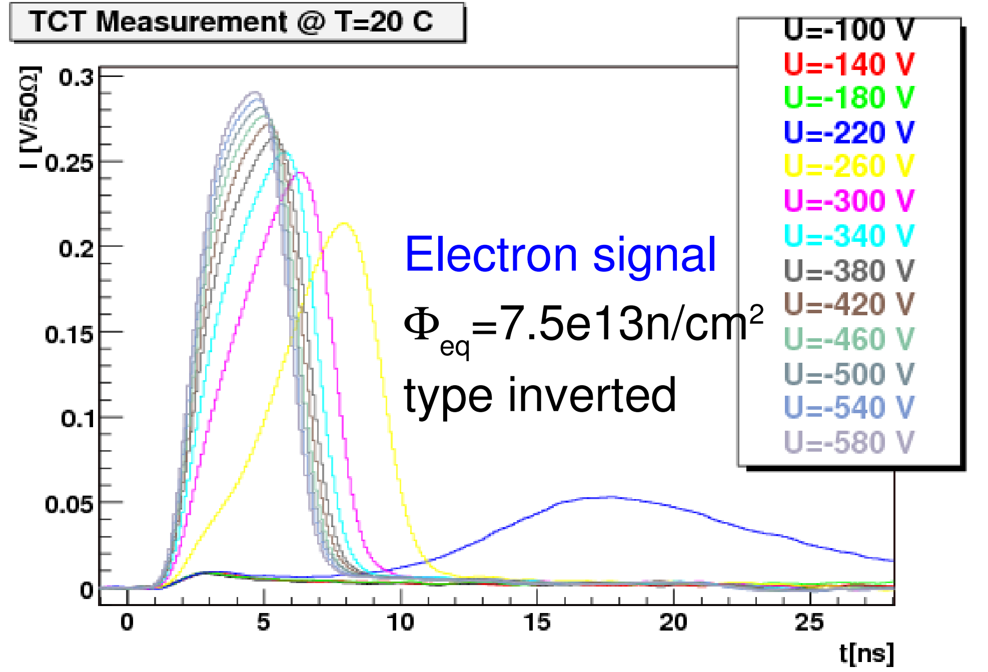
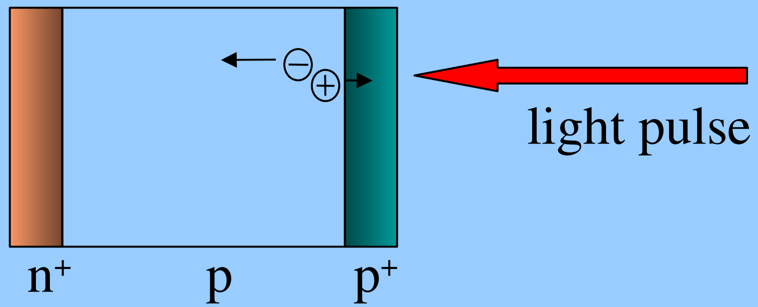


electron injection



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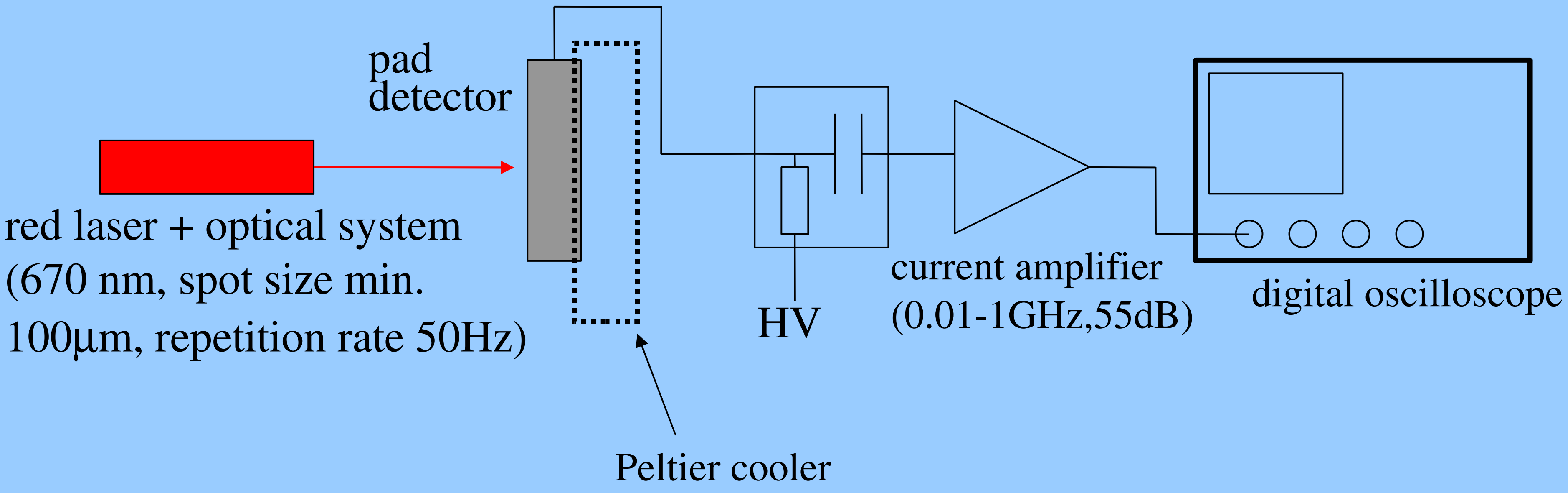
TCT setup



pad detector

red laser + optical system
(670 nm, spot size min.
100µm, repetition rate 50Hz)

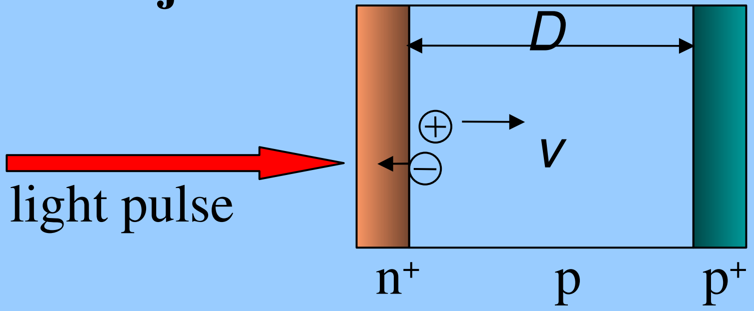
HV

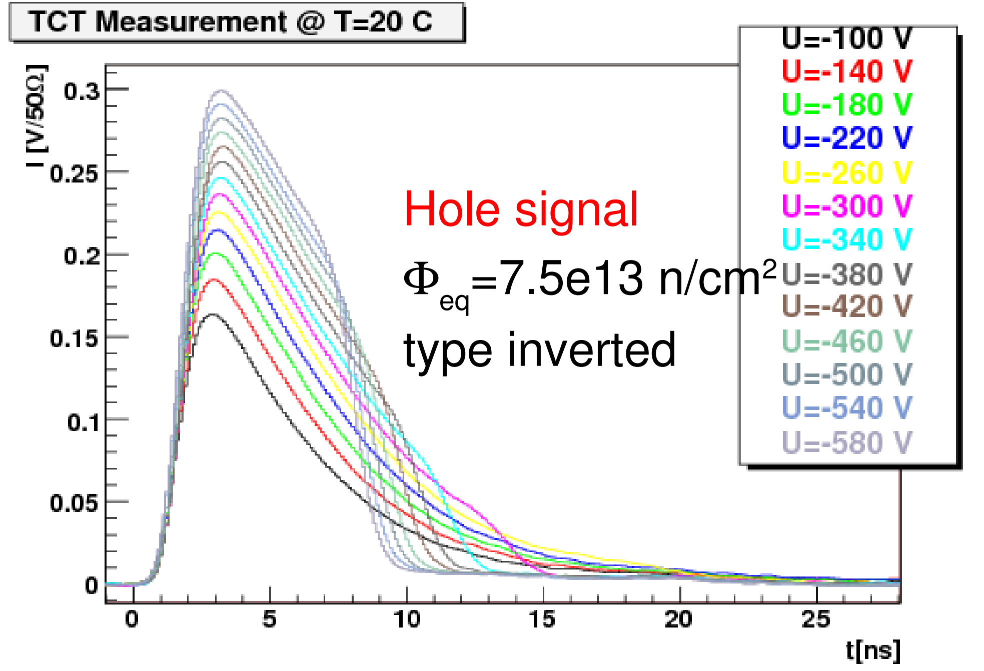
current amplifier
(0.01-1GHz,55dB)

digital oscilloscope

Peltier cooler

hole injection





Hole signal

Φ_{eq}=7.5e13 n/cm^2

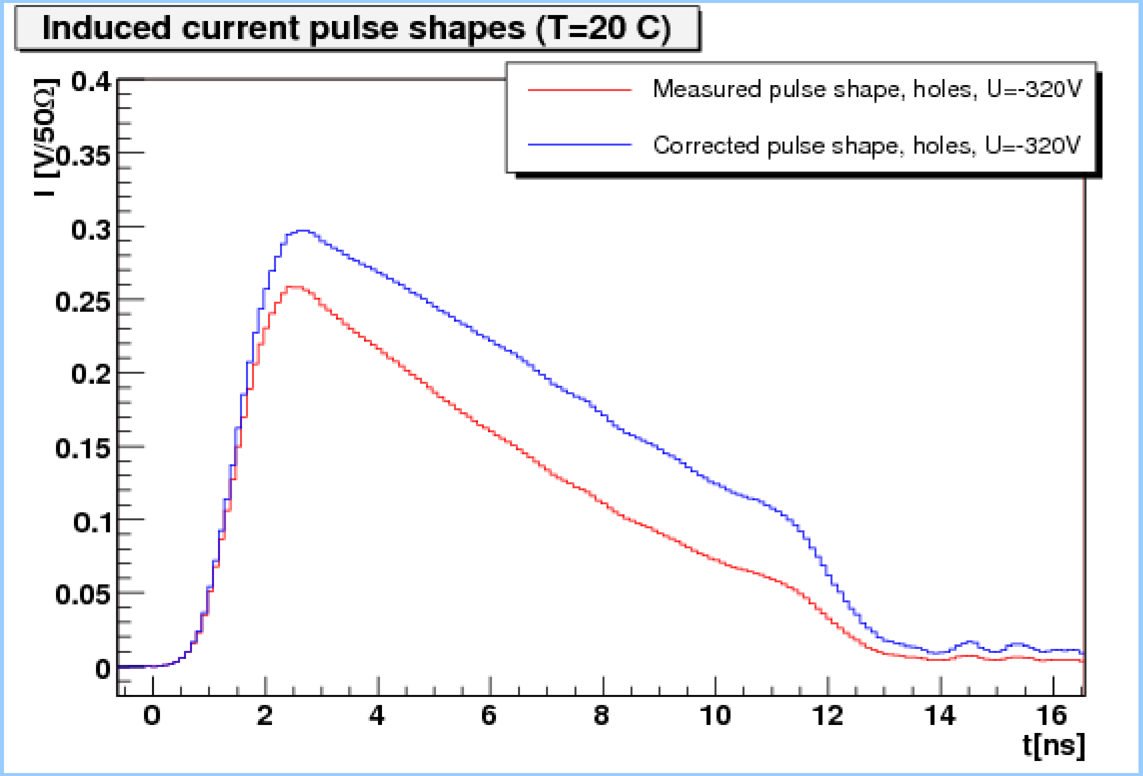
type inverted

Collected charge correction method

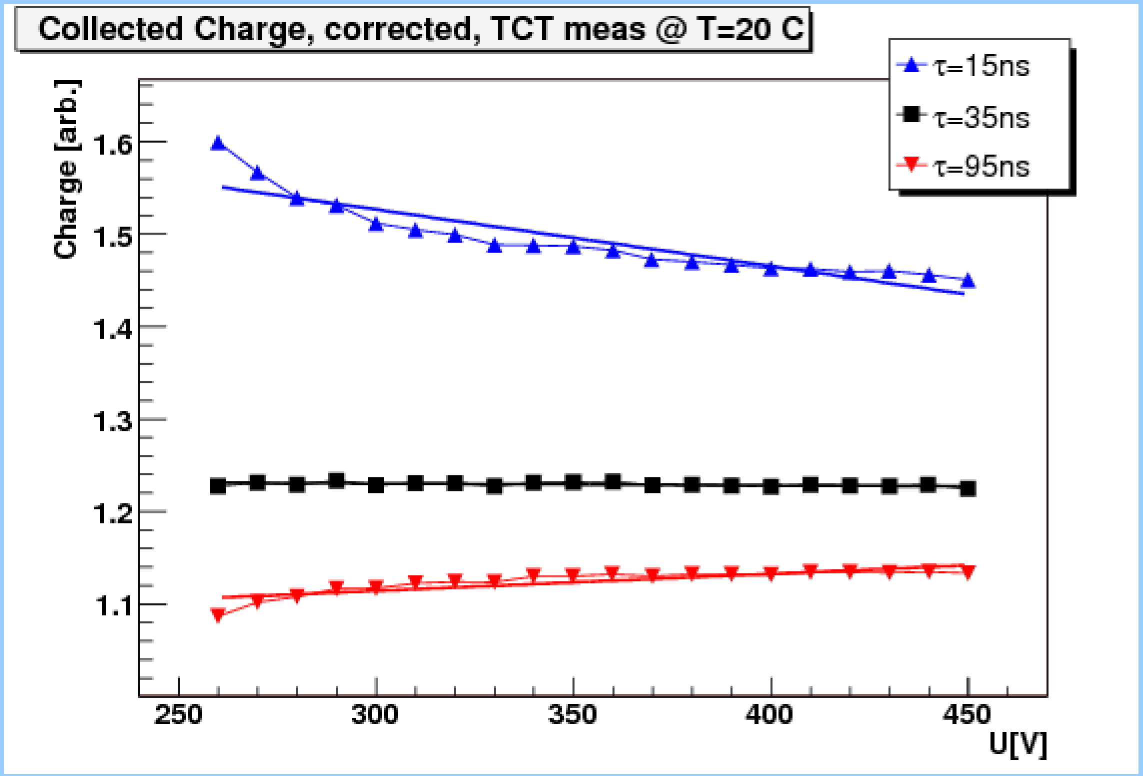
$$I_{e,h}^{meas}(t)=\left[e_0 N_{e,h}\frac{v_{e,h}(t)}{D}\right]\exp\left(-\frac{t}{\tau_{eff,e,h}}\right)$$

$$\Big\downarrow \text{correction}$$

$$I_{e,h}^{corr}(t)=I_{e,h}^{meas}(t)\exp\left(\frac{t-t_0}{\tau}\right)$$



Collected charge correction method



$$I^{meas}_{e,h}(t)=\left[e_0 N_{e,h}\frac{v_{e,h}(t)}{D}\right]\exp\left(-\frac{t}{\tau_{eff,e,h}}\right)$$

correction

$$I^{corr}_{e,h}(t)=I^{meas}_{e,h}(t)\exp\left(\frac{t-t_0}{\tau}\right)$$

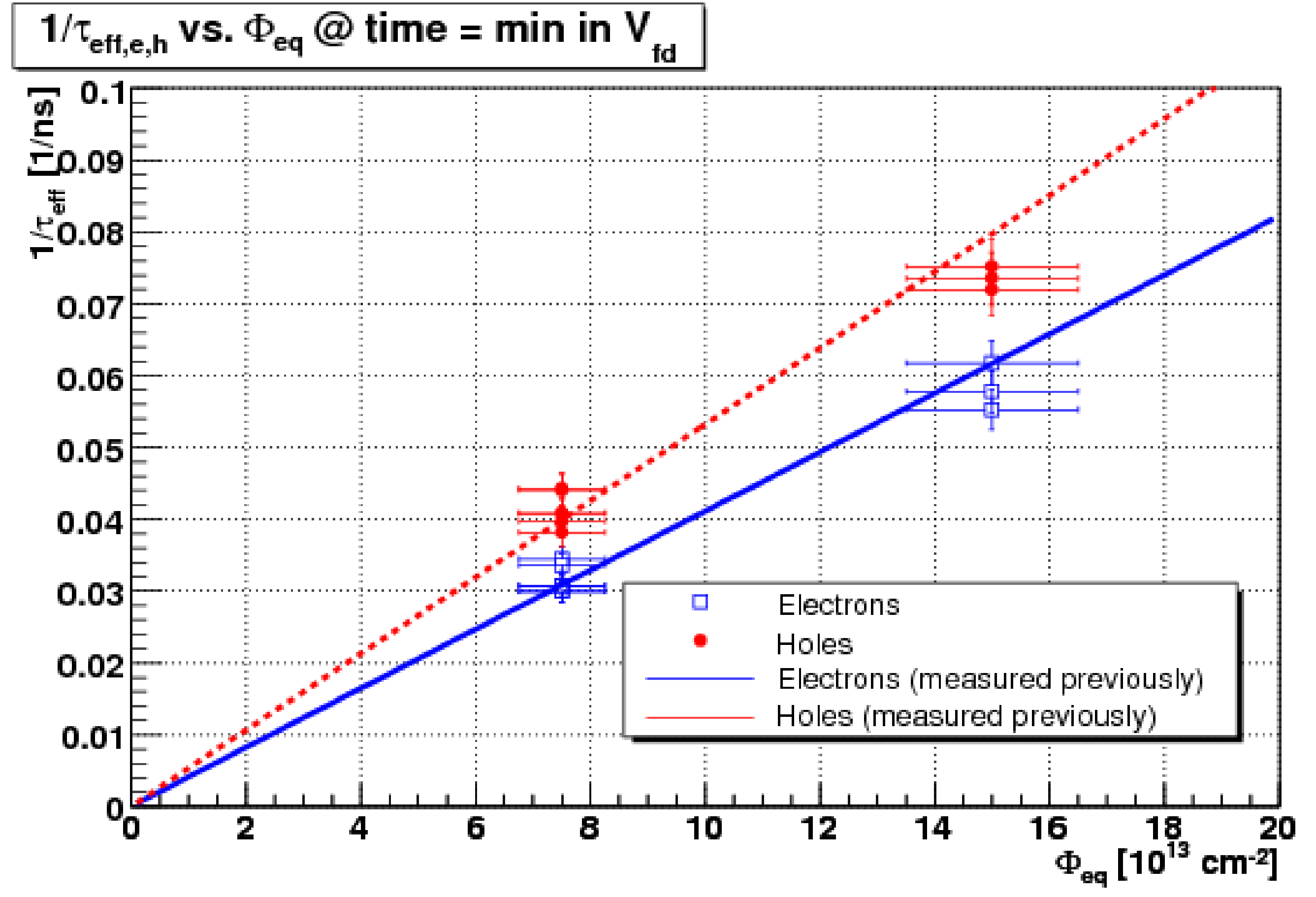
$$C=\int I\,dt$$

corrected charge is constant for voltages above V_{fd} when $\tau=\tau_{eff}$

Dependence of effective trapping time on fluence

The dependence of $1/\tau_{eff,e,h}$ on fluence agree with previously measurements:

$\beta_e = (4.2 \pm 0.4) \cdot 10^{-16}\ cm^2/ns$
$\beta_h = (5.3 \pm 0.4) \cdot 10^{-16}\ cm^2/ns$



Annealing of effective trapping times

Data can be fit with 1st order model:

[A](active) →[B](active/inactive)

$$\beta=\beta_0\exp\left(-\frac{t}{\tau_{ta}}\right)+\beta_\infty\left[1-\exp\left(-\frac{t}{\tau_{ta}}\right)\right]$$

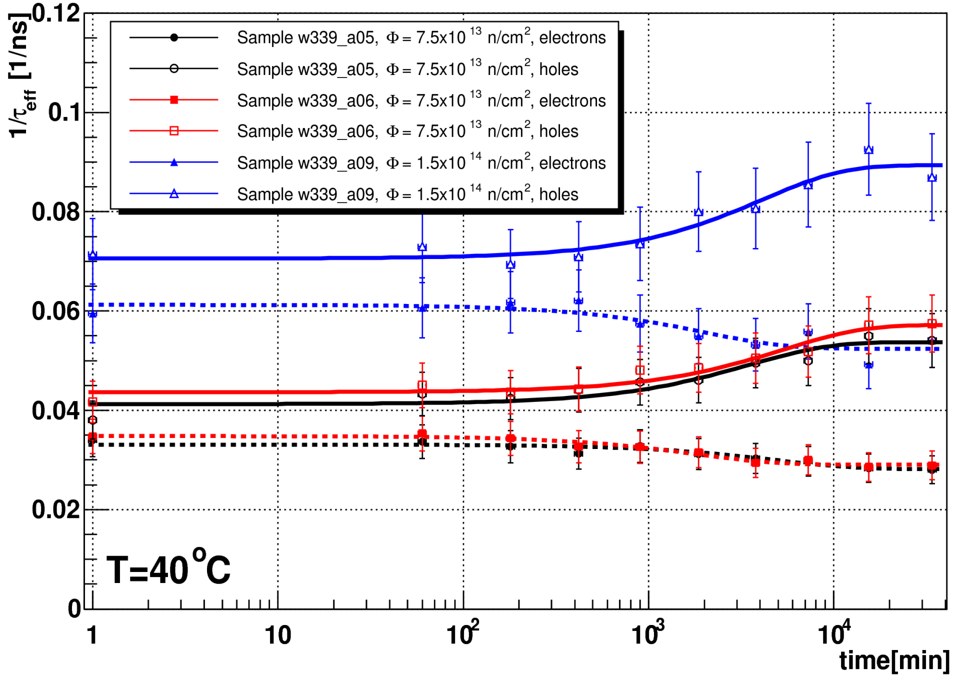
Φ_{eq}=7.5E13cm^{-2}

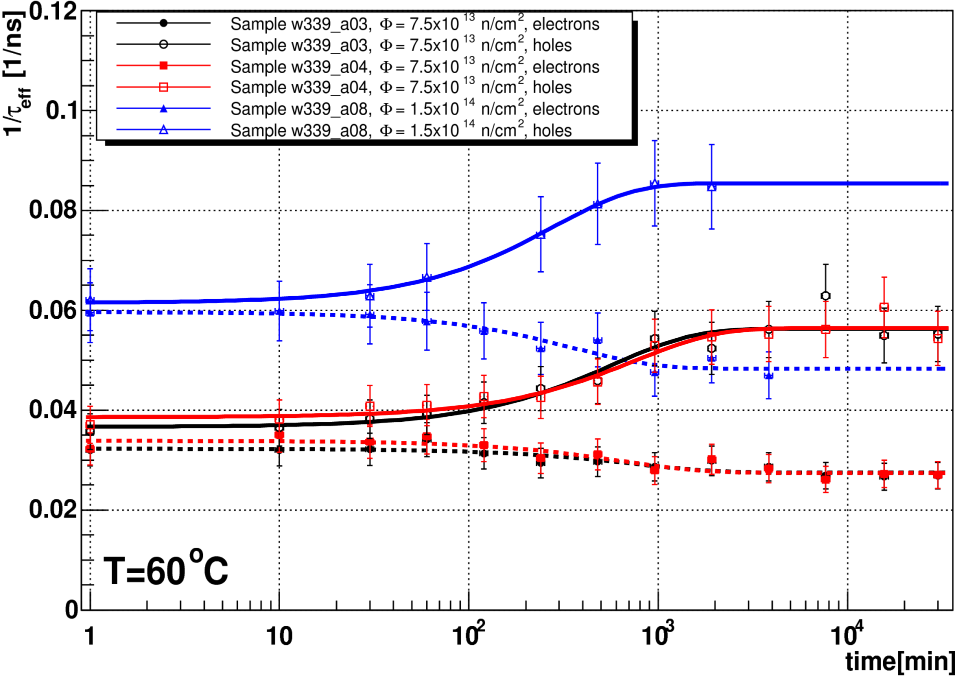
Φ_{eq}=7.5E13cm^{-2}

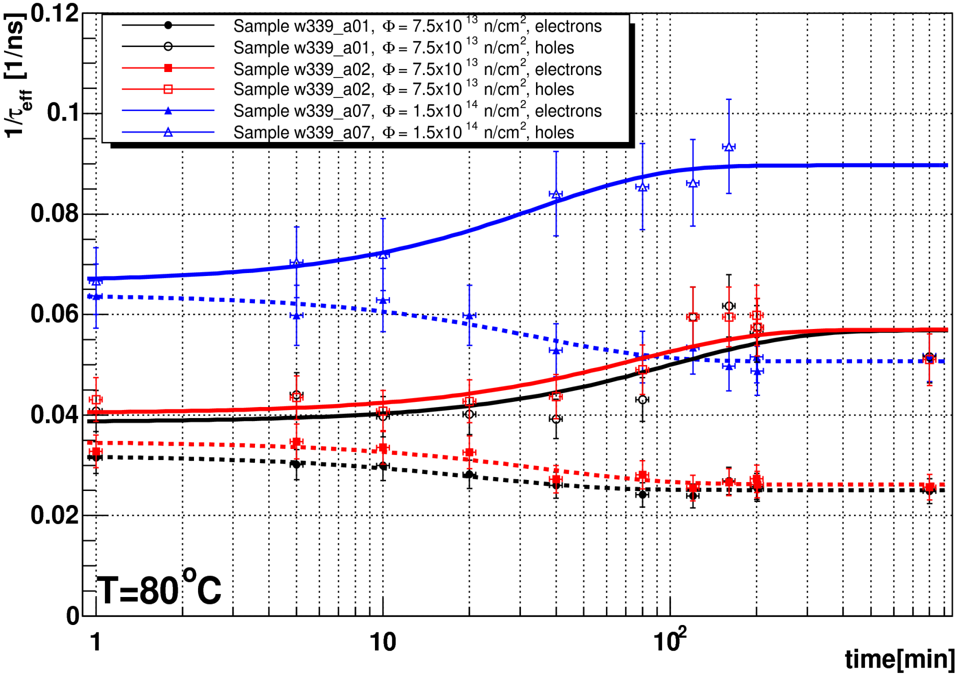
Φ_{eq}=1.5E14cm^{-2}

—— holes

– – – electrons







Annealing of effective trapping times

Electrons	40°C	60°C	80°C
$\frac{\beta_0-\beta_\infty}{\beta_0}$	0.20±0.03	0.23±0.05	0.20±0.03
τ_{ta}[min]	3347±1290	648±250	53±10

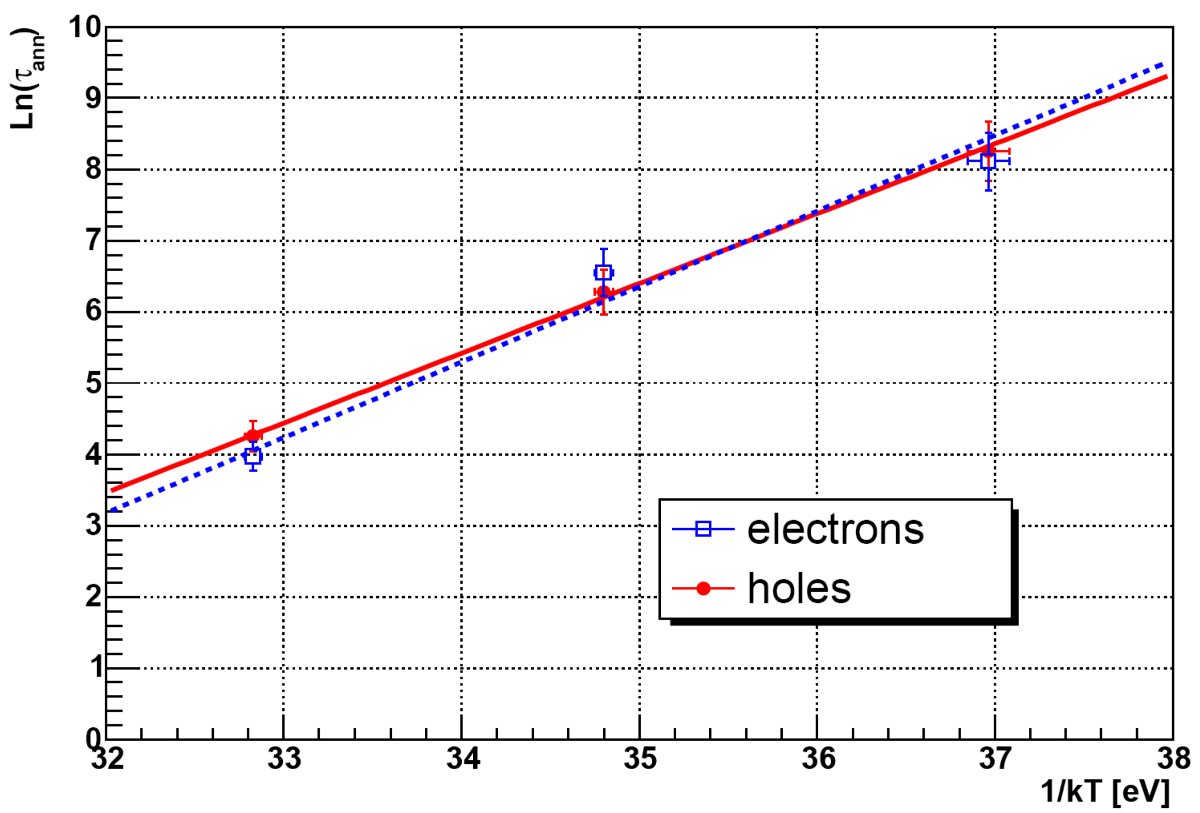
Holes	40°C	60°C	80°C
$\frac{\beta_0-\beta_\infty}{\beta_0}$	–0.29±0.04	–0.46±0.07	–0.40±0.06
τ_{ta}[min]	3852±720	534±240	70±35

Arrhenius relation

The scaling of annealing time constants can be obtained from Arrhenius relation assuming:

$$\tau_{ann}=\tau_0 \exp\left(\frac{E_{ta}}{k_B T}\right)$$

	τ_0 [min]	E_{ta} [eV]
electrons	$3.88 \cdot 10^{-14}$	1.06±0.1
holes	$8.44 \cdot 10^{-13}$	0.98±0.1



Conclusion

- Charge Correction Method was used to determine the evolution of trapping times after annealing steps at elevated temperatures of 40^{o}C,60^{o}C and 80^{o}C.
- Effective trapping probability of electrons decreases and of holes increases with annealing time. The change in $\beta_{e,h}$ is approx. -20% for β_e and +40% for β_h .
- The time constants and the change of β don't depend on fluence, indicating 1st order process.
- Scaling of annealing time constants to other temperatures is governed by activation energies of $E_{ta,e}$=1.06+0.1 eV and $E_{ta,h}$=0.98+0.1 eV.
- For HEP experiments annealing behaviour of trapping times strengthens the argument to use detectors where mostly electrons contribute to the signal.