Effect of bias voltage on full depletion voltage measured for different materials

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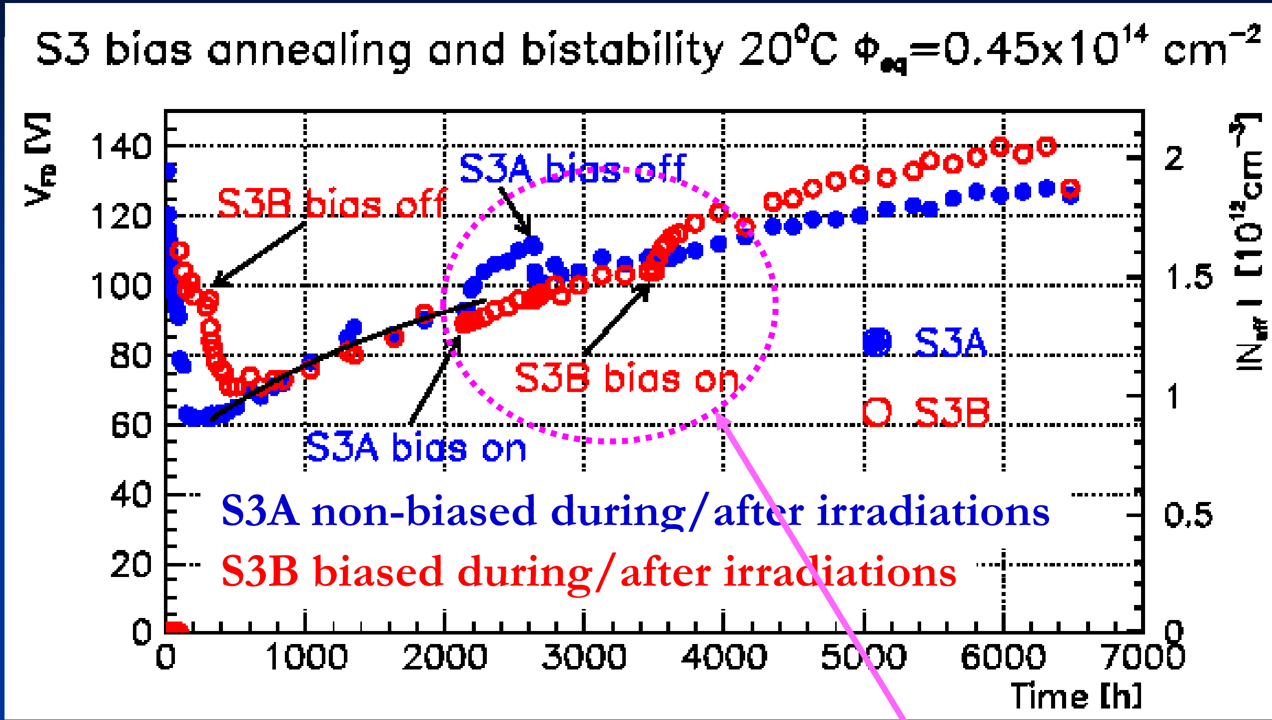
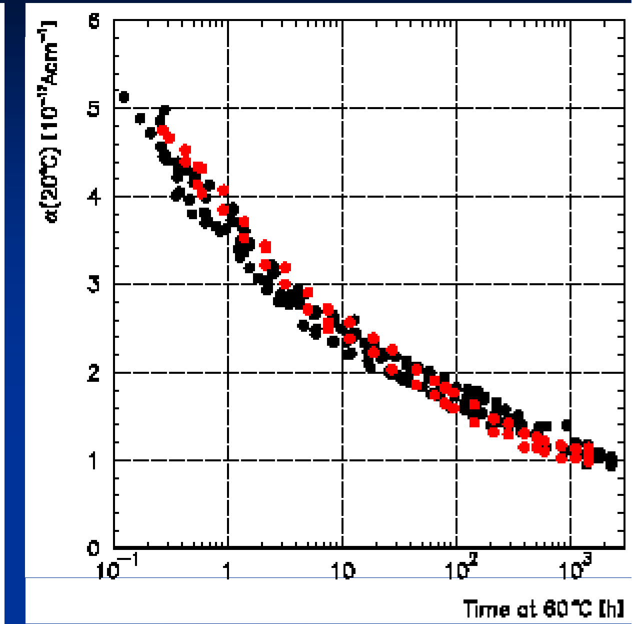
Reminder (I)





No effect on reverse current!

- Bias dependent damage
  - g_c bias ~ 2 · g_c unbiased
  - g_y bias ~ g_y unbiased
  - τ_{ra} bias ~ 2 · τ_{ra} unbiased

- Bistability

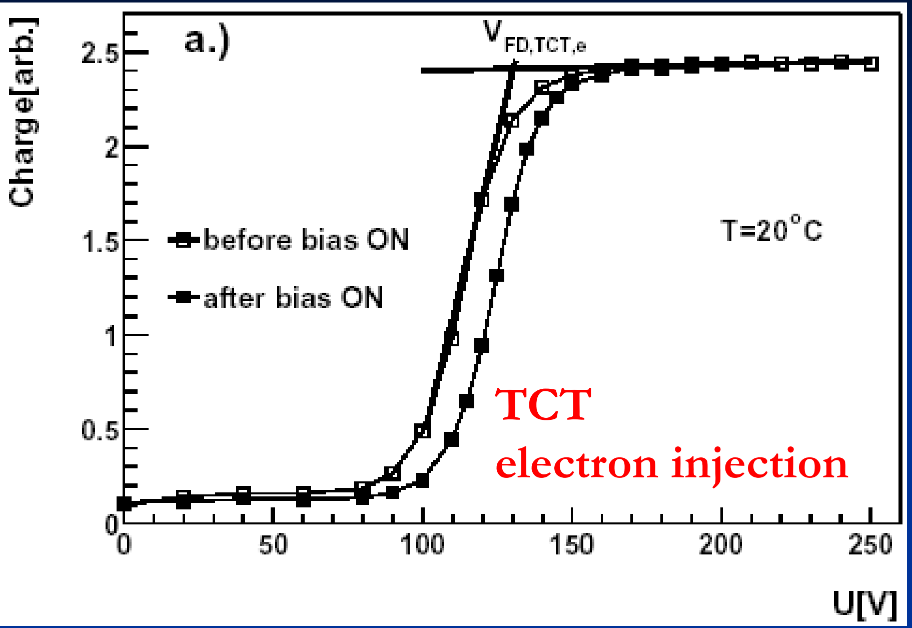
g_a ~ 0.4·10^{-2} cm^{-2}

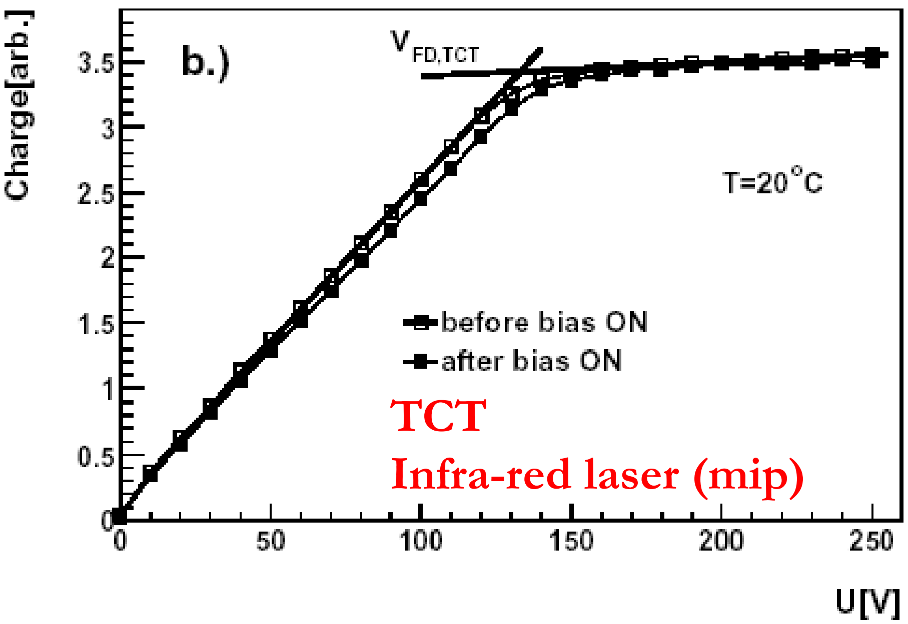
τ_a ~ 1 day @ room temperature, ~100 d at -7°C

τ_{da} ~ 1 day @ room temperature

First observation: V. Cindro et al, NIM A419 (1998) 132.
Detailed studies: V. Cindro et al, NIM A450 (2000) 288.

Reminder (II)





ITE - 5 kΩcm (STFZ-n material)

Irradiated to $\Phi_{eq}=5\cdot10^{13}$ n cm^{-2} and annealed to around ~30% of the reverse annealing amplitude

- A clear increase of V_{fd} is observed after 70 h of bias - **same results obtained by TCT or CV**!
- The effect is visible in the electric field (show at the last RD50 workshop and in charge collection)
- The samples irradiated to low fluences with neutrons (almost N_{eff}=const.) one can distinguish two parts with different N_{eff} in the detector.

Motivation

- Is the effect of applied bias on V_{fd} present also for new materials (MCz, Cz, epi-Si)?
- Are the data comparable with the old data for Fz detectors (time constants, amplitudes)?
- Do only acceptors get activated?
- What is the impact of the effect on detector performance?

And at last but not least to win the bet with Hartmut and get a beer …

Samples

Sample name	Material, thickness	Φ_{eq} [10^{14} cm^{-2}]	History
W339	STFZ, n-bulk, 300 μm, 15 kΩcm	1 n	~ 2000 h at RT
P503n7	STFZ, n-bulk, 300 μm, 2 kΩcm	1 n	~ 1000 h at RT
Cz36	MCz, n-bulk, 300 μm, 1 kΩcm	0.62, 3.1 p	~ 1000 h at RT
5337_3	Cz-Sumitomo, n-bulk, 300 μm,	0.75 p	~ 500 h at RT
6378_07	Epi, n-bulk,50 Ωcm, 75 μm	13 p, 10 n	~ 20000 h at RT
5856_01	Epi, n-bulk,50 Ωcm, 50 μm	10,20 n	~ 20000 h at RT

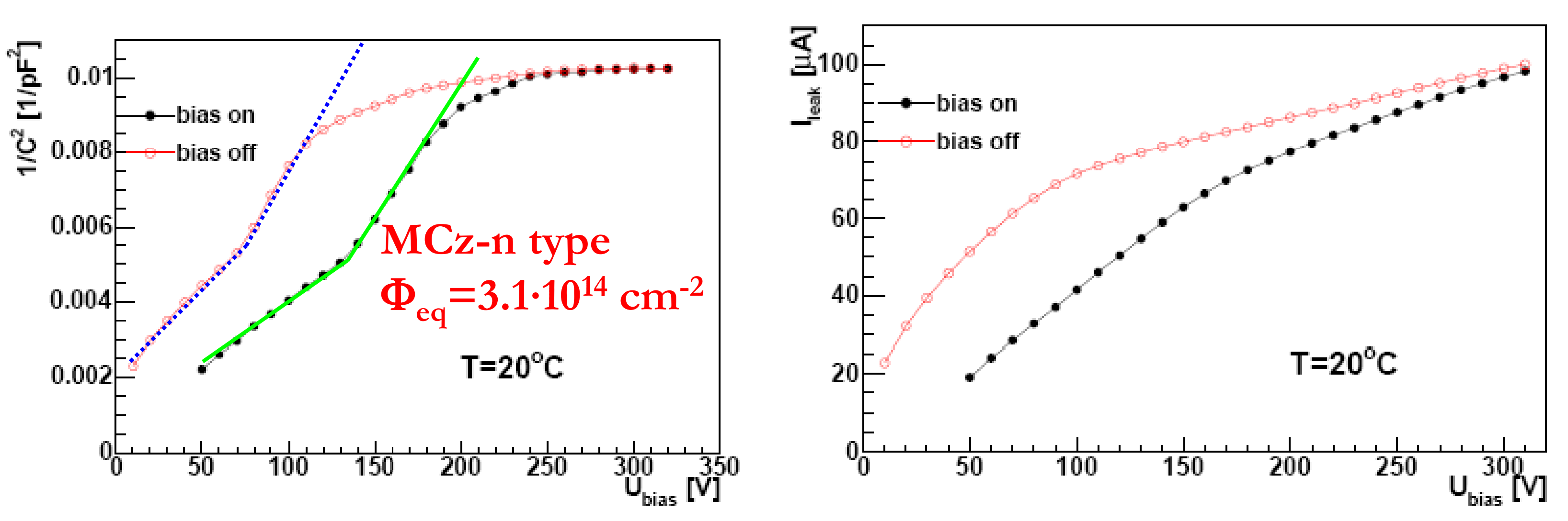
[C]=1.8e16 cm^{-3} (SIMS) → P503n7

High [O] → Cz36, 5337_3

High [O_{2i}] → 6378_07, 5856_01

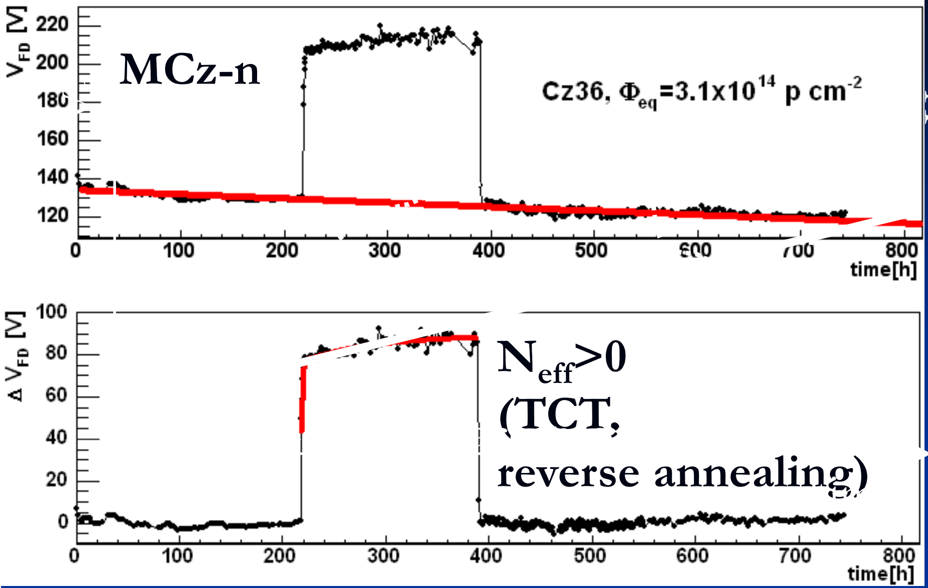
- Large number of different samples:
  - high [O], high [C], Cz, FZ, Epi-Si
  - different resistivity
  - different thicknesses
  - 24 GeV proton and rector neutron irradiated to fluences up to 2 ·10^{15} cm^{-2}
- Different annealing history – could influence the results?
- The samples were mounted in small Al boxes and connected to switching matrix. The whole setup was controlled by PC. The samples were put in temperature controlled environment!

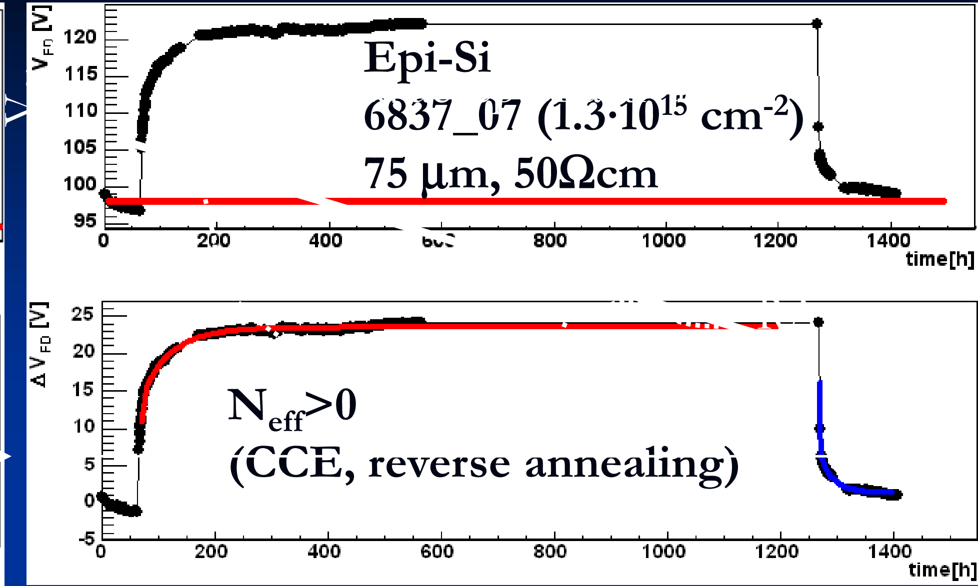
CV and IV of MCz samples



- The difference in V_{fd} can be seen from the C-V after 200 h with bias on !
  - From the $d(1/C^2)/dU_{bias}$ one can speculate about N_{eff}
  - The effect is well pronounced as the $g_c \sim g_b$
- $I_{meas}=I_{leak}+I_{guard}$: only the sum was measured, which is the reason of imperfect I-V plots: $I_{bias}<I_{unbias}$.
- However, I_{meas} at V_{fd} can be larger for I_{bias} due to higher V_{fd}.

24 GeV proton irradiated samples at T=20°C





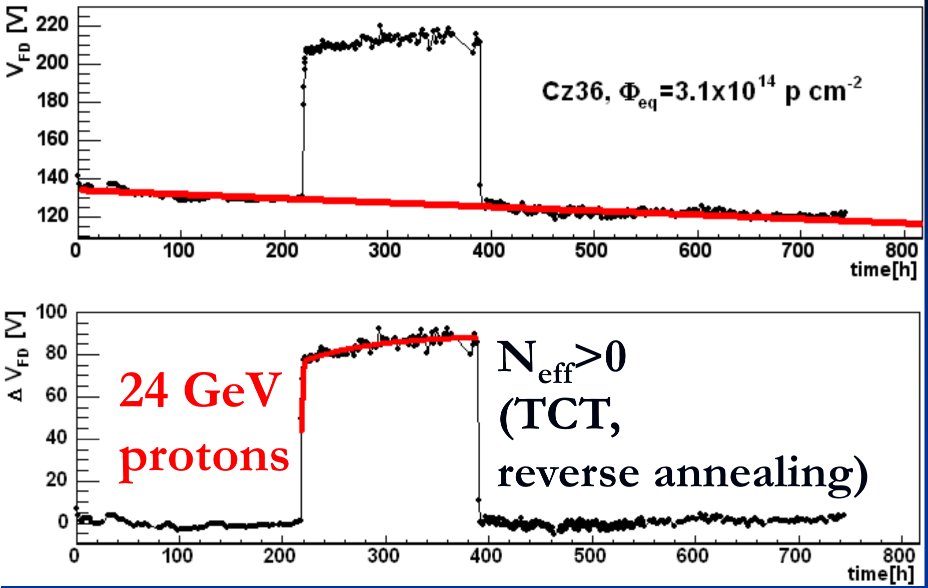
Previous hypothesis:

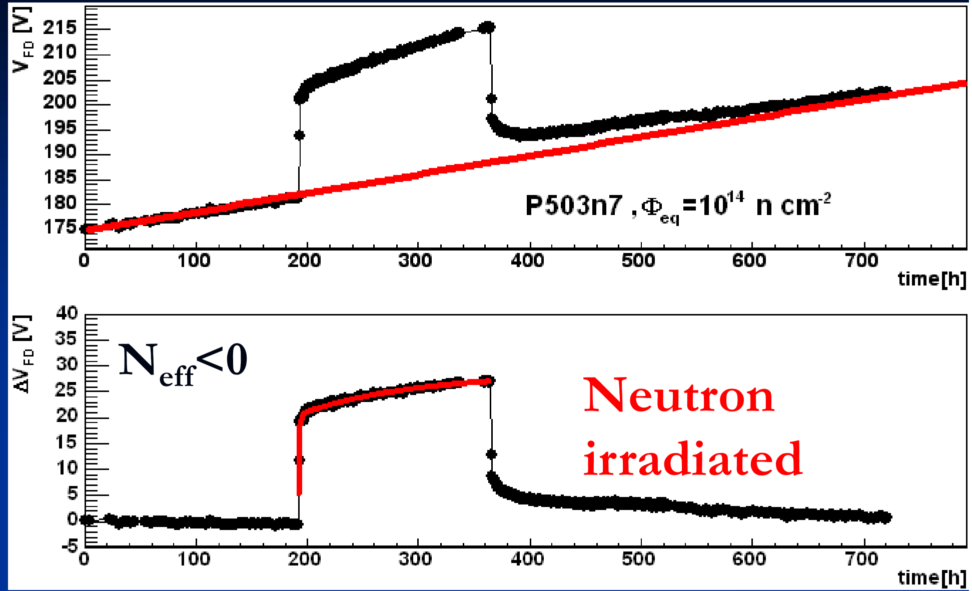
acceptors get activated with bias -> in n-type bulk the V_{fd} should decrease after the bias is applied! Stable donors would be partially compensated by activated acceptors!

New hypothesis:

Somehow, the additional contribution ($\Delta|N_{eff}|$) to the space charge due to the applied bias adjusts to the sign of the space charge !

MCz and C-rich FZ samples at T=20°C





Activation:

$$\frac{\Delta|N_{eff}|}{\Phi_{eq}} = g_1(1-\exp(-\frac{t}{\tau_s})) + g_2(1-\exp(-\frac{t}{\tau_l}))$$

$$g_b = g_1 + g_2$$

$\tau_s \sim 1$ h ; $\tau_l \sim 100$ h

$g_1/g_b \sim 0.8$; $g_2/g_b \sim 0.2$

(old data $g_1 \sim g_2 \sim 0.5\ g_b$)

$g_b = g_1 + g_2 \sim 0.004$ cm^{-1}

Deactivation:

$$\frac{\Delta|N_{eff}|}{\Phi_{eq}} = g_1' \exp(-\frac{t}{\tau_s'}) + g_2' \exp(-\frac{t}{\tau_l'})$$

$$g_b = g_1' + g_2'$$

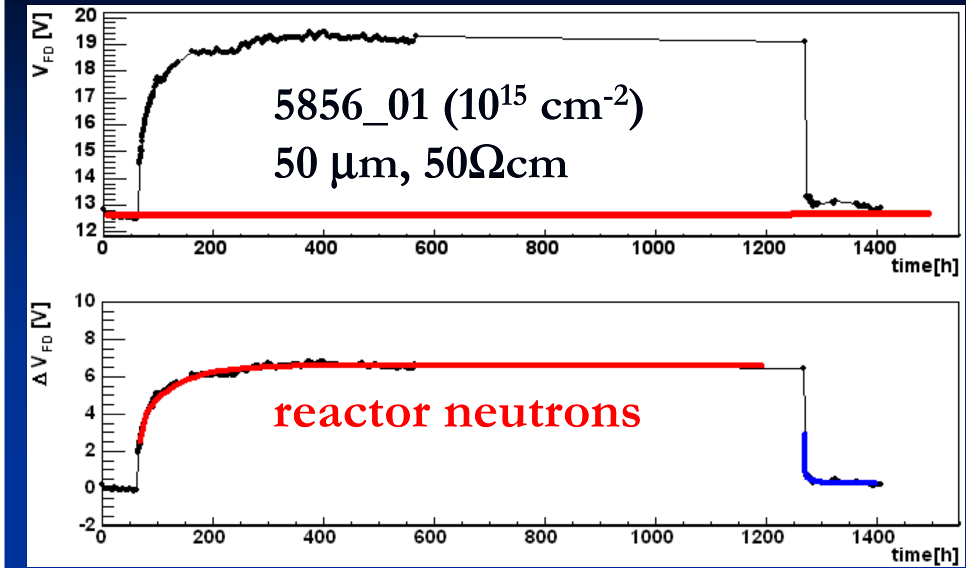
$\tau_s \sim 1$ h ; $\tau_l \sim$?

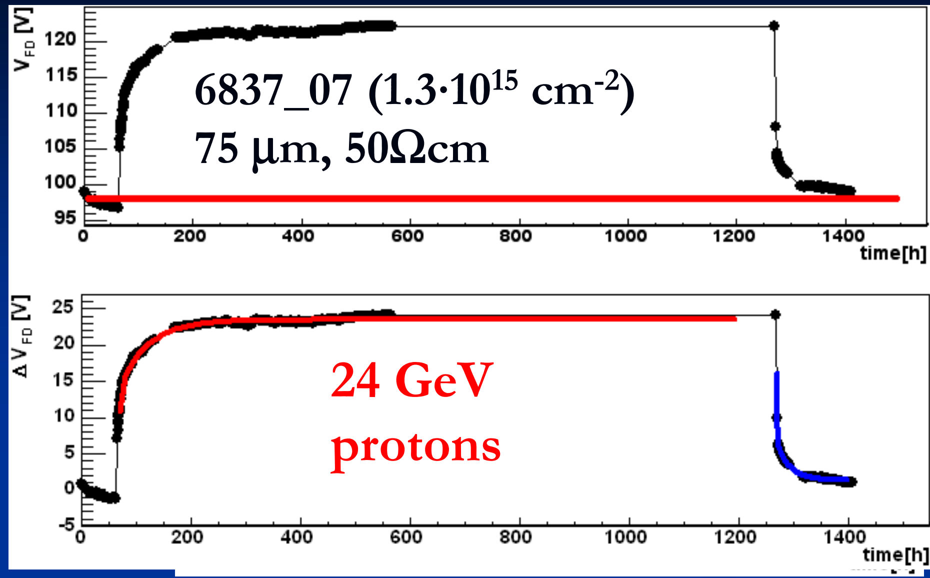
$g_1/g_b \sim$? ; $g_2/g_b \sim$?

$g_b = g_1 + g_2 \sim 0.004$ cm^{-1}

The effect is present for proton and neutron irradiated samples with the same magnitude !

Epitaxial samples at T=20°C



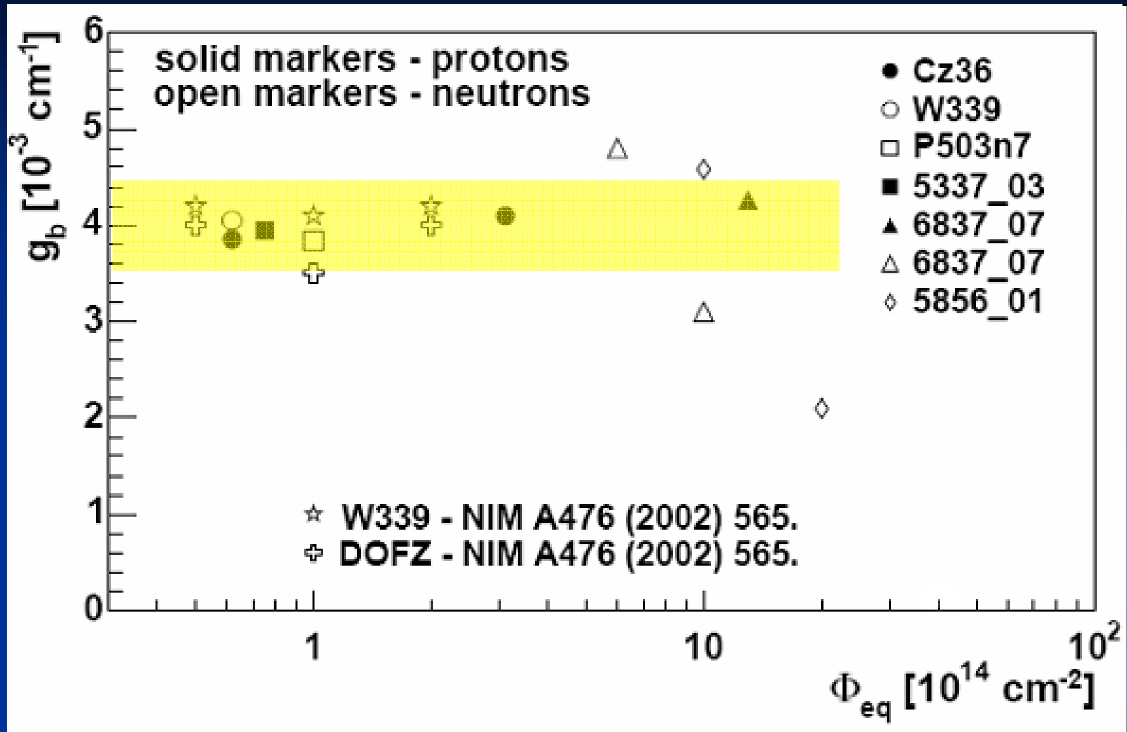


$\tau_s \sim 3.7$ h $\pm$ 1.7 h ; $\tau_l \sim 55 \pm 10$ h
$g_1/g_b \sim 0.5 \pm 0.15$;
$g_b = g_1 + g_2 \sim 0.004$ cm^{-1}

$\tau_s \sim 1$ h ; $\tau_l \sim$?
$g_1/g_b \sim$? ; $g_2/g_b \sim$?
$g_b = g_1 + g_2 \sim 0.004$ cm^{-1}

The activation of the epi-Si samples in agreement with old measurements!
Again no difference between proton and neutron irradiated samples!

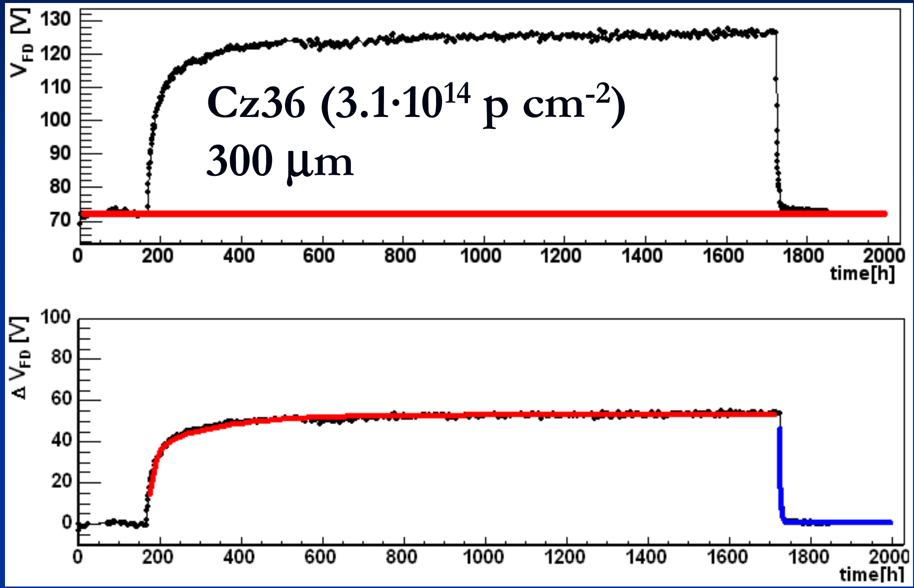
Introduction rate

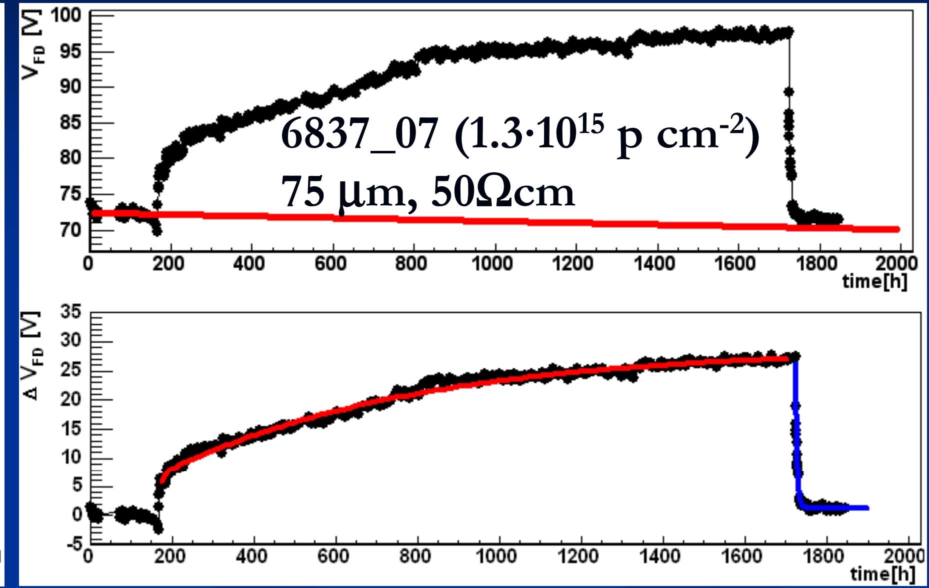


- g_b=0.004 cm^{-1} for all investigated materials except at the highest fluence
- the values agree with previously measured!
- the sign of the g_b is always such that the V_{fd} increases!

What about the operation temperature T=-8^{o}C

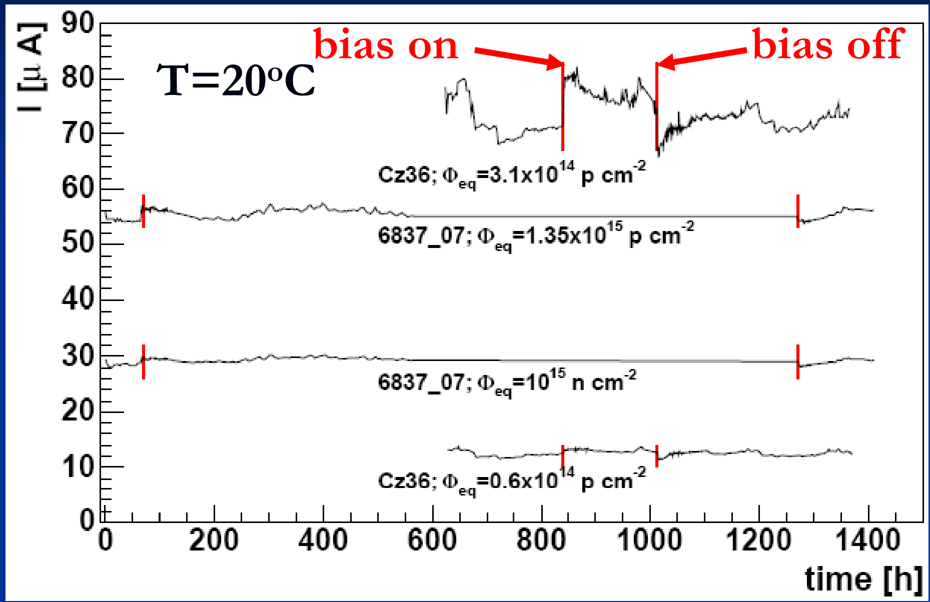
2 epi-Si 75 μm samples and 2 MCz-n samples (epi-Si: p-irr. and n-irr.),

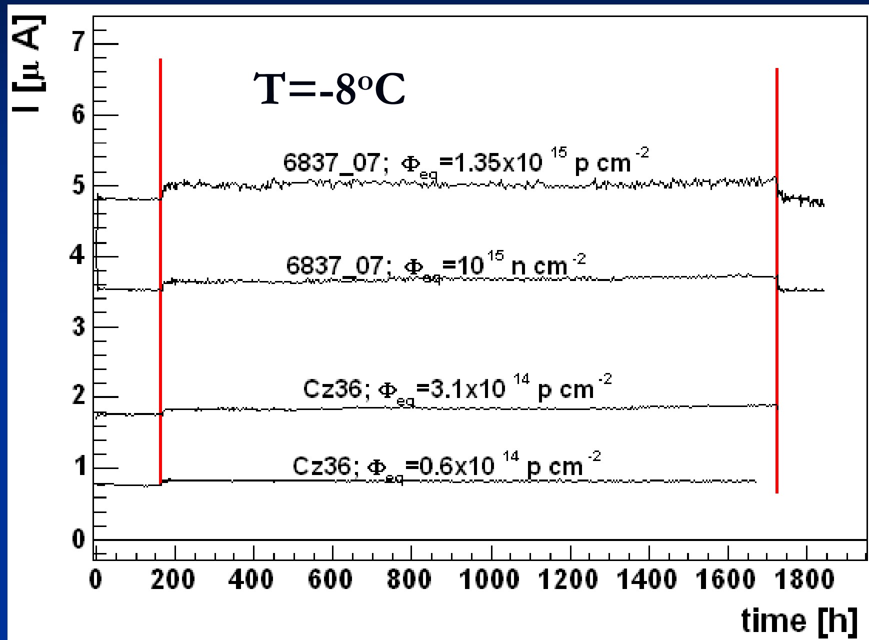




- Measurements were performed at ν=3kHz (10 kHz "too flat") Much longer time constants for activation:
  - tl=260 ± 150 h, ts=10 ± 4 h , g_1/g_b~0.7 , g_b=0.0036 cm^{-1} (for high Φ_{eq} g_b is 30% smaller than at 20^{o}C)
  - tl=700 ± 150 h, ts = 8 ± 3 h , g_1/g_b~0.7 , gb=0.0039 cm-1 (same results as at 20^{o}C)
- Deactivation: for epi-Si and MCz: a single exponential gives good fit with τ=4 h
- The scaling factor between 20^{o}C and -8^{o}C is:
  - τ_l(-8C)~**12**· τ_l(20^{o}C), τ_s(-8^{o}C)~**2.5**·τ_s(20^{o}C) for epitaxial devices
  - for MCz, STFZ difficult to give results due to uncertainty of results at T=20^{o}C

Leakage current

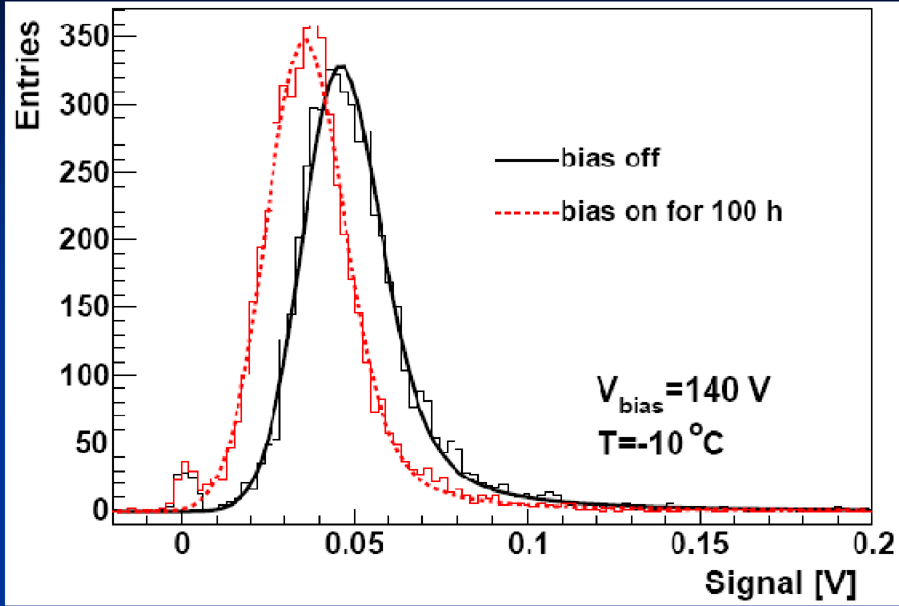


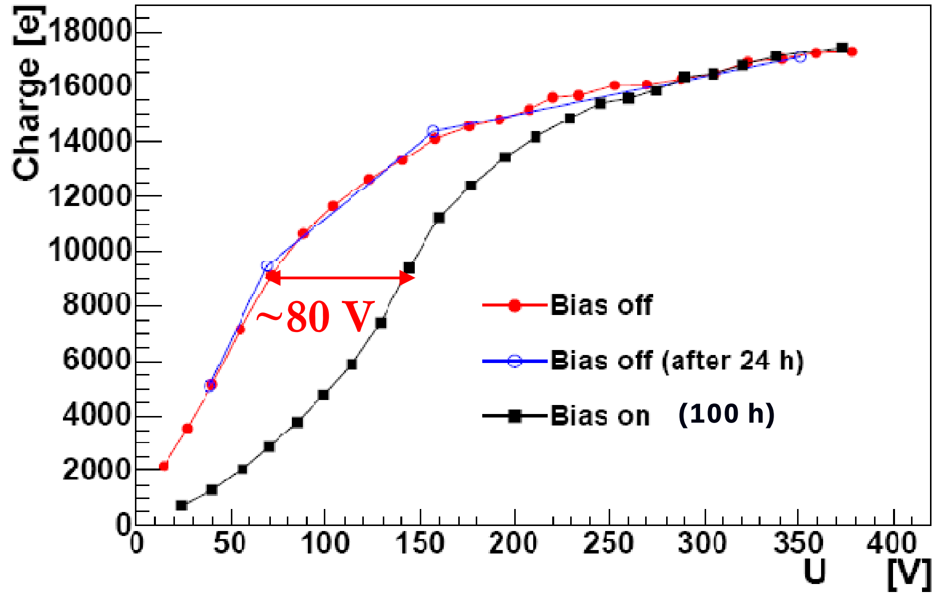


There is no effect of applied bias on leakage current:

- The small rise is due to different V_{fd} at which the I is measured
- The temperature is stable during the measurements (remember 7°C is around factor 2 in I_{leak})
- Although not shown these plots the same curves are obtained for all the samples in the study

Signal measurement



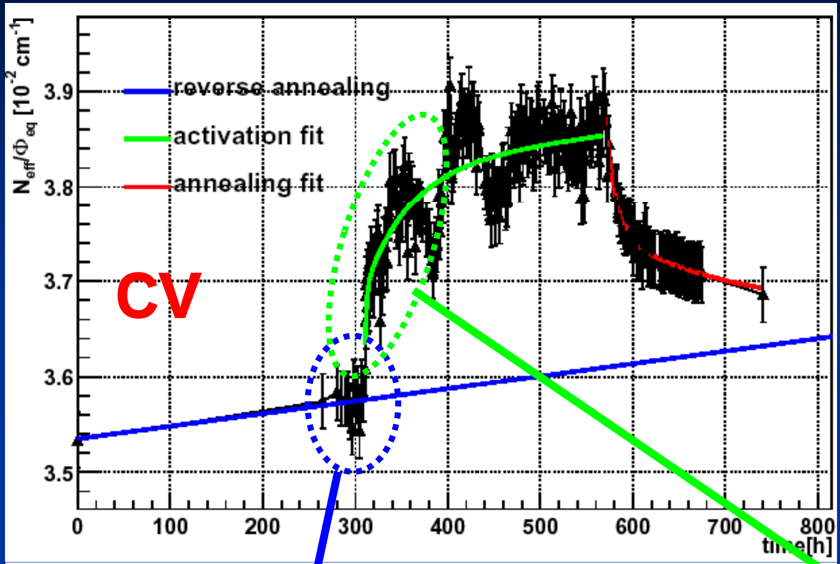


- MCz diode irradiated to $3.1 \cdot 10^{14}$ p cm^{-2} was used to measure the effect of applied bias on CCE!
  1. Measurement of charge collection with ^{90}Sr electrons (25 ns shaping time) at T=-10°C before the bias was switched on
  2. After a day at T=20°C another measurements with fewer points in order to make sure that many points (~7 min/point) didn't influence the V_{fd}
  3. Diode under bias for 100h at 20°C and then cooled down for the measurements
- Clear difference in spectrum and QV plot can be observed! The difference is comparable to the one from CV measurements
- At very high voltages the CCE is the same regardless of the "bias" history

Conclusions

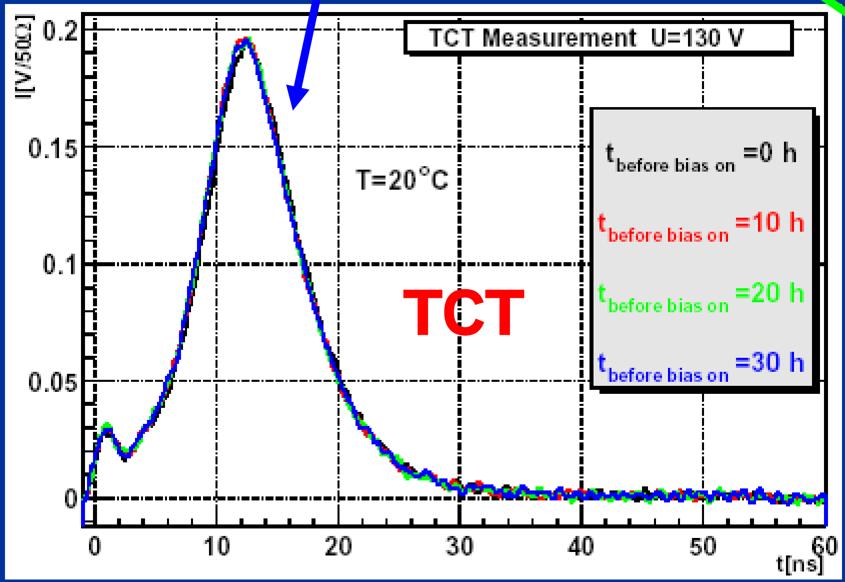
- The bias voltage affects the V_{fd} also in Cz, MCz, epi-Si and C enriched samples in the same way are previously measured with FZ
- Additional contribution to the $|N_{eff}|=g_b \cdot \Phi_{eq}$, where $g_b=0.004\ cm^{-1}$.
- The V_{fd} always increases regardless of the space charge sign ! The electrical state of the activated defects is equal to the sign of the space charge.
- The effect is the same for both 24 GeV protons and reactor neutrons
- The activation times are ~10 h for fast and ~few 100 h for slow component at -8°C. Deactivation times are of order of few h.
- In O rich materials irradiated with fast charged particles the stable damage of unbiased sensor is comparable to the "bias effect".
- We have no explanation of what it is, but it seems to be a bulk related …

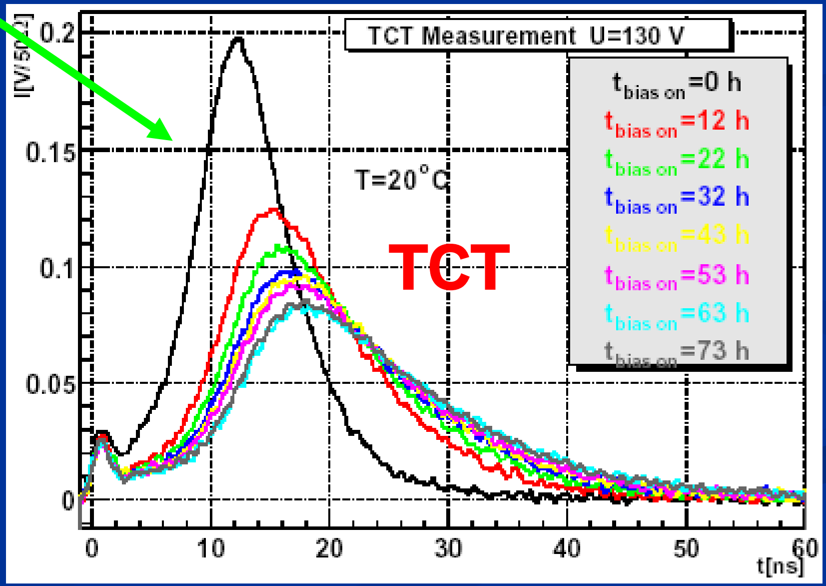
Reminder (II)



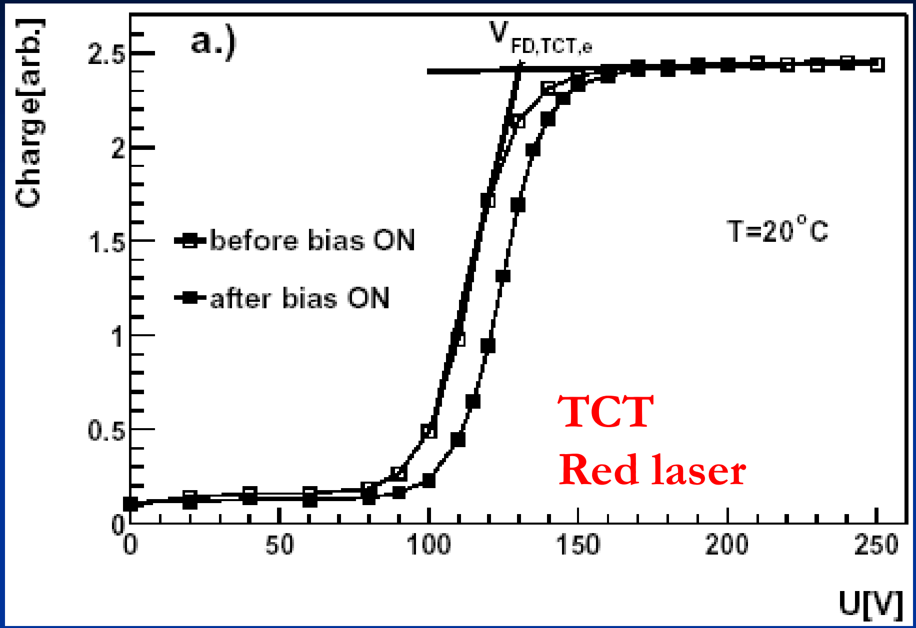
ITE - 5 kΩcm (STFZ-n material)
Irradiated to Φ_{eq}=5x10^{13} cm^{-2}
Annealed ~30% of the reverse annealing
V_{fd} ~ 130 V

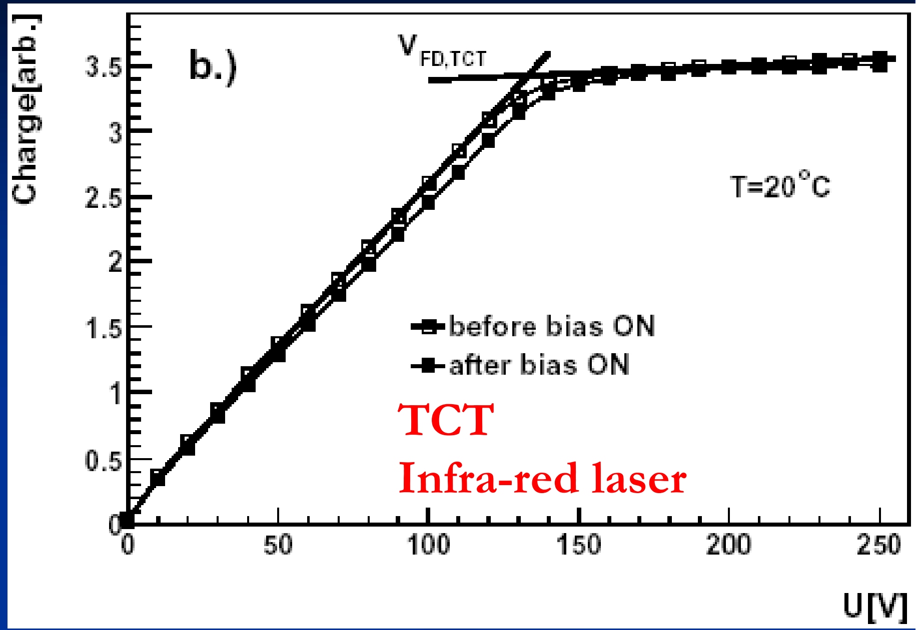
Electron injection **TCT**
clear changes in electric field observed!





Reminder (III)



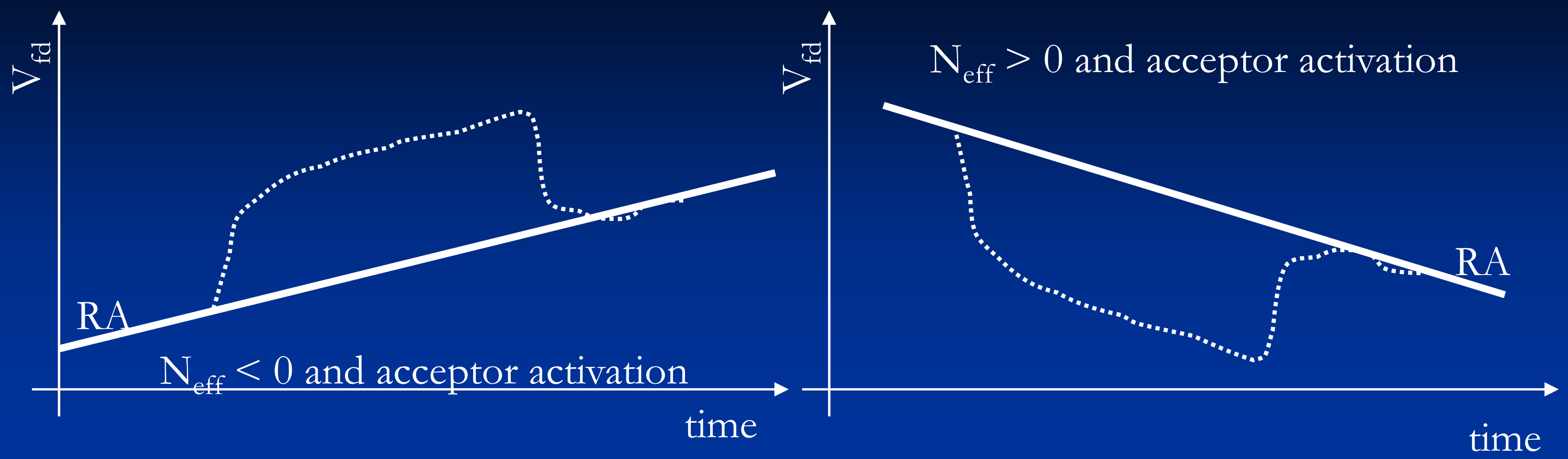


V_{fd} from TCT with red laser – electron injection

TCT with infrared laser – m.i.p. simulation

A clear increase of V_{fd} is observed after 70 h of bias applied

Same amplitudes when measeured by TCT or CV!



V_{fd}
RA
$N_{eff} < 0$ and acceptor activation
time
V_{fd}
$N_{eff} > 0$ and acceptor activation
RA
time