Systematic investigation of 24 GeV/c proton-irradiated Micron pad detectors made of different silicon materials

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Outline

- Introduction
- Studied sensors and irradiation details
- IV/CV results
- TCT & CCE results
    - Setup and sample preparation (Al-etching)
    - Results for non-irradiated diodes
- Conclusion & outlook

Introduction

Motivation:

- Radiation hardness limits of present silicon detector systems not sufficient for Luminosity upgrade for LHC

→ integrated radiation doses on the inner detector layers up to 2e16 n/cm^2

Problem of radiation damage in the bulk:

- Modification of basic electrical properties in silicon sensors

→ I_{leak} increase, V_{fd} change, CCE decrease
(charge trapping, modification of internal electric field distribution)

- Main source of SNR degradation

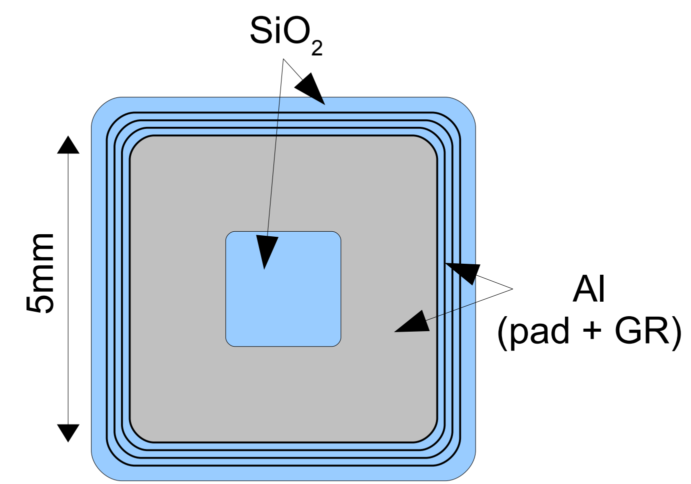
Main objectives of this work (within RD50):

→ Characterisation of new silicon sensor types in terms of operating ability beyond such irradiation levels (i.e. long-term impacts)
→ Deeper insight into underlying physics mechanisms (e.g. E-field distribution)

Investigated materials

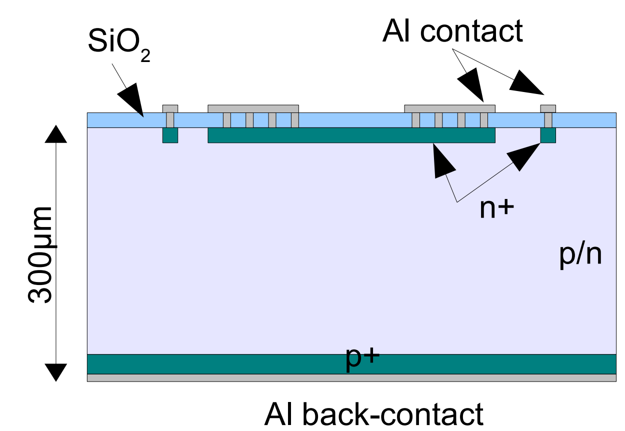
Common RD50 4” wafer production (2010) of MICRON Semiconductor ltd. (UK)

- Pad and strip detectors
- p- and n-type FZ and MCz
- Thickness ~ 300µm
- Resistivity $\rho = 1 \div 30$ kΩcm



Non-irradiated data

Material	Vfd [V]	Neff [cm^{-3}]	SIMS (O_2-conc. [cm^{-3}])
FZ n-in-p	13.6	1.96e11	2.2e16
MCz n-in-p	12.7	1.78e11	4.4e17
FZ p-in-n	21.2	-2.78e11	4.0e16
MCz p-in-n	62.2	-11.15e11	4.7e17
FZ n-in-n	18.6	-2.67e11	2.2e16
MCz n-in-n	-	-	4.0e17



Irradiation facts

- 24 GeV/c protons at CERN PS
- Flux: $1 \div 3 \times 10^{13}$ p/cm^2 h
- Annealing during irradiation (~ 27°C)
- Stored in freezer after irradiation

→ fluences received [p/cm^2]: 5.85e13, 1.03e14, 5.31e14, 9.84e14, 1.95e15, 4.42e16

(Φ_{eq} = 3.63e13, 6.39e13, 3.29e14, 6.10e14, 1.21e15, 2.74e16 n/cm^2)

IV/CV measurement

Measurement of leakage current & capacitance as function of reverse detector bias V and dependent on T, f, Φ, material

Deep defects proportional to non ionizing energy loss (NIEL) generated by radiation:

$$I_{leak} = \alpha \Phi_{eq} V$$

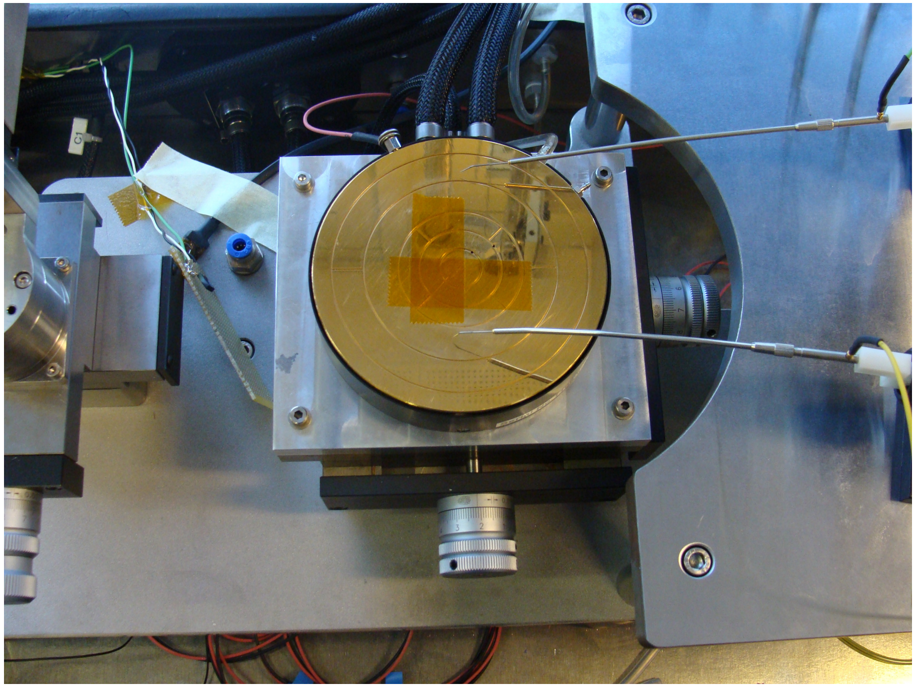
N_{eff} is related to depletion voltage and thickness of detector

→ information about N_{eff}:

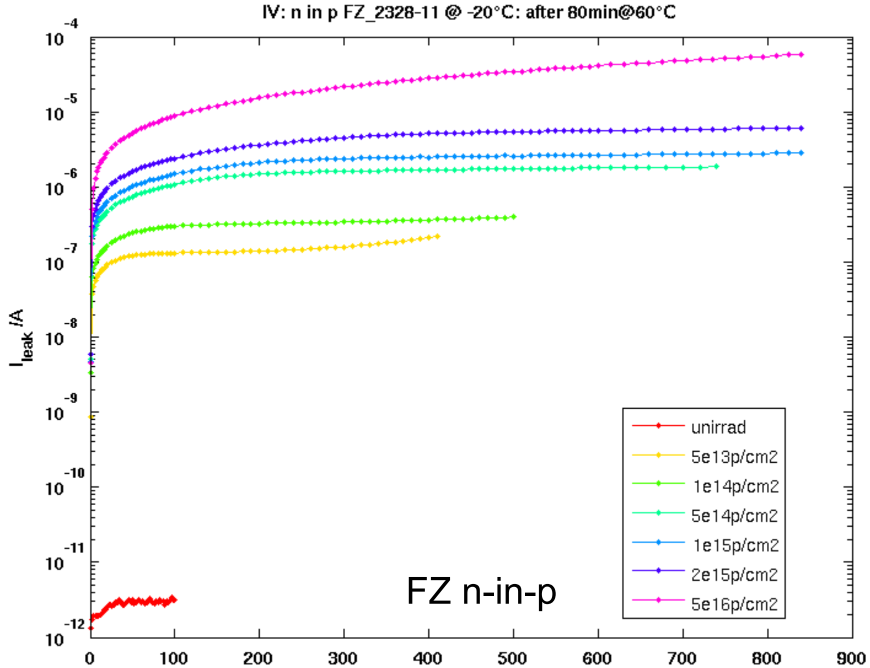
$$|N_{eff}| = \frac{2\epsilon\epsilon_0}{q_o} \frac{V_{fd}}{d^2}$$

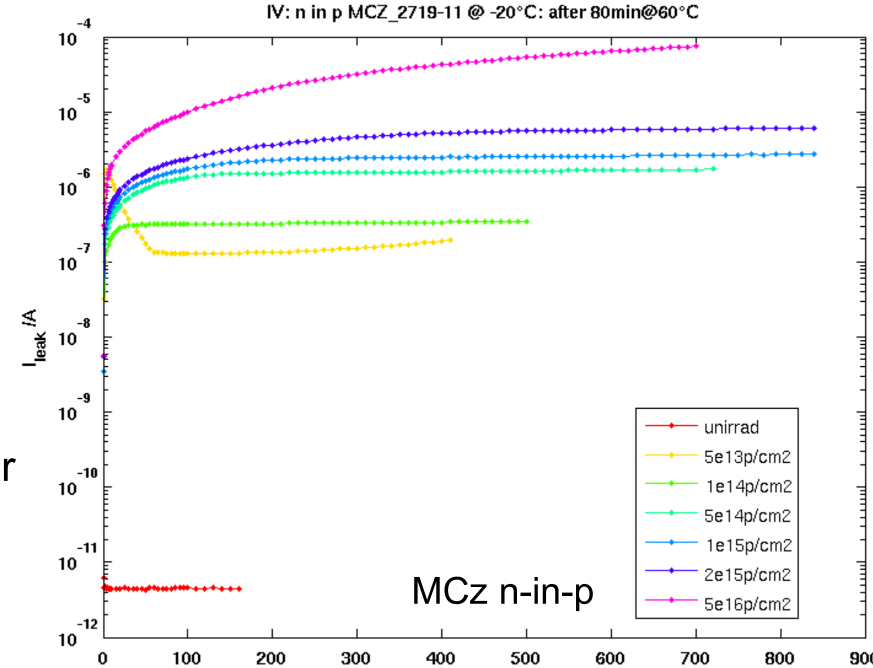
Parameters:

- GR to ground
- T = 20, 10, 0, -10, -20°C
- Dry air
- f = 1 kHz, 455 Hz
- 80min@60°C annealing

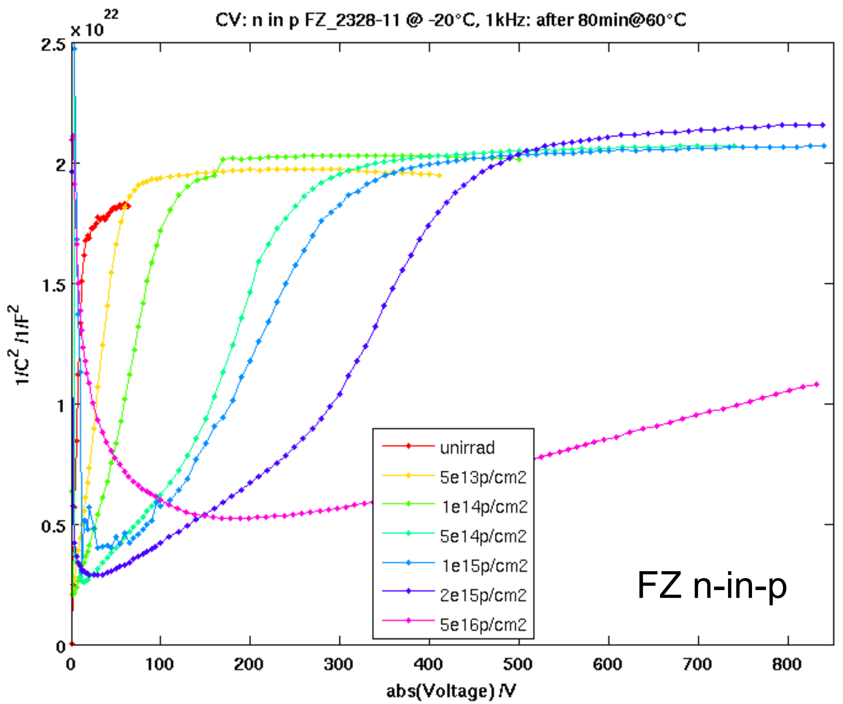


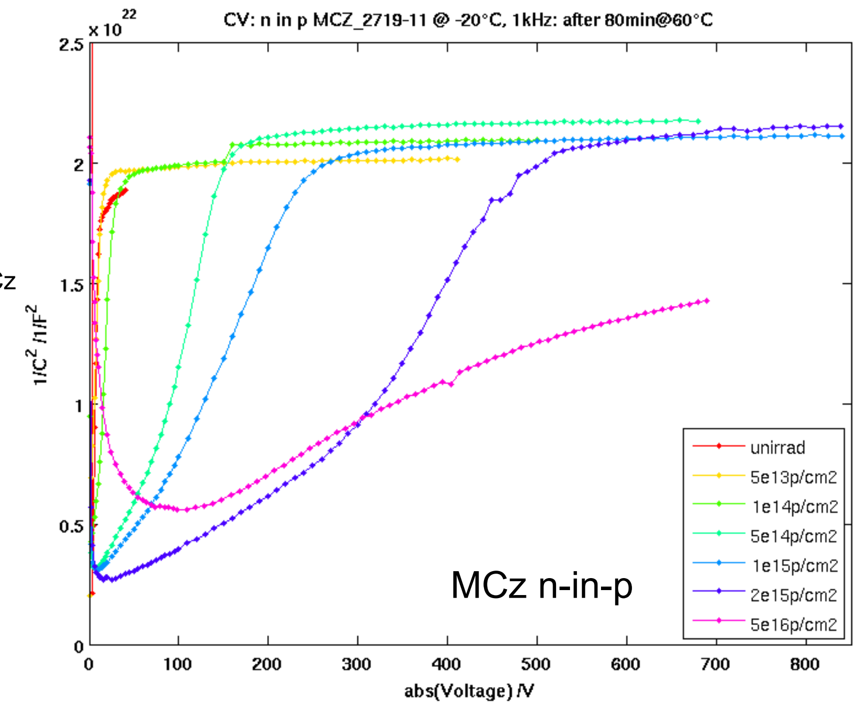
IV/CV comparison FZ vs. MCz n-in-p (-20°C)





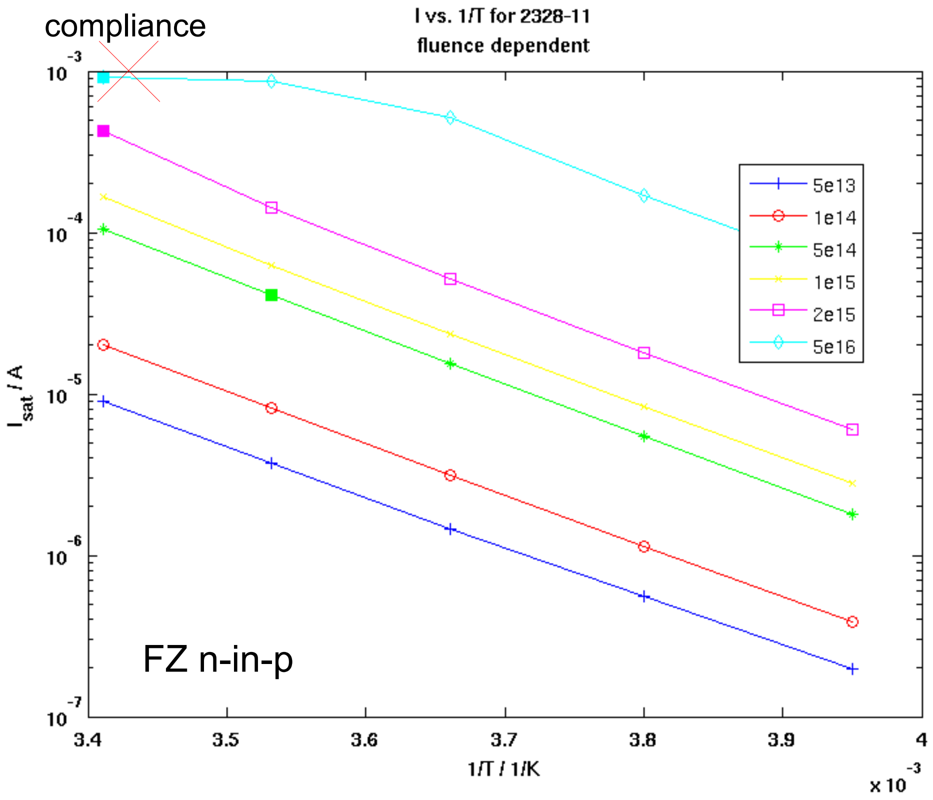
I_{leak} similar behaviour

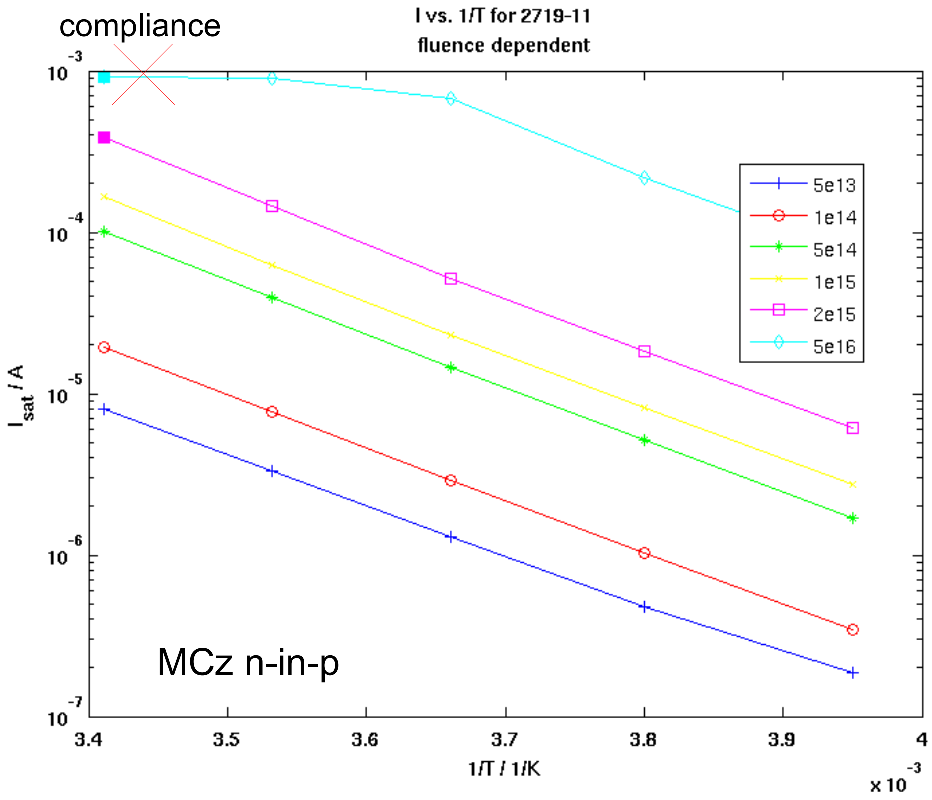




$V_{fd\ FZ} > V_{fd\ MCz}$

I vs. 1/T

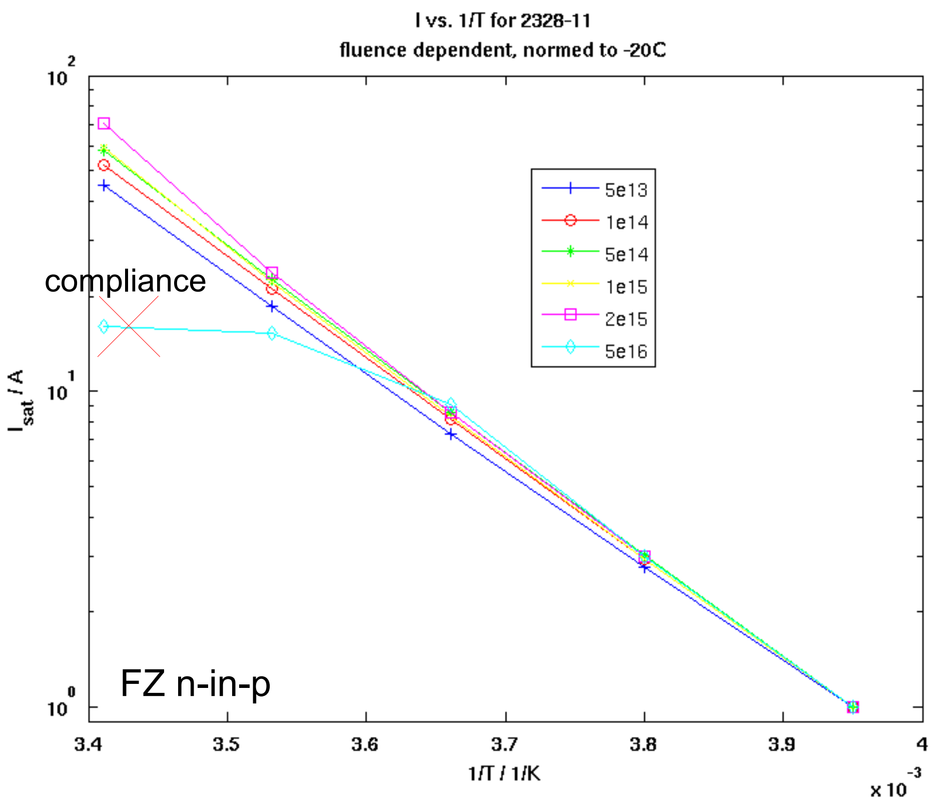


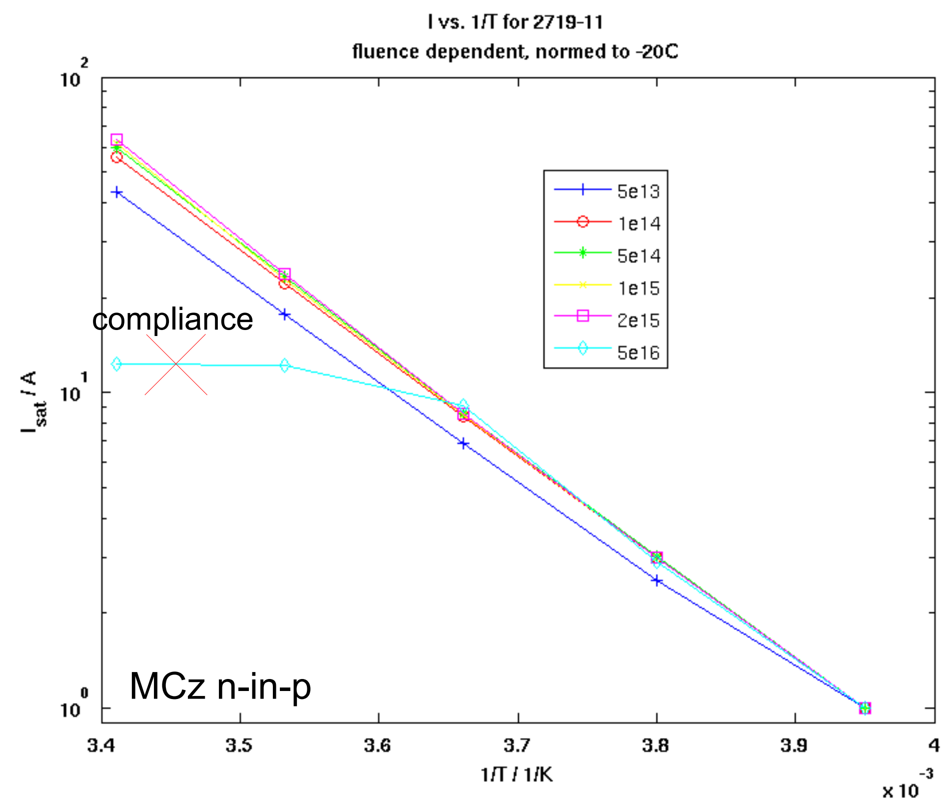


ln I_{leak} scales linear with 1/T

$\rightarrow E_{eff} = 1.195 - 1.209$eV (compare A.Chilingarov $E_{eff} = 1.214$eV)

I vs. 1/T





ln I_{leak} scales linear with 1/T

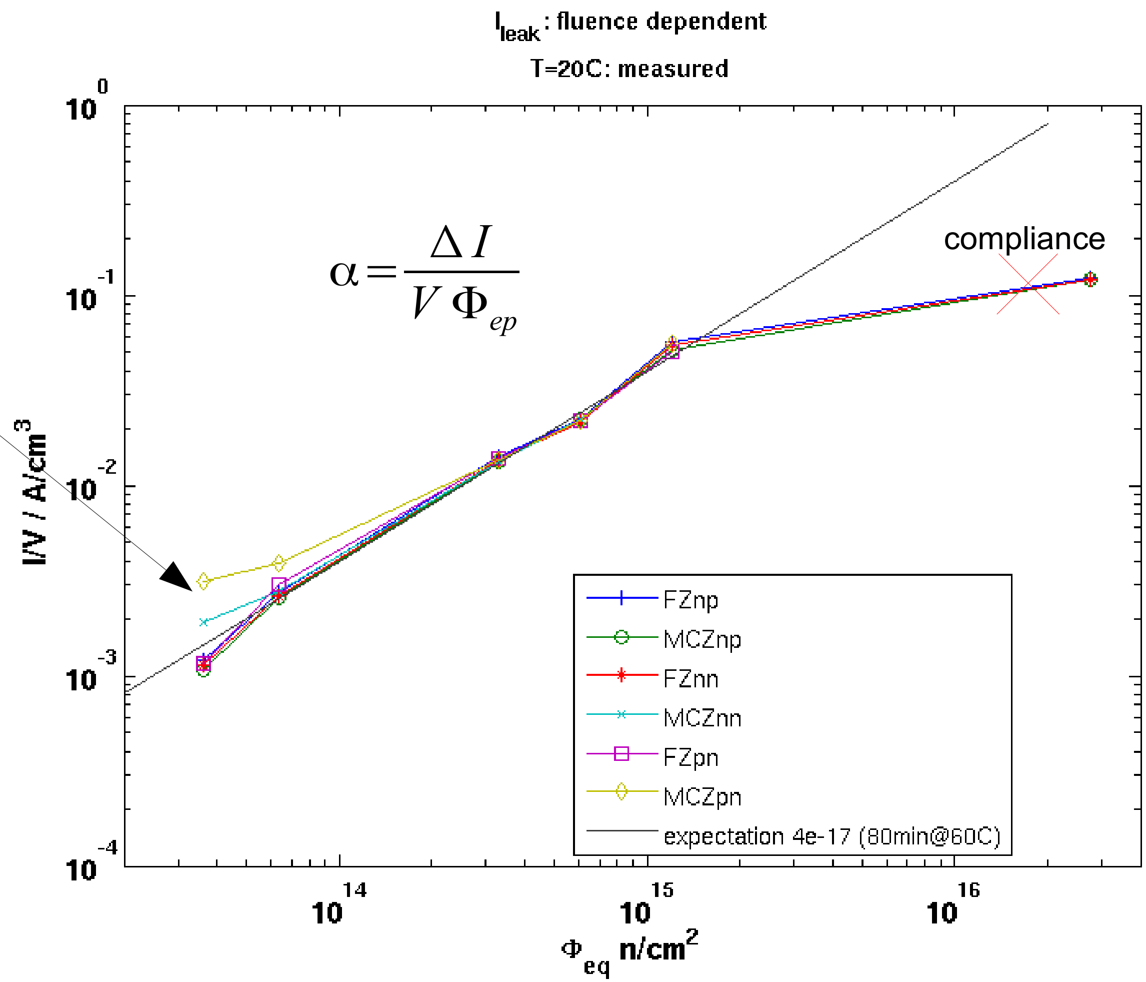
→ E_{eff} = 1.195 – 1.209eV (compare A.Chilingarov E_{eff} = 1.214eV)

slopes differ according to the fluence: low Φ – "gentle" slope
high Φ – "steep" slope

Volume current vs. fluence

- High leakage current of MCz (p-in-n and n-in-n) for non- and low irradiated samples
- p-in-n MCz behaves like n-in-p

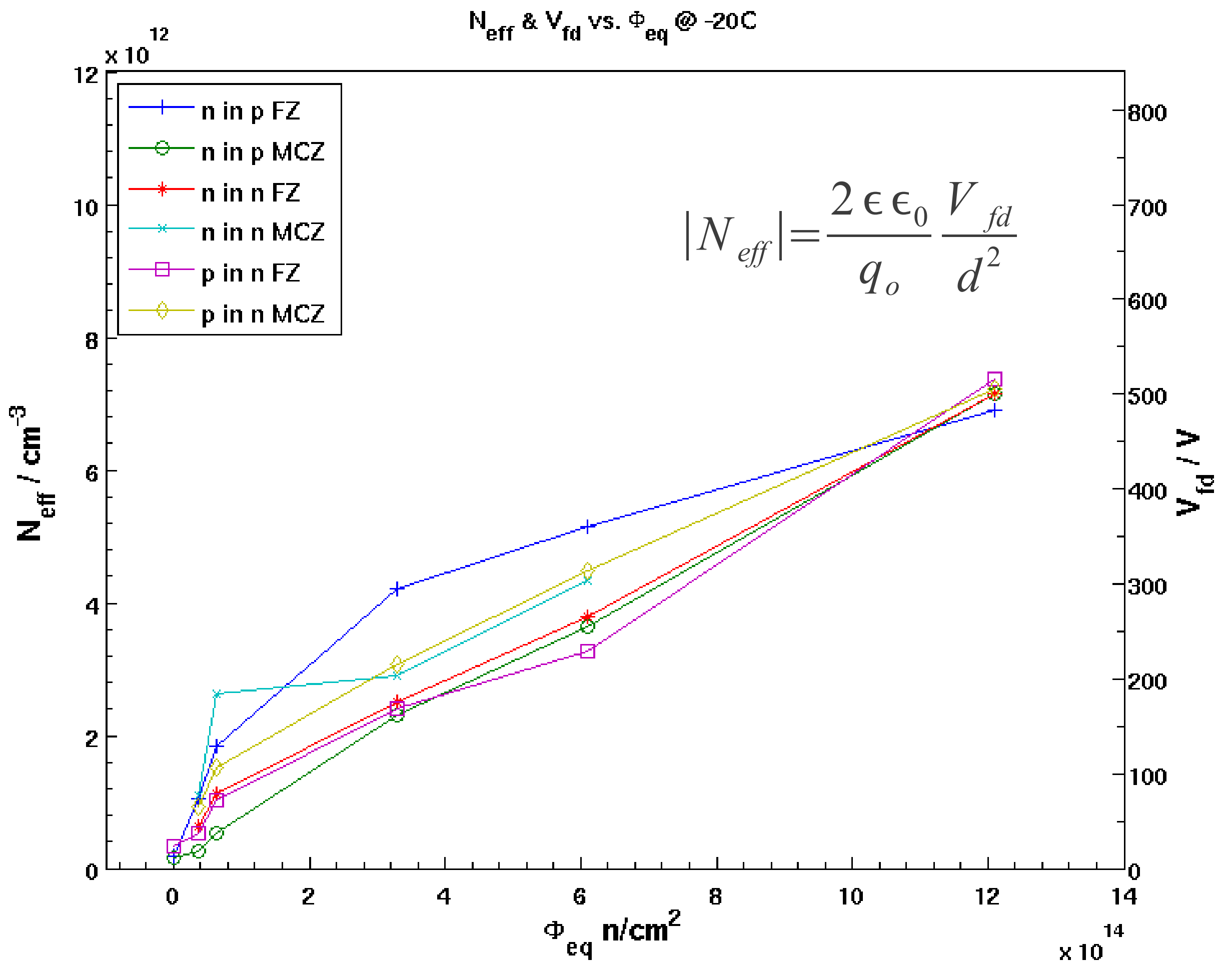
→ stated by SR&SIMS measurement and seen in TCT



α = 4.38e-17 A/cm^2

Damage parameter is nearly independent of leakage current per volume and material type. Almost linear increase between 1e13 cm^{-2} up to 2e15 cm^{-2}.

N_{eff} & V_{fd} vs. fluence



Comparison of effective doping concentration and depletion voltage for different materials dependent on the fluence (-20°C).

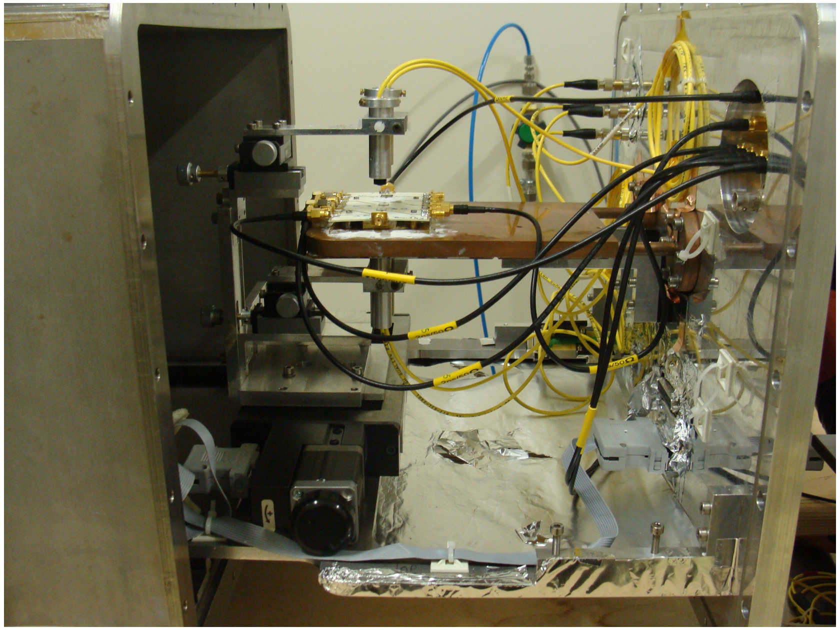
Next step: measure depletion voltage dependent on annealing, frequency and temperature

TCT measurement

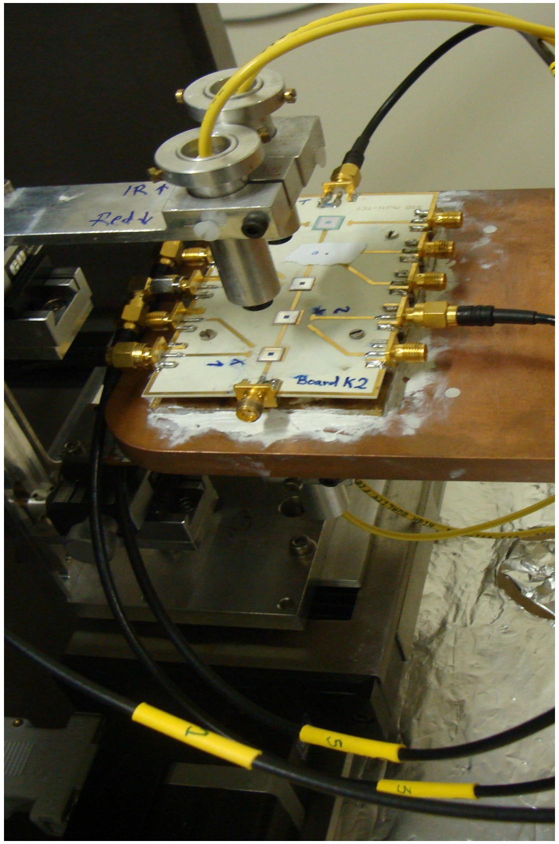
- Pulsed (ps) red/infrared laser illumination (front or back)
- Generates e-h-pairs in the detector

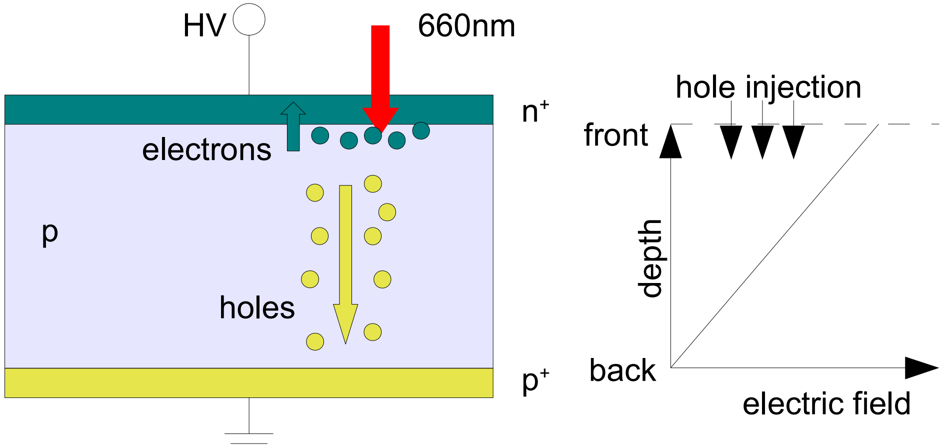
→ drift in externally applied electric field

→ record transient of induced current pulse



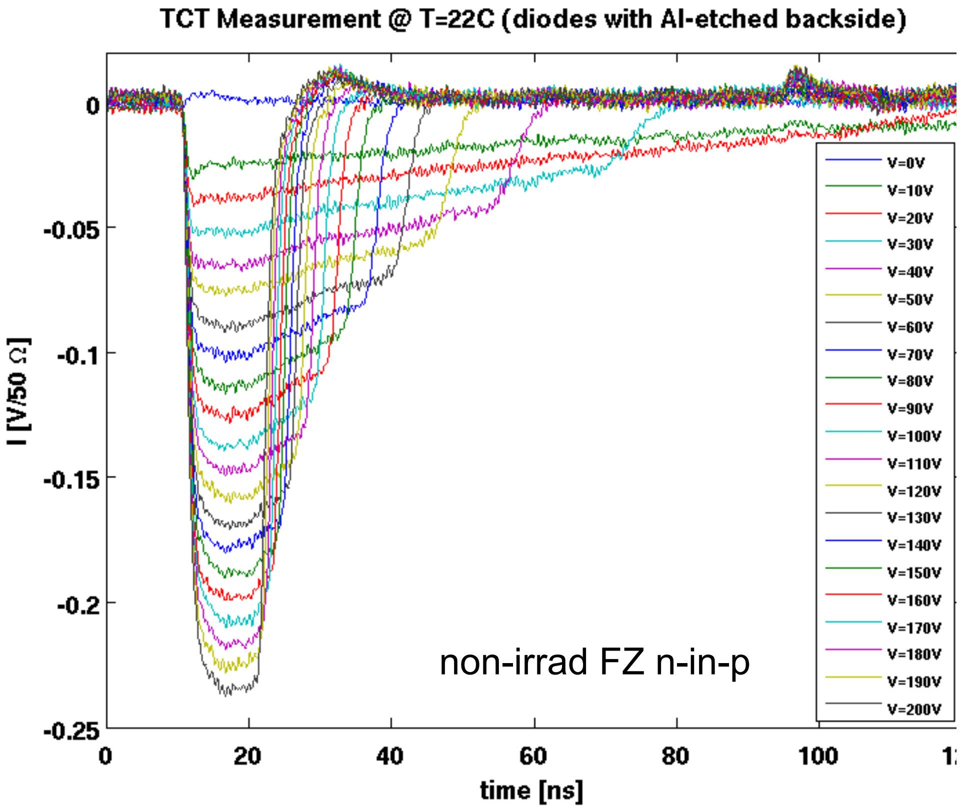
- Cooling to -20°C
- Red (665 nm) and Infrared (1060 nm) laser illumation
- FWHM pulse width 80 ps
- Miteq 1.5 GHz 44 dB low noise amplifier
- Agilent 2.5 GHz oscilloscope
- Detector bonded on thermally conductive PCB
- Front biasing, decoupling with 12 GHz BW Bias-Tee
- Laser delivery system with 4 focusers (front/back, red/IR)
- Humidity controlled: dry air atmosphere with dew point < -50C
- In-situ annealing of PCB with diodes possible

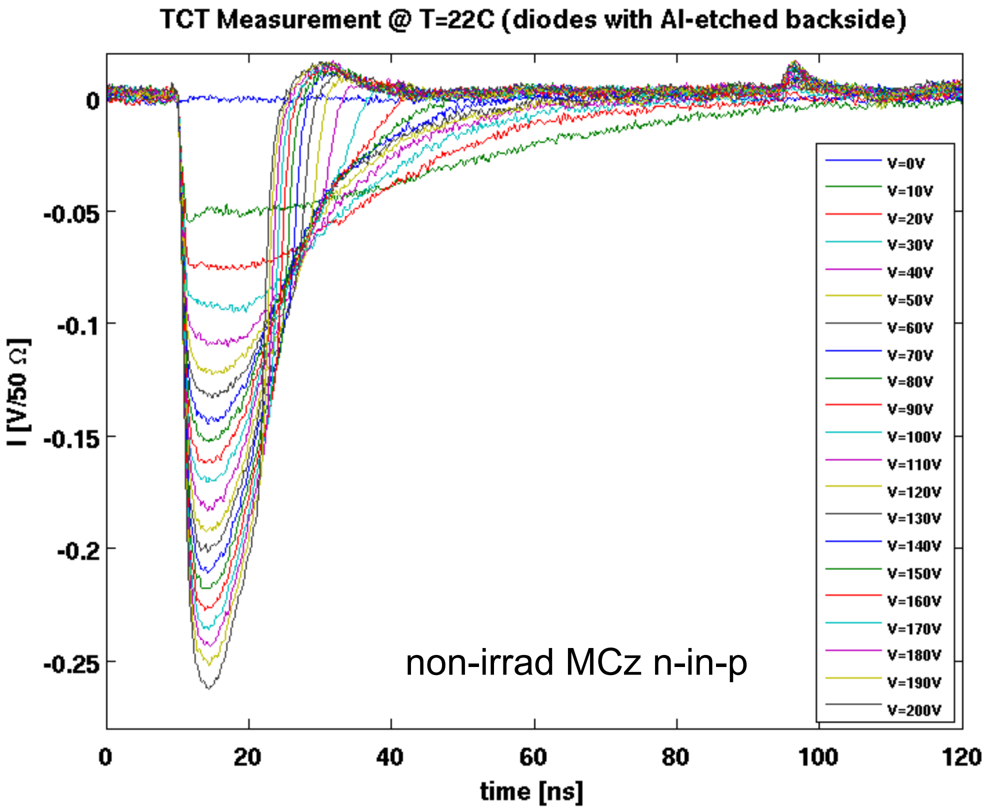




Induced current pulse from red TCT is
generated by only one kind of charge carriers

→ possible to disentangle the separate contributions from electrons and holes

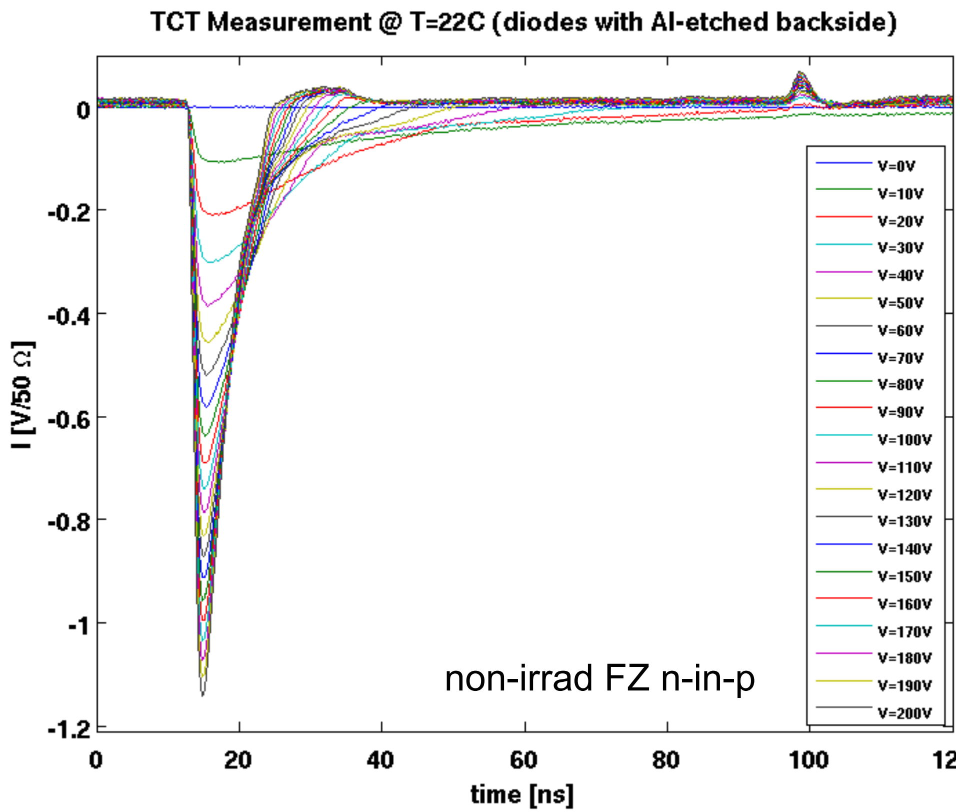


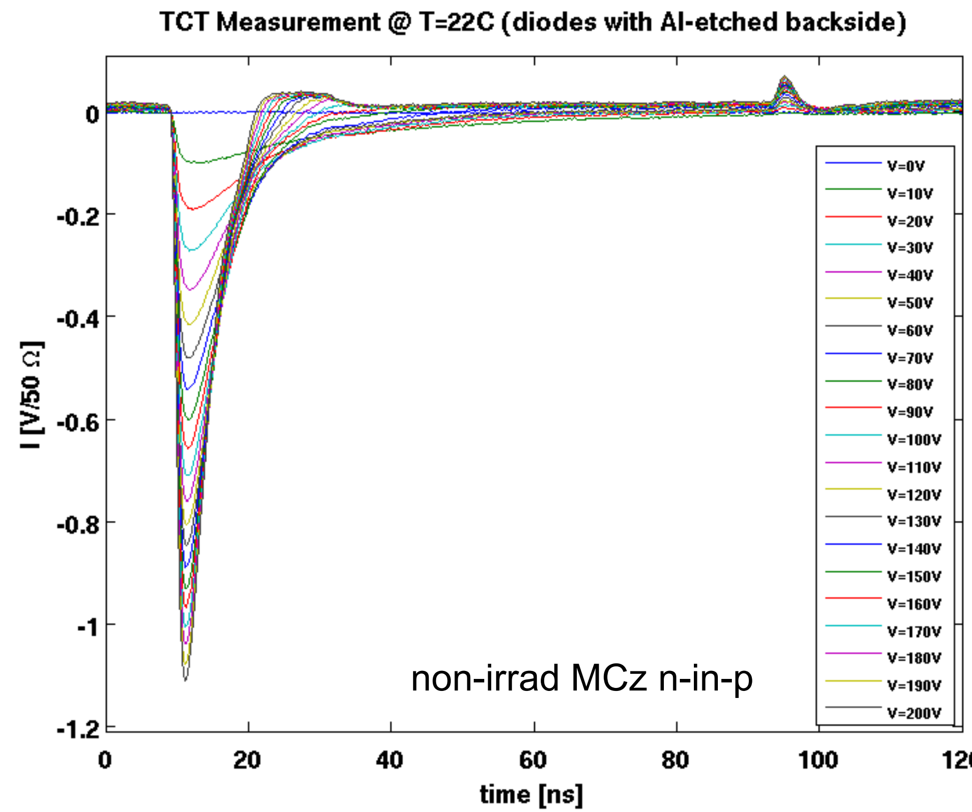


- Holes drift from a high to a low field for different voltages.

$v_{\text{drift FZ}} < v_{\text{drift MCZ}}$

TCT signal

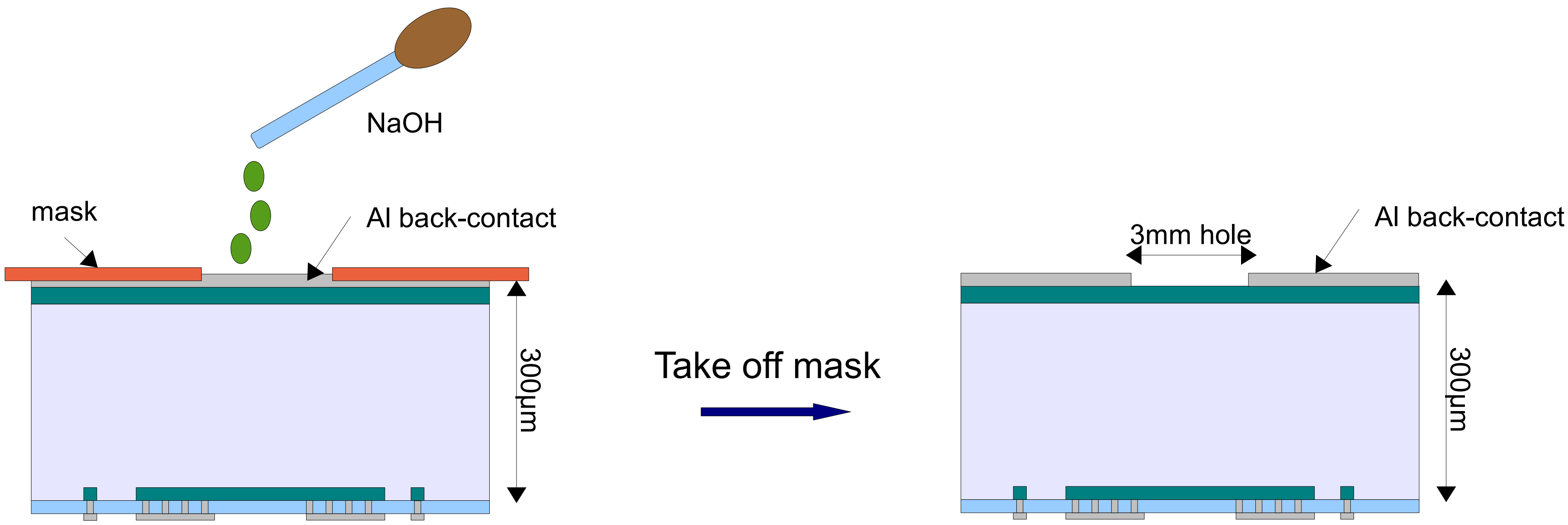




- TCT signals with IR illumination

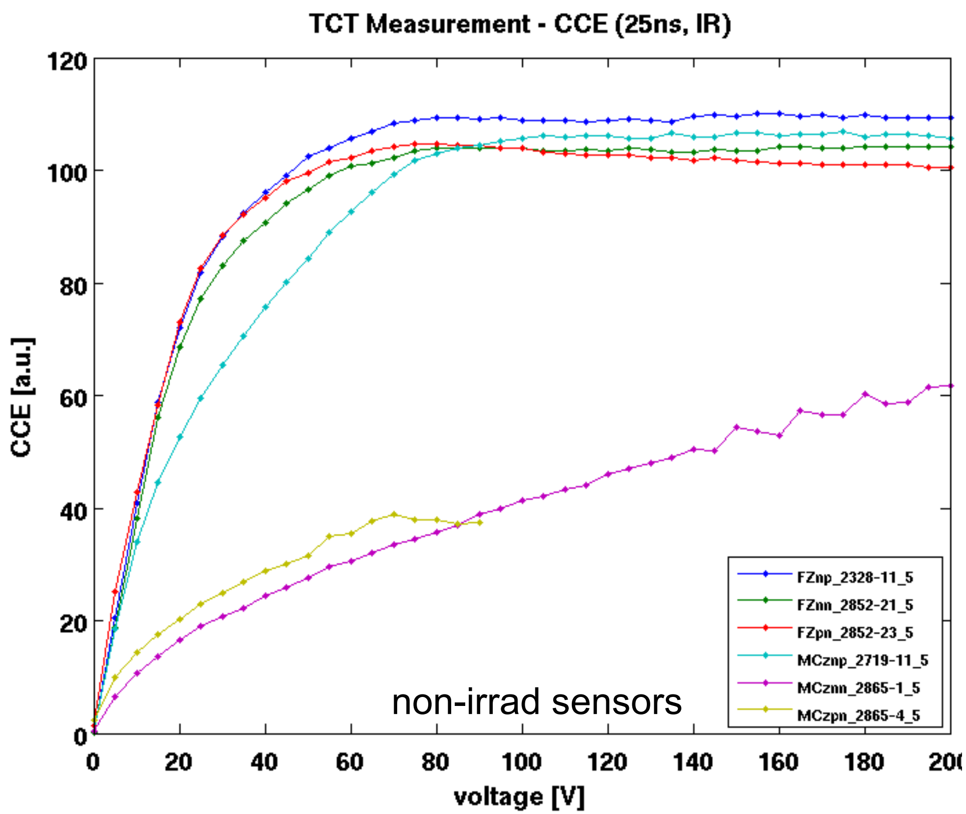
- IR laser light for proper CCE measurement
  → homogeneous introduction of charge carriers and represent MIP

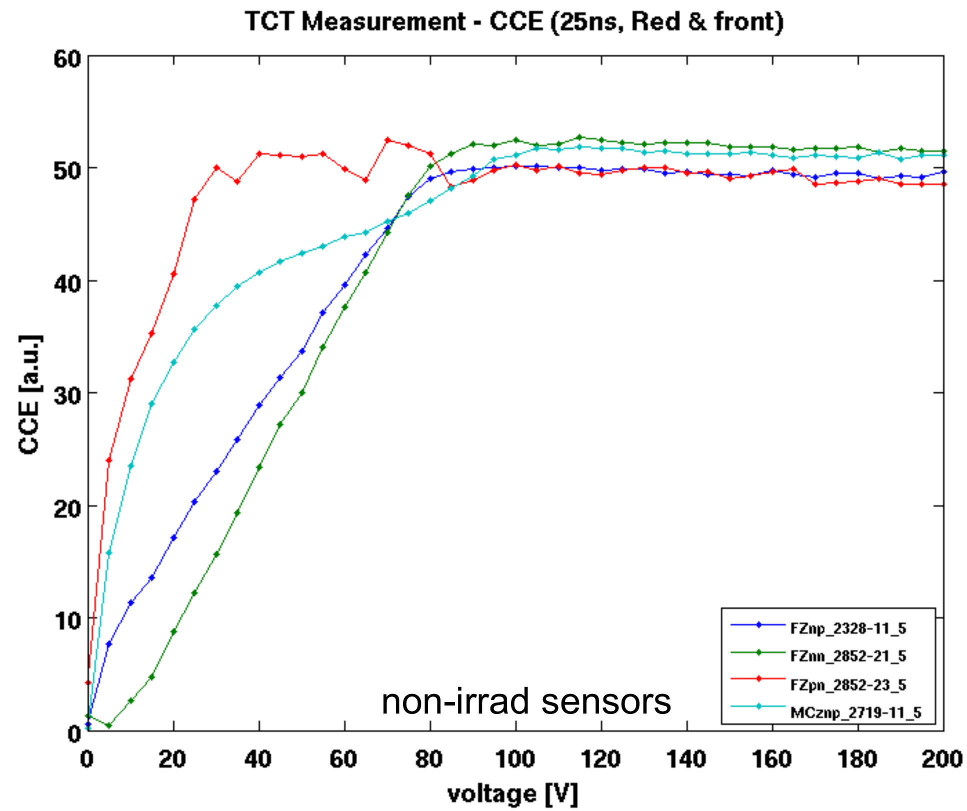
- Windows needed at both electrodes to avoid reflections
- Etching of full metallized Al-backside:
  - → simple mask of kapton: holes of d = 3mm
  - → sodium hydroxide solution (NaOH)



Comparison between IV/CV before and after Al-etching → no effect/changes!

CCE with TCT





- Charge collection efficiency (CCE) measured using TCT pulses
  → integration over the pulses: 25ns
- Non-irradiated sensors used as reference (100% CCE) compared to irradiated ones
- V_{fd} from CCE vs. CV:
  → frequency and temperature dependence of CV curve
  → extraction of effective working point of sensors from CCE (figure left: 25ns integr. time)

Conclusion & Outlook

Conclusion:

- IV/CV study of irradiated Micron diodes:
  - → Leakage current independent of material type, however:
    MCz n-in-n and p-in-n show high current for low irradiation levels
  - → I_{leak} scales linear with 1/T: agreement with Chilingarov for E_{eff}
    Slope dependent on fluence
  - → fluence-dependence of N_{eff}

- TCT measurements with non-irradiated samples
  - → Al-etching necessary for IR laser
  - → drift velocity in MCz seems faster

- CCE properties through TCT-signal (both red and infrared) were measured on non-irradiated sample as reference for irradiated sensors

Outlook:

- TCT measurements with irradiated samples running
- Alibava and e-TCT measurements on strip sensors
  (e-TCT runs with unirradiated strip detectors → Marcos: next talk)
- Annealing studies with diodes/strip sensor
- Comparison with simulation

Thank you for listening! Questions?!

Backups