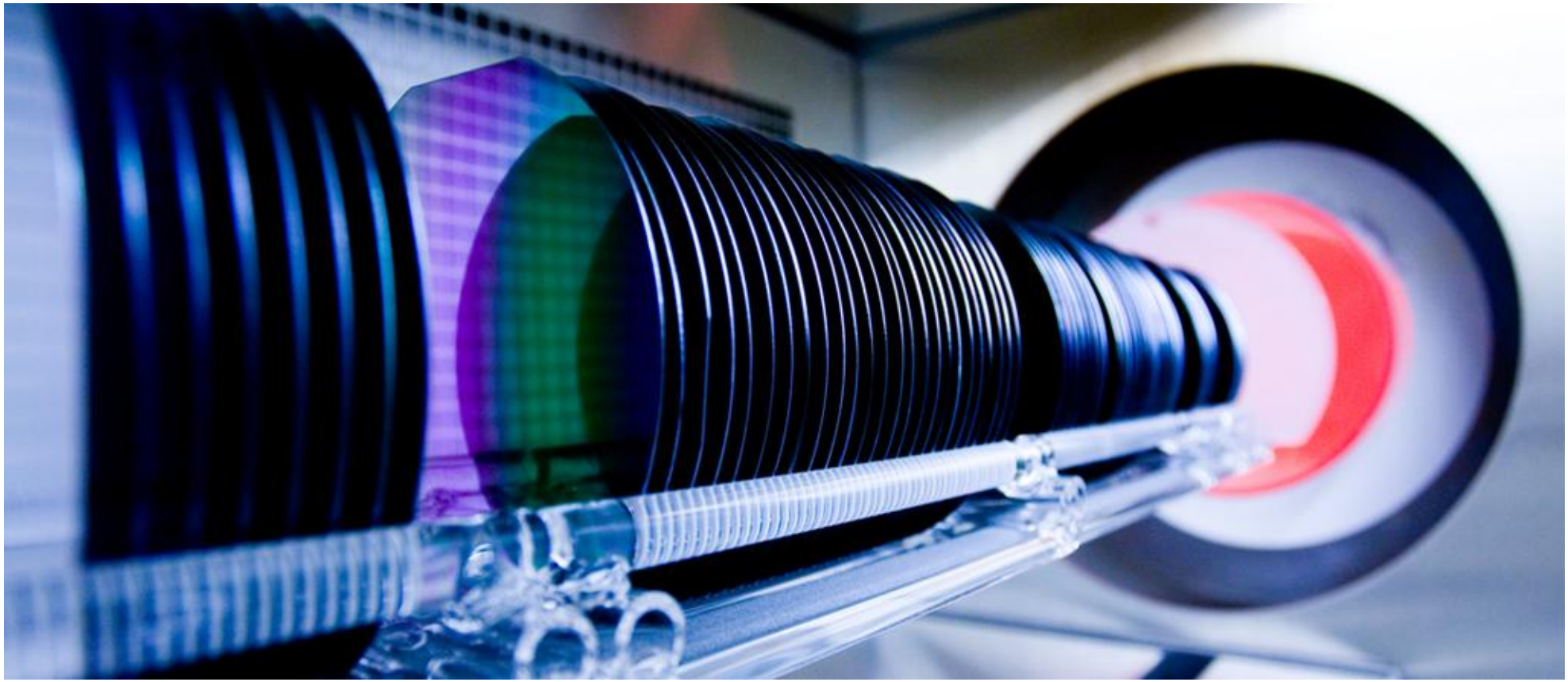

Impact of electron irradiation on N- and O-enriched FZ silicon p-in-n pad detectors

K. Lauer[1], X. Xu[1], D. Karolewski[1], U. Gohs[2], M. Kwestarz[3], P. Kaminski[4], R. Täschner[1], T. Klein[1], T. Wittig[1], R. Röder[1], T. Ortlepp[1]

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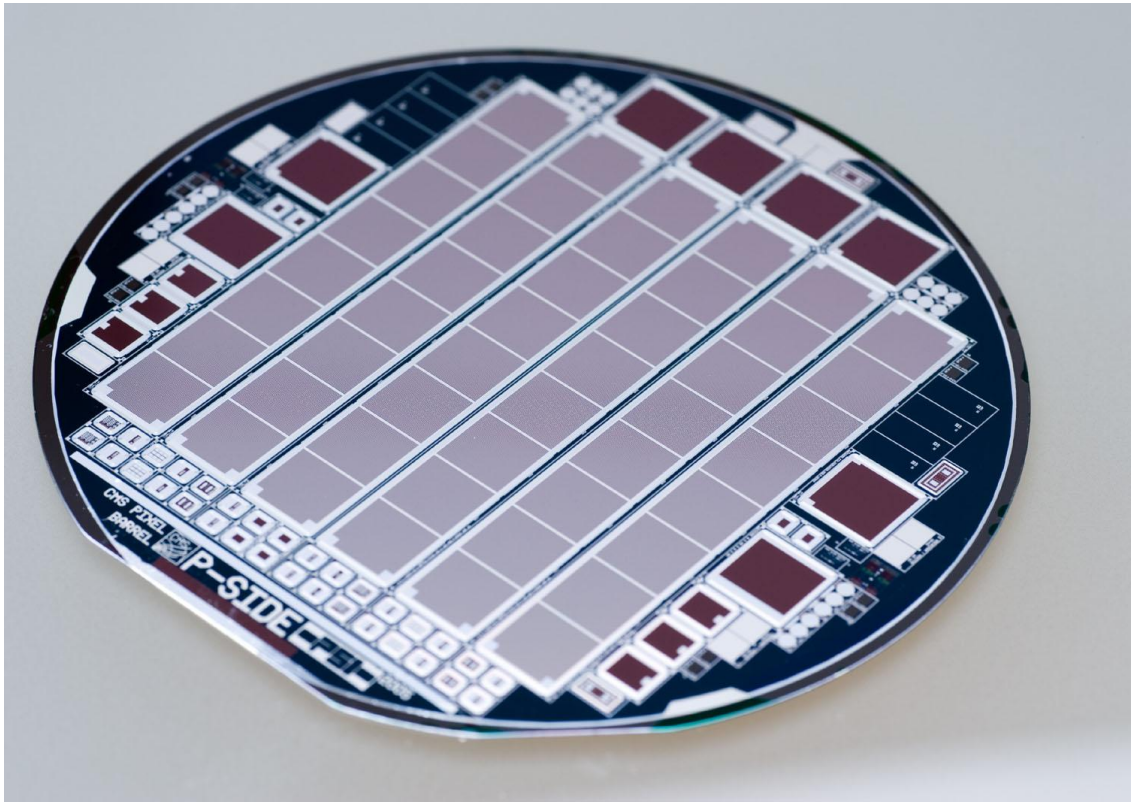
Radiation-hard Silicon Radiation Detectors

Development, Prototyping and Production for the Large Hadron Collider at CERN



- since 1996 successful development and processing of HEP detectors
- since 2000 more than 6000 detector (wafers) delivered
- CiS was awarded by CERN collaborations ATLAS and CMS the "Industrial Supplier Award" and the "Gold Award"
- Increasing luminosity requires increase in radiation hardness of silicon detectors

Overview

- Motivation
- Samples / experiment
- Low temperature FTIR characterization of samples
- P-in-n pad detector processing
- Current-voltage (IV) characteristics before and after irradiation
- Charge carrier lifetime before and after irradiation
- Summary

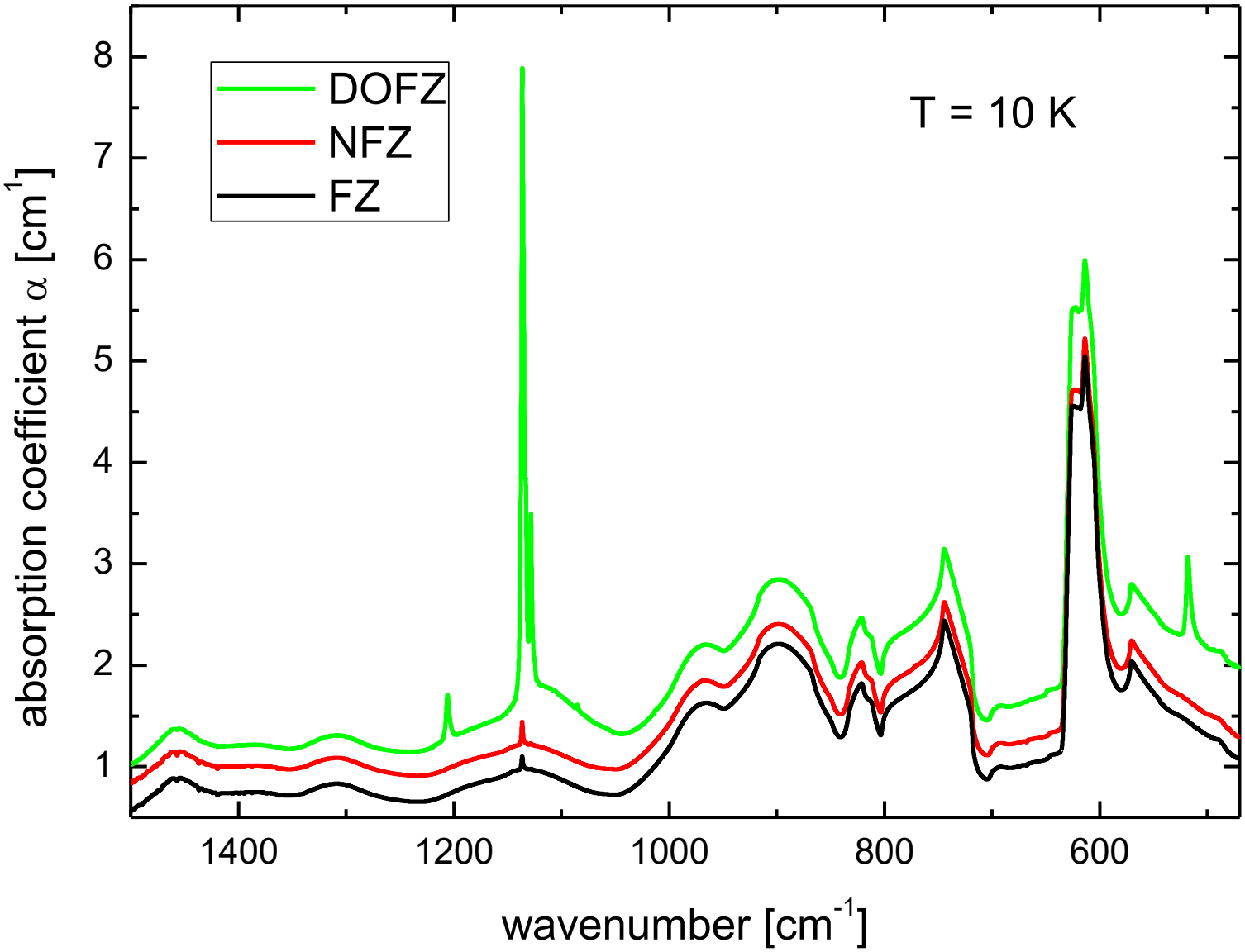
Samples / experiment

- Samples

name	doping type	resistivity [kΩcm]	enrichment
FZ	n, phosphorus	2.0-2.4	no
NFZ	n, phosphorus	1.5-1.9	nitrogen doping during crystal growth
DOFZ	n, phosphorus	2.0-2.4	oxygen by indiffusion from oxide layer (24h, 1150°C)
DOPFZ	n, phosphorus	2.0-2.4	DOFZ + O and Si precipitation annealing (4h, 650°C)

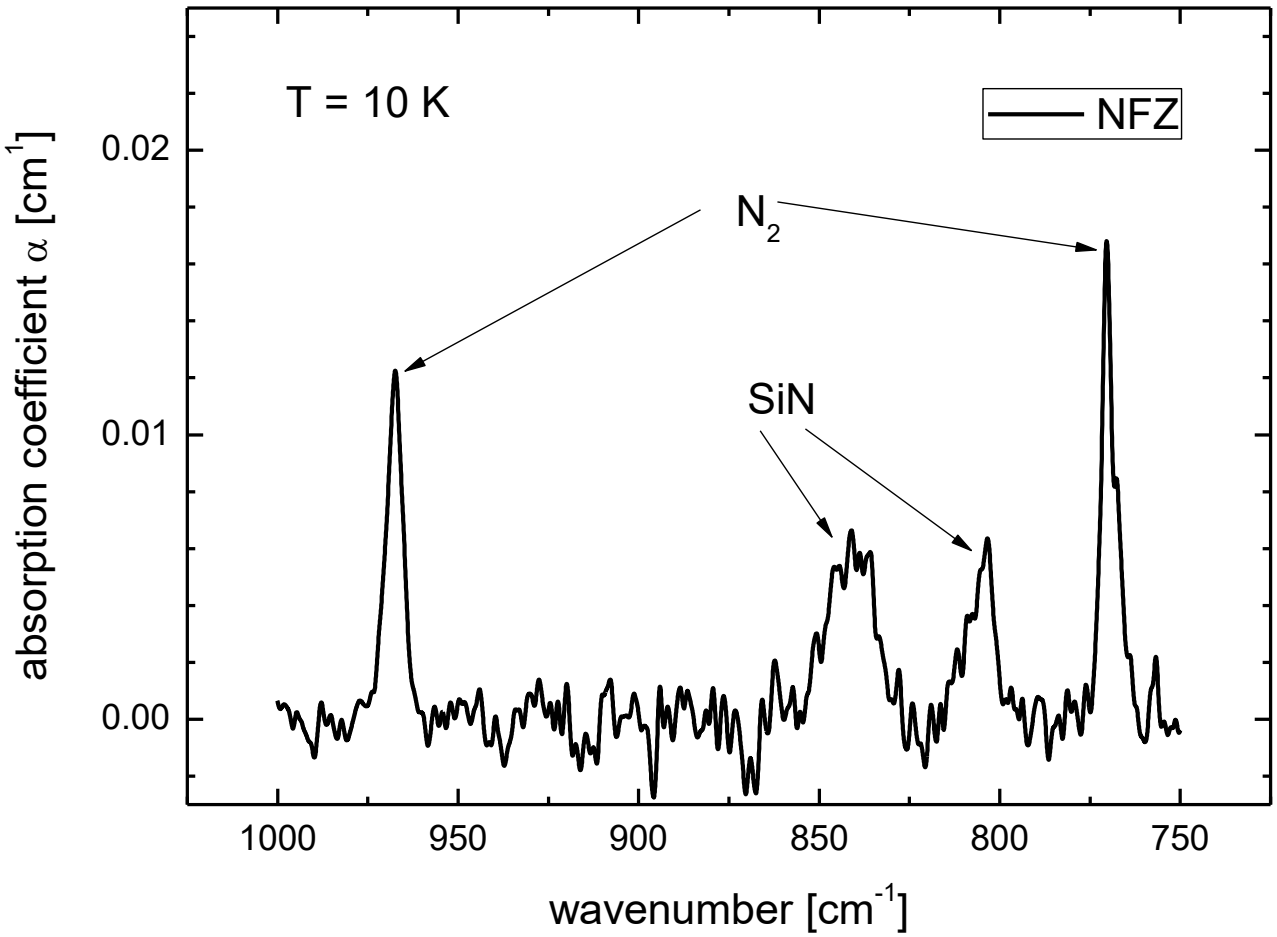
- p-in-n pad detectors manufactured
- Irradiation with 1MeV electrons (dose: $1x10^{14}cm^{-2}$ and $2x10^{14}cm^{-2}$)
- Generation of point defects used to qualify radiation resistance
- Impact of enrichment type on detector parameters after electron irradiation investigated

Low temperature FTIR spectroscopy



- Investigation of base material
- Measurement of oxygen and nitrogen content

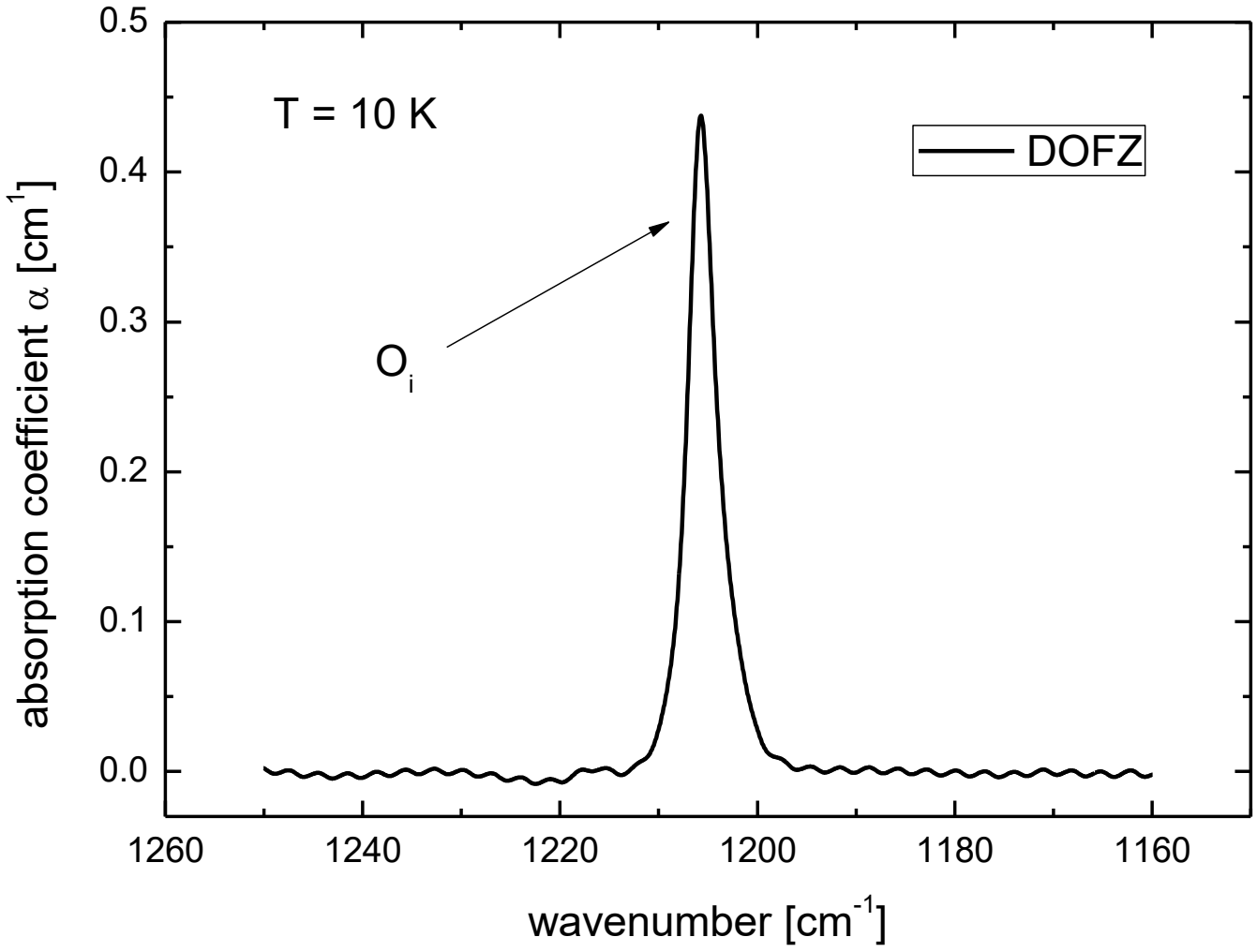
Low temperature FTIR spectroscopy, nitrogen



[1] K. Lauer, C. Möller, R. Porytskyy, H. Strutzberg, D. Schulze, M. Schley, and F. Schaaff, Solid State Phenomena 205-206, 234 (2013).
[2] Y. Itoh, T. Nozaki, T. Masui, and T. Abe, Applied Physics Letters 47, 488 (1985).

- Nitrogen concentration in NFZ samples, calibration factor from:
  - Ref. [1]: $[N]=(1.3 \pm 0.2)\times10^{15}cm^{-3}$
  - Ref. [2]: $[N]=(1.8 \pm 0.2)\times10^{15}cm^{-3}$
- Error from noise in FTIR spectrum
- SiN bonds are visible => indication for silicon nitride precipitates

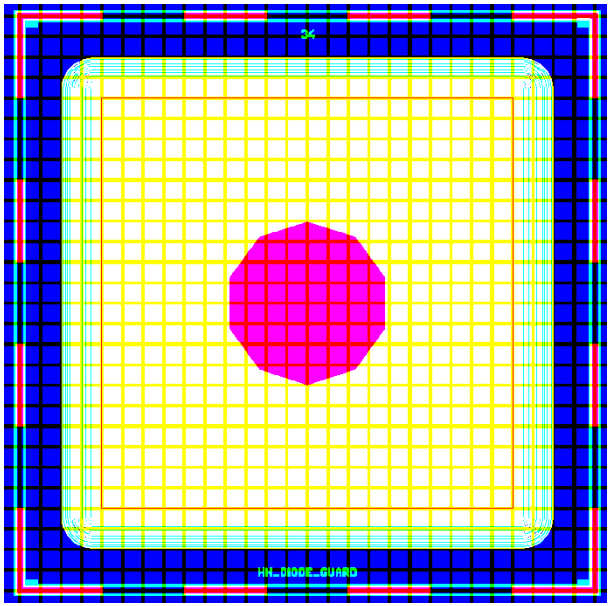
Low temperature FTIR spectroscopy, oxygen

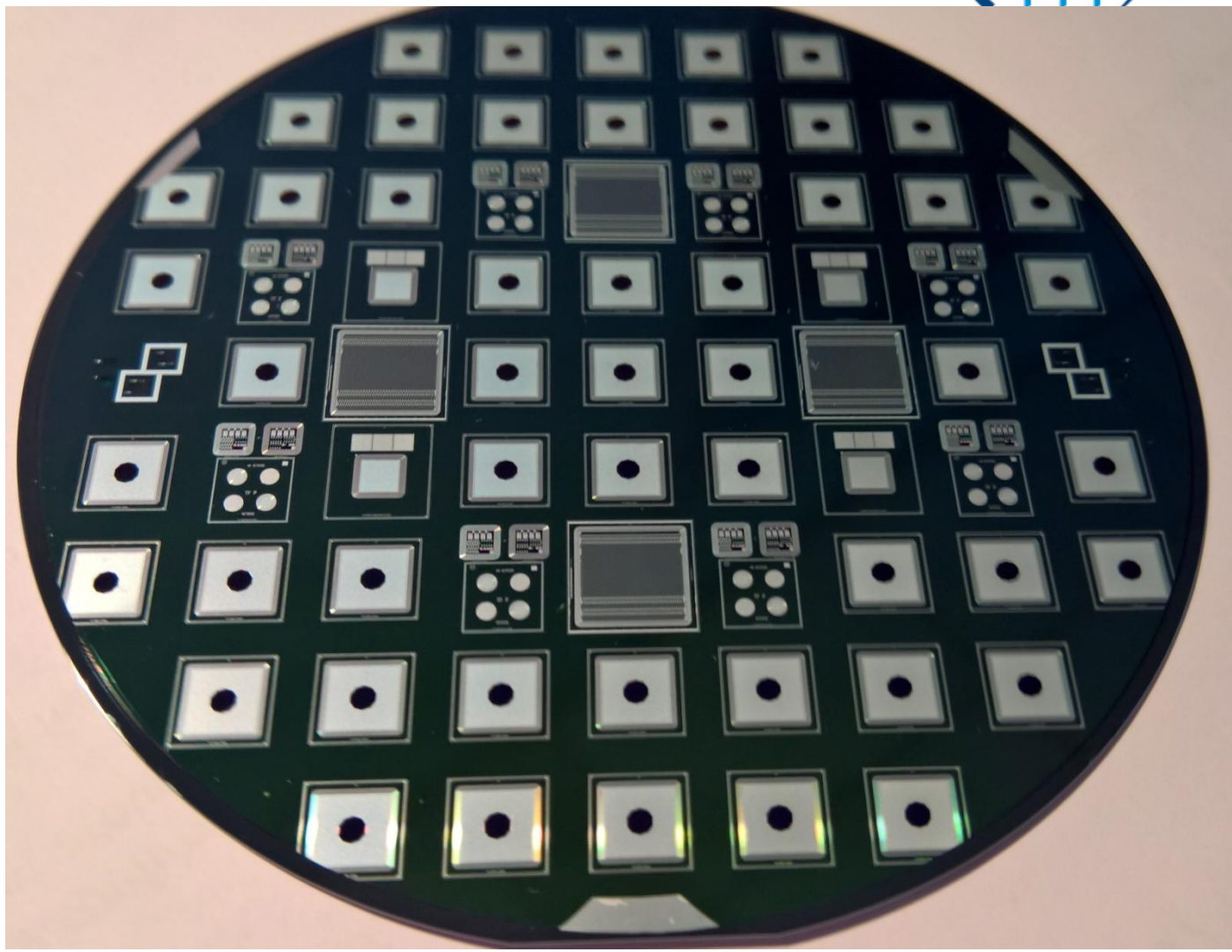


[1] P. Wagner, Applied Physics A 53, 20 (1991).

- Oxygen concentration using calibration factor of 1205cm^{-1} peak [1]: $[O_i]=(3.8 \pm 0.2)\times10^{17}$cm^{-3}
- Error from length variation of wafer pieces
- Solubility limit of oxygen at 1150 °C is $[O_i]\approx4\times10^{17}$cm^{-3}

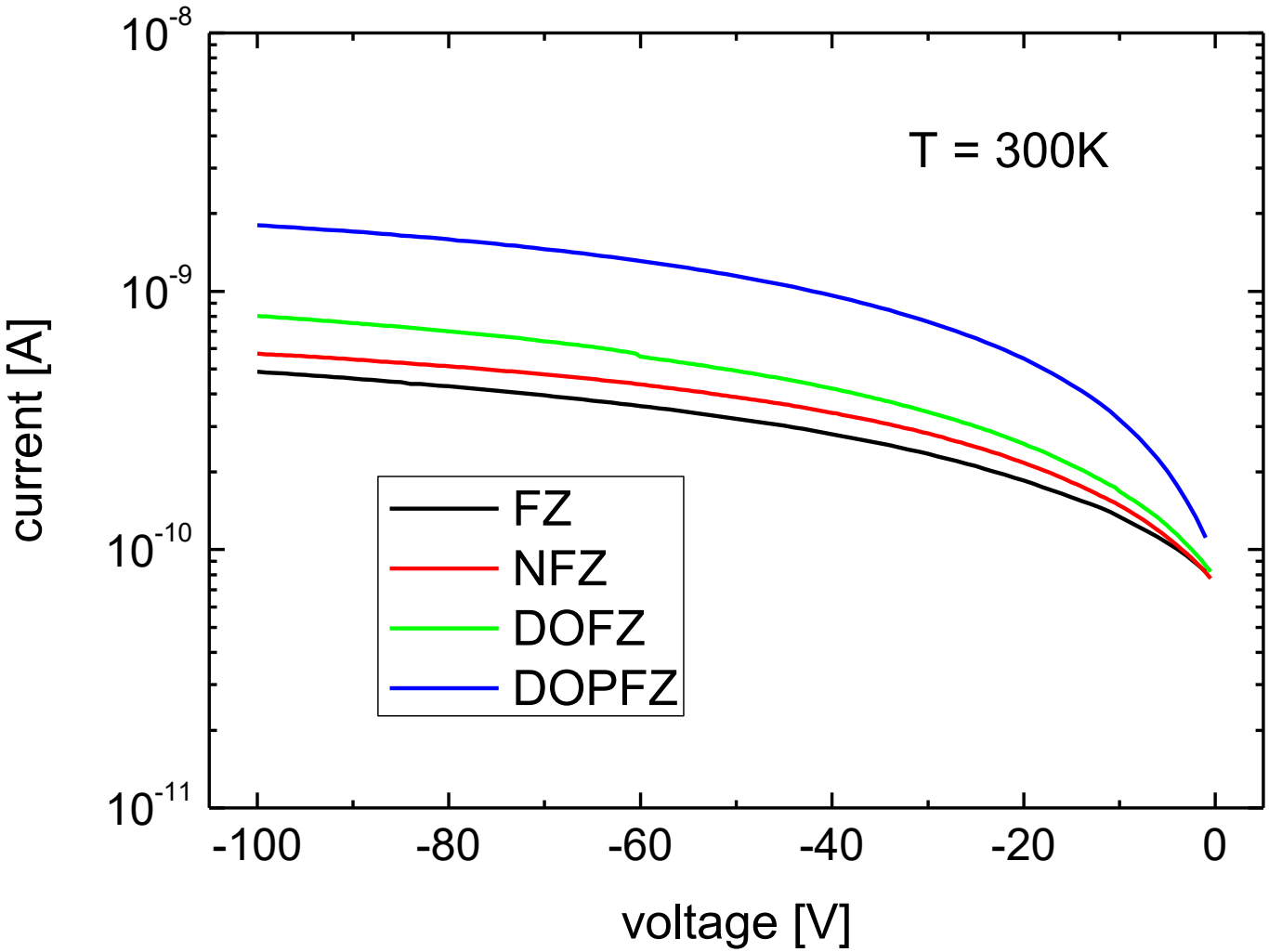
p-in-n pad detector manufacturing





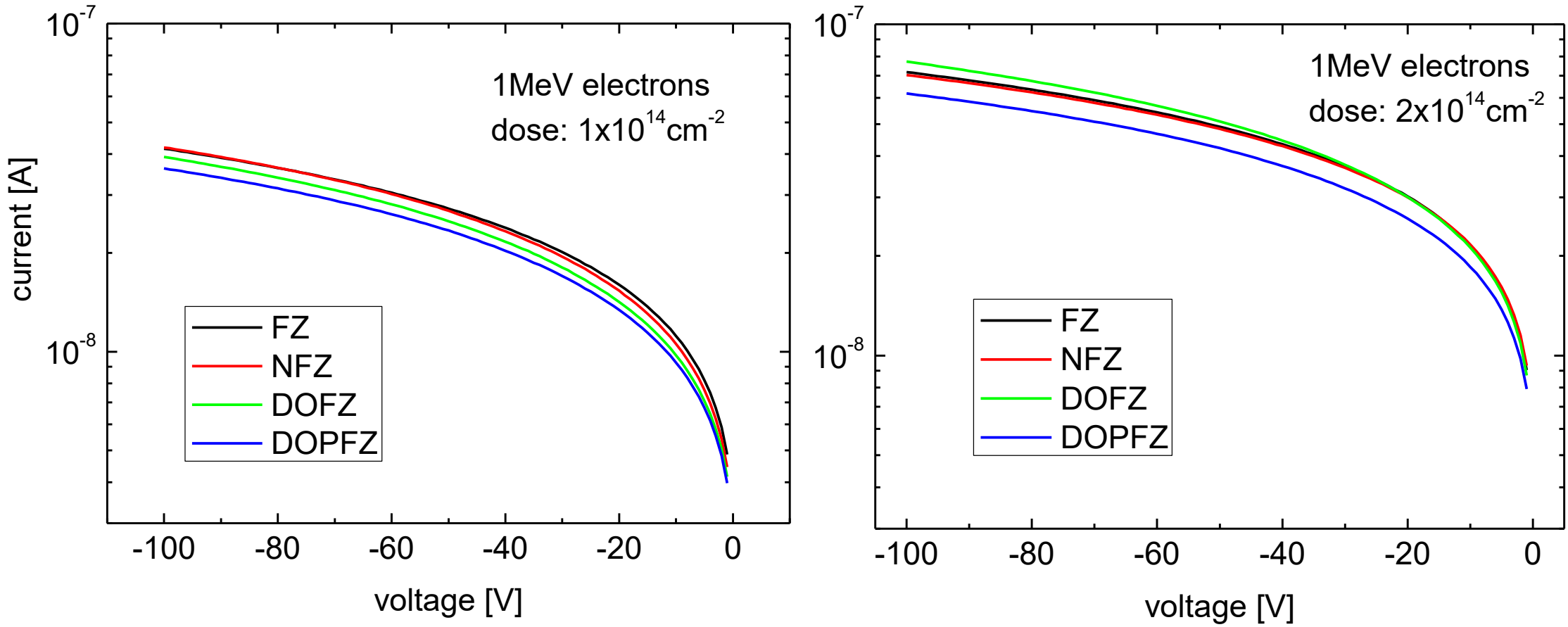
- Boron and phosphorus implantation on front- and backside, respectively

Current-voltage (IV) results



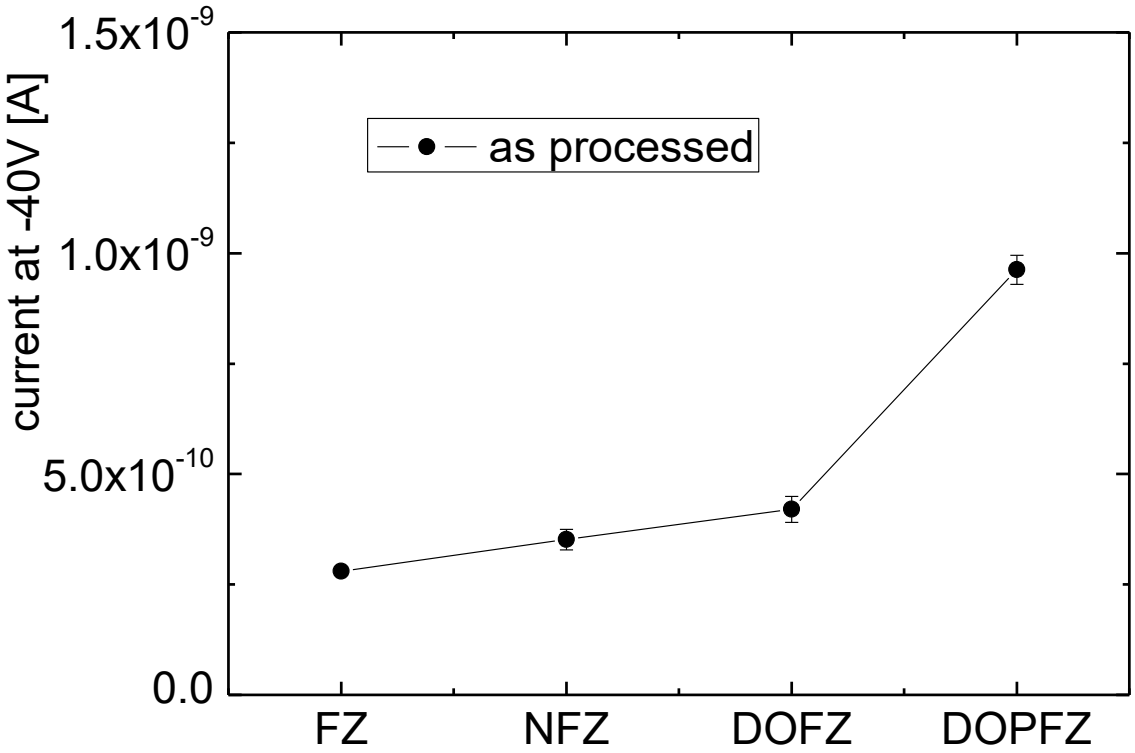
- As processed
- Average of 3 detector chips
- FZ, NFZ and DOFZ below 1nA at -100V

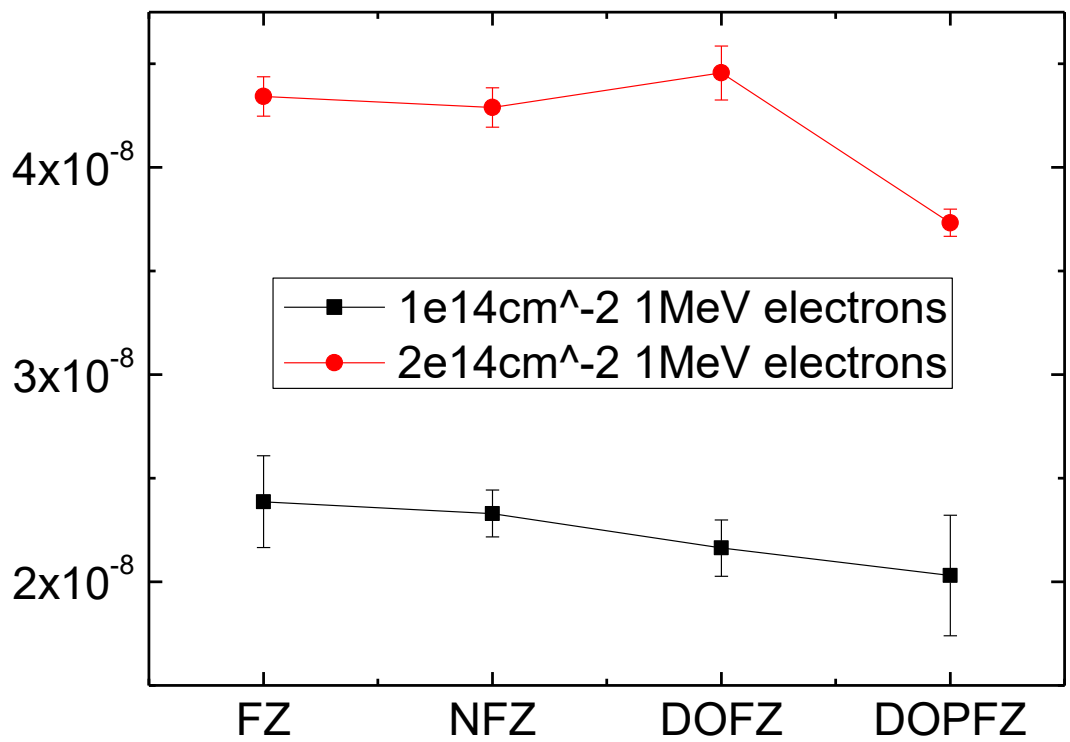
Current-voltage (IV) results



- Detectors irradiated by 1MeV electrons with two different doses
- Average of 3 detector chips
- DOPFZ shows lowest leakage current after irradiation

Current-voltage (IV) results

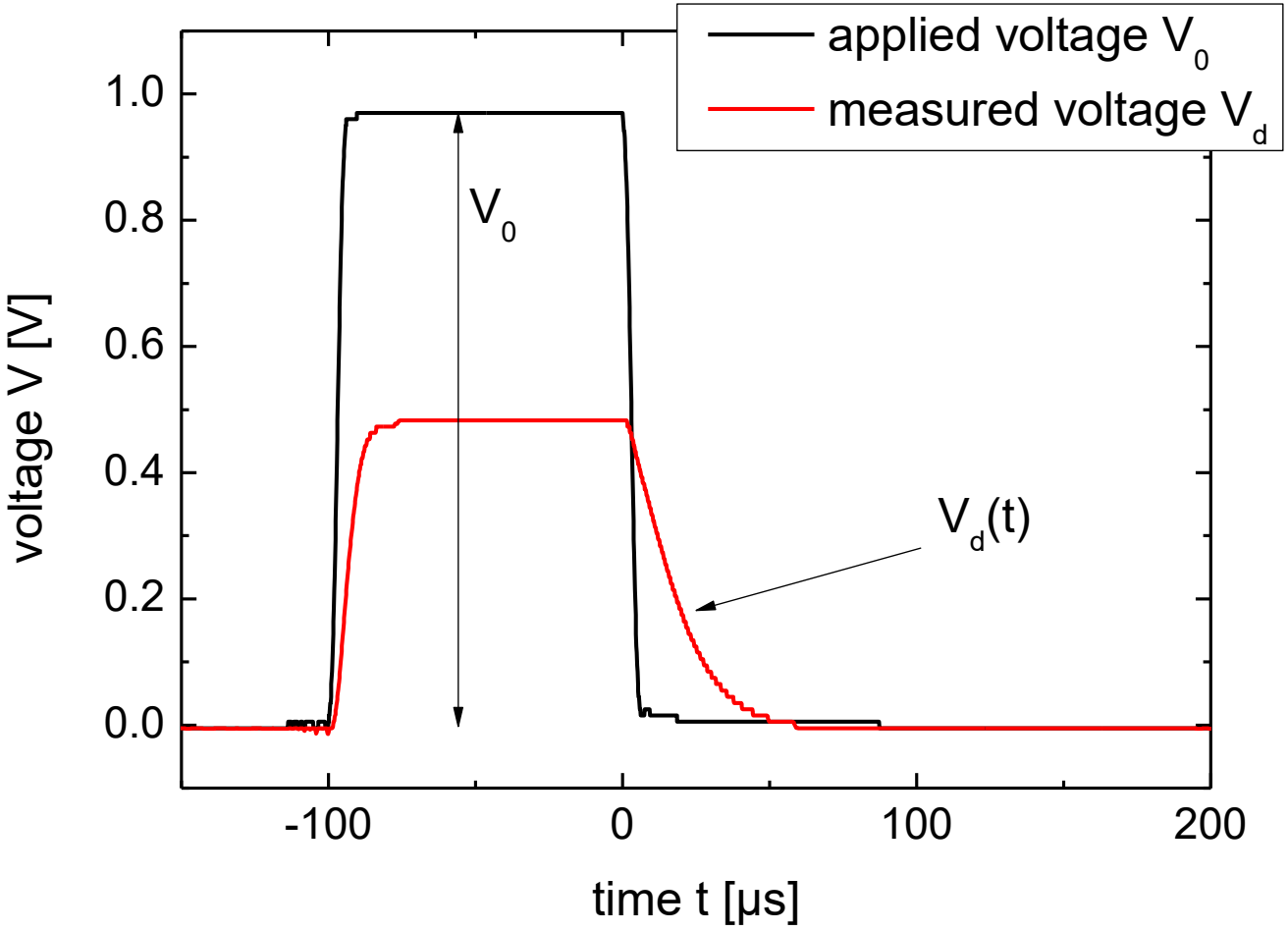




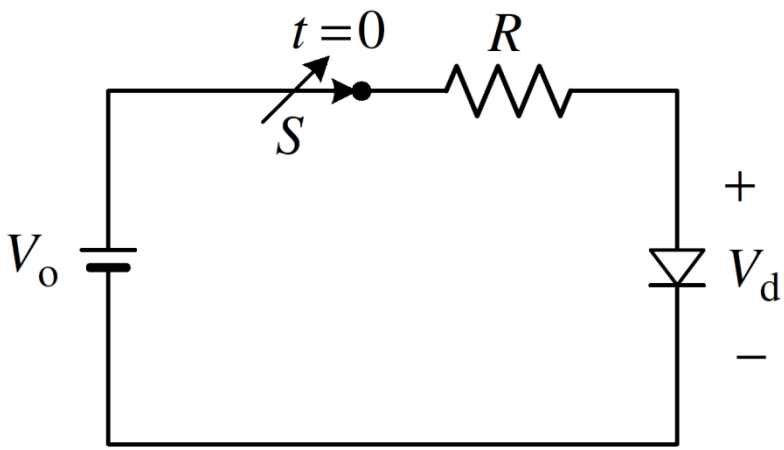
- Increased leakage current in as processed samples due to enrichment
- Large increase in DOPFZ sample

- After irradiation: enrichment leads to slight relative decrease of leakage current
- Except for DOFZ irradiated with high dose, reason unclear
- DOPFZ has significantly reduced leakage current in case of high dose

Charge carrier lifetime

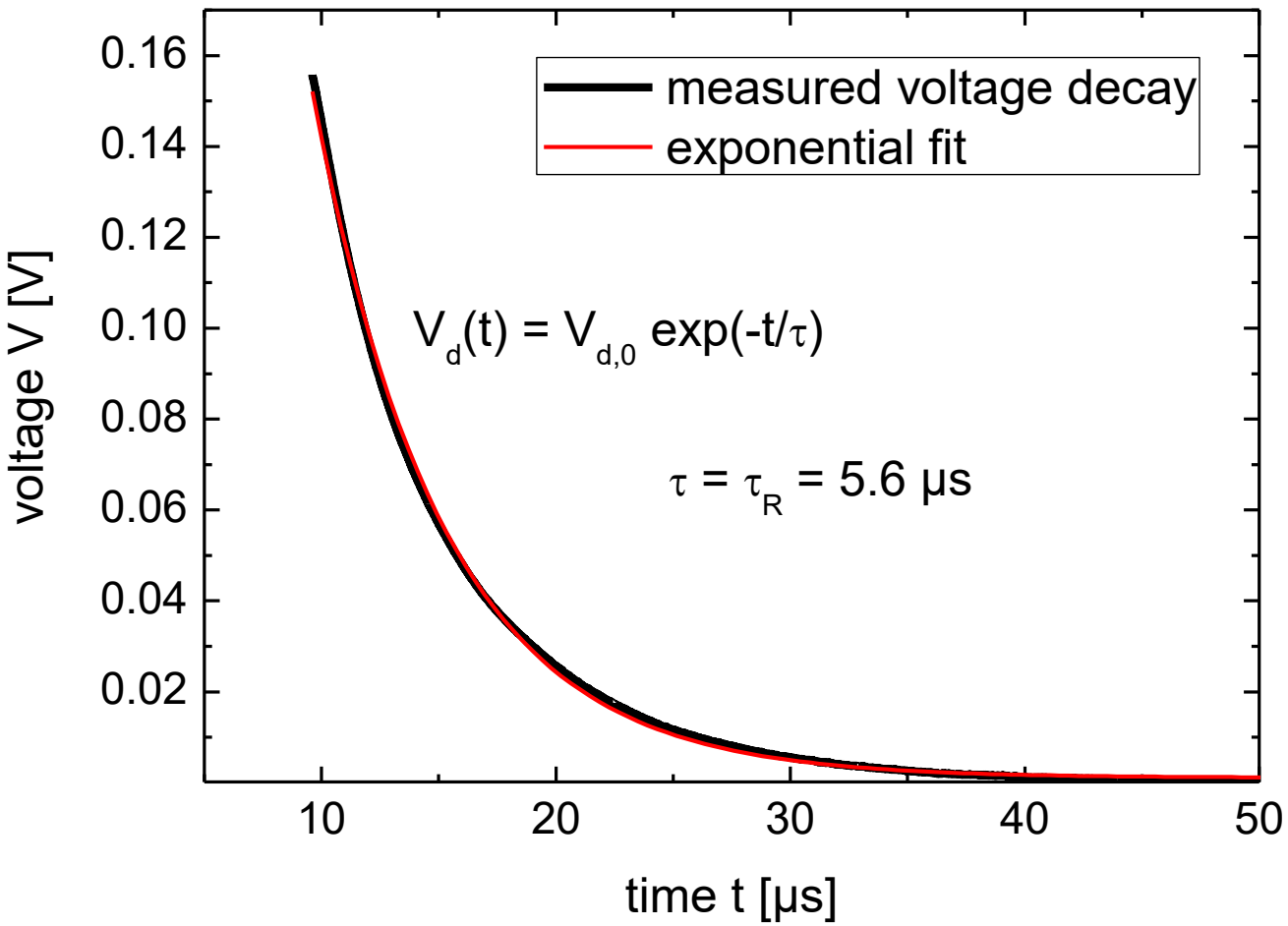


[1] D.K. Schroder, Semiconductor Material and Device Characterization, 3 edition (Wiley-IEEE Press, Piscataway, NJ : Hoboken, N.J, 2006).



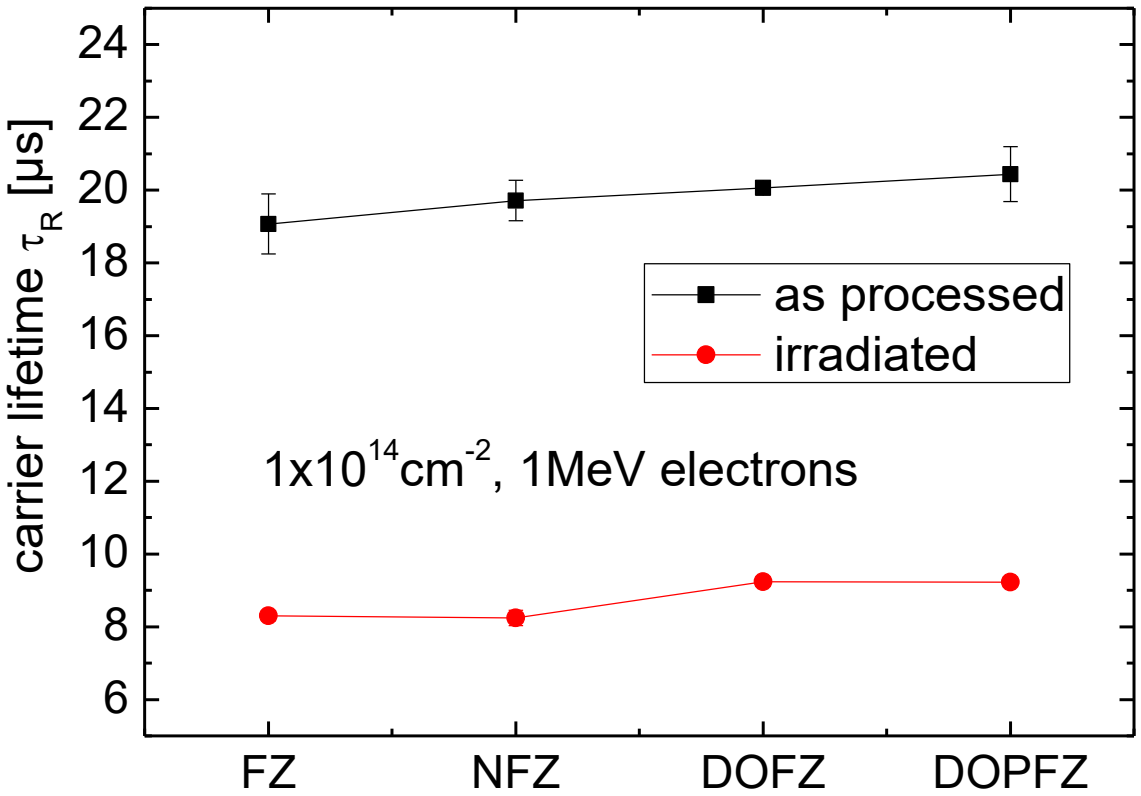
- Charge carrier lifetime obtained on pad detectors
- Open circuit voltage decay measured [1]
- Forward voltage pulse applied

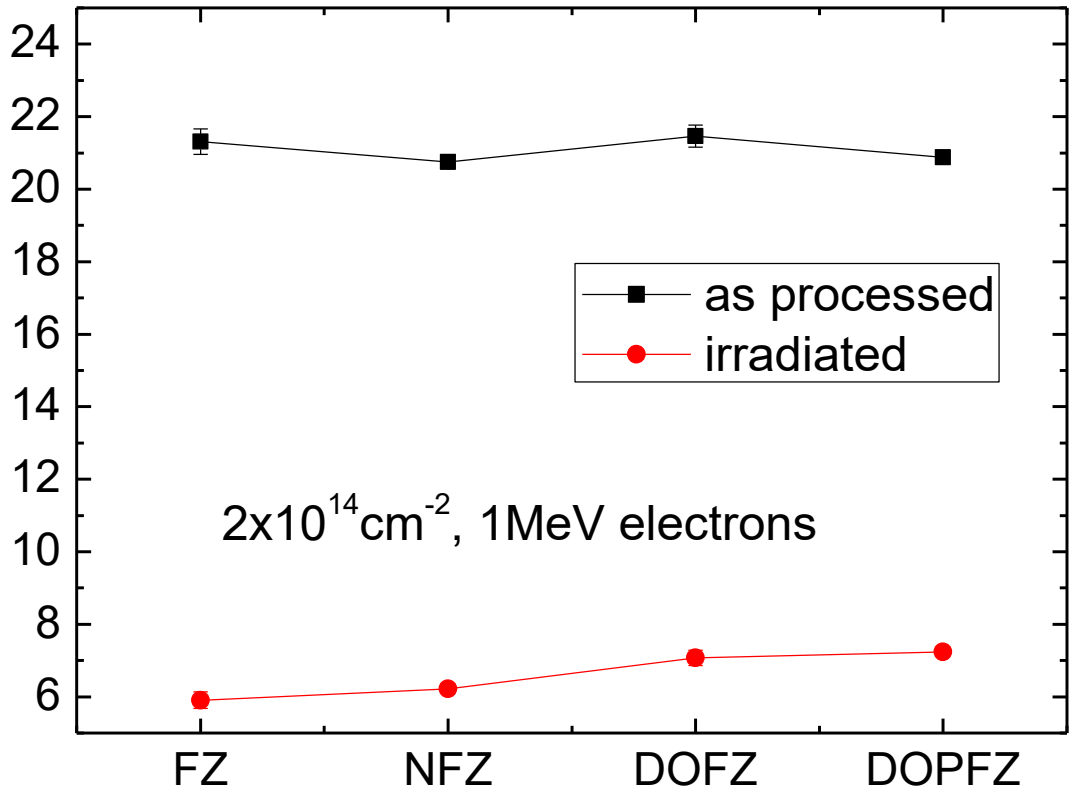
Charge carrier lifetime



- For t > τ, open circuit voltage decay is approximately a mono exponential function
- Time constant of exponential function is in first approximation the carrier recombination lifetime τ_R
- Carrier lifetime is a measure of the density of recombination active defects
- Defect density generated by irradiation can be obtained

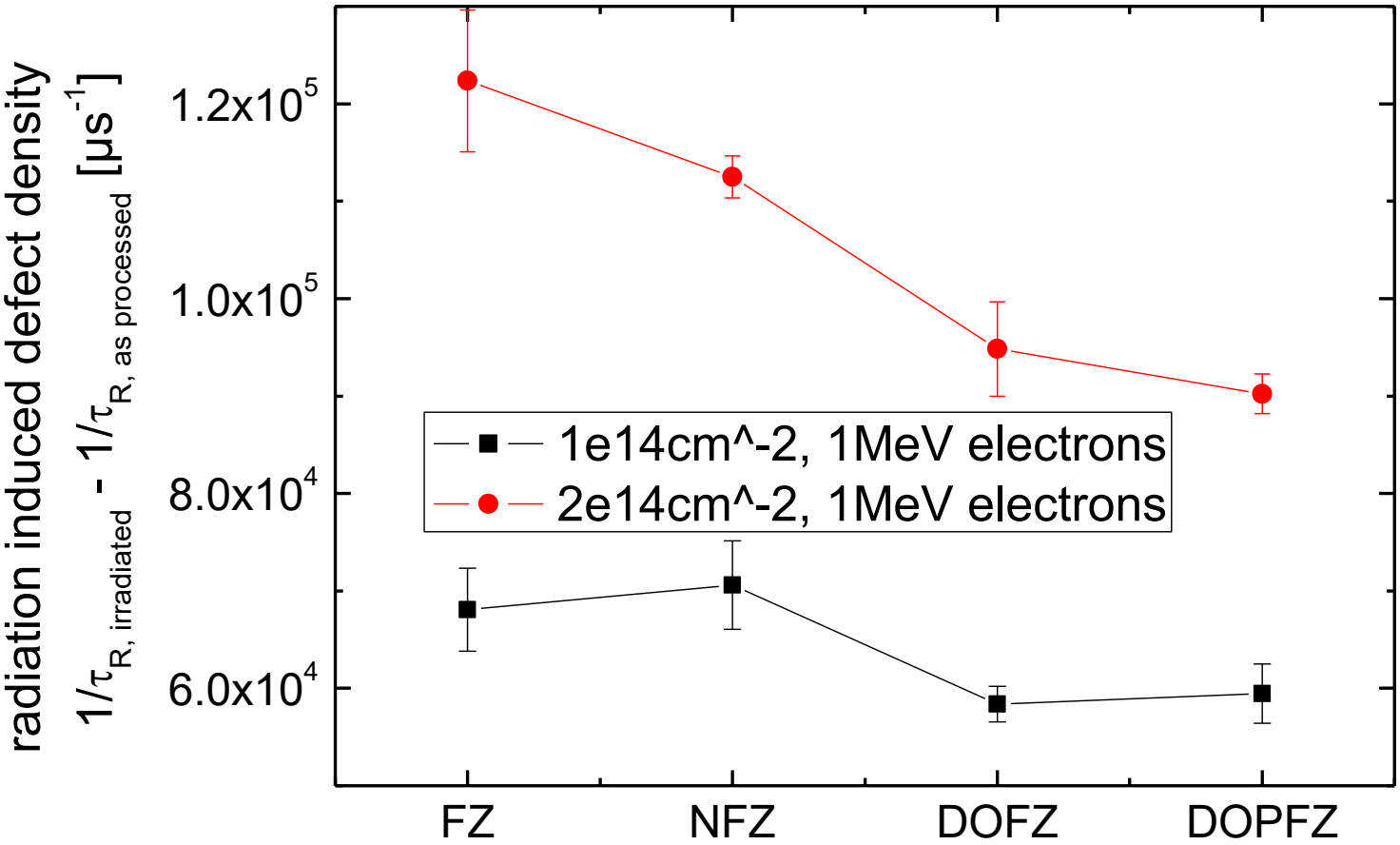
Charge carrier lifetime





- Carrier lifetime significantly reduced due to irradiation
- Inverse carrier lifetime is linear function of recombination defect density
- Radiation induced defect density measured by subtracting inverse carrier lifetime before and after irradiation

Radiation defect density



- Reduction for all types of enrichment in case of high dose
- If reduction in defect density is related to the nitrogen or oxygen content: NFZ has highest "defect reduction efficiency" since [N] concentration is two orders of magnitude less than oxygen concentration in DOFZ
- Largest reduction in defect density for DOPFZ

Summary

- Need to increase radiation hardness of silicon detectors
- One approach: engineering of defects in silicon
- Groups of defect-engineered silicon: standard FZ silicon (FZ), N-enriched FZ (NFZ), O-enriched FZ (DOFZ) and O-enriched FZ with precipitation treatment (DOPFZ)
- Nitrogen and oxygen concentration measured by low temperature FTIR
- P-in-n pad detectors manufactured for each group
- IV measurements after irradiation reveal a relative decrease of leakage current for all types of enrichment, most pronounced for DOPFZ
- Carrier lifetime measurements reveal decrease in radiation induced defect density for all types of enrichment, most pronounced for DOPFZ
- Nitrogen enrichment showed highest “defect reduction efficiency”
- What about p-type silicon?

Thank you for your kind attention!

Bundesministerium
für Wirtschaft
und Energie

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