Investigation of nitrogen enriched silicon detectors

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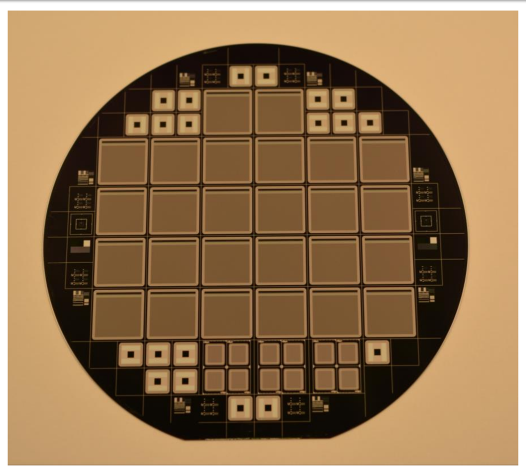
Introduction

- NitroSil project investigates defect engineered silicon for future detectors.
- Nitrogen interacts with vacancies during crystal growth and high temperature steps.
- Vacancies are replaced with nitrogen (N_2) interstitials.



FZ: Floatzone grown Silicon
NIT: Nitrogen enriched during floatzone growth
DOFZ: Diffusion oxygenated floatzone
MCZ: Silicon grown with Magnetic Czochralski process
Subjected to neutron transmutation doping (doping with phosphorus short: NTD).
- 300 +/- 15 µm thickness
- Sensors: 1 x 1cm with 80 µm pitch
- Diodes: active area of 4336 µm x 4336 µm

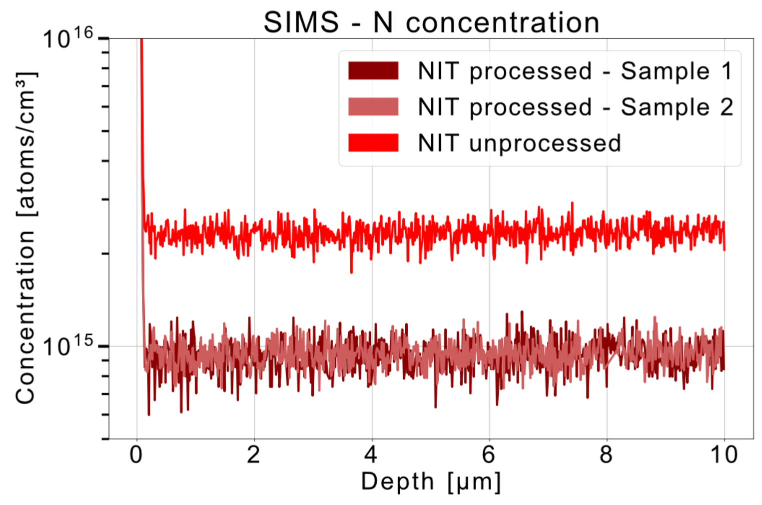
Outline

Wafer processing by IMB-CNM

- The di-interstitial nitrogen defect (N_2) is stable up to 900 ^{o}C and the high temperature process at 1100 ^{o}C is a possible cause for nitrogen loss [1,2].
- Samples are measured using the SIMS technique to determine nitrogen concentration, before and after processing.
- Wafer processing lowers nitrogen content to or below detection limit.

Irradiation with protons (KIT 25 MeV, CERN 24 GeV/c) and neutrons (Ljubljana)
- Strip sensors $10^{14}\ n_{eq}/cm^2$, $3 \cdot 10^{14}\ n_{eq}/cm^2$, $6 \cdot 10^{14}\ n_{eq}/cm^2$ and $10^{15}\ n_{eq}/cm^2$.
- Diodes were irradiated to the same fluences as well as $2 \cdot 10^{11}\ n_{eq}/cm^2$, $5 \cdot 10^{12}\ n_{eq}/cm^2$, $1 \cdot 10^{13}\ n_{eq}/cm^2$ and $5 \cdot 10^{13}\ n_{eq}/cm^2$

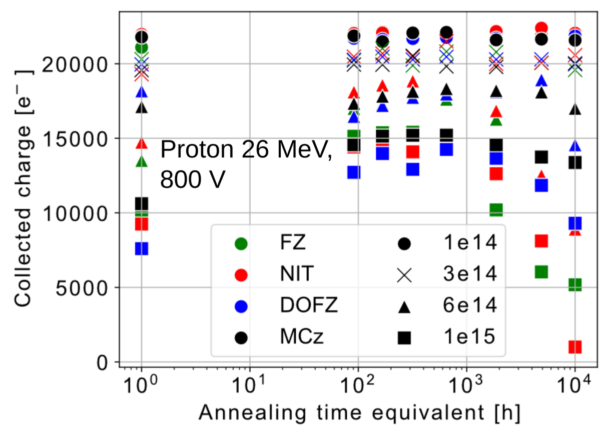
[Eurofins EAG Materials Science]

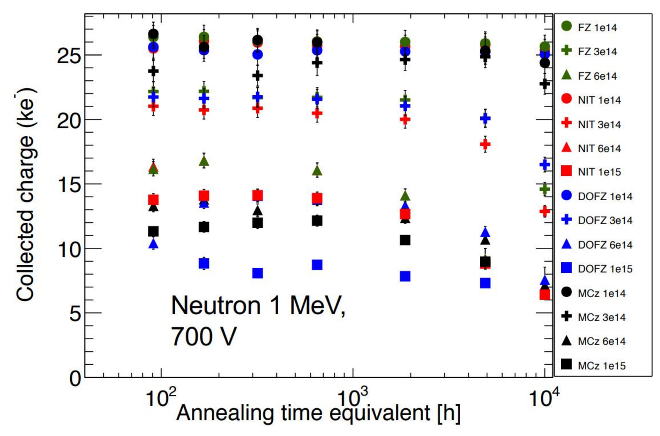


Measurements

Beta source measurements

- Particle from Sr-90 source.
- ALIBAVA readout system with 1 or 2 scintillator triggers.
- Measurements at -20 ^{o}C for proton irradiation and between -14 ^{o}C and -30 ^{o}C for neutrons.

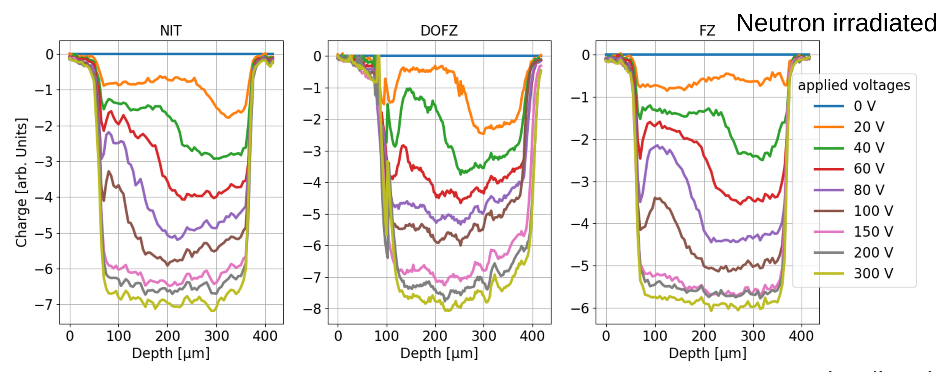


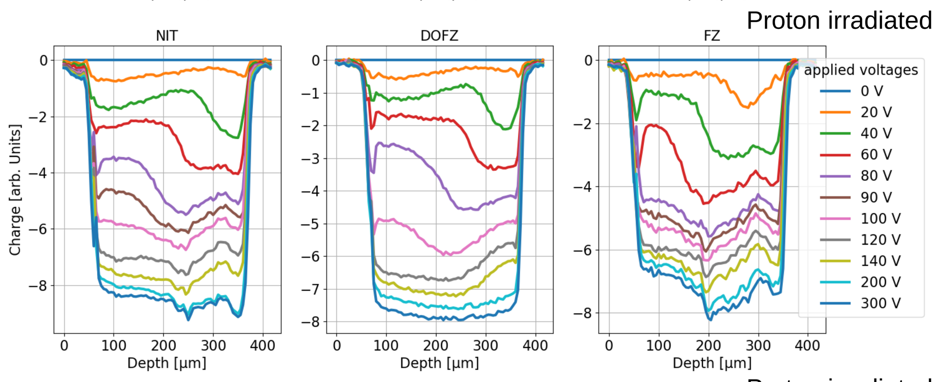


- Until 400h annealing at room temperature equivalent sensors are in beneficial annealing.
- Similar behaviour between **FZ** and **NIT.**
- The $6 \cdot 10^{14}\ n_{eq}/cm^2$ NIT sample shows higher charge collection until an equivalent annealing of 300h.
- Neutron irradiation yielded similar results to proton irradiation.

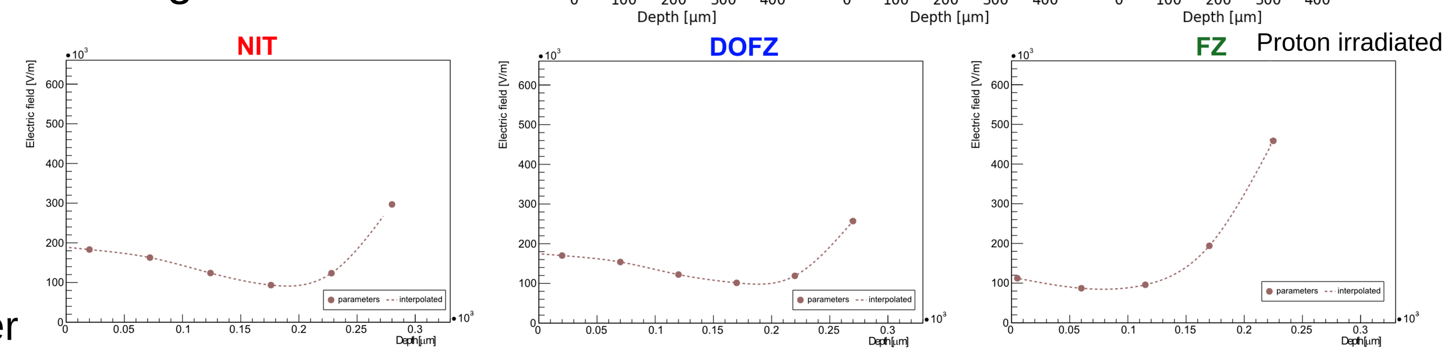
Edge-TCT measurements

- Low depth corresponds to top of the sensor.
- Neutron irradiated samples are fully type inverted and full depletion is reached ~150 V.
- The proton (CERN 24 GeV/c) irradiated sample of **FZ** is fully type inverted.
- **NIT** and **DOFZ** show depletion from front and back.
- Full depletion ~140 V.
- Bottom three plots show E-field calculated according to [3] at 40 V bias voltage.



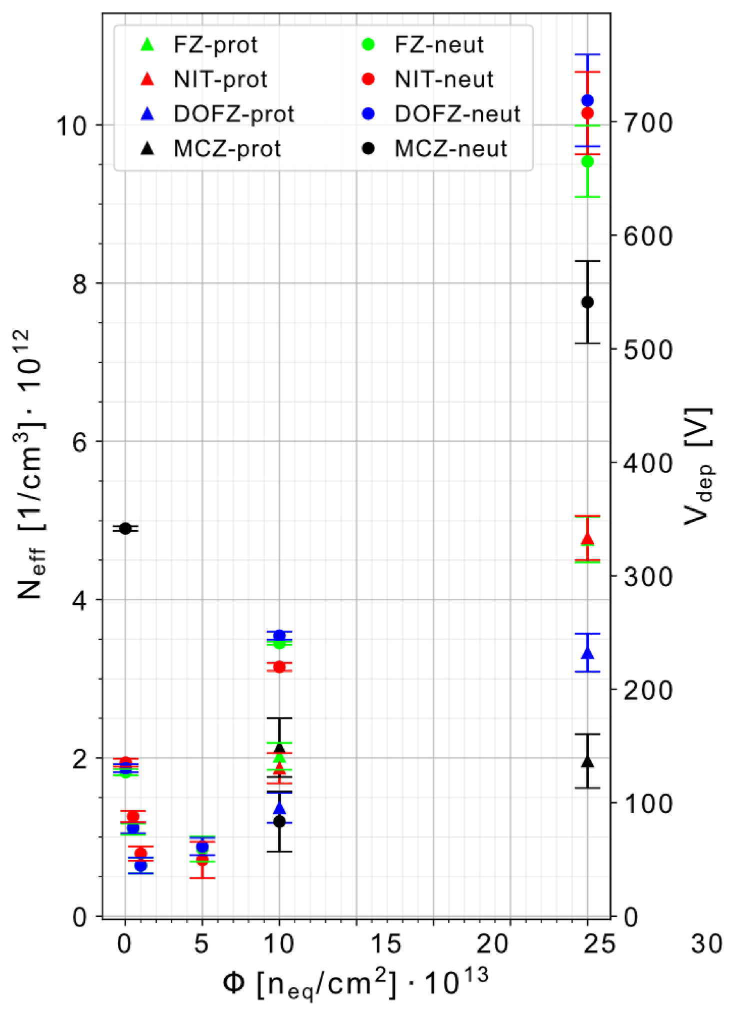


- **NIT** and **DOFZ** show similar behaviour.
- **FZ** E-field is growing back to front.



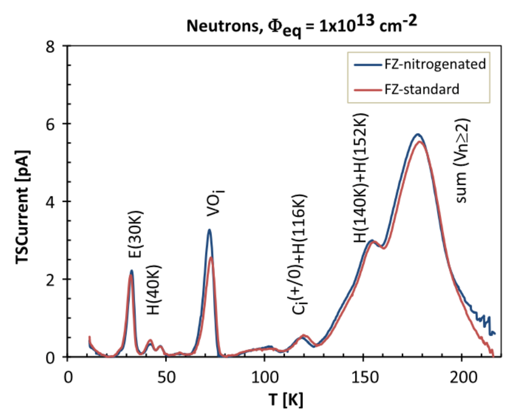
Electrical tests

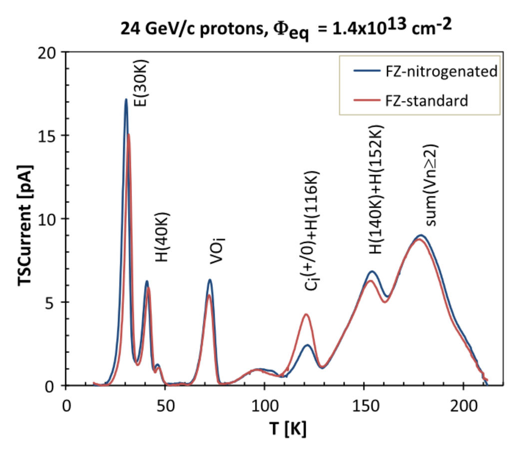
- Electrical characterization before irradiation shows no significant difference between materials.
- Under irradiation with neutrons no significant difference between different floatzone processed samples.
- Irradiation with protons (KIT 26 MeV) shows lower depletion voltages for the oxygen enriched sample.
- **MCZ** shows the lowest depletion voltage under irradiation with neutrons as well with protons (KIT 25 MeV).



TSC measurements

- **Technique**: cool sample (~10 K) → fill traps by applying forward current (1 mA) → apply reverse bias to the sensor → measure the emission of the trapped charge carriers as a function of increasing temperature.
- Spectrum fitted under assumption of single trap model.
- The lower concentration of H(116K) could be responsible for differences in field configuration observed in the Edge TCT measurements





Conclusion and Outlook

- SIMS measurements showed that nitrogen is lost during sensor processing and the concentration is at least decreased down to the detection limit.
- Electrical characterization showed no improvements in terms of effective doping concentration for **NIT**.
- Measurements with a beta source showed decreasing performance at radiation doses beyond $6 \cdot 10^{14}\ n_{eq}/cm^2$ for all float zone sensor types.
- Edge TCT measurements done with proton irradiated samples showed **NIT** behaving more similar to **DOFZ** than **FZ**, with **NIT** being not fully type inverted at $10^{14}\ n_{eq}/cm^2$, which could be caused by increased oxygen precipitation within the **NIT** sample.

[1] N. Fujita, R. Jones, J.P. Goss, P.R. Briddon, T. Frauenheim and S. Öberg, Diffusion of nitrogen in silicon, Appl. Phys. Lett. 87 (2005) 021902.
[2] V.V. Voronkov and R. Falster, Multispecies nitrogen diffusion in silicon, J. Appl. Phys. 100 (2006) 083511.
[3] R. Klanner et al., Determination of the electric field in highly-irradiated silicon sensors using edge-TCT measurements, NIMA (2019) 162987.

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