Defect engineering in PAD diodes mimicking the gain layer in LGADs

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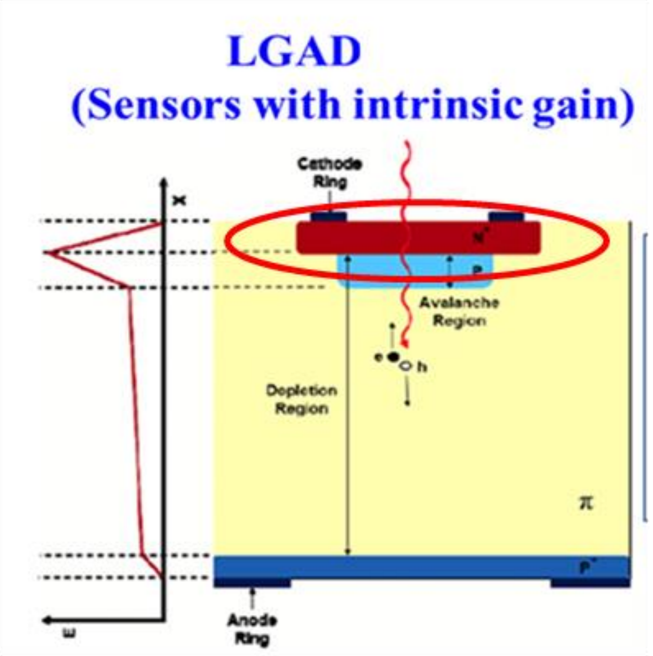
Outline

- **Motivation &Aim**
- **Project plan**
- **Costs**
- **Participants**

Motivation&Aims

Motivation:

- the impossibility of performing the needed defect investigations in the gain layer only, and determine the defects depth profile caused by B and C implantations in the p^+ gain layer.
    - DLTS does not work even for unirradiated devices
    - TSC can evidence only overall signals generated by all the layers in LGAD devices, including possible also the contribution from the highly B-doped back contact, making the gain layer' ARP characterization not reliable



B doping of $10^{16} – 10^{17}$ cm^{-3} in the gain layer and of $10^{12} – 10^{15}$ cm^{-3} in the bulk

Aims:

- *Understand* the acceptor removal process (ARP) in the irradiated gain layer of LGAD sensors
- Parametrize the ARP in the gain layer for various content of B, C and O impurities and irradiation fluences
- find proper defect engineering solutions to maximize the radiation hardness of the gain layers.

Project plan

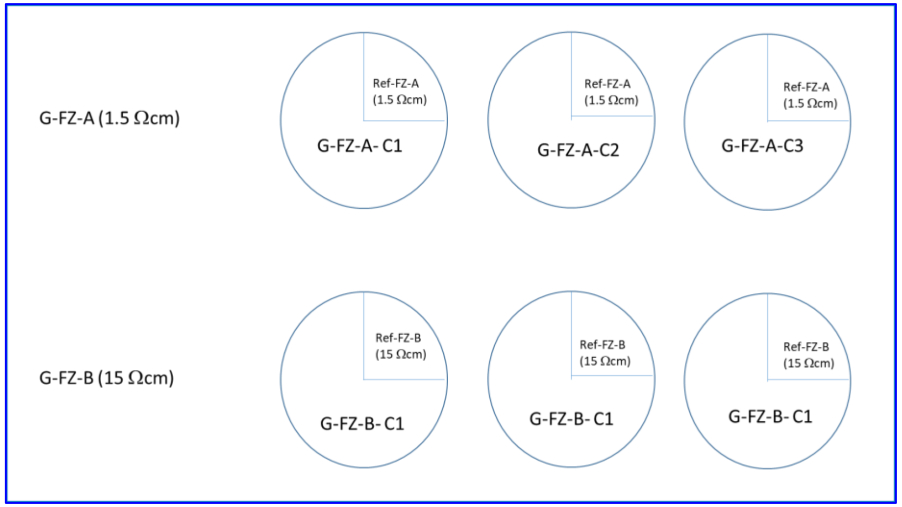
I) Fabrication of special samples, mimicking the gain layer (G- type PAD diodes) in the presence of different amounts of B, O and C impurities. CZ and FZ silicon wafers are preferred to start with because the B and O impurities are homogeneously distributed in the bulk of the samples. The variation of C content will be achieved by implantation.

1) on CZ material (p^+), by the required P and B implantations for the n^{++} and p^{++} sides of the diode – these PAD diodes will be labelled as G-CZ further on;
- p^+ in CZ – of 1.5 and 15 Ω cm resistivity, three 4” wafers of each resistivity
- three C implantations just below the n^{++} side: with C peak between 10^{17} and 10^{19} C/cm^3, preserving a quarter of each of the wafers as reference (with no C implantation).

2) on FZ material (p^+), by the required P and B implantations for the n^{++} and p^{++} sides of the diode

- p^+ in FZ – of 1.5 and 15 Ω cm resistivity, three 4” wafers of each resistivity

- three C implantations just below the n^{++} side: with C peak between 10^{17} and 10^{19} C/cm^3, preserving a quarter of each of the wafers as reference (with no C implantation)



Project plan

II) Investigation and modelling

- **Secondary Ion Mass Spectroscopy (SIMS)** in order to determine the impurity content and depth profile
- **Characterization of radiation induced defects in p-type silicon** (G-CZ and G-FZ)**, different doping and impurity content, different fluences and irradiations, trapping times etc.**

- *Deep Level Transient Spectroscopy (DLTS) – getting defect concentrations and depth profiles*
- *Thermally Stimulated Current/Capacitance (TSC/TSCap)* - parametrizing the variations in time of B_iO_i defect concentrations in connection with those of N_{eff} as determined from CV/IV characteristics.
- On all of the samples, experiments for getting the time constants of stabilizing the B_iO_i defect in the A configuration will be performed.
- Two types of annealing experiments will be successively performed:

(i) first - isothermal annealing at 60^0C – for indirect determining the C amount in the regions where the concentration of this impurity falls below the detection limit of the mass spectroscopies;

(ii) second - isochronal annealing studies above 140^0C, for following the B_iO_i dissociation and other possible Boron related defects (e.g. B_iO_{2i} and B_iB_s, the latter probable to form in the p^+ and p^{++} layers of the devices). This way also an estimation of how much of the defect concentration exists in the non-measurable B configuration of the defect can be estimated.

- *CCE, TCT* - charge collection, trapping times

- **Modelling and Simulations**

- Computing models for analyzing the TSC/TSCap signals in highly irradiated devices accounting for the temperature dependence of the charged stored on defects and the resulting change of the electric field which manifest in further changing the occupancy of defects showing PF effect.
- Numerical modelling of LC, N_{eff} and the time constants for stabilizing the devices
- Modelling the defect reactions taking place in the presence of impurities, during and after irradiation, account for the impurity content resulted from mass spectroscopies, determine the amount of B_s removed by forming B-containing complex defects, determine how much B is stored in B_iO_i (in both configurations) as well as other types (such B_iB_s or B_iO_{2i}) and parametrize ARP.

Costs

Costs Breakdown

The estimated costs in EUR are:

12 wafers processing run with C – implantation: **23.100 EUR**

Design of new test structures and waferlayout: **2.000 EUR**

Set of lithography masks: **4250 EUR**

SIMS measurements in the first 5 µm – **4970 EUR**:

4 samples for B, P, O, C (3090 EUR) and 3 samples for C implantations) (1880 EUR)

Total project cost estimate: 34.320 EUR

Partners

Activity	Institute	Lead
Wafer processing, sheet resistance, PL	CiS	Kevin Lauer
Secondary Ion Mass Spectroscopy	Dresden CiS	
Neutron irradiation	JSI	Gregor Kramberger
Proton irradiation	CERN	Michael Moll
Characterization (electrical, TCT, defects), modelling and simulations	NIMP	Ioana Pintilie
	CERN	Michael Moll
	HH	Eckhart Fretwurst
	JSI	Gregor Kramberger

Anyone else interested to join this project ?

Thank you for your attention !

the two B_iO_i configurations in PADs and LGADs

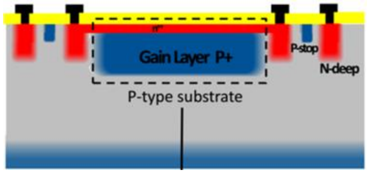
As seen in TSC

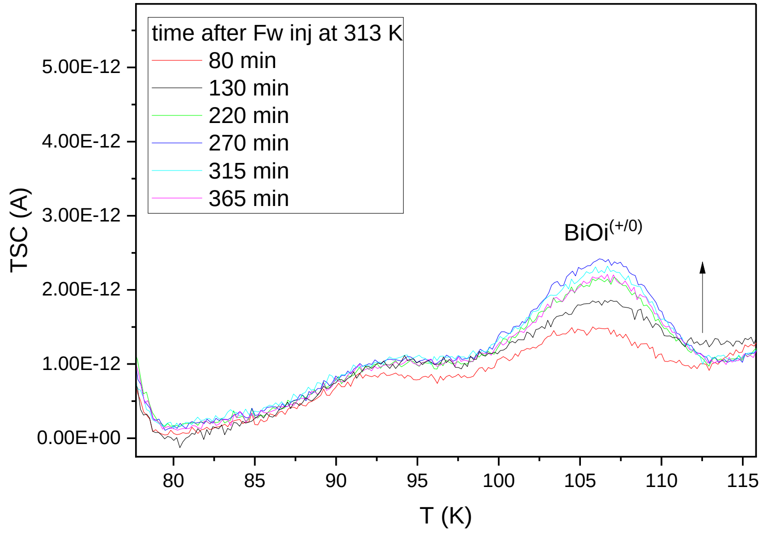
From B to A configuration,

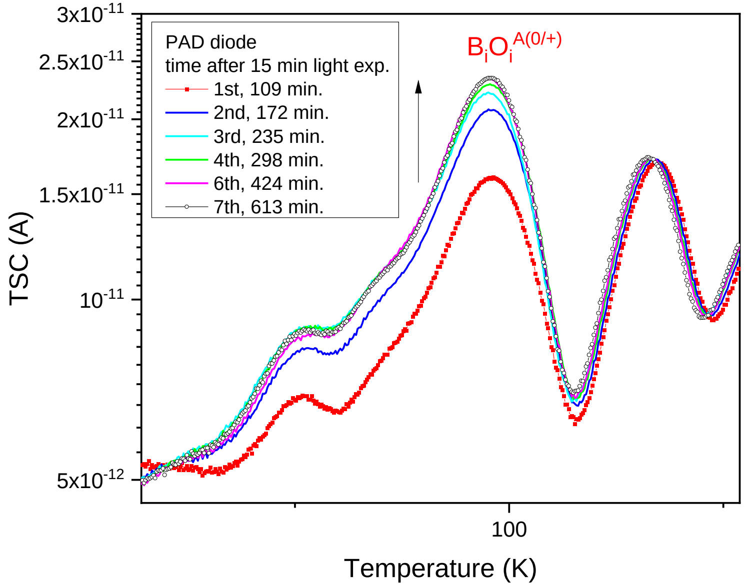
after light exposure at RT (I_{sc} =5.7 µA)

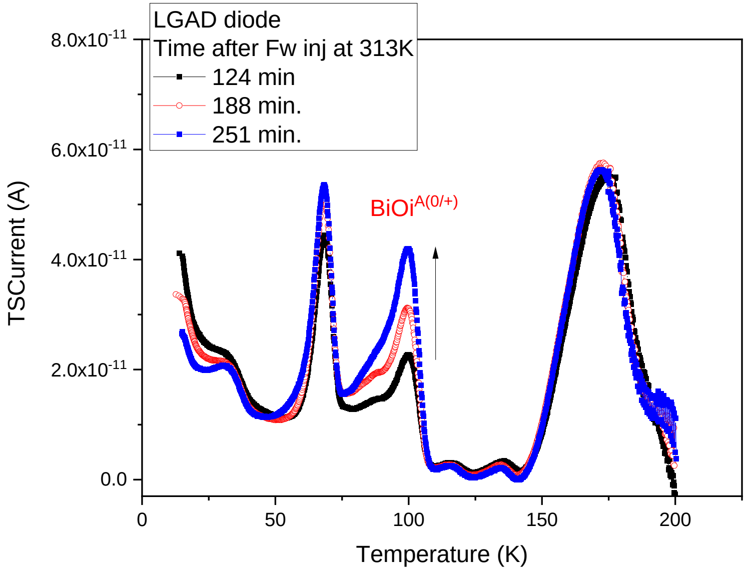
$\Phi_{eq} = 10^{14}$ n/cm²

$\Phi_{eq} = 10^{15}$ n/cm²









filling with 0.3 mA at 10K, heating rate 0.183K/s