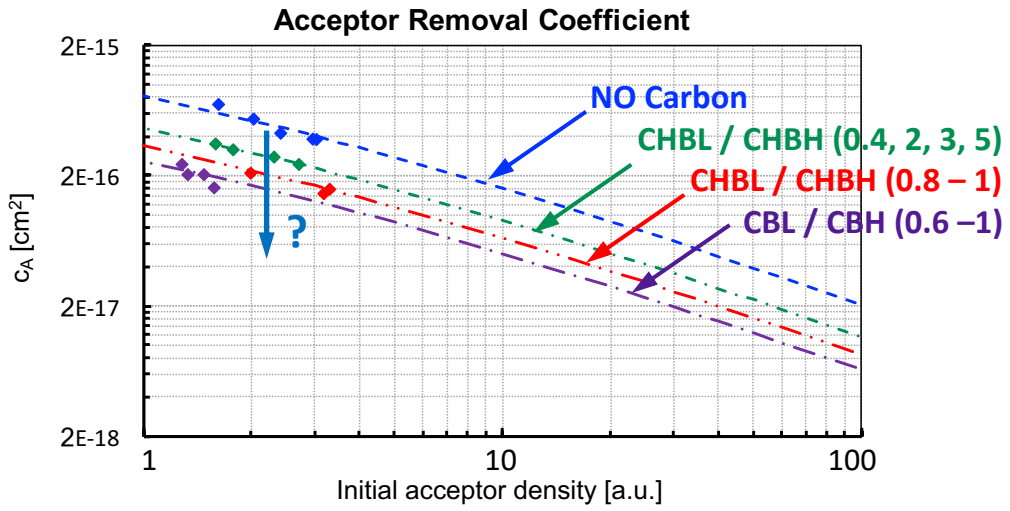
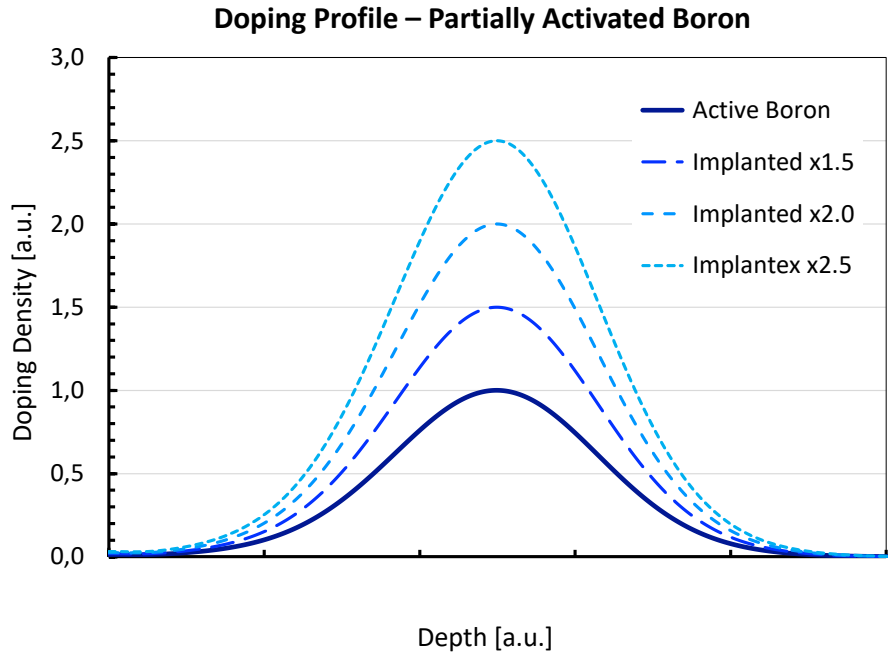
RD50 Common Project Proposal
Partial Activation of Boron to enhance the radiation tolerance of the gain implant (PAB)

V. Sola for the PAB team

The Idea

Investigate the partial activation of the boron atoms implanted in the LGAD gain layer to enhance the tolerance to radiation





The Motivation

If the reactions

$B_s + Si_i \rightarrow B_i$

$B_i + O_i \rightarrow B_iO_i$

are main players in the acceptor removal process, increasing the fraction of B_i already present in the lattice, may protect B_s from removal

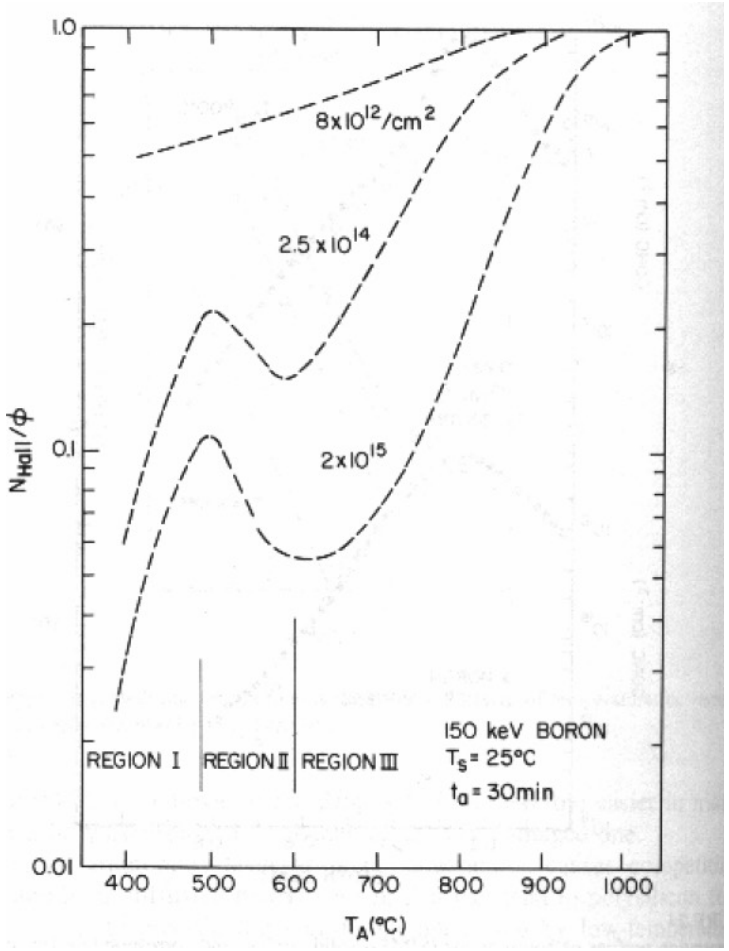
HPK already tested the half activation of boron (HAB) showing an improvement in the gain layer radiation tolerance [1]

It is possible that there is an interval in the fraction of active / implanted boron which minimise the acceptor removal and it needs to be carefully investigated

[1] K. Hara et al., Improvement of timing resolution and radiation tolerance for finely segmented AC-LGAD sensors, 18th "Trento" Workshop on Advanced Silicon Radiation Detectors (2023), indico.cern.ch/event/1223972/contributions/5262001

Partial Activation of Boron

Isochronal annealing of boron

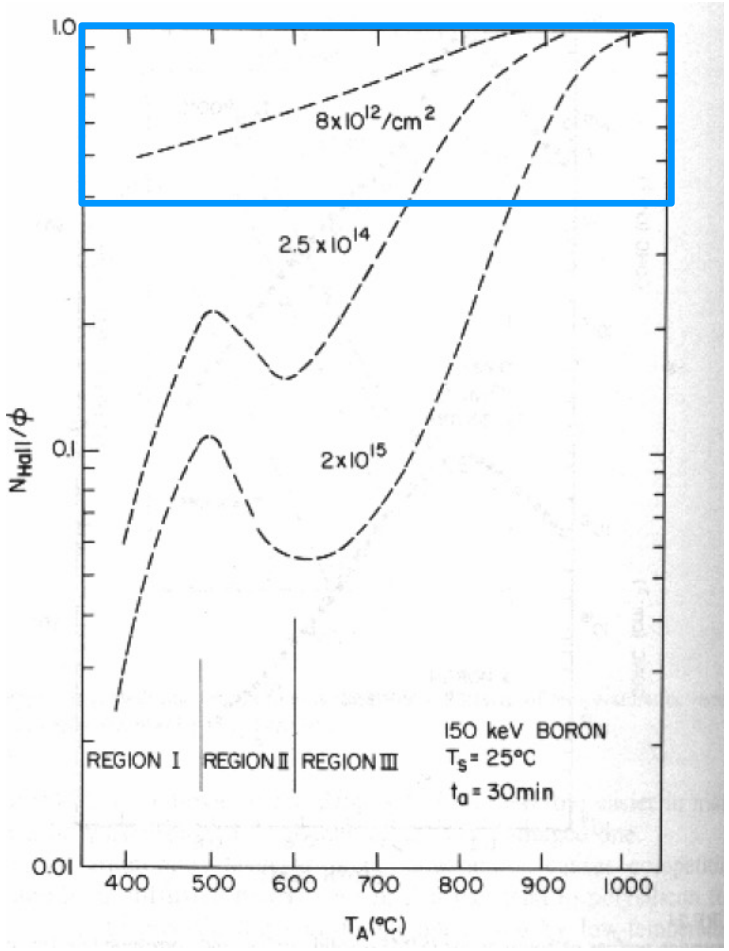


Region I	Region II	Region III
Below 500°C point defects dominate free carrier concentration. As temperature increases these defects diffuse and combine. Net carrier concentration increases as many traps anneal out.	Above 500°C extended defects are formed which reduce the number of substitutional boron atoms and cause a net decrease in carrier concentration. This is called **Reverse Annealing.**	Above 600°C fraction of activated dopant atoms increases as point defect generation and migration allows precipitates and dislocations to dissolve.

T.E. Seidel and A.U. Mac Rae, The isothermal annealing of boron implanted silicon, Radiation Effects 7 (1971) 1, doi:10.1080/00337577108232558

Partial Activation of Boron

Isochronal annealing of boron



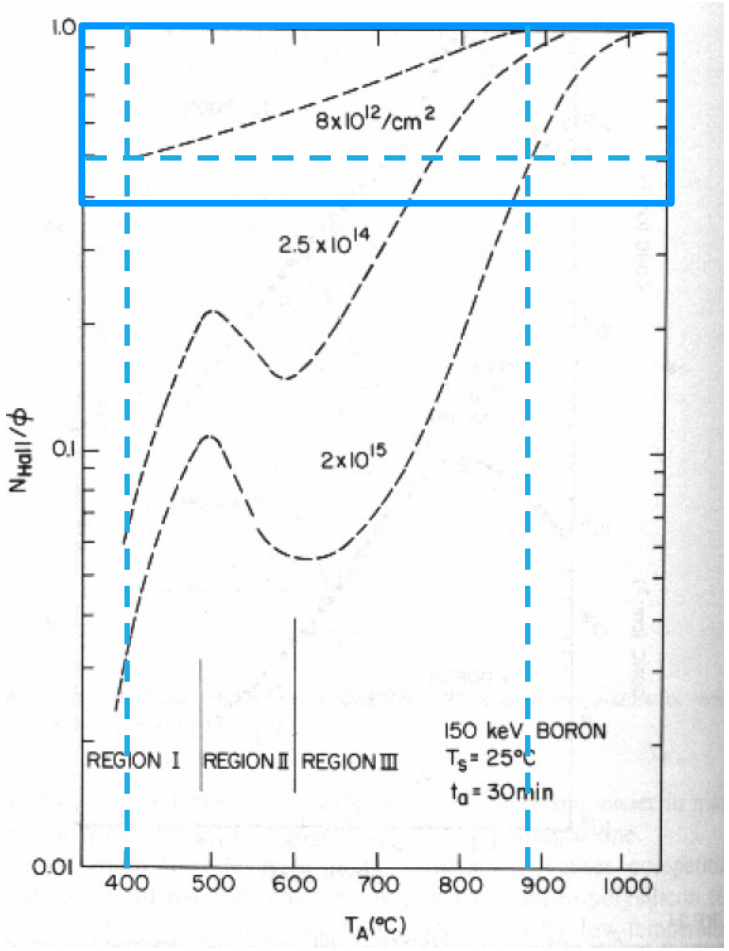
8E12/cm^2 is similar to the dose of the gain layer implant

Region I	Region II	Region III
Below 500°C point defects dominate free carrier concentration. As temperature increases these defects diffuse and combine. Net carrier concentration increases as many traps anneal out.	Above 500°C extended defects are formed which reduce the number of substitutional boron atoms and cause a net decrease in carrier concentration. This is called **Reverse Annealing.**	Above 600°C fraction of activated dopant atoms increases as point defect generation and migration allows precipitates and dislocations to dissolve.

T.E. Seidel and A.U. Mac Rae, The isothermal annealing of boron implanted silicon, Radiation Effects 7 (1971) 1, doi:10.1080/00337577108232558

Partial Activation of Boron

Isochronal annealing of boron



8E12/cm^2 is similar to the dose of the gain layer implant

→ **In this case, the activated fraction ranges from 50% at T = 400°C to 100% at ~ 900°C**

Region I	Region II	Region III
Below 500°C point defects dominate free carrier concentration. As temperature increases these defects diffuse and combine. Net carrier concentration increases as many traps anneal out.	Above 500°C extended defects are formed which reduce the number of substitutional boron atoms and cause a net decrease in carrier concentration. This is called **Reverse Annealing.**	Above 600°C fraction of activated dopant atoms increases as point defect generation and migration allows precipitates and dislocations to dissolve.

T.E. Seidel and A.U. Mac Rae, The isothermal annealing of boron implanted silicon, Radiation Effects 7 (1971) 1, doi:10.1080/00337577108232558

List of Participants – IN PROGRESS

INFN Torino – Coordination and characterisation

CNM – Sensor production

FBK – Sensor production

INFN Perugia – Simulation and characterisation

University of Montenegro – Characterisation

. . .

List of Participants & Activity Plan

INFN Torino – Coordination and characterisation

CNM – Sensor production

FBK – Sensor production

INFN Perugia – Simulation and characterisation

University of Montenegro – Characterisation

. . .

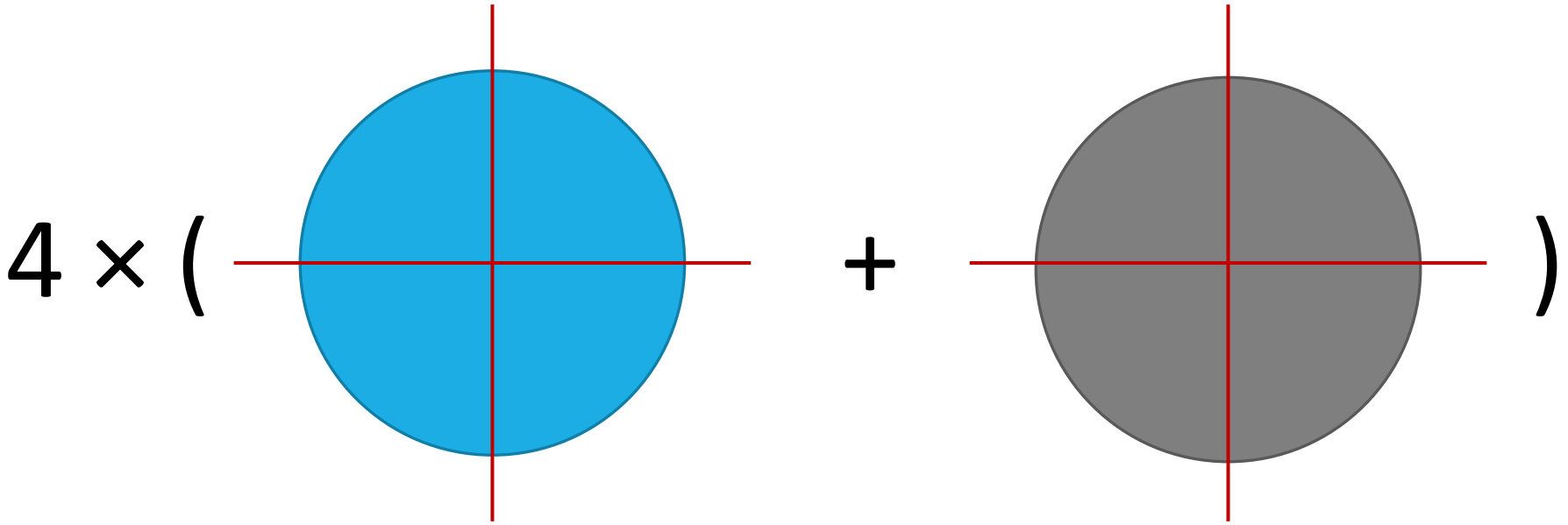
The production of two sensor batches is foreseen, one from CNM and one from FBK

The simulation of the process, the design and simulation of the devices, and the sensor characterisation before and after irradiation are necessary, and, of course, irradiation is crucial

Production Proposal by FBK & CNM

A production batch will consist of 8 wafers:

- ➢ 4 wafers with different implanted boron dose
- ➢ 4 wafers with same implanted boron dose + carbon
- ➢ each wafer will be cut in 4 parts that will receive different annealing



Estimate of the Core Cost by FBK

It is forseen a cost saving on
- layout design
- reticles
- substrates

resulting from previous production batches

Production costs:
- process
- external implant of Carbon
- on wafer testing
- dicing

Estimate of the Core Cost by CNM

It is forseen a cost saving on
- layout design
- reticles

resulting from previous production batches

Production costs:
- substrates ☞ usage of RD50 common substrates?
- process
- external implant of Carbon
- eventual external implant of Boron
- on wafer testing
- dicing

Summary

- **We propose an RD50 common project to investigate the Partial Activation of Boron to enhance the radiation tolerance of the gain implant**

- **Two foundries expressed their interest in participating to the project**
  → Two sensor batches will be produced, one by each foundry

- **We are looking for potentially interested institutes to join the project activity**

Acknowledgements

We kindly acknowledge the following funding agencies:

- INFN CSN5
- AIDAinnova, WP13
- Compagnia di San Paolo
- Ministero della Ricerca, Italia, FARE, R165xr8frt_fare
- Ministero della Ricerca, Italia, PRIN 2017, progetto 2017L2XKTJ – 4DinSiDe
- MIUR, Dipartimenti di Eccellenza (ex L. 232/2016, art. 1, cc. 314, 337)
- European Union's Horizon 2020 Research and Innovation programme, Grant Agreement No. 101004761

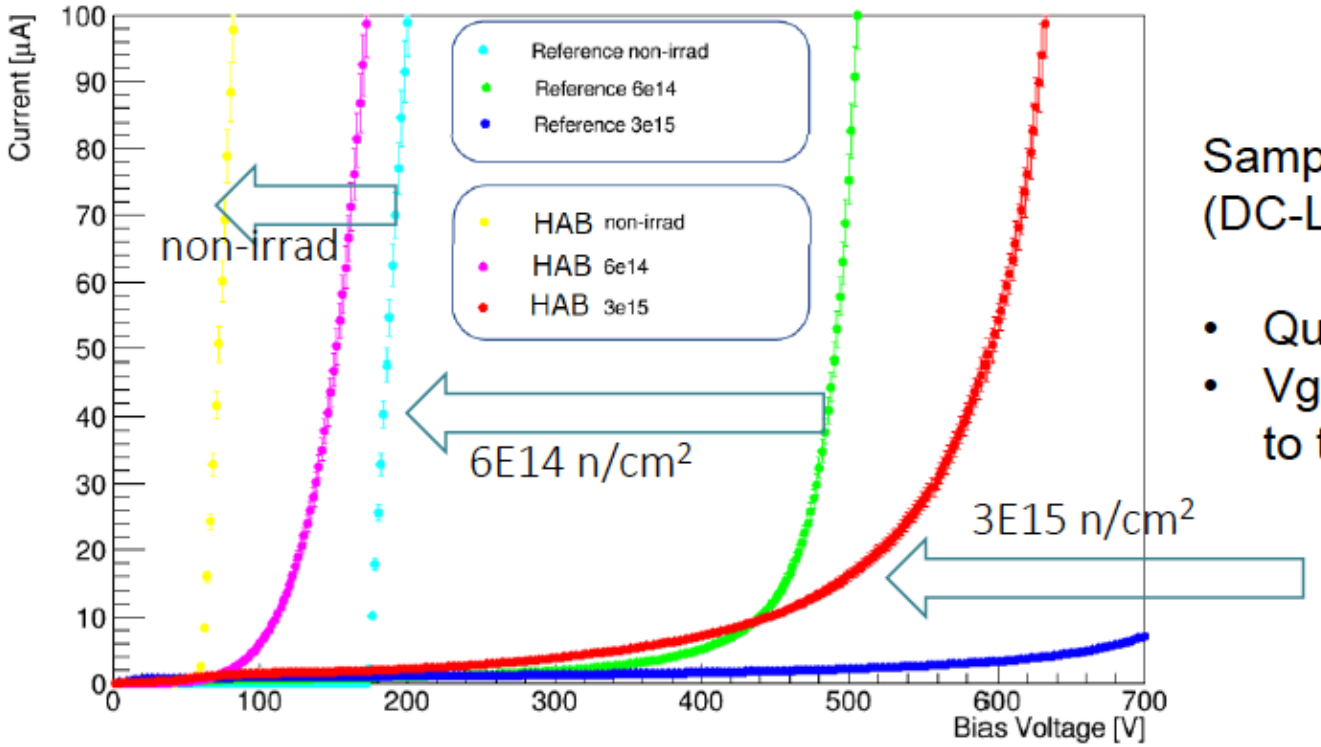
Backup

Radiation tolerance improvement – trial1

HPK is investigating to improve their (poor) radiation hardness !

HAB = Half Activated Boron

dope Boron more than required -> insufficient annealing process
->Borons not in Si lattice work to suppress “acceptor removal” e.g. capture O



Samples: HGTD prototype (DC-LGAD)

- Quite promising results
- Vgain at non-irrad needs to tune higher