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

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Abstract

The partial activation of the boron atoms implanted in the gain layer region will be investigated to mitigate the effect of radiation on the gain implant in LGAD sensors [1, 2]. Atoms of boron in the gain layer volume left as interstitials can interact with other impurities present in the silicon lattice, preventing the removal of boron atoms from substitutional positions.
The goal of the project is to investigate the effect of partial activation of boron (PAB) to mitigate the boron removal due to irradiation and to extend by more than a factor of 2 the radiation tolerance of the LGAD sensors.

Different concentrations of implanted boron need to be explored, together with different times and temperatures of activation, to define a standard procedure for the PAB. Different combinations of active/total concentrations of boron will be investigated, with total concentration ranging between 1.5 and 2.5 of the nominal dose.
The project foresees the process simulation and design of the boron implant with different activation strategies, together with the device simulation and the design of the structures that will be included in the batch. Irradiation of sensors with different types of radiation, such as neutrons and protons, is foreseen. Characterisation of the devices before and after irradiation will test the resilience to irradiation of the PAB design.

The ultimate goals of the project are to find the best combination of boron dose and activation parameters, enhance the gain implant resistance to radiation, and define a standard process with easy-to-use production parameters for LGAD sensors with PAB.

Project description

The aim of the project is to improve the radiation tolerance of the boron atoms in the gain layer implant by mapping different doses of implanted dopant while maintaining constant the activated dose, indicated as dose 1 in Fig.1. Promising results have been presented in [3], through the half activation of the implanted boron.

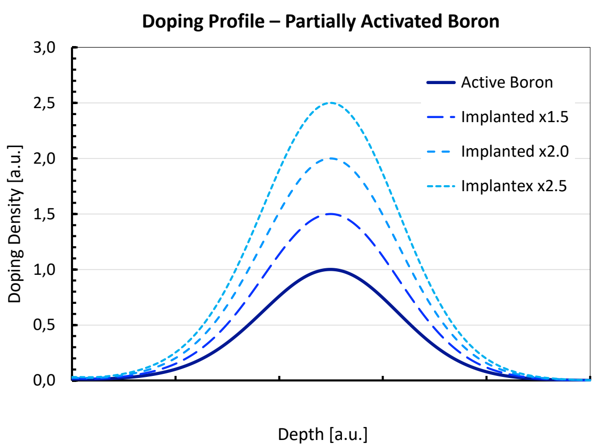

Figure 1: Profile of dopant density forming the gain implant of LGAD sensors exploiting partial activation of boron. Different doses of implanted boron are shown. The goal is to keep a constant dose of active dopant, indicated as dose 1, while studying the effect of different implant concentrations.

However, the electrical activation of boron atoms in the silicon lattice is not easy to control and strongly depends on the initial implanted dose, ϕ, and the temperature of annealing, T_A. Figure 2 shows the fraction of boron atoms in the substitutional position (active Boron) with respect to the total implanted dose, p/ϕ, for three different values of ϕ. It is possible to define three different regions depending on the temperature:

I. Below 500º C point defects dominate free carrier concentration. As temperature increases, these defects diffuse and combine. Net carrier concentration decreases as many traps anneal out.

II. Above 500º C, extended defects are formed, which reduce the number of substitutional boron atoms and cause a net decrease in the carrier concentration (reverse annealing).

III. Above 600º C fraction of activated dopant atoms increases as point defect generation and migration allows precipitates and dislocation to dissolve.

The typical boron dose used to form the gain layers in LGADs is quite low, and the activation fraction curve is expected to be similar to the upper curve in Fig. 2 (corresponding to a dose of 8E12/cm^2). Anyway, changes in the boron implanted dose may result in a different activation behavior, as shown by the different curves in Fig.2.

It should be noted that at a low dopant concentration, the activation fraction is quite high already at low temperatures (50% at 400ºC), and the thermal budget used during the fabrication process could lead to unwanted full activation of the implant. To avoid the latter effect, the process thermal budget subsequent to the Boron Ion Implantation has to be revised to reach the target activation fraction.

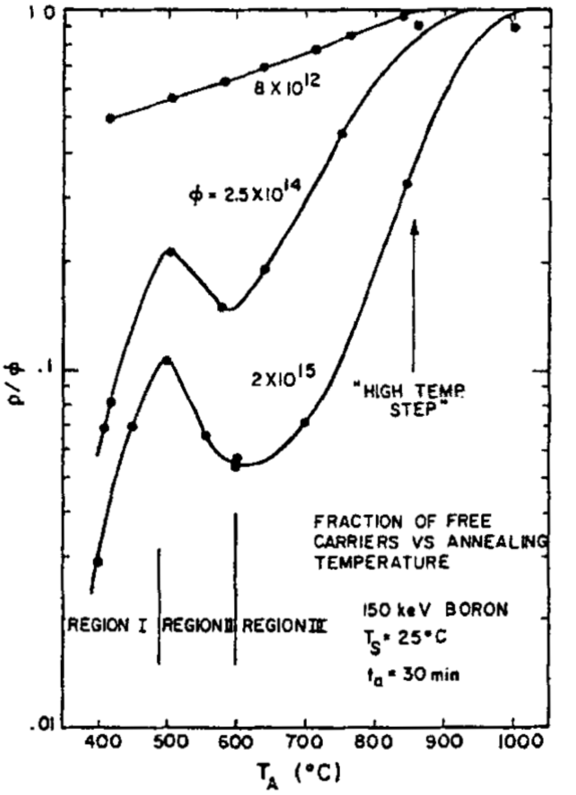

Figure 2: Isochronal annealing of boron. The fraction of activated boron, p/ϕ, is plotted against the annealing temperature, T_A, for different implant doses, ϕ. The annealing time is 30 minutes[3].

Initial doses of implanted dopant will be explored, together with different temperatures of annealing, to map the activation fraction in the region of interest for the LGAD.

Also, the concurrent implantation of different dopants, such as carbon, will be investigated to evaluate if the presence of different materials in an interstitial position concurs to enhance the radiation tolerance of boron atoms in a substitutional position.

Project activity and deliverables

To be defined with the participant groups.

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

Project costs

To be defined together with CNM and FBK foundries, and the RD50 management.

References

[1] G. Pellegrini et al., Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications, Nucl. Inst. Meth. A, 765 (2014) 12, doi:10.1016/j.nima.2014.06.008

[2] G. Kramberger et al. Radiation effects in Low Gain Avalanche Detectors after hadron irradiations. J. Instrum., 10 (2015) P07006, doi:10.1088/1748-0221/10/07/P07006

[3] 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

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