Technology of p-type microstrip detectors with radiation hard p-spray, p-stop and moderated p-spray isolations

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Abstract

A technology for the fabrication of p-type microstrip silicon radiation detectors using moderated p-spray implant isolation has been developed at CNM-IMB. The p-spray isolation has been optimized in order to withstand the ionizing irradiation dose expected in the middle region of the SCT-ATLAS detector of the future Super-LHC during 10 years of operation. A dedicated mask was designed in order to fabricate pad diodes with different sizes and test structures to measure the surface resistivity. The best technological options for the moderated p-spray implants were found by using a simulation software package and a dedicated calibration run. Detectors have been fabricated with Float Zone p-type high resistivity silicon substrates in the Clean Room facility of CNM-IMB, and characterized by reverse current and capacitance versus voltage measurements. The detectors fabricated with the moderated p-spray technology are compared to similar detectors fabricated with p-stop and p-spray isolation implants. A dedicated test structure was used to measure the interstrip resistance.

1. Introduction

The very high luminosity foreseen (~10^{35} $cm^{-2}s^{-1}$) implies that the detectors used in the upgrade of the Atlas Semiconductor Tracker will be exposed to fluences up to 10^{16} cm^{-2} 1 MeV neutron equivalent over the expected 10 years of operation. Present vertex detectors, relying on highly segmented silicon sensors, are designed to survive fast hadron fluences of about 10^{15} cm^{-2} [1].

Silicon detectors made on n-type bulk silicon undergo spatial charge sign inversion after being irradiated with hadrons to a fluence of a few 10^{13} cm^{-2} 1 MeV neutron equivalent. After type inversion, the charge collected by these detectors at low voltages is higher when read out from the n-side than from the p-side. The migration of the junction after type inversion can be avoided by using a p-type bulk substrate and as a consequence, p-type microstrip detectors have been proposed, within the RD50 collaboration, as candidates to survive the extreme radiation conditions of the Super-LHC environment [2]. Microstrip detectors on p-type silicon present, however, the challenge of achieving a proper interstrip isolation. Since positive charge in the field oxide layer is always present and will increase when the detectors are irradiated, it makes electrons from the bulk silicon to accumulate at the silicon surface leading to a short between the strips.

Irradiation studies gave evidence of a sensitive improvement in the CCE performances of detectors fabricated in p-type material (with n side read-out). In order to provide an adequate interstrip isolation it is necessary to use floating p-type zones, commonly known as p-stops, which surround the n-type strips. This is done at the expense of a more complex and expensive technology. The drawback for the p-stop technique is that it requires a minimum strip pitch depending on the design rules of the manufacturer, moreover, 'leaky channels' can severely reduce the yield, hence the necessity of a minimum width of the p-stop implant. Another problem which was pointed out in recent studies is the decreasing of the signal-to-noise ratio due to microdischarges [3].

Another alternative to achieve the interstrip isolation is the use of a uniform p-spray blanket ion implant performed on the silicon surface. The use of this technique does not require an extra mask as for the p-stop implant. Detectors with p-spray as isolating method have shown a better performance after irradiation than the ones fabricated with only p-stops. However, in order to ensure the strip isolation and avoid early breakdowns the p-spray implant profile has to be carefully calibrated. The need of high p-spray doses to avoid the inversion layer in the silicon surface in irradiated devices must be balanced with the decrease of the breakdown voltage (V_{BD}) and the increase of the leakage current as the p-spray implanted charge increases. The minimum p-spray dose that ensures a good isolation among the strips also at the highest irradiation doses must be used. Since the tuning of the p-spray implant is very critical this may lead to repeatability problem in the fabrication of a large number of detectors. Another problem of this technology is the possible surface damage due to the blanket implant which may cause higher leakage currents before irradiation.

Moderated p-spray is a convenient alternative of the two isolation methods described before. The moderated p-spray combines the p-stop and p-spray together in one single implantation through an oxide layer with different thicknesses. The region implanted trough the thinner oxide is referred as the p-stop which insures a good isolation between the active area and the guard ring (and/or between neighbouring strips) while the rest of the wafer is implanted trough a thicker oxide layer (referred as p-spray region). The p-spray is necessary to reduce the electric field at the edge of the p-stop, thus decreasing the probability of microdischarges. Typically, the p-stop guard surrounds each individual strip, meaning that between two strips there are two p-stop rings. Another advantage of adding the p-spray blanket is that the risk of leaky-channels in strip detectors is reduced and therefore the necessity of redundancy in the p-stop around the strip channels. The moderated p-spray was first proposed by Kemmer [4] using a silicon nitride layer deposited on the top of an oxide layer. The method proposed in this study simplifies the original idea by using only one oxide layer but with different thicknesses. The initial technological simulation was done to optimize the process and to find the optimum profile to fabricate a working n-on-p radiation detector. Both the technological and electrical simulation was performed using the ISE-TCAD v9 software package.

2. Simulation

Figure 1 shows the cross section of the structure simulated, it represent the interspaces between two neighbouring strips of an n-on-p radiation detector. This structure was used in the past for the optimization of the p-stop and the p-spray implants to fabricate strip detectors in p-type material [5]. The p-stop used is 10 μm wide and is placed in the middle of two strips which are 32 μm wide and have a pitch of 80 μm. The substrate used are (100) FZ silicon wafers with a nominal resistivity of 300 kohm*cm, which corresponds to a boron doping concentration of $N_{eff}=4.3*10^{11}$ cm^{-3}. The electrical simulation were performed considering no irradiated detectors therefore with an oxide charge density of $Q_{ox}=10^{11}$ cm^{-2}.

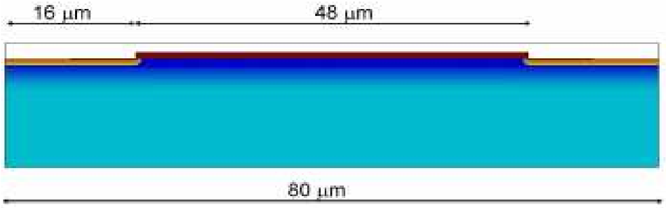


Fig. 1. Cross section of the simulated detector.

The profile of the moderated p-spray is obtained in one single implantation of boron ions though a silicon dioxide layer with two thicknesses, as it is shown in figure 2. The energy and the dose of the implantation were found in previous work [3, 6] where microstrip detectors were fabricated with only the p-stop or the p-spray isolations.

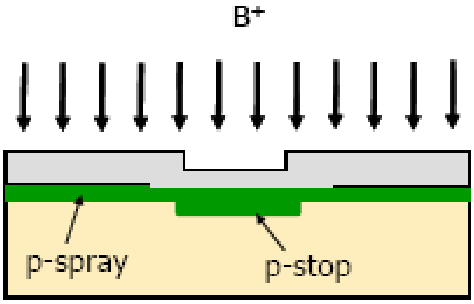


Fig. 2. Schematic of the boron implantation to obtain the moderated p-spray.

The energy and the dose of the p-stop implant are 50 keV and 10^{13} cm^{-2} respectively. The p-stop proved to be reliable and the detectors shown good electrical behaviour before and after irradiation with proton particles. Tests and simulation on variation of the p-stop implantation dose by one order of magnitude lower and higher lead to poor electrical characteristic of the detector due to insufficient isolation in the first case and early breakdown in the second. As starting point the parameters of the p-stop were fixed to the values reported above and the thickness of the thicker oxide which generates the p-spray region was used as a free parameter to find the optimum combination of the two techniques. By changing the thickness of the oxide it was possible to change the total dose at the silicon-oxide interface as shown in figure 3.

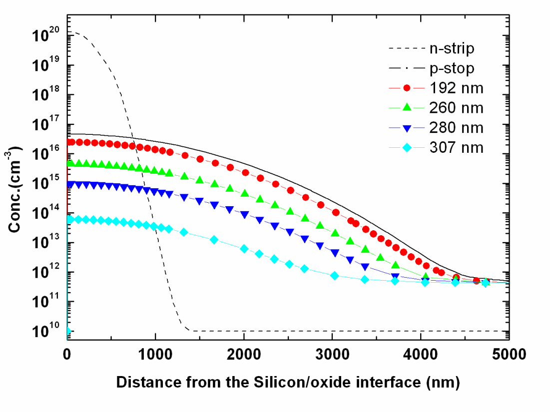


Fig 3. Profiles of the boron dopant implanted through different oxide thicknesses.

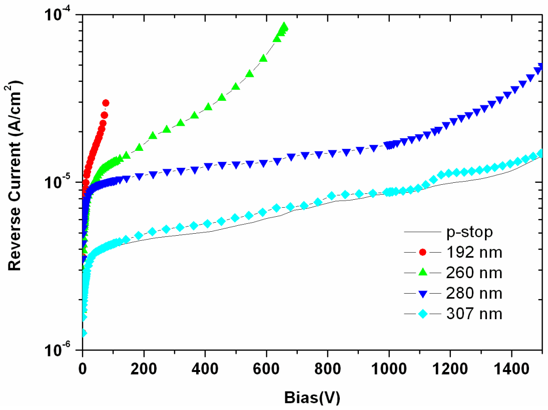


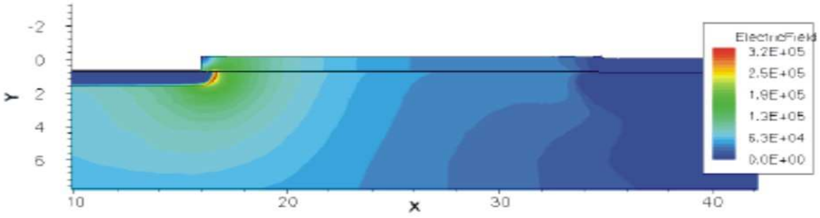
Fig 4. Current-Voltage characteristics for the different profiles.

Figure 4 shows the current voltage characteristics of the simulated devices and table 1 reports the breakdown voltage as a function of the oxide thickness for the implantation of the p-spray area. As it can be noticed in table 1 the breakdown voltage decreases as the total dose implanted increases since the highest electric field occurs at n-p junction of the strips. In similar bias conditions this electric field is higher when the gradient concentration of the dopant increases. Therefore in order to maximize the breakdown voltage it is important to minimize the total p-spray dose implanted in the silicon surface with the condition that the probability of microdischarges is minimized.

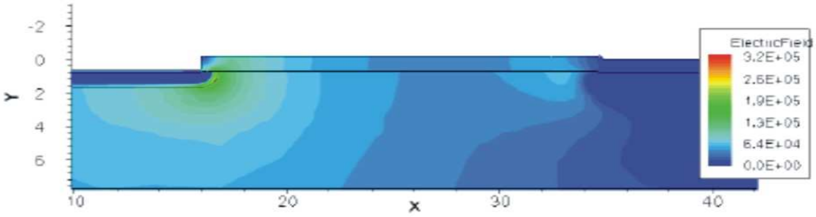
Table 1

t_{ox}(nm)	V_{BD}(V)
192	75
260	660
280	1500
307	>1500
Only p-stop	>1500

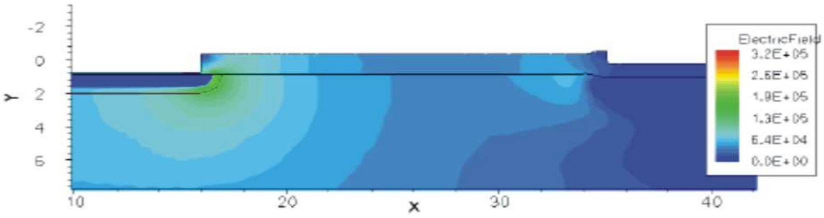
Considering the problem of microdischarges, we notice that the highest electric field in detector with only p-stop occurs at the p-stop edge. Figure 5 shows the electric field distribution in the simulated devices with different moderated p-spray doses and with only the p-stop isolation. The bias for the three devices is fixed at 1000 V. The figure shows that the maximum electric field is located at the strip edge for the devices with the moderated p-spray and at the p-stop in the case of the device with only the p-stop isolation. Therefore this is the region where the microdischarges may occur.



(a) **280 nm**



(b) **307 nm**



(c) **P-stop**

Fig. 5. Electric field distribution at 1000 V for the detectors with the moderated p-spray isolation, (a) and (b), and (c) with only the p-stop isolation. In figures (a) and (b) is shown the oxide thickness for p-spray region implant. Device a has the higher implant and device b the lower.

The value of the electric field in the p-stop region for devices with only p-stop isolation is 57.5×10^5 V/cm. In the case of the lighter p-spray (oxide thickness 307 nm) the electric field is 57.3×10^5 V/cm, only 0,2 % smaller. This means that the p-spray is too low to reduce the probability of microdischarges. On the contrary, the maximum electric field in the device with the oxide 280 nm thick is 40×10^5 V/cm, which is 29% smaller that the case with only p-stop. According to simulation the latter is the optimum profile for the moderated p-spray implant since it reduces the probability of microdischarges and does not decrease the breakdown of the devices.

3. Conclusions

An alternative to standard p-stop and p-spray isolation implants has been established by proposing a new technique for the fabrication of radiation detectors with a moderated p-spray implant. Simulation was used to find the condition for the fabrication of detectors in high resistivity p-type materials. The p-stop region of the moderated-spray isolation insure a proper isolation for the inversion electron layer at the silicon oxide interface, caused by radiation damage, while the uniform blanket, the p-spray, reduces the electric field at the p-stop edge which is the probable cause of microdischarges.

The simulation was used to find the optimum condition for the fabrication of working detector with an alternative moderated p-spray which insure a good isolation and reduce the probability of microdischarges. Detectors with the simulated isolation were fabricated at the CNM-IMB clean room facilities and are being tested electrically.

4. References

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