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Surface effects in segmented silicon sensors

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The voltage stability and the charge-collection properties of segmented silicon sensors are strongly influenced by the charge and potential distributions on the sensor surface, the charge distribution in the oxide and passivation layers, and by Si-SiO2 interface states. To better understand these complex phenomena, measure¬ments on test structures and sensors, as well as TCAD simulations related to surface and interface effects, are being performed at the Hamburg Detector Lab. The main results of these studies are presented, and some tentative conclusions, which are relevant for the sensor design, are drawn.

It has been observed that the charge distribution on the sensor surface changes with time. The time constants, which can be as long as days and weeks, show a strong dependence on environmental parameters like humidity and temperature. Using Gate-Controlled-Diodes (GCD) and MOS-FETs, the surface resistivity of SiO2 has been determined for different relative humidities at room temperature. They can explain the observed variation of the time constants. A method of implementing different charge distributions on the sensor surface and of simulating the time dependence of surface charges with SYNOPSYS TCAD has been developed, and simulation results of the time dependence of the electric field in sensors are presented. They are relevant for the break-down beha¬viour and the charge collection. A proposal how these long-term effects could possibly be avoided is discussed.

Oxide charges, in particular close to the Si-SiO2 interface, and interface traps, strongly influence the breakdown and charge collection properties of silicon sensors. Previously, the effective oxide charges and surface currents have been determined for X-ray doses of 0 Gy, and of 1 kGy(SiO2)/ to 1 GGy(SiO2) using MOS Capacitors (MOS-C) and GCDs built on <100> and <111> n-type silicon from 4 diffeent vendors. Most of the irradiations have been performed without biasing the test structures. The results have been implemented into SYNOPSYS TCAD and used to optimize the design the AGIPD p+n sensor, where a break-down voltage above 900 V for X-ray for doses between 0 Gy to 1 GGy has been demonstrated. In the simulations spatially uniform oxide-charge densities and surface recombination velocities, with the measured X-ray-dose dependencies, have been assumed.

For the <100> and <111> MOS-Cs built on n-type silicon, the time dependence of the effective oxide-charge density after biasing the MOS-C to different voltages in inversion and back to accumulation, has been determined before and after irradiation to 1 GGy. It is found that in inversion, the density of positive oxide charges increases with time and saturates after about 120 minutes. The results of the saturation values for different voltages in inversion, corresponding to different electric field values at the Si-SiO2 interface, are presented. In addition, a significant decrease of the positive oxide-charge density is observed, when the MOS-C, after having been for some time in inversion conditions, is biased in accumulation.
To study the build-up of oxide charges during and shortly after X-ray irradiations as a function of the electric field at the Si-SiO2 interface, the drain-source current for a given gate voltage of a MOS-FET has been measured and the time dependence of the threshold voltage determined. So far the measurements uses a p-channel MOSFET and X-ray doses between 10 Gy (SiO2) to 15 kGy (SiO2) have been investigated. The aim of this study is to understand to what extent the assumption of a uniform oxide-charge density, which is made in the simulations, is justified, and to provide the data, which allow implementing a non-uniform, electric field dependent oxide-charge density in future TCAD simulations.

The relevance of oxide charges on the charge collection properties has been investigated by long-term measurements on n+p-strip sensors with p-spray and p-stop strip isolation exposed to a 90Sr β source. Data with a dose rate of 50 Gy(SiO2)/day are presented. They show significant changes in the charge-collection properties already at doses as low as 10 Gy. The findings are understood with the help of SYNOPSYS TCAD simulations, and the relevance for sensor designs is discussed.

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