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Forward and reverse current of highly irradiated silicon pad diodes

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The current of initially p- and n-type bulk silicon pad diodes has been studied for low and high forward and reverse bias voltages at -30 ℃. The diodes were irradiated to neutron equivalent fluences $\Phi_{eq} > 10^{15}$ cm^{-2} with GeV protons.

At low bias voltages, the current is ohmic. The neutral bulk of highly irradiated diodes has approximately zero net fixed space charge and the free carrier concentrations are approximately equal to intrinsic silicon, which is known as carrier removal. Consequently, the resistivity of the neutral bulk is very high. Since the generation lifetime is very short, the resistivity of the space-charge region SCR has been found to be similar to the bulk resistivity for low bias voltages. Accordingly, the current at low bias voltages is determined by the bulk rather than the SCR.

It has been observed that the voltage-independent bulk resistivity $\rho = \left(en_i\left(\mu_0^e + \mu_0^h\right)\right)^{-1}$ measured at low bias voltages increases with the fluence. This is interpreted as a decrease of the carrier mobilities $\mu_0^{e,h}$ due to the scattering of carriers by ionized defects. The dependence of $\mu_0^{e,h}\left(\Phi_{eq}\right)$ on the fluence has been estimated from the measurements of the bulk resistivity assuming ionized impurity scattering.

At higher reverse bias voltages the current changes abruptly from the ohmic behavior $\rho\left(U\right) = const$ to a dependence $\rho\left(U\right) \propto U^S$ with $S < 1$. The transition occurs once the generation current of the SCR cannot sustain the linear ohmic current of the bulk anymore. The SCR partially depletes of free carriers and dominates the current for higher voltages. The transition between bulk-dominated behavior and SCR-dominated behavior occurs at a characteristic threshold $\frac{U_{th}}{d^2}\left(\Phi_{eq}\right) \propto \Phi_{eq}$, with the thickness of the diode d and the threshold voltage U_{th} . An empirical model has been developed to describe the current of pad diodes as function of the fluence and the applied voltage for small to medium reverse bias voltages. The measurements are described within a few percent by the model.

For forward bias the diode current is ohmic with the field-dependent carrier mobilities until the current suddenly increases exponentially at high bias voltages. The forward current at all bias voltages can be reasonably described within about 10 $\%$ assuming space-charge-limited currents for a semiconductor containing traps uniformly distributed in the band gap.

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