Radiation-induced defects in silicon

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This contribution gives an overview about the physics and the electrical characteristics of the radiation induced centers in silicon created by electrons, protons and helium ions. The parameters for the action as recombination centers, doping effects and discharging effects are described quantitatively, including temperature dependency and injection level dependency. The influence on the electric characteristics of power devices is discussed.

Table I gives an overview about radiation-induced defects, which are found after annealing at temperatures above 300°C The influence of the different levels on lifetime depends strongly on their position within the band-gap, but also on their capture rates and their densities. Thus the defect E(90K) controls the high-level lifetime, while E(230K) has influence on high-level-, low-level- and space-charge lifetime.

The generation of the different defects depends on the irradiation energy and their ratio depends on the irradiation energy. The generated number of defects increases approximately linear with the irradiation dose in a wide range. For very high doses, however, the number of generated secondary defect complexes containing impurities like, e. g., oxygen or carbon is expected to saturate according to the limited impurity concentration.

In the case of irradiation with protons and helium ions, the resulting vertical defect profile follows in a first approximation that of the primary defect profile. The maximum of the recombination center distribution is therefore found nearby the projected range of the ions, corresponding to the irradiation energy. A desired carrier lifetime profile in the device can be created by adjusting energy and fluence of the ions.

On the contrary, electron irradiation with energies higher than about 1 MeV results in a nearly uniform distribution of the generated defects in the device. It is even possible to apply electron irradiation to wafer stacks up to a thickness of about 1000µm.

Radiation-induced centers not only change the carrier lifetime, but also can cause doping changes. The generation of hydrogen-induced doping effects (figure 1) is discussed as well as the formation of defect centers modifying the effective doping concentration on helium-radiated Si devices (figure 2). This effect is analyzed as a function of the annealing temperature. Capacitance-voltage (CV) and spreading resistance profile (SRP) measurements show that annealing at 350°C results in the formation of an acceptor center, which is tentatively attributed to the V_2O center by means of deep level transient spectroscopy (DLTS) measurements. Annealing at 430°C leads to the disappearance of the acceptor center. Instead, pronounced donor formation in a range close to the penetration depth of the helium ions is observed.

Another effect is caused by the temporarily positively-charged center H(195K). These charged donor-states increase the effective doping concentration in n-type silicon which may cause the appearance of dynamic impatt oscillations. The frequency of this oscillation is governed by the carrier saturation velocity and the width of the low-doped region and is typically in the range between 200 and 1000 MHz. Dynamic impatt oscillations have been observed in both electron- and helium-radiated devices and must be avoided due to EMC reasons.

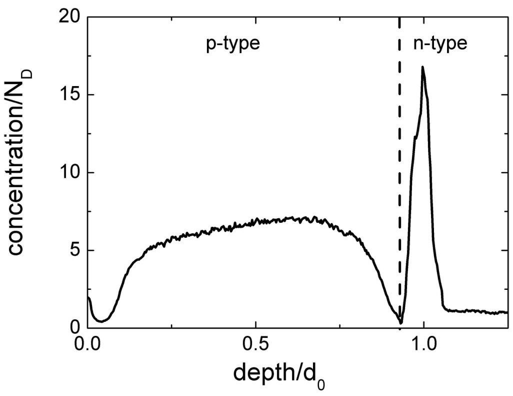

Fig. 1: Doping change after proton irradiation (N_D is the substrate doping and d_0 the projected range of the protons)

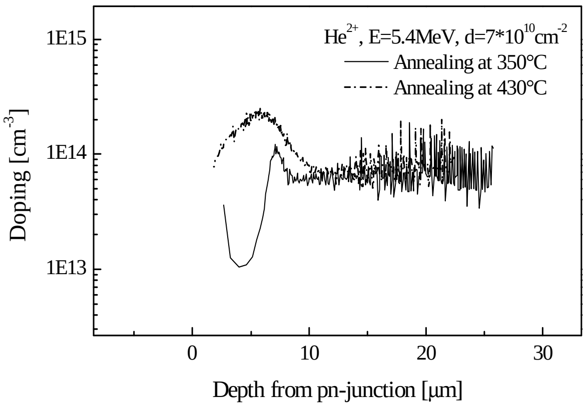

Fig. 2: Doping concentration measured in the n-layer of a diode after helium irradiation and subsequent annealing

Table I: Overview of relevant radiation-induced defects in silicon found after annealing with temperatures of T > 300 °C

Type	Physical Nature	DLTS-Signal	Energy Level
OV	Oxygen-Vacancy-Complex	E(90K)	E_C-0.169eV
VV	Divacancy Complex		
	--/-	E(130K)	E_C-0.24eV
	-/0	E(230K)	E_C-0.43eV
V_4/V_5 ?	Multivacancy-Complex	E(230K)	E_C-0.46eV
V_2O	Divacancy-Oxygen Comples	E(230K)	E_C-0.43eV
COOV	Carbon-Oxygen-Complex	H(195K)	E_V+0.35eV
STD(H)	hydrogen-related shallow thermal donor	-	E_C-0.034eV...E_C-0.053eV
TDD	thermal double-donor family	-	E_C-0.061eV...E_C-0.135eV