Dosimetry of background irradiations of accelerators based on hadrons fluence dependent carrier lifetime measurements

Tekorius, A (VU)

14 May 2012

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project AIDA, grant agreement no. 262025.

This work is part of AIDA Work Package 8: Improvement and equipment of irradiation and test beam lines.

Dosimetry of background irradiations of accelerators based on hadrons fluence dependent carrier lifetime measurements

A. Tekorius, E. Gaubas, T. Čeponis, A. Jasliūnas, A. Uleckas, J. Valtukas, A. Velička
Vilnius University, Institute of Applied Research

Abstract
The contactless technique and instrumentation for dosimetry of background irradiations within accelerators facilities are presented. The method is based on wide range variations of carrier lifetime dependent on irradiation fluence. Instrumentation is designed and fabricated for fast monitoring of these carrier lifetime changes based on analysis of the microwave probed photoconductivity transients.

Principles of technique and dosimetry instrument
The employed contactless technique is based on measurements and analysis of the microwave probed photoconductivity transients (MW-PCT). Radiation defects induced by large fluxes of ionizing radiation comprise a set of deep centres those act as carrier traps. Depending on types and activation parameters of these radiation defects, the deep traps associated to these defects play different role in redistribution of excess carrier flows and on electrical characteristics of materials, acting either as carrier trapping or recombination centres. In low and moderately irradiated material, big variety of extended and point defects of various species appears. Then, excess carrier decay exhibits a complicated behavior and photoconductivity relaxation transients are non-exponential, containing of several components dependent on carrier density, temperature, background illumination and other external factors. The non-exponential, a two-component transient is observed for the low level pulsed excitation regime, where an initial fast component is ascribed to recombination, while the second one indicates carrier trapping effect, which delays recombination. Such decay behavior indicates that several traps compete and interact within redistribution of carrier decay flows. Carrier decay becomes single-exponential, when steady-state broad-band additional bias illumination (BI) is applied. Then, recombination process prevails, as trapping to shallower levels is suppressed due to their filling by BI. Actually, a linear dependence between recombination lifetime ($\tau_{\text{R}}$) and hadrons irradiation fluence is obtained and serves as a basis for dosimetry by this MW-PCT technique.

Instrument VUTEG-5-AIDA for contactless dosimetry of irradiation fluence by MW-PCT technique

Characteristics of fluence dependent carrier lifetime variations
To simplify mounting and reliable positioning of the sample within measurement spot of spatial resolution of about 100 mm, to avoid surface contamination and to mark samples taken from different irradiation areas, methodology of measurements using VUTEG-5-AIDA instrument is designed by employing samples enveloped within plastic bags. These polythene bags, however, induce light scattering and some reduction of recorded MW-PCT signals. To verify characteristics of carrier recombination lifetime dependent on fluence, measured with and without plastic bag, the amplitude and decay rate parameters have been examined on several sets of Si wafer and device structures. It can be noticed that MW-PCT signal amplitude values are reduced for the sample-in-bag relatively to those obtained for bare sample. However, these amplitude characteristics are parallel, i.e. show the same dependence on fluence. Actually, a signal decreases within range of the highest fluences applied, due to approach of $\tau_{\text{R}}$ values to that of laser pulse duration and to a consequent decrease of the initially photo-excited excess carrier density. Carrier lifetime values as a function of irradiation fluence remain invariable irrespective of sample envelope.
To increase precision of the dosimetry of collected fluence by MW-PCT technique and VUTEG-5-AIDA instrument, the calibration measurements using different materials, various structures and irradiations have been performed. It can be deduced that the linear decrease is obtained within $\tau_{\text{R}}$, characteristic for wafer fragments and diode structures made of Si, grown by various (FZ, MCz, DOFZ) technologies, and irradiated with neutrons and protons of different energies. Additionally, absolute values of carrier recombination lifetime ascribed to a definite hadron fluence nearly coincide, irrespective of hadrons energy in the range of penetrative particles. These observations can be explained by the rather homogenous damage of irradiated Si materials when displacement extended defects (directly formed by irradiation or resulted from defects aggregation reactions) prevail and act as the dominant recombination centres.

Measurement results
MW-PC transients measured on non-irradiated n-Si wafer fragment at low level excitation regime without (1) and with (2-4) additional bias illumination.
Fluence dependent variations of MW-PCT signal amplitude (1,2) and of carrier lifetime (3,4) measured for bare (1,3) and enveloped (2,4) Si samples
Carrier lifetime variations as a function of irradiation fluence measured on Si wafer (1-3) and diode (4) samples made of different growth technology (FZ-1, MCz - 284, DOFZ - 3) material and irradiated by neutrons (284) and protons (183).

Summary
The MW-PCT technique, instrumentation and methodology for contactless dosimetry in wide range of hadrons irradiation fluences have been proposed. From the calibration measurements, it has been proved that absolute values of carrier recombination lifetime ascribed to definite hadron fluence nearly coincide, irrespective of hadrons energy, and these observations are explained by the rather homogenous damage of irradiated Si materials when displacement extended defects act as the dominant recombination centres.

Acknowledgement
The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project AIDA, grant agreement no. 262025.