Direct Study of Neutron Induced Single-Event Effects

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Abstract

A facility for direct study of neutron induced Single Event Effects (SEE) has been developed in Prague using collimated and monoenergetic neutron beams available on the Charles University van de Graaff accelerator. In this project, silicon diodes and LHC Voltage Regulator are being irradiated by neutrons of different energies (60 keV, 3.8 MeV, and 15 MeV). Furthermore, the associated particle method is used, in which 15 MeV neutrons produced in the ^{3}H(d,n)^{4}He reaction are tagged. The measurements in progress should allow estimating a probability of neutron interactions per sensitive volume of the junction and a probability of SEE occurrence in the LHC Voltage regulator chip.

I. INTRODUCTION

CMOS integrated circuits (CMOSICs) are largely used in space, aviation and particle accelerator environments, i.e. at high radiation environments. The use of submicron CMOS processes in these adverse radiation environments requires the application of special architectural and layout techniques. Failures could come not only from total dose effects but also from so-called Single Event Effects (SEE) believed to be responsible for latch-up that can destroy ICs completely or render them unusable indefinitely or for various periods of time. Therefore, there is a need to understand the importance of SEE in specific operational environments and to find ways of quantifying the tolerance of the different technologies to these effects. We tried to find out a probability of latch-up phenomena in CMOSICs caused by fast neutrons.

The experimental tests are oriented on estimation of SEE provoked by the following specific interactions of neutrons in the silicon chip: Si(n,n')Si, Si(n,n)Si, Si(n,α)C, Si(n,p)Al and B(n,α)He.

II. STUDY OF ENERGY THRESHOLD BEHAVIOUR OF IC-FAILURES

The experimental set-up of a collimated, monochromatic and tagged neutron beam has been realised at the van de Graaff accelerator of Charles University, in the collaboration with Montreal University and Czech Technical University, Prague. Neutrons are produced using several production reactions. Overview of the reactions is in Table 1. Beams of neutrons with energies of 60 keV (with an energy spread 10 keV), 3.8 MeV (100 keV) and 15 MeV (100 keV) are available. This provides a neutron beam energy range allowing one to estimate the expected energy threshold behaviour of SEE.

The experimental setup of neutron production is at Fig. 1. Beam of accelerated deuterons or protons strikes onto a tritium or deuterium target with the molybdenum backing. The interaction point of the beam with the target represents a nearly point source of monochromatic neutrons.
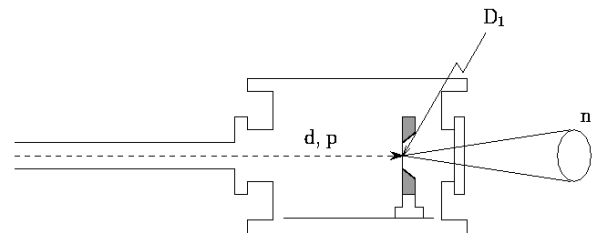

Figure 1: Experimental arrangement of neutron production target.
d (p): beam of deuterons (protons) from the van de Graaff accelerator, D$_1$:deuterium (tritium) target on molybdenum backing, n: neutron beam

Monitoring of neutron flux is based on Bonner spectrometer. This method allows precise determining neutron dose for each individual irradiation at one neutron energy. Furthermore, after calibration of its energy sensitivity, irradiations performed at different energies can be compared.

III. DIRECT SINGLE EVENT EFFECT OBSERVATION

In the case of ^{3}H(d,n)^{4}He reaction, so called associated-particle technique can be applied to obtain a tagged neutron beam. The technique is based on the spectroscopic detection of produced alpha particles by means of silicon diode what brings an information about neutron emission within the time uncertainty on the level of about 10 ns. The principle of the technique is displayed on Fig. 2. Registered recoiled alpha particle serves as a tag of neutron moving in a kinematically determined direction (e.g. in a direction to an IC). The conical neutron beam is collimated to the diameter of 3-4 mm at the distance of the target of 15 cm. The intensity in this beam is around 10^6 n/s, giving 10^7 n cm^{-2} s^{-1}. The detailed description of the tagged neutron beam facility is given in [1].
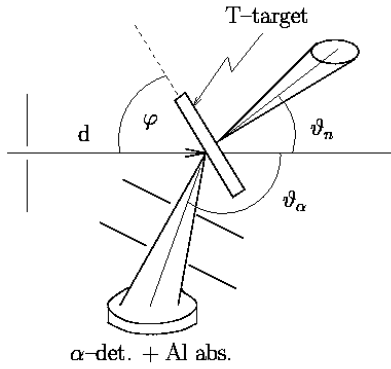
Figure 2: Sketch of kinematics of the associated particle method. The upper and lower cone denote outgoing neutrons and alpha particles, respectively. Aluminium foils are used to absorb elastically scattered incident deuterons.
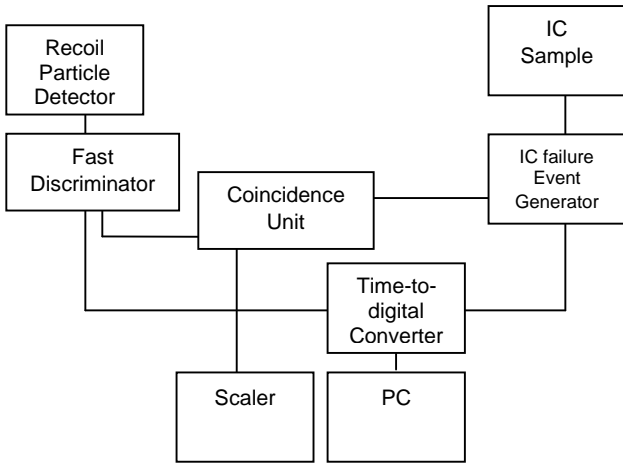

Figure 3: Block diagram for SEE monitoring using associated particle method

To estimate a probability of SEE, neutron beam intensity is monitored by the registration of associated particles and, directly by neutron Bonner sphere spectrometer.

The circuitry of SEE registration is at Fig. 3. IC failure event generator is connected to the coincidence unit together with the associated particle detector. This ensures that effects correlated to the neutrons are counted only. In addition to the coincidence unit time between associated particle registration and SEE is measured via TDC, to give more information about particular IC failure.

IV. APPLICATIONS

Tests of two types of devices are currently in progress using both methods. Silicon diodes of different sizes were put to the neutron beam and their response is studied. These measurements should allow estimating a probability of the reaction per sensitive volume of the junction and amount of energy deposited by reaction products in this volume using pulse-height analysis of silicon diode signal.

The same measurements are carried out with LHC Voltage Regulator (RD49 project [2]). The results will be published.

V. REFERENCES

[1] I. Wilhelm, P. Murali and Z. Dolezal, Production of monoenergetic neutrons... Nuclear Instruments and Methods in Phys.Res., A317(1992)553

[2] CERN-LHCC RD49 Project, http://rd49.web.cern.ch/RD49/

Reaction	T(p,n)^{3}He	D(d,n)^{3}He	T(d,n)^{4}He
Neutron energy	60 keV	3.8 – 5 MeV (tunable)	$E_n = 15$ MeV
Energy spread	10 keV	100 keV	300 keV
Reaction energy Q	-0.97 MeV	4.6 MeV	17.8 MeV
Intensity	10^5 n/s	10^5 n/s	10^6 n/s

Table 1: Overview of neutron production reactions