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DEVELOPMENT OF HIGH ENERGY NEUTRON COUNTERS FOR THE CHIPIR BEAM LINE AT ISIS-TS2

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ABSTRACT

The measurements of the so-called Single Event Effects (SEE) are becoming of great importance to assess the robustness of integrated circuits featuring dimensions of tens of nanometers. SEEs occur when a highly energetic particle (e.g. a neutron present in the environment) causes a disruption of the correct operation of an electronic component by striking its sensitive regions. Commercial-off-the-shelf devices are becoming popular in mission- or safety-critical applications, since they satisfy the designers' need for high-performance computing at moderate prices. However, to exploit such devices, fault-tolerant design techniques must be employed, and extensive analyses are needed to qualify their robustness. Experiments with atmospheric neutrons at different altitudes can be carried out but, due to the low intensity, they require very long periods of data acquisition. Neutron sources represent an opportunity due to the availability of high intensity fluxes which allow accelerated irradiation experiments. Recent experiments performed at ISIS on the VESUVIO spectrmeter to measure SEE rate in chips of different technologies demonstrated the suitability oft he ISIS source for this kind of application. The PANAREA project aims at the design and construction of a dedicated beam line for chip irradiation: the ChipIr instrument. A very important task for ChipIr design is the development of suitable and effective neutron beam monitors capable of locally measure the neutron fluence in the energy region above 1 MeV up to 800 MeV. In this contribution we will present the first test results obtained with Bonner Spheres and Single Crystal Diamond detectors.

1. Introduction

The growing availability of integrated circuits featuring minimum dimensions of the order of tens of nanometers is affecting properties and design methodologies of digital systems. These digital devices are more susceptible to random faults, known as Single Event Effects (SEEs), which can occur when a highly energetic particle such as a neutron present in the environment, causes a disruption of their correct operation by striking sensitive regions of an electronic device [1]. SEEs have already been identified as a predominant threat to aircraft safety [2] and the effects on electronic components from cosmic radiation is of significant importance for the semiconductor industry [3]. Commercial off-the-shelf devices are becoming popular in mission- or safety-critical applications since they satisfy the designers' need for high-performance computing at moderate prices. However, to exploit such devices, fault-tolerant design techniques must be employed, and extensive analyses are needed in order to qualify the robustness of the devices and systems. Experiments with atmospheric neutrons at different altitudes can be carried out, but due to low intensity, they require very long periods of data acquisition [4] In this context, neutron sources represent an opportunity thanks to the availability of high intensity fluxes, which allow accelerated irradiation experiments. Currently, semiconductor industries perform irradiation tests, for example, at the Los Alamos Neutron Science Center [5] (LANSCE) and TRIUMF [6] neutron sources. Recently, irradiation tests performed on the VESUVIO beam line at ISIS-TS1, have assessed the effectiveness of the facility for this kind of investigations. A new beam line, dedicated to chip irradiation is under construction on TS2 at ISIS and will benefit from the higher fluxes and from a properly designed moderator that will provide a neutron beam closely resembling the atmospheric spectrum but with a flux higher by almost seven order of magnitudes with respect to the atmospheric one. One important aspect in SEE measurement is both the matching of the neutron spectrum with the atmospheric one and the precise measurement of the neutron fluence onto an irradiated chip for the calculation of the SEE cross sections, defined as the ratio of the number of observed SEEs in a test to the neutron fluence. The spectrum of the neutrons may be measured in different detection systems, such as fission chambers [7], activation targets [8] or Bonner Spheres Spectrometers (BSS) [9]. These devices give a spatially integrated information due to their dimensions, typically of several tens of cm^2, that prevent to perform localised (mm^2) measurements. While spectral uniformity of a neutron beam could be a reasonable assumption, the intensity uniformity may not, so that the intensity within the beam spot at the irradiation distance from the moderator may show a spatial variation. Moreover in case of multiboards irradiation, the intensity along the beam may differ due to scattering and/or absorption. Thus, a key issue to be addressed is the development of ~mm^2-size fast neutron flux monitors, capable of being embedded close to the irradiated chip. In this contribution we report a few test results obtained on the VESUVIO beam line at the ISIS-TS1with Bonner Spheres and Single Crystal Diamond detectors [10-12].

2. Experiment

The tests with Bonner Spheres and the Single Crystal Diamond detector were performed on the VESUVIO instrument at the ISIS spallation neutron source (Didcot, U.K.). VESUVIO is a neutron spectrometer, with a primary flight path of 11.05 m, facing a 300 K liquid water moderator. The ISIS proton bunch extracted from the synchrotron is characterized by a double pulse 60-80 ns Full Width Half Maximum, separated by about 300 ns. The neutron spectrum from the moderator has a peak in the themal energy region and a E^{β} ($-1< \beta \leq -0.9$)-dependence in the epithermal neutrons region. The BSS is currently the most used, mature and validated technique for neutron dosimetry and spectrometry in complex neutron fields with energy distribution ranging from thermal up to hundreds MeV [13]. The BSS has been used around high-energy particle accelerators [14-17], on high altitude mountains [18] and at flight altitude [19]. Firstly used by Bramblett et al. [14], the BSS has been widely applied for almost 50 years in the field of neutron dosimetry and spectrometry, due to the wide energy range covered, the possibility to choose among different active or passive thermal neutron sensors according to the characteristics of the field to be measured (intensity, time structure, amount of photons), the isotropy of the response and the easy operation. The BSS relies on a thermal neutron detector placed at the center of a moderating sphere of variable diameter (2”- 15”). The central detector counts neutrons that are moderated and thermalized in the sphere. The neutron moderation process within a BS is mainly due to H(n,n)H and C(n,n)C elastic scattering, at energies below 4 MeV. At higher energies, the threshold reactions C(n,n’3γ) (threshold ~ 5 MeV), C(n, α) (7 MeV), C(n,n’3) (8 MeV), C(n,p) (15 MeV), C(n,n’p) (15.5 MeV), C(n,p) (18 MeV) become important [20]. A set of five-six well chosen spheres of pure polyethylene with diameters from 2” to 12” is sufficient to determine neutron spectra from thermal up to 20 MeV. To extend the upper limit up to 10^2-10^3 MeV, additional spheres with metallic inserts (Fe, Cu, W, Pb) are needed [18]. At energy > 20 MeV these metals act as (n,xn) radiators and energy shifters, making the detection of the high-energy neutrons possible. Figure 1 reports a picture of the spheres with metallic inserts.

Figure 1. Bonner spheres with metallic inserts.

The BSS exposures on VESUVIO took place on 9 – 10 May 2008. The proton current ranged between 170 µA and 190 µA. Each sphere was exposed for about 20 minutes. The Dy activation foils were counted and their saturation specific activity, ranging from 10^3 to 10^5 Bq·g^{-1}, was normalized to the proton current, obtaining a suitable set of input data for the unfolding code FRUIT ver 3.0 [21]. The the energy distribution of the neutron fluence rate is shown in Figure 2. As expected, the thermal component is dominating. The slope of the epithermal component is α=0.94, in agreement with previous determinations. The evaporation peak is located at about 0.8 MeV. In addition, a very small high-energy peak (less than 1% in terms of fluence) is present at about 100 MeV. The uncertainty of the total fluence value (about ±5%) includes the uncertainty of the spectrometer calibration (about ±4%, mainly due to the uncertainty of the ^{152}Eu calibration source) and the unfolding uncertainties (about ±3%). The latter comes from the propagation of the uncertainties on the input data (counting + response matrix uncertainties) over the unfolding procedure.

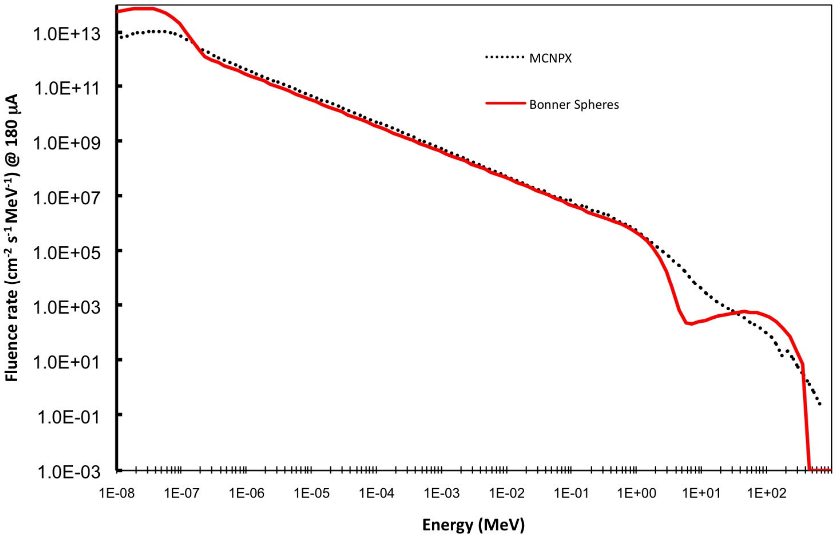

Figure 2: Energy distribution measurement of the neutron fluence rate on VESUVIO normalized to 180 µA proton current (red continuous line), and MCNPX calculation (black dotted line) [9].

The measurements with the diamond detector were done by collecting neutron time of flight spectra (TOF) using a fast (1 ns response time) preamplifier of DBA III type and recording spectra with a fast digital scope from Textronix (2.5 GHz band width and 50 GHz sampling rate). Figure 3 shows the neutron TOF spectrum recorded with the diamond placed at a distance of 11.4 m from the moderator, for a integrated proton current of 2100 μAh.

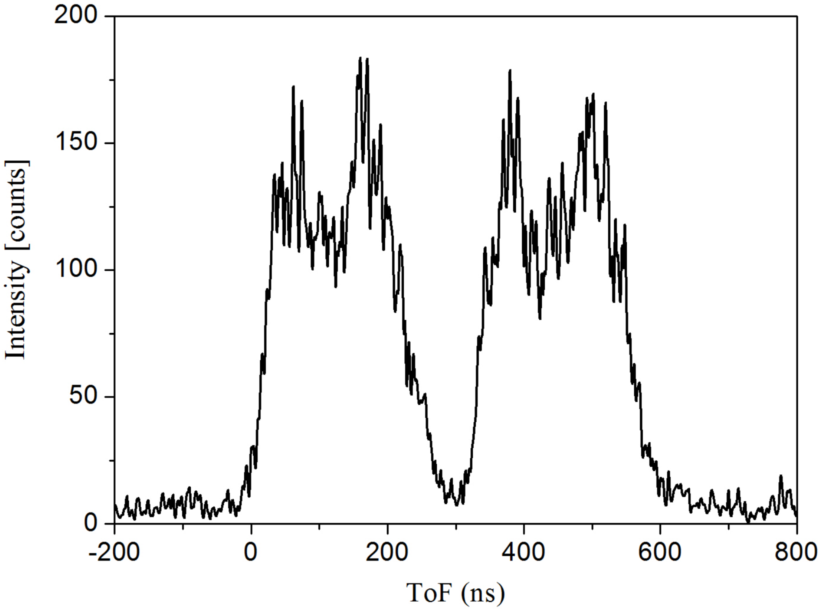

Figure 3: Neutron time of flight spectrum recorded by a single crystal diamond (70 μm thickness) placed into the direct VESUVIO neutron beam at a distance of 11.4 m from the 300 K water moderator

A double structure spectrum can be oserved featuring a time gap of about 320 ns that reflects the time structure of the ISIS proton pulse. Each structure of the spectrum has a Full Width at Half Maximum of about 210 ns. Moreover, two time distributions can be observed within each structure of the spectrum with peaks at t ≈ 62 ns and 161 ns, the other two being found with about 320 ns delay. A reasonable interpretation could be that the first time distribution peaked at 61 ns and 380 ns are neutrons above 30-40 MeV, while the region around the peaks at 161 ns and 480 ns are neutrons below that energy. This is an effect due to the convolution of the neutron spectrum and n-^{12}C cross section (mostly the inelastic one) shape. In order to have more precise information about the neutron energy measured by the diamond, biparametric (TOF vs Pulse Height) are going to be analyzed that were collected on the Rotax beam line at ISIS with different electronics set up.

3. Conclusions

An R&D activity is ongoing related to the design of the ChipIr beam line, the ISIS dedicated instrument for chip irradiation. In order to assess the robustness of an electrnic

device to Single Event Effects, the fluence onto the irradiated chip is to be determined (assuming an atmospheric like neutron spectrum), preferably close to the irradiation area.
Two different detection technique have been reported: 1) the Bonner Sphere spectrometer technique, that makes use of moderator-based detectors capable to extend neutron fluence measurements up to 800 MeV. A comparison with MCNPX simulations provides an assessment of the potential of this technique to characterize the beam line neutron field.
The test results obtained on VESUVIO using a single crystal diamond of 70 μm thickness connected to a fast preamplifer allow for an identification ad separation of the contributios of neutrons generated in the double bunch structure provided by the ISIS synchrotron. Despite explorative, these tests clearly show that the single crystal diamonds can be used to assess the spatial uniformity of a neutron beam on the scale of a few mm^2 (4-5 mm^2), a key feature in multiboards test on the ChipIr beam line. In the near future, the analysis of the biparametric data collected on the Rotax beam line and the investigation of the response function o the diamond detectors under irradiation of almost monochromatic neutrons will open the way to the use of these devices as fluence and spectrum monitors as well.

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