SHORT TERM IONIZING RADIATION IMPACT ON CHARGE-COUPLED DEVICES IN RADIATION ENVIRONMENT OF HIGH-INTENSITY HEAVY ION ACCELERATORS

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1. Introduction

This paper presents a first approach on studies of the results of short term ionizing radiation impact on charge-coupled device (CCD) chips in conditions typical for high-intensity ion accelerator areas. Radiation effects on semiconductor devices are a topical issue for high-intensity accelerator projects. In particular it concerns CCD cameras that are widely used for beam profile monitoring and surveillance in high radiation environment. 65 CCD cameras are going to be installed in the FAIR machines [1, 2]. It is necessary to have good understanding of radiation effects and their contribution to measured signal in CCD chips. A phenomenon of single event upset (SEU) in CCD chips is studied in the following experiment. By SEU in CCD chip we mean an event when an ionizing particle hits the CCD matrix cell and produces electron-hole pairs that are then collected and converted to a signal that is higher than certain level defined by author. Practically, it means that a certain cell will appear as a bright pixel on the resulting image from a chip.

2. Experimental Details

Cylindrical Aluminum thick target was installed in front of the beam dump in experimental hall and irradiated with fast extracted 500MeV/n Ta beam of approximately 2 cm in diameter. The thickness of the target was 5 cm, which is about double stopping range for given ions. Therefore we may consider this situation as 100% beam loss at a specified point. When such an ion beam is lost in the target, a lot of secondary particles are produced and they are the reason of ionizing effects in CCD chip and therefore SEUs. These conditions simulate typical situation for losses in accelerator and transport lines depending on beam intensity. The device under test (DUT) was a Basler scA640-74gm CCD camera. It was placed at approximately at 90 degree to the beam direction and at half meter distance from beam loss point with closed lenses (fig. 1).

Four different values of beam intensity from 3.19E+07 to 1.88E+09 ions/pulse were applied during the experiment. The beam was provided by fast extraction with approximately 2 second interval between the pulses and 250 nanoseconds pulse length. With typical frame ratio of 30 frames per second, frame acquisition time is much longer than pulse length. Therefore there is only one frame with beam induced radiation effects per each beam pulse. We may call it “event” frame.

Frames corresponding to the beam pulses were selected and processed to calculate the SEU number in the way described below. Each pixel on the frame has so called Digital Number (DN) value. DN is represented by number from 0 to 255 at 8bit coding and pixel luminance is proportional to DN for each pixel. DN is proportional to charge collected from this pixel. This charge is created by ionizing particles in our case, while normally visible light creates it through the photoelectric effect in sensitive pixel area.

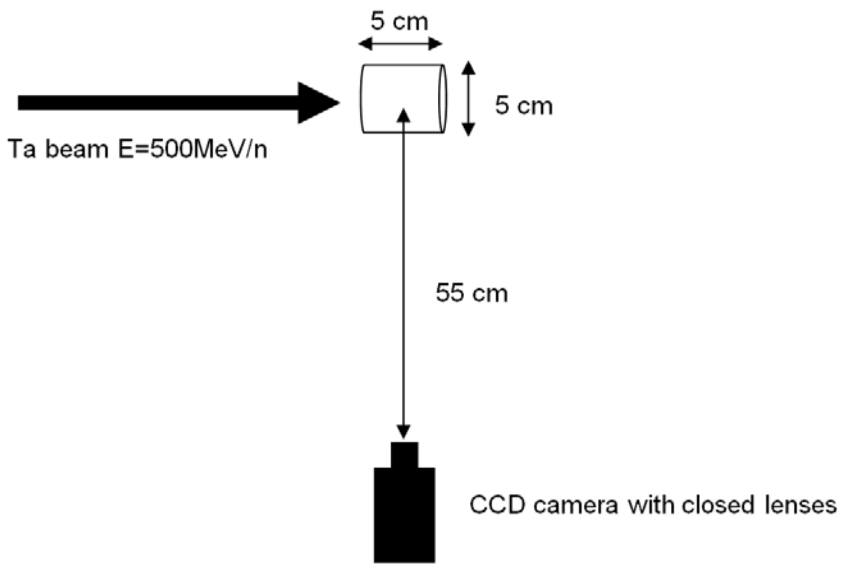

Fig.1: *Experimental setup scheme.*

The threshold level for pixel DN was selected on the basis of dark ("clean") image with closed lenses for an already damaged sensor with a significant dark current. It was selected so, that we don't see any pixels above threshold DN on "clean" image, but we see them there during the beam pulse (fig. 2). Number of pixels with luminance higher than this level is assumed to be the number of SEUs. SEU ratio is a number of SEUs divided by total number of pixels in the CCD matrix. For each beam intensity, about 20 images were processed and the mean value of SEU number and ratio was calculated for each case.

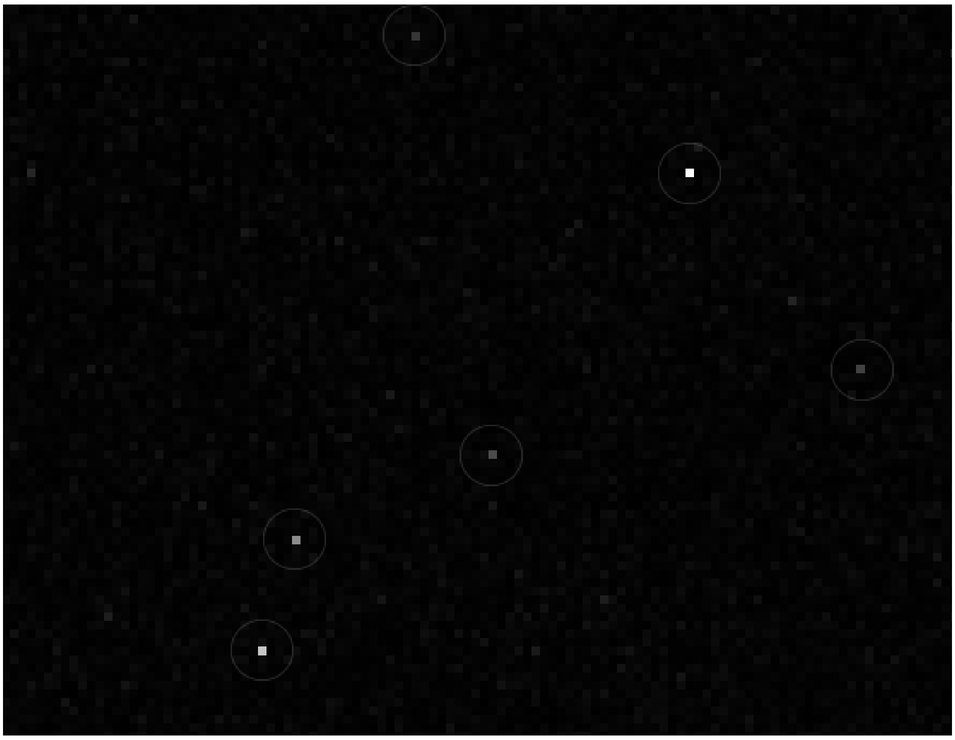

Fig.2.a*: Zoomed part of typical frame corresponding to beam pulse; SEUs are marked with circles.*

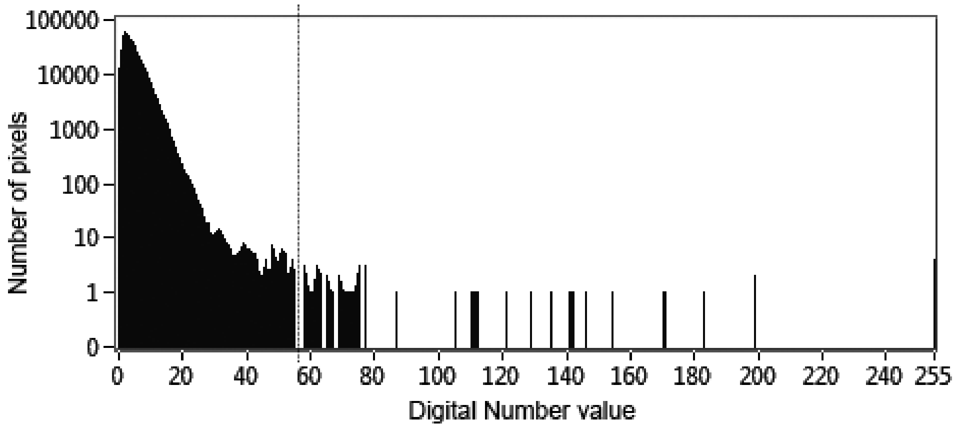

Fig.2.b: *Histogram of this image; threshold digital number is marked with dashed line.*

3. Results

The mean value of SEUs per shot for different beam intensities is presented in Table 1. One can notice that events produced by losses within 1E7 to1E8 ions/pulse are hardly noticeable, because absolute value of SEUs is lower than 10 events per pulse. With increase of beam intensity, number of SEUs rises linearly.

Tab. 1. *Mean values of SEU number and ratio for different beam intensities*

SEU number	SEU ratio	SEU ratio error	ions/shot
0.96	2.95E-06	1.47E-06	3.19E+07
11.25	3.45E-05	1.26E-05	3.17E+08
30.16	9.25E-05	3.70E-05	8.85E+08
71.73	2.20E-04	5.38E-05	1.88E+09

Linear fit and extrapolation can be used to scale SEU effect for different situations (fig. 3). With losses in the order of 1E9 ions/pulse, number of SEU is considerable and can interfere with regular data acquisition from CCD based cameras. At 100 times higher intensities – which are expected at FAIR facility – one can expect very noticeable SEU effects about several percent of all pixels in CCD matrix.

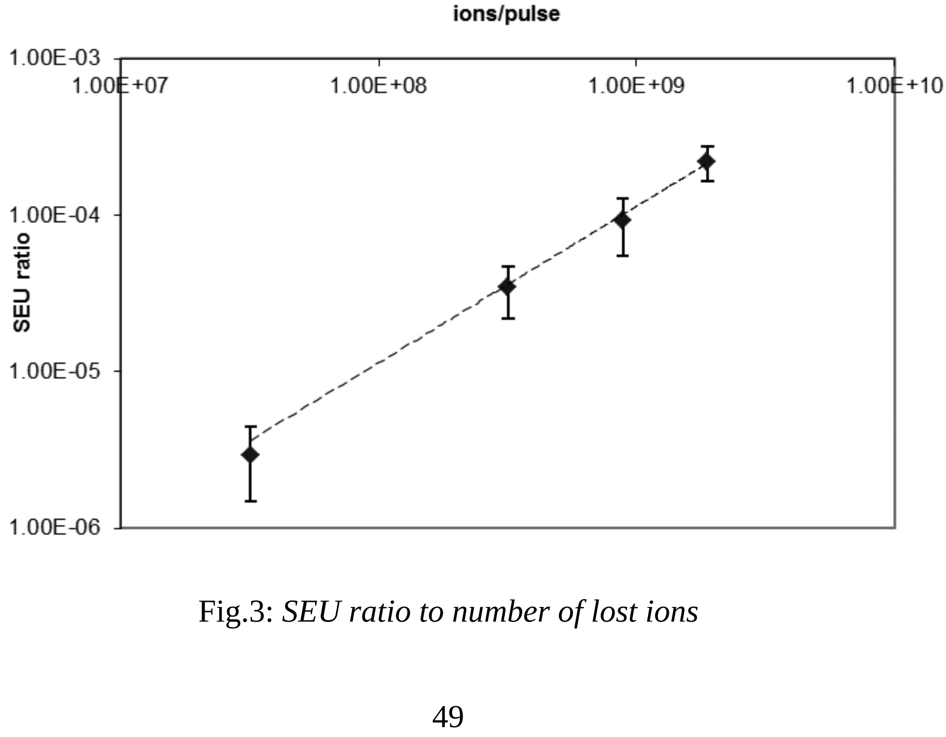

Fig.3: *SEU ratio to number of lost ions*

4. Discussion

This experiment shows that at high beam losses from 1E8 ions/pulse, secondary radiation makes noticeable SEU ratio in CCD chips located near the loss point. These effects may affect CCD based acquisition systems for beam profile-meters and scintillation screens, which could be critical for beam losses expected in FAIR. The above described method to measure the short term ionizing radiation effects on CCD is the simplest but it is also rather crude. To measure these effects more accurately one must study histograms of "event" frames more carefully. For example subtraction of "dark" frame histogram from "event" frame histogram will help to calculate the charge, induced by ionizing particles.

References:

[1] FAIR Technical Design Report: High Energy Beam Transport lines, 214 (2010).

[2] FAIR Technical Design Report: SIS100 & SIS300, 35 in appendix (2010).