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JINR HEAVY ION ACCELERATORS APPLICATION FOR SEE TESTING IN ISDE

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Abstract

Thousands satellites and spacecrafts are lunched worldwide every year. All of them, without exception, are exposed to space ionizing radiation. The radiation consists of galactic cosmic rays, solar energetic particles, as well as electrons and protons from Earth's radiation belts. Radiation environment results in upsets and even failures of spacecraft system electronics. To ensure mission success, electronic engineers must perform a series of operations to validate the radiation hardness level of electronic components used. For modern electronic parts the most hazardous upsets and failures are due to the impact of single high-energy particles. Such radiation effects are called as SEEs – Single Event Effects – since undesirable event is induced by a single particle strike. The spectrum of space radiation environment is extremely wide, but as the measure for the single particle environment with particular energy Liner Energy Transfer (LET) can be used. Ground tests are unable to reproduce the space environment, yet heavy-ion accelerators allow us to create experimental environment simulating LETs similar to space radiation. LET spectrum is from a few MeV cm/mg up to one hundred MeV cm/mg. The goal of SEE tests is to obtain the dependence of SEE cross-section from LET for each type of effects (upsets and failures). To ensure energy deposition in a sensitive region and register SEEs, particles with at least 30-40 um range in Device Under Test (DUT) die are required. To meet the test requirements, the wide range of ions – from O to Bi and energies from 3 MeV/nucleon – shall be used, while a lid should be removed from a DUT. A number of devices, due to their design, require the longer-range, and hence the higher-energy ions, while maintaining the requirements for LET. To meet the needs of Russian space equipment designers and manufacturers of integrated circuits and other semiconductor devices, ISDE in collaboration with JINR have created the unique in Russia SEE Test Facilities. In this paper, we introduce readers the test facilities specifications, ion beam formation and monitoring techniques, certified methods for ion energy and fluence measurement and technical means for their implementation. The paper presents statistics on the use of test facilities, directions for their further development and upgrade.

GENERAL INFORMATION ABOUT TEST FACILITIES

Since 2010, we have been acting in the field of SEE testing. Up to now, 3 test facilities on the basis of U-400 and U-400M accelerators that provide all types of SEE radiation tests of electronic components of any functional class are in operation. The test facilities allow to irradiate DUTs in the following test environments: range of ions from C to Bi; initial energy from 3 to 60 (for light ions) MeV/A; LETs (Si) from 1 to 100 MeV×cm^2/mg; ranges (Si) from 0.03 to 2 mm (depending on the energy); adjustable fluxes from 10 to 10^5 particles/(cm^2 × s); irradiation area up to 200×200 mm; beam nonuniformity less than 10 % [1]. The general structure of SEE Test Facilities is shown in Fig. 1. Equipment in green belongs to the heavy ion accelerator, and all others have been designed especially for SEE testing.

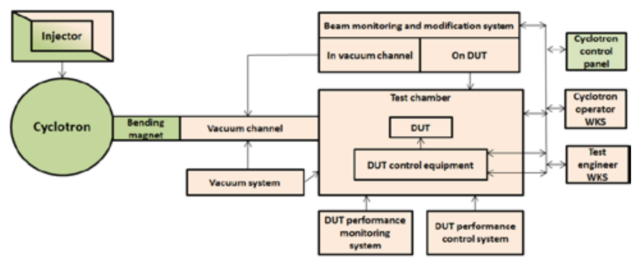

Figure 1: General structure of SEE Test Facilities based on ion sources.

In Fig. 2 we can see a layout of a beam transfer channel with a large number of tools which are used for beam formation, monitoring and measurement. To provide the high accuracy of the beam in a test chamber (on DUT) we use multistage control of the beam parameters [2].

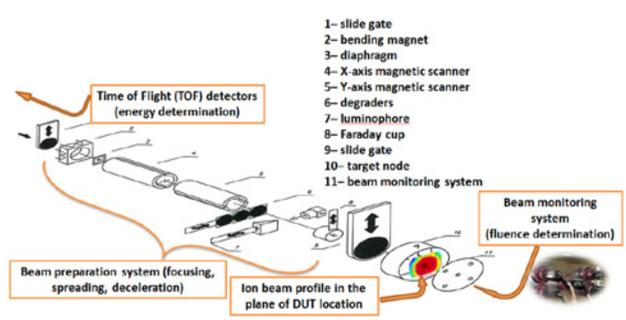

Figure 2: Beam transfer channel layout.

SEE tests are considered to be one of the most expensive parts of ground testing of spacecraft electronic equipment. And the largest expenses are related to the ion accelerators operation. Thus, it is essential to optimize the test procedure. A key advantage of our test facility is a

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large beam area that allows several items to be irradiated simultaneously. This provides the high levels of beam fluxes, which in turn allows the fast fluence production corresponding to the test standards. Also, test engineers to reduce the time for vacuum pumping must comply with the regulations of vacuum equipment operations for eliminating the extra gassing sources. Large amounts of test equipment are recommended to be preliminary outgassed in a special chamber.

To obtain a large irradiation area considering the specific structure and length of each test facility several beam modification systems have been designed. The beam spot from the heavy ion accelerator goes through two magnet scanners, which in turn move the beam in two directions (see Fig. 3). Using this technique, we scan the area in a vacuum chamber and seed the irradiation area with the heavy ions with low nonuniformity. For different facilities we use different scan frequency in X- and Y-axis and different current waveforms (saw-shape, sinus). The maximum amplitude of magnetic fields is about 300-350 Gs.

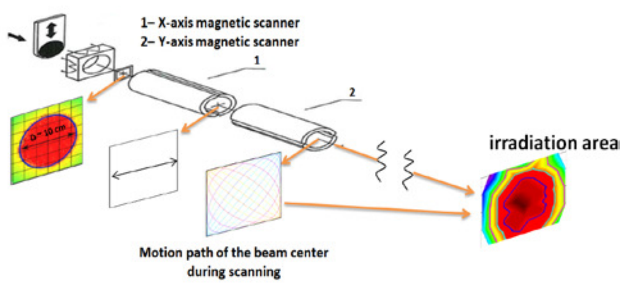

Figure 3: Beam modification system.

Examples of beam profile are shown in Fig. 4.

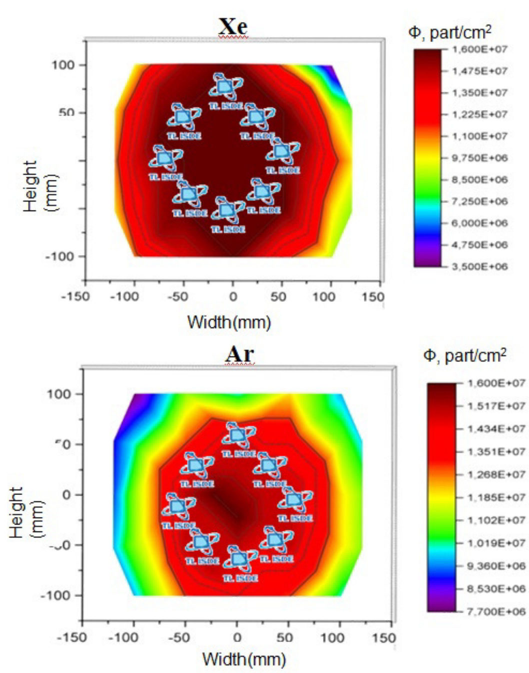

Figure 4: Typical shapes of ion beam profile & best location of DUTs.

CERTIFIED BEAM CONTROL TECHNIQUES

The main parameters of the heavy ions during SEE testing are the beam fluence and LET. To calculate fluence we use old and reliable method of holes calculation on irradiated track detector. Also, we have the scintillator-based detection system (orange spots in Figs. 5, 6), but it is used only for estimation of fluence value. To meet the dosimetry support requirement of each irradiation we put the track detectors nearby the DUT (Figs. 5,6). The fluence evaluation method is quasi-online (online: scintillators, off-line: track detectors), and yet it shows the excellent accuracy. The online detectors are used to determine the moment for stopping the irradiation after the fluence reaches >10^7 (3x10^5 for Power MOSFETs). To obtain a precise value, the track detectors placed close to the DUTs are used (Fig. 7). The measurement method is based on the calculation of etched holes formed due to the differences in etching rates of the damaged and undamaged areas of the plastic track detector after its irradiation with heavy ions, and then dividing this amount by the area of field on which holes were calculated.

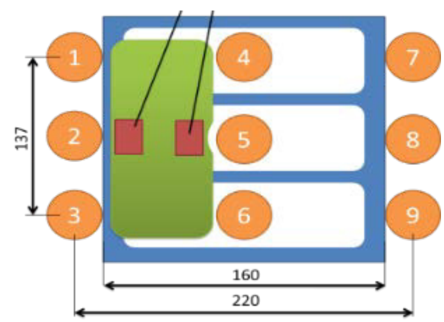

Figure 5: Track detectors (TD) mounting.

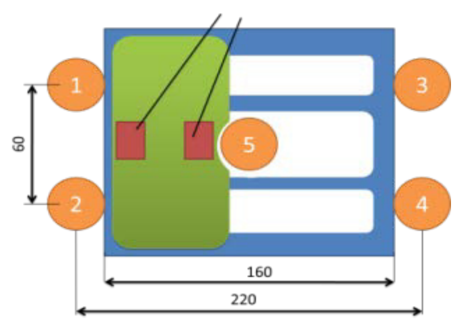

Figure 6: TD irradiation.

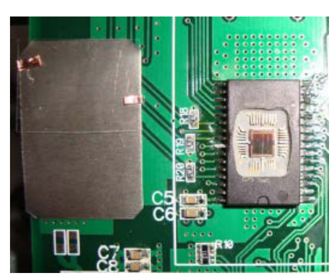

Figure 7: Holes calculation.

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To obtain the LET value we need to know the ion energy and after that it is easy to calculate LET using SRIM software. For energy measurements we use Time of Flight (TOF) technique and system based on scintillation detectors and high resolution electronics. Schematic of TOF technique is shown in Fig. 8. TOF technique based on one-to-one correspondence between the kinetic energy and the particle velocity. During the test campaign, energy measurements are performed once after each ion ejection (may be repeated if required). This method provides energy determination with up to 2% accuracy.

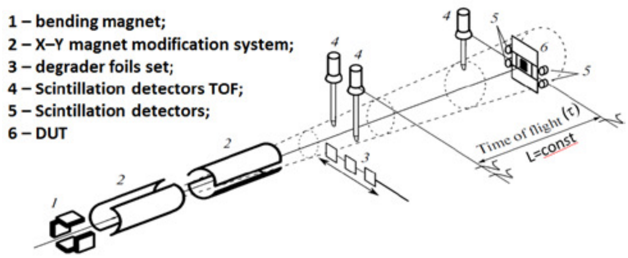

Figure 8: The energy measurements.

An important feature of the high-energy facility is the opportunity to use special thin aluminum or nickel stacked degrader in the beam line (Fig. 9). The use of degraders allows us to change the ion energy, and therefore, the ion LETs and ranges without changing its species (Fig. 10). As a result, we can obtain a number of LETs while irradiating with one ion. Thus, using degraders with all ion species, we obtain quasi-continuous LET spectrum in almost the whole required range (Fig. 11).

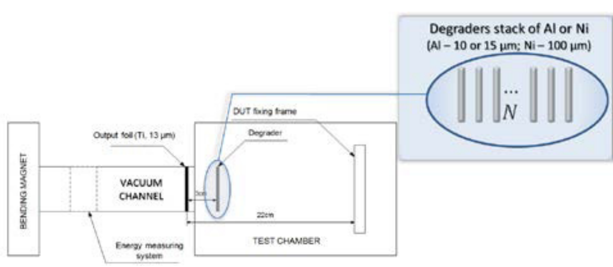

Figure 9: Special features of beam parameters determination for the High-Energy Test Facilities.

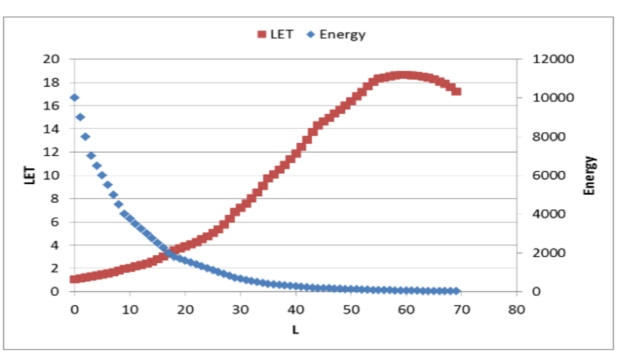

Figure 10: An example of dependence between ion energy, LET and range.

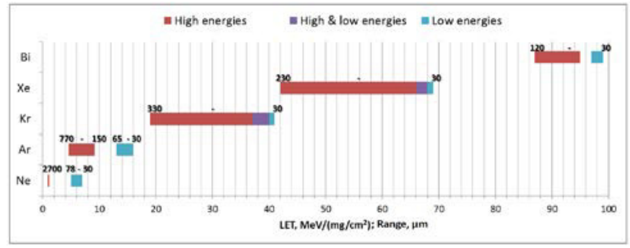

Figure 11: Quasi-continuous LET spectrum at the high-energy facility using degraders – LET & Range for different type of ions.

CONCLUSION

The ISDE & JINR collaboration have created and now successfully operates the unique in Russia test facilities for certification of microelectronics for space applications. Their application allow us to perform the comprehensive single event effect tests and failure analysis, and ensure the fault- and failure-free operation of spacecraft electronics in harsh space radiation environment. Since 2010, more than 4200 parts of electronic components for space application have been tested. To meet the growing demands of test customers, we do our best for the test facilities development and enhancement. We are looking forward to cooperating fruitfully in the field of SEE testing and space device engineering.

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