The Heavy Ion Irradiation Facility at CYCLONE - a dedicated SEE Beam Line

G. Berger, G. Ryckewaert

Université Catholique de Louvain, Cyclotron Research Center
Chemin du Cyclotron 2
B1348- Louvain-la-Neuve, Belgium

R. Harboe-Sørensen, L. Adams

Components Division, European Space Agency-ESTEC
2200 AG Noordwijk, The Netherlands

Abstract

After a two years evaluation and assessment period of the CYClotron of LOuvain la NEuve (CYCLONE) usability for heavy ion SEE testing, the European Space Agency has now initiated the set-up of a permanent beam line dedicated for SEE testing. This paper describes the CYCLONE accelerator, the beam line used so far, presents some experimental results which are compared with data obtained at the Tandem accelerator at Brookhaven National Laboratory (BNL) and details present and future developments.

I. Accelerator facility

CYCLONE is a multiparticle, variable energy, cyclotron capable of accelerating protons (up to 75 MeV), alpha particles and heavy ions. For the heavy ions, the energy range covered is between 0.6 MeV/AMU and 27.5 MeV/AMU. For these ions, the maximum energy can be determined by the formula $110\ Q^2 / M$ where Q is the ion charge state, and M is the mass in Atomic Mass Units.
The heavy ions are produced in a double stage Electron Cyclotron Resonance (ECR) source [1]. The ions are extracted at low energy (around 10 * Q keV), an analyzing magnet is used to select the desired M/Q ratio and then the ions are injected axially for subsequent acceleration. The use of an ECR source allows us to produce highly charged ions and ion "cocktails". These are composed of ions with the same or very close M/Q ratios. The cocktail ions are injected in the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency. One of the main advantages of the cyclotron - ECR source combination is the fast changing of ion species. Within the same cocktail, it takes only a few minutes to change from one ion to another. This time has to be compared to 30 minutes to 1 hour for a tandem machine

The two cocktails used for SEE studies are detailed in table 1

Cocktail # 1:

M/Q = 4,94	DUT energy [MeV]	Range [μm Si]	LET [MeV/mg/cm²]
$^{84}Kr^{17+}$	316	43	34

M/Q = 5	DUT energy [MeV]	Range [μm Si]	LET [MeV/mg/cm²]
$^{40}Ar^{8+}$	150	42	14,1
$^{20}Ne^{4+}$	78	45	5,85
$^{15}N^{3+}$	62	64	2,97
$^{10}B^{2+}$	41	80	1.7

M/Q = 5,07	DUT energy [MeV]	Range [μm Si]	LET [MeV/mg/cm²]
$^{132}Xe^{26+}$	459	43	55,9

Cocktail #2

M/Q = 4	DUT energy [MeV]	Range [μm Si]	LET [MeV/mg/cm²]
$^{12}C^{3+}$	79	130	1,67
$^{16}O^{4+}$	105	104	2,9
$^{40}Ar^{10+}$	259	68	10,9

Alpha beam

Ion	DUT energy [MeV]	Range [μm Si]	LET [MeV/mg/cm²]
α	9,2	63	0,4

Table1 Description of the two cocktails and the alpha beam used for SEE studies

As it can be seen from this data, CYCLONE does not reach high LET of in BNL (up to 82 MeV cm² / mg), but we maintain a minimum penetration depth larger than 40 µm in silicium.
In order to improve the low LET coverage, we added the boron beam to the first cocktail and we developed an alpha beam. These two ions can be useful for threshold LET determination.
The first cocktail covers a wide range of LET, which is needed for a complete SEE characterization (LET between 2 and 55 MeV cm² / mg). The second one can be used for research purposes when low LET and high penetration depths are needed.

II. Present beam line

A test chamber and a beam monitoring system have been installed on one of the beam transport lines. This test chamber, a cylinder of 50 cm in diameter and connected to a multichannel analyzer (MCA) and ratemeter. The fig. 1 represents an MCA spectrum of a nitrogen 15 beam. We can observe a perfect purity, even though this ion is a part of the cocktail #1 and is much less abundant than the other ions (natural enrichment in ^{15}N : 0.4%).
During irradiation, the beam flux monitoring is made with a Parallel Plate Avalanche Counter (PPAC) placed in front of the device. This PPAC detector is a transmission chamber under gas circulation which is used to measure the total fluence delivered to the sample.
The PPAC counting rate is compared with the surface barrier detector one in order to determine a ratio which will be used to measure the ion flux per cm². The maximum usable flux is 1E4 particles / s / cm², this limit is imposed by the dosimetry system. On the other hand, the lowest usable flux is only a few particles / s / cm².
The beam flux setting is made by source RF power tuning and adjustment of the injection parameters.

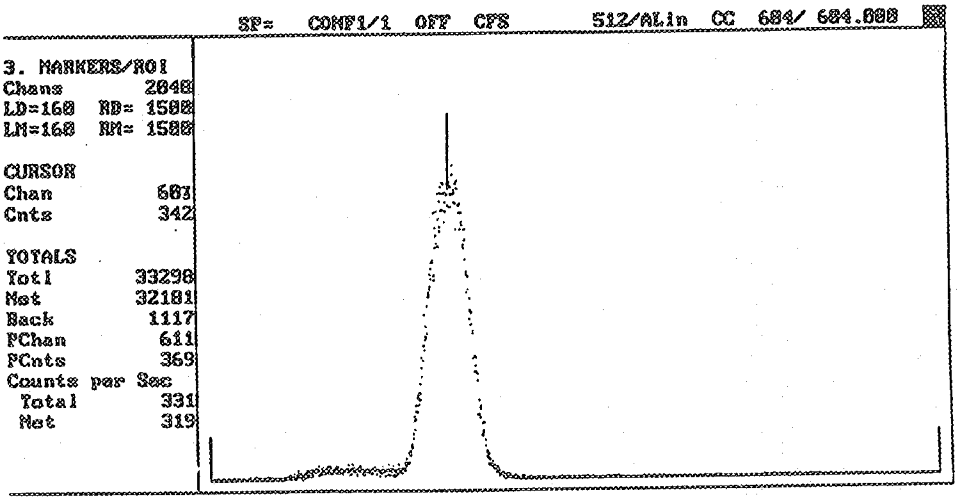

Figure 1 : MCA spectrum for N 15 beam
(relative intensity vs. Energy)

and 50 cm in length, was equipped with a frame of 25 cm X 25 cm. Translation movement allows the use of multi-device boards and a rotation (- 70° to + 90°) for effectice LET (LET_{eff}) variations.
In order to reach a good beam homogeneity at the device position, a gold diffusion foil with a thickness of 1,53 mg/cm² has been placed 4 m in front of the chamber. With this setup, we have a beam homogeneity of ± 10 % over a diameter of 20 mm. This homogeneity is measured with a collimated surface barrier detector on a one axis movement.
The flux and purity of the beam are controlled with a surface barrier detector placed in the chamber
Flux variation is within a few percent of the chosen value.

III. Experimental results

Prior to the start of the Heavy Ion Facility (HIF) activity a large number of studies and evaluations were carried out on the beam line. Device testing and beam development soon called for a correlation program with another well recognized facility. As ESA already had a large number of memory types SEE tested at the BNL Tandem facility it was decided to perform similar SEE tests at CYCLONE by using the same devices and tester. All test conditions were the same as at BNL i.e. 5 Volt, MOVI 50/50 test pattern, icc current measurement and latchup protection [2].
The irradiations were carried out using the M/Q = 5 cocktail, and the devices tilted at 0°, 45° and 60°.

Micron 4M1 DRAM s/n D08

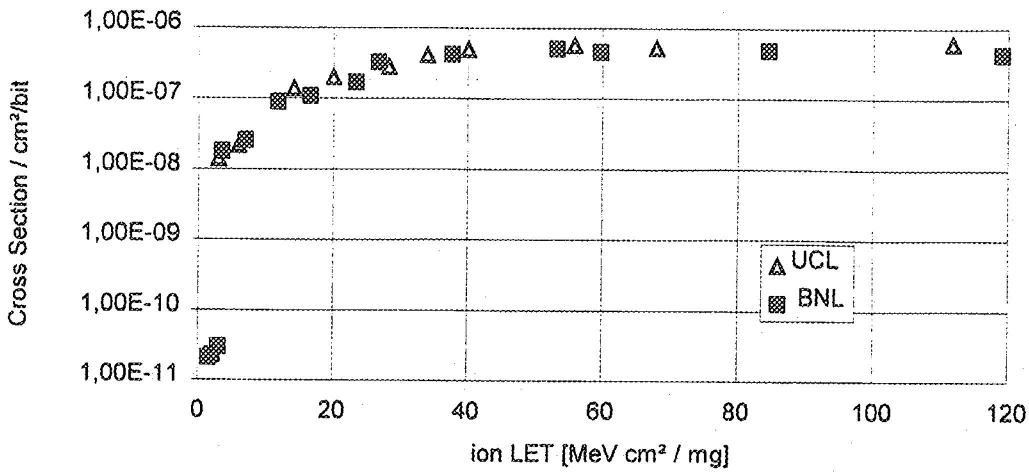

Figure 2: SEU test results for 4M Bits DRAM

With this method, we covered a LET_{eff} range from 2,97 MeV / mg / cm² to 111,8 MeV / mg / cm². The SEU results presented graphically in figure 2 were obtained on 4M X 1 DRAMs from MICRON [3]. This graph contains the results obtained at BNL (ref. ▩) and at CYCLONE (ref. Δ). By comparison of the threshold LET, the saturation cross section value and the shape of the curves, we can conclude excellent correlation between the two sets of results. SEU DRAM results for both 1M X 4 from MICRON and 4M X 1 from Texas Instruments showed the same inter-facility consistency [3].

Recent DRAM testing of 16M X 1 from Fujitsu,4M X 4 and 16M X 1 from Samsung also confirmed this high degree of consistency between BNL and CYCLONE [4].

IV. Present developments

Present development and upgrading of the SEU facility, followed by beam calibration and tuning, is a part of a CRC - ESA collaboration. The aim of this program is to have a dedicated SEE HIF set-up

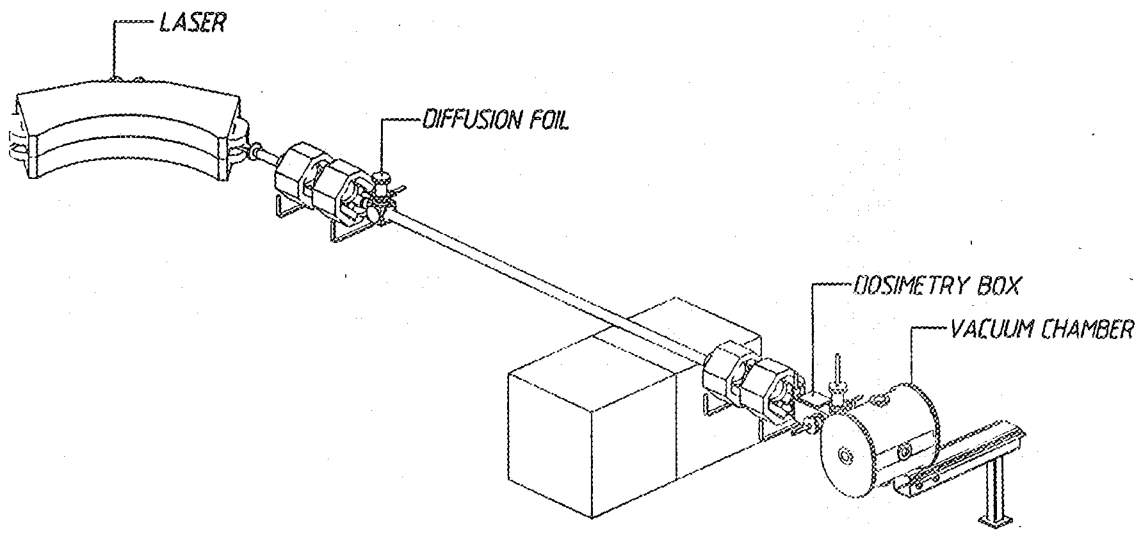

Figure 3 : Single Event Effect Beam Line

ready for commissioning in Q3 of this year. Over the past two years developments have been carried out on the beam line, on the dosimetry system, on the test chamber and on a user friendly interface.
Main upgrades and improvements can be summarized as follows.

A. Beam Line

In order to improve the beam homogeneity and be able to irradiate larger devices, we moved the diffusion foil upstream.
Beam transport calculations identified the optimum position for the same foil thickness as before. During a test run with argon we reached an homogeneity better than ± 10 % over a diameter of 60 mm (fig.4). The diffusion system is composed of a collimator for beam transport tuning and two diffusion foils (one in use and a second one as spare). The foil can be swapped easily via the user interface.
Another feature has been added in the injection line between the ECR source and the cyclotron. It consist of three independent grids which allows the user to lower the beam flux by a constant factor. Thanks to the large beam emittance in this low energy line, a « pepper pot » system is enough to reduce the flux by a factor of 10 for the first grid and around 100 for the two others. Moreover, as the grids are independent, it is possible to use any combination of these.
For any intermediate values or for very low fluxes, we still use RF power variation of the ECR source. With the new installation, this control is accessible to the users.
A laser equipped with a telescope has been installed on the axis of the beam line for device positioning purpose. Finally a beam dosimetry box has been installed in front of the test chamber.

B. Test Chamber

The test chamber has been enlarged. As it can be seen on the figure3, the actual one has the shape of a barrel stretched vertically, its internal dimensions are 71 cm in height, 54 cm in width and 76 cm in depth. One side flange is used to support the board frame and user connectors. This flange is placed on a rail system and can be removed as far as 1 m from the chamber. In this way, the user has a lot of space for device installation and adjustments.
The board holder has been replaced by a X,Y,Z mechanism frame. We still have the translation movement (with a stroke of 260 mm), which allows irradiation from side to side of the test boards. The rotation movement has been modified to rotate from -90° to +90°, and an additional translation movement has been added to properly place the component on the rotation axis. This last feature is useful when there are different device packaging or socket heights on the same board ; the stroke is 40 mm.
The frame dimensions are the same as before (25 X 25 cm compatible with BNL and the Proton irradiation Facility -PIF- in Switzerland). Thanks to the translation movement, the components can be placed from side to side on the test board. The use boards with non centered devices is possible by using an intermediate frame.
Each movement has been equipped with an optical encoder in order to allow a position storage. This is used for automatic positioning of the device during irradiation.
An iris is used to avoid irradiating neighboring components, the aperture is controlled by the users by means of a joystick. The aperture can be fixed between 6 and 60 mm and is stored in the device position file for each sample. A camera is placed

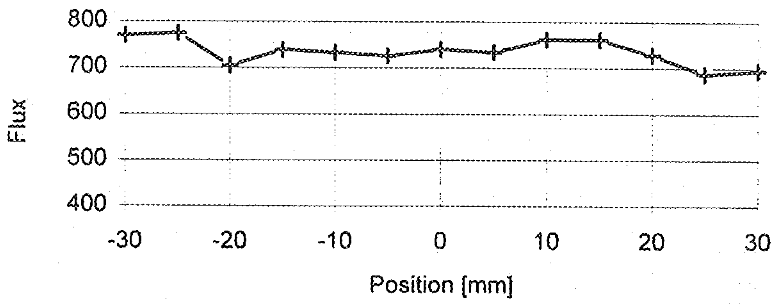

Figure 4 : Beam profile

in the chamber for device positioning.
The standard connector flange contains 6 D25, 10 BNC and 4 SHV, however, user adapter plates with special feed-through configurations can easily be accommodated.
The chamber is equipped with a vacuum system fast enough to pump down in less than 10 minutes.

C. Dosimetry

To control and monitor the beam parameters (flux and homogeneity) a new dosimetry system has been developed.
A box placed in front of the chamber contains a faraday cup, 4 scintillators and 2 Parallel Plate Avalanche Counters (PPAC). Two additional surface barrier detectors are placed in the test chamber.
The faraday cup is used during beam preparation at high intensity. When the beam is ready, defocused and the flux lowered, we proceed with a beam uniformity measurement with a collimated surface barrier detector. Contrary to the previous setup, this detector is placed on a X and Y movement. Scans can be done automatically by the user interface, the final profile is drawn on the user screen and the ± 10 % width is calculated. If the profile meets the user criteria a PPAC calibration is performed.
The PPAC are checked with a 1 cm^2 surface barrier detector during a similar calibration procedure as before. During the irradiation, the PPAC flux is integrated in order to give the delivered total fluence on the device. This detector can also be used to switch off the beam when a preset fluence is reached. The second PPAC is kept in stand by in case of failure of the first one.
The four scintillators are placed at 90 degrees to each other to measure the beam uniformity during irradiation. Different collimators are used as a function of the used beam flux. These collimators are placed on a wheel which allows automatic changing.
This new dosimetry system allows us to go higher in flux i.e. 1 E6 particles/s/cm^2. The lower reachable flux still a few ions /s /cm^2 .

D. User Interface

A complete user interface in C/C++ in a Windows environment has been developed. In this way, the users have access to all the beam flux control, dosimetry features, device positioning, vacuum controls and cross section versus LET via 3 screens and 10 icon tool bars. A fourth screen is reserved for CYCLONE staff. In addition, several warnings are provided to the users in case the uniformity or flux change during irradiation.
Screens are divided by function :

- BOARD-POSITION
- DATA-BEAM
- BEAM LINE
- OPERATOR.

The first screen, BOARD - POSITION, allows the users to store the device positions for different boards. While a laser light placed in the beam line simulates the beam, the users may use joysticks to center the device on the axis and select an iris aperture. These values are saved in a file which will be used latter for positioning.
The second screen, DATA - BEAM, (see figure 5) includes all the beam parameters (as the ion type, flux,...). When the users have selected a target material and ion type from a drop down list, the LET and range are automatically displayed. From there, it's also possible to tilt the device to a desired angle or to choose a LET_{eff} and automatically do a rotation to reach it. The users have also access to the run data such as fluence and calculated dose. The users may enter the memory size and error number to calculate the cross section and plot it. Moreover, an input is free for a TTL signal which, if this is connected to the test system, allows an automatic cross section measurement.
All run data (ion, fluence, cross section, ...) are stored in a logbook file for latter printout.
The BEAM LINE screen is used to do calibrations (scan and flux measure), to insert beam attenuation grids and pump down or vent the test chamber.
The OPERATOR screen is password protected for security reasons. This one includes access to the different detectors, detector biasing, access to all line valves, vacuum control of all the line and diffusion foil and PPAC swapping.
For the most frequently used features of the installation such as vacuum chamber, start/stop irradiation, grids, laser light, light in the chamber and defined rotation angles, the users have permanent access to a tool bar.
All the equipment is located in a shack just next to the beam line. This is equipped with a clean 220 V main to avoid undesired glitches during tests. All equipment needed (oscilloscope, PC, ...) are provided to users.
A check out procedure has been established with the radiation survey department and a neutron monitor has been installed close to the beam line.

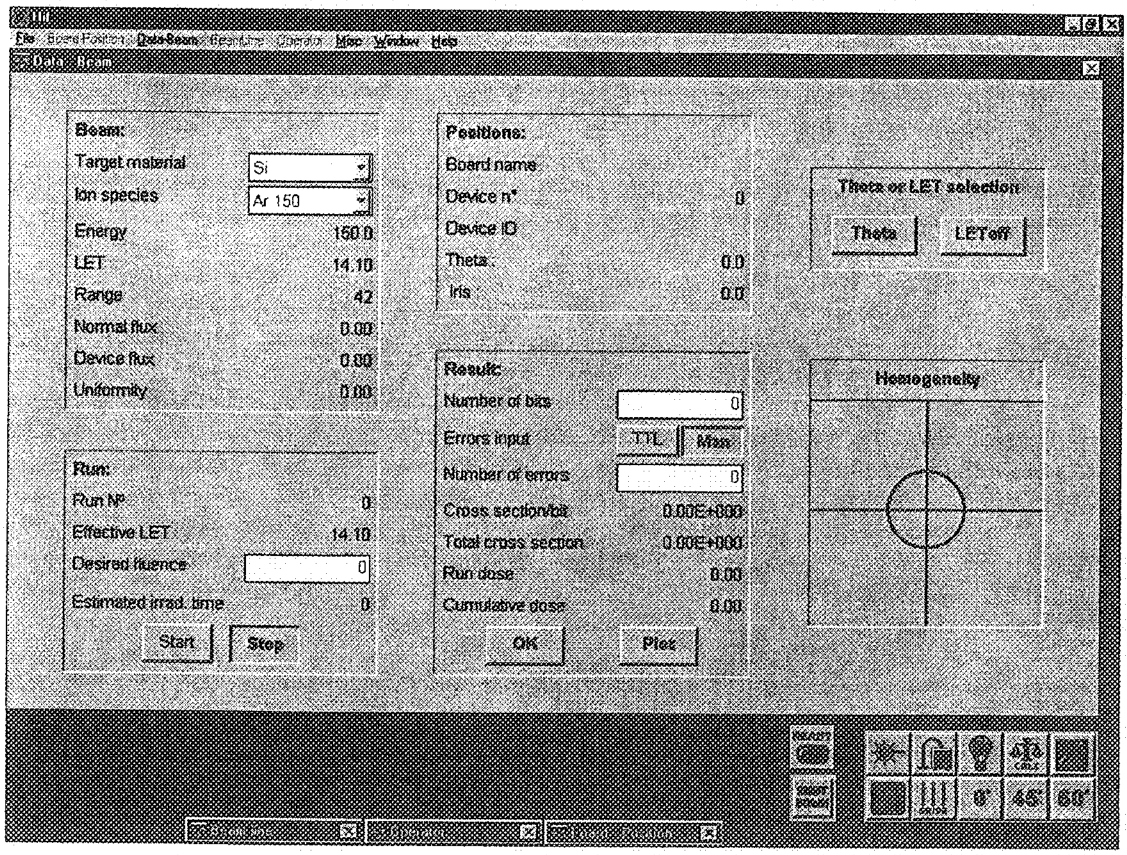

Figure 5 : DATA - BEAM screen

V. Conclusions

As an European alternative to SEE testing at BNL, a permanent Heavy Ion Irradiation Facility has been installed at CYCLONE, Belgium. This facility, initiated by the European Space Agency, will be made available to the space community with a hourly rate comparable to other SEE facilities. Additional advantages are a very low set-up time, quick ion change (minutes), full control and a user interface and DUT set-up comparable to BNL. This facility offers a very flexible SEE test set-up with the user controlling most functions. The HIF will be available for testing in Q4 of 1996.

References

[1] J.L. Bol, A. Chevalier, Y. Jongen, M. Lacroix, F. Mathy and G. Ryckewaert " Operation experience with the CYCLONE Octopus combination" Proc. 11th Int. Conf. on Cyclotrons, Tokyo, pp. 90-93

[2] R. Harboe-Sørensen, R. Müller, E. Daly, J. Schmitt and F.J. Rombeck "Radiation Pre-screening of 4Mbit Dynamic Random Access Memories for Space Application" RADECS '91, La Grande Motte, France pp. 489-493

[3] R. Harboe-Sørensen, P. Vuilleumier, L. Adams, B. Nickson, R. Müller "Radiation Testing of flight lots for MARS-94 Covering semiconductor types as 4M-BIT DRAM, 256 K-BIT SRAM, 256 K-BIT EEPROM and a 53C90 SCSI controller" RADECS '93, Saint Malo, France pp. 490-498

[4] R. Harboe-Sørensen and S. Fraenkel « Heavy Ion, Proton and Co-60 Radiation Evaluation Of 16 MBIT DRAM Memories For Space Application » NSREC '95, Madison, Workshop Record pp.42-49