High Penetration Heavy Ions at the RADEF Test Site

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Abstract--**Increasing demands for radiation testing at accelerators have already attracted ESA and European Space Industry to the JYFL/RADEF facility. Initial test campaigns have shown the facility to be of great importance for future testing as it offers a range of complementary features not available at the existing radiation test facilities in Europe.**

I. INTRODUCTION

TODAY many advanced semiconductor IC's are assembled with central bonding, lead frames and plastic package hardly larger than the memory die (TSOP package). They cannot be SEE tested from the front side due to shadowing lead frame and accelerator ion penetration limitations. Backside irradiation on thinned IC's with high penetration ions are the only solution out. Here the JYFL/RADEF [1] facility has the main advantage since the new 14 GHz Electron Cyclotron Resonance (ECR) ion-source provides very high charge state ions for the acceleration resulting in a much deeper ion penetration range, possible a factor of 2 to 3 improvement, compared to the values attained by using the old 6.4 GHz ECR ion source.

For probing the upper limits we have started a new development work with the aim to push the penetration range steadily over 100 micrometers and, with some specific ions and beam cocktails, obtain still a factor of 1.3 to 1.5 higher penetrations with the desired LET range.

II. THE JYFL ACCELERATOR

The K-130 cyclotron is a sector-focused accelerator of beams from hydrogen to xenon. It is equipped with two ECR ion sources (6.4 GHz and 14 GHz) designed for high-charge-state heavy ions and a multicusp ion source for protons. The maximum proton energy is 65 MeV. The maximum ion energy can be determined by using the formula $130 \cdot Q^2/M$ [MeV] (Q = ion charge state and M = ion mass in amu). Because of the proportionality to the Q^2 the electron stripping ability of the ion source is the most important issue in developing high-energy beams.

In conjunction with the ECR, the cyclotron can run ion cocktails. This property allows a fast swap of ions, which is especially valuable in the study of SEE effects. Also the MIVOC (Metallic Ions from Volatile Compounds) [2] technique allows one to use metallic ions in cocktails. By this way e.g. the LET gap between argon (LET~15 MeV·cm^2/mg) and krypton (LET~35 MeV·cm^2/mg) can be filled. Together with the increased energy range the MIVOC technique provides a wide variety of different ion combinations for the development of high penetration cocktails

III. ECR ION SOURCES

All gaseous elements from H to Xe can be produced from the ECR ion sources for the acceleration. The non-gaseous elements produced so far are C, Mg, Al, Si, S, Ca, Ti, Cr, Fe, Co, Ni, Cu, Zn and Ge. Sample high penetration and high LET cocktails already used in test campaigns are given in Table 1 (Ne and Ar ions have a slightly different M/Q value and need retuning of the cyclotron).

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TABLE I
SAMPLE COCKTAILS USED IN THE PREVIOUS TESTS

Ion	Energy [MeV]	LET [MeVcm^2/mg]	Range [µm]	Prod. Method
$^{15}\mathrm{N}^{4+}$	140	2.0	208	Gas
$^{20}\mathrm{Ne}^{6+}$	186	3.4	156	Gas
$^{30}\mathrm{Si}^{8+}$	280	7.0	133	Silane
$^{40}\mathrm{Ar}^{12+}$	372	11.8	117	Gas
$^{56}\mathrm{Fe}^{15+}$	523	18.0	103	MIVOC
$^{82}\mathrm{Kr}^{22+}$	766	29.4	99	Gas

Ion	Energy [MeV]	LET [MeVcm^2/mg]	Range [µm]	Prod. Method
$^{12}\mathrm{C}^{2+}$	43	2	57	MIVOC
$^{30}\mathrm{Si}^{5+}$	108	11	42	Silane
$^{54}\mathrm{Fe}^{9+}$	194	23	37	MIVOC
$^{84}\mathrm{Kr}^{14+}$	302	38	42	Gas
$^{132}\mathrm{Xe}^{22+}$	475	62	44	Gas

By adding a second frequency to strip the electrons from the atomic shells two different heating layers inside the ECR plasma can be obtained. By this way the amount of high-charge state ions as well as the stripping power can be considerably increased. The technique has been used for example in ANL (Argonne National Laboratory, Illinois, USA), where a remarkable improvement to the intensities of the highly charged iron beams has been achieved (see Fig. 1).

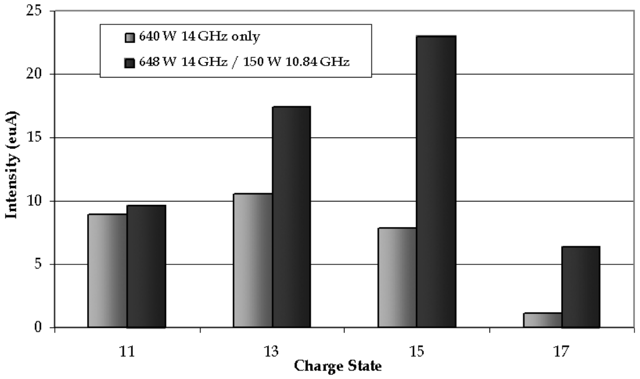

Fig. 1. The intensity of different charge states of ^{56}Fe ions produced at ANL by using the MIVOC Technique. Measurements have performed with and without the Two-Frequency Heating. The effect of the second frequency for the high charge state stripping is considerable.

The aim is to establish the double frequency heating in the JYFL 14 GHz ECR. The trial runs performed with the Argonne heater at JYFL have already now shown a remarkable increase of the charge states in e.g. Xe-ions. It seems that the double frequency technique will allow one to strip 36-37 electrons out from xenon, which means over 1.3 GeV energy and a range of 106 microns with a LET value of 57 MeV/(mg/cm^2).

This also gives more space for the developments of new cocktails. Two examples of high penetration cocktail candidates, but having low- and high LET values, are expressed in Table 2 (note the millimetre scale in the low-LET cocktail).

TABLE II
EXAMPLES OF HIGH PENETRATION COCKTAILS

Ion	Energy [MeV]	LET [MeVcm^2/mg]	Range [µm]	Source
$^{14}\mathrm{N}^{4+}$	149	1.5	258	6.4 GHz
$^{21}\mathrm{Ne}^{6+}$	223	3.3	198	6.4 GHz
$^{28}\mathrm{Si}^{8+}$	297	5.6	158	6.4 GHz
$^{56}\mathrm{Fe}^{16+}$	594	16.7	123	6.4 GHz
$^{84}\mathrm{Kr}^{15+}$	891	28.5	118	14 GHz
$^{115}\mathrm{In}^{33+}$	1231	43.7	109	14 GHz

Ion	Energy [MeV]	LET [MeVcm^2/mg]	Range [mm]	Prod. Method
$^{4}\mathrm{He}^{2+}$	130	0.056	5.56	Gas
$^{14}\mathrm{N}^{7+}$	455	0.69	1.61	Gas
$^{16}\mathrm{O}^{8+}$	520	0.90	1.43	Gas
$^{20}\mathrm{Ne}^{10+}$	650	1.40	1.15	Gas

The plan is to install the new heater during autumn 2003 and, including the testing phase, the aim is to finalise the commissioning during the first quarter of 2004. Together with the source testing a set of new cocktails will be prepared and, according to the plan, they will be in routine use before summer 2004.

In addition to the ECR development a new sensitive beam current measuring system will be developed. This will increase the detection accuracy from the recent nanoampere level to below picoamperes. This drastically helps to distinguish weak high charge-state beams from the ECR used in the irradiations.

IV. FACILITY UPGRADE

Simultaneously with the ECR development the aim is to increase the usability of the facility from its recent set-up. This includes modifications to the beam line, to test chamber equipment and to the user interface. In addition to these, a new test site will be furnished. These improvements help to shorten considerably the beam waiting time as well as the reliability of the data acquisition and results.

One major thing is to give up the use of diffusion foil without losing beam uniformity. With a careful tuning of quadrupole- and wobblers currents good homogeneity will be attained. The tuning will be done under users' control until the adequate homogeneity is achieved. Also, the fine-tuning of the beam flux will be made beyond operator's control. This users' empowerment will be done without running the risk of failures in accelerator or test equipment.

Also, the user interface will be upgraded. The users will get a chance to log in the local LAN network, which will be built for RADEF users. Through that the data acquisition and overall follow-up functions are displayed on a common screen and the users' monitors. The major principle during the developments will be to bear in mind the compatibility with the facilities at PSI (Switzerland) and at CRC-HIF (Belgium).

In addition to heavy ions, also protons play an important role in causing radiation damages. Therefore, the possibility to perform proton irradiation tests in RADEF facility will be developed. This offers an extra option for customers to perform the proton tests during the same test campaign by using the same set-up and test equipment, which were used for heavy ion test. By adding this capability needs more shielding and safety procedures against the radioactivity caused by protons, especially in heavy construction materials like iron and stainless steel. The plan is to take protons in the air and, therefore, a separate linear movement device will be built for protons and will be equipped with a fast fixing system allowing an easy change after the heavy ion experiment. All parts, which possible will be activated, will be stored afterwards to wait for cooling of radioactivity. Also, the proton upgrade is planned to be ready by the second quarter of 2004.

V. COMPARISON OF HEAVY ION TEST DATA

In order to validate the high penetration ions usability for back side irradiation, earlier and recent test data taken on a thinned Micron 128Mbit SDRAM were compared with data obtained from both the HIF, Belgium and from the LBNL, Berkeley, USA. SEU results, presented as cross section (cm^2/bit) versus ion LET (MeV/(mg/cm2) are shown in Fig. 2. The HIF data are front irradiated results obtained on a identical device whereas the LBNL data are from the same device as used at JYFL (back irradiated). Considering variability in test set-up, tester, ion counting and calibration, data analysis and interpretation, fairly good correlation can be reported between the four set of data. Noticeable is the tilted krypton results, which show no sign on ion penetration problems. This also indicates that the backside-thinned device, s/n #10.2, has successfully been thinned to < 50 micron. Finally, none of the backside results have been LET corrected taken ion penetration depth into consideration. This and other issues around backside irradiation will be addressed elsewhere. Here it was just to show a first set of SEU data obtained with high penetration ions as available and under development at the RADEF.

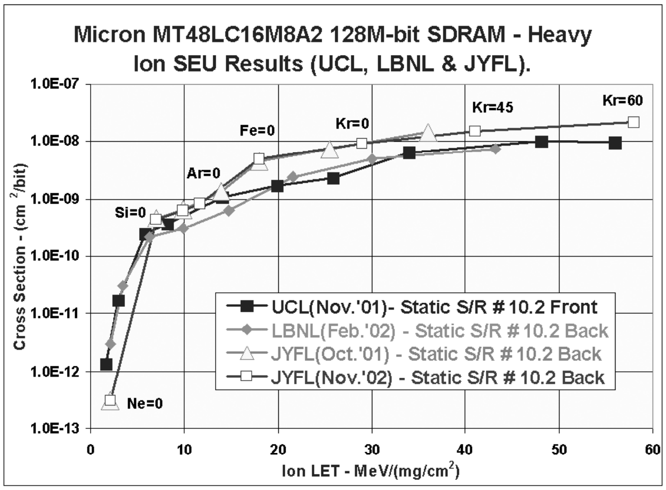

Fig. 2. A comparison of SEU data obtained at UCL, LBNL and JYFL.

To point out the importance of the proper penetration and the effects it has to the error cross-section we also carried out a test with slightly different ion energies achieved by using different degradation foils. The results are shown in the Fig. 3. Caused by the uneven thinning the deviations in the distances to the different banks become visible with only small differences in ion ranges, namely 89, 97 and 99 micrometres. These correspond to the energies of 689, 748 and 766 MeV, respectively (one should note the artificial differences in the LET-values made for visualisation)

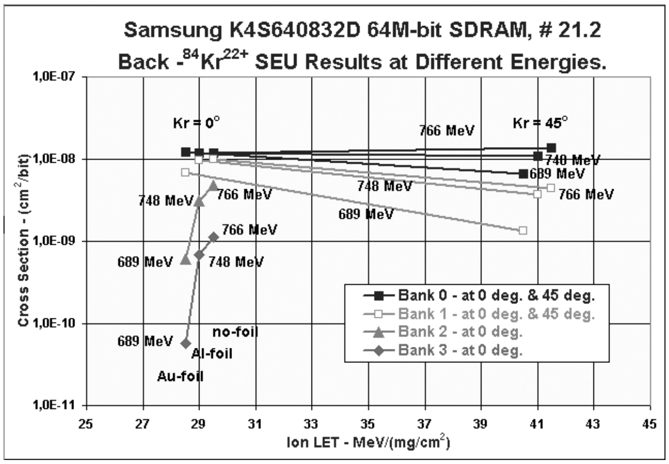

Fig. 3. The illustration of the effect of the different penetration lengths to the four Banks.

VI. CONCLUSIONS

In this paper we have introduced some upgrade procedures, which will be done to the JYFL/RADEF irradiation test station. These include improvements to the controlling of beam flux and homogeneity, to the user interface and to the new possibility to perform proton irradiations in the air. A special attention has been given to the changes, which will be done to the ECR ion source and the effects those have to the ion penetration in silicon. In addition, a comparison of the results of the SEE-tests, which have been performed in different test laboratories, is expressed. Finally, we have pointed out the importance of the sufficient penetration depth by giving an illustrative example about a SEE-test, where the SEE-error cross section in different banks of a sample component drastically changes according to only a small change in the ion penetration.

VII. REFERENCES

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