Synopsis V 1.0
Heavy Ion SEE Test of Micron and Samsung 4G NAND Flash Memories: Current Spike Experiment with JPL

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I. Introduction

This report describes the SEE and latchup testing and characterization of advanced Micron and Samsung 4G NAND flash nonvolatile memories. Researchers at JPL have reported high current spikes which appear to cause destructive write mode failures in their NAND flash tests. Similar tests at Goddard have not produced similar current spikes. While write mode failures sometimes occur in Goddard tests, the rate appears to be lower than in the JPL tests. The purpose of this test was to do a joint experiment to try to explain the differences in results in the different tests.

II. Devices Tested

Candidate devices for this test were the Samsung 4G SLC (K9F4G08U0A, LDC 907), and the Micron 4G (MT29F4G08AAAWP, LDC 748). These devices are non-volatile flash memories that use a floating gate NAND cell, manufactured using 63 nm technology. They have standard interfaces for pin and functional drop-in compatibility. Detailed device information is provided in Table I. The parts have 2Kx8 pages, with 64 pages/block, and 4096 blocks. In general, parts will have a few bad blocks, which have to be screened out. Up to 80 bad blocks are allowed, according to the spec sheet, although the actual number is usually much less, in our experience.

III. Test Facility

Facility: Texas A&M University Cyclotron Single Event Effects Test Facility, 15 MeV/amu tune.
Flux: 10^3 particles/cm^2/s, or slightly less.
Fluence: All tests were run to 1×10^4 Xe ions/cm^2 or until destructive or functional events occurred.

Table I. Ions used.

Ion	**LET (MeV/mg/cm^2)**
Xe	53.9

IV. Test Conditions

Test Temperature: Room Temperature
Operating Frequency: 40 MHz for dynamic test modes, 0 MHz for static test modes, using the GSFC LCDT. The JPL system was only able to go to about 17 MHz in the dynamic modes.
Power Supply Voltage: 3.3 V.

V. Test Methods

The testing was done at the Texas A&M Cyclotron, using the 15 MeV/nucleon tune. Since the purpose was to look for destructive effects, we started at relatively high LET, with Xe the first ion used. The original plan was to follow by with others in order of decreasing Z, Kr, Ar, and perhaps Ne, but time did not allow this. It was expected that the destructive events will occur primarily in dynamic test modes that involve high voltage operations, programming and erasing. Therefore, these modes were emphasized, but all the test modes were checked at least briefly. Normally, we test in static mode, both with and without bias, in dynamic read mode, dynamic R/W mode, and dynamic R/E/W mode. Angular effects and high temperature effects have been observed previously, but they are not the primary focus of this experiment. Some shots were taken at 45 degree angles, but all shots were at room temperature. The primary purpose of the test was to run the same parts on JPL test equipment and Goddard test equipment, side by side, and compare the results. Other variables will be considered, but the main point is to have them the same for both test systems. There were some difficulties with the JPL system, which limited the data actually obtained, however.

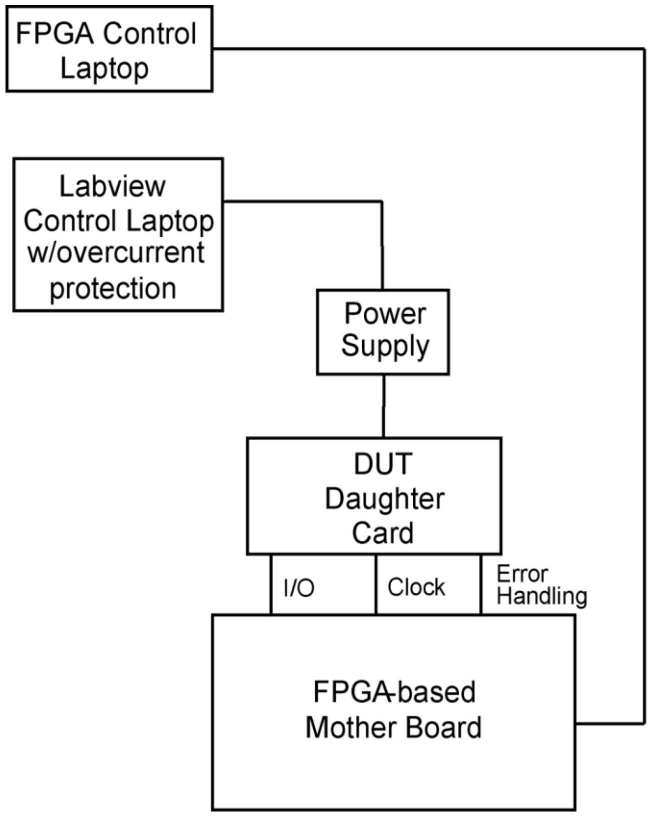

Figure 1. Overall Block Diagram for the testing of the NAND Flash.

Characterization:

A. Test system can write all ones, all zeroes, checkerboard, and checkerboard complement. Parts have a nominal 3.3 V power supply, and an internal charge pump to generate on-chip the higher voltages needed to write (program) and erase. After each exposure, the standby current was monitored to watch for latchup. No latchup was observed, however.

B. The first test was a static exposure, where a pattern is written, but the part is in standby mode while the beam is on. In this case, the errors were expected to be all zeroes turned into ones. The stored pattern was checkerboard (AA), however, because one-to-zero errors are an indication of errors in the control logic, possibly SEFIs. This test should be run both with no power supply, and with the power supply connected (biased and unbiased).

C. Second test will be a dynamic read test, with a pattern (AA) written, and read repeatedly with the beam on. It is expected that most of the errors will be static bit flips in this case, but some errors will be read multiple times, each time the whole memory is read. There are expected to also be SET errors in the peripheral circuits in this test. In this mode, the memory was checked after the beam is off, to determine how many bits were upset. If a SEFI is suspected, the memory should also be read after a power cycle—if the cells really upset, the errors will still be there, but errors due to the control logic may reset.

D. The third test was a dynamic read/write test, where a pattern is stored initially, and alternate read and write operations were performed with the beam is on. Because of the high voltage charge pump circuit, many effects besides static bit flips are possible—SEGR, SEFI, latchup. SEGR destroys the circuit, and latchup may also be destructive. If high current spikes occur, they are most likely in this test mode and the R/E/W test described below.

E. The fourth test was a dynamic read/erase/write test. The test pattern was AA (checkerboard) again in this case, because the ability to write zeroes and erase to ones were both being tested. In TID testing, the erase step usually fails before the write step, so there may be effects related to the high voltage charge pump in this test that were not observed in the write test alone.

VI. Results

There are three main conclusions about the results of this test. First, the results are absolutely consistent with our previous results on the same parts, as shown in Figs. 2-6, below. In each case, the new results are indicated as either GSFC or JPL, depending on which test system was used. Previous results obtained on the same parts are also shown for comparison purposes. There were 27 shots taken in total, 16 on Samsung parts, and 11 on Micron parts. The Samsung parts had one SEFI and one destructive failure, which was very similar to Write mode failures reported previously [1]. The Micron parts had a SEFI on every shot except two, where no bias was applied. Results are summarized in Table II, below.

Table II: Shot Log

Exposure	DUT	Mfg	# of bits	Vdd	Freq	Test	Pattern	Ion	Fluence	Angle	Errors	SEFI	Comments
1	SJ01	Samsung	4G	0	0	Static	AA	Xe	1.00E+04	0	1337	N	reset OK
2	SJ01	Samsung	4G	3.3	0	Static	AA	Xe	1.00E+04	0	1399	N	reset OK
3	SJ01	Samsung	4G	3.3	40	Dyn R	AA	Xe	1.00E+04	0	1500	N	1295 static--reset OK
4	SJ01	Samsung	4G	3.3	40	R/W	AA	Xe	1.00E+04	0	893	N	868 after--write fail 49 mA write current
5	SJ02	Samsung	4G	3.3	40	R/E/W	AA	Xe	1.00E+04	0	1434	N	no corrections--not writing
6	SJ02	Samsung	4G	3.3	40	R/E/W	AA	Xe	1.00E+04	0	1590	N	0 after
7	SJ02	Samsung	4G	3.3	40	R/E/W	AA	Xe	1.00E+04	45	2323	N	0 after
8	SJ02	Samsung	4G	3.3	40	R/W	AA	Xe	1.00E+04	45	1084	N	1076 after--reset OK
9	SJ02	Samsung	4G	3.3	40	Dyn R	AA	Xe	1.00E+04	45	1300	N	2182 after--reset OK
10	SJ02	Samsung	4G	3.3	0	Static	AA	Xe	1.00E+04	45	2263	N	reset OK
11	SJ02	Samsung	4G	0	0	Static	AA	Xe	1.00E+04	45	2200	N	reset OK
12	MJ01	Micron	4G	0	0	Static	AA	Xe	1.00E+04	0	250	N	reset OK
13	MJ01	Micron	4G	3.3	0	Static	AA	Xe	1.00E+04	0	811266	Y	811242 second--OK after PC
14	MJ01	Micron	4G	3.3	40	Dyn R	AA	Xe	1.00E+04	0	apprx 1e6	Y	1478049 after--OK after PC
15	MJ01	Micron	4G	3.3	40	R/W	AA	Xe	1.00E+04	0	1770100	Y	1864107 second--reset OK after PC
16	MJ01	Micron	4G	3.3	40	R/E/W	AA	Xe	1.00E+04	0	appr 1e6	Y	1618013 after--reset OK after PC
17	MJ01	Micron	4G	0	0	Static	AA	Xe	1.00E+04	45	349	N	OK after reset
18	MJ01	Micron	4G	3.3	0	Static	AA	Xe	1.00E+04	45	1081717	Y	OK after PC
19	MJ01	Micron	4G	3.3	40	Dyn R	AA	Xe	1.00E+04	45	appr. 4e5	Y	811383 after--OK after PC
20	MJ01	Micron	4G	3.3	40	R/W	AA	Xe	1.00E+04	45	1351898	Y	1351898 after--OK after PC
21	MJ01	Micron	4G	3.3	40	R/E/W	AA	Xe	1.00E+04	45	405692	Y	1892767 after, single pass--repeat
22	MJ01	Micron	4G	3.3	40	R/E/W	AA	Xe	1.00E+04	45	appr 3e6	Y	1890241 after--OK after PC
start JPL system													
23	SJ02	Samsung	4G	0	0	Static	AA	Xe	1.00E+04	0	363	N	1081344 bad blocks only--OK after reset
24	SJ02	Samsung	4G	3.3	0	Static	AA	Xe	1.00E+04	0	1309 net	N	OK after reset
25	SJ02	Samsung	4G	3.3	17	Dyn R	AA	Xe	1.00E+04	0	270565	Y	1345 net after--OK after reset
26	SJ02	Samsung	4G	3.3	17	Write	AA	Xe	1.00E+04	0	??	N	erased by mistake
27	SJ02	Samsung	4G	3.3	17	Write	AA	Xe	1.00E+04	0	>1M total	N	1128 net after--OK after reset
28	SJ02	Samsung	4G	3.3	17	Dyn R	AA	Xe	1.00E+04	0			no data--equipment failure

Second, there was no significant difference in the results between the GSFC system and the JPL system. There were minor differences in some cases, but these were within normal statistical variation. Due to technical difficulties, there was less data taken with the JPL system than either group would have liked, but the systems agreed well when they were both used for the same measurement. It had been suggested that the differences between the two groups, current spikes in one case but not in the other, was due to differences in the test equipment. This appears not to be the case.

Third, there were no high current spikes observed with either test system on any of the shots in this test series, for parts from either manufacturer. Since the planned test sequence was not completed, due to equipment difficulties, it is not possible to say with certainty why not. There are two alternative hypotheses that might be offered to explain why no current spikes were observed. These tests, like all the recent Goddard tests, were done at relatively low flux, 10^3 particles/cm^2 or less. The JPL tests with current spikes were done at higher fluences, usually much higher, on the other hand. Therefore, one hypothesis is that the current spikes are a collective effect, and not due to single ions. The other hypothesis rests on the fact that the total fluence was also lower in these tests than in those that produce current spikes. A fluence of 10^7 Xe ions/cm^2 will only produce a few current spikes, if it produces any. The total fluence in all 27 shots in this test run was between 10^5 and 10^6 ions/cm^2. Therefore it is possible that the small cross section will produce less than one current spike at the fluences reached in these tests. Based on the results now available, it is not possible to eliminate either hypothesis. Both groups are planning to conduct experiments, in a collaborative manner, to test the flux dependence, for example, to try to resolve the remaining differences.

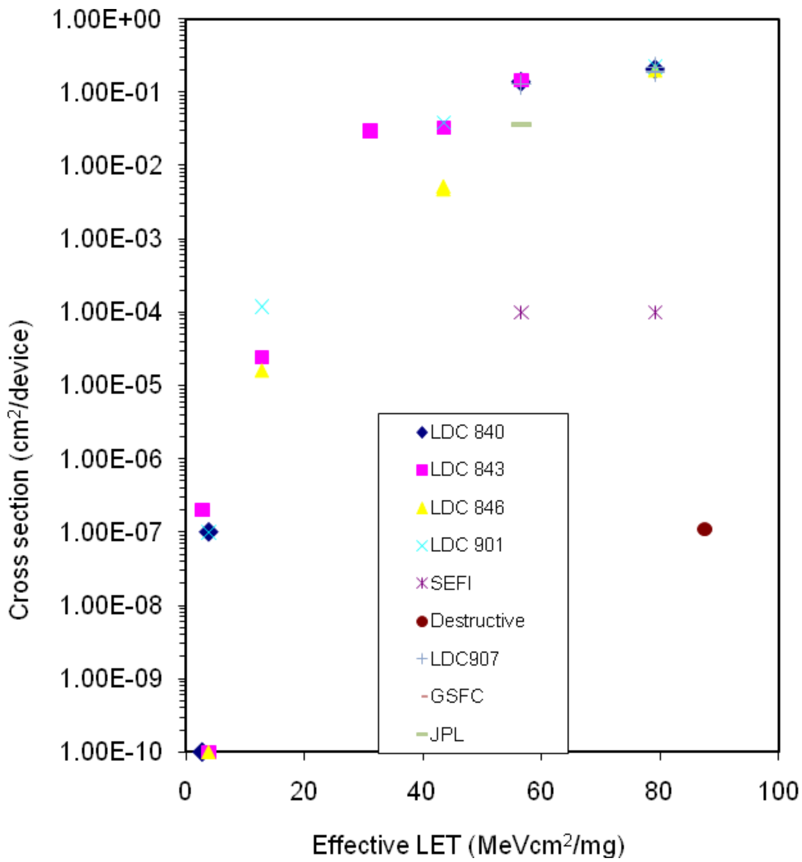

Fig. 2(a) Samsung 4G results in static, unbiased test mode.

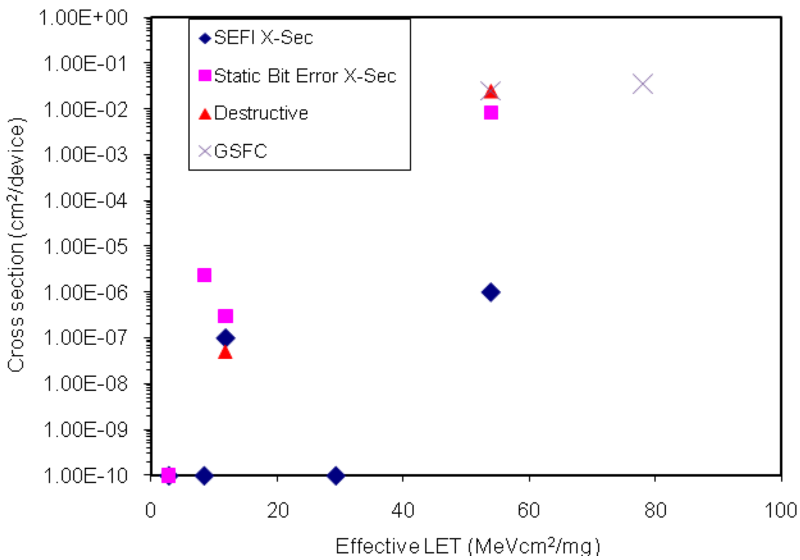

Fig. 2(b). Micron results in static unbiased test mode.

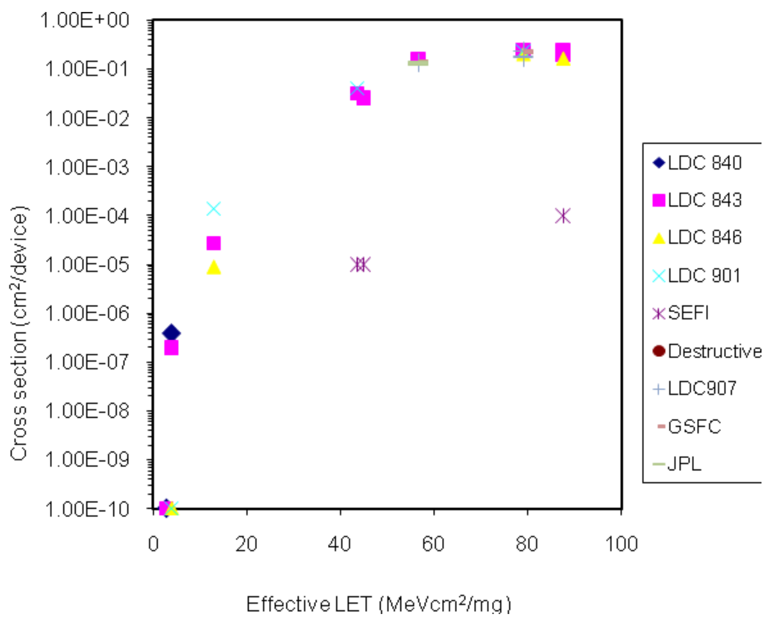

Fig 3(a). Samsung results in static test mode, with bias applied.

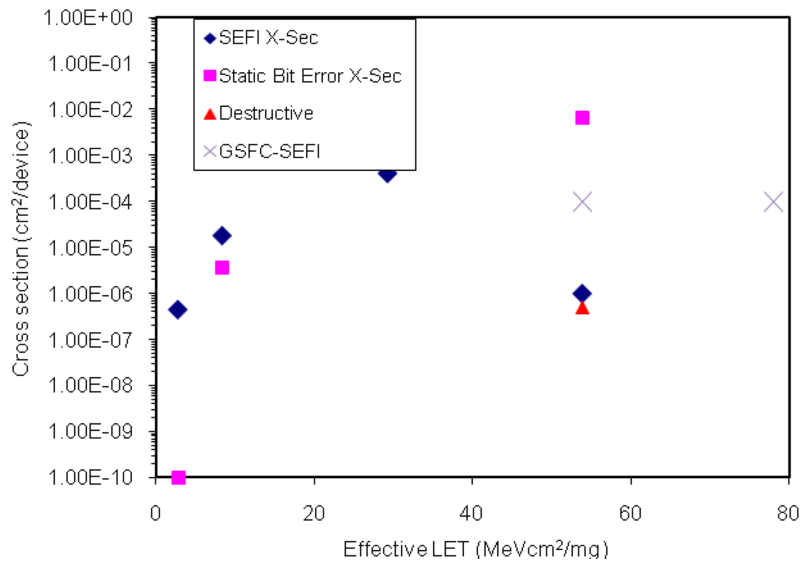

Fig 3(b). Micron results in static test mode, with bias applied.

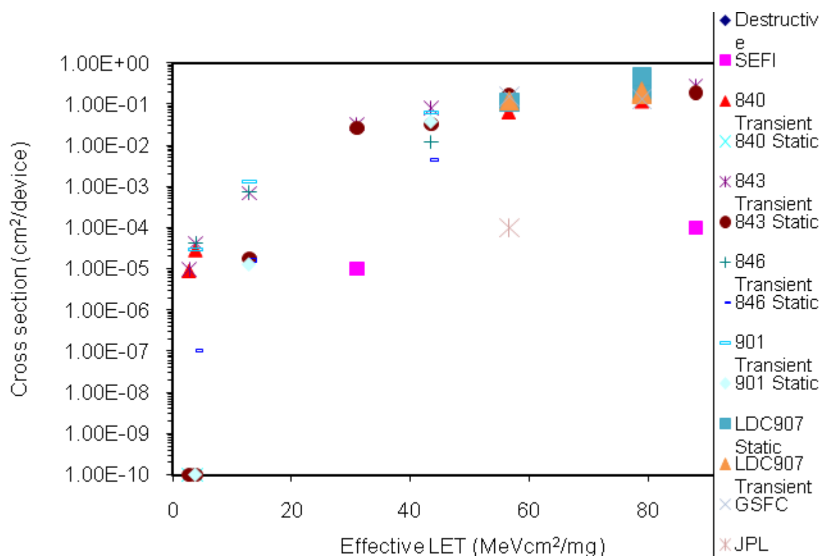

Fig 4(a). Samsung results in Dynamic Read mode.

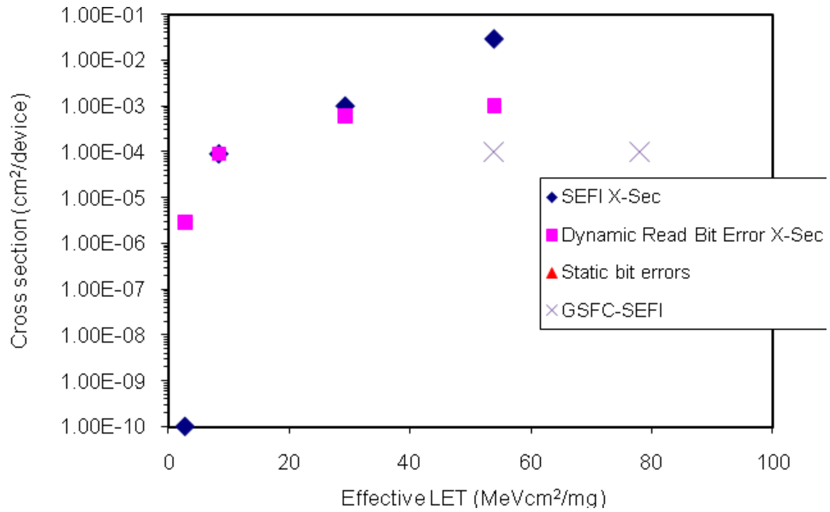

Fig 4(b). Micron results in Dynamic Read mode.

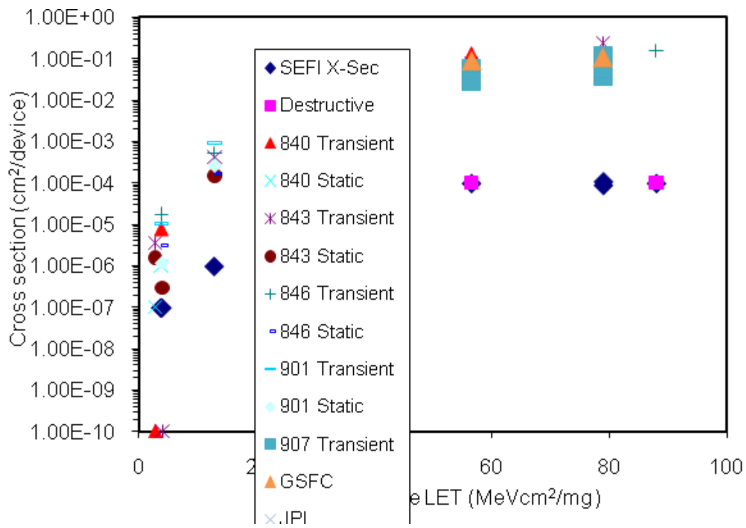

Fig 5(a). Samsung results in Dynamic R/W mode.

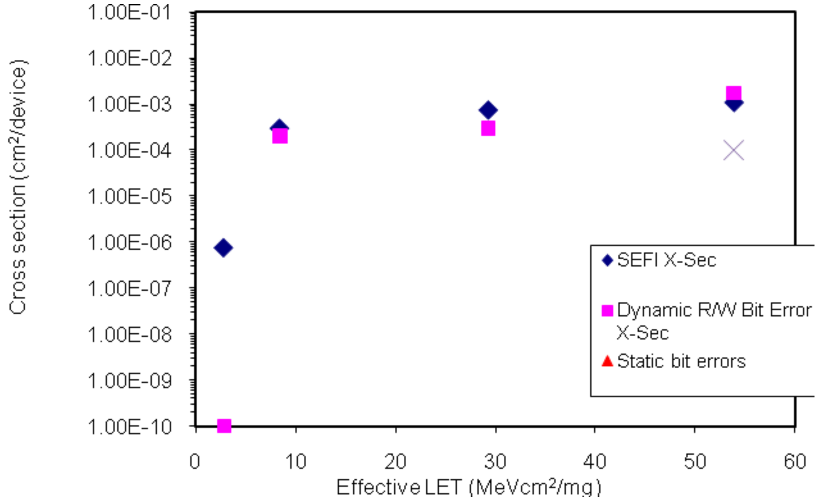

Fig. 5(b). Micron results in Dynamic R/W mode.

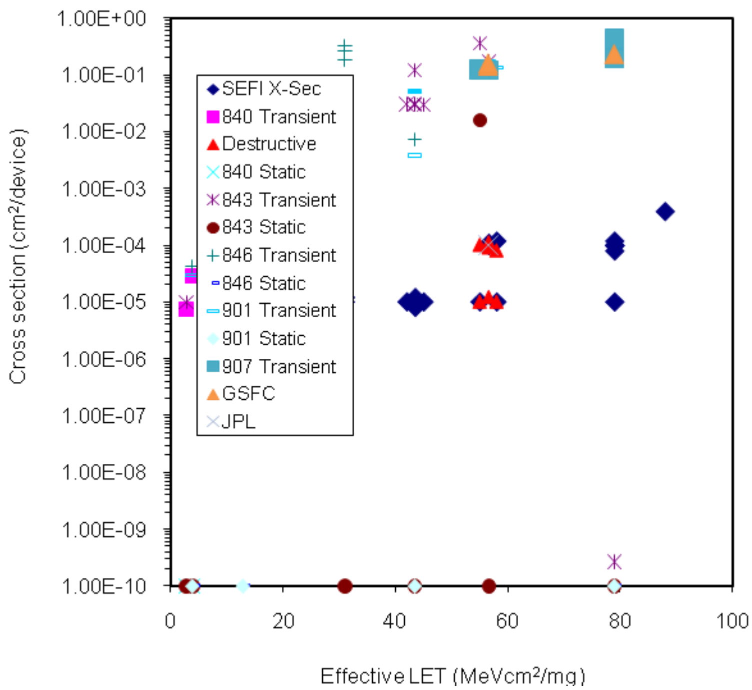

Fig 6(a). Samsung results in Dynamic R/E/W mode.

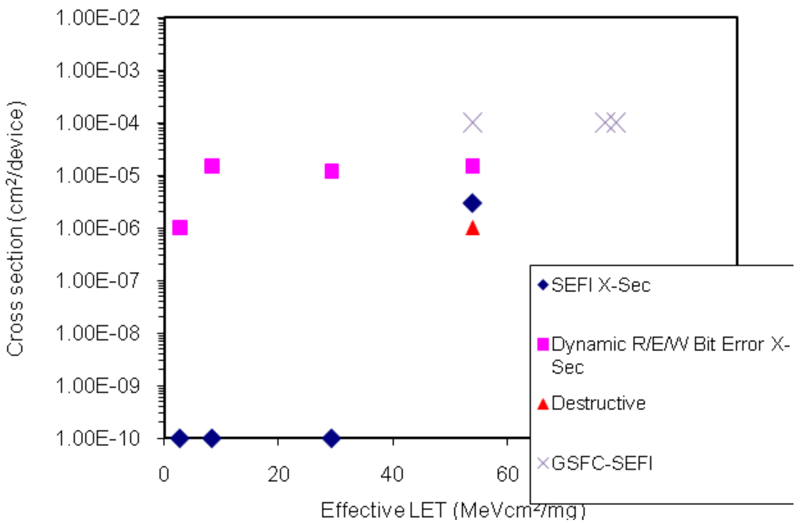

Fig 6(b). Micron results in Dynamic R/E/W mode.