IOR HiRel
An Infineon Technologies Company

Radiation Test FAQs

Power Discretes

About this document

Scope and purpose

This document is intended to provide additional information on radiation testing performed by International Rectifier HiRel (IR HiRel) and answer the frequently asked questions.

Intended audience

This document is intended for design engineers, application engineers, and system engineers to understand IR HiRel discretes qualified for use in space applications.

Table of contents

1 Rad hard devices

1.1 What is rad hard?

Radiation hardened (rad hard) refers to the process by which the devices are made to be resistant against effects of radiation that otherwise would result in destructive or non-destructive damage.

1.2 How rugged are your devices against single-event effects and degradation due to total ionizing dose?

IR HiRel's MOSFETs are tested for SEE with heavy ions having LET of 37-92 MeV·mg/cm^2. The beam energy can be in range of 300 MeV – 2.2 GeV. These devices are designed to withstand total ionizing dose from 100 krad to 1 Mrad without damage.

1.3 How has the radiation testing changed or improved over the past years?

For the older generation devices (e.g. R4), SEE testing using heavy ions was performed at Brookhaven National Laboratory (BNL)'s Tandem Van De Graff facility. During radiation testing, IR HiRel's goal is to test devices such that heavy ions initiate an SEE event and so that a safe operating area can be accurately established. Initially the beam energy available was limited (up to 500 MeV) however a higher energy beam became available at the Cyclotron Institute of Texas A&M University (TAMU). The newer devices are tested with beam energy of upto 2.2 GeV at this facility and allows to have the range at Bragg's peak to be near the sensitive area of the device under test (DUT).

2 Radiation testing

2.1 What is the flux and fluence level?

The flux and fluence* ranges in the order of 10^4 ions/cm^2/sec and 10^5 ions/cm^2 respectively.

2.2 What is Bragg's peak?

When a charged particle hits the device, as it traverses through the material of device, it loses its energy through ionization. This distance is called Bragg Depth. Energy of the charged particle is at its maximum before stopping and subsequently reduces to zero. The distance at which the stopping power is maximum is called Bragg Peak.

2.3 Why are degraders used?

The purpose of degrader is to manipulate beam energy so that range at Bragg peak is close to the sensitive region of DUT. Degrader can be moved at different angles or have different thickness which will change the beam energy.

2.4 What is the reason behind selection of ions?

As the ion traverses through the device it deposits energy and travel to certain distance inside the DUT. IR HiRel typically selects Krypton, Xenon and Gold ions with LETs of approximately 37, 60 and 90 MeV·mg/cm^2 respectively which can potentially induce an SEE event.

2.5 What is range? Why does it say "range in Si"?

Range (as mentioned in the datasheet) is the distance that the heavy ion traverses inside the DUT. Silicon (Si) is primarily used as a reference material since semiconductor devices are built on silicon.

2.6 What's the relation between ion size, energy, range and LET?

With a beam of particular MeV/u, larger ions having higher atomic number also have higher energy. The LET at Bragg's peak is the highest. (For example, See Figure 2)

2.7 Why is angle of incidence equal to zero?

Si MOSFETs are a vertical device and the worst-case for radiation testing is when the beam is at a normal to the DUT.

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* Flux: The number of ions passing through a one cm^2 area perpendicular to the ion beam per unit of time, expressed as ions/cm^2•s
Fluence: The ion flux integrated over the time required for the run, expressed as ions/cm^2.

2.8 Based on what criteria do you qualify the devices (i.e. pass or fail)?

Si MOSFETs are tested for SEE performance based on MIL-PRF-19500, TM 1080. During irradiation I_{DSS}, I_{GSSf} and I_{GSSr} are measured whose limits are predetermined. The device fails if it passes these threshold limits. Post-irradiation, the device is tested for gate-integrity in PIGS test. It requires two failures for characterization and three passes for qualification.

2.9 What's the difference between standard and worst-case beam conditions?

The heavy ion beam available at Tandem Van De Graff Facility, BNL has kinetic energies that are lower compared to the beam available at Cyclotron Institute, TAMU so the range at Bragg peak (inside the device) is lesser. These are called standard beam conditions.

Worst case beam conditions refer to the testing conditions when the heavy ions are penetrating deeper into the device structure. This becomes possible when the same ions have higher kinetic energy and have larger range at Bragg peak. In other words, ion beam settings which place the Bragg peak at the bottom epi/substrate interface has been proposed as “worst case.” This interface is often called as critical area or the most sensitive region for SEE. Such beam conditions are available at TAMU.

2.10 What's the difference between radiation testing performed at BNL versus TAMU ?

BNL uses Tandem Van De Graff accelerator to deliver heavy ion beams with kinetic energy of upto 5 MeV/nucleon (for high atomic number) and the testing is available only in vacuum.

TAMU has superconducting cyclotron at Cyclotron Institute with heavy ion beam energy of 10, 25 and 40 MeV/nucleon. The testing is available in both, vacuum and air.

2.11 Why do you perform radiation test on bare die?

Different test samples can have different packages and using a delidded device removes that variable. The package does not degrade the radiation performance of device.

2.12 What is PIGS test?

PIGS stands for Post Irradiation Gate Stress. After each irradiation run, a gate-stress test is performed to verify device functionality.

2.13 What's the purpose of Al degrader and degrader angle?

The beam energy is reduced by means of a *degrader* system with foils having a suitable thickness and *orientation* with respect to the incident beam. Each foil can be inserted, withdrawn, and rotated remotely through use of computer controls.

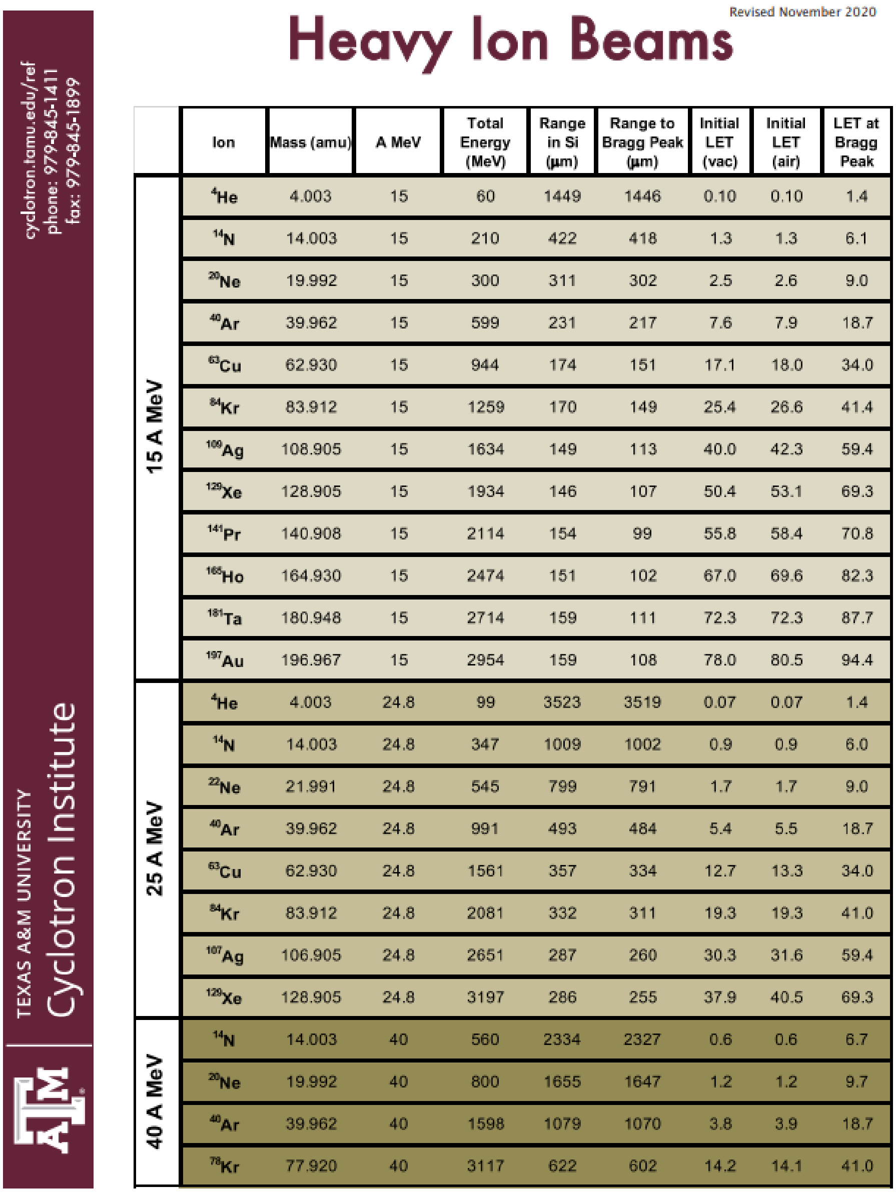
2.14 What is "Clean and Baked"?

If there's an “unexpected” failure, or a failure that doesn't match other samples, we may perform a clean and bake to confirm that the part wasn't somehow contaminated and is presenting a false failure.

An SEE failure will not recover. So, if we are able to perform a clean and bake and the part recovers, it means that the failure was not related to the SEE test. As SEE samples have no lids, there is a danger that handling (such as loading and unloading onto boards) can expose the part to this potential false failure mode.

Appendix A – SEE beam data

Texas A&M University:



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TEXAS A&M UNIVERSITY
Cyclotron Institute

Heavy Ion Beams

Revised November 2020

	Ion	Mass (amu)	A MeV	Total Energy (MeV)	Range in Si (µm)	Range to Bragg Peak (µm)	Initial LET (vac)	Initial LET (air)	LET at Bragg Peak
15 A MeV	^{4}He	4.003	15	60	1449	1446	0.10	0.10	1.4
	^{14}N	14.003	15	210	422	418	1.3	1.3	6.1
	^{20}Ne	19.992	15	300	311	302	2.5	2.6	9.0
	^{40}Ar	39.962	15	599	231	217	7.6	7.9	18.7
	^{63}Cu	62.930	15	944	174	151	17.1	18.0	34.0
	^{84}Kr	83.912	15	1259	170	149	25.4	26.6	41.4
	^{109}Ag	108.905	15	1634	149	113	40.0	42.3	59.4
	^{129}Xe	128.905	15	1934	146	107	50.4	53.1	69.3
	^{141}Pr	140.908	15	2114	154	99	55.8	58.4	70.8
	^{165}Ho	164.930	15	2474	151	102	67.0	69.6	82.3
	^{181}Ta	180.948	15	2714	159	111	72.3	72.3	87.7
	^{197}Au	196.967	15	2954	159	108	78.0	80.5	94.4
25 A MeV	^{4}He	4.003	24.8	99	3523	3519	0.07	0.07	1.4
	^{14}N	14.003	24.8	347	1009	1002	0.9	0.9	6.0
	^{22}Ne	21.991	24.8	545	799	791	1.7	1.7	9.0
	^{40}Ar	39.962	24.8	991	493	484	5.4	5.5	18.7
	^{63}Cu	62.930	24.8	1561	357	334	12.7	13.3	34.0
	^{84}Kr	83.912	24.8	2081	332	311	19.3	19.3	41.0
	^{107}Ag	106.905	24.8	2651	287	260	30.3	31.6	59.4
	^{129}Xe	128.905	24.8	3197	286	255	37.9	40.5	69.3
40 A MeV	^{14}N	14.003	40	560	2334	2327	0.6	0.6	6.7
	^{20}Ne	19.992	40	800	1655	1647	1.2	1.2	9.7
	^{40}Ar	39.962	40	1598	1079	1070	3.8	3.9	18.7
	^{78}Kr	77.920	40	3117	622	602	14.2	14.1	41.0

Figure 1 Heavy Ions Beam List – Ion Species, LET, Range to Bragg Peak

Radiation testing

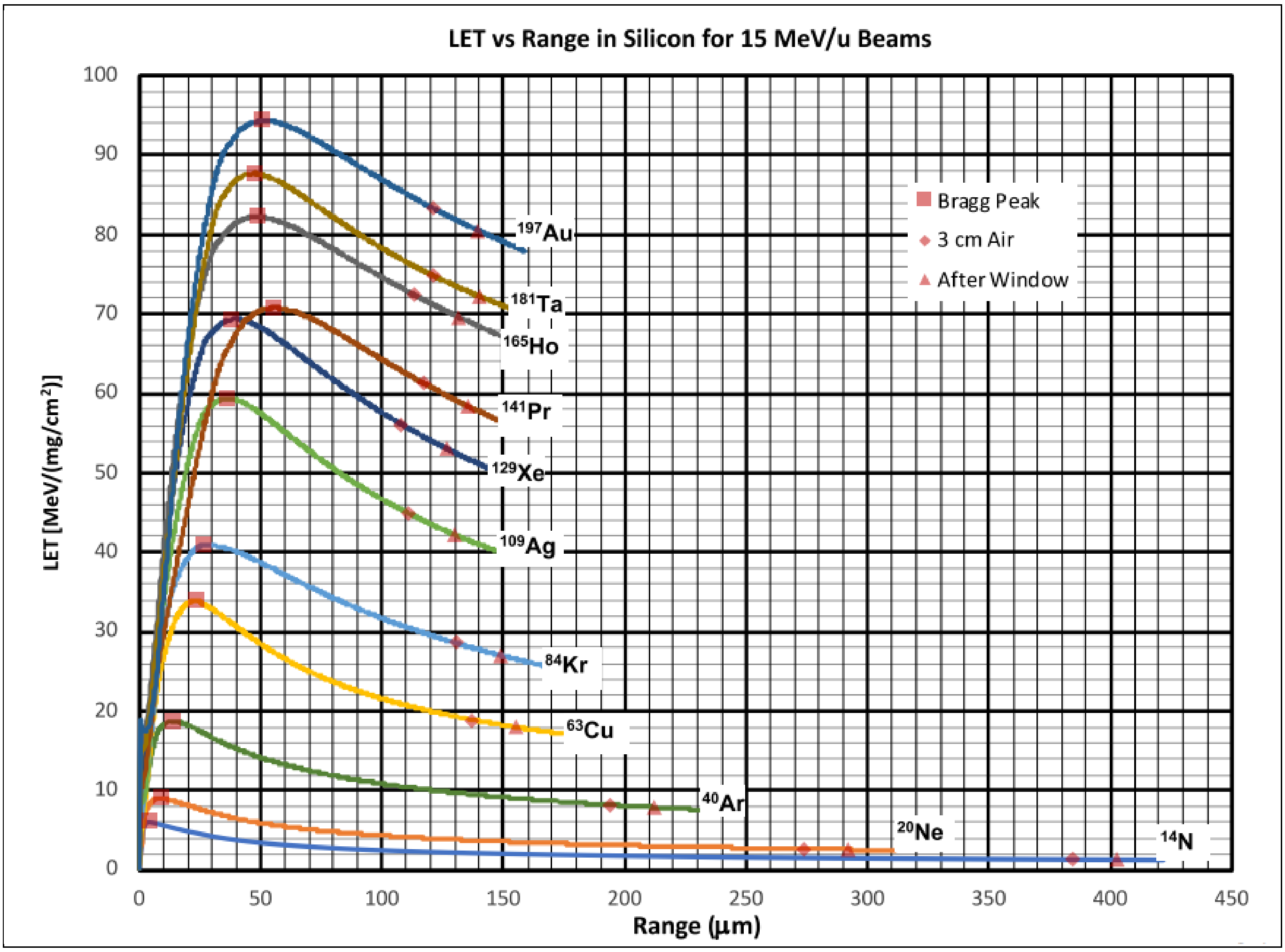
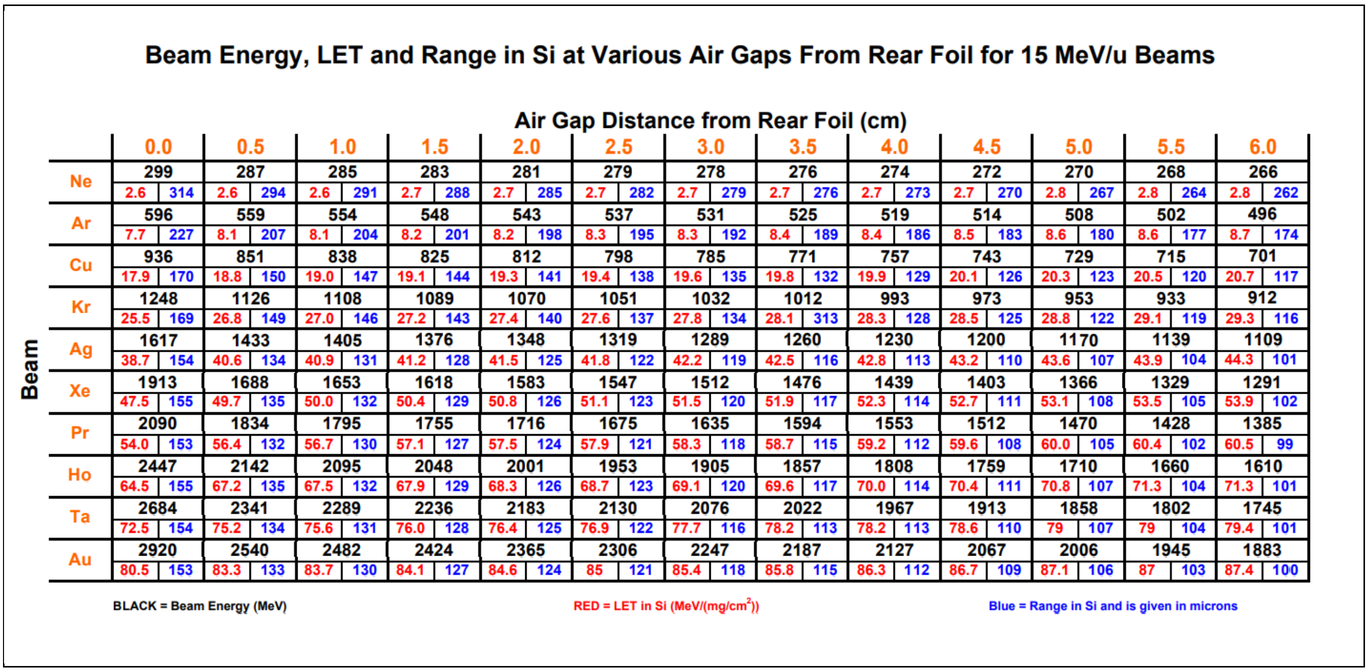


Figure 2 LET v/s Range in Si for different ions (Image Courtesy: Texas A&M University)

Radiation testing



Beam Energy, LET and Range in Si at Various Air Gaps From Rear Foil for 15 MeV/u Beams

Air Gap Distance from Rear Foil (cm)

Beam	0.0		0.5		1.0		1.5		2.0		2.5		3.0		3.5		4.0		4.5		5.0		5.5		6.0	
Ne	299		287		285		283		281		279		278		276		274		272		270		268		266	
	2.6	314	2.6	294	2.6	291	2.7	288	2.7	285	2.7	282	2.7	279	2.7	276	2.7	273	2.7	270	2.8	267	2.8	264	2.8	262
Ar	596		559		554		548		543		537		531		525		519		514		508		502		496	
	7.7	227	8.1	207	8.1	204	8.2	201	8.2	198	8.3	195	8.3	192	8.4	189	8.4	186	8.5	183	8.6	180	8.6	177	8.7	174
Cu	936		851		838		825		812		798		785		771		757		743		729		715		701	
	17.9	170	18.8	150	19.0	147	19.1	144	19.3	141	19.4	138	19.6	135	19.8	132	19.9	129	20.1	126	20.3	123	20.5	120	20.7	117
Kr	1248		1126		1108		1089		1070		1051		1032		1012		993		973		953		933		912	
	25.5	169	26.8	149	27.0	146	27.2	143	27.4	140	27.6	137	27.8	134	28.1	313	28.3	128	28.5	125	28.8	122	29.1	119	29.3	116
Ag	1617		1433		1405		1376		1348		1319		1289		1260		1230		1200		1170		1139		1109	
	38.7	154	40.6	134	40.9	131	41.2	128	41.5	125	41.8	122	42.2	119	42.5	116	42.8	113	43.2	110	43.6	107	43.9	104	44.3	101
Xe	1913		1688		1653		1618		1583		1547		1512		1476		1439		1403		1366		1329		1291	
	47.5	155	49.7	135	50.0	132	50.4	129	50.8	126	51.1	123	51.5	120	51.9	117	52.3	114	52.7	111	53.1	108	53.5	105	53.9	102
Pr	2090		1834		1795		1755		1716		1675		1635		1594		1553		1512		1470		1428		1385	
	54.0	153	56.4	132	56.7	130	57.1	127	57.5	124	57.9	121	58.3	118	58.7	115	59.2	112	59.6	108	60.0	105	60.4	102	60.5	99
Ho	2447		2142		2095		2048		2001		1953		1905		1857		1808		1759		1710		1660		1610	
	64.5	155	67.2	135	67.5	132	67.9	129	68.3	126	68.7	123	69.1	120	69.6	117	70.0	114	70.4	111	70.8	107	71.3	104	71.3	101
Ta	2684		2341		2289		2236		2183		2130		2076		2022		1967		1913		1858		1802		1745	
	72.5	154	75.2	134	75.6	131	76.0	128	76.4	125	76.9	122	77.7	116	78.2	113	78.2	113	78.6	110	79	107	79	104	79.4	101
Au	2920		2540		2482		2424		2365		2306		2247		2187		2127		2067		2006		1945		1883	
	80.5	153	83.3	133	83.7	130	84.1	127	84.6	124	85	121	85.4	118	85.8	115	86.3	112	86.7	109	87.1	106	87	103	87.4	100

BLACK = Beam Energy (MeV)

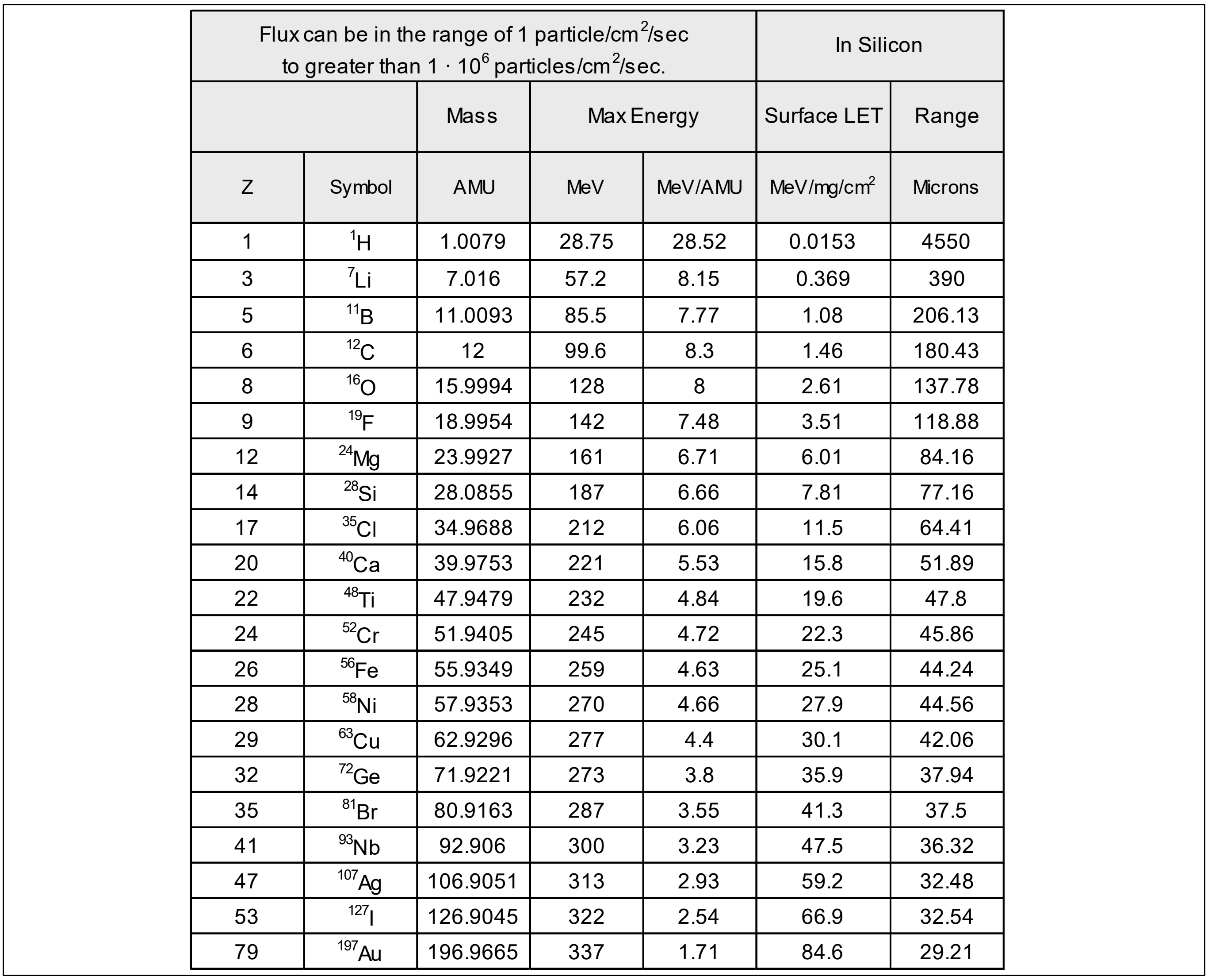
RED = LET in Si (MeV/(mg/cm^2))

Blue = Range in Si and is given in microns

Figure 3 Beam Energy, LET and Range in Si for different air-gaps (Image Courtesy: Texas A&M University)

Radiation testing

Brookhaven National Laboratory



Flux can be in the range of 1 particle/cm^2/sec to greater than 1 · 10^6 particles/cm^2/sec.					In Silicon	
		Mass	Max Energy		Surface LET	Range
Z	Symbol	AMU	MeV	MeV/AMU	MeV/mg/cm^2	Microns
1	^{1}H	1.0079	28.75	28.52	0.0153	4550
3	^{7}Li	7.016	57.2	8.15	0.369	390
5	^{11}B	11.0093	85.5	7.77	1.08	206.13
6	^{12}C	12	99.6	8.3	1.46	180.43
8	^{16}O	15.9994	128	8	2.61	137.78
9	^{19}F	18.9954	142	7.48	3.51	118.88
12	^{24}Mg	23.9927	161	6.71	6.01	84.16
14	^{28}Si	28.0855	187	6.66	7.81	77.16
17	^{35}Cl	34.9688	212	6.06	11.5	64.41
20	^{40}Ca	39.9753	221	5.53	15.8	51.89
22	^{48}Ti	47.9479	232	4.84	19.6	47.8
24	^{52}Cr	51.9405	245	4.72	22.3	45.86
26	^{56}Fe	55.9349	259	4.63	25.1	44.24
28	^{58}Ni	57.9353	270	4.66	27.9	44.56
29	^{63}Cu	62.9296	277	4.4	30.1	42.06
32	^{72}Ge	71.9221	273	3.8	35.9	37.94
35	^{81}Br	80.9163	287	3.55	41.3	37.5
41	^{93}Nb	92.906	300	3.23	47.5	36.32
47	^{107}Ag	106.9051	313	2.93	59.2	32.48
53	^{127}I	126.9045	322	2.54	66.9	32.54
79	^{197}Au	196.9665	337	1.71	84.6	29.21

Figure 4 **Heavy Ions Beam List (Credits: BNL)**

Radiation testing

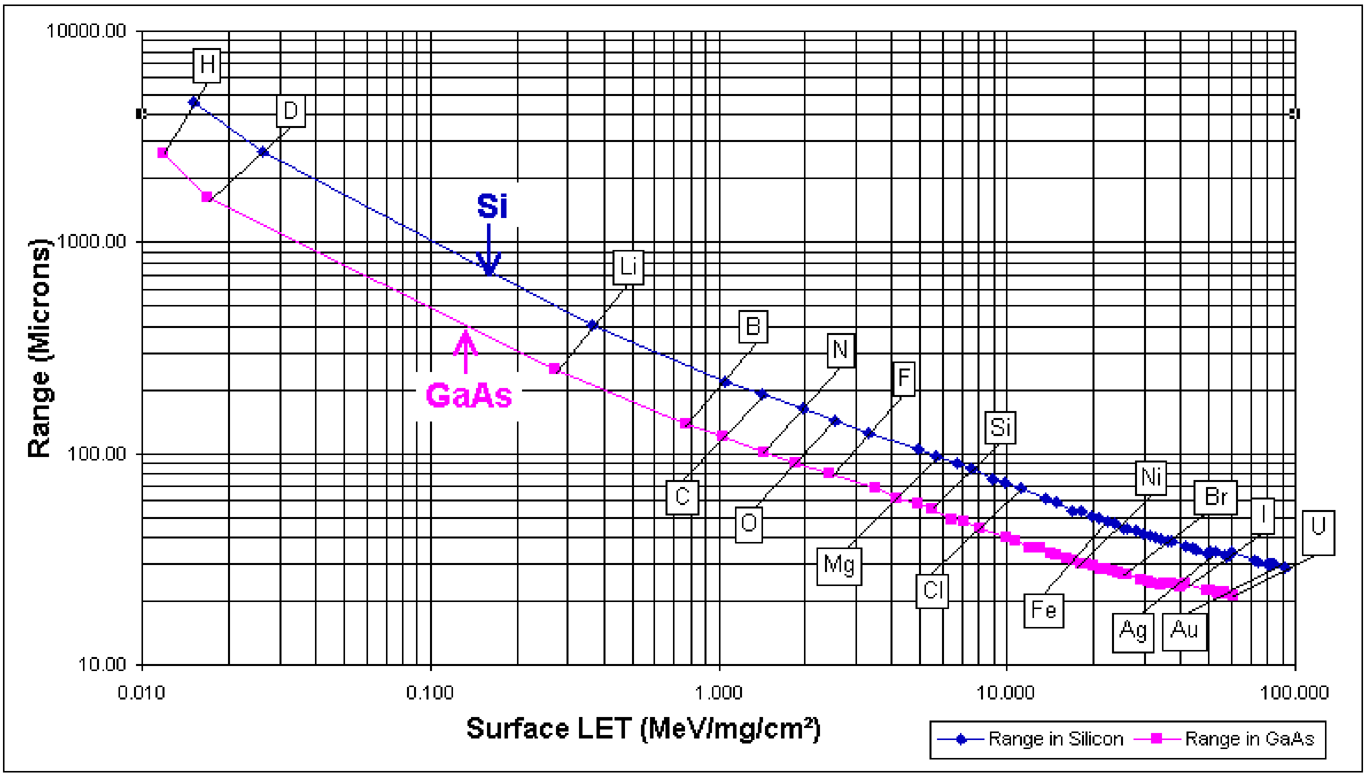


Figure 5 Range v/s Surface LET in Si for different ions (Credits: BNL)

Revision history

Document version	Date of release	Description of changes
1.0	2021-11-08	Initial release

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