RIKEN Accel. Prog. Rep. 51 (2018)

Beam preparation for industrial utilization of Ar, Kr, Xe, and Au beams

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Through the fee-based industrial utilization of RIBF facilities, a space-use semiconductor company has been using Ar and Kr beams at the E5A beam line[1)] a few times in a year. The client irradiates semiconductor devices in the air to test the radiation tolerance of single event effects (SEEs).

Figure 1 shows the configuration for the irradiation. A uniform beam-flux distribution is achieved[2)] with wobbler magnets and a beam scattering foil placed 4.5 m upstream of a vacuum separation window. Downstream of the window, an air-ionization chamber (IC1) that consists of a stack of 24 μm-thick Al-Mylar foils is used as a total beam intensity monitor for all beams. To monitor beam intensity below 1 M cps, a thin plastic scintillator (PL) covered by a 48-μm-thick Al-Mylar foil is used. An adjustable energy degrader follows to control the LET, where the beam energy is adjusted by inserting up to ten Al foils with thickness ranging from 5 to 975 μm. At the sample irradiation position, the range value of the beam is measured using a small air-ionization chamber (IC2), and the beam energy is measured with a replaceable Si-detector stack (SSDs) 2 mm in total thickness.

As a next step, the client plans to use heavier beams with a higher linear energy transfer (LET) for the SEE test. Therefore, we have studied the characteristics of ^{136}Xe and ^{197}Au beams in the air. In Table 1, the measurement results and the irradiation parameters for the Xe and Au beams are summarized and compared with those of Ar and Kr beams. Since the Xe and Au beams are slow, we minimized the thickness of materials in the beam line. The vacuum separation window was replaced with a 25-μm thick Kapton foil. For the Xe beam, we used a 100-μm-thick PL scintillator, while for the Au beam, we did not use a PL scintillator or a beam scattering foil. The air path lengths Lair1 and Lair2 indicated in Fig. 1 were minimized as well.

We first measured the range of the beams in Al at the exit of the energy degrader. On increasing the degrader thickness, the IC2 current increased until the Bragg peak and dropped at the range of the ions. From this measured range of values, we obtained the maximum beam energy on a sample placed in the air by referring to the thickness-energy relation from SRIM[3)] calculations. In the same manner, the SSDs were energy-calibrated by changing the degrader thickness.

From the measured energy spectra of SSDs, the LET peak value and its 1σ width in a Si sample were calculated. The corresponding range of values of the beam in Si is listed. According to the client, a beam range of 50–100 μm is indispensable for the SEE test of usual semiconductor devices. A high-LET condition near the Bragg peak was also measured by controlling the thickness of the degrader.

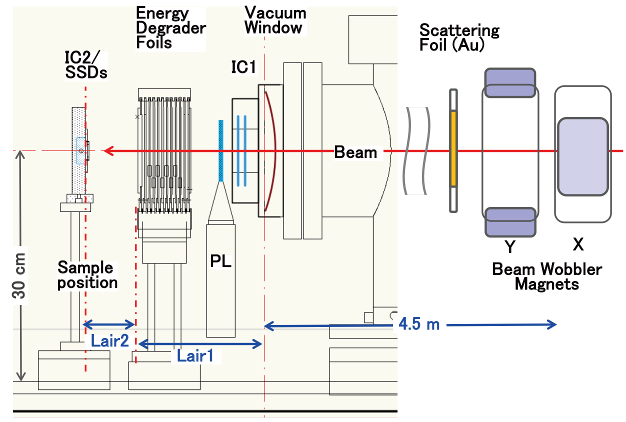

Fig. 1. Irradiation setup at the E5-A beam line.

Table 1. Summary of irradiation parameters.

	Beam	40Ar	84Kr	136Xe	197Au	
	Accelerators	AVF +RRC	AVF +RRC	RILAC1 +RRC	RILAC1 +RRC	
	E in vacuum	95.0	70.0	39.0	18.4	A.MeV
	Scattering foil : Au	75	50	20	0	μm
	Vacuum foil: Kapton (diameter)	75 (Φ6)	75 (Φ6)	25 (Φ5)	25 (Φ5)	μm (Φcm)
	PL scintillator	500	500	100	0	μm
	Air path: Lair1	14.5	14.5	14.5	10.5	cm
	Lair2	16.0	16.0	2.0	2.0	cm
*	Exp.Range in Al	3260	715	175	60	μm
	without energy degrader Al-foil; *max. E on sample surface*					
*	E on sample	81.19	41.82	17.34	4.62	A.MeV
*	σE on sample	8.4	18.0	32.7	41.8	MeV
	Range (σR) in sample: Si	3567.0 (16.5)	722.7 (6.3)	180.2 (4.4)	56.6 (1.7)	μm
	corresponding LET (σLET) in Si	2.21 (0.03)	13.48 (0.07)	47.19 (0.32)	94.09 (0.11)	MeV/ (mg/cm2)
	maximum LET in Si at Bragg peak	18.7	41.0	70.0	95.0	MeV/ (mg/cm2)
	with energy degrader Al-foil ; *near to the Bragg peak*					
	Degrader foil: Al	3124.8	586.8	113.6	15.7	μm
*	E on sample	6.78	5.90	6.01	2.50	A.MeV
*	σE on sample	48.2	49.8	52.2	22.6	MeV
	Range (σR) in sample: Si	77.8 (14.6)	59.6 (6.3)	61.9 (3.4)	37.5 (1.2)	μm
	corresponding LET (σLET) in Si	11.69 (0.93)	37.10 (0.96)	66.50 (0.67)	91.35 (0.70)	MeV/ (mg/cm2)

*) measured value

From this result, the ^{136}Xe beam is available for the SEE test with a LET value ranging from 47 to 67 MeV/(mg/cm^2). On the other hand, the maximum energy of the ^{197}Au beam in the air corresponds to its maximum LET at the Bragg peak. More detailed information on the E5A beam line is provided in our home page.[4)]

References

1) T. Kambara, RIKEN Accel. Prog. Rep. **48**, 239 (2015).
2) T. Kambara, RIKEN Accel. Prog. Rep. **49**, 193 (2016).
3) J. F. Zeigler, `http://www.srim.org/`
4) `http://ribf.riken.jp/sisetu-kyoyo/equipments/e5a.html`.

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