TEST OF SEC

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Abstract

Two sets of SEC of the same structure with different thickness of Al foils were tested by using 135 MeV/u heavy ion beams, C^{6+} and Ne^{10+}. The SEC in the HIMAC for other heavy ion beams of different energies is designed based on the output charge which can be estimated from this experimental result.

Introduction

Secondary-electron Emission Chamber (SEC) is popular as a intensity monitor in slow extracted beam lines of electron and proton accelerators. It has a unique characteristics of fast response, good linearity over many orders of magnitude and simple structure.

At NIRS, the particle radiotherapy is scheduled to start in 1994 with the heavy ion (He to Ar) beam of the energy from 100 MeV/u to 800 MeV/u. In order to use the high energy heavy ion beam to the radiotherapy, it is required to measure the fluence of the beam precisely to estimate the physical dose at the irradiation field. Such a requirement must be fulfilled even if the intensity of the beam extracted from HIMAC synchrotron is not ideally stable, especially when it has a steep spike structure.

We use a SEC as a dose monitor supplementary to the main dose monitor. For the main dose monitor we use a conventional parallel plate ionization chamber which shows a character of saturation arising from general recombination in case of an intense irradiation. Though a SEC has not such a character, it cannot supply an enough output current for the beam of low intensity. It is apparent that a SEC equipped with many electrodes can supply a large current output for the beam of low intensity. But it will result in the increase of material along the beam line and cause the deterioration of the beam quality. Therefore when a SEC is used as a dose monitor, it should satisfy two requirements ; it should have a wide range to measure the beam intensity, and the material on the beam line should be as little as possible. These requirements are mutually incompatible so that we must find a compromise in the design of SEC.

Although the SEC is used widely and the data on the efficiency (ε) for electron and proton beams are seen in the literature, reports on the high energy heavy ion beams covering the HIMAC region are few. They are only for light ions, d, He^{2+} in high energy of 3 GeV/u[1], and heavy ions in low energies of few MeV/u[2]. Therefore we constructed two sets of chamber of SEC and tested them with C^{6+} and Ne^{10+} beams of 135 MeV/u at RIKEN. The point of view in the test was to study the dependencies of the efficiency ε on the variation of the following quantities;

- the beam energy
- atomic number of the beam
- foil thickness of SEC
- high voltage of SEC
- gas pressure of SEC

Here the definition of the efficiency ε of SEC is given as follows;

$$\varepsilon = \frac{Q/(1.602 \times 10^{-19})}{(\text{no. of projectiles})} \tag{1}$$

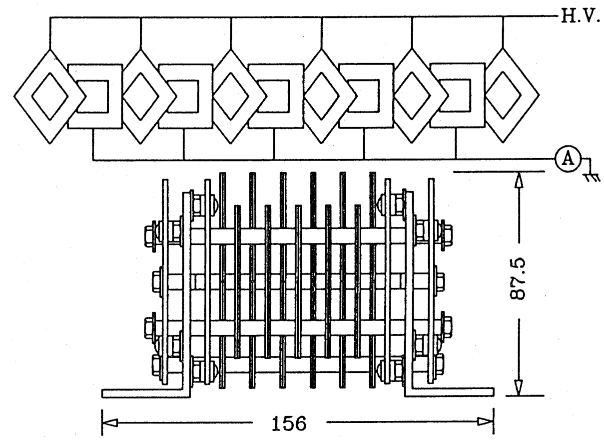


Fig. 1: The test chamber of SEC ; schematic (upper) and design (lower) illustrations.

where Q is the charge measured in the SEC. This charge Q is the total current output from the SEC. For the comparison between the SECs with different number of foils, the efficiency normalized by the number of surfaces of electrodes of SEC, ε/(surface), is later used in this paper.

Construction of test chambers

Two sets of test chamber of SEC were constructed at NIRS. They have the same structure but have different thickness of foils ; one has 7 μm thick foils and another has 15 μm thick foils. The material of the foil is aluminum. The number of the foil is eleven for both sets, which corresponds to twenty as the number of surfaces of electrodes. At the operation the five foils were connected together and used as a collector electrode, and the other six foils were connected together and used as a potential electrode. The gap distance between neighboring foils are 8 mm. The effective area of the chamber is about $^{\phi}$20 mm.

Experimental Set Up

The test chambers of SEC were installed in a large scattering chamber in the E5B course of ring cyclotron of RIKEN. The operating pressure in the chamber was in the range of $4 \sim 8 \times 10^{-7}$ Torr throughout the experiment. The beam fluence was monitored by the beam monitor placed at the end of the course, which is a parallel plate ionization chamber. The output of the monitor was transformed by I/F converter with conversion efficiency of 102.4 pC/pulse and then counted by a scaler. The beam size was about $^{\phi}9 \sim 11$ mm at the places of SECs. The output charge of a SEC was measured by a electrometer (Keithley 617). High voltage was fed to SECs by a high voltage power supply (Ortec 665), and it was monitored by a multimeter (Sanwa FD-750C). The electrometer was connected to one of the two SECs while the other was terminated with 50Ω. The beam intensity was kept almost the same at 10^8 pps for C^{6+} and Ne^{10+} beams.

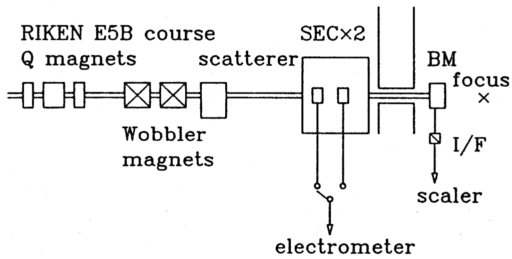
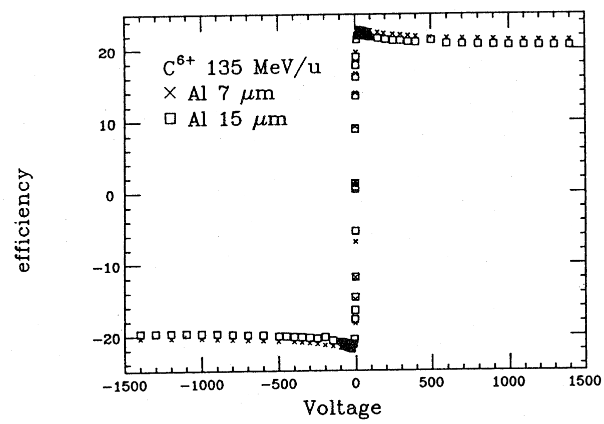
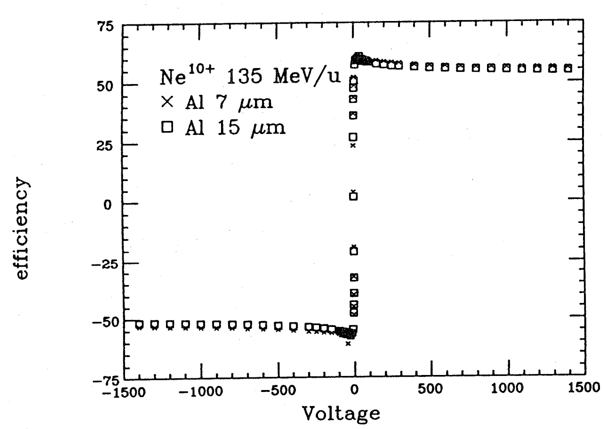


Fig. 2: The schematical diagram of the experimental set up.



(a)



(b)

Fig. 3: The results of the efficiency ε of SEC for C^{6+} (a) and Ne^{10+} (b) beams of energy 135 MeV/u. Error bars are not shown which are lower than 3.1 %.

Results

Figure 3 (a) and (b) shows the results of ε for the beams of 135 MeV/u C^{6+} and Ne^{10+}, respectively. Some characteristics are seen as follows ;

- ε makes peaks at about ± 20 V.
- ε changes abruptly between about -20V and +20V.
- ε changes rather slowly at the region higher and lower than about ± 100V.
- ε's of the aluminum foils of the thickness of 7 μm and 15 μm are almost the same.

The ε's of the SECs per surface of foil are tabulated in Table 1, which also gives the ratio ε/(surface)/STP, the efficiency per Stopping Power (STP) (keV/μm) of aluminum for the projectile. The ε/(surface)/STP in Table 1 were 0.023 ± 0.001 for the cases of the different thicknesses of the foils and different ions of the beam. The data shows that the yield of secondary electrons per number of surface is proportional to the energy loss of the beam in the material foils. If we assume that some part of the energy loss of the projectile in the foil are converted to produce the secondary electrons and their kinetic energies, we can estimate the ε/(surface)/STP for other projectiles with other energies, and also the output charge Q from SEC.

Table 1: SEC efficiency at H.V.=+1400V

projectiles	thickness of Al	ε/(surface)	ε/(surface)/STP
C^{6+}	7 μm	1.1	0.024
	14 μm	1.0	0.023
Ne^{10+}	7 μm	2.8	0.023
	14 μm	2.7	0.022

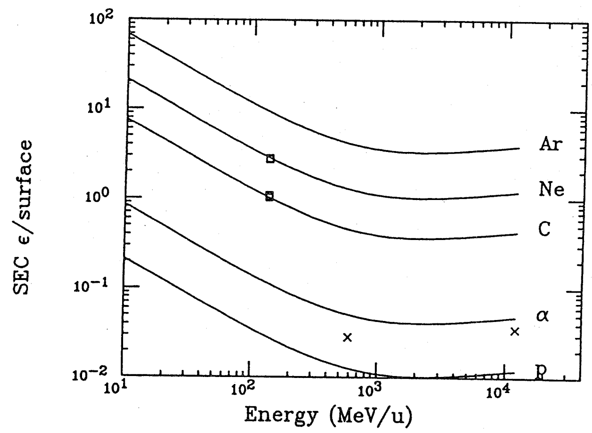


Fig. 4: ε/(surface) for several ions. The data □'s are from this experiment. The data ×'s are those for protons of CERN[3] 591 MeV and KEK[4] 12 GeV.

Figure 4 shows the variation of of ε/(surface) for several ions and energies. The curves were drawn according to the values given by ε/(surface)/STP(= 0.023)×STP, where stopping powers (STP) were calculated on the formula of Bethe[6]. We can estimate the output charge Q by using three parameters; the value of ε/(surface), the number of surfaces of SEC and the beam fluence. Our estimation of ε/(surface) for proton underestimates for the data of CERN[3] and KEK[4]. It suggests some dependence of ε on atomic number and/or energy, or some dependence on the surface condition of the foil.

Figure 5 shows such estimated output charges Q of our test chamber of SEC for the beam fluence of 10^8 particles. The number of 10^8 particles will be a typical value of beam intensity in the radiotherapy, which corresponds to several Gy. It is seen that the SEC can produce measurable output charge by the fluence of 10^8 beam particles in the HIMAC.

We did not examine the dependence of ε on the gas pressure. The pressure changed from 8 to 4×10^{-7} Torr during this experiment.

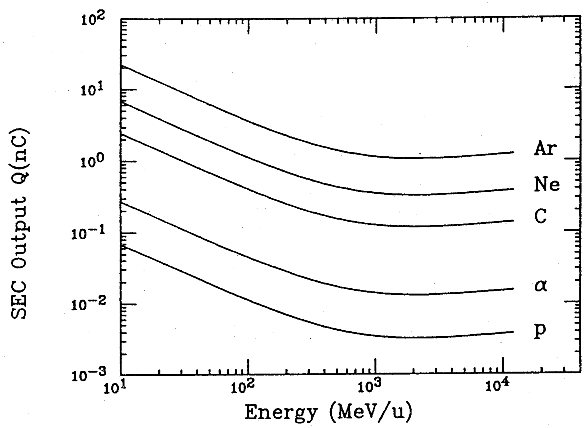
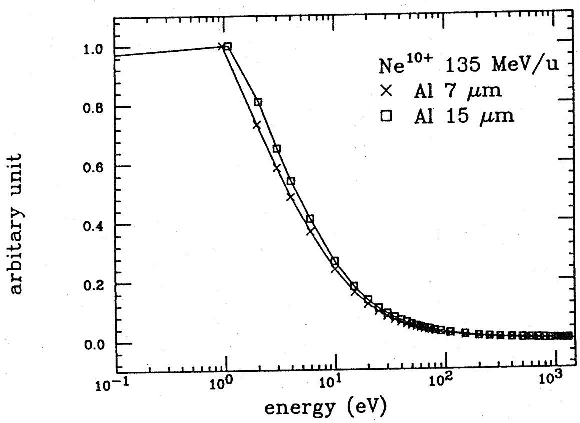
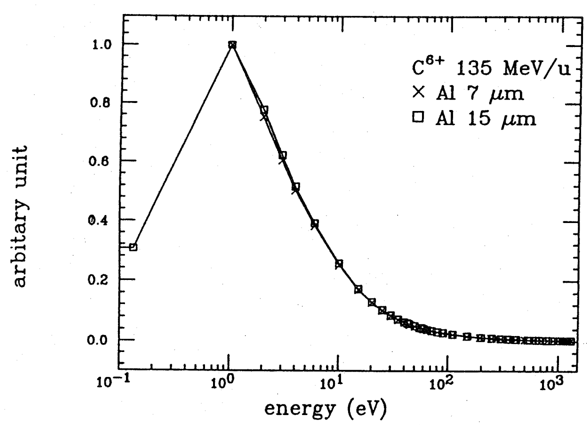


Fig. 5: The expected output charge Q of SEC for 10^8 projectiles.

The value of ε corresponds to an integral over the energy of the secondary electron. If we differentiate the ε with H.V. , we can yield an energy spectrum of the secondary electron. Figure 6 shows such energy spectra where the data of figure 3 were differentiated assuming the angular distribution[5] of a cosine dependence. It shows that the secondary electrons consist of large amount of slow electrons, lower than 10 eV, and the other faster electrons are few. We deduced the energy spectra assuming an isotropic shape on the angular distribution, which resulted in almost the same as above case. Similar result is also seen in the reference of Oda and Lyman[2].



(a)



(b)

Fig. 6: The energy spectrum of the secondary electrons.

Conclusion

We measured the efficiency of SEC equipped with 7 μm and 15 μm thickness of aluminum foil with C^{6+} and Ne^{10+} of energy 135 MeV/u. We assumed the efficiency ε of SEC depends on the stopping power of the projectile. On the assumption we estimated the ε/STP and the output charge Q of SEC for different projectiles and different energies. The underestimation of ε/STP for proton data shows a need for further study on the atomic number and/or energy dependence of ε or some dependence of the suface condition of the foil..

Design of SEC for HIMAC

The SEC for HIMAC as a dose monitor has been designed considering the stopping power dependence of output charge from the SEC. It was confirmed that there would be an enough output charge from the SEC to measure the dose of the beam for the radiotherapy. The main features of the SEC are as follows;

- SEC includes 6 collector electrodes and 7 potential electrodes.
- All electrodes are made of 7 μm thick aluminum foils.
- SEC has a wide sensitive area of $^{\phi}$166 mm.
- Electrodes are contained in a vacuum chamber electrically isolated.
- SEC should have a clean inside vacuum kept by an ion pump.

The SEC will be set between the main dose monitor and the flatness filter in the therapy room. It will be controlled by the irradiation control computer of the irradiation system. The SEC is now under fabrication and will be installed in August, 1993.

Acknowledgement

We wish to thank the staffs of RIKEN ring cyclotron for the helpful operation. The authors thank Dr.Yamanoi of KEK for discussions. The authors also thank Dr.Tomitani of NIRS and Nihon Seihaku Corp. for the precious materials supplied.

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