

CALIBRATION AND PERFORMANCE OF A SECONDARY EMISSION CHAMBER AS A BEAM INTENSITY MONITOR

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Abstract

We report on a study of the behavior of a secondary emission chamber (SEC). We show the dependence of the SEC signal on the charge and velocity of the primary beam for beams of protons, and heavy ions including Helium, Neon, Chlorine and Iron. We fill the SEC with a selection of different gases including Hydrogen, Helium, Nitrogen, Argon, and air, studying the SEC response when it is acting as an ion chamber. We also investigate the behavior of the SEC at intermediate pressures between 10^{-8} torr and atmospheric pressure.

INTRODUCTION

The Secondary Emission Chamber (SEC) uses thin conducting foils as the source and collector of electrons in a vacuum chamber. When charged particles traverse the vacuum chamber, they pass through a series of thin conducting foils, alternating anode and cathode. Ionization produced in the cathode foils travels across the intervening gap due to an applied high voltage and is collected on the anode foils. Electron production is very inefficient because most of the ionization in the foils remains trapped within the foil due to the short range of most delta-rays and the work function of the foil. It is this inefficiency that allows the SEC to operate at high dose rates and short pulse duration where the standard ion chambers cannot function reliably [1,2].

The SEC was placed in the NSRL ion beam to receive a variety of heavy ion beams under different beam conditions. We used these ion beams to study the response of the SEC to different species of heavy ion, comparing with proton beams. We studied the response to beam of different energies, and as a function of different counting rate. We compared the behaviour of the SEC when operating under positive and negative high voltage.

The SEC can operate as an ion chamber if it is filled with gas. We measured the response of the SEC when filled with a variety of gases, from Hydrogen to Helium, Nitrogen, Argon and air. The performance of the SEC as an ion chamber is compared with the standard NSRL ion chamber, QC3.

By evacuating the SEC and filling it with Nitrogen through an adjustable leak valve, we were able to measure the response of the SEC to beam as a function of gas pressure. Many interesting features of the SEC were revealed in these tests.

DESCRIPTION OF THE SEC

The SEC is a series of five thin aluminum foils, $6.35 \mu\text{m}$ ($0.00025''$) thick with vacuum deposited silver coating that is $0.020 \mu\text{m}$ thick to improve conductivity.

The foils have been baked to out-gas the surfaces, and then cleaned with an Argon glow discharge. The foils are separated from each other by 1 cm gap. The foils are centered in the vacuum vessel, with 5 cm gap from the aluminum vacuum window to the foils at each end.

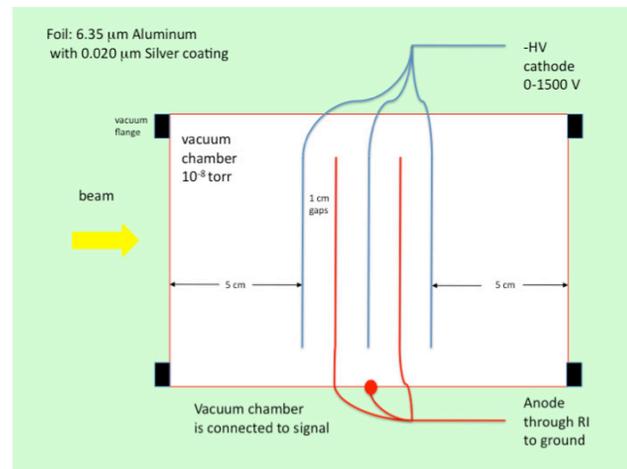


Figure 1 shows a schematic of the SEC with an entrance and exit vacuum flange, thin vacuum windows and five emitter foils, alternating cathode and anode.

We have two identical SECs; one has an ion pump with a vacuum gauge that is capable of an operating vacuum of 10^{-8} torr, while the other has only a roughing pump with 20 millitorr as its ultimate vacuum. The roughing pump also has a calibrated leak valve and a convection vacuum gauge allowing the vacuum chamber to be back-filled through the leak valve up to atmospheric pressure.

Readout of the SEC is accomplished using a Keithley 6514 electrometer to measure the collected charge. This allows operating the SEC at either positive or negative high voltage. For some measurements, we used the Recycling Integrator (RI) system that is standard at NSRL for ion chamber readout, and supports only positive HV.

NSRL BEAM CHARACTERISTICS

The NSRL beamline provides a beam of protons or heavy ions with energies in the range 50 MeV/nucleon to 1000 MeV/n. It can be tuned to provide a square beam spot with good uniformity across a $20 \times 20 \text{ cm}^2$ area, or squeezed down to a 1 cm Gaussian spot size. When running protons, beam intensities up to 10^{12} protons per spill have been utilized. With a small beam spot, it is possible to produce dose rates of several thousand cGray per minute, a range where the ion chambers suffer saturation and recombination. A typical minimum ionizing proton will create 56 electrons per cm path length in Nitrogen, the operating gas of our ion chambers. Thus a beam of 10^{12} protons in a 1 cm spot will produce

close to 10 μC of charge in the 1.02 cm gap of the chamber. At these rates, most ion chambers will cease to be linear in their response, due to saturation of the ionization along the particle track, or recombination of the charges before the electrons can be collected at the anode.



Figure 2 showing the entrance window, vacuum port with calibrated leak valve and vacuum gauge.

CALIBRATION OF THE SEC

The operating voltage for the SEC was chosen by passing the beam simultaneously through the QC3 ion chamber and the SEC as both devices were read out simultaneously using the NSRL Recycling Integrator System. This system injects charge onto a capacitor until it equals the charge generated in the device. Each packet of charge is 10 pC. The charge collected on the SEC was normalized by taking the ratio with the QC3 charge. The voltage on the SEC was raised until the charge collection became efficient, as evidenced by the plateau in the SEC/QC3 ratio. From Figure 3 it is clear that at voltages less than 100 volts the efficiency is maximized. Unexpectedly, there is a peak in the SEC/QC3 ratio at low voltages, between 30 and 100 volts, with the response continuing to drop off as the SEC voltage is raised to 2000 volts. The high voltage response is as much as 15% below the peak response. The reason for this is currently not understood, and will be the focus of future study.

We performed plateau curves for the SEC while delivering 5 different ion species; protons, Helium, Neon, Chlorine, and Iron. It was expected that the response of both the ion chamber and the SEC would scale with Z^2 , the square of the nuclear charge, but we observed that the ratio of SEC to QC3 dropped slightly with increasing Z . This can be modelled by the expression

$$S = k(Z^2 - \epsilon Z^3) \tag{1}$$

where S is the SEC response, k is a normalization constant and ϵ is the correction coefficient, determined to be 0.0041 by the data shown in Figure 3 below.

Using the QC3 calibration, we determined that the SEC electron emission efficiency is 0.025 ± 0.003 per proton at 1000 MeV.

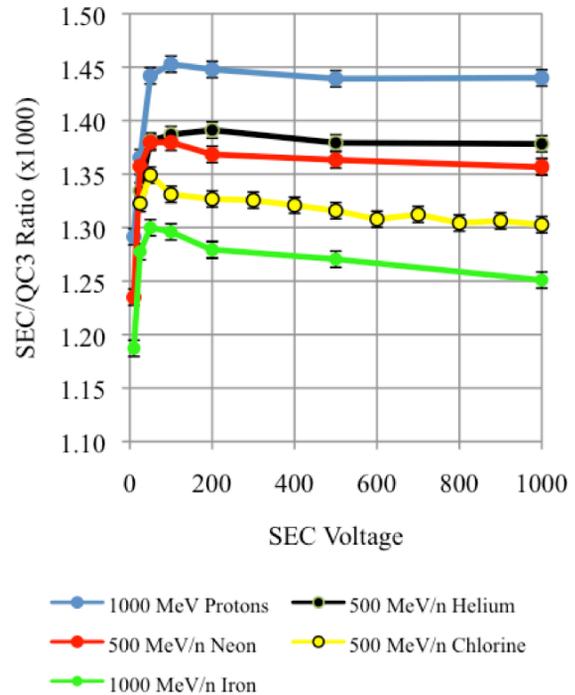


Figure 3 shows the ratio of the SEC to QC3 as a function of the voltage on the SEC, for a variety of different ion species in the beam. The ratio has been scaled by 1000.

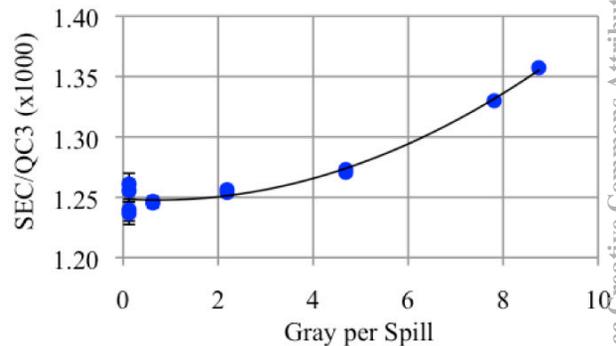


Figure 4 shows how the ratio SEC/QC3 (x1000) changes with beam intensity.

We also compared how the ion chamber and SEC responded to high intensity beam. Figure 4 shows the expected behavior of saturation and recombination in the QC3 ion chamber. Uncertainties in the SEC signal due to fluctuations in the leakage current become large relative to the signal at low intensities when the signal is small leading to a greater uncertainty in the ratio at low intensities.

OPERATING SEC AS AN ION CHAMBER

Although the SEC is typically operated in vacuum so that the ionization from the foils is not swamped by ionization of the gas, by filling the SEC with an operating gas it can behave like an ion chamber.

The QC3 ion chamber is 1.02 cm thick, and is filled with Nitrogen at STP. A minimum ionizing particle passing through QC3 will create 56 electron-ion pairs per cm, or 57 charges for the chamber per track. The SEC has an active region that is approximately 4 cm thick (less 3 times the foil thickness). So we expect that the ratio of SEC to QC3 signals will be 3.92 normally. What we find in practice is a ratio of 3.72, which is probably due to a reduced gap size between foils. We plan to measure the gap size the next time the low vacuum SEC is opened up.

By filling the SEC with different operating gases, we can compare the ionization generated by different ion species and different energies, as seen in Figure 5. The response of the chamber when operating with different gases is proportional to the density of the gas, and the average ionization potential of the gas molecules. We plan to continue our studies with Methane, Xenon and Krypton in the near future. Figure 6 shows the three different operating ranges of the SEC: low pressure where secondary emission from the foils dominates, high pressure where electrons from the gas dominates, and intermediate pressure where the gas produces electron amplification.

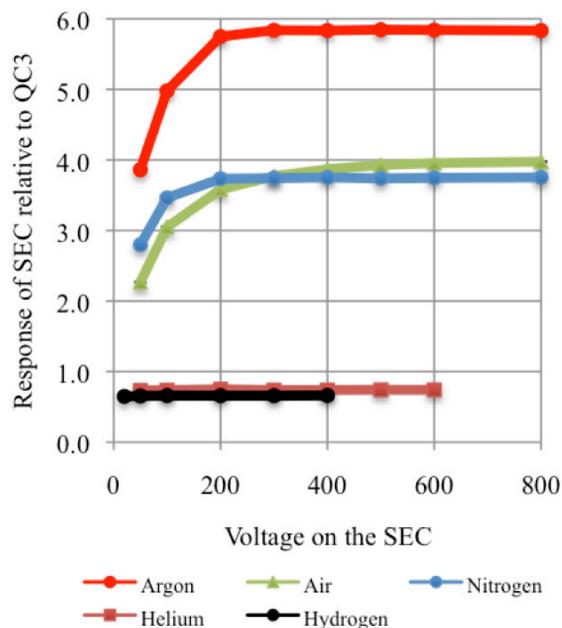


Figure 5 shows the HV plateau of the SEC for 5 different operating gases. Horizontal axis gives the voltage on the SEC. Vertical axis is the ratio of the charge on the SEC to QC3.

QC3 has been calibrated with a NIST-traceable ion chamber, and with a scintillator. Both calibration methods yield consistent results. Using the Recycling Integrator System to read out QC3, we can determine the number of electrons generated by the passage of the beam, and relate this to the total delivered dose. It is possible to use this information to calibrate the SEC in terms of dose. There are caveats, however, in that the SEC can function well only if the beam is fully contained within the thin entrance and exit windows of the SEC.

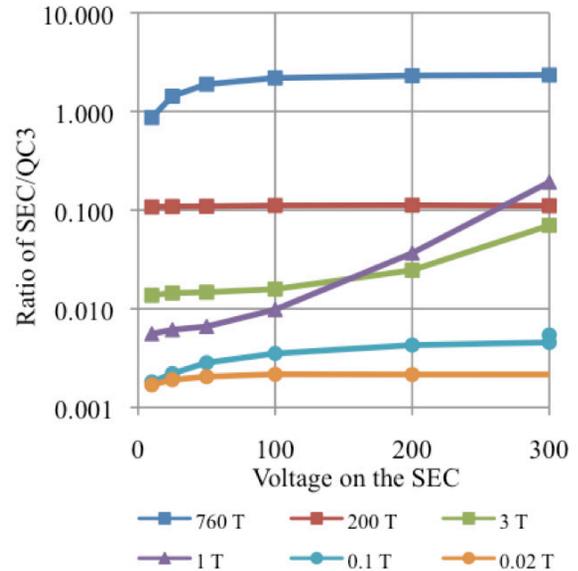


Figure 6 shows the performance of the SEC as a function of the pressure of the operating gas, Nitrogen.

SUMMARY

We have shown the results of a study of the properties of a secondary emission chamber, and described the techniques used to calibrate it to measure beam flux and dose.

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