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Characteristics of Electron Beam Extraction in Large Area Electron Beam Generator

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Abstract - A large area electron beam generator has been developed for industrial applications, for example, waste water cleaning, flue gas treatment, and food pasteurization. The operational principle is based on the emission of secondary electrons from the cathode when ions in the plasma contact the cathode, which are accelerated toward the exit window by the gradient of the electric potential. Conventional electron beam generators require an electron beam scanning mechanism because a small area thermal electron emitter is used. The electron beam of the large area electron beam generator does not need to be scanned over target material because the beam area is considerable. We have fabricated a large area electron beam generator with peak energy of 200keV, and a beam diameter of 200mm. The electron beam current has been investigated as a function of accelerating voltage and distance from the extracting window while its radial distribution in front of the extracting window has been also measured.

Keywords: large area electron beam generator, glow discharge, secondary electron emission.

1. Introduction

Recently, the electron beam has been applied in diverse fields. The electron beam is used not only for industry applications such as the excitation of gas lasers, treatment of metal surfaces, and machining of various materials, but also for medical and environmental applications such as sterilization, radiation therapy and removal of volatile organic compounds [1-12]. We have created a large area electron beam generation system with an energy of 200keV, beam current of 135mA, 20us pulse width, and pulse repetition rate of 25pps. The important distinguishing feature of this type of accelerator is the capability of the simultaneous irradiation of treatment surfaces or volumes since the area size of the electron beam is related to the treatment efficiency in application. The area size of the exit electron beam is equal to the area of the exit window as well as equal to the area size of the active volume discharge chamber or plasma reactor. It has a large cross sectional area of up to 300 ㎠. Acceleration of the electrons takes place in a single accelerating high voltage electrode gap. Another important feature of this system is easy maintenance because it has a simple structure and a low vacuum relative to the conventional electron beam generators. Furthermore, the system is characterized by a cold cathode, which is simpler than a system based on thermionic emission. The conventional electron beam generators require electron beam scanning capability because a small area thermal electron emitter is used. However, the electron beam of this system does not need to be scanned over target material because the beam area is enlarged by 300 ㎠. We carried out theoretical research regarding the principle of an electron beam generation system and devised the conceptual designs of a main high voltage pulse modulator. We performed research on the characteristics of an auxiliary glow discharge as a function of helium gas pressure at dc positive voltage of a few hundred volts. We also researched the characteristics of electron beam generation as a function of the glow discharge current, helium gas pressure, accelerating voltage and its radial distribution. We composed a study of the normalized transmittance versus propagation distance from the exit window to the air.

2. Principle of Electron Emission and Acceleration

How the electron beam is produced in our accelerator is shown in Fig. 1. The voltage supplied for discharge ignition and plasma excitation is positive potential relative to the chamber, then the negative high voltage pulse is supplied to the cathode for electron emission and acceleration. As a pulse is applied to the cathode, sheath appears in plasma and the ions existing in the sheath region accelerate to the cathode, emitting secondary electron. These secondary electrons emitted from the cathode are accelerated through the inner grid and plasma region, and

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exit through the foil exit window to the air. These processes are associated with a pulse shape applied to the cathode. An extracted electron beam current is inversely proportional to the pulse rising time. The reason for this is that the secondary electron emission increases in proportion to the ion matrix sheath area, which increases as pulse rising time decreases. If the electrons mean free path is much greater than the distance between electrodes, then the electrons have sufficient energies to penetrate the foil window and their energy consumption is also small since they have not collided with any neutral or charged particles. Therefore, low pressure is desirable.

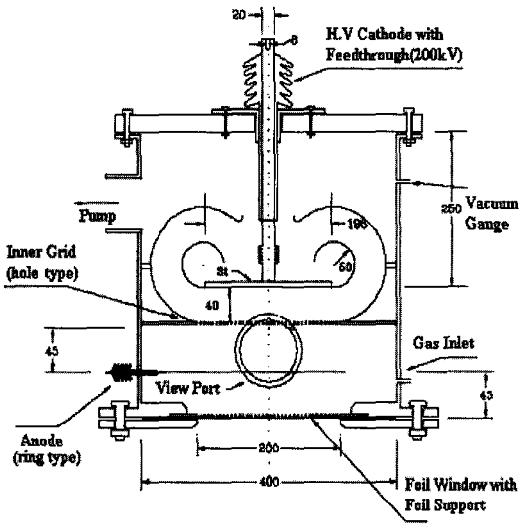

Fig. 1 Schematic of the large area electron beam generator

3. Construction of the Electron Beam Generator

Fig. 2 shows a total block diagram of the electron beam generation system developed in our study. Construction of the electron beam generator consists of the following parts: DC auxiliary power supply for ion source, main power supply for electron beam generation, vacuum system, gas supply system and cooling system. We particularly manufactured an X-ray shielding room (3mx2mx2.6m) and its ventilation system to the electron beams or X-ray radiation. The shielding room has an inspection window with lead glass the thickness of 8mm and is the size of about 30x30cm^2 along one wall. The height from the floor is 1.2m with two apertures in the top part of one wall, 90mm in diameter, for a ventilation tube, and high voltage and signal cables. Helium gas flows at a low rate into the chamber through a needle valve and is circulated by means of a rotary pump to minimize impurities in the chamber. The chamber is then pumped to a few milli-torr by a 600ℓ/min turbo-molecular pump (ATP Series). Working gas pressures are measured with a Baratron gauge of an absolute pressure transducer (MKS Baratron Type 622A) and a control system (MKS Type 146C Cluster Gauge). Glow discharge is generated by applied voltage between a ring type aluminum anode of 300mm diameter, 4mm thickness and a vacuum chamber of 400mm long, 400mm in diameter as shown in Fig. 1.

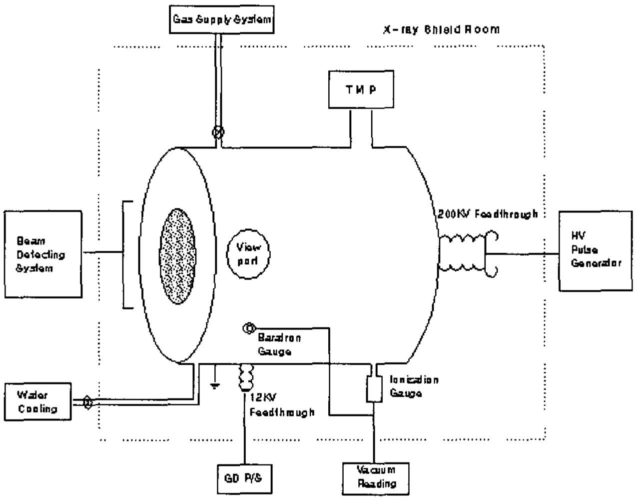

Fig. 2 Block diagram of an electron beam generator system

The cylinder type vacuum chamber made of stainless steel is grounded and constitutes the cathode of the glow discharge. The inner grid in the chamber has ground potential. It is an anode for a cold cathode. The effective cross section of the inner grid is about 80 percent. The plasma is shielded by the inner grid, which can allow the passage of some helium ions. Ions coming through the inner grid are accelerated toward the cathode, which is supported with a M.C nylons insulator, and then secondary electrons are generated and accelerated in the reverse direction to the inner grid. The electrons, coming through the plasma and the exit window, finally contact the air. For efficient electron production using cold cathodes, a cathode material with a high secondary electron emission coefficient by ion bombardment is required. For prolonged lifetime of the electron beam device under the glow discharge, cathodes with a low sputtering yield are also required. From the point of view of secondary electron emission, sputtering, energy loss in the cathode heating, and cost-effectiveness, we used a stainless steel cathode material (composition rate of SUS 304; C:0.08, Mn:2.0, P:0.045, S:0.03, Cr:18.0~20.0, Ni:8.0~10.5, the rest: Fe). The high voltage cold cathode is 200mm in diameter, which equals the diameter of the inner grid and exit window. To protect the breakdown between the cathode and the chamber, we made a screen in the shape of a cathode keeping a distance of 40mm from the entire cathode surface. The length of the electrode gap between the cold cathode and the inner grid is 40mm.

4. Experimental Results and Discussion

4.1 Electron Beam Extraction to the Air

In general, a Faraday cup is used for obtaining the measurements of an electron beam current. However, in this study, we used a stainless steel disk with positive bias in the auxiliary vacuum chamber for the examination of the secondary electron emission by electron bombardments. Fig. 3 depicts the electron beam current measuring system with auxiliary vacuum chamber. The beam collector is positive biased from 0V to 300V for suppressing the emission of the secondary electrons. The distance between the disk and the extraction window is variable and the disk is big enough to cover the window, 40cm in diameter. The resistance of 50Ω is connected in parallel with an oscilloscope. The auxiliary chamber is evacuated, just as in the case of the electron beam accelerator.

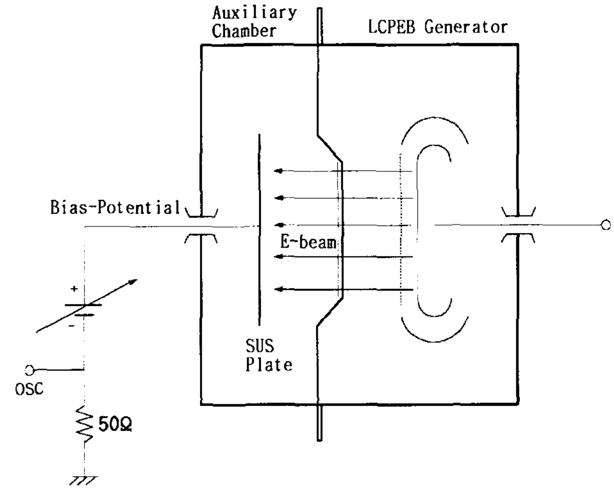

Fig. 3 Schematic of pulsed electron beam current measuring

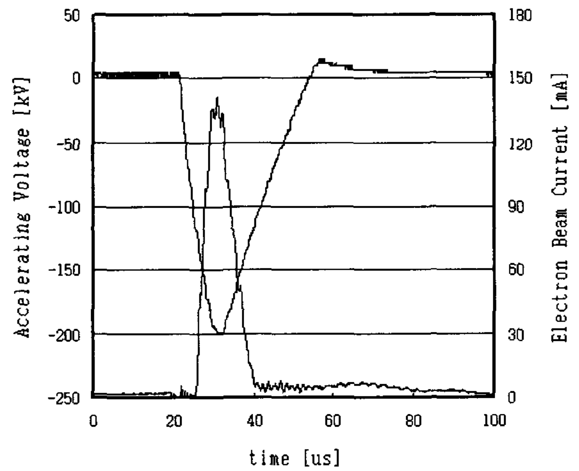

Fig. 4 High voltage pulse and electron beam current

Fig. 4 shows the high voltage pulse-shape on the cathode and the electron beam current profile extracted through the aluminum foil window to the air, measured with the system in Fig. 3. The experimental conditions were helium gas pressure of 5mTorr, glow discharge current of 0.5A and bias of 45V. We can see that a cut-off accelerating voltage of electrons to extract through the 50um aluminum foil is about 115kV. This means that the electrons accelerated at lower than 115kV are stopped up in aluminum foil.

4.2 Characteristics of Electron Beam Current

The electron beam current extracted through the 50um aluminum foil window is shown as a function of accelerating voltage in Fig. 5. The electron beam current was measured as a peak value that was averaged at more than a thousand shots of pulse. The solid line is a curve fitted with a fifth order polynomial as a function of the accelerating voltage. We can see that the electron beam current extracted through the 50um aluminum foil strongly depends on the accelerating voltage. This signifies that the energy loss of electrons in aluminum foil is considerable, and electron beams below the cut-off energy turns to a loss in heating. As such, the rising and falling times of the high voltage pulse, as shown in Fig. 4, are important for reducing the loss and running costs for cooling the system.

Fig. 6 shows the normalized electron beam current as a function of distance from the extracting window. The electron beam to be penetrated from the extracting window disappears after 25cm propagation to the air. Namely, energy loss occurs when the electron to be accelerated to 200kV runs through the 50um of aluminum foil. We can see that the electron beam current is exponentially decreased according to an increase in the distance from the

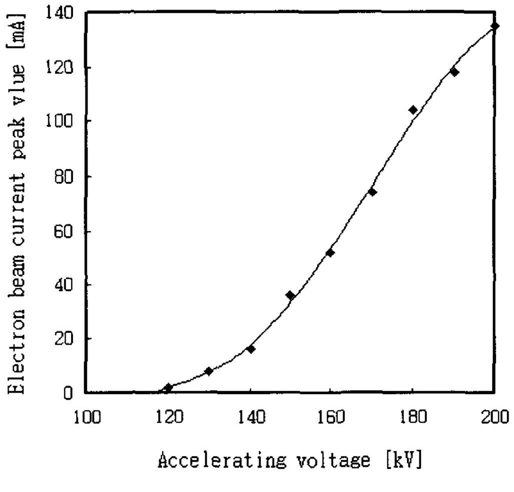

Fig. 5 Electron beam current extracted through the 50um of aluminum foil

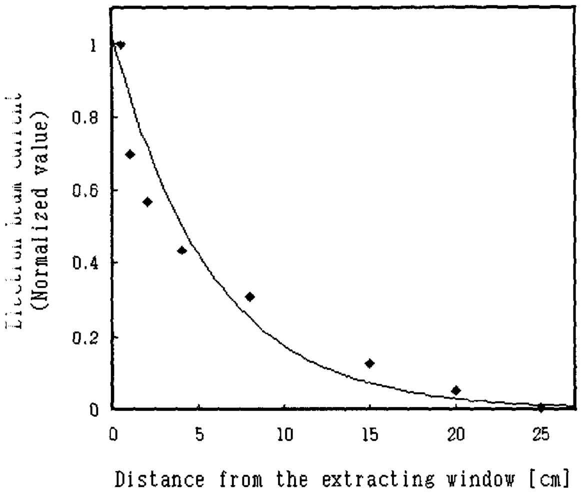

Fig. 6 Electron beam current as a function of distance from the extracting window

extracting window. This is due to the electron energy distribution function, which is more greatly distributed at the low energy portion. Namely, because the maximum propagating distance of the electrons running through the air depends on their energy, the electrons in the lower energy area lose their energy faster. Therefore, the maximum propagating distance is decided by the electrons with high energy.

4.3 Electron Beam Distribution

The most important feature of this electron beam generator is the large beam area compared to the conventional electron beam generators. The shape of the electron beam depends on the shape of the cathode and beam exit window. In this study, we used a circular disk cathode and therefore the shape of electron beam is circular. However, the window of the exit beam requires support because the 50um of aluminum foil can't withstand the pressure difference of 1atm in our structure of the window.

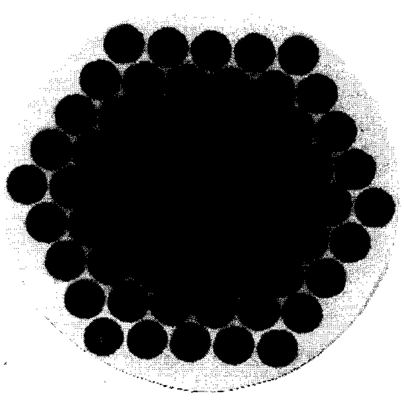

Fig. 7 Radiation form of electron beam

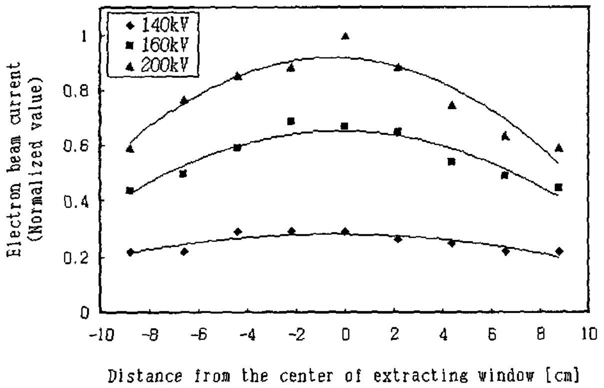

Fig. 8 Radial distribution of electron beam

Actually, the shape of the electron beam area is a set of 61 small circles, 20mm in diameter. Fig. 7 shows the shape of the electron beam area visualized by using photo-paper that obtained accelerating voltage of 180kV. The shots of pulse electron beam were around 1000. It consists of dark spaces due to the irradiated electron beam and bright spaces emitted by the foil supporting structure. In addition, the form is flickering by means of a pulse repetition rate.

Normalized radial electron beam current distribution in front of the extracting window is shown in Fig. 8. The current of the electron beam was measured at 140kV, 160kV, and 200kV respectively. The difference between the maximum and minimum of the electron beam current is about 25%, 36% and 40% at accelerating voltages of 140kV, 160kV and 200kV respectively. The value of the electron beam current in the center area is higher than the most outer area as voltage increases. We can see the result coincides with Fig. 7.

5. Conclusion

We have designed and established a large area electron beam generator. The maximum accelerating voltage was 200kV, and maximum peak pulsing electron beam current extracted through the 50um of aluminum foil was 135mA. The effective beam area was 200cm^2. The electron beam had a threshold value of electron energy of about 115kV. Also, we have measured the electron beam current as a function of the accelerating voltage, and distance from the extracting window and its radial distribution in front of the extracting window has been also measured. As a result, we found that the energy loss of the electron beam in the aluminum foil, as an extracting window, is considerable at this energy level. The electron beam current is exponentially decreased according to the increase of distance from the extracting window. The radial distribution of the electron beam can be told to be uniform in the range of 40%. We are next going to upgrade a large area electron beam generator in energy, current, uniformity and beam stability for various applications.

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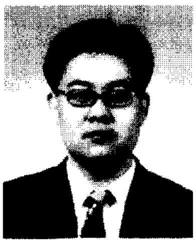

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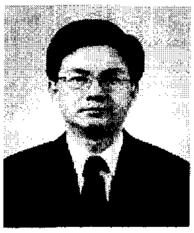

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