Indian Journal of Pure & Applied Physics
Vol. 50, July 2012, pp. 482-485

Design, development and characterization of tetrode type electron gun system for generation of low energy electrons

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Received 20 April 2012; accepted 10 May 2012

A tetrode type electron gun system for the generation of low energy electrons has been designed, developed and characterized. The electron gun, designed for irradiation experiments, has four electrodes namely, cathode, focusing electrode, control electrode and anode. This electron gun is capable to provide electrons of energy over the range of 1 keV to 20 keV, with current maximum 100 μA. The electron gun and a Faraday cup are mounted in the evacuated cylindrical chamber. The samples are fixed on the Faraday cup mounted at a distance of 200 mm from the anode in the chamber and irradiated with low energy electrons at a pressure around 10^{-6} mbar. In this electron gun system, at any electron energy over the entire range, the electron beam diameter can be varied from 5 to 120 mm on the Faraday cup. Also, the circular shape of the beam spot was maintained, even though the beam current and beam diameter are varied. The uniformity of the electron beam over the entire beam area was measured with a multi-electrode assembly and found to be 15%. This system is being used for the synthesis and diffusion of metal and semiconductor nanoparticles in polymeric and glass materials.

Keywords: Tetrode electron gun, Low energy electrons, Beams current, Irradiation chamber

1 Introduction

Design, fabrication and utilization of electron sources have gained unique importance in the areas of fundamental research as well as for industrial and space applications. The different parameters of an electron beam such as energy, current, beam size, beam uniformity, etc are decided by the end use applications[1,2]. In any electron gun, the geometry of the electrodes decides the main beam optics comprising of uniform flow of electrons, beam waist, focusing and defocusing and the axial location of the beam spot[2,3]. High electron current sources are used for some special applications such as single electron bunch in electron accelerator, ion cooling system, welding of special type metals, etc. However, most of the low energy electron guns are developed for assembling systems like small electron accelerators, T.V., SEM, TEM, or even applications related to micro engineering, etc. Using low energy electrons, a number of investigations are being carried out in several areas such as irradiation effects on the surface properties of semiconductors, dye ability in electron irradiated polymers, charge storage property of insulators, X-ray generation, discharge characteristics of the spacecraft materials, etc[4-6]. These electron guns provide focused beam with diameter in the range of μm to a few mm. Such types of electron gun systems are not suitable for simulating irradiation effects of electrons on materials in which the sample area may vary from 1 cm^2 to 10^2 cm^2. It is, therefore, desirable to have an electron gun system in which the spot size of the electron beam can be varied for a wide range so as to cover the entire sample area. Moreover, this kind of system can be used to study the materials, components and circuits under space environments. Therefore, in the present work, a tetrode type electron gun system for the generation of low energy electrons has been designed, developed and characterized.

2 Experimental Details

2.1 Electron gun

The present electron gun was designed to provide electrons of different energies in the range 1-20 keV which can mostly be used to study the irradiation effects on different materials and synthesis of metal and semiconductor nanoparticles. An electron gun was designed by considering the shape of electrodes, the trajectory of the electrons and the equi-potential planes. On the basis of these parameters, the final design of a tetrode type electron gun was optimized using SIMION-7 computer code[7,8] in such a way that the electron beam diameter varies from 5 to 120 mm over an energy range of 1 keV to 20 keV.

The electron gun consists of four electrodes, namely cathode (K), focusing electrode (F), control electrode (C) and anode (A). All these electrodes are made from non-magnetic stainless steel. The electrodes are held by ceramic rods of suitable lengths for maintaining the desired distance between the respective electrodes. The schematic of the electrode assembly and its photograph is shown in Fig. 1.

The electron emitting element is an oxide impregnated tungsten matrix, fixed into a nickel cylinder of length 7 mm and 4 mm diameter. This nickel cylinder is mounted into the coaxial hole of the cathode electrode. A filament (coil heater) inserted into the nickel cylinder controls the temperature of the tungsten matrix.

2.2 Irradiation chamber

The other parts of the electron irradiation system are a cylindrical shape stainless steel chamber, current meter, power supplies, control system, sample holder, Faraday cup, plexiglas flanges coated with ZnS(Ag) and vacuum system. The cylindrical chamber has four small size side ports welded to the main body. The electron gun and the Faraday cup were mounted on two separate plexiglas flanges. One of the end ports of the chamber was closed by the plexiglas flange carrying the Faraday cup, whereas the other end port of the chamber was closed with the flange carrying the electron gun. For viewing the electron beam spot and measurement of the beam diameter, the Faraday cup flange can be replaced by another transparent plexiglas flange coated with ZnS(Ag). The Faraday cup was electrically connected to the feed through mounted to one of the side ports. The pressure inside chamber was maintained at ~ 10^{-6} mbar.

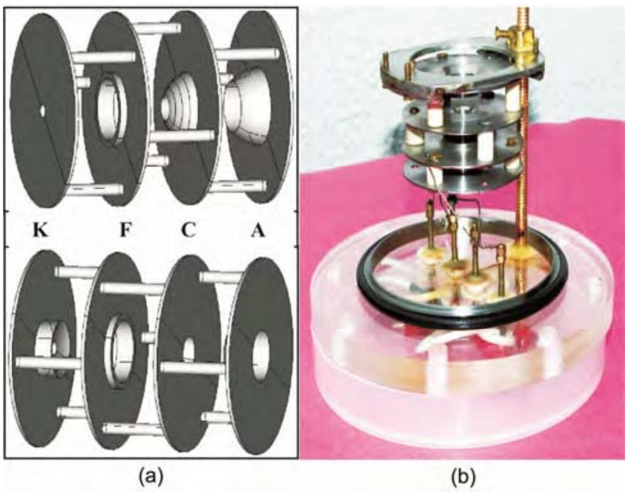

Fig.1 — (a) Schematic of different views of electrode assembly and (b) Photograph of electrode assembly mounted on Plexiglas

2.3 Measurements and Characterization of Electron gun

2.3.1 Beam Diameter

Out of four electrodes, the cathode, the focusing electrode and control electrode are kept at negative potential with respect to the anode which was at ground potential. To study the variation of electron beam diameter, bias voltage of electrodes V_K, V_F and V_A were kept constant and V_C was varied. Fig. 2 shows a schematic view of the configuration of electrodes, the trajectory of electrons and equipotential lines simulated with the SIMION-7 code for different beam diameter.

To measure the beam diameter, other end of the irradiation chamber was closed with a flange made of transparent plexiglas. A thin layer of TiO_2 was coated on the plexiglas to make it conducting. On this transparent conducting coating, a thin layer of

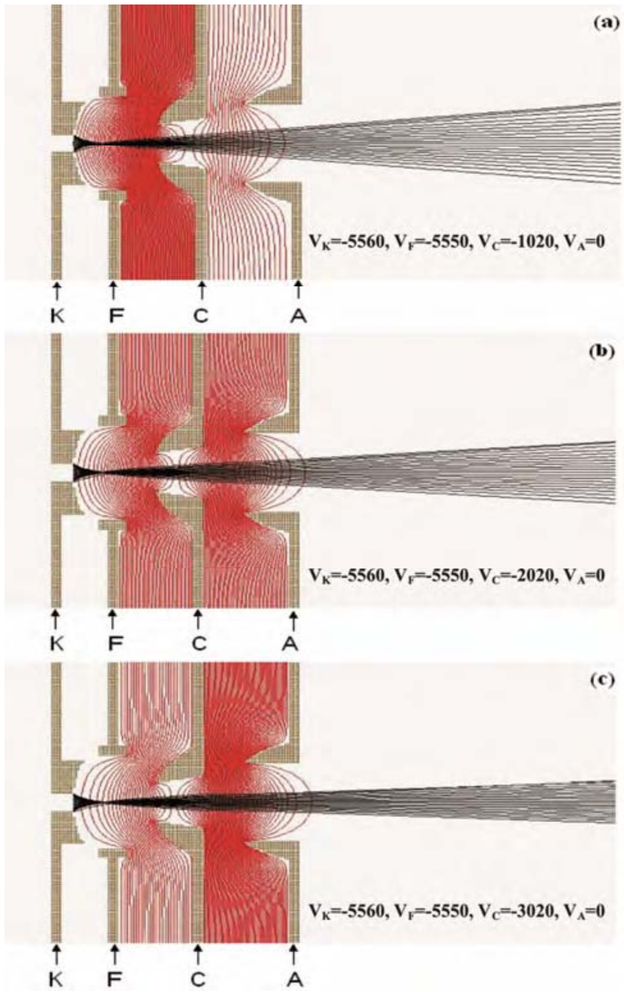

Fig. 2(a), (b) and (c) — Change of electron beam diameter with control electrode voltage (V_C) at constant values of V_K, V_F, and $V_A = 0$ (in volts)

ZnS(Ag) was made using chemical spray technique. Electrical connection was provided from the conducting coating to a current meter through a BNC connector. When electrons fall on the ZnS(Ag) coating, a blue colour glow could be observed through the plexiglas flange. In this way, it was possible to measure the beam current and diameter using standard technique from outside the chamber. The system parameters were optimized for obtaining the beam spot of any diameter varying from 5 mm to 120 mm by changing the potentials at the control electrode (V_C) of the electron gun.

2.3.2 Emission Current

The electron emitting cathode having oxide matrix was heated by indirect heating method. The emission property of the oxide matrix has been studied by varying filament voltage. After applying the filament voltage, the oxide impregnated tungsten matrix started emitting electrons. By applying proper negative bias voltage to the electrodes, electrons were accelerated. These electrons after coming out of the gun geometry, traveled to the Faraday cup. In this way, the electron emissive property of the oxide matrix was studied independently by replacing the anode electrode with a small size graphite plate, which acted as a Faraday cup. The variation of electron emission current with filament voltage for three values of the accelerating voltages between the cathode and the graphite plates is shown in Fig. 3.

2.3.3 Electron Beam Current

The electron beam current was measured using the Keithley made current meter. In this case,the Faraday cup was mounted on the closing flange of the chamber. The cathode, the focusing electrode and the control electrode were made negative with respective to grounded anode electrode. The variations in the electron beam current with the electron energy (E_B) have been studied for different filament voltages (V_{Fil}=8-17 V). The variations in the electron beam current I_E with beam energy at different values of filament voltages is shown in Fig. 4.

2.3.4 Beam Uniformity

A special type of Faraday cup was designed for measuring the beam uniformity. This consists of 200 small circular graphite cylinders, each having diameter 4 mm and length 5 mm. These circular cylinders were fitted in the grooves made on a plexiglas plate, which could be directly fitted on the chamber as a closing flange. Each groove had a small hole through which the electrical connection to the graphite cylinder could be made from the other side of the plexiglas plate. Electron beam was allowed to fall on this flange and the beam current from each cylindrical Faraday cup was measured using current meter. Beam current (I_B) from each of the graphite Faraday cup mounted along the X-axis was measured. In the similar manner, measurements were also made from the graphite Faraday cups mounted along the Y-axis. The variations in the beam current with the position of the graphite cylinder have been studied for three beam energies 5, 10 and 20 keV, respectively is shown in Fig. 5.

3 Results and Discussion

Figure 2 shows that the electron beam diameter depends on the bias voltage of the control electrode.

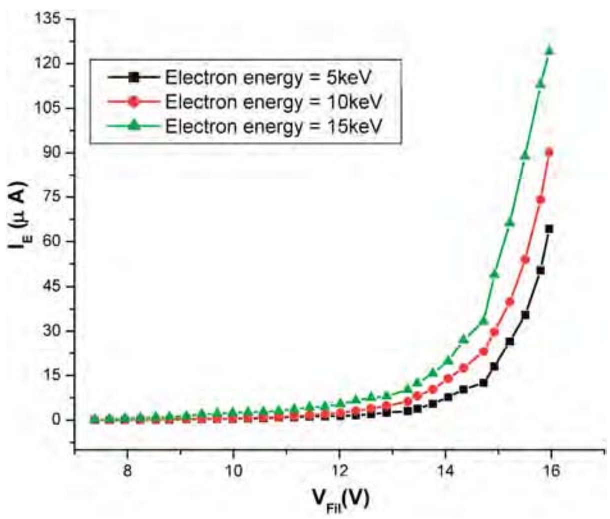

Fig. 3 — Variations in the electron emission current (I_E) with the filament voltage (V_{Fil}) for accelerating voltages 5 kV, 10 kV and 15 kV

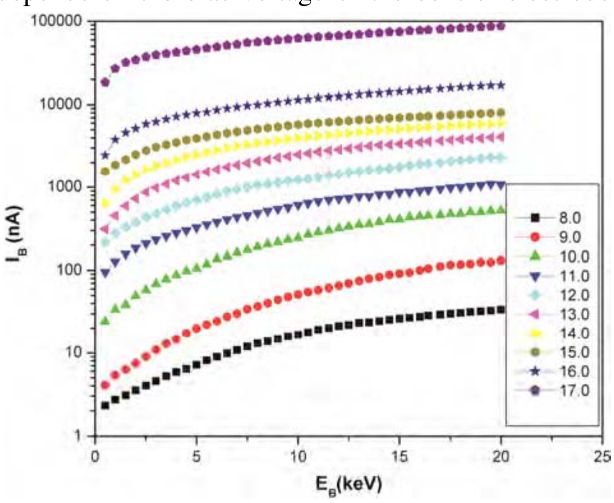

Fig. 4 — Variations in the beam current (I_B) with beam energy (E_B) at different filament voltages (V_{Fil})

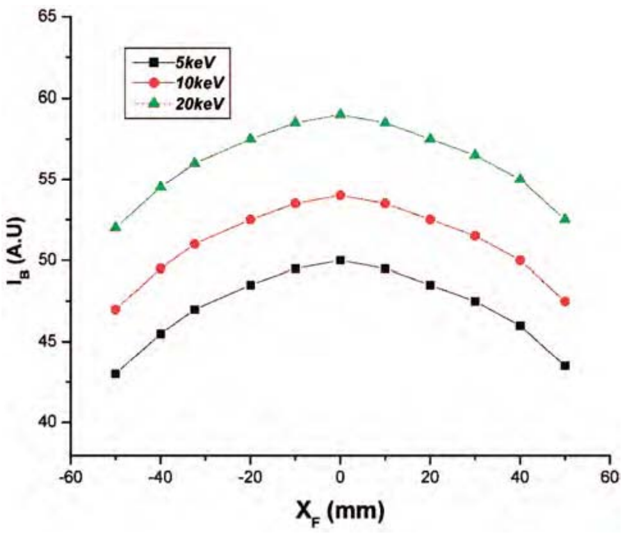

Fig. 5 — Variations in the beam current (I_B) along the X-axis over the beam spot at beam energy 5, 10 and 20 keV

The beam diameter decreases with increasing the bias voltage of the control electrode, when V_k, V_F, and V_A are kept at constant values. Thus, it is possible to vary beam diameter for any energy over the range of 1 to 20 keV. It is also possible to keep the beam diameter same for different electron energy. The results are shown in Fig. 3 indicate that the electron emission current (I_E) initially increases slowly with the filament voltage, but later on increases rapidly when the filament voltage (V_{Fil}) exceeds 14 V. These bench test results reveal that even at 5 keV, a large electron current could be obtained. The results show that an electron beam current ~100 µA can be obtained in the present system. Fig. 4 shows that the beam current (I_B) gradually increases with increasing beam energy (E_B) at a constant filament voltage. These results indicate that at a given beam energy (E_B) the beam current (I_E) can be changed over a wide range by changing the filament voltage (V_{Fil}). Such type of electron gun is required for special studies in which electron beam current (I_B) can be easily varied. This type of facility is also required in the study related to the dose-dependence degradation in polymeric materials. The electron density over the beam spot has also been measured with a multielectrode assembly and found to be better than 15% as shown in Fig. 5. This level of beam uniformity is sufficient for synthesis of nanoparticles in polymers and glass matrix.

4 Conclusions

In conclusion, this electron gun system can provide electrons over an energy range of 1 keV to 20 keV and beam current up to 100 µA at all electron energies. The special features of this electron gun system are that, at a set value of the electron energy of 1 keV and above, the electron beam diameter can be varied from 5 to120 mm on Faraday cup. One can also maintain beam diameter the same for all electron energies up to 20 keV. The electron beam current can also be varied continuously from 10 nA to 100 µA at the set values of the energy and beam diameter. The uniformity of the electron beam, over the entire beam area, is found to be 15%. The shape of the electron beam is maintained even when the parameters such as the beam current, energy and diameter are changed. This electron gun system is being used for synthesis and diffusion of metal and semiconductor nanoparticles in polymer films.

Acknowledgement

One of the authors, AV D thanks Dr S K Mahapatra, BIT, Ranchi (India) for his suggestions and fruitful discussion.

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