Abstract

A novel sheet-beam plasma cathode electron (SPCE) gun is presented. The discharge in the SPCE-Gun is an axially symmetric self-sustained transient low pressure gas discharge, which has been used to generate the sheet electron beam. A delayed voltage breakdown together with a fast current rise in this device results in a class of highly intense sheet electron beam generation. To diagnose the generated beam, the beam has been extracted in drift space region. An arrangement of three isolated metallic sheets has been proposed for qualitative assessment of the beam. Also the actual shape and size of the sheet electron beam have been obtained through a non-conventional method by proposing a dielectric charging technique and SEM based image analysis. The beam current density ~1 kA/cm^2 has been achieved and propagated more than 200 mm distance in the drift space region maintaining the sheet structure without assistance of any external magnetic field.

We claim:

1. A novel sheet-beam plasma cathode electron (SPCE) gun which comprises of:

a vacuum compatible enclosed volume filled with ionizable and non-reactive gas;

a ferroelectric cathode emitter **6** for providing the seed electrons;

a ceramic hollow cylinder **7** of appropriate thickness for enclosing the plasma and providing the electrical insulation between the electrodes;

sheet form apertures **5** on the hollow cathode **1A** and hollow anode **1B** walls facing each other;

separate discharge power supply **17**and trigger power supply **9**;

a transparent drift space region **11** for the sheet electron beam propagation and study.

2. A device as claimed in claim 1, wherein sheet electron beam with current density more than 1kA/cm^2 is generated.

3. Sheet-beam propagation, that is generated by the SPCE gun as claimed in claim 1, for more than 200 mm inside the said drift space without any assistance of any external magnetic field.

4. A technique for characterization of sheet-beam as focusing and defocusing point estimation inside the drift space, used in the device as claimed in claim 1, which comprises of:

a set-up of three aligned rectangular metallic sheets **18** separated by 0.25 mm;

COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH **Sheet No.:1**

Patent Application No.: **No. of sheets:8**

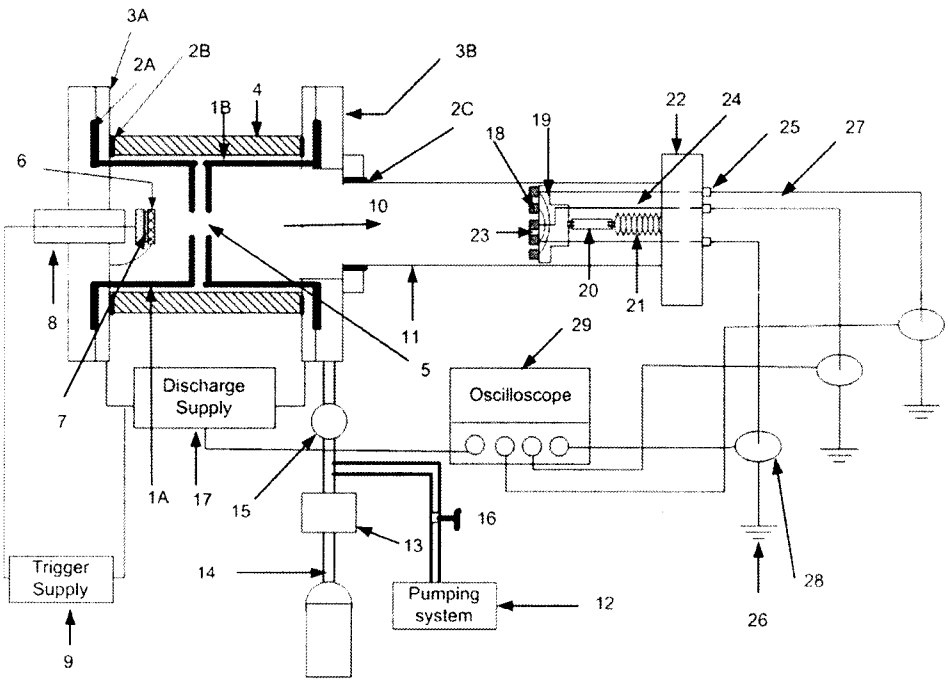


FIG.1

CSIR APPLICANTS

चेतन कुमार / CHETAN KUMAR
वैज्ञानिक/Scientist
आई. पी. यू (सी.एस.आई.आर.)
I.P.U. (C.S.I.R.)
14,संत्सग विहार मार्ग/14,Satsang Vihar Marg
नई दिल्ली-110067/ New Delhi-110067

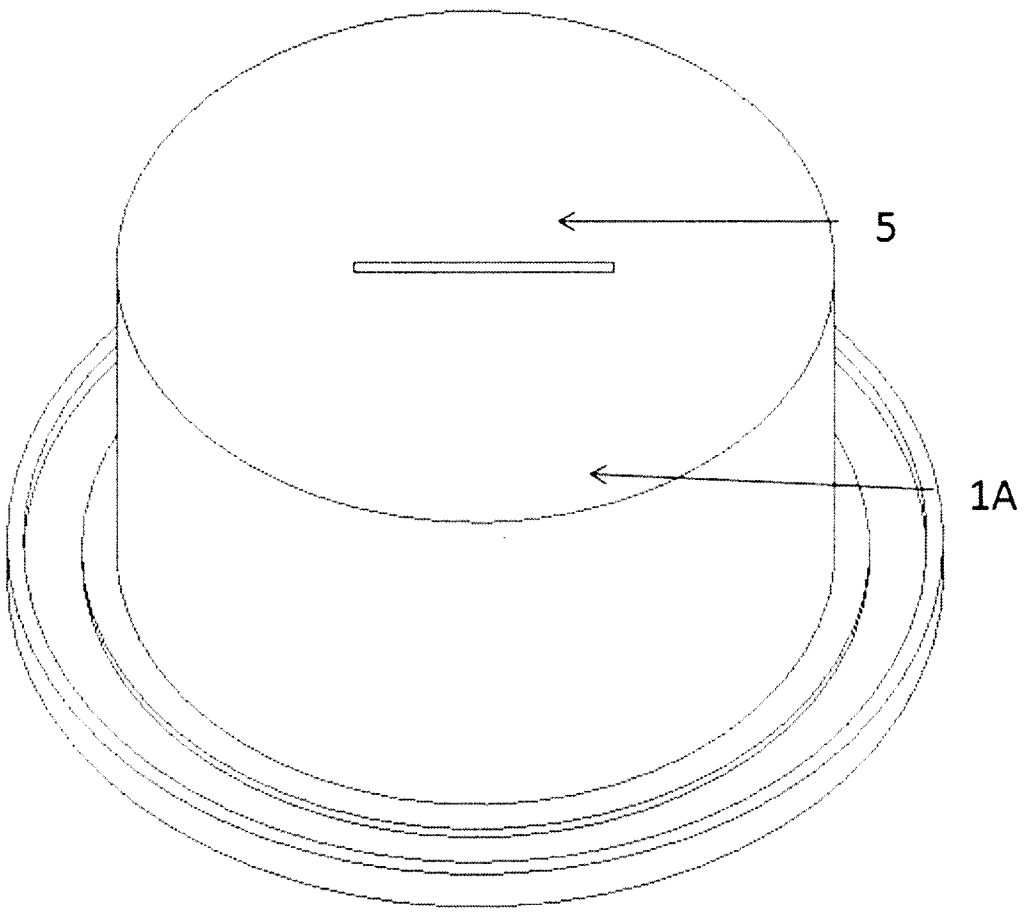


FIG.2

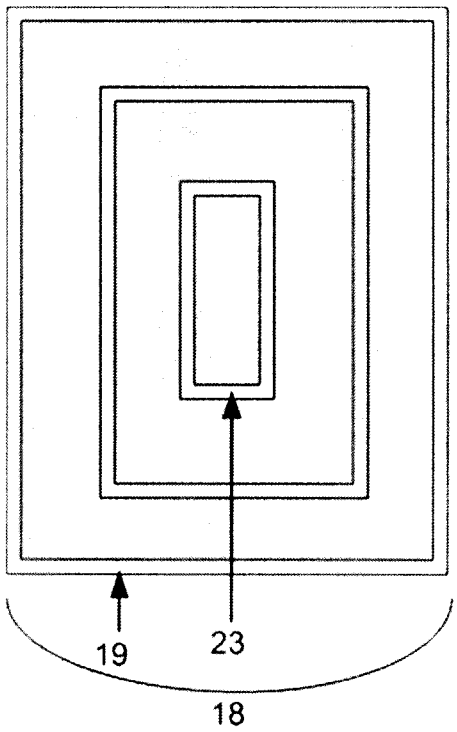


FIG.3

चेतन कुमार / CHETAN KUMAR
वैज्ञानिक / Scientist
आई. पी. यू (सी.एस.आई.आर.)
I.P.U. (C.S.I.R.)
14,संतसग विहार मार्ग/14,Satsang Vihar Marg
नई दिल्ली-110067/ New Delhi-110067

FOR APPLICANTS

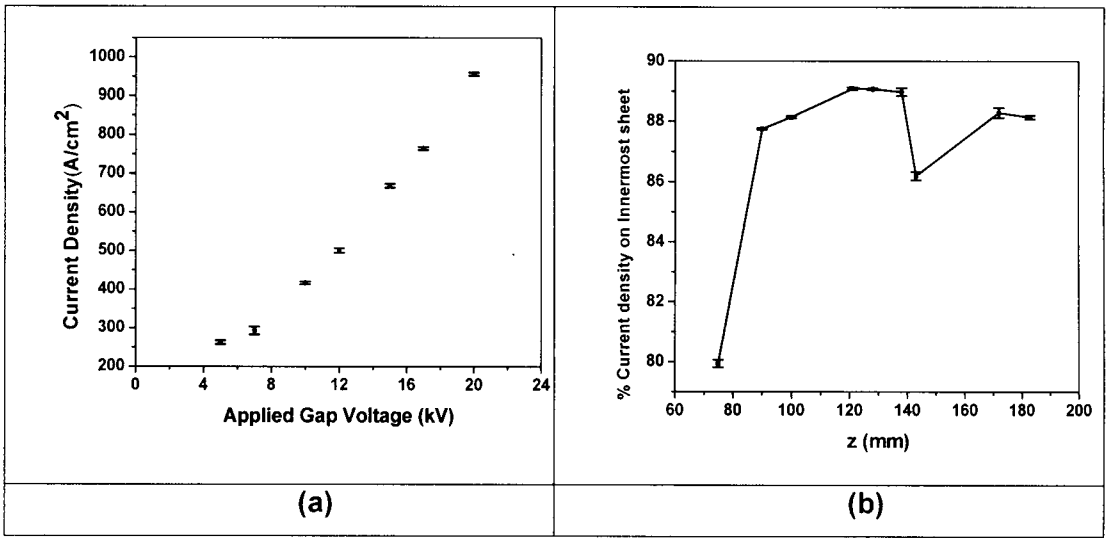


FIG.4

CSIR
APPLICANTS
चेतन कुमार / CHETAN KUMAR
वैज्ञानिक/Scientist
आई. पी. यू (सी.एस.आई.आर.)
I.P.U. (C.S.I.R.)
14,संत्सग विहार मार्ग/14,Satsang Vihar Marg
नई दिल्ली-110067/ New Delhi-110067

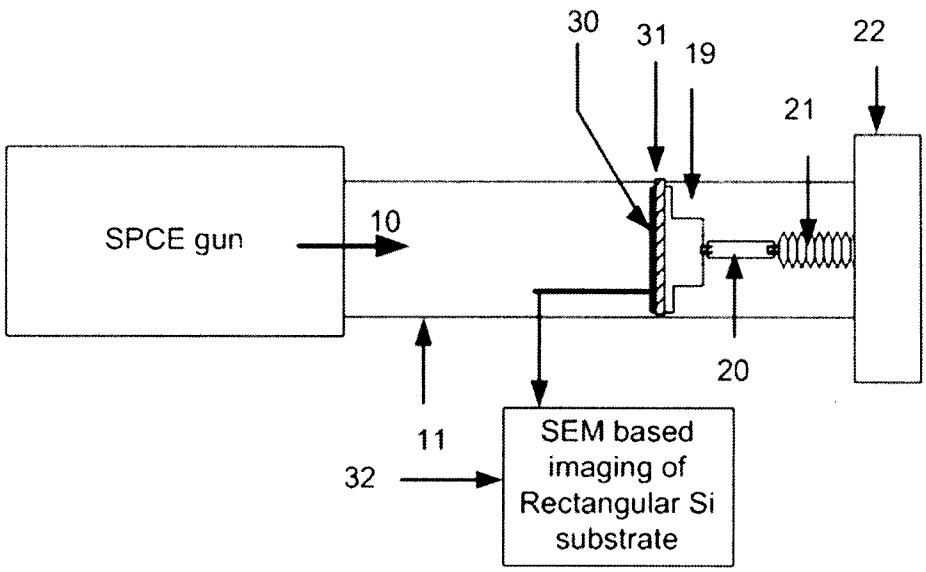


FIG.5

CSIR
चेतन कुमार APPLICANT'S
वैज्ञानिक/Scientist
आई. पी. यू. (सी.एस.आई.आर.)
I.P.U. (C.S.I.R.)
14,सत्संग विहार मार्ग/14,Satsang Vihar Marg
नई दिल्ली-110067/ New Delhi-110067

COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH Sheet No.:6

Patent Application No.: No. of sheets:8

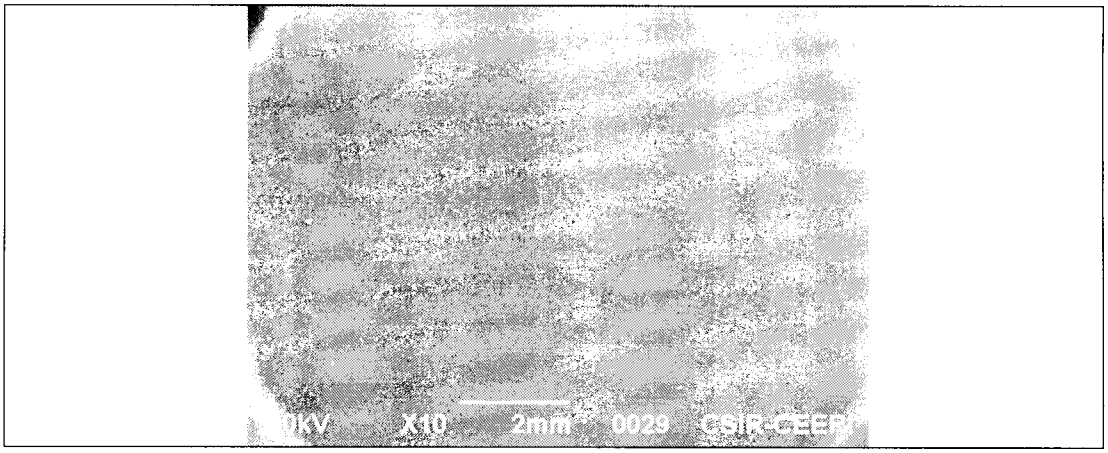
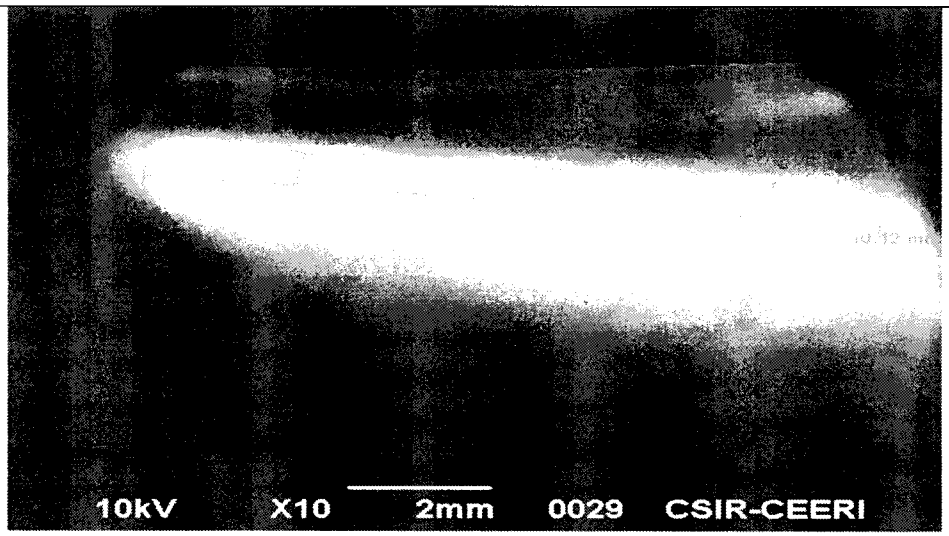
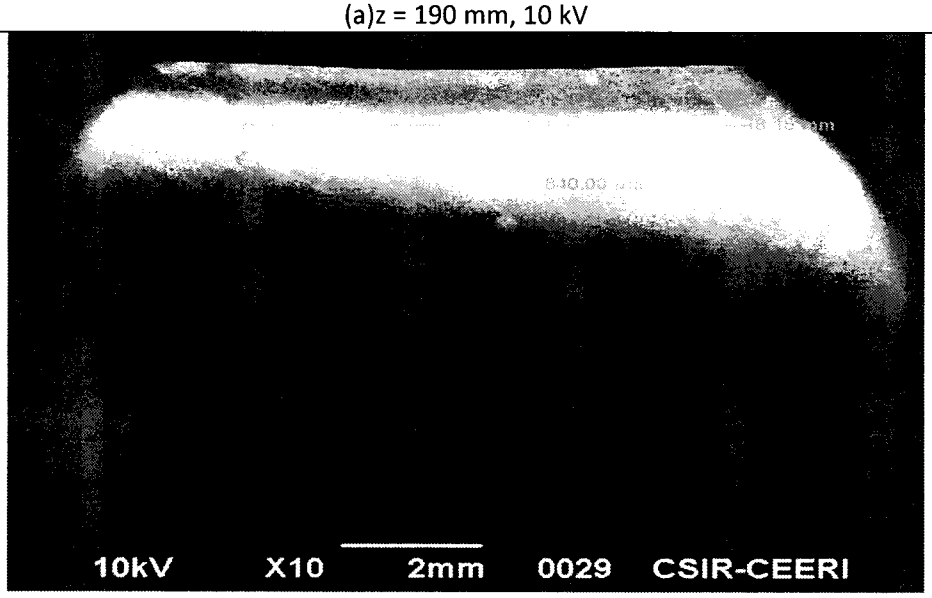


FIG.6

CSIR
APPLICANTS
चेतन कुमार / CHETAN KUMAR
वैज्ञानिक/Scientist
आई. पी. यू (सी.एस.आई.आर.)
I.P.U. (C.S.I.R.)
14,संत्सग विहार मार्ग/14,Satsang Vihar Marg
नई दिल्ली-110067/ New Delhi-110067



(a)z = 190 mm, 10 kV

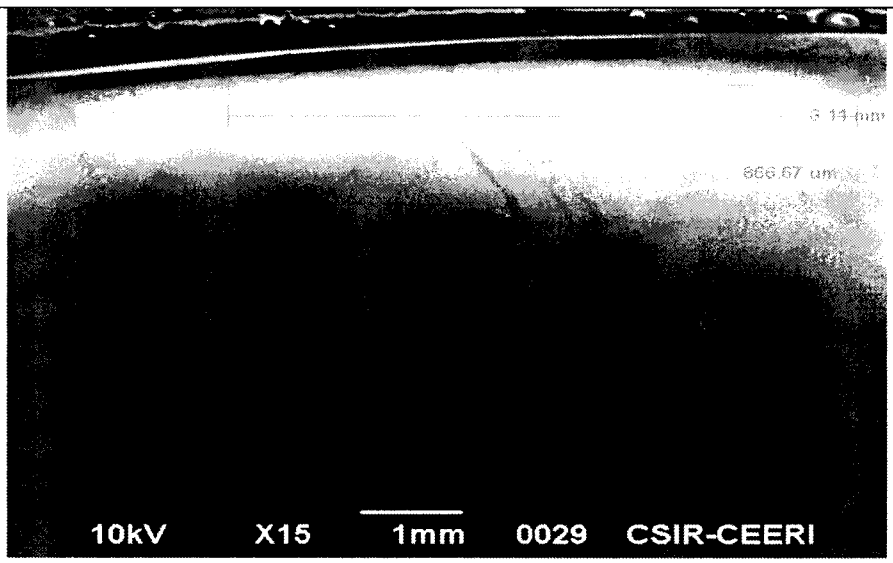


(b) z = 190 mm, 20 kV

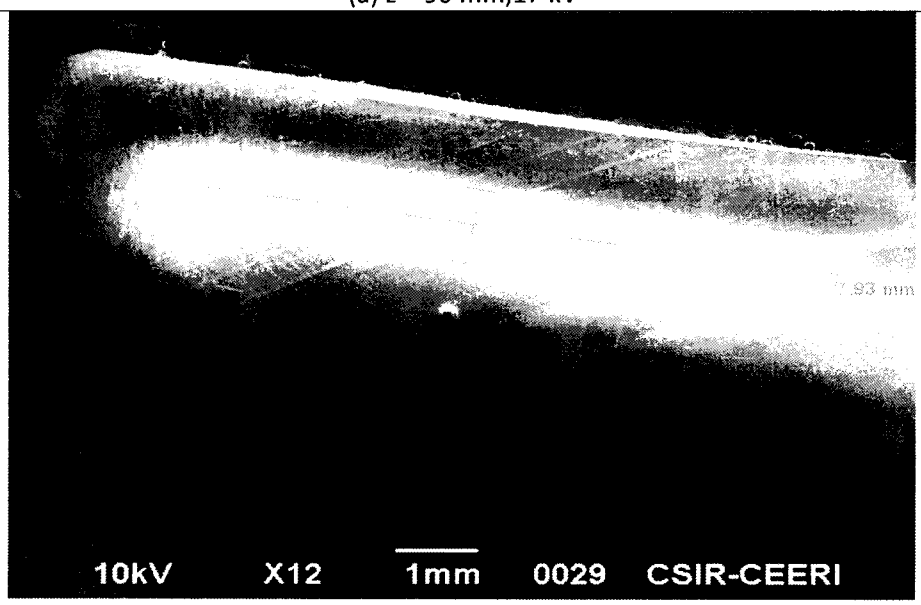
FIG.7

CSIR APPLICANTS

चेतन कुमार / CHETAN KUMAR
वैज्ञानिक/Scientist
आई. पी. यू (सी.एस.आई.आर.)
I.P.U. (C.S.I.R.)
14,संत्सग विहार मार्ग/14,Satsang Vihar Marg
नई दिल्ली-110067/ New Delhi-110067



(a) z = 90 mm,17 kV



(b) z = 143 mm, 17 kV

FIG.8

CSIR
APPLICANTS
चेतन कुमार / CHETAN KUMAR
वैज्ञानिक/Scientist
आई. पी. यू (सी.एस.आई.आर.)
I.P.U. (C.S.I.R.)
14,संत्सग विहार मार्ग/14,Satsang Vihar Marg
नई दिल्ली-110067/ New Delhi-110067

FIELD OF INVENTION

The present invention particularly relates to the development of sheet-beam plasma cathode electron (SPCE) gun and more particularly relates to the generation of sheet electron beam from the SPCE-Gun and its diagnostics using dielectric charging technique.

BACKGROUND OF INVENTION AND RELATED PRIOR ART

The developed SPCE-Gun is a cold cathode gun for sheet electron-beam generation. The SPCE-Gun consists of trigger unit, discharge unit and hollow cathode-anode assemblies. Two apertures cut in the rectangular sheet form in the inverted cup structure of hollow cathode-anode assemblies have been used for the geometrical construction. The discharge in the SPCE-Gun is an axially symmetric self-sustained transient low pressure gas discharge. In a hollow cathode cavity the plasma is a profuse source of electrons, which has been used to generate the sheet electron beam. Together with delayed voltage breakdown and a fast current rise an intense sheet electron beam has been generated from this device.

The sheet electron beam generation and its propagation has great impact in microwave sources due to its special virtues: 1) Higher net current can be transport at reduced space-charge field when it is used to produce high-power radiation. 2) Planar slow wave structure (SWS) driven by the sheet-beams with small dimensions are quite suitable for producing high-frequency microwaves. 3) Planar SWS is easier to be fabricated for smaller dimensions with micro-fabrication techniques. 4) The extended interaction area can eliminate the breakdown and can best avoid the loss of power. Hence the developed SPCE-Gun can also be a useful source for the sheet electron beam generation and its application in high frequency microwave sources.

In the present invention, apart from the novel developed SPCE-Gun, the sheet-beam characterization is also reported. For diagnosing the generated sheet electron beam, the electron beam has been extracted in a drift space region which is kept at lower pressure gaseous atmosphere. The electron beam is then allowed to fall on rectangular dielectric wafer of SiO_2 with dimension 28 mm x 20 mm x 1μm. The bombardment of the electron beam on the dielectric wafer leads to accumulate the electron charges on the dielectric surface and provides a unique method to diagnose the size and shape of the sheet electron beam. The images of the dielectric wafer before and after the single shot bombardment of the electron beam have been analyzed using scanning electron microscope (SEM), which confirms the shape of the electron beam in the sheet form.

Features and advantages of the present invention are brought out. Applications of the developed SPCE-Gun find wide scope in high frequency microwave generation, surface treatment, etc. Our description includes drawings and examples of specific embodiments, to give a broad representation of the invention. Various changes and modifications within the spirit and scope of the invention will become apparent while practicing the invention from the given description. The scope of the invention is not intended to be limited to the particular forms disclosed herewith. Basically it covers all the modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

Prior art search in literature and patent database provided t he following references.

Reference may be made to U. S. Pat. No. 4,873,468A issued on October 10, 1989 where sheet electron beam has been generated using thermionic cathode. The cathode mentioned in the above cited reference is a solid materialistic cathode with limited current density while the SPCE-Gun overcomes the limitations over thermionic cathodes with more current density. The operating life due to absence of hot cathode filament will also be more in the SPCE-Gun.

Reference may be made to U. S. Pat. No. 5,537,005, wherein the low pressure high current multi-aperture plasma cathode electron gun is described. A thermionic emitter has been used to create the electron beam from the plasma face. A magnetic system has been implemented to enhance the ionization efficiency. Nevertheless, it has also increased the overall complexity of the system.

A paper described by S. Tanaka et al (see S. Tanaka, et al , "Design and experimental results of a new electron gun using a magnetic multi-pole plasma generator", Review of Scientific Instruments, pp. 761-771, 1991) discusses about a new plasma electron gun. The structure includes three grid arrangements with Samarium-Cobalt (Sm-Co) permanent magnets attached to outer surface for formation of multi-pole configuration in a vacuum chamber. This reported gun is limited to produce beam current up to 4A.

Reference may also be made to U.S. Pat. No. 3,831,052 that is related to plasma-cathode structures. In this reference an electron beam is directed to the ionization of the gas in a laser cavity for maximum laser beam propagation.

A reference can be made to B. E. Carlsten et al (Stable two plane focusing for emittance dominated sheet-beam transport, Physical Review Special Topics- Accelerators and Beams, 062002:1-17, 2005) where an analytical study on complexity involved in transporting a sheet electron beam with the help of external magnetic has been reported. In fact, the transportation of sheet-beam in microwave tubes is quite challenging task due to complex magnetic system requirement. However, the SPCE-Gun has wide possibility for propagating a sheet electron beam without any assistance of external magnetic field due to the ion-channel formation in the drift space region. It can thus lead the SPCE-Gun highly applicable for the high frequency microwave sources.

Reference may be made to U.S. Pat. No.7,348,568 issued on Aug 24, 2006 where an apparatus for characterization of a high power beam has been described in detail. The apparatus comprises of a slit disk assembly made of an electrical conducting refractory material and having at least one radial slit extending through the slit disk assembly. There are other diagnostic methods, which utilizes a modified Faraday cup, and are illustrated in U.S. Pat. No. 5,382,895, U.S. Pat. No. 5,468,966, U.S. Pat. No. 5,554,926 and U.S. Pat. No. 5,583,427. These types of beam characterization systems are not much feasible for sheet-beam characterization in plasma filled drift space region and require innovative diagnostic technique.

OBJECTS OF THE INVENTION

The main objective of the present invention is to provide an alternative for conventional sheet electron beam generation for intense and high current density electron sheet beam.

Another objective of the present invention is to provide a novel diagnosing technique for the sheet electron beam characterization, which can also be applicable for characterization of electron beam in conventional microwave sources.

Still another objective of the present invention is to provide a technique for sheet beam generation and its propagation for distance more than 200 mm without any assistance of external magnetic field.

The development of the SPCE-Gun for the sheet electron beam generation, its diagnostics and its propagation in the plasma filled drift space without external magnetic field are hereby described.

BRIEF DESCRIPTION OF DRAWINGS

Figures 1 to 5 show the detailed drawings including different parts and components alongwith experimental results while figures 6 to 8 show the diagnosed sheet electron beam at different operating conditions. In the drawings, numbers and letters indicate corresponding parts. These figures accompany the following specifications.

FIG. 1 shows the schematic view of the SPCE-Gun along with its characterization set-up for sheet-beam focusing and defocusing location estimation inside the drift space region.

FIG. 2 shows the hollow cathode-anode geometry with aperture.

FIG. 3 shows the schematic view of three aligned isolated rectangular metallic sheets on Teflon base plate

FIG. 4 shows the experimental results from three aligned isolated rectangular metallic sheets diagnostic for current density estimation on the innermost sheet (10 mm X 2 mm) (a) for z = 190 mm at different applied gap voltages (b) percentage current density estimation for fixed applied gap voltage 17 kV for different locations inside the drift space region.

FIG. 5 shows the schematic view of the dielectric charging set-up for SEM based image analysis.

FIG. 6 shows SEM image of a SiO_2 dielectric wafer before sheet electron beam bombardment.

FIG. 7 shows sheet-beam SEM image for same location at two different breakdown voltages.

FIG. 8 sheet-beam SEM image for same applied breakdown voltage at two distinct locations inside the drift space.

SUMMARY OF THE INVENTION

The present invention relates to a novel sheet-beam plasma cathode electron (SPCE) gun which comprises of a vacuum compatible enclosed volume filled with ionizable and non-reactive gas; a ferroelectric cathode emitter for providing the seed electrons; a ceramic hollow cylinder of appropriate thickness for enclosing the plasma and providing the electrical insulation between the electrodes; sheet form apertures on the hollow cathode and hollow anode walls facing each other; separate discharge power supply and trigger power supply; a transparent drift space region for the sheet electron beam propagation and study.

The port outputs are connected to the ground **26** with the help of connecting wires **27.** Each wire is passing through the calibrated current transformers **28**. Currents have been measured through standard process corresponding to electrons collected by each rectangular sheet **18** with the help of oscilloscope **29**. The current densities for different metallic sheets **18** have also been calculated. These calculations have been performed at different axial location inside the drift space **11** to identify the focusing and defocusing points. The estimated current density on the innermost sheet (10 mm X 2 mm) for z = 190 mm at different applied gap voltages is shown in FIG. 4 (a) whereas FIG. 4 (b) shows the percentage current density estimation for fixed applied gap voltage 17 kV but at different locations inside the drift space region. These results show comparative assessment of beam size under different operating conditions.

FIG. 4(a) depicts that the current density on the inner most sheet has shown increasing trend with respect to the increase in the applied voltage. As the applied voltage increases the beam compression factor also increases, which subsequently result in to the higher current density at higher applied voltages. The sheet electron beam current density >1 kA/cm^2 has been achieved from the developed SPCE-Gun for ~20 kV applied voltage (see FIG. 4(a)). It has also been estimated that for the same circular aperture area in the plasma cathode electron gun with the same applied conditions, the current density is typically ~ 250 A/cm^2. The percentage current density on the innermost sheet with respect to the total current density is shown in FIG. 4(b), which clearly shows the sheet-beam focusing and defocusing points inside the drift space region at fixed applied voltage. This has helped to identify the focusing and defocusing locations inside the drift space region for the assessment of the beam.

Example-3

A technique for the sheet electron beam **10** diagnostic based on dielectric charging and the SEM based imaging has been developed. This technique provides an opportunity for the shape and size estimations of the sheet electron beam. In this technique, the thermally grown dielectric surface of 1 μm SiO_2 layer **30** on a rectangular sample of Si substrate (28 mm X 20 mm) **31** has been mounted on Teflon base **19** which is connected to axial motion feed through **22** inside the drift space region **11** and it is facing anode aperture **5**. The samples before and after the sheet electron bombardment from the developed SPCE-Gun has been analyzed using SEM based imaging. In fact, the bombardment of the electron beam on the dielectric surface (i.e., SiO_2) leads to accumulate the beam electrons, which has confirmed the electron beam in the sheet form from the SEM images of the electron beam bombarded samples. The obtained images has been utilized for the evaluation of the beam divergence and convergence, which has been compared and correlated by the current density estimation using three aligned isolated rectangular metallic sheets diagnostic arrangement.

The main advantages of the present invention are:

1. It gives a new way for generation of highly intense and focused sheet electron beam useful for various strategic and industrial applications.
2. No assistance of external magnetic field is required in the cathode-anode assembly as well as in the plasma filled drift space for the sheet-beam propagation.
3. It provides higher current density sheet electron beam generation over cylindrical beam of the same aperture area.