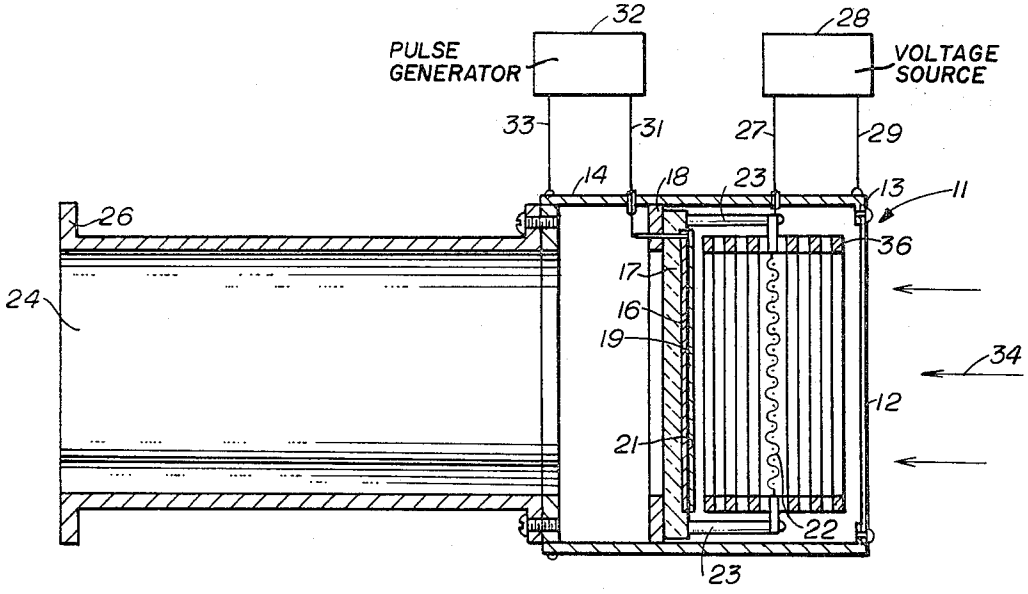
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DEVICE FOR FORMING REPLICA IMAGES OF PARTICLE DISTRIBUTIONS IN A PLASMA STREAM

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DEVICE FOR FORMING REPLICA IMAGES OF PARTICLE DISTRIBUTIONS IN A PLASMA STREAM

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ABSTRACT OF THE DISCLOSURE

Device for forming visible replica images indicative of instantaneous particle distributions in a plasma stream, including a semi-transmissive element for attenuating the plasma stream, and having an electrically polarized grid arranged to repel undesired charged particles from the attenuated stream and converting selected particles impinging thereon into a replica stream of electrons emerging therefrom. A scintillator screen is arranged to intercept portions of the replica electron stream, which are accelerated through light excluding means by means of an electrostatic field applied between said grid and scintillator to provide said replica image.

The present invention relates generally to devices for observing nuclear particles and more particularly to a device for forming visible replica images indicative of the spatial distribution of streaming nuclear particles termed "a camera" hereinafter, for simplicity.

As more is learned about the behavior of nuclear particles, the potential benefits derivable from atomic energy is greatly increased. One of the characteristics of nuclear particles not completely understood is particle interaction in the presence of electromagnetic fields, for example, encountered in the generation and utilization of nuclear particle beams and magnetically confined high temperature plasmas. In confining plasmas, various types of instability problems have been encountered which to a large extent have prevented the full realization of the potential of high temperature plasmas. As is well known, most of the instabilities result in the extremely rapid movement of the plasma across the magnetic confining field to eventually encounter the container walls and become destroyed. By observing the spatial distribution of the plasma particles and the rapid movement of the plasma, the characteristics of the various types of instabilities can be investigated and studied. In the present art, there is usually insufficient radiation from the plasma for conventional time-resolved photographic techniques such as those using a Kerr cell as a shutter. Furthermore, even in cases where the radiation is sufficient, interpretation of the data often is complicated by intense radiation from sources other than the plasma under observation. Another difficulty is encountered in pulse operated plasma systems and unstable plasmas where investigations are complicated in that the plasma distribution is not reproducible. In such a case, a composite picture built up of data from several operations gives only a statistical average.

The present invention operates independently of the light or other radiations from the plasma and provides a time resolved image whose intensity is a function of the instantaneous plasma flux being viewed. As a brief description, the invention approaches the solution to the problems set forth supra in the following manner. A grid placed in the path of a stream of nuclear particles is selectively biased either positively to repel positively

charged particles and pass negatively charged particles or neutrals, or biased negatively to repel negatively charged particles and pass positively charged particles and neutrals. Where particles other than electrons are to be observed, it is preferable to convert them to secondary electrons. These electrons, either secondary or primary, are distributed in facsimile to the particle stream cross section. By electrostatically accelerating these electrons for example, through a light-impervious, high-energy-electron pervious sheet to impinge on an energetic-particle-to-light converter, e.g., plastic scintillator, an image is produced which is a replica of the stream cross-section. An ordinary light-sensitive camera can then be used to record the image. The light-impervious, high-energy-electron pervious sheet serves to eliminate the effects of any accompanying undesirable radiation which would otherwise make it difficult if not impossible to obtain and record the image of the distribution of the particles of the nuclear particle stream.

The camera of the present invention further includes the feature of an extremely fast electronic shutter capable of shutter speeds in the nanosecond time range. The electronic shuttering action is obtained by controlling the electrostatic acceleration of the electrons which are directed to impinge on the energetic-particle-to-light converter. As is known, such conversion requires that the impinging particles have an energy above a minimum threshold level. Rapid shuttering is obtained by maintaining the electrostatic accelerating field at a level below that required to impart sufficient energy to the electrons to initiate the conversion, and at a predetermined time increase the accelerating field for a selected period to a level whereby the electrons are accelerated above the energy threshold level necessary for initiating the conversion. As a consequence of the rapid shutter characteristic of the present camera, an image representative of a substantially instantaneous distribution of selected particles of a nuclear particle stream can be obtained.

Accordingly, it is an object of the present invention to provide a device for observing the cross-sectional distribution of particles in a stream of nuclear particles.

A further object of the present invention is to provide a replica of the distribution of particles in a plasma stream, which replica is capable of being photographed.

Further, it is an object of the present invention to permit the application of time resolved photographic techniques to the study of plasmas.

Still another object of the present invention is to obtain plasma stream cross-sectional particle distribution data which is not complicated by radiation from sources other than the plasma stream under observation.

Another object is to provide a time resolved image whose intensity is a function of the instantaneous particle flux of the plasma being viewed.

It is yet another object of the present invention to provide a time resolved replica of particle distribution in a plasma stream.

More particularly, it is an object of this invention to capture a replica of an instantaneous cross-section of a plasma stream whose cross-section varies with time and is not reproducible.

The means of achieving these and other objects will become more apparent from the following detailed description of a preferred embodiment of the present invention, taken in conjunction with the accompanying drawing which is a cross-sectional elevation view of one preferred embodiment of the present invention.

The plasma camera, i.e., image-forming device, of the present invention is employed to selectively observe the spatial distribution of any of the various nuclear particles, e.g., positive and negative ions, electrons, or neutral

particles, that may be found in a stream of nuclear particles. The camera obtains an image of the spatial distribution of the nuclear particles of a particle stream by linearly converting the energy of selected particles to light without altering the relative positions of the selected particles in the beam. The light thus generated is an indication of the spatial distribution of the selected particles of the stream, and by observing or recording this light, the particle distribution of the stream can be analyzed.

To accomplish this observation, the plasma camera of the present invention takes advantage of the coaction of the three principal sections comprising the camera: A particle selector, an image generator, and an image recorder. The particle selector is positioned to receive a stream of nuclear particles and functions to selectively extract therefrom the particles to be analyzed. In its simpliest form, the particle selector accelerates and transmits selected particles from the particle stream to the image generator without altering the particles' positional relationship while simultaneously impeding the transmission of any accompanying undesired particles. However, in the analysis of high density particle streams, it is most beneficial to attenuate the density of the particle stream prior to generating an image reproduction of the selectively transmitted particles. As will be set forth in more detail hereinafter, this can be accomplished by positioning a semi-pervious particle shield in front of the surface of the image selector facing the impinging particle stream.

The selected particles are accelerated and directed to impinge on an energetic-particle-to-light converter, i.e., image generator, wherein light is emitted therefrom in proportionate relation to the number of impinging particles to form an image of the cross-sectional distribution of the particles in the nuclear particles stream. In those cases where the plasma camera is employed to observe selected particles in the presence of extensive background light, e.g., particles originating from a plasma, the image generator may be shielded from the undesired light by means of a suitable particle-pervious-light-impervious shield. The light emitted by the image converter is an accurate representation of the spatial distribution of the selected particles in the particle stream and may permanently be recorded by the simplest of light-sensitive cameras.

As set forth hereinbefore, the present camera includes the feature of an extremely fast electronic shutter. Hence, in those cases where it is desired to observe all types of particles of a particle stream including, for example, both positively and negatively charged particles, the particle selector could be synchronously operated with the shutter to obtain sequential observations of the various types of particles. More specifically, the particle selector would be operated to pass first one type of particles than another. Simultaneously, the accelerating electrostatic field would be adjusted to impart sufficient energy to the selected particles whereby upon impingement upon the image generator light is produced.

Although the plasma camera may take the form of various embodiments in accordance with the present invention, the specific embodiment contemplated as best carrying out the invention is set forth in the immediately following description and accompanying drawing. Such specific embodiment may be employed, for example, by being coupled at one end of an accelerator, fusion device such as a magnetic mirror machine, etc., which is capable of delivering a charged particle or plasma beam.

In the figure, camera **11** is adapted to operate in an evacuated atmosphere and is comprised of an electrically conducting particle semi-transmissive plate **12** capping a first end **13** of an electrically conductive housing **14**. End **13** of housing **14** is adapted to allow camera **11** to be mounted hermetically to a particle stream source (not shown). A plastic scintillator sheet **16** or other suitable energetic-particle-to-light conversion means is mounted on transparent backing plate **17** which in turn is secured to a mounting ring **18** secured within housing **14** spaced apart substantially parallel to plate **12**. A light-impervious high-energy-electron-pervious element **19** is disposed between scintillator **16** and plate **12**. This may be a two thousand Angstrom aluminum coating insulatingly disposed on the surface **21** of scintillator **16** facing plate **12**. A grid **22** having a surface which is electron emissively responsive to impinging particles, is mounted by stand-off insulators **23** between, parallel to, and insulatingly apart from scintillator **16** and plate **12**. The second end **24** of housing **14** is provided with mounting means **26** to receive appropriate light recording means, e.g., a conventional light sensitive camera (not shown). Plate **12** and housing **14** are electrically grounded and grid **22** is connected via wire **27** to a variable voltage source **28** having a range, e.g. of ± 300 volts. Source **28** is referenced to housing **14** via wire **29**. Metal film **19** is electrically connected via conductor **31** to a high voltage pulse generator **32** which is referenced to housing **14** via wire **33**.

In practice, 5/8 inch Lucite has been used as the transparent backing plate **17**, Lucite being an acrylic resin, e.g., polymethyl methylacrylate, manufactured by E. I. du Pont de Nemours and Company. The scintillator can be polystyrene containing terphenyl or any of the other numerous scintillators used in high energy physics research.

The operation of camera **11** will be described with reference to its use to observe particles from a high temperature magnetically confined plasma which includes both positively and negatively charged particles. A stream of plasma particles **34** originating from a high temperature plasma moving in an evacuated atmosphere is directed to impinge on semi-transmissive plate **12**. This plate **12**, comprised of a stack of three TV color masks, passes approximately one-thousandth of the plasma into the chamber between grid **22** and plate **12**. Although quantitative figures are unavailable, it has been observed in practice that voltage breakdown will occur between grid **22** and sheet **19** if the plasma stream density is not reduced utilizing a means such as plate **12**. With a negative voltage on grid **22**, the electrons in the plasma are repelled and the ions are accelerated to impinge on the electron emission grid **22**. Those ions striking the grid **22** release secondary electrons. With a positive voltage on grid **22** the ions in the plasma are repelled and the secondary electrons therein are accelerated through the grid **22**. In either case, electrons appearing at grid **22** are distributed in replica to the cross-sectional distribution of the plasma stream particles of the polarity which are attracted to the grid.

A positive high voltage pulse, e.g., 20 kv. applied for 0.2–0.4 microsecond, is imposed on film **19** to accelerate those electrons which appear at grid **22** towards film **19**. Note that this film **19** serves as a light shield and functions as a camera shutter which opens when subjected to the high voltage positive pulse. This high voltage pulse imparts sufficient energy to some of these electrons emerging from grid **22** so that they are able to penetrate metal film **19** and produce point source fluorescence in scintillator **16**. In preferred practice, the image produced on the scintillator **16** may then be recorded by ordinary photographic techniques or may be sensed by other appropriate light sensing means, e.g., an array of photocells. The most important single feature of this invention is the fact that this image has a cross section which is substantially identical to the spatial distribution of those electrons or ions flowing in that portion of the plasma stream **34** which is viewed by camera **11** a moment before the high voltage pulse is applied to plate **19**. It is to be noted that particle stream cross section size that can be viewed by camera **11** is limited only by the effective size of camera **11**. The effective size of camera **11** is determined by diameter of unimpeded path from plate **12** to the camera attached at the second end **24** of housing **14**.

Although to date use of the camera **11** of the present invention has not been extended beyond observation of streams of charged particles, it conceivably may be used to observe streams of uncharged particles, provided a significant number of the particles possess energy sufficient to cause secondary emission of electrons from grid **22**. In such a case, grid **22** may be well placed at ground potential, there being no requirement to select particles of a particular polarity. However, if streams of charged particles are to be analyzed which include positively and negatively charged and neutral particles, a second grid having a mesh selected to allow transmission of all particles would be interposed between grid **22** and plate **12**. This second grid would serve as a first stage of selectivity with grid **22** serving as a second stage of selection and electron generation. For example, to observe neutral particles from a stream including charged particles, the first grid would be charged negatively to repel the negatively charged particles, and grid **22** would be charged positively to repel the positively charged particles and allow only neutrals to impinge grid **22** and produce secondary electrons.

In the figure, there are shown six circular metallic field aligning rings **36** insulated apart from each other and from grid **22**. In practice, these rings **36** serve merely to provide a uniform electric field across the face of the scintillator **16** to prevent image distortion. It is felt that use of these rings **36** is well within the skill of the art and their use may be desirable where beam spreading problems are likely to be encountered.

As an aid to those who wish to practice the present invention, there is provided below a table of relevant design values:

Outside diameter of housing **14**	12 inches.
Effective camera diameter	9.5 inches.
Front plate **12**	Stack of 3 TV color masks.
Front plate **12** transmission	0.72×10^{-3}.
Grid **22**	58% electron transmission. 52-mesh stainless steel.
Number of field aligning rings **36**	6.
Field aligning ring **35** separation	0.25 inch.
Front plate **12** to grid **22** separation	1 inch.
Grid **22** to scintillator **16** separation	Do.
Depth of metallic coating material **19**	2000 angstroms.
Grid **22** bias	−300–+300 volts.
High voltage potential at accelerator electrode **19**	20 kv. (approximately).
Optical camera	Speed-Graphic Pacemaker with 15 inch *f*5.6 Wollensak lens and Polaroid film back.

As this plasma camera has been used to date, the incident plasma density has not exceeded 5×10^{12} ions/cm.^{3}. With these ion densities, three seventeen-inch TV masks with 0.01-inch holes, obtained from Buckbee Mears, Inc., St. Paul, Minn., have been found to work well as the attenuating front plate **12**.

It may be noted that the term "plasma stream" as used in this application includes any stream of charged particles and is not necessarily limited to those situations where there is a net zero charge, i.e., the positive charges equal in number to the negative charges.

Although the invention has been described above in terms of a preferred embodiment, it should be construed liberally, and it will be understood that various changes and modifications may be made without departing from the spirit and scope of the invention. For example, by providing an appropriate particle-transmissive electrode in the position now occupied by the semitransmissive plate **12**, it may be possible to eliminate that plate and also the above-mentioned camera housing **14**. Also, should there be no troublesome light effects accompanying the particle beam, it may be possible to omit the light impervious metallic plate **19** from the surface of the scintillator **16**. As a further modification, it may be considered that means other than a light sensitive camera may be used to sense and/or record the light image appearing on the above-mentioned scintillator **16**. Furthermore, should the plasma stream contain particles of a single polarity, it may be unnecessary to provide the above-described grid means **22** to electrostatically select and reject selected particles.

Hence, the scope of the present invention is intended to be limited only by the terms of the appended claims.

What is claimed is:

1. Device for forming visible image replicas indicative of the spatial distribution of energetic particles in a plasma stream in an evacuated region, comprising, in combination:

(a) an elongated double-ended electrically conductive tubular housing in communication with said evacuated region, and arranged for entry of said plasma stream at one end for passage longitudinally therethrough;

(b) perforate semi-transmissive, electrically conductive plate means disposed across said first end of said housing to uniformly reduce and attenuate the particle density of said plasma stream passing therethrough;

(c) a grid disposed in insulated, spaced relation in said housing transversely across said attenuated plasma particle stream;

(d) a variable bipolar voltage source electrically connected between said plate and said grid for applying an electrostatic potential therebetween to repel particles of undesired polarity and to select and accelerate particles of the desired polarity from said attenuated plasma particle stream to impinge upon one side and cause emission of a corresponding replica stream of secondary electrons from the second side of said grid;

(e) sheet phosphor means disposed in spaced relation to the second side of said grid in said housing;

(f) second electrode means disposed across said tubular housing between said grid means and phosphor means, said second electrode means being pervious to high energy electrons and impervious to light; and

(g) voltage supply means connected between said grid and said second electrode means to apply an electrical pulse thereto for accelerating said secondary electrons to a sufficiently high energy level to penetrate said second electrode means and impinge upon said phosphor means.

2. Apparatus according to claim **1** for sampling high density plasma particle beams, further defined in that said first pervious electron means has a porosity sufficient to attenuate said beam to less than about one one-thousandth of the original density thereof.

3. Apparatus according to claim **1**, further defined in that voltage supply means is a voltage pulse generator for impressing upon said grid and secondary electrode means a voltage pulse of fractional microsecond duration to accelerate said secondary electrons during a preselected time interval exclusively.

4. Apparatus according to claim **3**, wherein said phosphor means comprises a sheet scintillator plastic material, said second electrode means is a thin metallic film deposited on the first side of said sheet scintillator material, and a transparent backing plate is disposed at the second side of said sheet scintillator material in capping relation to said housing.

5. Apparatus according to claim 4, wherein said perforate semitransmissive plate means comprises three superposed color television masks with 0.01-inch holes.

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