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(54) Title: SECONDARY ELECTRON DETECTOR FOR USE IN A GASEOUS ATMOSPHERE			
(57) Abstract The invention provides for a device and method for generating, amplifying, and detecting secondary electrons from a surface of a sample. The device contains a vacuum envelope (1) having a pressure limiting aperture (2), a charged particle beam source (3), means (4, 5) for focusing and directing the charged particle beam through the aperture (2) to a sample mounted on a sample platform (6) located in a gaseous environment outside of the vacuum envelope (1), an electrode (7) located outside of the vacuum envelope (1) and close to the sample platform (6). In operation, the electrode is biased by a voltage source (8) to accelerate secondary electrons emitted by the sample so that they collide with gas molecules to produce negative charge carriers which multiply by further collisions. The negative charge carriers are collected by the electrode (7) to produce a current which is amplified by a current amplifier (9) and output to a detector (10).			

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SECONDARY ELECTRON DETECTOR FOR USE IN A GASEOUS ATMOSPHERE

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Background of the Invention

To obtain an image of a sample by electron microscopy,
10 the sample is scanned with an electron beam and the electrons reflected or emitted from the sample are detected. The sample is usually scanned within a vacuum to maintain the vacuum integrity of the electron
15 optics column and to permit the operation of electron detectors.

Scanning samples with an electron beam within a vacuum
20 presents many problems. Biological specimens cannot survive in a vacuum for the length of time needed to obtain an accurate image. Wet specimens experience evaporation of their fluid content in the vacuum before
25 an accurate image can be obtained. Objects that outgas at high vacuum require special consideration. Nonconducting samples accumulate a surface charge which obscures the details of the sample's surface and lowers
30 the resolution of the image obtained. To avoid the problem of accumulating charge samples can be coated with a thin layer of metal to enable them to conduct

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away the charge. The metal coating however, can damage samples such as semiconductors and therefore often eliminates the possibility of nondestructive examination.

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In an early work on environmental microscopy (W.C. Lane, "The Environmental Control Stage", Scanning Electron Microscopy/1970, pp. 43-48) Lane used an Everhart-Thornley system (a biased scintillator/photomultiplier) to detect electrons emitted from a specimen in a gaseous environment in a scanning electron microscope. He claimed that the secondary electrons emitted from the specimen surface ionized the cover gas (water vapor) producing free electrons that were then collected by the Everhart-Thornley detector. He concluded that, through this mechanism, the gas was responsible for amplification of the secondary electron signal prior to scintillation events in the Everhart-Thornley detector.

25 Lane's claims and conclusions are invalid, because useful amplification of the secondary electron signal was impossible in his experimental setup. The ionization energies (thresholds) of both constituents of 30 water, hydrogen and oxygen, are too high to be ionized by the emitted secondary electrons and the claimed amplification process can only occur in the area immediately above the specimen where there is substantial

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gas pressure. The bias field of the Everhart-Thornley system cannot raise the energy of the secondary electrons sufficiently to allow for secondary electron signal amplification. The secondary electrons must 5 acquire enough energy to ionize the gas while still in the gas filled region and the metal collar around the specimen reduces the strength of the bias field in this region. The gas filled region also only takes up a 10 very small fraction of the vertical distance between the detector and the specimen and the secondary electrons can therefore only acquire a very small fraction 15 of the total maximum potential difference between the detector and specimen before leaving the gas filled region. Thus the electron energies could not be raised to a high enough level to ionize the gas inside the 20 collar.

The most likely explanation of Lane's observations of 25 gas induced signal amplification is that higher energy emitted backscattered electrons ionized the gas in the collar. The resulting ionization products (electrons and/or ions) were detected by the scintillator.

30 Danilatos, Micron and Microscopica Acta 14(4):307-318 (1983) discloses that gas can act as a detection medium (citing the above Lane reference) using a conventional detector, and that it is possible to collect 35

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charge carriers with a low bias, or even no bias at all, on the detector. Danilatos says,

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"The scope and efficiency of the gaseous detector device depends on a number of variables such as: (a) nature of the gas, (b) pressure of the gas, (c) temperature of the gas, (d) electrode configuration, (e) electrode bias, (f) accelerating voltage, (g) intensity of the primary beam current, (h) scanning speed, (i) nature of specimen."

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Danilatos concludes that a detailed study is needed to understand various ion pair phenomena in the system.

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"...it was not possible to obtain a secondary electron image for a direct comparison. Alternatively some sort of trajectory contrast might be present. Furthermore, no external bias was applied, and it is not known to what extent the specimen and the attached electrode might have been self-biased. The results presented indicate that additional information can be obtained in the new system but the precise nature of this information requires further investigation."

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Summary of the Invention

The present invention concerns a device for generating, amplifying and detecting secondary electrons from a 5 surface of a sample. The device comprises a vacuum envelope having a pressure limiting aperture, a charged particle beam source located within the vacuum envelope and capable of emitting a charged particle beam, focusing means located within the vacuum envelope 10 capable of directing a charged particle beam emitted by the charged particle beam source through the pressure limiting aperture, sample platform means disposed outside 15 the vacuum envelope, capable of maintaining a sample enveloped in gas at a pressure of at least .05 torr in registration with the pressure limiting aperture such that a surface of the sample may be 20 exposed to a charged particle beam emitted from the charged particle beam source and directed through the pressure limiting aperture, an electrode disposed 25 outside of the vacuum envelope and positioned within between about 1 and about 200 mm from the sample platform means such that secondary electrons emitted from a 30 surface of a sample located on the sample platform means and exposed to a charged particle beam emitted from the charged particle beam may come into contact with it, a voltage source connected between the electrode and an electrical ground capable of maintaining 35

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an electrical potential difference between the electrode and the sample platform means of greater than about 50 volts and less than about 2000 volts, the electrode potential being positive relative to the sample platform means potential so as to accelerate secondary electrons emitted from a surface of a sample located on the sample platform means with an electric field of sufficient strength so as to cause emitted secondary electrons to collide with gas molecules and produce negative charge carriers which can subsequently produce additional negative charge carriers through multiple collisions with other gas molecules resulting in a number of negative charge carriers greater than and proportional to the number of original secondary electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical discharging or arcing, a current amplifier connected to the electrode and current detection means connected between the current amplifier and an electrical ground.

The present invention also provides a scanning electron microscope which comprises a vacuum envelope having a pressure limiting aperture, an electron beam source located within the vacuum envelope and capable of emitting an electron beam, focusing means located within the vacuum envelope and capable of directing an

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electron beam emitted by the electron beam source through the pressure limiting aperture, electron beam scanning means located within the vacuum envelope and capable of scanning an electron beam emitted by the 5 electron beam source across the diameter of the pressure limiting aperture, sample platform means disposed outside the vacuum envelope and capable of maintaining a sample enveloped in gas at a pressure of 10 at least .05 torr in registration with the pressure limiting aperture such that a surface of the sample may be exposed to an electron beam emitted from the 15 electron beam source and directed through the pressure limiting aperture, an electrode disposed outside of the vacuum envelope and positioned within between about 1 and 200 mm of the sample platform means such that 20 secondary electrons emitted from a surface of a sample located on the sample platform means and exposed to an electron beam emitted from the electron beam source may come into contact with it, a voltage source connected 25 between the electrode and an electrical ground and capable of maintaining an electrical potential difference between the electrode and the sample platform means of greater than about 50 volts and less 30 than about 2000 volts, the electrode potential being positive relative to the sample platform means potential, so as to accelerate secondary electrons 35 emitted from a surface of a sample located on the

sample platform means with an electric field of sufficient strength so as to cause emitted secondary electrons to collide with gas molecules and produce negative charge carriers which can subsequently produce 5 additional negative charge carriers through multiple collisions with other gas molecules resulting in a number of negative charge carriers greater than and proportional to the number of original secondary 10 electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical discharging or arcing, a current amplifier connected to the electrode and current detection means 15 connected between the current amplifier and an electrical ground.

20 The present invention also concerns a method for generating, amplifying and detecting secondary electrons emitted from a surface of a sample. The method comprises scanning the surface of the sample under a 25 suitable gaseous pressure with a charged particle beam having sufficient energy so as to cause secondary electrons to be emitted from the surface of the sample. The secondary electrons are accelerated with an 30 electric field of sufficient strength so as to cause them to collide with gas molecules and produce negative charge carriers which can subsequently produce 35 additional negative charge carriers through multiple

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collisions with other gas molecules resulting in a
number of negative charge carriers greater than and
proportional to the number of original secondary
electrons, the strength of the electric field being
5 sufficiently low so as to avoid catastrophic elec-
trical discharging or arcing. The electrical current
resulting from electrons and ionized gas molecules is
10 detected, thereby detecting a signal proportional to
the number of secondary electrons emitted from the
surface of the sample.

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Brief Description of the Figure

Fig. 1 is a schematic cross-sectional view of a device
which embodies the present invention in a particular
5 form.

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Detailed Description of the Invention

The present invention provides a device for generating, amplifying and detecting secondary electrons from a surface of a sample. Referring in more particularity to Figure 1, the invention comprises a vacuum envelope 1 having a pressure limiting aperture 2, a charged particle beam source 3 located within the vacuum envelope and capable of emitting a charged particle beam, focusing means 4 located within the vacuum envelope capable of directing a charged particle beam emitted by the charged particle beam source through the pressure limiting aperture, sample platform means 6 disposed outside the vacuum envelope, capable of maintaining a sample enveloped in gas at a pressure of at least .05 torr in registration with the pressure limiting aperture such that a surface of the sample may be exposed to a charged particle beam emitted from the charged particle beam source and directed through the pressure limiting aperture, an electrode 7 disposed outside of the vacuum envelope and positioned within between about 1 and about 200 mm from the sample platform means such that secondary electrons emitted from a surface of a sample located on the sample platform means and exposed to a charged particle beam emitted from the charged particle beam may come into contact with it, a voltage source 8 connected between the elec-

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trode and an electrical ground capable of maintaining an electrical potential difference between the electrode and the sample platform means of greater than about 50 volts and less than about 2000 volts, the 5 electrode potential being positive relative to the sample platform means potential so as to accelerate secondary electrons emitted from a surface of a sample located on the sample platform means with an electric 10 field of sufficient strength so as to cause emitted secondary electrons to collide with gas molecules and produce negative charge carriers which can subsequently 15 produce additional negative charge carriers through multiple collisions with other gas molecules resulting in a number of negative charge carriers greater than and proportional to the number of original secondary 20 electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical discharging or arcing, a current amplifier 9 connected to the electrode and current detection 25 means 10 connected between the current amplifier and an electrical ground. Within this application, negative charge carriers includes ionized gas molecules and free 30 electrons.

In one embodiment of the invention the charged particle beam source is an electron beam source. In another 35 embodiment of the invention the electrode is positioned

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approximately 10 mm from the sample platform means. In yet another embodiment of the invention the voltage source is adjustable.

5 The present invention also provides a scanning electron microscope. Referring in particularity to Figure 1, the scanning electron microscope comprises a vacuum envelope 1 having a pressure limiting aperture 2, an
10 electron beam source 3 located within the vacuum envelope and capable of emitting an electron beam, focusing means 4 located within the vacuum envelope and capable of directing an electron beam emitted by the
15 electron beam source through the pressure limiting aperture, electron beam scanning means located within the vacuum envelope and capable of scanning an electron beam emitted by the electron beam source across the
20 diameter of the pressure limiting aperture, sample platform means 6 disposed outside the vacuum envelope and capable of maintaining a sample enveloped in gas
25 at a pressure of at least .05 torr in registration with the pressure limiting aperture such that a surface of the sample may be exposed to an electron beam emitted from the electron beam source and directed through the
30 pressure limiting aperture, an electrode 7 disposed outside of the vacuum envelope and positioned within
35 between about 1 and 200 mm of the sample platform means such that secondary electrons emitted from a

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surface of a sample located on the sample platform means and exposed to an electron beam emitted from the electron beam source may come into contact with it, a voltage source 8 connected between the electrode and an 5 electrical ground and capable of maintaining an electrical potential difference between the electrode and the sample platform means of greater than about 50 volts and less than about 2000 volts, the electrode 10 potential being positive relative to the sample platform means potential, so as to accelerate secondary electrons emitted from a surface of a sample located on the sample platform means with an electric field of 15 sufficient strength so as to cause emitted secondary electrons to collide with gas molecules and produce negative charge carriers which can subsequently produce 20 additional negative charge carriers through multiple collisions with other gas molecules resulting in a number of negative charge carriers greater than and proportional to the number of original secondary 25 electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical discharging or arcing, a current amplifier 9 connected to the electrode and current detection means 30 10 connected between the current amplifier and an electrical ground.

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In one embodiment of the invention the electrode is positioned approximately 10 mm from the sample platform means. In another embodiment of the invention the voltage source is adjustable. In yet another embodiment 5 of the invention the electron beam source is capable of emitting an electron beam with energy within the range from about 1 kiloelectron volt to about 40 kiloelectron volts.

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The present invention also concerns a method for generating, amplifying and detecting secondary electrons emitted from a surface of a sample. The method 15 comprises scanning the surface of the sample under a suitable gaseous pressure with a charged particle beam having sufficient energy so as to cause secondary 20 electrons to be emitted from the surface of the sample. The secondary electrons are accelerated with an electric field of sufficient strength so as to cause them to collide with gas molecules and produce negative 25 charge carriers which can subsequently produce additional negative charge carriers through multiple collisions with other gas molecules resulting in a 30 number of negative charge carriers greater than and proportional to the number of original secondary electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical 35 discharging or arcing. The electrical current

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resulting from electrons and ionized gas molecules is detected, thereby detecting a signal proportional to the number of secondary electrons emitted from the surface of the sample.

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In one embodiment of the invention the charged particle beam is an electron beam. In another embodiment of the invention the electron beam has energy within the range 10 from about 1 kiloelectron volt to about 40 kiloelectron volts. In yet another embodiment of the invention the gaseous pressure is within the range from about .05 torr to about 20 torr. In still another embodiment of the invention the electric field comprises an electrical potential of at least about 50 volts and 15 less than about 2000 volts.

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What is claimed is:

1. A device for generating, amplifying and detecting secondary electrons from a surface of
5 a sample which comprises:

a) a vacuum envelope having a pressure
10 limiting aperture;

b) a charged particle beam source located
15 within the vacuum envelope and capable
of emitting a charged particle beam;

c) focusing means located within the vacuum
20 envelope and capable of directing a
charged particle beam emitted by the
charged particle beam source through the
pressure limiting aperture;

25 d) sample platform means, disposed outside
the vacuum envelope, capable of maintaining a sample enveloped in gas at a
30 pressure of at least .05 torr in
registration with the pressure limiting
aperture such that a surface of the
sample may be exposed to a charged
35 particle beam emitted from the charged

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particle beam source and directed through the pressure limiting aperture;

5 e) an electrode disposed outside of the vacuum envelope and positioned within between about 1 and about 200 mm from the sample platform means such that secondary electrons emitted from a surface of a sample located on the sample platform means and exposed to a charged particle beam emitted from the charged particle beam source may come 10 15 into contact with it;

20 f) a voltage source, connected between the electrode and an electrical ground, capable of maintaining an electrical potential difference between the electrode and the sample platform means of 25 greater than about 50 volts and less than about 2000 volts, the electrode potential being positive relative to the sample platform means potential so as to 30 accelerate secondary electrons emitted from a surface of a sample located on the sample platform means with an electric field of sufficient strength so 35

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as to cause emitted secondary electrons to collide with gas molecules and produce negative charge carriers which can subsequently produce additional
5 negative charge carriers through multiple collisions with other gas molecules resulting in a number of negative charge carriers greater than and proportional to the number of original secondary electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical discharging or arc-
10 ing;
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20 g) a current amplifier connected to the electrode; and
h) current detection means connected between the current amplifier and an electrical ground.
25
30 2. A device of claim 1 wherein the charged particle beam source is an electron beam source.

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3. A device of claim 1 wherein the electrode is positioned approximately 10 mm from the sample platform means.
- 5 4. A device of claim 1 wherein the voltage source is adjustable.
- 10 5. A scanning electron microscope which comprises:
 - 15 a) a vacuum envelope having a pressure limiting aperture;
 - b) an electron beam source located within the vacuum envelope and capable of emitting an electron beam;
 - 20 c) focusing means located within the vacuum envelope and capable of directing an electron beam emitted by the electron beam source through the pressure limiting aperture;
 - 25 d) electron beam scanning means located within the vacuum envelope and capable of scanning an electron beam emitted by the electron beam source across the
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diameter of the pressure limiting aperture;

5 e) sample platform means, disposed outside the vacuum envelope, capable of maintaining a sample enveloped in gas at a pressure of at least .05 torr in registration with the pressure limiting aperture such that a surface of the sample may be exposed to an electron beam emitted from the electron beam source and directed through the pressure limiting aperture;

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15 f) an electrode disposed outside of the vacuum envelope and positioned within between about 1 and about 200 mm of the sample platform means such that secondary electrons emitted from a surface of a sample located on the sample platform means and exposed to an electron beam emitted from the electron beam source may come into contact with it;

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35 g) a voltage source, connected between the electrode and an electrical ground,

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capable of maintaining an electrical potential difference between the electrode and the sample platform means of greater than about 50 volts and less than about 2000 volts, the electrode potential being positive relative to the sample platform means potential, so as to accelerate the secondary electrons with an electric field of sufficient strength so as to cause the secondary electrons emitted from the sample to collide with gas molecules and produce negative charge carriers which can subsequently produce additional negative charge carriers through multiple collisions with other gas molecules resulting in a number of negative charge carriers greater than and proportional to the number of original secondary electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical discharging or arcing;

h) a current amplifier connected to the electrode; and

i) current detection means connected between the current amplifier and an electrical ground.

5 6. A scanning electron microscope of claim 5 wherein the electrode is positioned approximately 10 mm from the sample platform means.

10 7. A scanning electron microscope of claim 5 wherein the voltage source is adjustable.

15 8. A scanning electron microscope of claim 5 wherein the electron beam source is capable of emitting an electron beam with energy within the range from about 1 kiloelectron volt to about 40 kiloelectron volts.

20 9. A method for generating, amplifying and detecting secondary electrons from a surface of a sample which comprises:

25 30 35 a) scanning the surface of the sample under a suitable gaseous pressure with a charged particle beam having sufficient energy so as to cause secondary electrons to be emitted from the surface of the sample;

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5 b) accelerating the secondary electrons with an electric field of sufficient strength so as to cause them to collide with gas molecules and produce negative charge carriers which can subsequently produce additional negative charge carriers through multiple collisions with other gas molecules resulting in a number of negative charge carriers greater than and proportional to the number of original secondary electrons, the strength of the electric field being sufficiently low so as to avoid catastrophic electrical discharging or arc-
10 ing; and

15 c) detecting electrical current resulting from electrons and ionized gas molecules, thereby detecting a signal proportional to the number of secondary electrons emitted from the surface of the sample.

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10. A method according to claim 9, wherein the charged particle beam is an electron beam.

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11. A method according to claim 10, wherein the electron beam has energy within the range from about 1 kiloelectron volt to about 40 kilo-electron volts.

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12. A method according to claim 9, wherein the gaseous pressure is within the range from about .05 torr to about 20 torr.

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13. A method according to claim 9, wherein the electric field comprises an electrical potential of at least about 50 volts and less than about 2000 volts.

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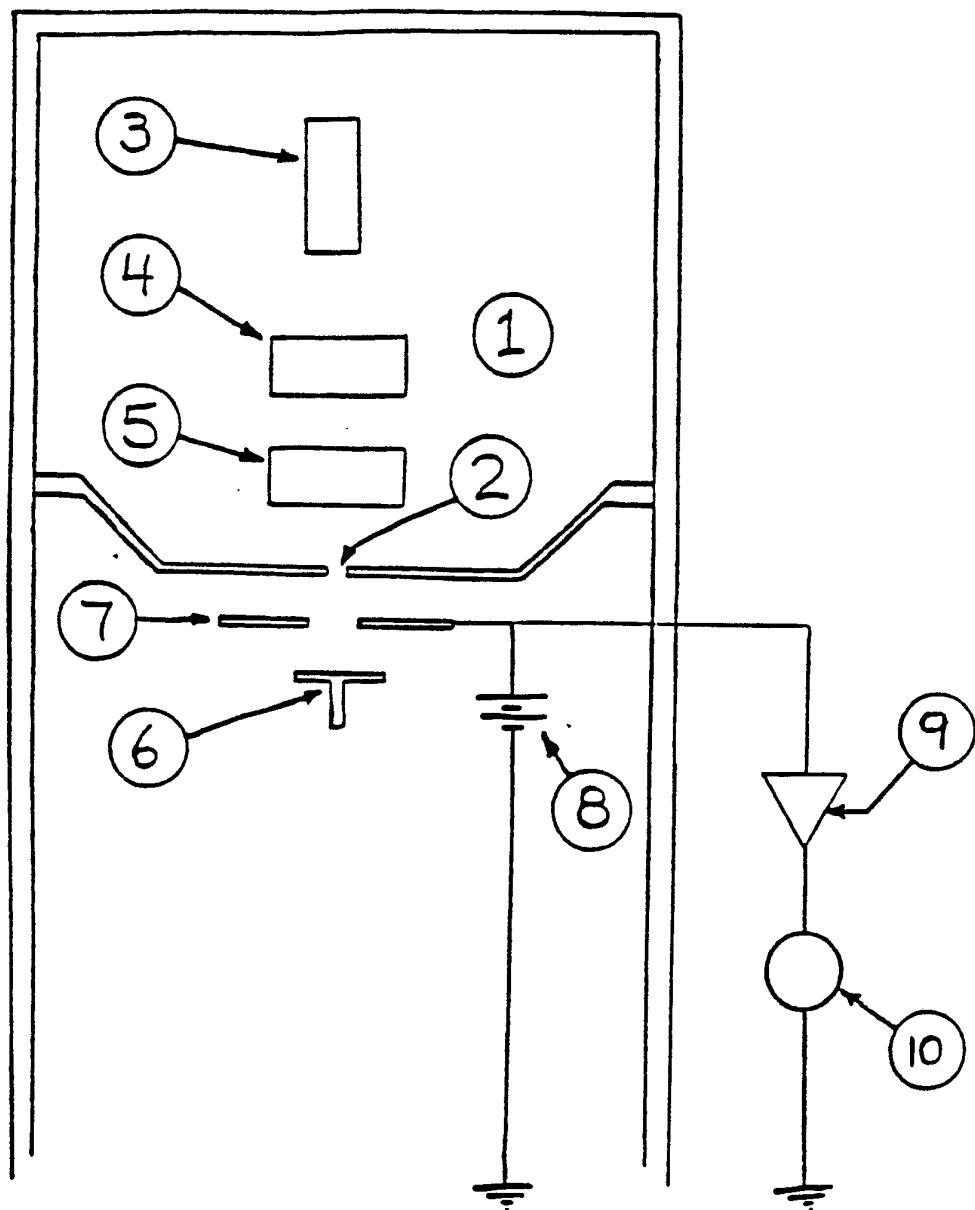


FIGURE 1

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US88/01654

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶

According to International Patent Classification (IPC) or to both National Classification and IPC
 IPC⁴ HO1J 37/252
 U.S. Cl. 250/310, 307, 397

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System	Classification Symbols
U.S. Cl.	250/310, 307, 397

Documentation Searched other than Minimum Documentation
 to the Extent that such Documents are Included in the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 3,612,859 (SCHUMACHER), 12 October 1971 (12.10.71)	1-13
A, E	US, A, 4,596,928 (DANTILATOS), 24 June 1986 (24.06.86)	1-13
A, P	US, A, 4,720,633 (NELSON), 19 January 1988 (19.01.88)	1-13

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

18 June 1988

Date of Mailing of this International Search Report

10 AUG 1988

International Searching Authority

ISA/US

Signature of Authorized Officer


Jack Berman