



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/US88/01654 <b>(22) International Filing Date:</b> 17 May 1988 (17.05.88) <b>(31) Priority Application Number:</b> 052,700 <b>(32) Priority Date:</b> 21 May 1987 (21.05.87) <b>(33) Priority Country:</b> US  <b>(71) Applicant:</b> ELECTRO-SCAN CORPORATION [US/US]; 100 Rosewood Drive, Danver, MA 01923 (US). <b>(72) Inventors:</b> MANCUSO, James, F. ; 50 Prospect Street, Rowley, MA 01969 (US). MAXWELL, William, B. ; 75 Horseshoe Drive, Dracut, MA 01826 (US). DARNILATOS, Gerasimos, D. ; 98 Brighton Boulevard, North Bondi, NSW 2026 (US).		<b>(74) Agent:</b> EVANS, Barry, L.; Curtis, Morris & Safford, 530 Fifth Avenue, New York, NY 10036 (US).  <b>(81) Designated States:</b> AT, AT (European patent), AU, BE (European patent), BR, CH, CH (European patent), DE, DE (European patent), DK, FI, FR (European patent), GB, GB (European patent), IT (European patent), JP, KR, LU (European patent), NL, NL (European patent), NO, SE, SE (European patent), SU.  <b>Published</b> <i>With international search report.</i>
<b>(54) Title:</b> SECONDARY ELECTRON DETECTOR FOR USE IN A GASEOUS ATMOSPHERE		
<b>(57) Abstract</b>  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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- 1 -

**SECONDARY ELECTRON DETECTOR FOR USE IN A GASEOUS  
ATMOSPHERE**

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Background of the Invention

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To obtain an image of a sample by electron microscopy, 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 optics column and to permit the operation of electron detectors.

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Scanning samples with an electron beam within a vacuum 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 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 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.

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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 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

- 3 -

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 of the total maximum potential difference between the  
15 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 gas induced signal amplification is that higher energy  
25 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 Microscopa 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  
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- 4 -

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

"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."

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

"...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 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 capable of directing a charged particle beam emitted by the charged particle beam source through the pressure limiting aperture, 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 a charged particle beam emitted from the charged particle beam source and directed through the pressure limiting aperture, 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 may come into contact with it, a voltage source connected between the electrode and an electrical ground capable of maintaining

- 6 -

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



- 7 -

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 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 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, an electrode disposed outside of the vacuum envelope and positioned within between about 1 and 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, a voltage source connected 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 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

- 8 -

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 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 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 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

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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  
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-

- 12 -

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 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 9 connected to the electrode and current detection means 10 connected between the current amplifier and an electrical ground. Within this application, negative charge carriers includes ionized gas molecules and free electrons.

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

- 13 -

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  
10 envelope 1 having a pressure limiting aperture 2, an 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  
15 capable of directing an 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  
20 beam emitted by the electron beam source across the 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 between about 1 and 200 mm of the sample platform means such that secondary electrons emitted from a  
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- 14 -

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 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 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 9 connected to the electrode and current detection means 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 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.

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 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 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 arcing. The electrical current

- 16 -

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 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 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 a sample which comprises:

a) a vacuum envelope having a pressure limiting aperture;

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

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

d) 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 a charged particle beam emitted from the charged

- 18 -

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  
10 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  
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 elec-  
25 trode 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  
30 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  
35 electric field of sufficient strength so

- 19 -

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;

g) a current amplifier connected to the electrode; and

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

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;
- 20 b) an electron beam source located within the vacuum envelope and capable of emitting an electron beam;
- 25 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;
- 30 d) electron beam scanning means located within the vacuum envelope and capable of scanning an electron beam emitted by
- 35 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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- 20 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



- 23 -

- 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  
20                   about 40 kiloelectron volts.

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

            a)       scanning the surface of the sample under  
                    a suitable gaseous pressure with a  
30                   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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- 24 -

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 arcing; and

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.

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

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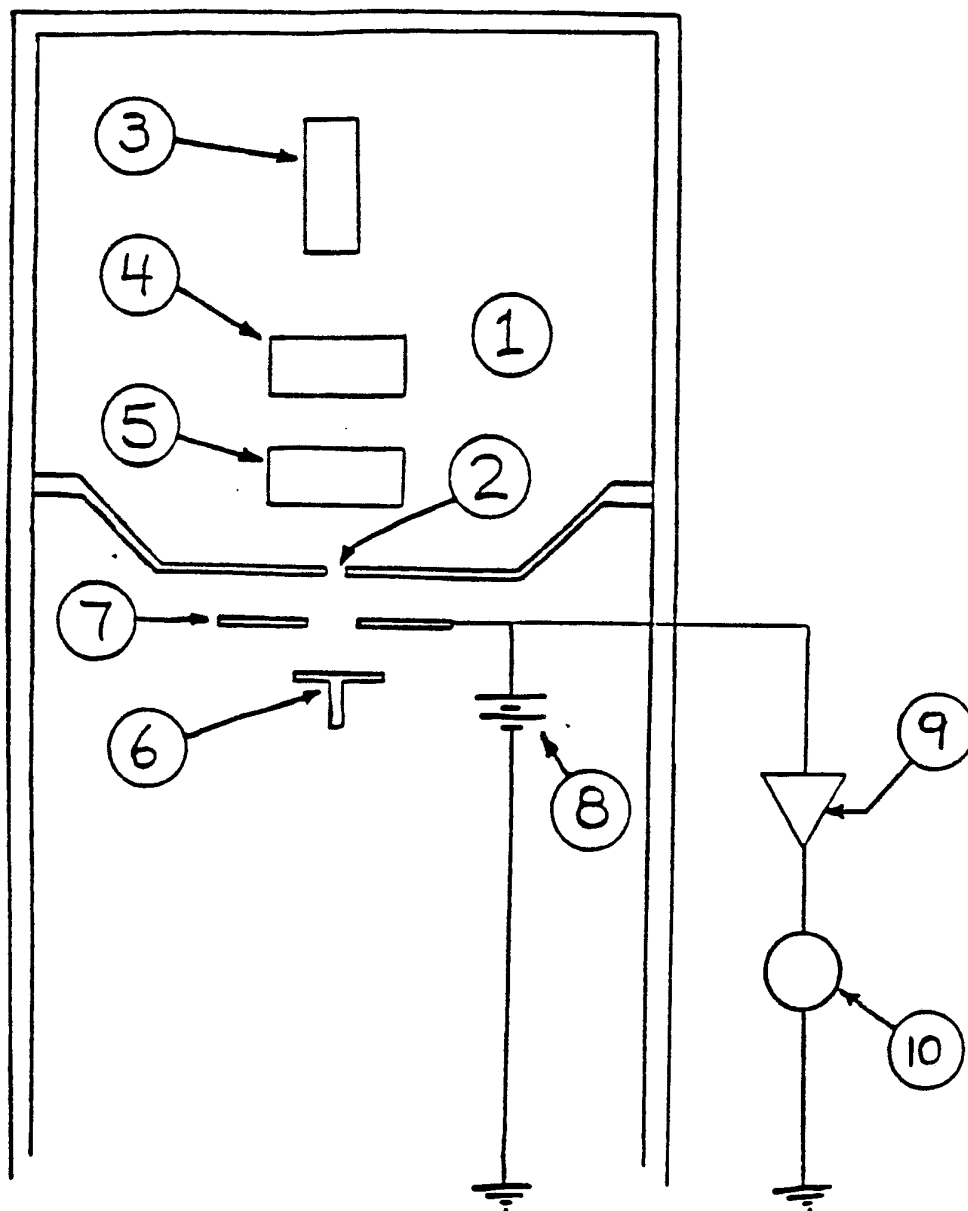
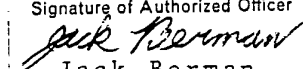


FIGURE 1

# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US88/01654

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC <sup>4</sup> H01J 37/252 U.S. CL. 250/310, 307, 397		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
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 <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>9</sup>		
Category *	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
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
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>* Special categories of cited documents: <sup>10</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"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</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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.</p> <p>"Δ" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
18 June 1988		10 AUG 1988
International Searching Authority		Signature of Authorized Officer
ISA/US		 Jack Berman