United States Patent [19]

Coates et al.

[11] **3,766,427**

[45] **Oct. 16, 1973**

[54] **FIELD EMISSION ELECTRON GUN**

[75] Inventors: **Vincent J. Coates,** Los Altos; **Leonard M. Welter,** Saratoga, both of Calif.

[73] Assignee: **American Optical Corporation,** Framingham, Mass.

[22] Filed: **Feb. 7, 1972**

[21] Appl. No.: **224,362**

Related U.S. Application Data

[63] Continuation of Ser. No. 46,425, June 15, 1970, Pat. No. 3,678,333.

[52] **U.S. Cl.** ..... **315/31 R,** 250/49.5 C, 250/49.5 R, 250/49.5 GC, 250/49.5 A

[51] **Int. Cl.** **H01j 29/56**

[58] **Field of Search** .... 315/30, 31; 250/49.5 A, 49.5 C, 49.5 GC, 49.5 R

[56] **References Cited**

UNITED STATES PATENTS

3,394,281	7/1968	Lafferty	315/30
2,363,359	11/1944	Ramo	250/49.5
3,394,874	7/1968	Marshall	230/69

OTHER PUBLICATIONS

Crewe, Electron Gun Using Field Emission Source, Review of Scientific Ins., Vol. 39, No. 4.

Primary Examiner—Carl D. Quarforth
Assistant Examiner—J. M. Potenza
Attorney—William C. Nealon et al.

[57] **ABSTRACT**

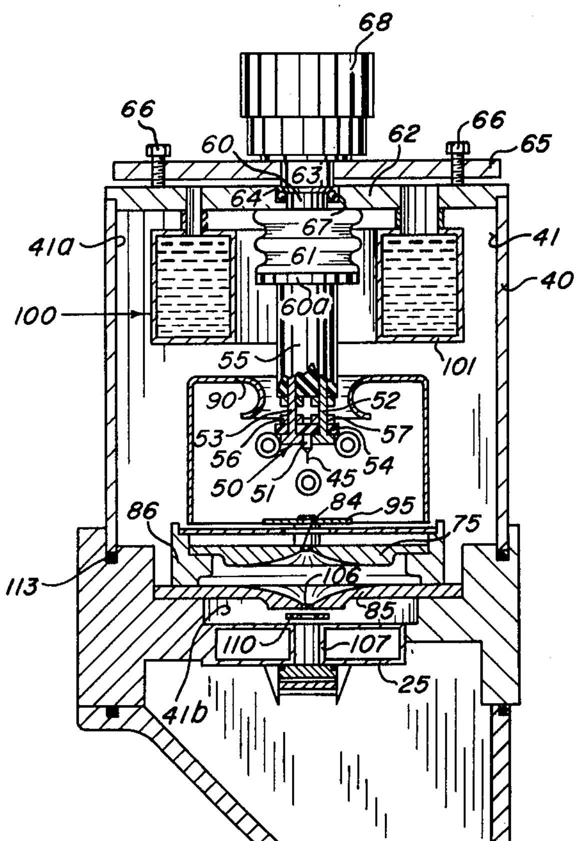
A field emission electron gun comprises a field emission tip as its source of electrons. A first anode is spaced downstream from the tip and when a voltage is applied between the first anode and the tip, electrons from the tip are accelerated toward the first anode. An opening in the first anode limits the angular spread of the electron beam. A second anode is spaced downstream from the first anode and when a voltage is applied between the second anode and the tip, the energy level of the electrons at the image or specimen plane is controlled. The electrostatic field between the first and the second anode brings the electron beam into focus.

For protecting the field emission tip against high voltage discharges, a third electrode in the form of a shield surrounds the field emission tip and is maintained at or near the electrical potential of the tip. Within the shield is a fourth electrode which serves, when voltage is applied thereto, to draw electrons from the tip and to restore or maintain normal operating conditions for the field emission electron gun. An ion-getter vacuum pump and a reactive sublimator vacuum pump are formed in the electron gun by evaporating a highly reactive element or getter material on the inner walls of the third electrode, which serves as a collector by inducing gas molecules which strike this surface to adhere thereto and to be imbedded therein. The inner walls of the third electrode react with reactive gasses present in the region of the tip and the fourth electrode. The ion getter pump operates by ionizing residual gas molecules which are then impelled by electric fields and are imbedded under the coating of sublimed getter material. The primary electron beam from the tip strikes the surface of the fourth electrode, thereby causing reflected and secondary electrons to be emitted from the surface, which electrons form an electron cloud capable of ionizing molecules within the chamber. The electron cloud is formed and the ionized gas molecules are collected by applying the appropriate potentials to the electrodes in the gun assembly. The third electrode may be cooled by a liquid nitrogen cooling system, which functions as a cryogenic vacuum pump. This cooling system can also be used to cool the tip in order to reduce the tip flicker noise resulting in greater stability of electron emission.

9 Claims, 8 Drawing Figures

United States Patent [19]
Coates et al.

[11] 3,766,427
[45] Oct. 16, 1973



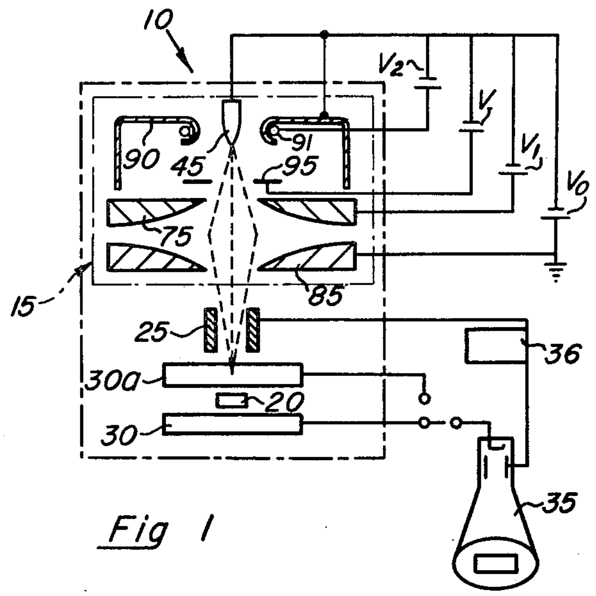

10
V2
V
V1
V0
90
45
91
95
75
85
15
25
36
30a
20
30
35

Fig 1

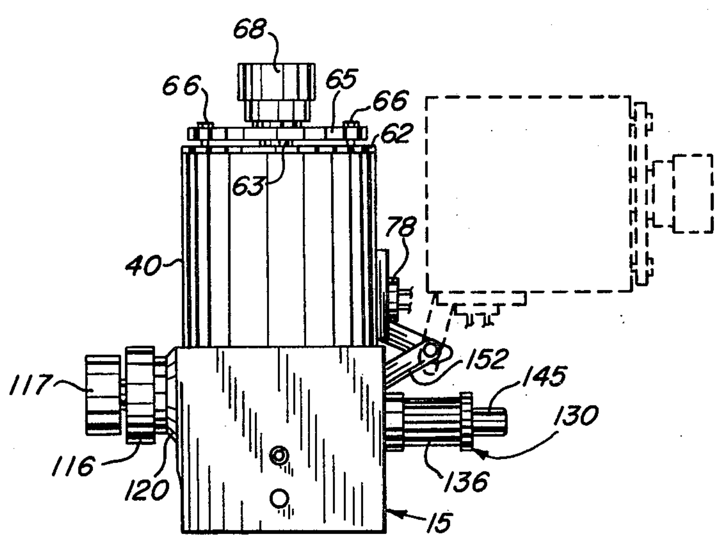

68
66
65
66
62
63
78
40
152
145
117
130
116
120
136
15

Fig 2

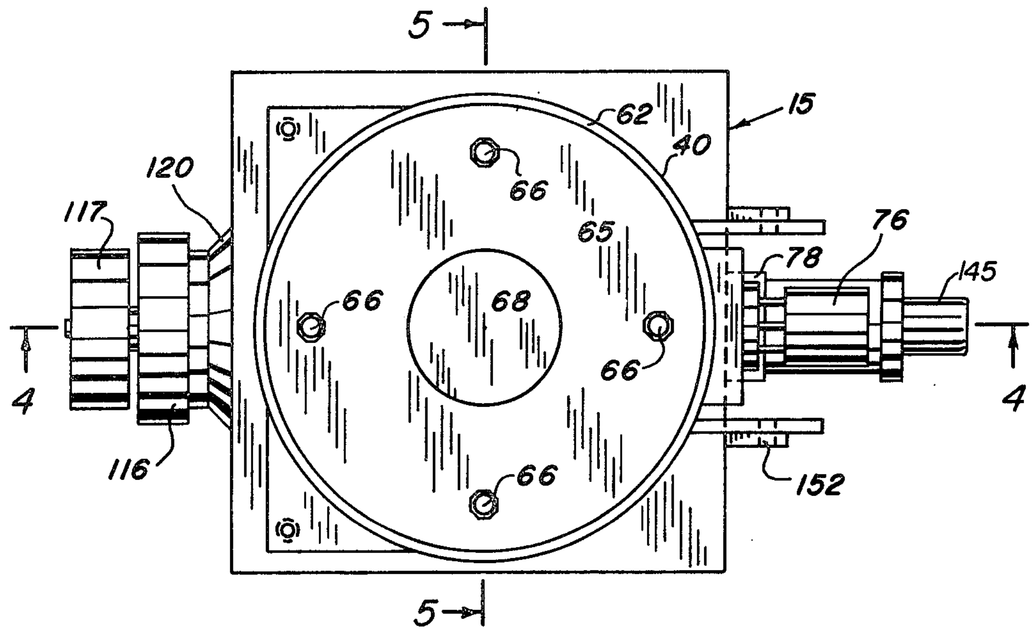

5
15
62
40
120
66
117
76
65
78
145
66
68
4
66
4
116
66
152
5

Fig 3

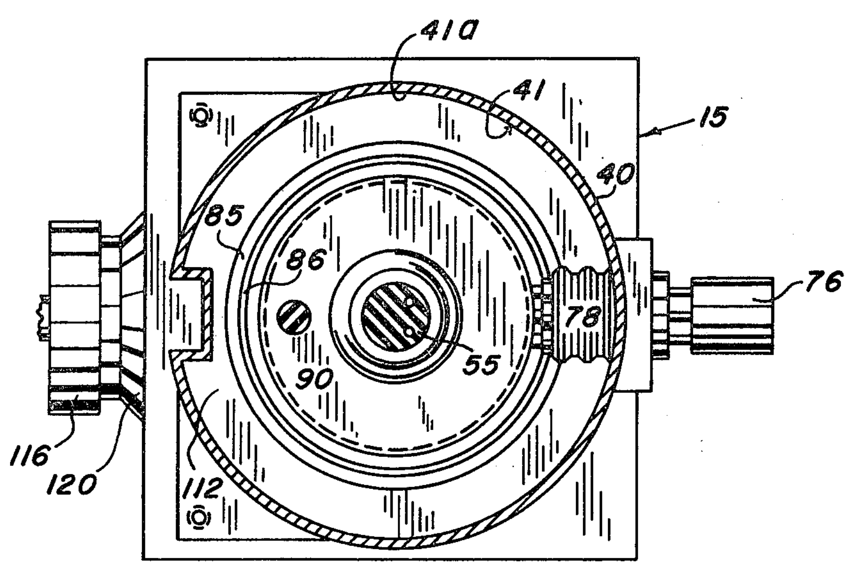

41a
41
15
40
85
86
76
78
90
55
116
120
112

Fig 6

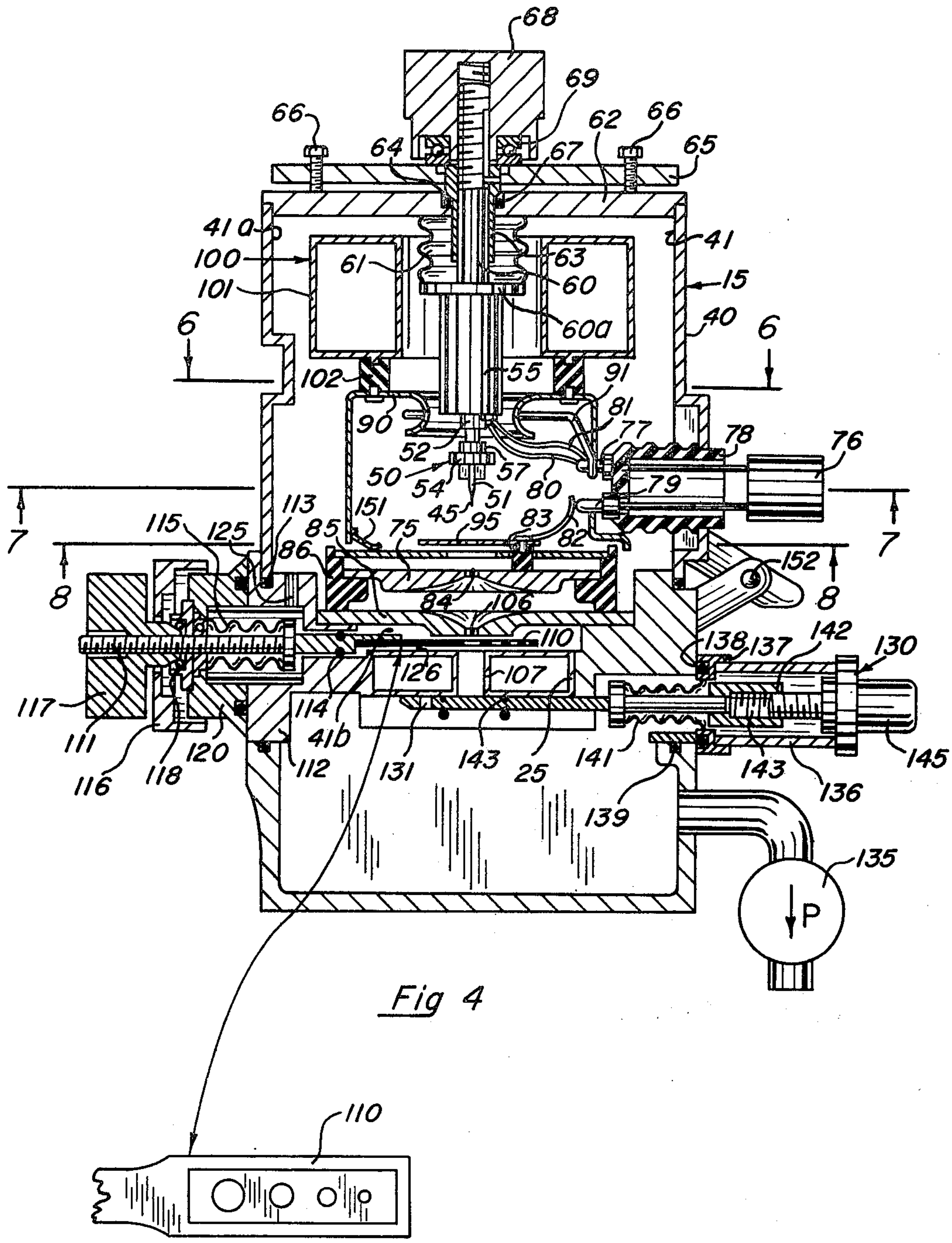

68
69
66
64
67
62
66
65
41a
41
100
61
63
15
101
60
60a
40
6
6
102
55
91
90
81
77
78
76
52
50
57
80
79
54
51
45
95
83
82
7
7
113
115
125
151
85
75
86
84
106
152
8
8
110
138
137
142
130
126
107
114
41b
117
111
116
118
120
112
131
143
25
141
143
136
145
139
135
P
110

Fig 4

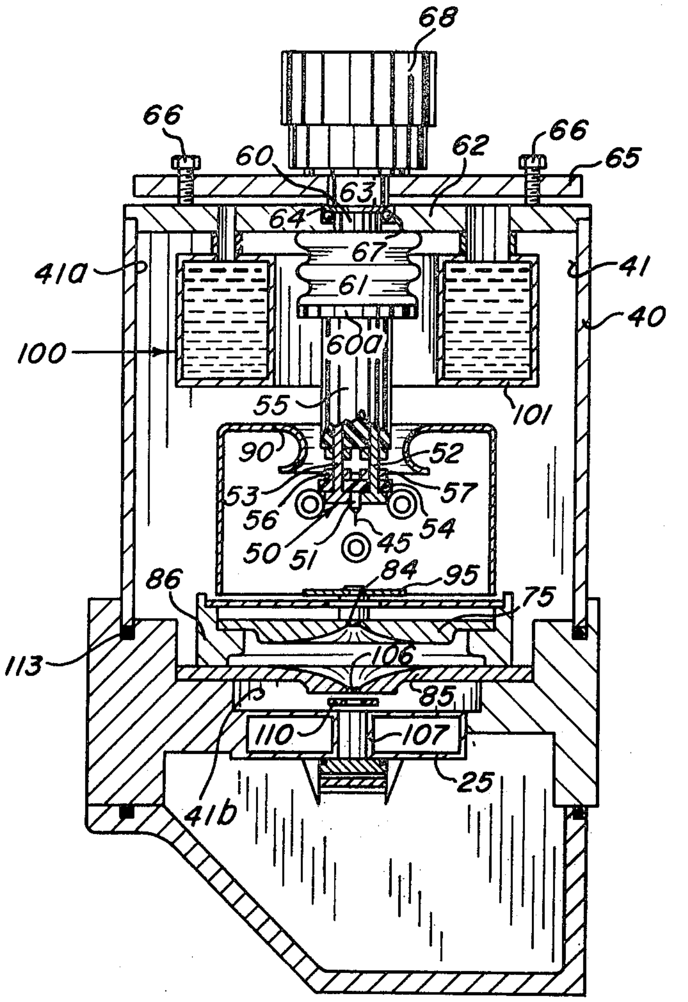

68
66
60
63
62
66
65
64
67
41a
61
41
40
100
60a
55
101
90
52
53
57
56
54
50
51
45
84
86
95
75
113
106
85
110
107
25
41b

Fig 5

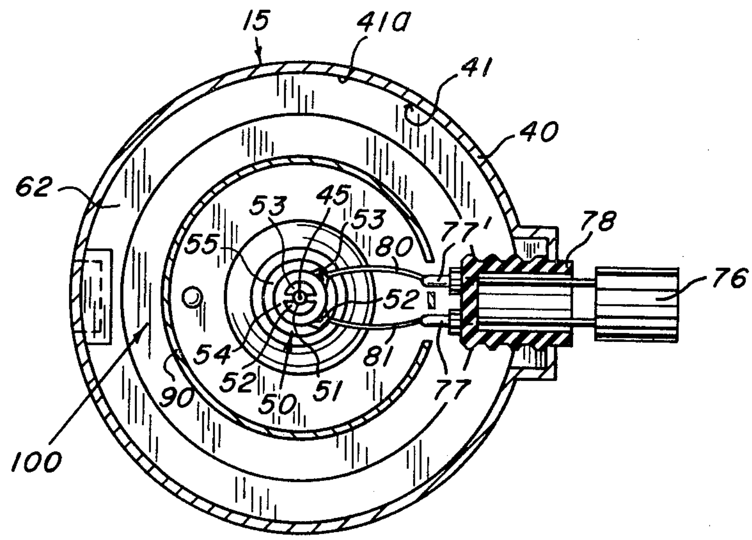

15
41a
41
40
62
53
45
53
77'
78
55
80
76
52
54
81
52
51
77
90
50
100

Fig 7

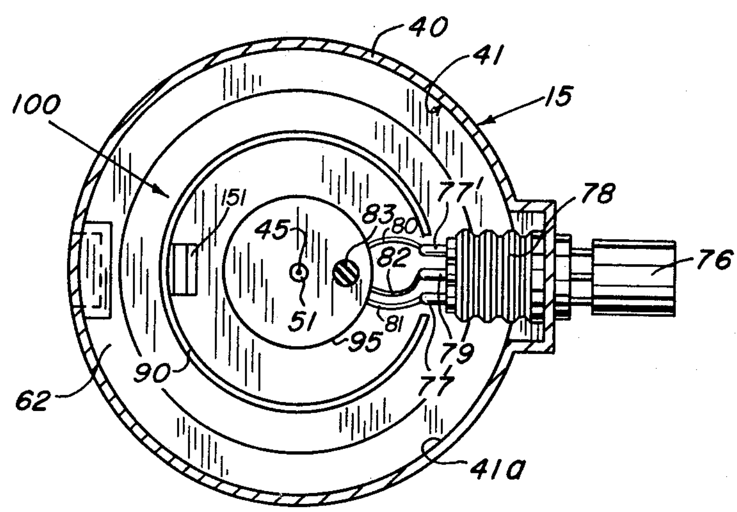

40
41
100
15
151
77'
78
45
83
80
82
76
51
81
95
79
90
77
62
41a

Fig 8

FIELD EMISSION ELECTRON GUN

This is a continuation, of application Ser. No. 46,425, filed June 15, 1970, now U.S. Pat. No. 3,678,333.

BACKGROUND OF THE INVENTION

The present invention relates in general to electron optical systems, and more particularly to a field emission electron gun.

Electron microscopes have heretofore comprised a field emission gun which included a field emission tip as its source of electrons. Spaced downstream from the tip was a first anode. A voltage applied between the tip and the first anode drew electrons from the tip and accelerated the electrons. Generally, the applied voltage was in the order of 500–5,000 volts. A second anode was spaced downstream from the first anode and a voltage applied between the tip and the second anode further accelerated the electrons. Generally, the applied voltage was in order of 1,000–100,000 volts.

High voltage discharges taking place within the field emission gun subjected the field emission tip to excessive potentials, which resulted in high tip current and subsequent melting of the field emission tip. As a consequence thereof, the field emission tip failed prematurely and required frequent replacement.

Field emission tips have been disposed within chambers at ultra high vacuums in the order of 10^{-8} Torr. or lower in order to operate with stability. Instability arises out of excessive gas molecules in the vicinity of the tip, which strike the tip or absorb to the tip surface to cause erratic electron emission. Vacuums in the order of 10^{-8} Torr. or lower have been produced by expensive, complex pumping systems.

Disclosures of field emission electron guns of the type above-described are found in the article entitled "Electron Gun Using a Field Emission Source" by A. V. Crewe, D. N. Eggenburger, J. Wall, and L. M. Welter, published in The Review of Scientific Instruments, Volume 39, Number 4, April 1968, Pages 576–583; U.S. Pat. to A. V. Crewe, No. 3,191,028, issued on June 22, 1965, for Scanning Electron Microscope; an article entitled "A High-Resolution Scanning Electron Microscope" by A. V. Crewe, J. Wall and L. M. Welter, published in the Journal of Applied Physics, Volume 39, No. 13, Pages 5861–5868, December 1968.

SUMMARY OF THE INVENTION

A field emission electron gun for an electron optical system having a field emission tip as a source of electrons. A shield electrode surrounding the field emission tip is electrically connected to the field emission tip for protecting the field emission tip against voltage discharges.

A further feature is that another electrode is disposed within the shield electrode to draw electrons from the tip and to maintain normal operating conditions for the field emission gun.

From the foregoing arrangement, the delicate field emission tip is not subjected to a high current flow when a voltage discharge occurs, and, therefore, the life expectancy of the field emission tip has been greatly extended.

In order to help improve tip current stability by improving the local vacuum and by reducing ion damage to the tip, the shield electrode is held at an electrical potential equal to or less positive than that of the field emission tip. Thus, there is a tendency for the shield

electrode to attract positive ions away from the tip. The electrons produced by the incident primary beam current from the tip at the electrode within the shield electrode are in a negative electric field, and, hence, tend to form a constrained, high density electron cloud within the shield electrode. The electron cloud increases the probability of ionizing gas molecules in the region contained by the shield electrode, and these ionized molecules are then attracted toward the shield electrode.

In the exemplary embodiment of the present invention, a reactive element or getter material is evaporated on the inner wall of the shield electrode to induce molecules impinging on the shield electrode to adhere thereto and to be imbedded in the inner wall of the shield electrode. In addition, when the beam of electrons is emitted from the tip, the inner wall of the shield electrode serves as an ion collector to attract and capture in the reactive coating those gas molecules which are ionized by the primary beam and by the electron cloud which the beam generates. Through this action, a getter-ion pump is present for producing and maintaining ultra high vacuums by ionizing gas molecules which are then impelled to the shield wall by electric fields and are buried there under the coating of sublimed getter material. A reactive sublimator pump is also present by inducing reactive gas molecules which happen to strike the shield electrode to stick there and to be buried under the getter material.

It has been found that the number of gas molecules liberated from the electrode within the shield electrode increases as the current emitted from the field emission tip increases. The number of secondary and reflected electrons generated at the surface of the electrode within the shield electrode also increases as the current emitted from the field emission tip increases. Therefore, the pumping efficiency of the present getter-ion pump increases as the pumping requirements increase. In addition, the shield electrode may be cooled to improve the overall pumping efficiency of the vacuum system. This improvement occurs because of the increased pumping for the condensable gases and the more efficient pumping of reactive gases. The same cooling system is used to cool the tip which reduces flicker noise and improves tip current stability.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an electron optical system embodying the field emission gun of the present invention.

FIG. 2 is a front elevation view of the field emission gun incorporating therein the present invention.

FIG. 3 is an enlarged top view of the field emission gun shown in FIG. 2.

FIG. 4 is a vertical section view taken along line 4—4 of FIG. 3.

FIG. 5 is a vertical section view taken along line 5—5 of FIG. 3.

FIG. 6 is a horizontal section view taken along line 6—6 of FIG. 4.

FIG. 7 is a horizontal section view taken along line 7—7 of FIG. 4.

FIG. 8 is a horizontal section view taken along line 8—8 of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Illustrated in FIG. **1** is an electron optical system in the form of a scanning electron microscope **10** which embodies therein a field emission gun **15** of the present invention. The field emission gun **15** produces from its electron source a bright, focused spot of electrons at its image plane to illuminate a specimen **20.** The focused spot is scanned by means of a deflection system and stigmator **25.** Information about the specimen **20** is obtained by detecting transmitted electrons, secondary electrons, reflected electrons, absorbed electrons, photons, or X-rays, any or all of which are generated by the incident electron beam. Detectors **30** and **30a** are often used to detect one of these signals which is then used to modulate the intensity of a synchronously scanned display tube **35** with a sweep generator **36** to form an image of the specimen **20.**

In FIGS. **2–8** is illustrated the field emission gun **15** of the present invention, which comprises a substantially cylindrical housing **40** defining a vacuum chamber **41** (FIGS. **4** and **5**). Disposed within the vacuum chamber **41** and the high vacuum area **41**a thereof is a source of electrons, such as a field emission tip **45.** The field emission tip **45** is an etched tip which does not employ any filament voltage or power to emit electrons. The cold field emission tip **45** is very small in diameter, such as 1,000A.

For supporting the field emission tip **45** for movement along the *x*, *y* and *z* planes and for the removal of the field emission tip **45** for replacement, a tip support assembly **50** comprises a V-shaped mount **51,** which has the tip **45** attached thereto. The V-shaped mount **51** is crimped between electrodes **52** and **53** in fixed relation. An insulator disc **54** for the tip **45** receives the electrodes **52** and **53** and the electrodes **52** and **53** are secured to the insulator disc **54** by nuts **56** and **57.** The electrodes **52** and **53** are received as prongs by the lower end of a high voltage insulator post **55.** Nuts **56** and **57** on the electrodes **52** and **53** limit the extent of the entry of the electrodes **52** and **53** into the distal end of the post **55.** From this arrangement, the tip **45,** the disc **54** and the electrodes **52** and **53** are in the form of a plug which is detachably secured to the distal end of the post **55.** For replacing the tip **45,** the plug is detached as a unit and replaced as a unit.

The upper end of the insulator post **55** is fixedly secured to a metal shaft **60** having an end cap **60***a* with a depending flange fixed within a tapped hole of the upper end of the post **55.** Mounted on the cap **60***a* in fixed relation is a bellows **61.** The bellows **61** are welded to the cap **60***a* to form a vacuum wall or seal with the high vacuum chamber while permitting axial and transverse movement of the tip support assembly **50.** The bellows **61** are welded directly to an end cap **62** to complete the vacuum seal. Surrounding the shaft **60** is a sleeve **63** (FIG. **4**) that is received with the shaft **60** by an opening **64** in the cap **62.** Spaced from the cap **62** is a support plate **65** that has a suitable opening therein for receiving the shaft **60** and the sleeve **63.**

To tilt the plate **65** relative to the cap **62** in two different planes, screws **66** engage the cap **62** at their free ends and are in threaded engagement with the plate **65.** This produces *x* and *y* motion of the tip by pivoting sleeve **63** on pivot bearing **67** fixed to the cap **62** by a pivot bearing mount. Thus, as sleeve **63** pivots, so does shaft **60** and tip support assembly **50** resulting in *x* and *y* motion of the tip. Springs, not shown, cooperate with the screws **66** and **67** to maintain the plate **65** in its adjusted position relative to the cap **62.** A knob **68** is in threaded engagement with the upper end of the shaft **60** and is rotatable at a fixed height. Thrust bearings **69** permit the rotation of the knob **68** relative to the plate **65.** Thus, rotation of the knob **68** imparts axial or vertical movement to the shaft **60** without rotating the shaft **60.** Vertical movement of the shaft **60** imparts a vertical movement to the tip **45** through the post **55** and the electrodes **51** and **53.** Movement of the tip **45** in the vertical direction serves as a means for focusing the electron beam emitted from the tip **45.**

Spaced downstream from the tip **45** in the low vacuum area **41**b of the vacuum chamber **41** is a first anode **75** of a first focusing electrode formed with an outer cylindrical wall and a central opening **84.** The first anode **75** is well-known and is described in the aforementioned article by A. V. Crewe et al. entitled "Electron Gun Using A Field Emission Source."

Spaced downstream from the first electrode **75** is a second anode or second focusing electrode **85,** which has an annular cylindrical wall and an axial cylindrical wall. An annular insulating support **86** with a stepped inwardly facing configuration supports the first anode **75** on the shoulder thereof and is fixed to the second anode **85** to be supported thereby.

When a positive voltage V_o is applied between the tip **45** and the second anode **85,** the electrons emitted from the tip **45** are further accelerated. In the typical embodiment, the voltage V_o is equal to 20,000 volts. The second anode is attached to the chamber of the gun and in turn to the more positive terminal of the V_o supply. The second anode **85** is well-known and is described in the aforementioned article by A. V. Crewe et al. entitled "Electron Gun Using A Field Emission Source." It is the second anode **85** that controls the energy level of the electrons impinging on the specimen **20.**

It has been found that the tip **45** fails, when subjected to excessive discharge voltages, because of the high tip current which then flows and melts the end of the tip. According to the present invention, a third electrode **90** or shield electrode is disposed within the high vacuum area **41***a* of the vacuum chamber **41** to reduce premature failure of the tip **45** and to extend the life thereof.

The shield electrode **90** has an outer cylindrical wall with an upper end wall of a reduced diameter opening and with an inwardly turned, arcuate central wall. As shown in the drawings, the shield electrode **90** surrounds the tip **45** and is connected to an output terminal **77** of the insulator **78** (FIG. **4**). Thus, the third electrode **90** is substantially at the same electrical potential as is the tip **45** and is electrically connected thereto through a low impedance. It is the shield electrode **90** that protects the tip **45** from excessive voltage discharges from the first and second anodes, and, hence, the tip **45** is not exposed to high voltage transients. As a consequence thereof, the life of the tip **45** is extended. In the exemplary embodiment, the shield electrode **90** is made of mu metal, which provides a shield against stray outside magnetic fields that tend to deflect the electron beam emitted by the tip **45.**

A fourth electrode **95** is disposed within the shield electrode **90.** When a voltage is applied to the fourth electrode 95, electrons are drawn from the tip 45. It is the fourth electrode 95 that restores the electron emission gun 15 to normal operation or maintains the operation of the electron gun normal, when a shield electrode is employed to protect the tip 45 from excessive voltage transients. The source of high voltage, herein referred to as V_1, is in the typical embodiment in the order of a positive 500 –3,000 volts. When the voltage V_1 is applied between the tip 45 and the fourth electrode 95, electrons are drawn from the tip 45 and are accelerated toward the first anode 75. The fourth electrode 90 is connected to the first anode through a current limiting resistor.

For this purpose, a suitable high voltage supply 76 has its low voltage output connected to a terminal 77 of the high voltage insulator 78. The terminal 77 is also connected to the electrode 52, of the tip mounting assembly 50 over conductor 81 (FIG. 7) as well as to the shield electrode 90. A terminal 77′ is connected to the electrode 53 over the conductor 80. The terminal 79, which is the high voltage V_1 output, is connected over a conductor 82 to the fourth electrode 95 and, in turn, is connected to the first anode 75 through a voltage dropping resistor 83 (FIG. 4). This voltage dropping resistor 83 serves to maintain the fourth electrode 95 at normal V_1 voltage when a high voltage discharge causes the first anode 75 to arc to the second anode 85. The beam of electrons eminating from the tip 45 passes through a small opening in the fourth electrode 95, which is narrower than the beam of electrons and thereby controls the angular spread of the beam of electrons passing on to the first anode 75 and through its opening 84. Note that the electrons that are incident on the fourth electrode 95 and generate the electron cloud, initiate the pumping action of the getter-ion of the shield electrode 90.

It is to be observed that the assembly for adjusting the location of the tip 45, which has movement in the *x*, *y* and *z* planes, is separate and apart from the high voltage insulator 78. When the high voltage insulator established its connections through the tip support assembly 50, the tip 45 was subjected to vibrations. Vibrations on the tip 45 tend to cause degradation in the resolution of the scanning electron microscope 10. Thus, permanent connections are established with the electrodes 52 and 53 through the flexible conductors 80 and 81, yet enabling the tip 45 to be moved within the vacuum chamber 41 in the *x*, *y* and *z* planes.

It is known that excess gas molecules in the vicinity of the tip 45 cause erratic or noisy electron emission from the tip 45. This results in poor resolution for a scanning electron microscope. Thus, it was customary to employ powerful and expensive pumping systems to obtain a high vacuum area for the field emission tip.

According to the present invention, a very reactive element, or getter material, such as titanium, is evaporated from an annular filament 91 onto the inner wall of the shield electrode 90. One end of the filament 91 is connected to the terminal 77 and the other end of the filament 91 is connected to the voltage 62. The evaporation of the titanium on the inner wall of the shield electrode 90 may be either a continuous process or a periodic process. The titanium on the wall of the shield electrode 90 will react with and imbed therein reactive gasses that arrive at its surface. It therefore helps produce ultra high vacuums by collecting and burying gas molecules under its coating of sublimed getter material.

However, electrons emitted from the tip 45 are accelerated toward and strike the fourth electrode 95 causing large local pressure increases by liberation of positive ions, negative ions and neutral molecules from the surface of the fourth electrode 95. In addition, secondary electrons, reflected electrons and energetic X-rays are emitted. The liberation of the molecular species plus molecules which enter from other places would cause the tip to contaminate and the electron emission from the tip to become unstable. Such a condition would impair the operation of the electron emission gun by making it noisy, erratic and subject to premature failure. Further, instability may be caused by some positive ions which are accelerated back to the field emission tip and damage it.

The shield electrode 90 of the present invention is held at an electrostatic potential which attracts these positive ions away from the tip 45 as an ion collector. The secondary and reflected electrons produced at the surface of the fourth electrode 95 are within a negative electrostatic field and tend to form a high density electron cloud confined within the shield of the third electrode 90. The electron cloud increases the probability of ionizing any gas molecules in the high vacuum area which are then attracted toward the shield electrode 90. Thus, a local getter-ion pump operation is established in conjunction with the sublimation pumping.

Although the above-described operation can be performed with the shield electrode 90 at ambient temperatures, the pumping efficiency of the molecules in the titanium covered shield electrode 90 can be improved by cooling the shield electrode 90. Toward this end, the shield electrode 90 is cooled by a liquid nitrogen cooling system 100. The cooling system 100 comprises a container 101 of toroidal configuration for storing liquid nitrogen, which container 101 is connected to the shield electrode 90 through a beryllium oxide insulator 102 (FIG. 4) also of an annular configuration. The beryllium oxide insulator 102 is not only a good high voltage insulator but also has a high thermal conductance. The shield electrode 90 because of its strong negative electrostatic field not only produces the electron cloud of secondary electrons but also holds back the secondary electrons from being accelerated onto the inner wall of the housing 40, which defines the vacuum chamber 41, thus causing further outgassing and pressure increases. Therefore, a cryogenic pump operation is performed in the high vacuum area 41a of the vacuum chamber 41.

Through the getter-ion pump operation of the shield electrode 90 and the cryogenic pump operation of the nitrogen cooling system 100, a high vacuum in the order of 10^{-10} Torr. is created in the vacuum chamber 41 without expensive, independent vacuum pumps.

Electrons emitted from the tip 45 travel through the opening in the fourth electrode 95, through the opening 84 of the first electrode 75, through a similar opening 106 in the second electrode 85, through a beam guide tube 107 disposed axial of the deflection system and stigmator 25 to impinge on the specimen 20. For controlling the cross-sectional area of the electron beam, an aperture selector plate 110 is disposed between the second anode 95 and the deflecting system and stigmator 25. The aperture selector plate 110 includes a series of openings varying in diameter. In the exemplary embodiment, there are four such holes ranging in diameter from 25 to 250 microns.

By sliding the plate **110** horizontally, a selected aperture is aligned with the tube **107** and the opening **106** of the second anode **85** to control the size of the electron beam advancing therethrough. For this purpose, a shaft **111** is secured to the plate **110** for imparting a horizontal movement thereto. A housing **112** is fixed in sealing engagement with the housing **40** through O-rings **113.** O-rings **114** provide a seal between the shaft **111** and the housing **112.** Seated in the housing **114** and surrounding the shaft **111** are bellows **115,** which are welded thereto to permit the shaft **111** to have axial movement while maintaining a fluid seal. Outside the housing **40,** the shaft **111** is threaded to knobs **116** and **117.** Suitable bearings **118** enable the knobs **116** and **117** to be rotated relative to a cap **120** for the housing **112.** Thus, rotation of the knob **117** imparts reciprocal movement to the shaft **111** without rotating the shaft **111** to align a selective opening of the plate **111** with the path of travel of the electron beam to control the diameter thereof. Knob **116** is an eccentric that imparts transverse motion to the plate **110** about the O-ring **114** which serves as a pivot point for the transverse motion.

When the tip **45** is changed, the chamber **41** is at atmospheric pressure. To facilitate the reduction of pressure in the chamber **41** from atmospheric to a high vacuum, the chamber **41** is exposed to the atmosphere by fully retracting the shaft **111** through the knob **117.** When this is done, a vent **125** in the housing **112** communicates through an opening **126** with the chamber **41** by the O-rings **114** adavancing into the increased diameter portion of the housing **112.** By returning the shaft **111** to its initial position, the valve is closed and the chamber **41** is not vented through the opening **125,** since the O-rings **114** occupy the position shown in FIG. **4.** Differential pumping occurs between the high vacuum in the chamber **41a** and the chamber **41b** through the opening **84** on the first anode **75.**

For isolating the chamber **41** from atmospheric pressure while the specimen **20** is being changed, a valve **130** (FIG. **4**) with an opening **131** formed in a valve shaft **143** is slidable in a horizontal direction so as to remove the opening **131** from alignment with the lower end of the tube **107** to block the same. O-ring **143'** seals the end of the opening **107** when the valve **130** is closed. After the specimen is changed, the opening **131** is realigned with the bottom of the tube **107.** A suitable vacuum pump **135** is attached to the lower wall of the emission gun **15** and draws out the air under atmospheric pressure in the chamber **41** until the chamber is under a vacuum in the order of 10^{-6} or 10^{-7} Torr.

For sliding the valve **130** into and out of venting position, a valve housing **136** is fixed to the housing **40.** The housing **136** is sealed by a cap **137** and O-rings **138.** O-rings **139** provide a seal between the housing **136** and the housing **40.** Bellows **141** welded to the cap **137** and a sleeve **142** surrounding the valve shaft **143** permit rectilinear motion of the valve shaft **143** without breaking the seal. A knob **145** in threaded engagement with the valve shaft **143** is rotated to impart a rectilinear movement to the shaft **143** without rotating the same.

After the chamber **41** has been evacuated to about 10^{-6} or 10^{-7} Torr., the shaft **111** is moved to close off the vent **125,** thereby closing the differential valve and the opening **131** is aligned with the tube **107** through the movement of the valve shaft **143.** When the opening **131** is aligned with the tube **107,** electrons are permitted to impinge on the specimen **20.** At this time, the vacuum in the chamber **41** is maintained by the cryogenic pump **100,** the titanium sublimator and ion getter pump **90,** and the vacuum in chamber **41*b*** is maintained by the pump **135** at about 10^{-6} Torr. These pumps are adequate to evacuate the high vacuum chamber to 10^{-10} Torr. This vacuum provides stable operating conditions for the tip **45.** The differential pumping now takes place through the opening **84** of the first anode **75,** since this is the only path for establishing communications between the high vacuum chamber **41a** and a low vacuum chamber **41b** below the opening **84.**

In changing a specimen, the valve shaft **143** is employed to isolate the high vacuum chamber **41*a*** of the field emission gun **15** keeping it at a high vacuum, while the low vacuum chamber **41*b*** is pressurized to atmospheric pressure.

The shield electric **90** has its cylindrical wall connected to its base by suitable means such as a hinge contact **151.** In addition thereto, the housing **40** has separable sections in its cylindrical wall at the O-rings **113,** which are suitably connected through a suitable hinge **152.** When it is desired to replace the tip **45,** the gun **15** is pivoted at the hinges **151** and **152** to provide access for the replacement of the plug mounting for the emission tip **45.**

We claim:

1. A field emission gun comprising:

a housing defining a vacuum chamber;

a field emission tip disposed in said vacuum chamber for providing a source of charged particles;

a first electrode disposed in said chamber and spaced downstream of said field emission tip;

a second electrode farther downstream of said field emission tip, said first electrode and said second electrode establishing focus and acceleration fields for forming a beam of said charged particles;

an intermediate electrode located mediate of said field emission tip and said first electrode for developing an electric field to generate said charged particles; and

voltage means connected to said first and second electrodes, said field emission tip, and said intermediate electrode for supplying electrical potential to establish said focus, acceleration and particle generation fields.

2. The field emission gun of claim **1** wherein said charged particles are electrons, and said potentials of said first, second and intermediate electrodes are positive with respect to said field emission tip.

3. The field emission gun of claim **1** wherein a shield electrode disposed in said vacuum chamber defines a region in which said field emission tip is disposed for preventing excessive voltage discharges to said field emission tip, and said intermediate electrode is operatively effective within said defined region to generate said charged particles.

4. The field emission gun of claim **3** wherein said voltage means includes impedance means interconnecting said intermediate electrode and said first electrode for limiting said intermediate electrode potential with respect to said field emission tip during discharge conditions from said second electrode to said first electrode, and said intermediate, first and second electrodes have centrally located apertures axially aligned with said field emission tip for passage of said charged particles forming said beam.

5. The field emission gun of claim 2 including means operatively associated with said intermediate electrode means and said field emission tip for vacuum pumping an area contiguous with said field emission tip.

6. The field emission gun of claim 5 wherein said field emission tip is disposed within a region defined by a shield electrode, and said means for vacuum pumping said area includes electrons from said field emission tip, and secondary and reflected electrons which ionize contamination particles, and means for capturing said ionized particles.

7. The field emission gun of claim 6 wherein a getter material is located within said area for capturing said contamination particles, and said ionized particles are attracted to said shield electrode.

8. The field emission gun of claim 1 including a second contiguous vacuum chamber for housing specimens upon which said charged particles beam impinges, said chamber and said specimen chamber being interconnected by at least one orifice of area selected so as to permit maintenance of said chambers at different vacuum levels.

9. The field emission gun of claim 6 wherein said chambers are interconnected by at least one orifice through which said charged particle beam passes, said charged particles are electrons, and said chamber is thereby maintained at a substantially lower pressure than said specimen chamber.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,766,427 Dated October 16, 1973

Inventor(s) Vincent J. Coates and Leonard M. Welter

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the Patent front page, delete data element identifier [63] and substitute:

[62] Division of Ser. No. 46,425,
June 15, 1970, Pat. No. 3,678,333.

In column 1, line 2, delete "continuation" and substitute therefor --division--.

Signed and sealed this 6th day of August 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
☆ U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,766,427 Dated October 16, 1973

Inventor(s) Vincent J. Coates and Leonard M. Welter

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On the Patent front page, delete data element identifier [63] and substitute:

[62] Division of Ser. No. 46,425, June 15, 1970, Pat. No. 3,678,333.

In column 1, line 2, delete "continuation" and substitute therefor --division--.

Signed and sealed this 6th day of August 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents