United States Patent [19]

Aihara et al.

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[45] May 7, 1974

[54] **FIELD EMISSION TYPE ELECTRON GUN**

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[73] Assignee: **Nihon Denshi Kabushiki Kaisha**, Tokyo, Japan

[22] Filed: **Apr. 18, 1972**

[21] Appl. No.: **245,232**

[30] **Foreign Application Priority Data**

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May 11, 1971	Japan	46-31405
Sept. 7, 1971	Japan	46-69070

[52] U.S. Cl. **328/10**, 313/336, 315/307, 315/310, 328/8

[51] Int. Cl. **H02h 7/20**

[58] Field of Search 315/106, 107, 175, 176, 315/307, 310, 311; 328/8–10

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Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—William D. Larkins
Attorney, Agent, or Firm—Webb, Burden, Robinson & Webb

[57] **ABSTRACT**

This invention relates to a field emission type electron gun capable of protecting the emitter tip from damage when electrical breakdown occurs in the gun chamber. The preferred embodiments incorporate circuitry for decreasing the impedance between the emitter and its associated electrode when electrical breakdown occurs.

2 Claims, 11 Drawing Figures

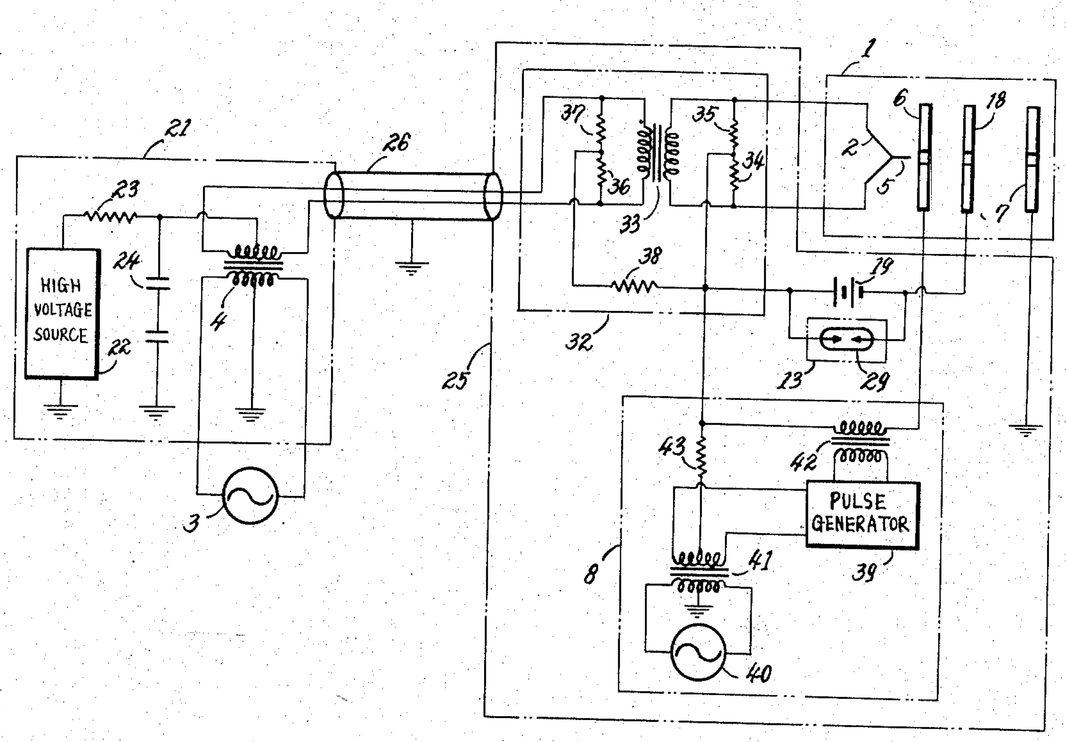


Fig. 1 (b)

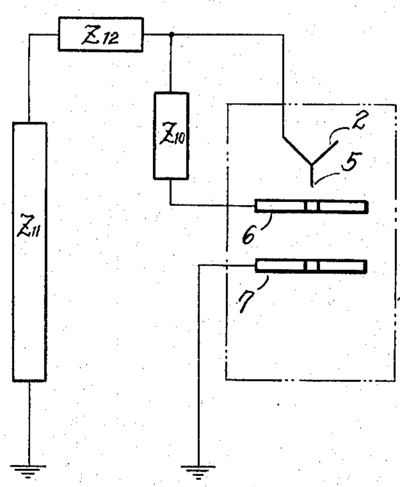


Fig. 1 (a)

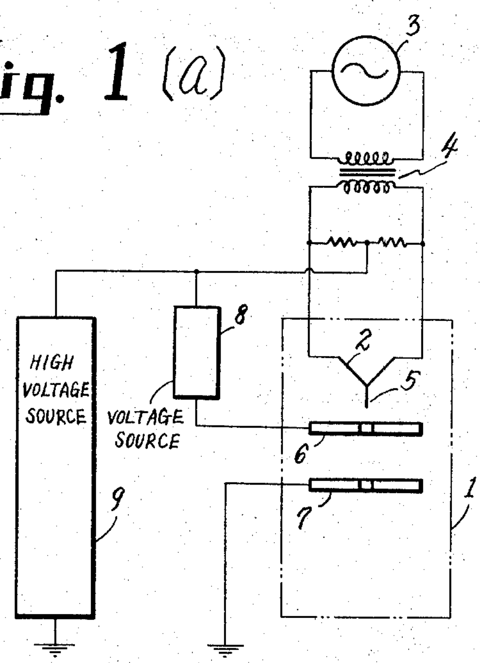


Fig. 2

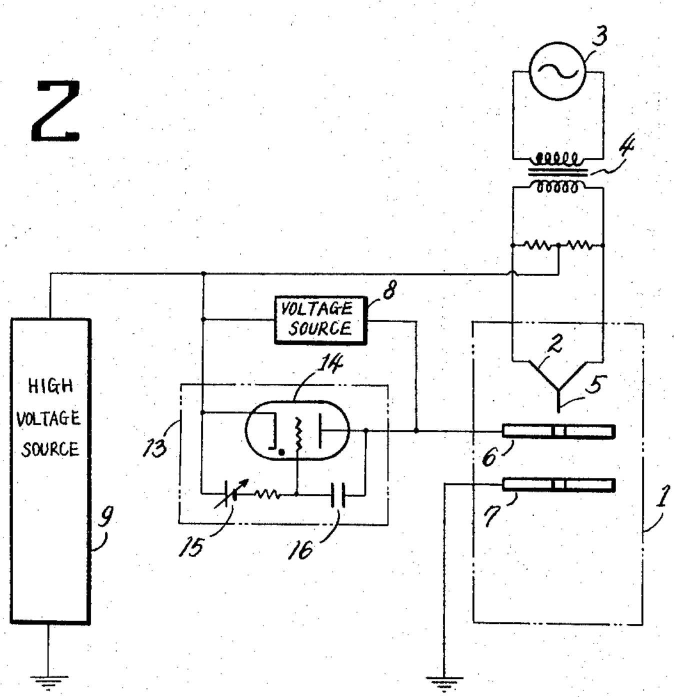


Fig. 3

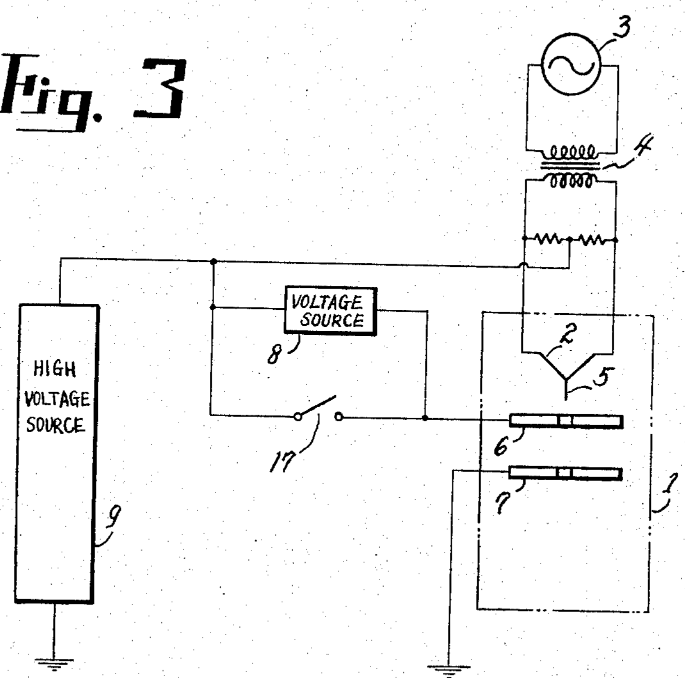
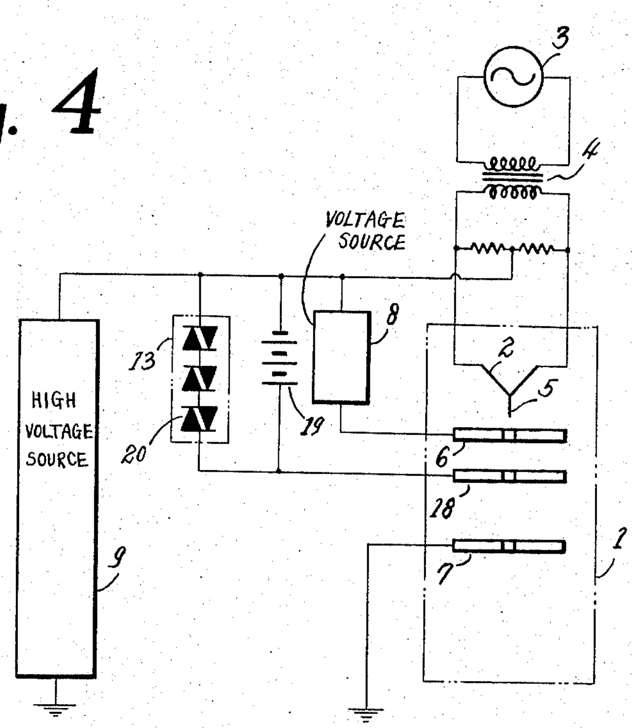

3
4
VOLTAGE SOURCE
8
HIGH VOLTAGE SOURCE
9
2
5
6
7
17
1

Fig. 4


3
4
VOLTAGE SOURCE
8
HIGH VOLTAGE SOURCE
9
13
20
19
2
5
6
18
7
1

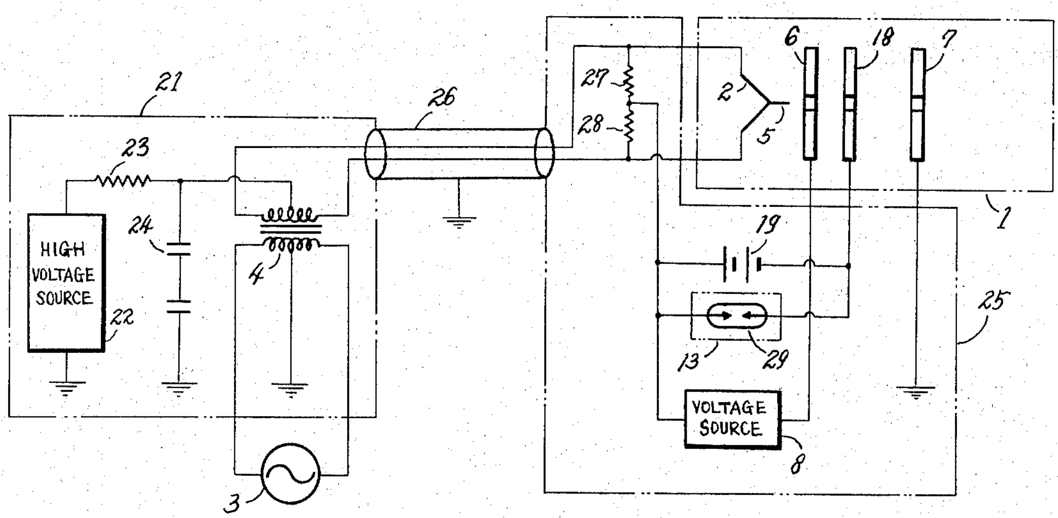

HIGH VOLTAGE SOURCE
VOLTAGE SOURCE
21
22
23
24
26
27
28
6
18
7
2
5
1
19
25
13
29
8
4
3

Fig. 5

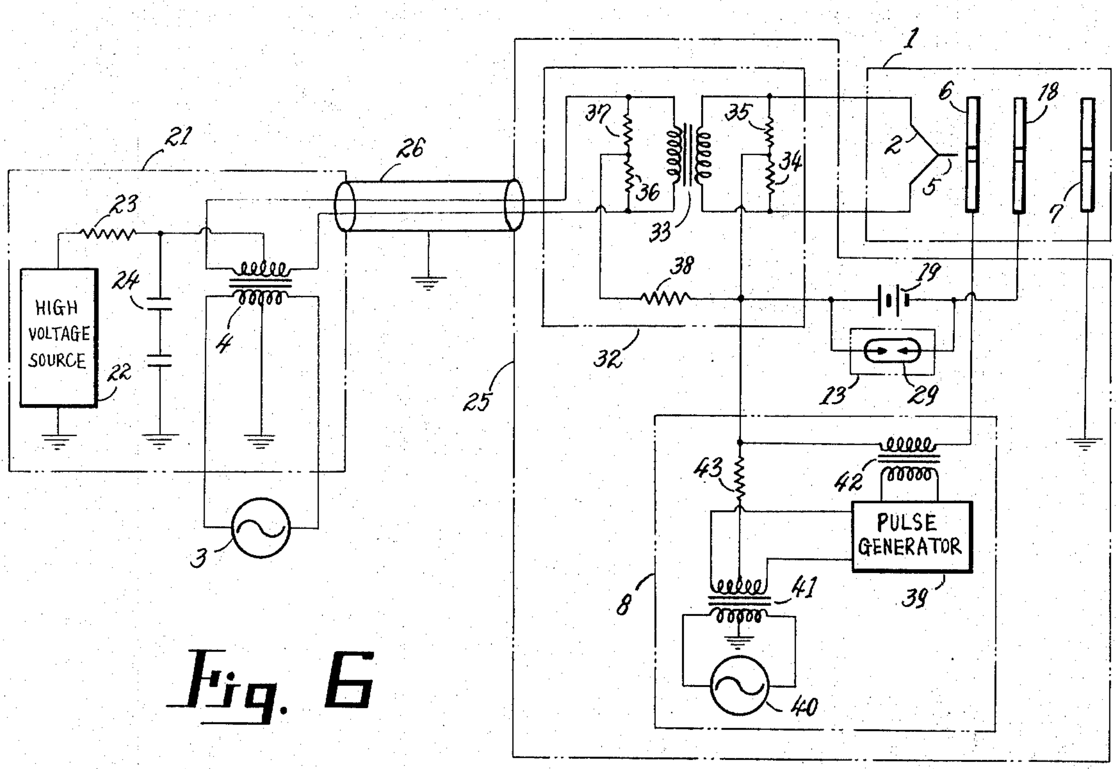
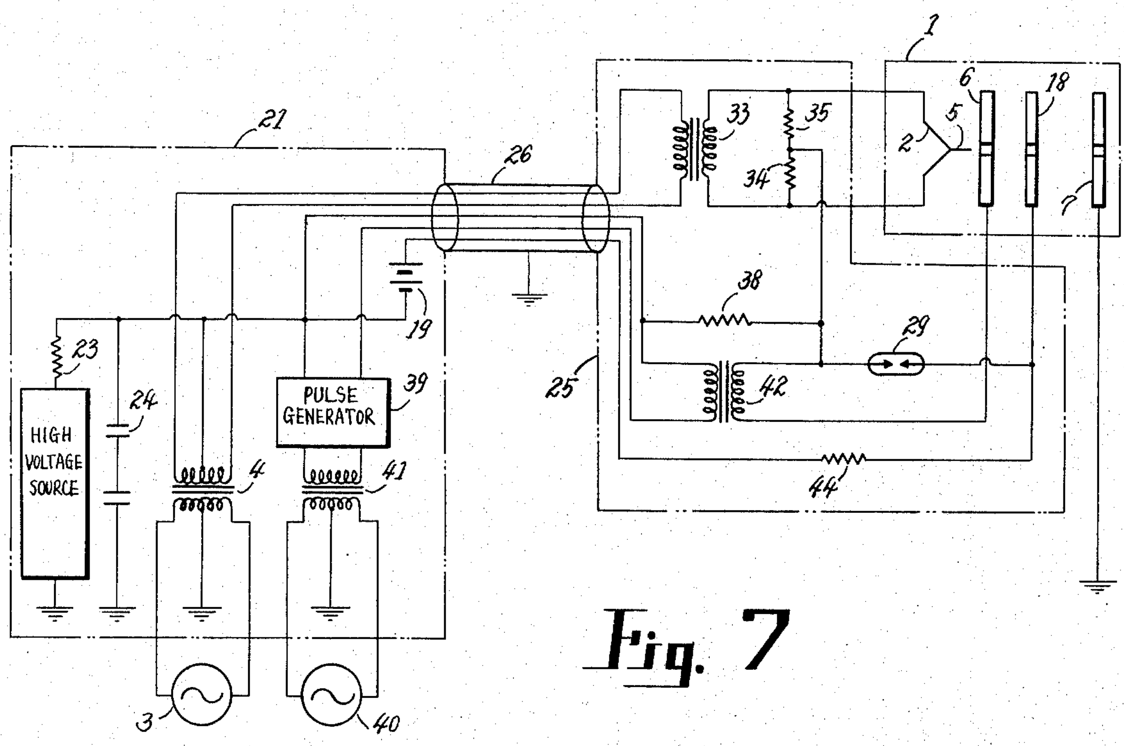

HIGH VOLTAGE SOURCE
PULSE GENERATOR
21
22
23
24
26
37
36
35
34
33
32
38
1
6
18
7
2
5
19
13
29
25
43
42
39
41
40
8
4
3

Fig. 6


HIGH VOLTAGE SOURCE
PULSE GENERATOR
1
2
3
4
5
6
7
18
19
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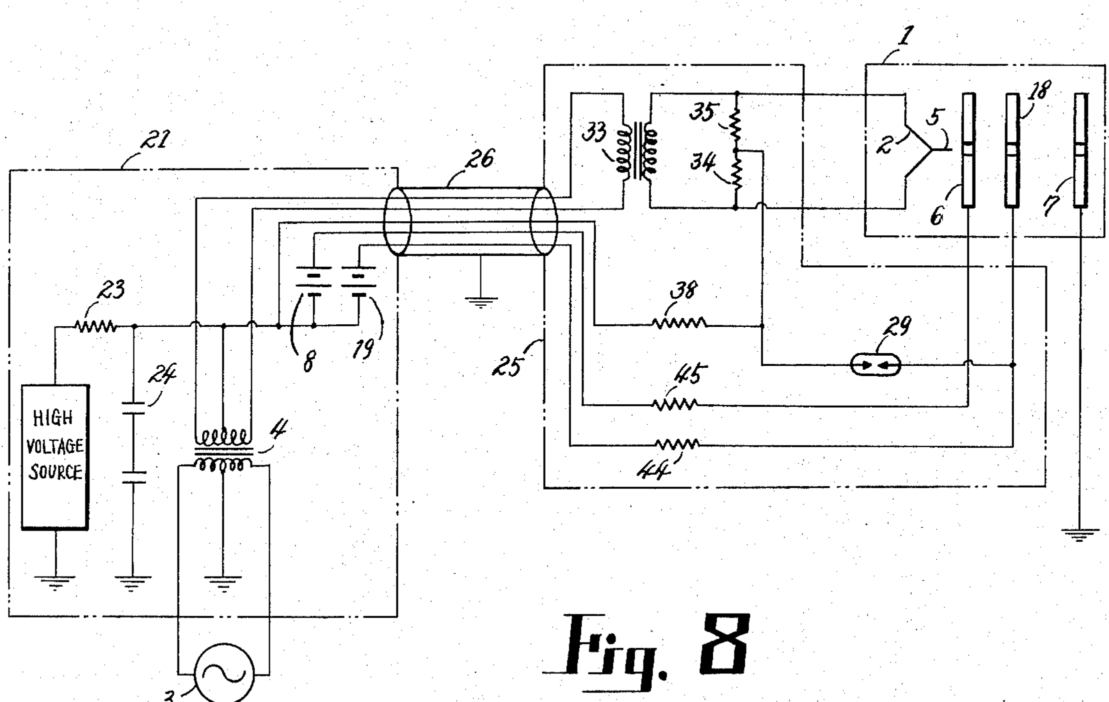
41
42
44

Fig. 7


HIGH VOLTAGE SOURCE
1
2
3
4
5
6
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8
18
19
21
23
24
25
26
29
33
34
35
38
44
45

Fig. 8

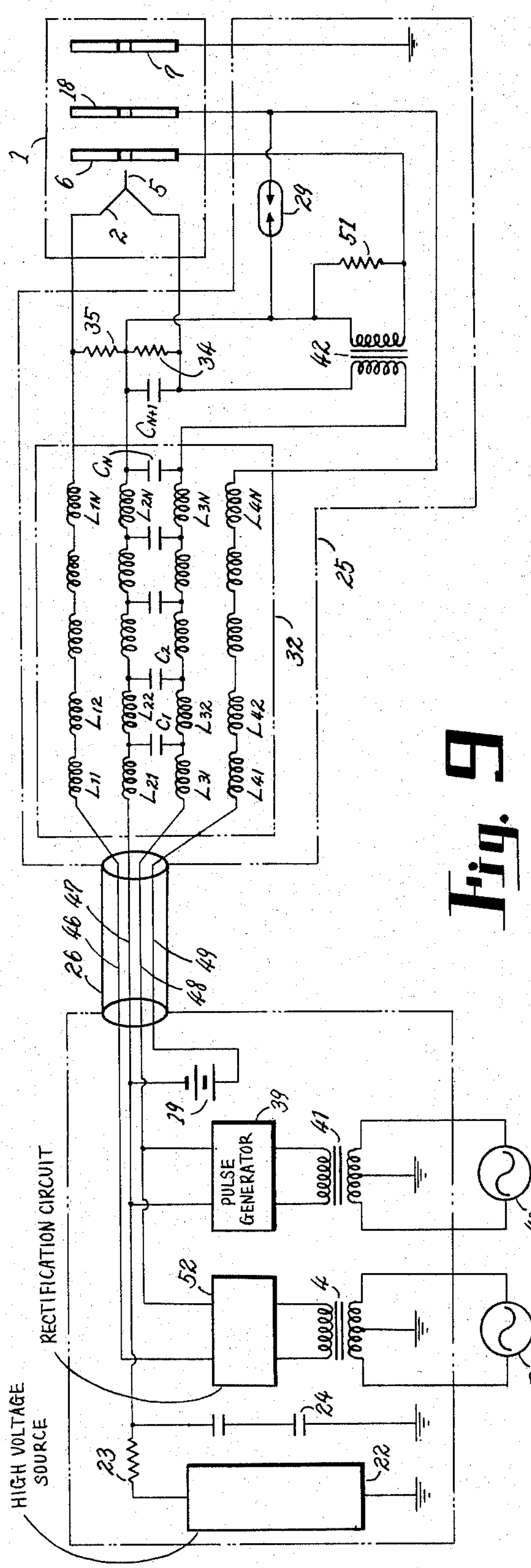
PULSE GENERATOR
RECTIFICATION CIRCUIT
HIGH VOLTAGE SOURCE

Fig. 9

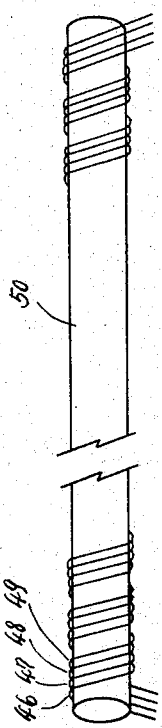

Fig. 10

FIELD EMISSION TYPE ELECTRON GUN

This invention relates to a field emission type electron gun capable of protecting the emitter tip from damage when electrical breakdown occurs in the gun chamber. The advantage of a field emission type electron gun in electron microscopes and the like as compared with the ordinary thermionic emission type electron gun, is that it is possible to obtain a high current electron beam forming a microspot. Unfortunately, however, in the case of the field emission type gun, the emitter is very easily damaged due to electrical breakdown caused by a deterioration in the gun chamber vacuum or other phenomena, resulting in the generation of an unusually strong electric field in the vicinity of the emitter tip. As a result the tip is overheated due to large current during vacuum arc discharge. This inevitably results in a change in shape in the emitter tip which then becomes useless.

It is a principal object of this invention to prevent electrical breakdown from damaging the emitter tip.

Briefly, according to this invention, a field emission electron gun comprises a circuit for preventing an unusually high potential difference between the emitter and an electrode spaced near the emitter resulting from an electrical breakdown between that electrode and the grounded anode. The preferred means of preventing the unusually high potential difference is to provide a circuit between the emitter and electrode which has a reduced impedance at the time of breakdown and preferably a circuit to increase impedance between the high voltage source and the emitter when breakdown occurs.

Further features of this invention will become apparent by reading the following detailed description in conjunction with the accompanying drawings, in which:

FIGS. **1**(*a*) and (*b*) are schematic diagrams of a conventional field emission type electron gun.

FIG. **2** is a diagrammatic circuit of one embodiment according to the invention.

FIGS. **3** to **10** show other embodiments according to this invention.

Referring to FIG. **1**(*a*), a gun chamber **1** contains a filament **2** heated by an A.C. current source **3** through an insulating transformer **4**, an emitter **5** attached to the filament **2**, first electrode **6** for producing a strong electric field (for example, about 10^7 volt/cm) in the vicinity of the emitter tip and an anode **7** maintained at ground potential. A voltage source **8** supplies a voltage so as to create a constant or pulsed potential difference between the emitter **5** and the first electrode **6**, in order to draw electrons from said emitter tip. Another voltage source **9** maintains the emitter at a high negative D.C. potential in order to accelerate the emitted electrons.

In this electron gun, electrical breakdown occurs mostly between the first electrode **6** and the anode **7**, due to the high potential difference existing there compared with that existing between the first electrode **6** and the emitter **5**.

In FIG. **1**(*b*), **Z10** and **Z11** represent the impedances of sources **8** and **9** (FIG. **1**(*a*)) respectively, and **Z12** the impedance between the two sources.

When electrical breakdown occurs between the first electrode **6** and the anode **7**, the potential of the first electrode **6** becomes zero (ground) and discharge current flows through impedances **Z10**, **Z12** and **Z11**. Accordingly, if the impedance **Z10** is not sufficiently small as compared with the sum total of impedance **Z11** and **Z12**, the potential difference between the emitter **5** and the first electrode **6** will be large, resulting in damage to the emitter tip.

FIG. **2** illustrates one embodiment of this invention in which the above possibility, viz., damage to the emitter tip, is eliminated by providing a protection circuit.

Referring to FIG. **2**, the protection circuit **13** is arranged in parallel with voltage supply source **8**, said circuit comprising a thyratron **14**, a variable D.C. voltage source **15** for adjusting the firing voltage of the thyratron **14**, and a coupling condenser **16**.

When surge voltage, resulting from electrical breakdown, is applied to circuit **13**; that is to say, across source **8**, the impedance of the circuit decreases, thereby protecting the emitter tip from damage due to said surge voltage.

FIG. **3** illustrates another embodiment according to this invention in which an "on-off" switch **17** is provided in place of protection circuit **13**.

This particular embodiment is very effective when electrical breakdown is predetermined as, for example, when applying the so-called "conditioning" technique whereby electrical breakdown between the first electrode and the anode is caused by setting the output voltage of voltage source **9** slightly higher than the regular working output voltage, in order to improve the withstand voltage in the gun chamber. In this case, switch **17** is switched on during the "conditioning" operation, and switched off during regular operation.

FIG. **4** illustrates yet another embodiment of the invention in which an additional electrode **18**, hereinafter referred to as "the second electrode," is provided between the first electrode **6** and the anode **7**. The potential applied to the second electrode **18** is determined by a D.C. voltage source **19** and the voltage source **9**. In this case, the output voltage of the voltage source **19** is almost the same as that of source **8** if the output of source **8** is D.C., and is almost the same as the pulse height of the output of source **8** if the output of source **8** is pulse. Moreover, the output voltage of source **19** is much smaller than the output voltage of source **9**. Accordingly, electrical breakdown between the second electrode **18** and the anode **7** almost always occurs before the occurrence of breakdown between the second electrode **18** and the first electrode **6**.

The moment breakdown occurs between the second electrode **18** and the anode **7**, the potential of the second electrode **18** changes from negative high potential to ground potential. As a result, the potential difference between the second electrode **18** and the first electrode **6** increases drastically due to the sudden outflow of discharge current through the impedance of D.C. voltage source **19**. This, in turn, activates protection circuit **13**, comprising a silicon symmetric switch (S.S.S.) **20**, thereby decreasing the impedance between the two electrodes and, in so doing, prevents the reoccurrence of electrical breakdown since the potential fluctuation of said electrodes and the emitter **5** are about the same.

An additional advantage of this embodiment is the fact that the range of the protection circuit firing voltage is much wider than that of the protection circuit described in the embodiment shown in FIG. **2**. This is because, in the case of the embodiment shown in FIG. 2, it is necessary to adjust the firing voltage in accordance with the output voltage of voltage source 8 which has to be varied every time the emitter is exchanged. In the case of this embodiment, however, the relevant voltage source is source 19 which is seldom varied. Hence, in the case of this embodiment, there is almost no necessity to adjust the firing voltage of protection circuit 13. For this reason, it is possible to utilize a simple S.S.S. 20 switching device in place of the more complicated thyratron and its associated circuit.

The embodiment illustrated in FIG. 5 is substantially the same as that illustrated in FIG. 4. In this embodiment, however, an insulation column 21 containing an insulating transformer 4, a high voltage source 22 and a filter circuit consisting of a resistor 23 and capacitors 24 is connected to gun chamber circuit 25 by high voltage cable 26. Further, the potential at the junction of balancing resistors 27 and 28 is used instead of the potential of the emitter 5, and protection circuit 13 which, in this case, incorporates a surge voltage protection tube 29 is connected between said junction and the second electrode 18.

In an "on-off" switch is provided in place of the protection circuit 13, this particular embodiment is very effective when electrical breakdown is predetermined as mentioned in the explanation of the embodiment shown in FIG. 3.

In the embodiment shown in FIG. 5, theoretically speaking, when electrical breakdown occurs between the second electrode 18 and the anode 7, vacuum arc discharge between the emitter and the first electrode 6 does not occur. In practice, however, if the residual impedance in the protection circuit is fairly large, the potential difference between electrode 6 and electrode 18 will be correspondingly large due to the outflow of discharge current.

The peak voltage E_D of the potential difference is given by the following equation:

$$E_D \approx (Z30/Z31+Z31)\times(C_A/C_A+C_B)\times V_H$$

where, Z30 represents the impedance between the second electrode 18 and the emitter 5, Z31 represents the impedance of the difference between the impedance Z30 and the total impedance existing in the discharge path of the discharge current due to electrical breakdown, C_A represents the stray capacity between electrode 6 and the emitter, C_B represents the stray capacity between electrode 6 and electrode 18, and VH represents the output voltage of the voltage source 22.

The embodiments shown in FIGS. 4 and 5 are designed to decrease impedance Z30 during discharge so as to keep E_D as low as possible, that is to say, minimize the potential difference between electrode 6 and electrode 18.

FIG. 6 illustrates an embodiment designed to further reduce E_D by increasing the impedance Z31 during discharge in addition to decreasing the impedance Z30.

This is made possible by incorporating a circuit 32 consisting of a transformer 33, balancing resistors 34, 35, 36 and 37 and a high order resistor 38 capable of withstanding the high voltage output of source 22. The two ends of the resistor 38 are connected to the junction of resistors 36 and 37 and the junction of resistors 34 and 35, respectively. When there is no discharge, the embodiment functions the same way as the embodiment shown in FIG. 5. If electrical breakdown occurs between the second electrode 18 and the anode 7, the amount of discharge current flowing through high order resistor 38 is very much reduced, and the potential difference between the emitter 5 and the first electrode 6 is not so large.

Voltage source 8 consisting of an A.C. voltage source 40, insulating transformer 41, a pulse generator 39, a transformer 42 and a high order resistor 43 generates a pulse voltage which is applied to electrode 6 through transformer 42. When electrical breakdown occurs in the gun chamber, the discharge current due to the stray capacity of transformer 41 flows through resistor 43.

FIG. 7 illustrates a practical embodiment of the present invention in which function and operation is substantially the same as the embodiments shown in FIGS. 5 and 6. In this embodiment, pulse generator 39, insulating transformer 41, and D.C. voltage source 19 etc. are all housed in insulation column 21. Also, the potential at the center tap of the output winding of transformer 4 is used instead of the potential at center tap of the input winding of transformer 33. The function of resistor 44 is the same as that of resistor 43 in FIG. 6.

FIG. 8 illustrates an embodiment for D.C. field emission operation corresponding to the embodiment shown in FIG. 7. In this embodiment, the function of resistor 45 is the same as that of resistors 44 and 38.

FIG. 9 illustrates an embodiment designed to increase the impedance 231 inductively instead of resistively as in the case of the embodiments shown in FIGS. 5, 6, 7 and 8. For this purpose, the embodiment incorporates a circuit 32 consisting of coils L11, L12, ... L4N and capacitors C1, C2, ... CN. Coils L11, ... L1N, L21, ... L2N, and L31, ... L3N forming part of said coils are required to have the same inductance and be unidirectionally wound, whereas coils L41, ... L4N may have a different or the same inductance and may be wound in the opposite or the same direction to the above coils.

FIG. 10 illustrates the physical equivalent of the circuit 32 shown in FIG. 9 in which conducting wires 46, 47, 48 and 49 leading from the high voltage cable 26 are wound on a core 50. By so doing, it is possible to eliminate capacitors C1, C2, etc., so long as the stray capacity between the conducting wires is adequate.

Accordingly, in the embodiment shown in FIG. 9, discharge current flows through circuit 32 which has a fairly high inductance; whereas, under normal operating conditions, the inductance of circuit 32 is cancelled out by the coils and is, therefore, zero. For example, the pulse signals generated by pulse generator 39 are transmitted to the input winding of the transformer 42 and capacitor CN+1 via the transmission line consisting of coils L21 . . . . L2N, L31 . . . . L3N and capacitors C1 . . . . CN without loss. Moreover, resistor 51 connected across the output winding of transformer 42 compensates for the sag in the pulse voltage applied between the emitter 5 and the first electrode 6. The filament heating current is D.C. rectified by rectification circuit 52. Even if A.C. current is used for heating the filament, there is practically no loss in circuit 32, because coils L11, ... L1N and coils L31, ... L3N have the same inductance and are unidirectionally wound.

It is possible, of course, to incorporate coils of circuit 32 between the high voltage source 9 and the junction of the emitter and voltage source 8 in the embodiment shown in FIG. 2.

We claim:

1. A field emission type electron gun device comprising:

i. an emitter for emitting an electron beam,

ii. an anode for accelerating the electron beam,

iii. a high voltage source for supplying negative high potential to said emitter in order to accelerate said electron beam,

iv. an electrode located between said emitter and said anode.

v. a voltage source for generating a potential difference between said electrode and said emitter in order to generate a strong electric field in the vicinity of said emitter tip, and

vi. a protection means for preventing the generation of an unusually high potential difference between said emitter and said electrode comprising a switching circuit for rapidly decreasing the impedance of said protection means in the event that the voltage between said emitter and said electrode increases beyond the firing voltage of the switching circuit, and

vii. means for heating the emitter comprising a first and second isolation transformer, the secondary of the first transformer being in series with the primary of the second transformer, the primary of the first transformer being connected to an AC voltage supply, the secondary of the second transformer being in series with the emitter of the electron gun, the high voltage supply being connected to the circuit between the said first and second transformers and the emitter being connected through a high value resistor to the circuit between said first and second transformers.

2. A field emission type electron gun device comprising:

i. an emitter for emitting electron beam,

ii. an anode for accelerating the electron beam,

iii. a high voltage source for supplying negative high potential to said emitter in order to accelerate said electron beam,

iv. a first electrode located between said emitter and said anode,

v. a voltage source for generating a potential difference between said first electrode and said emitter in order to generate a strong electric field in the vicinity of said emitter tip,

vi. a second electrode located between said first electrode and said anode,

vii. a D.C. voltage source for supplying a potential to said secondary electrode, and

viii. a protection means for preventing the generation of an unusually high potential difference between said second electrode and said emitter comprising a switching circuit for rapidly decreasing the impedance of said protection means in the event that the voltage between said emitter and said second electrode increases beyond the firing voltage of the switching circuit, and

ix. means for heating the emitter comprising a first and second isolation transformer, the secondary of the first transformer being in series with the primary of the second transformer, the primary of the first transformer being connected to an A.C. voltage supply, the secondary of the second transformer being in series with the emitter of the electron gun, the high voltage supply being connected to the circuit between the said first and second transformers and the emitter being connected through a high value resistor to the circuit between said first and second transformers.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,810,025 Dated May 7, 1974

Inventor(s) Ryuzo Aihara and Susumu Ota

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

Column 3 Line 24 --In-- should read --If--.

Column 3 Line 41 --Z31-- (first occurrence) should read --Z30--.

Column 3 Line 49 --VH-- should read --V_H--.

Column 4 Line 29 --231-- should read --Z31--.

Signed and sealed this 29th day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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