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Someya et al.

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[45] **July 23, 1974**

[54] **CONSTANT CURRENT FIELD EMISSION ELECTRON GUN**

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

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[21] Appl. No.: **245,328**

[30] **Foreign Application Priority Data**

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July 12, 1971 Japan 46-51610

[52] **U.S. Cl.** **328/9,** 315/106, 315/107, 315/307, 315/310, 315/311, 328/8, 328/10

[51] **Int. Cl.** **H01j 29/46,** H02h 7/00, H02h 9/02

[58] **Field of Search** 315/106, 107, 175, 176, 315/307, 310, 311; 328/8–10; 313/357

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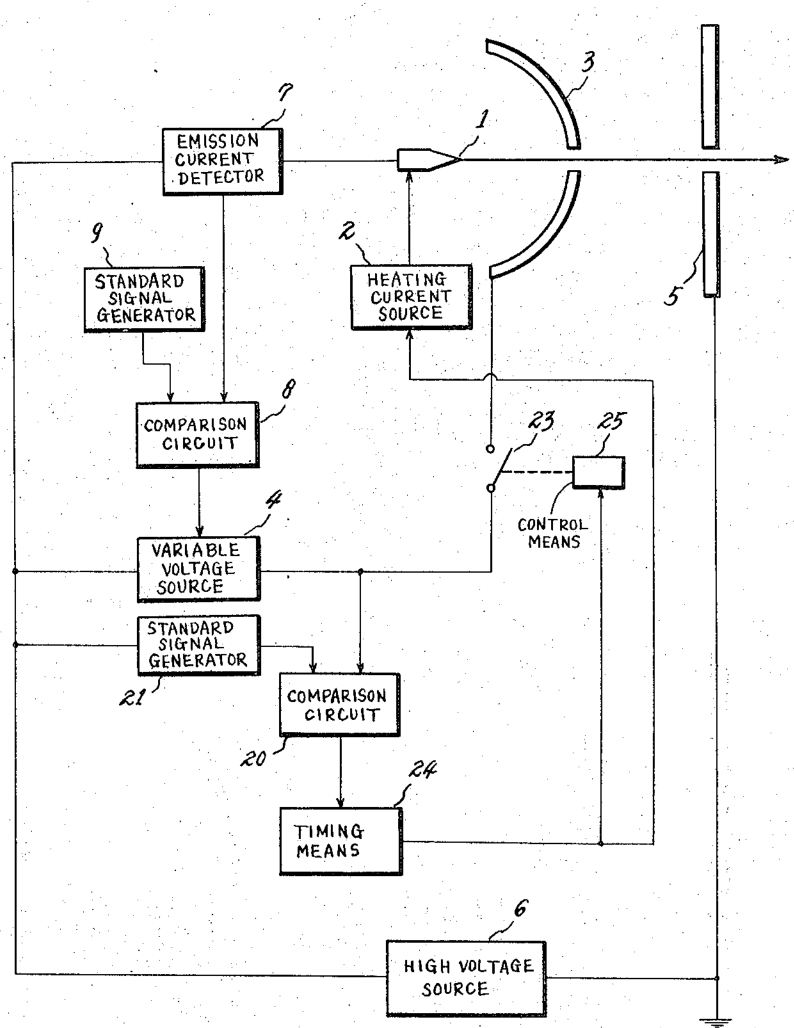
Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—William D. Larkins
Attorney, Agent, or Firm—Webb, Burden, Robinson & Webb

[57] **ABSTRACT**

An improved field emission type electron gun is automatically controlled so as to generate a stable emission current. The preferred embodiment employs a detecting means for detecting the emission current fluctuation and a control means for controlling the electric field for field emission according to the output signal of said detecting means.

6 Claims, 14 Drawing Figures



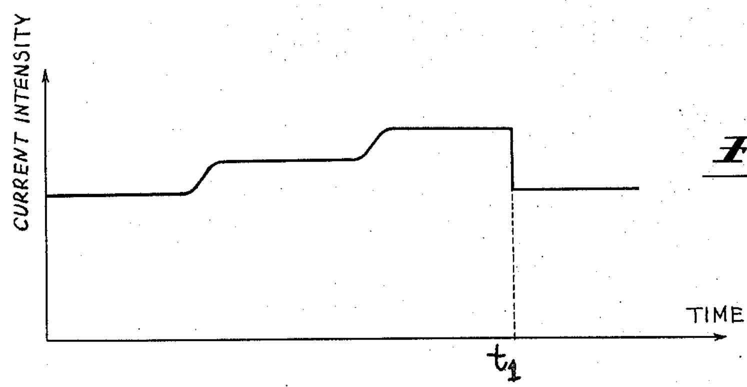


Fig. 1(a)

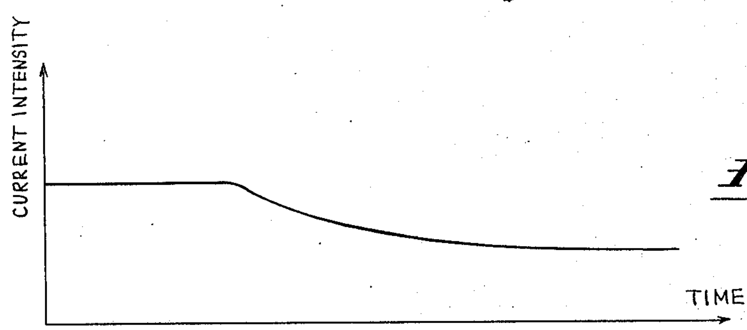
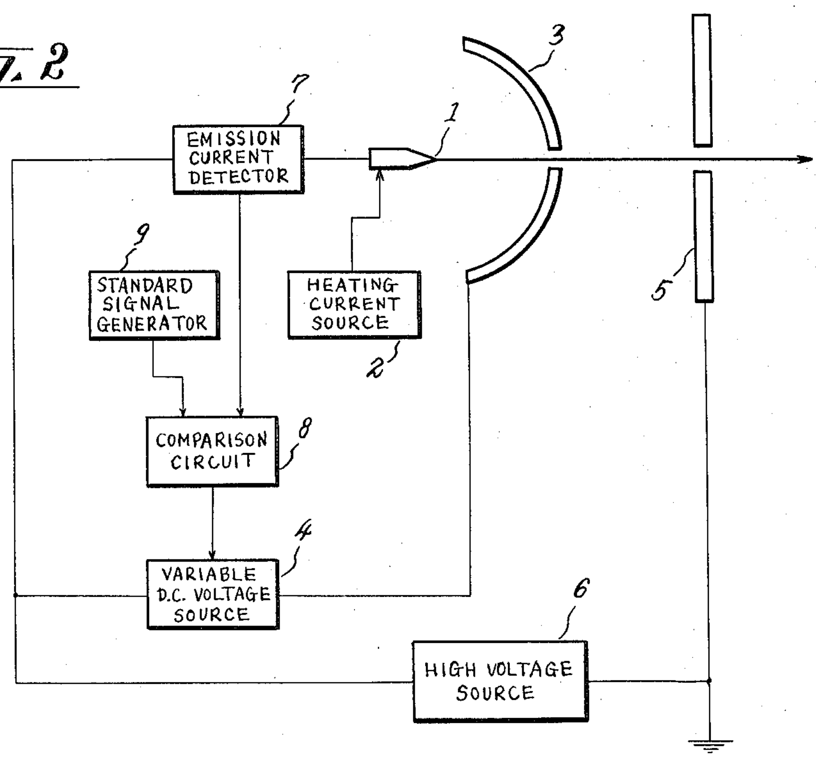


Fig. 1(b)

Fig. 2



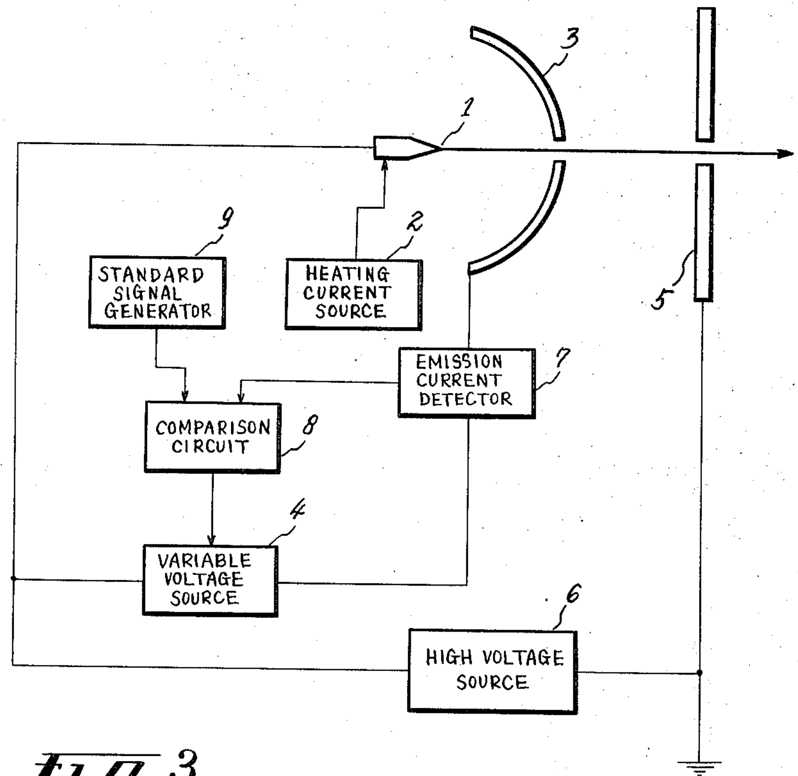
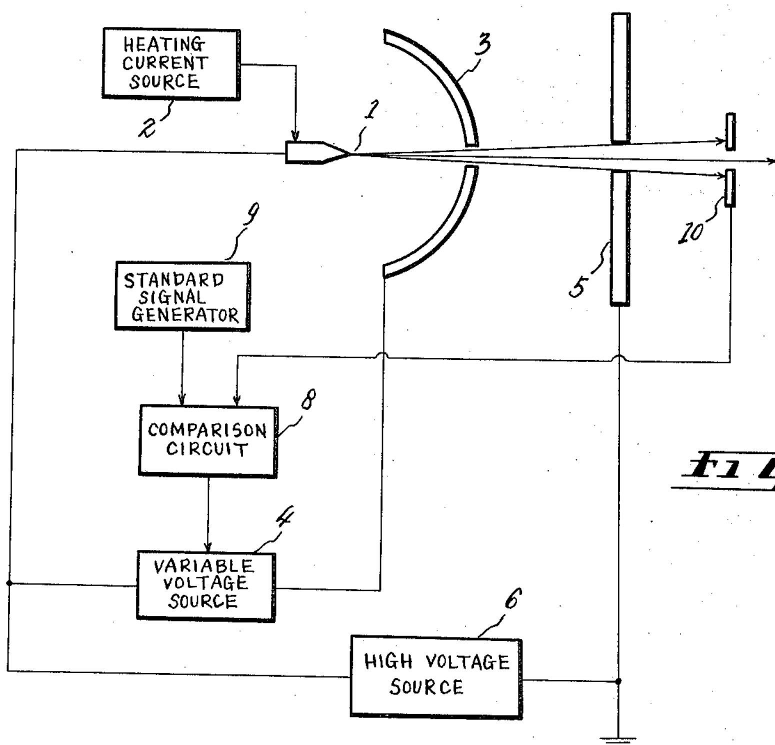

3
1
9
2
STANDARD SIGNAL GENERATOR
HEATING CURRENT SOURCE
5
EMISSION CURRENT DETECTOR
7
COMPARISON CIRCUIT
8
4
VARIABLE VOLTAGE SOURCE
6
HIGH VOLTAGE SOURCE

Fig. 3


HEATING CURRENT SOURCE
3
2
1
10
9
5
STANDARD SIGNAL GENERATOR
8
COMPARISON CIRCUIT
4
VARIABLE VOLTAGE SOURCE
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HIGH VOLTAGE SOURCE

Fig. 4

Fig. 5

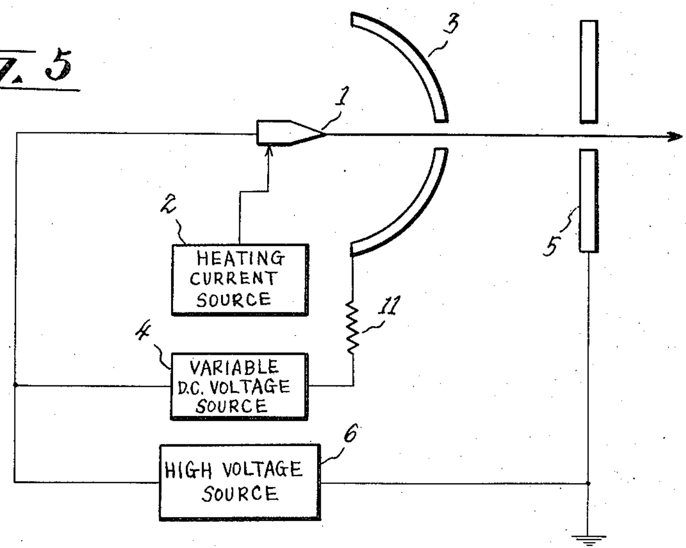
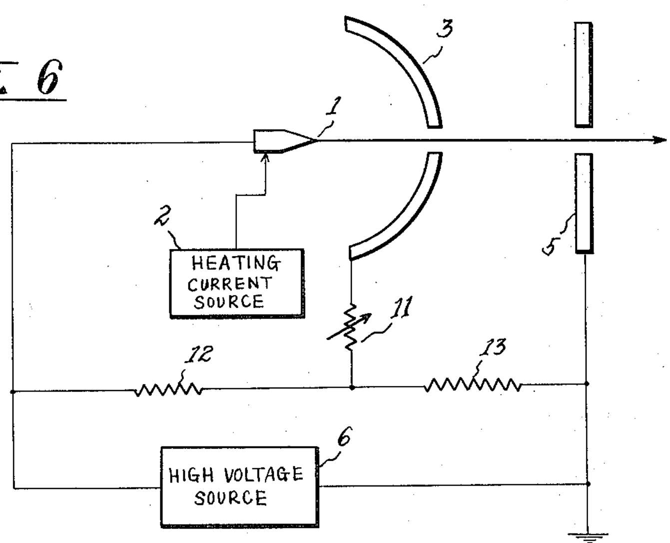


Fig. 6



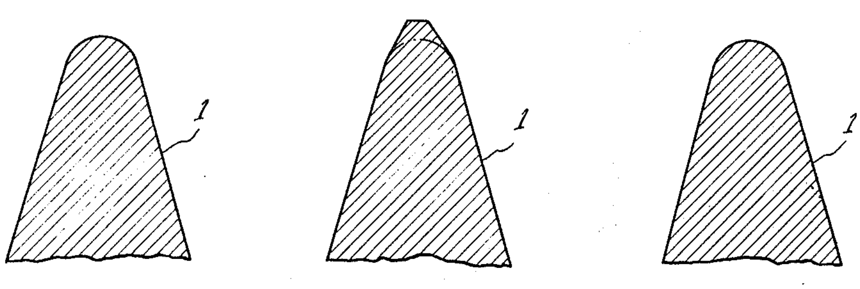


Fig. 12

Fig. 7

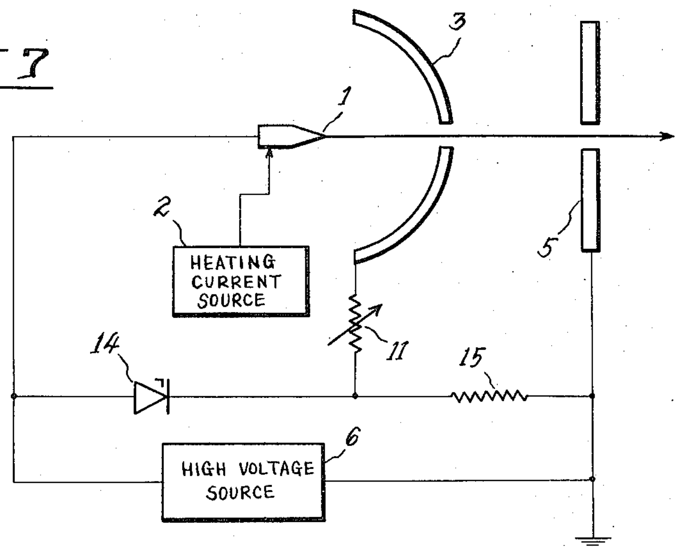

3
1
2
HEATING CURRENT SOURCE
5
14
11
15
6
HIGH VOLTAGE SOURCE

Fig. 13

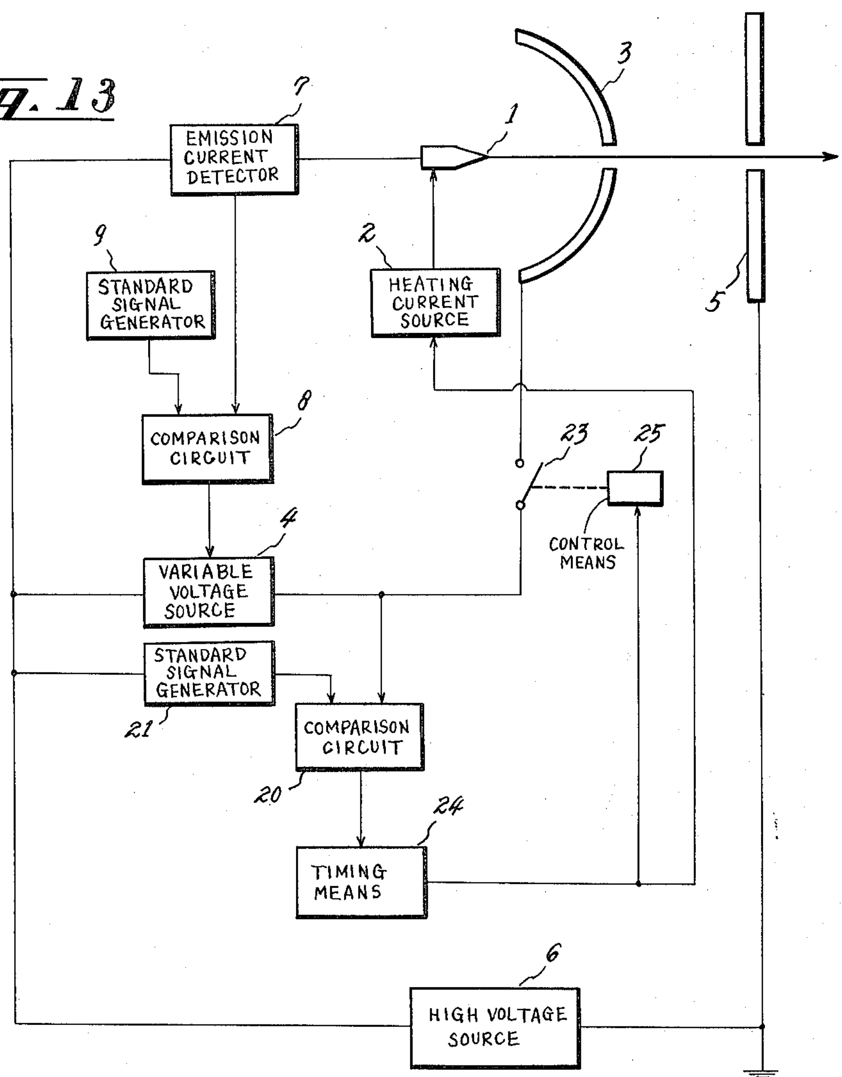
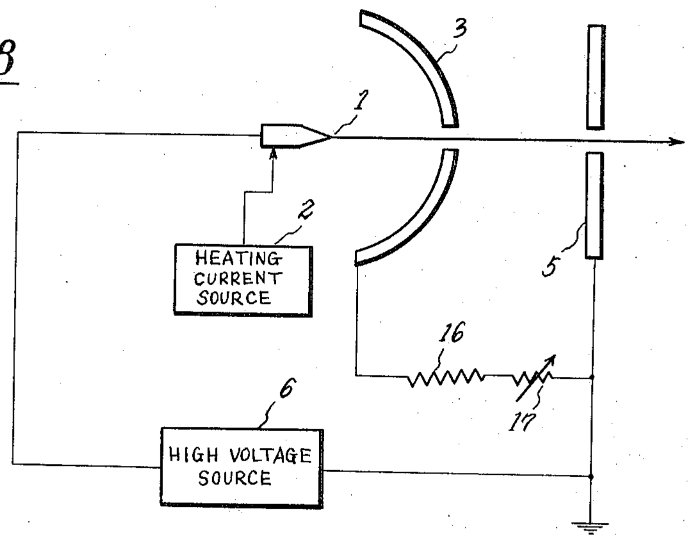

7
EMISSION CURRENT DETECTOR
3
1
9
STANDARD SIGNAL GENERATOR
2
HEATING CURRENT SOURCE
5
8
COMPARISON CIRCUIT
23
25
CONTROL MEANS
4
VARIABLE VOLTAGE SOURCE
STANDARD SIGNAL GENERATOR
21
COMPARISON CIRCUIT
20
24
TIMING MEANS
6
HIGH VOLTAGE SOURCE

Fig. 8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2
HEATING CURRENT SOURCE
5
16
17
6
HIGH VOLTAGE SOURCE

Fig. 11

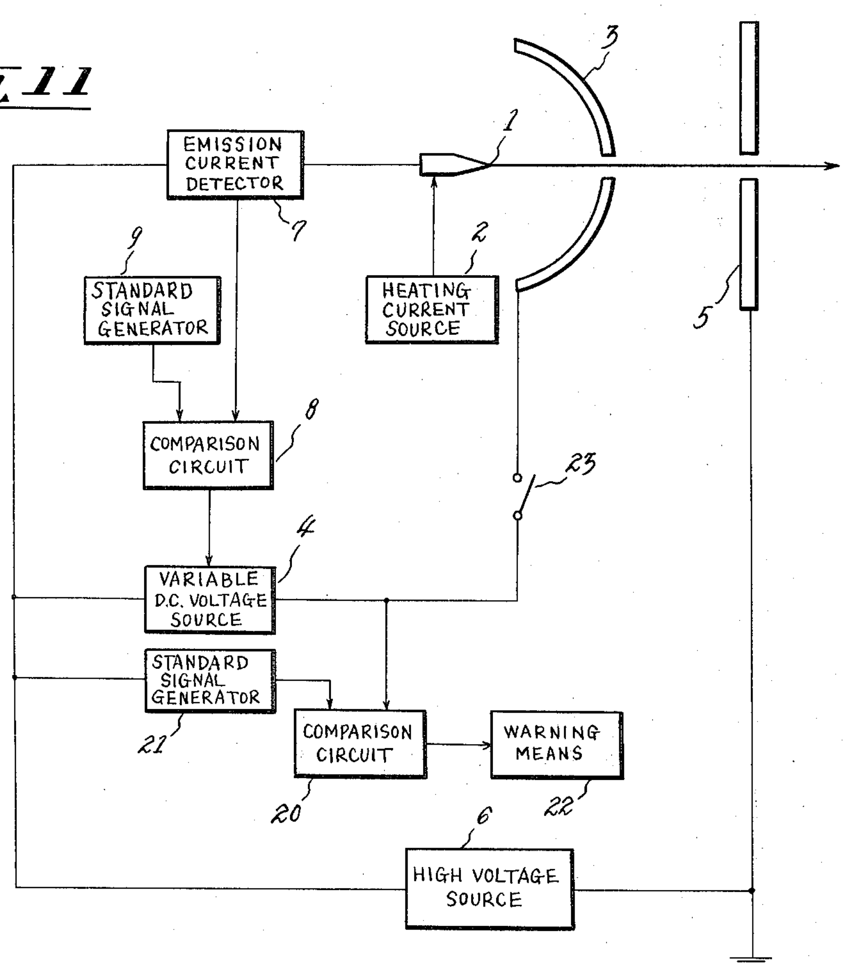
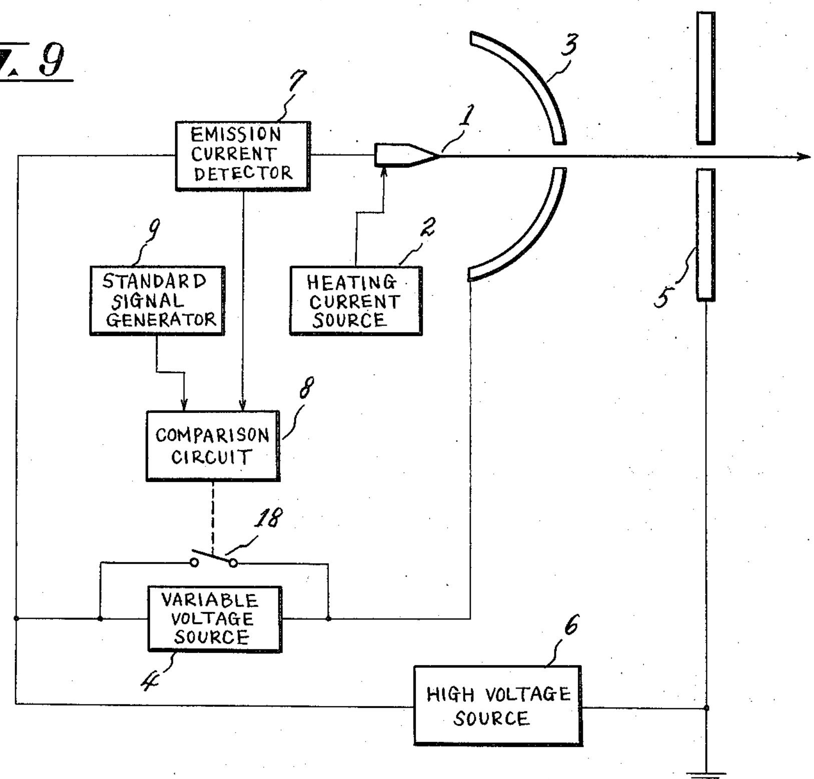

3
EMISSION CURRENT DETECTOR
1
7
9
STANDARD SIGNAL GENERATOR
2
HEATING CURRENT SOURCE
5
8
COMPARISON CIRCUIT
23
4
VARIABLE D.C. VOLTAGE SOURCE
STANDARD SIGNAL GENERATOR
21
COMPARISON CIRCUIT
WARNING MEANS
20
22
6
HIGH VOLTAGE SOURCE

Fig. 9


EMISSION CURRENT DETECTOR
STANDARD SIGNAL GENERATOR
HEATING CURRENT SOURCE
COMPARISON CIRCUIT
VARIABLE VOLTAGE SOURCE
HIGH VOLTAGE SOURCE
1
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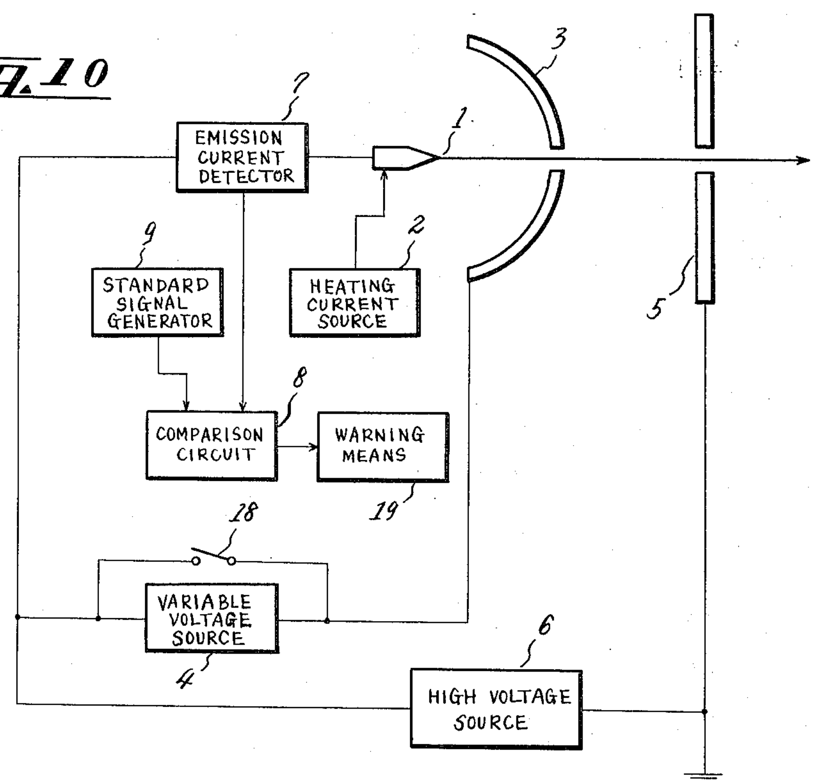
18

Fig. 10


EMISSION CURRENT DETECTOR
STANDARD SIGNAL GENERATOR
HEATING CURRENT SOURCE
COMPARISON CIRCUIT
WARNING MEANS
VARIABLE VOLTAGE SOURCE
HIGH VOLTAGE SOURCE
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19

CONSTANT CURRENT FIELD EMISSION ELECTRON GUN

This invention relates to a field emission type electron gun for use in scanning and transmission type electron microscopes.

The advantage of the field emission type electron gun as compared with the ordinary thermionic emission type electron gun, when used in electron microscopes, lies in the fact that the current density of the electron beam is very high and the electron source is very small. Such being the case, the field emission type electron gun, when used in a scanning type electron microscope, provides better image resolution than would be possible with the thermionic emission type electron gun. Also, when used in a transmission type electron microscope, this type of gun ensures better image contrast than in the case of the thermionic emission type electron gun, as a result of improved coherency of electron beams.

However, in spite of the aforementioned advantages, the field emission type electron gun possesses certain defects foremost of which is the fact that the current density of the electron beam gradually becomes unstable as a result of contamination on the emitter surface and also deformation of the emitter tip. Various ways have been devised to counteract this instability. A popular method, although somewhat impractical due to high manufacturing costs and maintenance, is to maintain the gun chamber at a super-high vacuum, for example, on the order of 10^{-9} to 10^{-10} Torr. By so doing, the local work functions of the emitter remains stable since the emitter surface contamination is prevented.

Another method is to maintain the emitter at a high temperature during field emission. By so doing, contamination is prevented and the electron beam current remains stable in spite of the comparatively low degree of vacuum. Heating the emitter, however, as described above, causes the emitter tip to become soft which results in a gradual buildup of crystal planes on the surface of the emitter. This crystalline formation or buildup, if allowed to progress, would cause the electric field intensity at the emitter tip to increase locally and irregularly resulting in excess emission and eventual damage to the emitter tip.

The field emission gun according to this invention is characterized by the provision of a device or circuit for detecting the electron beam current fluctuation and a device or circuit for controlling the electric field in accordance with the output (feedback) signal of the detecting circuit.

Accordingly, an advantage of this invention is to control this so called buildup of crystals on the emitter surface. A second advantage of this invention is to prevent the electron beam current from becoming unstable and to reform the emitter tip after deformation due to crystal buildup.

Further features and other objects and advantages will become clear from a reading of the following detailed description made with reference to the drawings in which:

FIGS. **1**(*a*) and **1**(*b*) are graphs showing the relationship between the emission current and elapsed time in a field emission type electron gun;

FIGS. **2** to **11** and **13** are block diagrams of the field emission type electron guns according to this invention; and,

FIGS. **12**(*a*), **12**(*b*) and **12**(*c*) are schematic views of the various emitter tips.

FIGS. **1**(*a*) and **1**(*b*) are graphs showing the relationship between the electron beam current and elapsed time in a conventional field emission type gun. The graded increase of the electron beam current shown in FIG. **1**(*a*) is due to crystal buildup but by weakening the electric field at the emitter tip at t_1, the current intensity may be reduced to its initial value. After remaining at this value for some time, the current intensity gradually decreases as shown in FIG. **1**(*b*) and may be restored once more to its original value by intensifying the electric field. Thus, by controlling the electric field, the current intensity of the electron beam can be kept stable.

FIG. **2** shows one embodiment of this invention. Emitter **1**, made of tungsten or the like, is heated to a suitable temperature, for example 1,600°C, by applying current from a heating current source **2**. The first anode **3** is maintained at a potential positive to that of the emitter by means of a variable D.C. voltage source **4**. A second anode **5** is connected to the positive output terminal of a high voltage accelerating source **6**, said terminal being maintained at ground potential. The negative output terminal of the source **6** is connected to the emitter **1** via an emission current detector **7** which detects all the electrons emitted from said emitter and converts them into an electrical signal. The output signal from the emission current detector **7** is then applied to a comparison circuit **8** where it is compared with a reference signal from a standard signal generator **9**. The compared signal is applied to the variable D.C. voltage source **4**, thereby controlling the potential of the first electrode **3** so as to keep the electron current constant.

By so doing, even if the emitter tip is slightly deformed by a strong electric field, the emitter can be used over a long period of time, because the potential of the first electrode **3** decreases so as to prevent an increase of emission current. Again, since the emitter tips do not necessarily have to be exactly identical, in view of the fact that the constant electron beam current is obtained at all times, emitter exchange presents no problems.

FIG. **3** shows another embodiment of this invention in which the emission current detector **7** is arranged between the variable D.C. voltage source **4** and the first electrode **3**. In this arrangement, the inflow of electrons to the first anode **3** is detected and since this inflow is proportional to the outflow of electrons from the emitter, the control function of this embodiment is exactly the same as that in the embodiment shown in FIG. **2**.

FIG. **4** shows a third embodiment of this invention in which an electron beam detector **10** arranged behind the second anode **5** is used instead of the emission current detector **7** described in the previous embodiments. In this case, the detector **10** comprised of a semiconductor, for example, a simple electric conducting plate or a converter for converting the electron beam into a light or X-ray, said light or X-ray then being converted into an electrical signal.

FIG. **5** shows a fourth embodiment of this invention in which a resistor **11** is connected between the variable D.C. voltage source **4** and the first anode **3** so as to control the electric field automatically. The resistor **11** has two functions, one being to detect the electron beam fluctuation and the other to control the electric field in accordance with said fluctuation. In this embodiment, the potential difference between the emitter 1 and the first anode 3 is equal to the sum of the output voltage V_E of source 4 and the voltage across the resistor 11, the polarity of which is opposite to that of the output voltage V_E (volt). The reason for this is that the voltage across the resistor 11 (R ohm) is determined by the electron current Ie (ampere) flowing into the anode 3. Accordingly, voltage $V_{EA} = V_E - Ie \cdot R$ is applied between the emitter 1 and the anode 3. In this case, if Ie increases, V_{EA} decreases so as to reduce the electron current by weakening the electric field. Conversely, if Ie decreases, V_{EA} increases so as to increase the electron current by strengthening the electric field. Thus, by utilizing this embodiment, the stability of the electron beam current is improved. As a result, electron beam fluctuation due to the elapse of time or emitter exchange does not occur.

If a variable resistor is used instead of the fixed resistor 11, a simple constant voltage source can be used instead of the variable voltage source 4, because it would then be possible to vary voltage V_{EA} by varying the variable resistor instead of varying the output of the voltage source 4.

FIG. 6 shows a fifth embodiment of this invention in which voltage V_{EA} is obtained by dividing resistors 12 and 13 instead of voltage source 4. In this case, resistor 11 can be omitted without affecting the circuit functionally.

FIG. 7 shows a sixth embodiment of this invention in which a constant voltage element 14, for example, a Zener diode, and a resistor 15 are used instead of resistors 12 and 13.

FIG. 8 shows a seventh embodiment of this invention in which the voltage V_{EA} is obtained by a fixed resistor 16 and a variable resistor 17 through which the electron current flows from the first anode 3 to second anode 7.

FIG. 9 shows an eighth embodiment of this invention in which the intensity of the electric field between the emitter and the first anode is controlled intermittently by means of an "on-off" switch 18 connected in parallel with the variable voltage source 4. In this arrangement, if the electron beam current reaches a set value determined by the standard signal generator 9, the resultant output of the comparison circuit 8 causes the switch 18 to activate. In other words, it is changed from "on" to "off" or vice versa. By so doing, the electron beam current is kept to within the set value, because crystal buildup on the emitter surface is prevented.

The embodiment shown in FIG. 10 is essentially the same as that shown in FIG. 9 but includes a warning device 19 (e.g., a buzzer) which is brought into operation when the output signal of the comparison circuit 8 reaches a certain intensity. As soon as the buzzer sounds, the switch is operated manually by the operator.

The various embodiments described thus far are all designed to prevent crystal buildup on the emitter surface. The remaining embodiments described below, on the other hand, are expressly designed to reform or restore the emitter tip to the original shape after deformation due to crystal buildup.

FIG. 11 shows one embodiment capable of achieving this restoration. In the figure a comparison circuit 20 compares the output voltage of the variable voltage source 4 and the output voltage of the standard signal generator 21. The comparison circuit is applied to the warning device 22. A switching means 23 controls the potential of the first anode 3. In this embodiment the heating current source 2 is designed to produce an output current capable of heating the emitter up to a sufficiently high temperature (for example about 2,000°C).

Referring to FIG. 12, (*a*) shows the shape of an unused emitter tip and (*b*) shows the change in the shape of the tip resulting from crystal buildup. If under the condition shown in (*b*), the electric field at the emitter is sufficiently weakened and the emitter is heated to a sufficiently high temperature, the emitter can be restored to its original shape as shown in (*c*) by thermal surface tension.

The comparison circuit 20 in FIG. 11 is able to monitor the progress of the crystal buildup because as the buildup progresses, the electric field at the emitter tip becomes more intense which causes the output voltage of source 4 to decrease more or less proportionately in order to keep the electron beam current constant. Thus, the decrease in the output voltage of source 4 results in a corresponding decrease in the output of the comparison circuit 20, thereby monitoring the progress of crystal buildup accurately. When the output voltage of source 4 becomes less than that of the standard signal generator 21, the comparison circuit 20 activates the warning device 22 which tells the operator to disengage switch 23. After which, the operator manually increases to output current of the current source 2 so as to increase the temperature of the emitter to a predetermined temperature thereby restoring the emitter tip to its original shape.

FIG. 13 shows an embodiment capable of automatically restoring the emitter tip to its original shape. This is made possible by the provision of a timing circuit 24 which is activated by the output signal of comparison circuit 20. In the activated state the timing circuit 24 generates a signal, having a constant time interval, which in turn activates a control means 25 for controlling the switch 23 which remains disengaged during the time the signal is being generated. Simultaneously, said time signal activates the heating current source 2 so as to raise the temperature of the emitter to a point where it is restored to its original shape.

Additionally, this invention is not limited to the above mentioned embodiments. For example, this invention can be applied to the so called "cold emission type field emission gun" which corresponds to the embodiments where the heating means 2 is omitted in FIGS. 2 to 10, in order to prevent the emission current fluctuation due to the contamination on the emitter surface.

Having thus described the invention with the detail and particularity as required by the Patent Laws, what is desired protected by Letters Patent is set forth in the following claims.

We claim:

1. A field emission type electron gun comprising:
an emitter for emitting an electron beam,
a heating means for heating said emitter,
a first anode for generating a strong electric field at said emitter,
a first voltage source for generating a potential difference between said first anode and said emitter,

a second anode located behind the first anode maintained at ground potential,

a second high voltage source for supplying negative high potential to said emitter for accelerating said electron beam,

a first detecting means for detecting the electron beam emitted from said emitter and providing a signal indicative of electron beam fluctuation,

a comparing means for comparing the output signal of said first detecting means with a reference signal and providing an output signal indicative of the comparison,

a control means for controlling the output voltage of said first voltage source in response to the output signal of said comparing means, and

a second detecting means for detecting the change in output voltage of said first voltage source providing an output signal indicative of the progress of crystal buildup on the emitter surface.

2. A field emission type electron gun according to claim **1** in which said second detecting means comprises a second comparison circuit for comparing the output voltage of said first voltage source and a reference signal voltage.

3. A field emission type electron gun comprising:

an emitter for emitting an electron beam,

a heating means for heating said emitter,

a first anode for generating a strong electric field at said emitter,

a first voltage source for generating a potential difference between said first anode and said emitter,

a second anode located behind the first anode maintained at ground potential,

a second high voltage source for supplying negative high potential to said emitter for accelerating said electron beam,

a first detecting means for detecting the electron beam emitted from said emitter and providing a signal indicative of the electron beam fluctuation,

a comparing means for comparing the output signal of said first detecting means with a reference signal and providing an output signal indicative of the comparison,

a control means for controlling the output voltage of said first voltage source in response to the output signal of said comparing means,

a second detecting means for detecting the change in output voltage of said first voltage source, and

a warning means for indicating the state of crystal buildup on the emitter surface, said warning means responsive to the output signal of said second detecting means.

4. A field emission type electron gun comprising:

an emitter for emitting an electron beam,

a heating means for heating said emitter,

a first anode for generating a strong electric field at said emitter,

a first voltage source for generating a potential difference between said first anode and said emitter,

a second anode located behind the first anode and maintained at ground potential,

a second high voltage source for supplying negative high potential to said emitter for accelerating said electron beam,

a first detecting means for detecting the electron beam emitted from said emitter and providing a signal indicative of the electron beam fluctuation,

a first comparing means for comparing the output signal of said first detecting means with a reference signal and providing a signal indicative of the comparison,

a first control means for controlling the output voltage of said first voltage source in response to the output signal of said first comparing means,

a second detecting means for detecting the change in output voltage of said first voltage source and providing an output signal indicative thereof, and

a second control means for controlling said heating means in response to the output signal of said second detecting means to restore the emitter tip after deformation due to crystal buildup.

5. A field emission type electron gun according to claim **4** in which said second control means comprises a timing circuit for controlling the time during which the emitter is heated so as to restore the emitter tip after deformation due to crystal buildup.

6. A field emission type electron gun comprising:

an emitter for emitting an electron beam,

a heating means for heating said emitter,

a first anode for generating a strong electric field at said emitter,

a first voltage source for generating a potential difference between said first anode and said emitter,

a second anode located behind the first anode and maintained at ground potential,

a second high voltage source for supplying negative high potential to said emitter for accelerating said electron beam,

a first detecting means for detecting the electron beam emitted from said emitter and providing a signal indicative of electron beam fluctuation,

a comparing means for comparing the output signal of said first detecting means with a reference signal and providing an output signal indicative of the comparison,

a first control means for controlling the output voltage of said first voltage source in response to the output signal of said comparing means,

a second detecting means for detecting the change in output voltage of said first voltage source and providing an output signal indicative thereof,

a second control means for controlling said heating means in response to the output signal of said second detecting means, and

a switching means arranged between said emitter and said first anode, said switching means controlled in response to the output signal of said second detecting means.

* * * * *