July 6, 1948. J. HILLIER 2,444,700

METHOD OF OPERATING ELECTRON GUNS

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Fig. 1.

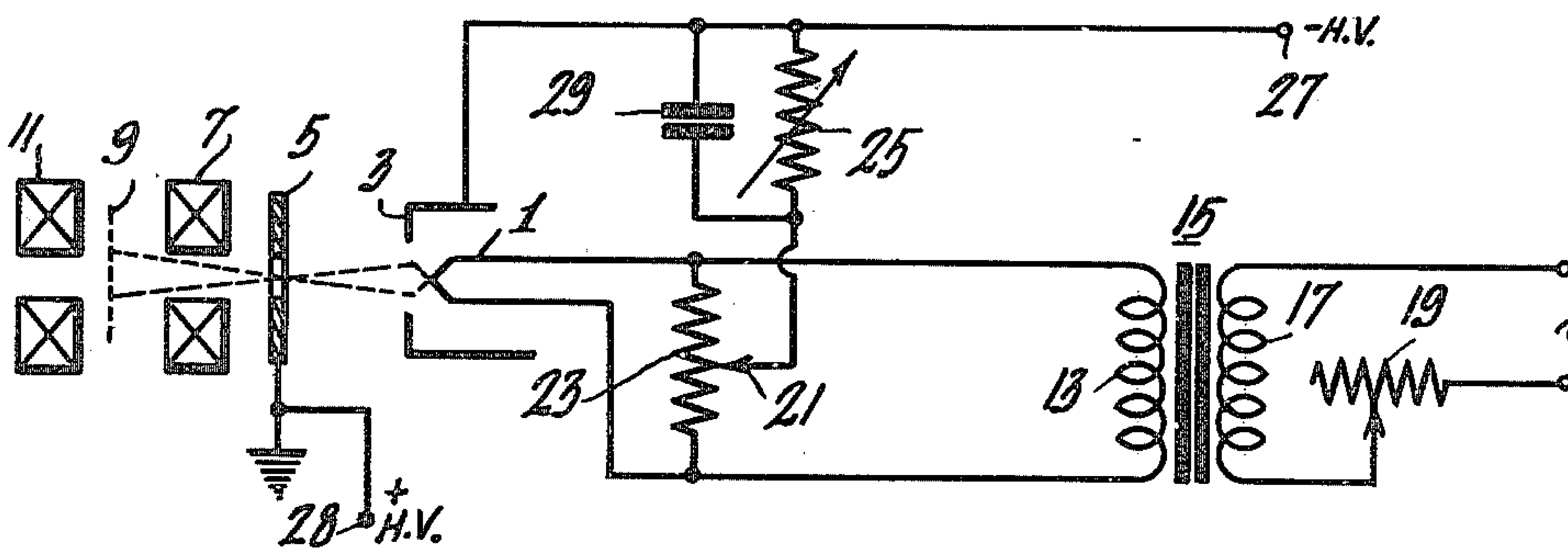

Fig. 6.

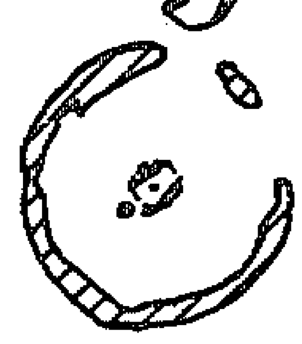

Fig. 7.

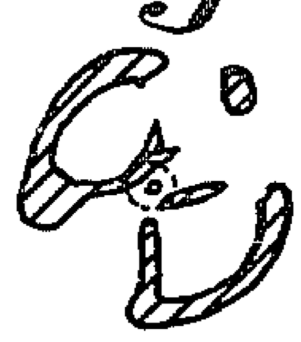

Fig. 8.

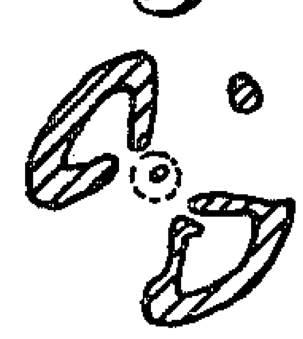

Fig. 9.

Fig. 10.

Fig. 11.

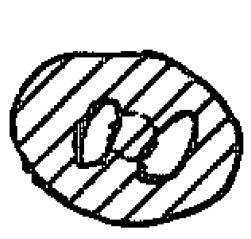

Fig. 12.

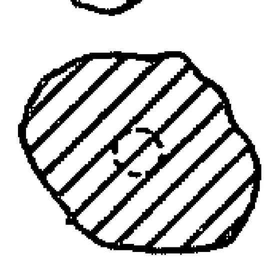

Fig. 13.

Fig. 14.

Fig. 15.

Fig. 16.

Fig. 17.

Fig. 18.

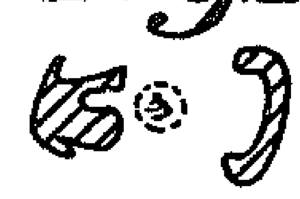

Fig. 19.

Fig. 20.

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Fig. 3.

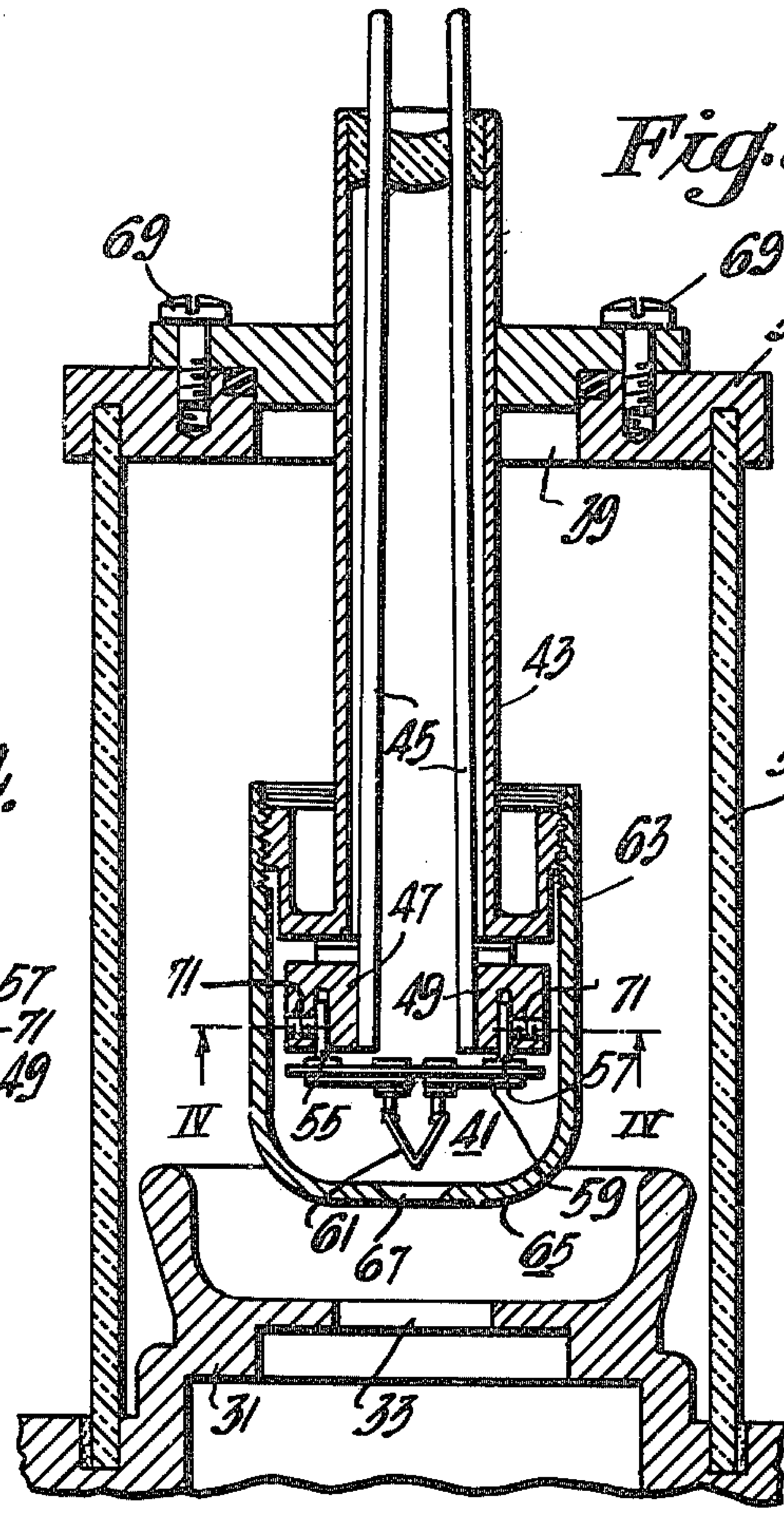


Fig. 4.

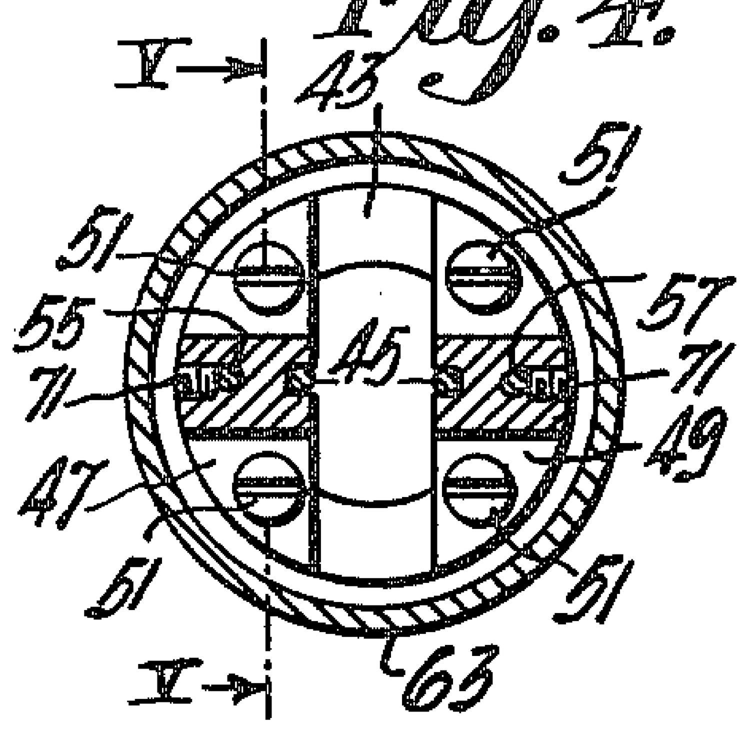


Fig. 5.

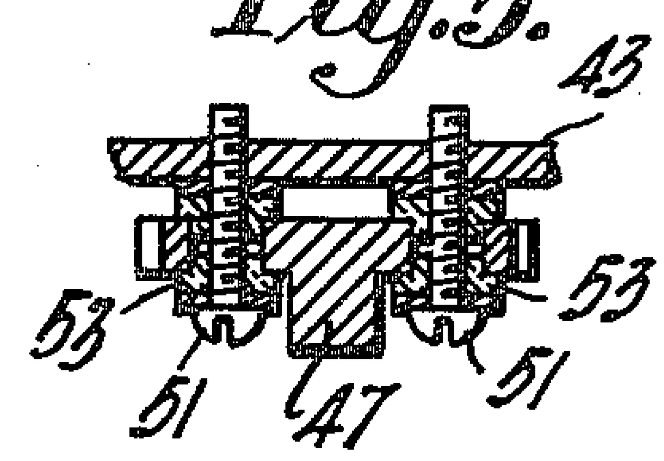
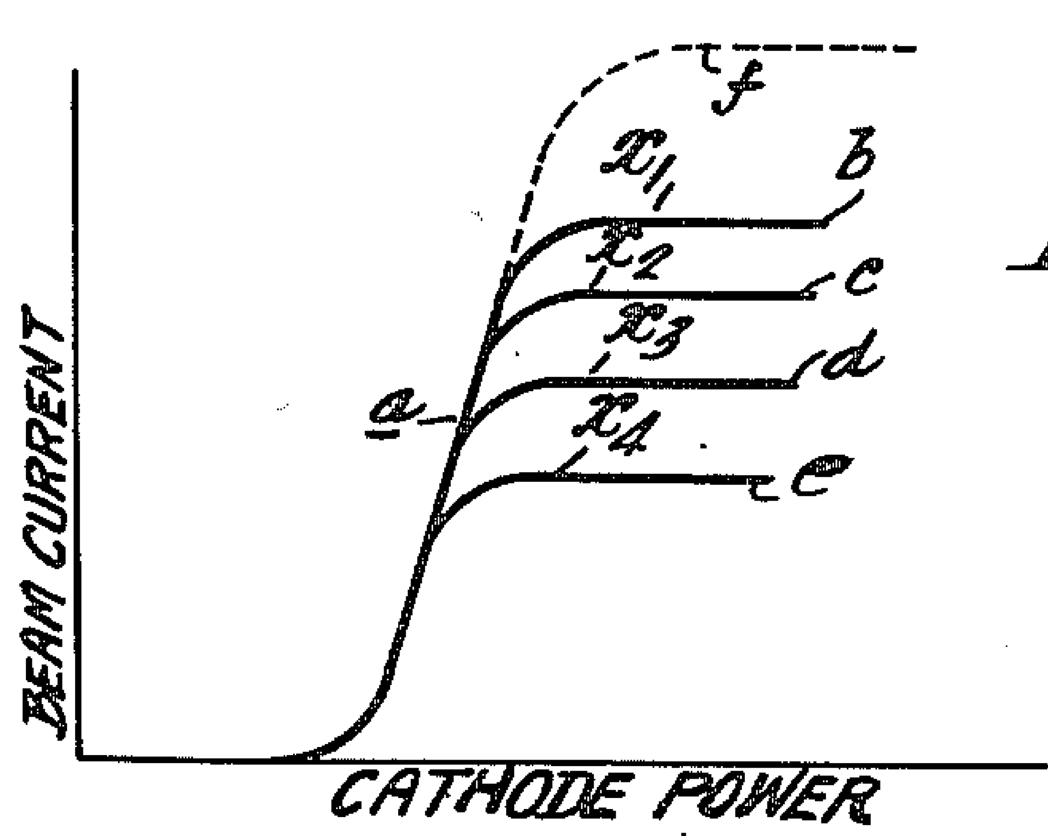


Fig. 2



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UNITED STATES PATENT OFFICE

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METHOD OF OPERATING ELECTRON GUNS

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8 Claims. (Cl. 250—49.5)

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This invention relates generally to electron optical systems and more particularly to an improved method for operating an electron gun for electron microscopy.

Heretofore one of the most troublesome aspects of operating an electron microscope or electron diffraction camera has been the necessity of very accurately adjusting and aligning the electron source with respect to the axis of the electron optical system. Complicated micrometer adjustments generally are provided for centering and tilting the electron gun in an electron microscope in order to provide a suitable, substantially uniform, area of electron irradiation at the microscope specimen. Standard electron microscopes usually require that the thermionic cathode be adjustable to within one or two thousandths of an inch of the microscope axis and that extremely sensitive and precise adjustments be provided for tilting the electron source to overcome remaining inaccuracies in alignment and structure.

It has been customary to include an apertured cathode diaphragm adjacent to the electron-emissive tip of the thermionic cathode, and to apply a bias potential to the apertured diaphragm to provide some focusing of the emitted electrons prior to their passage through the apertured microscope anode electrode. Such biasing of the apertured diaphragm customarily is at relatively low negative voltage values. However, the electron beam current in existing microscopes is substantially dependent upon the energizing currents and potentials applied to the thermionic cathode and anode electrodes, and hence provides a temperature-limited electron gun. Due to the rather slight focusing action of the apertured cathode diaphragm, electrons are emitted from a relatively large area on the thermionic cathode and thus provide objectionable side images of the cathode with resultant low efficiency due to the small portion of the emitted electrons which may be focused upon the microscope specimen by means of the usual electron condenser lens.

The instant invention comprises an improved method for operating conventional electron guns for electron microscopy wherein the apertured cathode diaphragm is biased to a relatively high negative voltage which provides substantially saturated space charge limitation of the thermionic cathode emission. The high negative bias voltage applied to the apertured cathode diaphragm is derived from a resistor effectively connected in series with the cathode beam current and thus may be utilized to control degener-

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atively the beam current by means of the grid action of the apertured cathode diaphragm. The bias resistor preferably should be shunted by a suitable capacitor in order substantially to minimize control voltage variations due to ripple in filament excitation and beam voltage.

Heretofore it always has been considered essential that the cathode diaphragm be operated at a sufficiently low voltage to provide an actual electron image of the tip of the cathode at the plane of the specimen. However, customary methods of operation provide a relatively widely divergent cathode beam which permits a relatively large proportion of the cathode ray to impinge upon the apertured anode electrode, causing out-gassing and metallic sputtering therefrom. By utilizing a sufficiently high negative bias voltage upon the cathode diaphragm, the resultant substantially saturated space charge condition effectively limits the cathode emission to a minute area close to the cathode diaphragm. This results in a minute, substantially symmetrical electron source which is focused to an extremely narrow diverging electron beam by the relatively high focusing action of the high negative potential applied to the cathode diaphragm. The resulting narrow cathode beam substantially entirely passes through the anode aperture, and is readily focused by the condenser lens to form a greatly intensified area of electron irradiation a the plane of the specimen.

A unique feature of the improved method of operation is that micrometer adjustments for the alignment and tilting of the thermionic cathode may be eliminated, since the electron-emissive area of the cathode is automatically centered by means of the space charge limitation provided by the highly negatively biased cathode diaphragm. Also since the automatically centered electron source has a minute area of substantially symmetrical or circular shape, the resulting intense area of irradiation at the plane of the specimen is susbtantially uniform and of the desired relatively small size. Objectionable side images of the cathode encountered with older methods of operation are susbtantially eliminated, and the efficiency of the cathode gun is increased in the order of twenty times.

The increase in electron gun efficiency permits much lower values of beam current while providing suffiicent electron irradiation to permit visual observation of specimen images at desired final magnifications as high as 50,000 x. Heretofore observation of images at such high magnification was possible only by photographic means, and focusing adjustments had to be made at magnifications lower by at least an order of magnitude. Reduced electron beam current magnitudes permit more efficient filtering of the beam voltage thus providing more stable operation.

Among the objects of the invention are to provide an improved method of operating an electron gun. Another object is to provide an improved method of operating an electron gun in an electron microscope wherein the electron emissive-area of the cathode is automatically aligned with the electron accelerating and focusing elements of the electron gun. A further object of the invention is to provide an improved method of operating an electron gun wherein a cathode focusing electrode is biased sufficiently negatively to provide substantially saturated space charge limitation of the thermionic cathode emission. An additional object of the invention is to provide an improved method of operating an electron gun for electron microscopy wherein micrometer adjustments of the alignment and tilting of the thermionic cathode may be eliminated.

Another object of the invention is to provide an improved method of operating an electron gun having an apertured cathode lens electrode wherein said electrode is biased sufficiently negatively with respect to the thermionic cathode to provide electron beam current saturation. A further object is to provide an improved method of operating an electron gun in an electron microscope to provide increased and more uniform electron irradiation of the microscope specimen. An additional object is to provide an improved method of operating an electron gun in electron microscopy to provide greater cathode electronic efficiency and improved reliability in operation. Another object of the invention is to provide an improved method of operating an electron gun in an electron microscope wherein a relatively high negative bias voltage, dependent upon beam current, is applied to a cathode focusing electrode to provide substantially saturated space charge limitation of the cathode emission and substantially automatic self-focusing of the cathode emission with respect to the axis of the electron gun. An additional object is to provide an improved method of operating such a cathode gun circuit including the step of filtering and smoothing the bias voltage applied to the cathode focusing electrode.

The invention will be described in greater detail by reference to the accompanying drawings of which Figure 1 is a schematic circuit diagram of a preferred circuit for performing the novel method of applicant's invention; Figure 2 is a family of graphs illustrative of the operating characteristics of the space-charge-limited cathode; Figure 3 is an elevational cross-sectional view of a typical electron gun which may be operated in accordance with applicant's novel method; Figure 4 is a cross-sectional view taken along the section lines IV—IV of the device of Figure 3; Figure 5 is a cross-sectional view taken along the section lines V—V of Figure 4; Figures 6–10 inclusive, are diagrammatical views of the effective area of electron irradiation of a microscope specimen as the cathode diaphragm bias voltage is successively negatively increased; Figures 11–15 are views of the effective areas of electron irradiation of a microscope specimen for successively increasing negative bias voltages applied to the cathode diaphragm, wherein the cathode is located substantially closer to the cathode diaphragm than in the instances illustrated in Figures 6–10; and Figures 16–20 are views of the effective areas of electron irradiation of a specimen for successively increased negative bias voltages applied to the cathode diaphragm, showing the automatic self-centering of the effective cathode ray when the cathode structure is out of alignment with the axis of the electron gun. Similar reference characters are applied to similar elements throughout the drawings.

Referring to Figure 1 of the drawing, a conventional electron gun energizing circuit is shown wherein a thermionic cathode **1**, having an apertured cathode diaphragm **3** disposed adjacent thereto, provides an electron beam which is accelerated by a high positive potential applied to an apertured anode electrode **5**. The electron beam passing through the anode aperture is focused by a conventional electromagnetic or electrostatic condenser lens **7** to irradiate a predetermined area on the microscope specimen **9**. The irradiated area of the specimen **9** is imaged by a conventional electromagnetic or electrostatic objective lens **11**. The magnified image provided by the objective lens may be further magnified, if desired, and applied to a fluorescent screen or photographic plate, not shown, in accordance with conventional electron microscope technique.

The thermionic cathode **1** is energized either by low or high frequency alternating currents derived from the secondary winding **13** of a filament transformer **15**, the primary winding **17** of which is connected through a control resistor **19** to a source of alternating potential. The adjustable center tap **21** of a resistor **23** connected across the thermionic cathode **1** is connected through a variable high resistor **25** to the negative terminal **27** of the source of beam accelerating potential. The positive terminal **28** of the beam accelerating potential source is connected to the anode **5** and to ground. The negative high potential terminal **27** is connected to the cathode focusing diaphragm **3** whereby the diaphragm is biased negatively with respect to the thermionic cathode **1** as a function of the voltage drop in the variable resistor **25**.

The variable bias resistor **25** is shunted by a by-pass capacitor **29** to minimize the effects of ripple in the electron gun energizing and accelerating potential sources. The circuit arrangement described is conventional in all respects except that the value of the variable bias resistor **25** is made sufficiently high to provide a negative bias voltage of the order of 500 volts on the apertured cathode diaphragm **3** for providing substantially saturated space charge limitation of the cathode emission. Also the resistor **19** in the cathode energizing circuit is adjusted to provide a cathode temperature which is slightly above the value at which the beam current reaches saturation. Thus due to the space charge limiting of the high negative bias potential applied to the cathode focusing diaphragm, variations in cathode energizing current have substantially no effect upon the beam current or focusing. Also, due to the fact that the cathode focusing bias is dependent upon beam current, variations therein provide corresponding changes in the cathode diaphragm voltage which degeneratively regulate the beam current. As explained heretofore, the space charge limiting action of the high negative potential applied to the cathode diaphragm **3** tends to center automatically the effective source of cathode electronic emission with respect to the axis of the cathode diaphragm and anode aperture, thus eliminating the necessity for micrometer adjustments for cathode alignment and orientation. The saturation value of the beam current is determined principally by the axial separation of the thermionic cathode tip from the plane of the focusing aperture, as is indicated in the family of graphs illustrated in Figure 2.

Figure 2 shows a family of graphs illustrating the relation between beam current and cathode power, for different spacings between the tip of the cathode and the plane of the apertured cathode diaphragm. Heretofore, electron microscope cathode diaphragms have been biased in a manner whereby the electron gun operated in the region A of its static characteristic. In accordance with the present invention the electron gun is operated under saturated conditions as indicated by the points x_1, x_2, x_3, x_4, on the graphs b, c, d, e, respectively. The graphs b, c, d, e, represent, in the order named, the static characteristics of the electron gun for progressively closer spacing between the tip of the thermionic cathode and the plane of the apertured cathode diaphragm. The dash line graph f represents the static characteristic of electron guns employed heretofore in electron microscope apparatus.

Due to the more efficient utilization of the cathode emission and the more effective focusing thereof provided by the high negative cathode lens bias and the resultant saturated space charge limitation, the increased efficiency in electron irradiation of the specimen permits the use of beam currents as low as 150 microamperes, in comparison to customary beam currents of the order of 1–5 milliamperes, thus permitting better regulation and filtering of the beam accelerating voltage source.

Figures 3, 4 and 5 show the structure of an electron gun which may be operated in accordance with the present invention. The grounded anode structure **31** includes an anode aperture **33** located on the axis of the microscope. The anode supports a cylindrical glass insulator **35** which in turn supports an annular ring **37** having a central aperture **39** of sufficient size to permit the cathode assembly **41** to be removed for adjustment and for replacement of the thermionic cathode. The cathode assembly **41** includes a tubular member **43** through which the cathode energizing conductors **45** extend to terminating blocks **47** and **49** which are slotted to receive the conductors **45**. The terminating blocks **47** and **49** are fastened to the end of the tubular member **43** by means of screws **51** extending through insulating grommets **53**. The terminals **47** and **49** are apertured to receive connecting pins **55** and **57**, respectively, which support a mica sheet **59** upon which a hair-pin tungsten filament **61** is mounted. The pins **55** and **57** are connected directly to the ends of the hair-pin filament **61**.

The end of the tubular member **43** adjacent to the conductor terminals **47** and **49**, is folded backwards and threaded to the complementarily threaded end portion **63** of the apertured cathode diaphragm **65**, whereby the axial spacing may be adjusted between the tip of the cathode filament **61** and the plane of the aperture **67** of the apertured diaphragm. The entire cathode assembly may be removed from the gun by removing screws **69** which are threaded into the annular supporting ring **37**. The thermionic cathode assembly is held in position in the cathode terminals **47** and **49** by means of set screws **71** which engage the cathode pins **55** and **57**.

Figures 6–10 inclusive show greatly enlarged views of the electron irradiation pattern at the microscope specimen plane for progressively increased negative bias applied to the cathode diaphragm for a relatively wide spacing between the thermionic cathode and the plane of the cathode diaphragm aperture. The small circle shown in dash lines in each of the figures indicates the useful area of specimen irradiation, and the density of shading in each of the views indicates the relative intensity of electron irradiation at the specimen.

Figures 11–15 are similar to Figures 6–10, respectively except that they indicate the relative distribution and intensity of electron irradiation at the specimen as the cathode diaphragm bias is varied for relatively closer spacing between the thermionic cathode and the plane of the cathode diaphragm. Figures 6–15 are illustrative of electron gun irradiation patterns when the thermionic cathode is accurately aligned with the microscope axis. Figures 16–20 show the effect of progressively increased negative bias voltage on the cathode apertured diaphragm in automatically centering the irradiation pattern at the microscope axis. Figures 10, 15 and 20 show that the use of a sufficiently high negative bias potential on the cathode diaphragm to provide substantially saturated space charge limitation of the cathode emission and provides a relatively intense, circular, uniform area of electron irradiation at the specimen plane. Objectionable side images of the thermionic cathode are substantially eliminated and a very large proportion of the cathode emission is effectively focused uniformly within a useful region at the specimen plane.

Thus the invention disclosed comprises an improved method for operating an electron gun in electron optical apparatus by utilizing space charge limitation of the cathode emission under substantially saturated conditions to provide an accurately focused, uniformly distributed, region of intense electron irradiation at the image plane.

I claim as my invention:

1. In an electron optical system having an electron gun including a thermionic cathode and an apertured cathode lens electrode, the method of providing effective self-centering of the electronic emission of said cathode with respect to the axis of said lens aperture comprising energizing said cathode and biasing said lens electrode with respect to said cathode to provide electron beam current saturation.

2. In an electron optical system having an electron gun including a thermionic cathode and an apertured cathode lens electrode, the method of providing effective self-centering of the electronic emission of said cathode with respect to the axis of said lens aperture comprising energizing said cathode and biasing said lens electrode with respect to said cathode to provide electron beam current saturated space charge limitation.

3. In an electron optical system having an electron gun including a thermionic cathode and an apertured cathode lens electrode, the method of providing effective self-centering of the electronic emission of said cathode with respect to the axis of said lens aperture comprising energizing said cathode, adjusting the spacing between said cathode and said lens, and biasing said lens electrode with respect to said cathode to provide electron beam current saturated space charge limitation.

4. In an electron optical system having an elec-

tron gun including a thermionic cathode and an apertured cathode lens electrode for electron irradiation of an object, the method of providing maximum and substantially uniform irradiation of said object comprising energizing said cathode and biasing said lens electrode with respect to said cathode to provide electron beam current saturation.

5. In an electron optical system having an electron gun including a thermionic cathode and an apertured cathode lens electrode for electron irradiation of an object, the method of providing effective self-centering of the electronic emission of said cathode with respect to the axis of said lens aperture and said object comprising energizing said cathode and biasing said lens electrode with respect to said cathode to provide electron beam current saturated space charge limitation.

6. In an electron optical system having an electron gun including a thermionic cathode and an apertured cathode lens electrode for electron irradiation of an object, the method of providing effective self-centering of the electronic emission of said cathode with respect to the axis of said lens aperture comprising energizing said cathode, deriving an electron beam current for irradiating said object, deriving a bias voltage in response to said beam current, and applying said bias voltage between said lens electrode and said cathode to provide electron beam current saturated space charge limitation.

7. The method according to claim 6 including filtering said bias voltage to minimize variations in cathode lens focusing and beam current due to variations in energizing potentials.

8. The method according to claim 6 including degeneratively controlling said beam current by said bias voltage.

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