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[54] **ELECTRON BEAM INJECTOR AND FOCUSING MEANS SUITABLE FOR ELECTRON MICROSCOPE**
6 Claims, 1 Drawing Fig.

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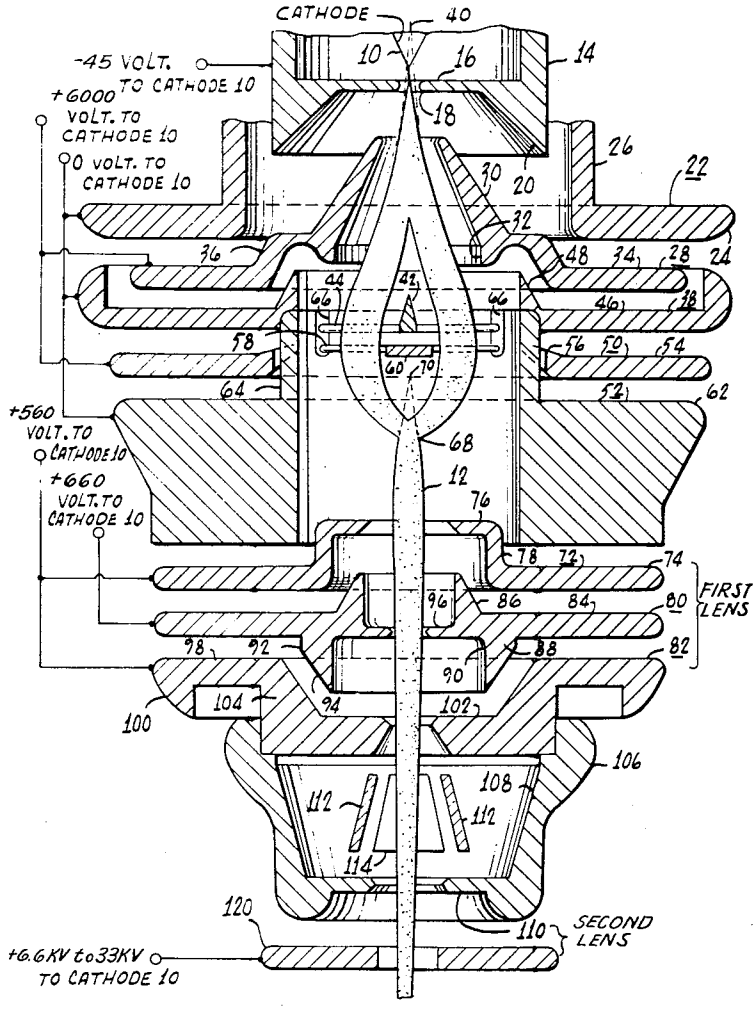
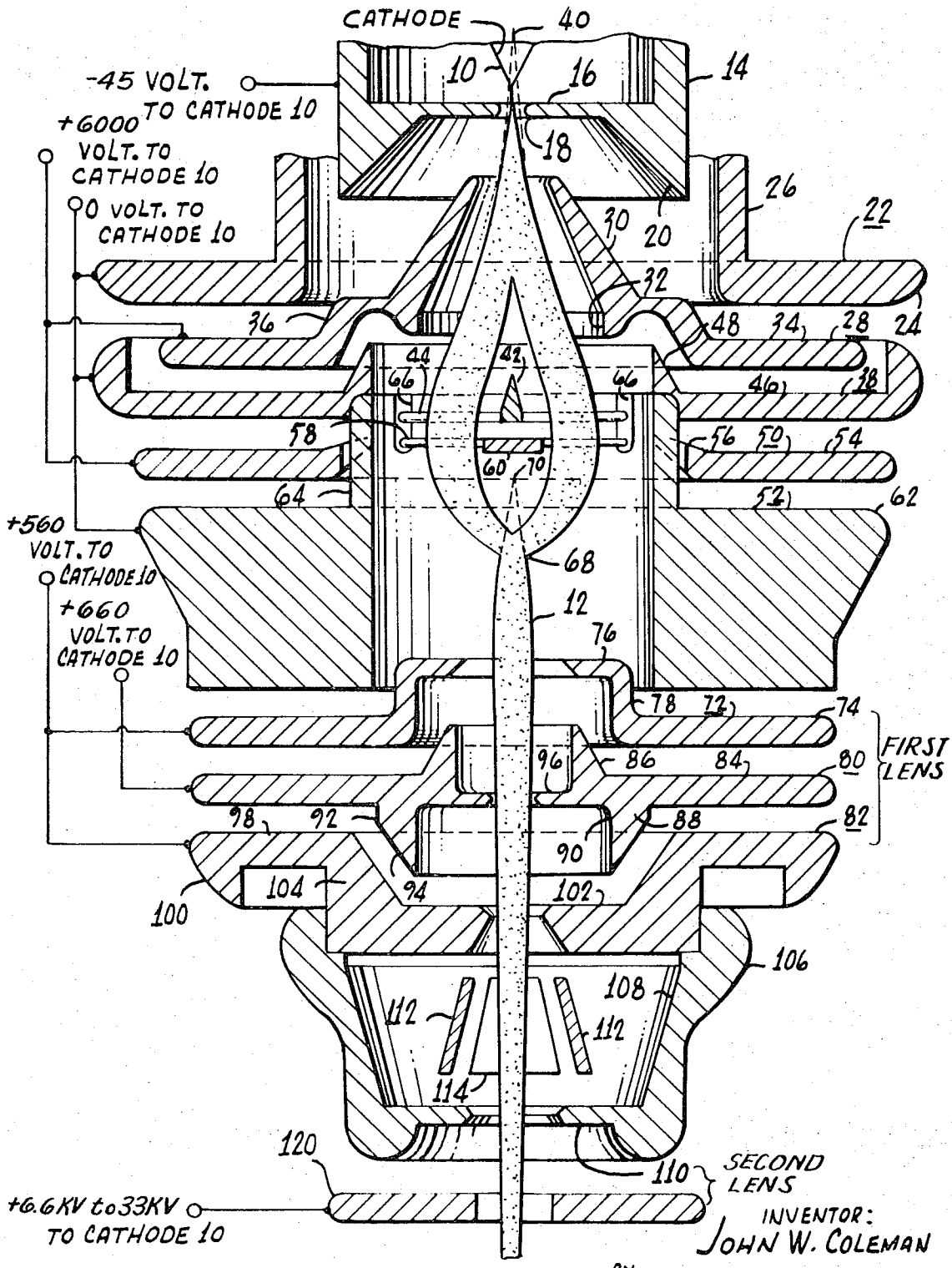
ABSTRACT: An electron beam focusing means including a grid cap and accelerating lenses is provided. To permit a small change of voltage on the grid cap to overcome the defocusing effect of a great change in voltage on the accelerating electrodes, a short focal length accelerating lens is positioned in the front focal length of the long focal length lens constituted by the high voltage accelerating electrodes.





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ELECTRON BEAM INJECTOR AND FOCUSING MEANS SUITABLE FOR ELECTRON MICROSCOPE

This application is a division of application Ser. No. 577,353, filed Sept. 6, 1966 now U.S. Pat. No. 3,452,241.

This invention relates to an electron beam producing means, for example, an electron gun which produces a collimated electron beam that is particularly suitable for use in an electron microscope but is not limited to that use.

When an electron beam produced by a beam producing means or gun is accelerated, as by accelerating electrodes, the voltage applied to the accelerating electrodes has a lens effect on the beam, whereby a change in accelerating voltage requires a change in focusing of the beam.

It is an object of this invention to provide an electron beam source for a linear electron accelerator in which defocusing of the beam by changes of acceleration voltage is minimized.

In accordance with this invention, lens means are provided for focusing the beam and means are provided for accelerating the electrons thereof, the lens means and the accelerating means including an element in common. While the electron beams so provided can be used for many purposes for which an electron beam gun is suitable, such as the beam gun of a cathode-ray tube, it can also be used in a high-voltage beam microscope with further beam accelerating means. When so used, the defocusing of the beam resulting from changes in voltage of the further acceleration means is minimized by the construction of the electron gun.

The invention may be better understood upon reading the following specification in connection with the accompanying drawing in which the sole FIGURE is a fragmentary section of an election microscope taken through a vertical axis thereof.

Turning to the FIGURE, a filamentary cathode **10** which is heated and held at a high negative accelerating potential with respect to ground by suitable means, not shown, acts as a source of electrons for the beam **12**. A grid cap **14** which is held at a bias voltage such as −45 volts with respect to the filamentary cathode **10** surrounds the cathode **10**. The grid cap **14** is symmetrical about its central vertical axis as viewed in the FIGURE. The central portion of the cap **14** is in the form of a plate **16** having a hole **18** therethrough for the passage of electrons from the cathode **10**, and the outer portion of the grid cap **14** is formed to provide an outwardly and downwardly slanting conical wall **20**. A further axially symmetrical electrode **22** which comprises an annular-shaped disk **24** and a cylindrical portion **26** is positioned coaxially with the cap **14** and with the disk **24** below the cap **14**, the cylindrical portion **26** surrounding the grid cap **14**. The electrode **22** is maintained by suitable means, not shown, at the voltage of the cathode **10**. An axially symmetrical electrode **28**, which is maintained at about 6,000 volts positive with respect to the cathode **10** by suitable means, not shown, is also positioned coaxially with the cap **14**. The electrode **28** comprises a hollow portion **30** which is frustoconical both at its outer and inner surfaces, the top of the portion **30** extending up into the conical portion **20** of the grid **14**. The upper end of the portion **30** has a hole therethrough for passage of electrons. The lower part **32** of the conical portion **30** is cylindrical in internal shape. The conical portion **30** is joined to an annular disklike portion **34** by an intermediate portion **36**. The lower edge of the intermediate portion **36** is hollowed out as shown to provide clearance between the electrode **28** and an electrode **38** as will be more fully explained.

Due to the shape of the lower surface of the grid cap **14** and to the shapes of the electrodes **22** and **28** and due to the potentials applied thereto, the beam of electrons **12** exiting through the hole **18** will expand radially in a symmetrical manner as it goes down and will therefore take the conical shape shown, the cylindrical portion **32** causing a speeding up of the radial expansion of the beams since the surface **32** does not recede from the beam as does the internal conical surface portion just above it. This expanding portion of the beam **12** acts as if it originated at the point **40**, at the apex of the lines comprising the extensions in an upward direction of the envelope of the beam **12**. Means are provided to hollow out the beam **12** and then to contract it in a radial direction. The beam hollowing out means includes the axially symmetrical electrode **38** which is maintained at the same voltage as the cathode **10** by suitable means, not shown. The electrode **38** includes a pointed portion **42**, the point thereof extending upwardly, the portion **42** being supported by spider arms **44** from an annular disk **46** comprising another portion of the electrode **38**. While only two spider arms **44** are shown, there may be as many spider arms (three for example) as is desired.

The outer portion of the electrode **38** is turned up and surrounds the outer edges of the disk **34** forming part of the electrode **28**. The inner edge of the disk **46** is formed into an upstanding portion **48** whose inner shape is cylindrical and whose outer shape is conical and slants outwardly in a downward direction. The lower portion of the disk **46** is formed to receive a portion of an electrode **52** as will be explained. Since the electrode **38** is at a high negative potential, that of the cathode **10**, and since the electrode **28** is at a high positive potential with respect thereto, the portion **36** of the electrode **28** is cut away to prevent arcing between the electrodes **28** and **38**. Also the turning up of the outer portion of the electrode **38** to surround the electrode **28** is to prevent arcing between the electrode **28** and the microscope casing, not shown, of which the described electron gun may be a part. The shape and position of the pointed electrode portion **42**, and the negative voltage applied to it, causes the electron beam to be hollowed out to provide a substantially electron free space within the beam **12** immediately surrounding the pointed portion **42**, the space so formed being symmetrical with respect to the axis of the beam **12**.

The means for causing the beam **12** to contract in a radial direction includes the electrodes **38**, **50** and **52**. The electrode **50**, which is also axially symmetrical, includes an outer annular disk portion **54**, a transitional portion **56**, spider arms **58** and a central disk portion **60**. The transitional portion **56** has a conical upper surface and a more steeply conical lower surface and joins the lower annular portion **50** to the spider arms **58** which support the disk **60**. While only two arms **58** are shown, there may be as many thereof (three for example), as may be desired. The electrode **50** is maintained at the same high positive potential with respect to the cathode **10** as the electrode **28** by suitable means, not shown, whereby the arms **58** are also highly positive, and whereby the electrons of the beam **12** are attracted thereby. To reduce attenuation of the beam **12** by the arms **58**, the arms **58** are positioned in the shadow of the arms **44** which are at the same potential as the cathode.

The electrode **52**, which is held at the potential of the cathode **10** by suitable means, not shown, comprises an annular disk **62** having an inner diameter equal to the inner diameter of the central upstanding portion **48** of the electrode **38** surrounding the beam **12** and an upstanding cylindrical portion **64** having the same inner diameter as the disk **62** and a much smaller outer diameter. The cylindrical portion **64** extends up into and fits into the electrode **38** and is electrically connected thereto, to form with the inner surface of the portion **48** a long equipotential cylindrical surface. To provide clearance for the spider arms **44** and **58**, vertical slots **66** are cut in the upper end of the cylinder **64**. While no insulation is required for the arms **44**, the arms **58** and the portion **56** of the electron **50** are insulated by vacuum from the cylinder **64**. Due to the voltages applied to the electrodes **38**, **50** and **52**, the electrons are attracted inwardly by the positive voltage on the disk **60**, and the electrons are also repelled inwardly by the negative voltage on the inside surface of the electrodes **38** and **52** causing the beam **12** to consolidate and to cross over at the point **68** and to become a solid beam. The electrons of the beam **12** go downward from the point **68** so that they appear to originate at the point **70** which is the point of intersection of straight lines tangent to the envelope of the beam. An axially symmetrical electrode **72** is positioned coaxially with the electrodes **28**, **38**, **50** and **52**. This electrode **72**, which is main-

tained at a positive potential of about 560 volts with respect to the cathode **10** by suitable means, not shown, comprises an outer annular disk **74** and an inner annular disk **76** connected by a transitional portion **78**. The disk portion **76** extends up into the lower part of the annular disk **62** to produce the necessary electronstatic field shape to cause the beam to appear to come from point **70**. The hole in the disk **76** increases in diameter in a downward direction in a known manner. The beam **12** passes through the hole in the portion **76**, and the beam emerging therefrom, due to the electrodes mentioned and to the voltage applied thereto, appears as if it originated at the point **70** with the same angular divergence and envelope as if it originated from point **40**. However, an ion that originates in the portion of the described gun below the ion impermeable disk **60** hits the disk **60** and is stopped thereby. The ion cannot hit and therefore does not injure the cathode **10**, whereby the life of the cathode **10** is extended by the provision of the described ion trap thereof.

The electron beam is accelerated and further focused by the electrode **72** in conjunction with electrodes **80** and **82**, whereby the electrode **72** acts both as an element of the coaxial ion trap described as well as an element of a beam accelerator. The axially symmetrical element **80** comprises an outer annular disk portion **84** and a centrally positioned upstanding hollow portion **86** having a conical upper surface and a cylindrical inner surface. The electrode **80** also includes a downwardly extending hollow portion **88** having a cylindrical inner surface **90** and a cylindrical outer surface **92** adjacent to the disk **84** and an outer conical surface **94** which decreases in diameter in a downward direction joining the cylindrical surface **92** and **90**. The diameter of the surface **90** is greater than the inside diameter of the portion **86**. An apertured disk **96** closes the top of the cylindrical surface **90**. The aperture in the disk **96** may be biconical as shown. The disk **96** is thinner than the disk **84** and the lower surfaces of the disk **84** and **96** are in the same plane. The upper end of the portion **86** of the electrode **80** extends into the transitional portion **78** of the electrode **72**. The voltage applied to the electrode **80** by suitable means, not shown, may be 660 volts positive.

The electrode **82**, which is axially symmetrical, has a positive voltage of 560 volts applied thereto by suitable means, not shown. This electrode **82** comprises an outer annular disk portion **98** having a turned down rim **100**. The electrode **82** also includes a central annular disk portion **102** having a hole therethrough (for the passage of electrons) which hole has a biconical shape comprising a shorter frustoconical portion, whose diameter decreases in a downward direction, and a longer frustoconical portion whose diameter increases in a downward direction, the two smaller diameter portions of the frustrums being joined. The shape of the aperture through the disk portion **102** aids in maintaining focus of the beam **12**. The electrode **82** also includes a transitional portion **104** having an upper conical surface conforming in angle with the surface **94** of the electrode **80** and spaced therefrom, the conical surface **94** extending into the transitional portion **104**. The outer surface of the transitional portion **104** is cylindrical. The portion **106** of the electrode **82**, which, as shown, may be made up as a separate part from the portions **98**, **100** and **104** thereof for the purpose of ease of manufacture, fits over the lower end of the cylindrical outer surface of the transitional portion **104**. The portion **106** has a conical inner surface **108** whose diameter decreases in a downward direction. An apertured plate **110** closes the lower part of the lower portion **106**. The aperture in the plate **110** may have a wedge-shaped inner edge as shown. X-deflecting plates **112** and Y-deflecting plates **114**, only one of the Y-plates being shown, are provided in the chamber within the conical surface **108** and between the apertured disks **102** and **110**. By adjustment of potentials provided by suitable means, not shown, applied to the deflection plates X and Y, the direction of the beam **12** emerging below the disk **10** may be controlled.

The device so far described may be used as a complete electron gun requiring no additional acceleration and including the described ion trap. However, the described gun may also be used as a source of a beam of accelerated electrons subject to further acceleration, as in an electron microscope. When so used, a further acceleration electrode **120** may be provided. This electrode **120** comprises a disk apertured for passage of the electron beam **12** therethrough, to which high positive voltage in the order of 6.6 to 33kv. may be applied. This accelerating electrode **120** may be one of a plurality (up to 15) of similar electrodes positioned along the beam **12** below the electrode **120** to which successively higher positive voltages are applied, the highest of which may be as high as 500 kv. when the voltage on the electrode **120** is 33 kv. The voltage on the accelerating electrodes, of which only the electrode **120** is shown, while accelerating the beams **12** passing therethrough also produces an electron lens action which results in a defocusing of the beam **12**. Using the described electron gun with accelerating electrodes such as electrode **120**, only the voltage on the grid cap **14** need be changed to retain focusing of the beam **12**, as the voltage of the accelerating electrodes such as electrode **120** is changed. This is due to the fact that the accelerating electrode **120** and any subsequent accelerating electrodes such as electrode **120** (not shown) constitute a weak electrostatic aperture lens having a very long focal length. This long focal length extends in both directions from the electrode **120**. The electrodes **72**, **80** and **82**, on the other hand, constitute a much stronger electrostatic lens having a much shorter focal length. Because of the proximity of this strong lens comprising the electrodes **72**, **80** and **82** to the electrode **120** and to the subsequent accelerating electrodes (not shown), the strong lens **72**, **80** and **82** is immersed in the focal length of the weak lens comprising the electrode **120** and subsequent electrodes (not shown). In this situation a small focusing change in the stronger lens **72**, **80** and **82** can overcome a focusing change due to a great voltage change in the weaker lens. The small focusing change in the strong lens **72**, **80** and **82** is provided by varying the voltage in the grid cap **14**, without varying the voltages in the electrodes **70**, **80** and **82**. Since change of the voltage on the grid cap **14** changes the position of the point **70**, where the electrons of the beam **12** appear to originate, the focusing effect on the beam of electrons of the lens **72**, **80** and **82** is changed.

This change of potential on the grid cap **14** is from about −45 volts to about −60 volts, or about 33 percent, as the voltage on the electrode **120** is changed from about 6.6 kv. to about 33 kv. or about 500 percent. Therefore, the electron gun described minimized the defocusing of the beam thereof upon further acceleration of the beam and reduces the changes in potential of the grid cap **14** necessary to track, that is to keep the beam focused, as the acceleration voltage on the electrodes, such as electrode **120**, is changed.

While the several electrodes (except the cathode which may be made of tungsten) may be made of any solid nonmagnetic conductor, preferably they may be made of nonmagnetic stainless steel.

What is claimed is:

1. An electron gun of particular utility in the environment of an electron microscope comprising, in combination,

means to produce an electron beam;

a first accelerating lens of a relatively short focal length so positioned that the beam passes therethrough, and at a positive potential relative to said means to produce an electron beam;

a second accelerating lens of a relatively long focal length compared with the focal length of said first lens and so positioned that the beam passes through the second lens after it passes through the first lens,

said second lens being at a potential significantly more positive than said first lens,

said second lens being spaced from said first lens by a distance less than the focal length of the second lens,

whereby defocusing of said beam as a result of a significant change in the potential applied to said second lens is readily corrected by a relatively small change in the

potential difference between said beam producing means and said first lens.

2. An electron gun according to claim 1 wherein said first accelerating lens comprises

a plurality of electrodes spaced from each other and each at a potential significantly lower than the potential of said second accelerating lens.

3. An electron gun according to claim 2 wherein said means to produce an electron beam includes

a cathode; and

a grid cap in proximity to said cathode and having an opening therethrough for passage of electrons from said cathode; said grid cap being at a potential negative with respect to the potential of said first lens, and said grid cap potential being adjustable to provide said relatively small change in the potential difference between said beam producing means and said first lens.

4. An electron gun according to claim 1 which further includes

means to deflect said electron beam, said means to deflect being positioned between said first accelerating lens and said second accelerating lens.

5. An electron gun according to claim 4 wherein said means to produce an electron beam includes

a cathode; and

a grid cap in proximity to said cathode and having an opening therethrough for passage of electrons from said cathode; and

an ion trap between said means to produce the electron beam and said first accelerating lens.

6. An electron gun according to claim 5 which further includes

additional lens means extending around said ion trap and between said means to produce the electron beam and said first accelerating lens.