July 21, 1964 E. HAHN 3,141,993

VERY FINE BEAM ELECTRON GUN

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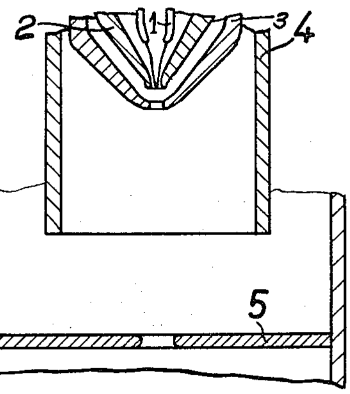

Prior Art

Fig. 1

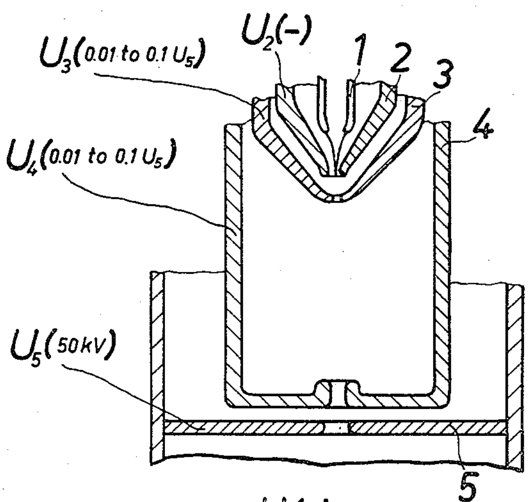

Fig. 2

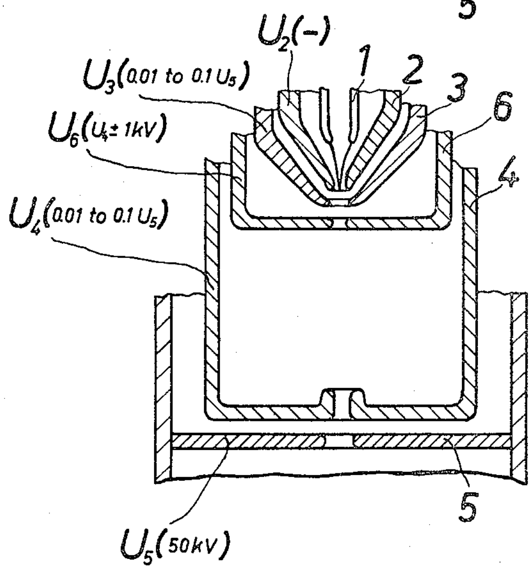

Fig. 3

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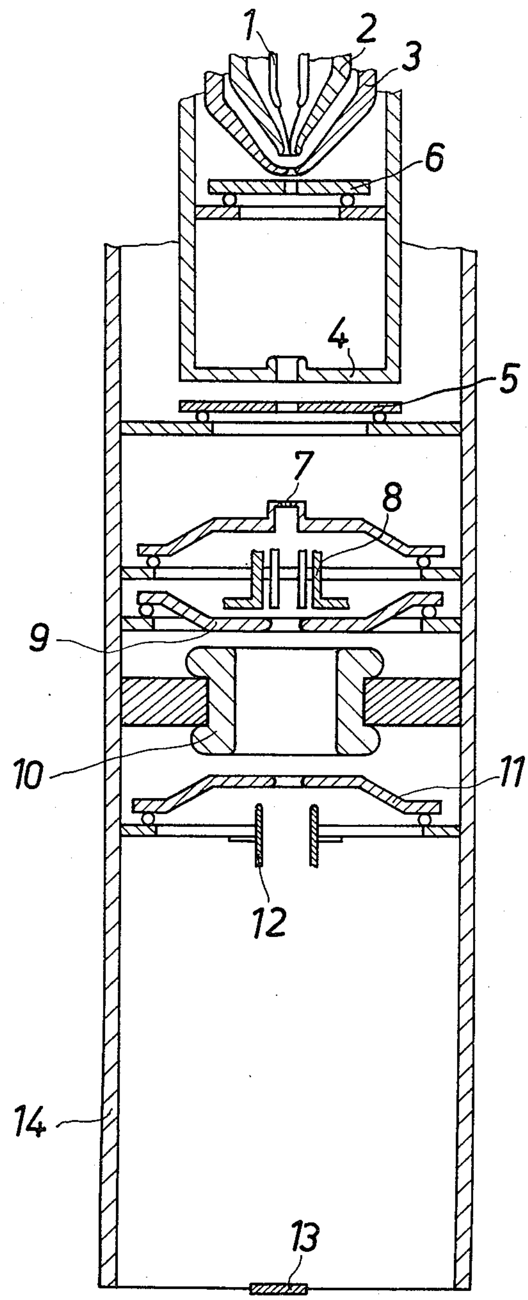

Fig. 4

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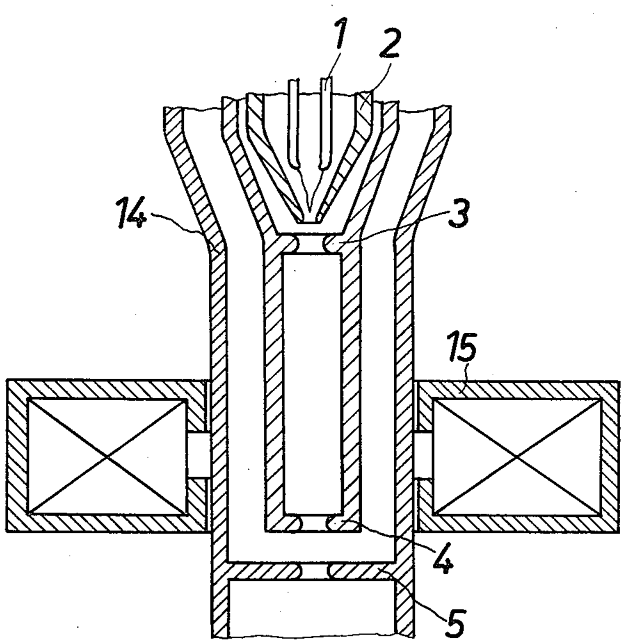

Fig. 5

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VERY FINE BEAM ELECTRON GUN

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This invention relates to an electron gun for corpuscular-ray apparatus, particularly electron microscopes, in which a suitably constructed accelerating field produces a very fine focal spot adjustable in size.

In electron-microscopy, an illumination system permitting the beam diameter to be narrowed down to only a few μ is of much importance especially for small-area diffraction. As the imaged object areas are very small, it is desirable to illuminate only the object surface under observation, which goes far to keep the object undamaged. It has accordingly been suggested that devices be used in which a beam produced for instance by a triode is focussed through magnetic lenses very strongly in a distant object plane.

In a known system, a magnetic lens of small focal length produces near its rear focal plane a highly reduced image of the focal spot of a triode. As the object cannot for constructional reasons be approached near enough to the focus, use is made also of another weak magnetic lens which operates at a magnification ratio of approximately 1:1. A system of this kind is however somewhat bulky and difficult to adjust.

The idea to obtain the focusing effect by using also the accelerating field of the beam-producing system has already been carried into practice, for instance in television tubes, X-ray tubes and the like. The respective devices consist substantially of a funnel, which surrounds the hot cathode and controls the beam current, and a tube-shaped cap which has a potential near cathode voltage and whose anode-bounded field is electron-optically convergent. A characteristic of these systems is however that the emission field-strength near the cathode is produced by the penetrating anode field. The tube-shaped electrode has therefore a wide bore, which means that devices of this kind can produce focal spots only down to diameters of about 30 μ.

Another known electron gun has not only the usual control electrode round the cathode but, directly in front thereof, an additional electrode of positive voltage for independent control of the field strength in front of the cathode. Such an electrode system, which acts as a "cathode-field lens," has the properties of a divergent lens the refractive power of which is a function of the bore of the positive electrode and the distance apart of this electrode and the cathode. The virtual spot produced by the cathode-field lens is imaged in a distant plane by means of the other part of the accelerating field, which is near the anode and hereinafter called "anode-field lens." This anode-field lens, which is produced by the anode and a wide-bore third intermediate electrode, has the properties of a weakly convergent electron-optical immersion lens.

According to the present invention a considerably finer focal spot can be obtained in a beam-producing system of this kind by reducing the spacing between the third intermediate electrode and the anode to the lowest magnitude compatible with high-voltage technics. The end of the third intermediate electrode facing the anode has to this effect the form of a diaphragm with a small aperture, this aperture being approximately equal to said spacing. This measure considerably increases the refractive power of the anode-field lens and permits the creation near the anode of a fine focal spot corresponding to the distance apart of the cathode-field lens and the anode-field lens. With bores and distances of the electrodes of the cathode-field lens in the order of 1 millimeter and bores and distances of the anode-field lens in the order of 3 millimeters, and with a distance apart of the cathode-field lens and the anode-field lens of 50–100 millimeters and a voltage ratio of approximately 1:10 to 1:100 of the positive electrodes and the ray voltage of for instance 50 kilovolts, the system according to the invention can produce focal spots of a diameter of about 1 μ in the immediate vicinity of the anode bore. For purposes of X-ray microscopy, the plane of the focus can be made to contain the anticathode, which may be part of the anode.

For electron-microscopic purposes, this fine focal spot can be imaged in the same manner by means of a weak condenser lens over a great distance with a magnification ratio of approximately 1:1 or 2:1 for instance in the object plane or in a screen plane, as is already known in the imaging of focal spots produced e.g. by a simple triode system.

The condenser system is in this case generally provided with a diaphragm bounding the radiation aperture, which, if too great, would let image errors of the electron-optical lenses appear very pronounced. Adjustment to the object area at low magnification grades requires the illumination spot to be magnified by the condenser lens, which produces mostly a weak field, in consequence whereof an often rather undesired reduction of radiation intensity proportional to the illuminated surface needs must be tolerated.

The said disadvantage is eliminated in the electron gun according to the present invention, in another embodiment of which the two intermediate electrodes at positive potential have between them one or more further intermediate electrodes, which converge the beam more or less according to the applied potential difference and thus permit continuous changes of the focus magnitude in the rear focal plane of the entire system. As the use of such an "intermediate-field lens" guarantees practically non-displacement of the rear focal plane of the entire system, the imaging conditions of the adjacent condenser system, particularly the aperture magnitudes, are maintained, and the intensity of the size-controllable illumination spot remains constant.

In order that the invention may be more readily understood reference is made to the accompanying drawings, in which FIGURE 1 is a schematic diagram of the electrode arrangement of a tetrode system for distant focusing, FIGURE 2 a schematic diagram of a tetrode system for fine focusing constructed according to the invention, and FIGURE 3 the schematic diagram of a development of this tetrode system to a pentode system with adjustable focus. FIGURE 4 of the drawings represents schematically a diagram of an embodiment of an electron gun according to the invention which is provided with a condenser system for distant imaging of the fine focus and with ray centering means. FIGURE 5 shows another embodiment of a pentode system according to FIGURE 3.

In the tetrode system shown in FIGURE 1, an accelerating field lies between a hot cathode **1** and an electrode **3** which has a positive voltage of approximately 1 kv. and is opposite the cathode. This accelerating field emits the electrons as a conically widening beam into the space which is surrounded by a tubular electrode **4** and which lies between the electrodes **3** and **5**. The current of this beam is controlled in the known manner by changing the negative voltage of a control electrode **2**. The divergent beam is converged by the accelerating field penetrating into the wide bore of the tubular electrode **4**. The distance apart of the anode and the "cathode-field lens" consisting of the electrodes **1**, **2**, **3**, the diameter of the bore of the electrode **4**, the distance apart of the anode and the electrode **4**, and the ratio of the voltages of the electrode **4** and the anode, all these are decisive of the formation at any desired distance in the rear of the anode of a focus having for instance in an object plane at a distance of about 200 mm. a diameter of approximately 100 μ.

In the electron gun FIGURE 2, which shows an embodiment of the invention, the tubular electrode **4** has its bore facing the anode so restricted that a field is created between electrodes **4** and **5** which has the properties of a strongly convergent immersion lens. It can be proved theoretically and by experiment that for instance a distance and bore of 4 mm., a distance apart of cathode-field lens and anode of about 50 mm., a voltage ratio of electrodes **3**, **4** and anode **5** of 0.1 to 0.01, and a beam voltage of 50 kv. will produce in the exterior bore a focal spot 2 μ in diameter. By means of a weak condenser lens (not shown), this spot can be imaged in known manner in a distant object plane for instance at a magnification ratio 1:1.

To enable the diameter of this focus to be altered for orientation in the object plane to for instance the dimension of the field of vision at the lowest magnification grade, e.g. 50 μ, the refractive power of the weak condenser lens could be regulated accordingly. This however presents the disadvantage of a steep decline in the image brightness, which for instance a fine-focus change from 2 μ to 20 μ dia. will reduce to the one hundredth part.

To obviate this disadvantage, the embodiment according to FIGURE 3 has in the normally field-free space bounded by the electrodes **3** and **4** an electrode **6**. If this electrode **6** is given a voltage of for instance 0 to ± 1 kv. in respect of the space surrounding it, there arises substantially between the electrodes **3** and **6** an electron-optically effective field of controllable refractive power which reduces the refractive power of the entire system to for instance one tenth, the axial position of the focus produced by the entire system remaining practically constant. This is due to the fact that the additional intermediate-field lens while being regulated as to refractive power magnifies the anyway great distance apart of the virtual focal point and the anode until the front focal plane of the intermediate-field lens has reached the plane of the virtual focal spot lying a little above the cathode. The virtual focal spot is in this case imaged by the lens system consisting of intermediate field and anode field at a magnification equal to the quotient of the front focal length of the anode-field lens and the rear focal length of the intermediate-field lens. This magnification would otherwise equal the quotient of the front focal length of the anode-field lens and the object width of the virtual focal spot relative to the anode-field lens. In the relations represented in FIGURE 3, which are given as examples only, a voltage ratio of 1:3 of the two electrodes **3** and **6** corresponds to a rear focal length of the intermediate-field lens of about 5 mm., and to an object width of the virtual focal spot relative to the anode-field lens of 50 mm. Accordingly, the focus produced by the entire system can be continuously regulated from 2 μ to 20 μ dia. and this practically without displacement along the axis.

FIGURE 4 shows how such an electron gun can be used to advantage in connection with a weak-remote-image condenser lens and a ray centering system, and how suitable adjusting possibilities within the electron gun are utilized. The illustrated system is comparatively simple and easy to manipulate and at the same time fulfils all demands normally made in respect of illumination systems with controllable fine focus:

(1) Adjustability of ray locus in object plane,

(2) adjustability of ray-incidence direction in object plane,

(3) concentric movement of focus when spot magnitude is being adjusted at constant intensity and aperture,

(4) concentric movement of illumination spot when aperture is being adjusted,

(5) constancy of ray-incidence direction in manipulations according to (3) and (4).

The functions of the various centering means are now discussed one after the other with a view to proving that the normally required properties (1) to (5) are those of the system represented in FIGURE 4.

In fine focusing, the electrode **6** is at the same potential as the electrodes **3** and **4**, in consequence whereof a displacement of **6** at right angles to the axis is without influence. By displacing the upper exterior electrode **9** of the condenser lens at right angles to the axis as well as altering the field strength in the electric deflecting condenser **12**, the ray locus in the object plane **13** can be changed and directed to approximately the object centre to be imaged. To enable the illumination spot to be found easily, the radiation diaphragm **7**, which is centrable and whose aperture is changeable, can be either entirely removed from the ray path or given a great aperture. Owing to the unavoidable apertural error of the weak condenser lens, the caustic figure narrowing to a fine focus is surrounded by a broad luminous circle of aberrating rays which facilitates finding the peak of the caustic. If the voltages at the condenser and at the objective (not shown) below the object plane **13** are wobbled 100 volts, a small diaphragm aperture **7** in the ray path will cause the appearance of, first, a double luminous spot, which can be made concentric by adjustment of diaphragm **7**, and, second, a double image of the object, which can be aligned, likewise concentrically to the image centre, by joint manipulation of the adjusting means **9** and **12** in such a manner that there is no drifting away of the fine focus in the object or image plane. Thus, fine-focus adjustment has been achieved, and the demands (1), (2) and (4) are fulfilled.

If the voltage of electrode **6** is now regulated and a considerable broadening of the focus at constant intensity ensues, the broadening focus will drift sideward in the object or image plane. However, such drifting can be corrected by adjusting the electrode **6**, thus changing the angle of the beam incident on the anode-field lens and, accordingly, altering the position of the focus in the anode bore relatively to the axis. As the focus broadens, the aperture of the beam striking diaphragm **7** becomes smaller, which means that a contraction of the pencil to a locus in the diaphragm plane **7** departing from the adjusted diaphragm hole must generally be taken into account. Such a departure, which is made conspicuous by loss of intensity, can be avoided by providing that the anode electrode **5** is centrable. Accordingly, demand (3) as well as demand (5) are fulfilled.

The functions of the electric or magnetic deflecting system **12** can be taken over by the exterior electrode **11**, if adjustable as in FIGURE 4. As producing a fine focus and imaging it at great distance gives rise to axially unsymmetric interference fields of astigmatic distortion, the condensing lens **10** is provided with a correction system **8** of known construction and effect which consists of a plurality of annular segments and corrects for instance axial astigmatism of the second or third order. The entire system is housed in an evacuated vessel, indicated by the numeral **14**, having vacuum-tight sealings for the mechanic adjusting pinions and the electric contacts.

For controlling the magnitude of the focus at approximately constant intensity and aperture, use can be made of a magnetic lens instead of the intermediate-field cathode **6**. An embodiment of a system with a magnetic lens is illustrated schematically in FIGURE 5. As the electrons in the space bounded by the electrodes **3** and **4** are comparatively slow, a slight magnetic field strength will suffice to influence the electrons in the desired manner. For this reason a respective magnetic lens **15** can be disposed outside the evacuated vessel **14**, which is of advantage as regards constructional design and in particular for the adjustment. Furthermore, continuous control of the refractive power is simpler with a current-fed magnetic lens than with an electrode at high voltage, since the latter can receive part of the space current, which causes an undesired change in the voltage of the respective electrode.

The means which according to FIGURE 4 are provided for imaging the fine focus in the object plane 13 and adjusting the rays, can also be replaced by magnetically acting focusing and deflecting means, which may advantageously lie outside the vacuum tube.

I claim:

1. An electron gun for corpuscular-ray apparatus, particularly electron microscopes, fine-focus X-ray tubes and television tubes, comprising an incandescent cathode, an anode and a system of intermediate electrodes between said cathode and said anode, the first of said intermediate electrodes being funnel-shaped and surrounding said incandescent cathode and having means for applying an adjustable voltage negative with respect to said cathode, the second of said intermediate electrodes being funnel-shaped and surrounding said first intermediate electrode, and means for applying a positive potential with respect to said cathode so as to act together with said cathode as a diverging lens, the third of said intermediate electrodes being tubular and surrounding that portion of said second intermediate electrode which is remote from said cathode, said third intermediate electrode having an apertured diaphragm facing said anode with a small spacing, means for applying with respect to said cathode a positive potential to said anode and another positive potential to said third intermediate electrode which is in the order of $1/100$ to $1/10$ of the anode potential, said spacing being as small as admissible by the high potential difference between said anode and said third intermediate electrode, the aperture diameter of said diaphragm being approximately equal to said spacing, said third intermediate electrode and said anode acting together as a strongly convergent immersion lens.

2. An electron gun as claimed in claim 1, wherein means for adjusting the potentials of said second and said third intermediate electrode independently of each other are provided to adjust the magnitude and the position of the focus of said corpuscular ray respectively.

3. An electron gun as claimed in claim 1, wherein a fourth intermediate electrode is disposed between said second and said third intermediate electrode, said fourth intermediate electrode being tubular and disposed concentrically within said third intermediate electrode and having an apertured diaphragm facing the diaphragm of said third intermediate electrode, and wherein a means for applying with respect to the adjacent electrodes an adjustable potential to said fourth intermediate electrode is provided for producing an additional lens effect changing and in particular reducing the refractive power of the entire system without the axial position of the rear focal plane of the entire system being noticeably displaced.

4. An electron gun as claimed in claim 3, wherein said fourth intermediate electrode is adjustable at right angles to the axis of said electrode system.

5. An electron gun as claimed in claim 1, wherein the space bounded by said electrodes at high voltage, in which the electrons are comparatively slow, is screened in known manner from electric and magnetic interference fields.

6. An electron gun as claimed in claim 1, wherein the adjustable fine focus produced by said electrode system is imaged in a distant object or screen plane by a condenser system having ray-adjusting means and a weak condensing lens.

7. An electron gun as claimed in claim 1, wherein a magnetic lens is disposed outside said vessel surrounding the space between said second and said third intermediate electrode, said magnetic lens being adapted to change and in particular to reduce the refractive power of the entire system without the axial position of the rear focal plane of the entire system being noticeably displaced.

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