

Nov. 21, 1944.

S. RAMO

2,363,359

ELECTRON MICROSCOPE

Filed Sept. 11, 1942

2 Sheets-Sheet 1

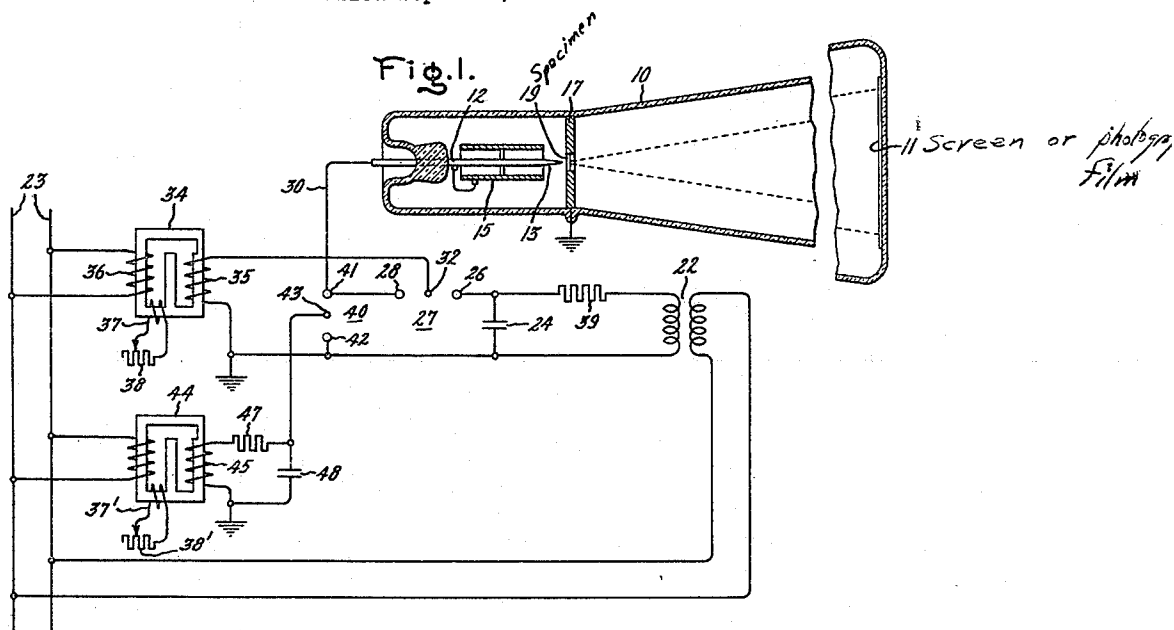


Fig. 2.

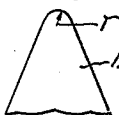
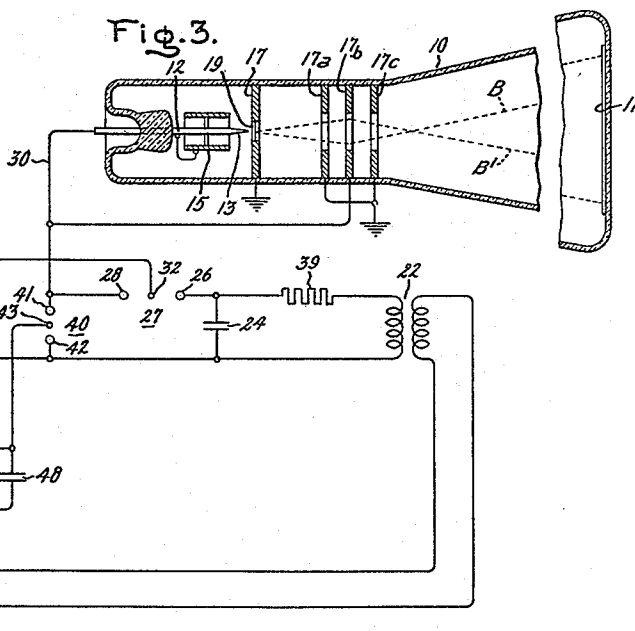


Fig. 3.



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Cancelled:
315-246

ADDED:
315-1

31
194
228
237
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252
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ELECTRON MICROSCOPE

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2 Sheets-Sheet 2

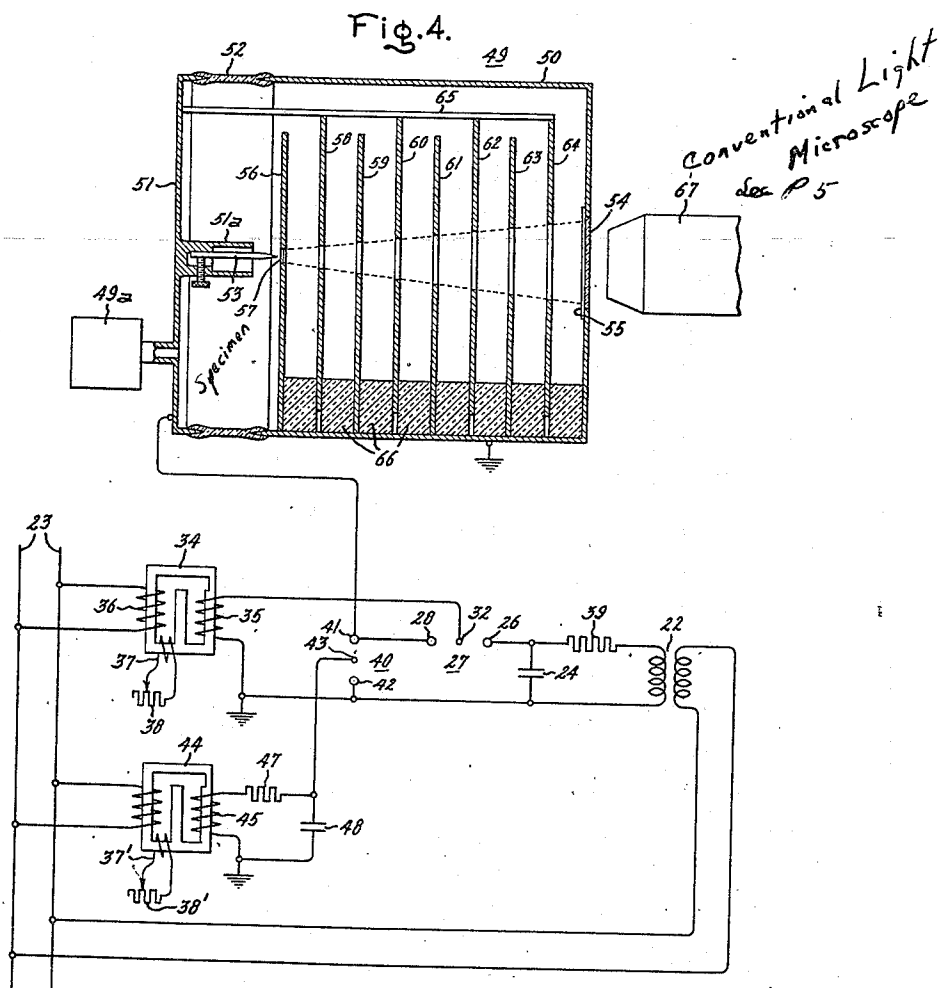
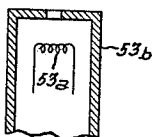


Fig. 5.



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UNITED STATES PATENT OFFICE

2,363,359

ELECTRON MICROSCOPE

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Application September 11, 1942, Serial No. 457,952

19 Claims. (Cl. 250—49.5)

The present invention relates to improvements in electron microscopes.

This application is a continuation-in-part of my copending application Serial No. 391,380, filed May 1, 1941, and which is assigned to the assignee of the present application.

The electron microscope may be described briefly as an apparatus for producing by electronic means a magnified image of an object desired to be examined. In such apparatus, the image-producing functions performed by light in optical microscopy are accomplished in a somewhat analogous manner by a stream of electrons.

Since the electron microscope possesses theoretically enormous resolving power it promises to be an extremely valuable instrument for scientific investigation. However, the types of electron microscope now available are very much limited in application because of their structural complexity and resultant high cost.

In order to provide a simpler form of microscope it has been suggested to make use of divergent rays of electrons produced from a finely pointed cathode having its tip in close proximity to the object to be examined. By projecting these rays through the object, it is possible to obtain an enlarged shadow replica of the object without the use of a complex electron lens system. From a practical standpoint, however, this type of microscope has also proven of limited utility for the reason that its use at voltages sufficiently high to assure penetration of the object by the electrons tends to produce very rapid deterioration of the emitting surface of the cathode. Such microscopes have been characterized by large size and relatively high evacuation, the high vacuum necessitating elaborate evacuating equipment which is bulky, expensive, and time-consuming in operation. Ordinarily, in order to avoid arcing between the electrodes at operating voltages it has been found necessary to evacuate the tubes to pressures of the order of 0.01 micron.

From a practical standpoint the operating voltage necessary to provide an image of suitable intensity is fixed by the necessity for imparting to the electrons a velocity sufficient to penetrate the specimen. At the present time voltages of the order of 25,000 to 50,000 are regarded as suitable for satisfactory image reproduction. At such voltages positive ion action has heretofore imposed drastic limitations upon spacing of elements within the tube and the necessary degree of evacuation. In electron microscopes provided

with electrostatic focusing lenses, it has been necessary to maintain substantial spacing of the lens electrodes and a high degree of evacuation in order to render the mean free path of electrons sufficiently great to prevent the formation of positive ions in sufficient quantity to cause arcing over at the lenses and destructive bombardment of the screen. High vacuum has been necessitated also by the need for maximizing the mean free path of positive ions further to preclude ionization of the residual gas. In the shadow type of electron microscope, which utilizes a point source of electrons, satisfactory operation above 10,000 volts has heretofore been unobtainable even with the usual spacing and vacuum because of the fact that the effectiveness of the finely pointed cathode is very quickly destroyed by positive ion bombardment at higher voltages.

If positive ion bombardment can be substantially prevented, it is evident that all types of electron microscopes, both the lens and the shadow types, can be reduced in size and the degree of evacuation within the limitations imposed by the mean free path of electrons. By the same token higher voltages would be permissible in either the shadow type or lens type of microscope at conventional spacing and pressure. Heretofore the limitations imposed by the mean free path of electrons has not been even remotely approached, since at vacuums ordinarily maintained, this path is of the order of 100 meters. Thus if the electron free path can be approached as the limiting factor, electron microscope tubes may be substantially reduced in size and operated at a relatively high internal gas pressure, i. e., poor vacuum sufficient only to render the electron mean free path of the same or at least as great as the desired source-to-screen distance within the tube.

Accordingly, one aspect of my invention, which relates to shadow-type microscopes of the character just referred to, consists in the provision of means for preventing destruction of the cathode while nevertheless permitting the examination of objects of such density as to require high voltage. In this connection, an important feature of the invention consists in the use with the microscope of an energizing circuit of such character as to limit the application of voltage to intervals of less than about 10^{-6} seconds. By this means instantaneous electron currents of sufficient penetration and intensity to permit the production of useful images are realized, while

at the same time effects tending to produce deterioration of the cathode are minimized.

Accordingly, it is a general object of my invention to eliminate positive ion action as the limitation upon gas pressure and electrode spacing in electron discharge apparatus, thereby to permit structures limited only by the length of the mean free path of the active electrons.

It is a further object of my invention to provide an electron microscope having a substantially reduced source-to-screen length which is capable of satisfactory image reproduction in a relatively poorly evacuated chamber.

Further, and specific objects of my invention reside in the provision of means for reducing the source-to-screen length of an electron microscope to the same order of magnitude as the length of the mean free path of the imaging electrons, and also for permitting satisfactory operation of such a device with internal gas pressures sufficiently high to cause destructive positive ion action in electron microscopes heretofore known.

It is still another object of my invention to provide means for precluding cathode destruction in shadow type electron microscopes when operating at practical image producing voltages.

My invention also contemplates means for operating well known types of electron microscopes at high voltages heretofore thought to be destructive.

According to my invention, positive ion action is substantially eliminated and the accompanying space, pressure and voltage limitations heretofore mentioned in connection with existing electron microscopes are thereby removed by using in connection with the microscope an energizing circuit of such character as to limit the application of voltage to intervals of the order of 10^{-6} seconds (that is, within or close to the range from 10^{-3} to 10^{-9} seconds). By this means substantially instantaneous electron currents of sufficient penetration and intensity to permit the production of useful images are realized, while at the same time effects tending to produce lens sparkover and deterioration of the cathode and screen are substantially avoided.

For a better understanding of my invention, reference may be had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims. Fig. 1 is a diagrammatic representation of an electron microscope and associated circuit embodying certain aspects of my invention; Fig. 2 is an enlarged fragmentary view of one of the elements shown in Fig. 1; Fig. 3 illustrates an alternative embodiment of my invention; Fig. 4 diagrammatically illustrates a still further embodiment of my invention relating to an electron microscope and associated energizing circuits, and Fig. 5 illustrates a modified form of the electron microscope suitable for connection to the energizing circuit shown in Fig. 1.

Referring particularly to Fig. 1, there is illustrated a discharge vessel 10, assumed to be of highly evacuated character and shown partly broken away. At one end of the vessel is provided an image-reproducing surface 11, which may consist, for example, of an electron-responsive fluorescent screen or, alternatively, of an electron-sensitive photographic film. At the other end of the vessel, there is mounted a pointed non-thermionic cathode in the form of a metal body 12, suitably of tungsten. The cathode has 75

a smoothly rounded tip 13 (shown greatly magnified in Fig. 2), which is formed, for example, by etching, and the radius of curvature of which (indicated by r) is preferably less than about 10^{-3} centimeters. In order to eliminate the possibility of undesired emission from the lateral surfaces of the cathode it may be surrounded by a metal shield 15 which is maintained at cathode potential.

In cooperative relation with the cathode there is provided another electrode 17 which is shown as an annular metal disk, and which is adapted to establish an electron-accelerating field in the vicinity of the cathode. The sharply pointed character of the cathode makes it possible to establish very intense fields at the cathode tip by the application of readily attainable potentials to the electrode 17 and by this means to obtain cold cathode emission from the tip.

Due to the symmetry of the electrode 17, electrons proceeding from the cathode tip may be expected to follow divergent lines extending from the center of curvature of the tip toward the image-reproducing surface 11. In order to make use of this fact an object desired to be investigated (for instance, a bacteriological specimen) is positioned in close proximity to the extremity of the cathode. This may be done, for example, by supporting the specimen in the central aperture of the electrode 17 as indicated at 19 or, alternatively, by the provision of an object mount (not shown) which is structurally independent of the electrode 17.

If the cathode tip is in very close proximity to the object under investigation, and if the potentials involved are sufficient to assure penetration of the object by the emitted electrons, a magnified shadow picture of the object will be projected on the image-reproducing surface, the image produced being characterized by varying degrees of light and shadow depending upon local variations in density or thickness of the object. The magnification which can be obtained in this way is a direct function of the ratio of the distance between the cathode and the reproducing surface to the distance between the cathode and the object and may readily be made very great.

Unfortunately, it is found in practice that the small dimensions to which the emitting surface of the cathode is required to be limited seriously restricts the permissible operating conditions of the apparatus. In particular, it is observed that unless the operating potential is maintained below about 10,000 volts, rapid deterioration of the cathode occurs. This is believed to be due in part to bombardment of the cathode by ions of the residual gas in the discharge space and in part to excessive heating of the cathode tip as a result of the relatively large current drawn from it. In some cases, the heating of the cathode due to these causes may become so great as to result in the establishment of a destructive arc supported by evolution of metal vapor from the cathode itself. Because of these effects, the cathode quickly deteriorates to a condition in which it is unsuitable for its intended use. Inasmuch as most of the objects which are amenable to investigation by the electron microscope require for their penetration electrons of velocity corresponding to a potential field greatly in excess of 10,000 volts, it will be seen that the considerations just stated apparently pre-

clude any widespread use of the shadow microscope.

In accordance with the present invention, the limitations implied in the foregoing are removed by the provision of means for preventing deterioration of the cathode point while at the same time permitting operation at voltages of the order of 50,000 volts or higher. This is accomplished, as will be explained more fully in the following, by the use of an energizing system of such character as to limit the application of voltage to intervals of less than about one micro-second. By this means ion bombardment is substantially avoided and heating of the cathode due to this and other causes is restricted to a safe (non-destructive) value.

The energizing system shown in Fig. 1 comprises a circuit which is operative to apply very short pulses of voltage between the cathode 12 and the electrode 17. In this connection voltage is derived from the secondary of a transformer 22 which is assumed to have its primary winding connected to an alternating current supply source 23, the transformer being preferably chosen to provide a voltage on the order of or greater than 50,000 volts.

The voltage thus obtained is impressed on a condenser 24 which has one terminal connected to the electrode 17 through ground. The other terminal of the condenser connects with an element 25 comprising one main electrode of a spark gap 27, the other main electrode of the gap being indicated at 28. A conductor 30 connected between the latter electrode and the cathode 12 assures that the voltage across condenser 24 shall be applied between the cathode and the grounded electrode 17 whenever the gap 27 becomes conductive.

The gap 27 should be of such dimensions as normally to sustain without breakdown any voltage apt to be impressed across it during its intended use. However, there is provided in connection with it an auxiliary electrode 32 adapted, when appropriately energized, to permit spark-over of the gap, assuming, of course, that the voltage across the gap is favorable to such an occurrence. The auxiliary electrode 32 is connected to a triggering circuit which enables it to be subjected to voltage pulses tending to cause such sparkover. In the arrangement illustrated, the triggering circuit includes a so-called "peaking transformer" 34 which possesses a readily saturable magnetic circuit of such character as to facilitate the production of sharp pulses of voltage in the transformer secondary 35. (The theory and construction of transformers of this type are fully described in B. D. Bedford Patent No. 1,918,173, granted July 11, 1933.) The primary winding 36 of the transformer is connected to the supply source 23 so that the pulses of voltage induced in its secondary winding are synchronized with the variation of the potential developed across the condenser 24 by the transformer 22. A saturating winding 37, excited from a direct current source 38, permits the phase relationship between the voltage pulses developed in the winding 35 and the voltage across the condenser 24 to be adjusted within close limits.

The circuit connected with the electrode 32 is preferably so adjusted as to trigger the spark gap 27 at a time when the terminal of the condenser 24 which is connected to the electrode 26 approaches maximum negative potential. Under

these conditions breakdown of the gap obviously impresses full condenser potential between the cathode 12 and the electrode 17, thus initiating a cold cathode discharge from the former. The electrons produced in this way from the cathode tip will, because of the high potential at which they are created, penetrate the object 19 and produce a magnified shadow image of the object on the surface 11 in accordance with principles previously stated.

In order to limit the duration of the discharge to a period sufficiently short to avoid excessive heating of the cathode and consequent destruction of the cathode tip, provision is made for terminating the discharge very soon after the initiation. The means employed in this connection comprises in the arrangement shown a second spark gap 40 having main electrodes 41 and 42 and a discharge controlling auxiliary electrode 43. The energization of the electrode 43 is preferably correlated to that of the electrode 32 to assure that the gap 40 shall be triggered within less than a micro-second after the breakdown of the gap 27. This is accomplished by energizing the electrode 43 from a triggering circuit consisting of a second peaking transformer 44 which is identical with the transformer 34 and which is supplied from the same source. However, in circuit with the transformer secondary winding 45 there is included a time delay circuit including a resistor 47 and a condenser 48. If the values of the elements 47 and 48 are properly chosen, the voltage pulses impressed on the electrode 43 will be slightly delayed with respect to the pulses impressed on the electrode 32. As has been previously indicated, it is desired for present purposes that this delay should be on the order of a micro-second or less. Sparkover of the gap 40 obviously has the effect of grounding the cathode 12 and of making the continuation of a discharge from it impossible.

Restoration of both spark gaps to a condition of non-conductivity will be accomplished in due course by passage through zero of the potential derived from the transformer 22. For this reason, it is possible to obtain a cyclically renewed discharge through the electron microscope at a frequency corresponding to the frequency of the source to which the transformer 22 is connected. The total current flow in each discharge cycle may be regulated by the use of a series resistor 39 which limits the rate of charging of the condenser 24 and consequently restricts the amount of charge available for dissipation during the discharge period.

With this mode of operation, and assuming the duration of each conductive interval of the microscope to be limited to from 10^{-6} to 10^{-9} seconds, destructive heating of the cathode tip 13 can be avoided, and the possibility of the establishment of a destructive arc due to vaporization of the cathode metal may be made negligible. On the other hand, in view of the high velocity of the electrons projected through the object, the energy supplied by the electrons to the reproducing surface 11 will be relatively great and images may be obtained which are quite as satisfactory as those realizable with a continuous discharge at low voltage. The invention therefore provides a means for extending the field of useful application of the shadow microscope to the examination of objects requiring high velocity electrons for their penetration.

It will be understood that the spark gaps 27 and 40 may be replaced by other means for providing controlled conductivity. For example, one may use, in lieu of the gaps, controlled gaseous discharge tubes such as thyratrons.

A further modification of the invention is shown in Fig. 3, which differs from the construction previously described mainly in the provision of means for permitting the use of a shorter discharge chamber. (In this figure, elements which have been previously described in connection with Fig. 1 are identified by the same index numerals.)

As has been previously pointed out, the magnification obtainable with the shadow microscope depends upon the ratio of the distance between the cathode tip and the image-reproducing surface to the distance maintained between the cathode tip and the object under investigation. In situations which require the maintenance of a relatively large gap between the cathode and the object (for example, due to the nature of the object) the length of the discharge space required to yield satisfactory magnification may obviously be quite great. In such situations, in order to avoid the use of an unduly elongated structure, one may provide an electron lens system adapted to produce in the image-reproducing plane a replica of the cross-sectional pattern of the electron stream at a point at which the stream has already attained substantial divergence.

This is illustrated in Fig. 3 by the use of a series of annular lens elements 17a, 17b and 17c adapted to provide a lens system of short focal length. The potentials of the various lens elements are maintained most conveniently in appropriate relationship by connecting the elements to terminals of the impulse voltage source. With the arrangement shown, the lens may be expected to focus the electron beam as indicated by the dotted lines B and B', it being assumed that the imaging plane of the lens corresponds to the surface 11.

By this means, with a discharge space of given length, an image of greater magnification may be obtained than would be realized merely by relying upon the unfocused divergence of the electron rays proceeding from the cathode. Moreover, in view of the fact that the lens system is, in effect, concerned solely with the magnification of a virtual image of appreciable size (as distinguished from the object itself), it does not require to be of high resolving power, and its design may be carried out without reference to those complicating factors which make the construction of a microscope dependent wholly upon lens action so difficult. The result is, therefore, that the use of a lens system in this connection does not sacrifice the inherent advantages of the shadow type microscope with respect to simplicity of design, low cost, etc.

Referring now to Fig. 4 of the drawings, there is illustrated another embodiment of my invention comprising a discharge vessel 49 formed of a hollow metallic body portion 50 and a metallic end closure 51 suitably sealed together by an intermediate section of insulating material such as a glass annulus 52. It will be understood that the discharge vessel 49 may also suitably be formed entirely of glass or other ceramic insulating material. The discharge vessel or envelope 49 may be evacuated by suitable pumping means 49a arranged to maintain within the envelope any desired pressure of residual gas,

which may be air. The metallic end portion 51 provides support for an inwardly extending cathode 53. The form of the cathode 53 may differ in accordance with the type of electron microscope which is desired. For example, in the focusing lens type of electron microscope the cathode 53 may be of any well known thermionic type comprising an electrically heated electron-emitting filament 53a disposed within an apertured directing shield 53b, as shown at Fig. 5. On the other hand, in a shadow type electron microscope it is necessary to provide a very finely pointed cathode of the non-thermionic type, suitably of tungsten. The pointed type of cathode is shown at Fig. 4 and comprises a smoothly rounded tip (shown greatly magnified at Fig. 2) which is formed, for example, by etching, and the radius of curvature of which (indicated by r) is preferably less than 10^{-3} centimeters. In order to eliminate the possibility of undesired emission from the lateral surfaces of the cathode it may be surrounded by a metal shield 51a which is maintained at cathode potential and may be formed integrally with the end plate 51. At the end of the vessel 49 opposite the cathode 53 there is provided an image-reproducing surface comprising a glass window 54 coated internally with an electron-responsive fluorescent screen 55. It will be understood that, if desired, the screen 55 may be replaced by a removable electron-sensitive photographic film.

In cooperative relation with the cathode 53 for the production of a shadow image there is provided another electrode 56 which is shown as an annular metal disk and which is adapted to establish an electron accelerating field in the vicinity of the cathode. The sharply pointed character of the cathode makes it possible to establish very intense fields at the cathode tip by the application of readily attainable potentials to the electrode 56 and by this means to obtain cold cathode emission from the tip. The electrode 56 may be used also to position an object to be investigated (for example a bacteriological specimen) in close proximity to the extremity of the cathode. This may be done, for example, by supporting the specimen in the central aperture of the electrode 56 as indicated at 57. It will be understood that, if desired, an object mount structurally independent of the electrode 56 may be provided.

If a pointed cathode tip is used, as indicated in the drawings, and if the tip is in very close proximity to the object under investigation, electrons will be drawn from the point source at the end of the cathode and, due to the specified shape of the tip, may be expected to follow divergent lines extending from the cathode tip toward the image-reproducing surface 55. In following this path the electrons penetrate the object 57 and project upon the image-reproducing surface a magnified shadow picture of the object, the image being characterized by varying degrees of light and shadow depending upon local variations in density or thickness of the object. Without further refinement only shadow magnification can be obtained in this way, and the degree of magnification possible is a direct function of the ratio of the distance between the cathode and the reproducing surface to the distance between the cathode and the object.

For the purpose of increasing the magnification possible with a predetermined source-to-screen distance, I provide an electrostatic lens

system comprising a series of metallic disks 58-64, inclusive, each of which is centrally apertured to permit the passage of the image-producing electrons. Alternate disks, for example, the disks 59, 61 and 63, are mounted directly upon the metallic container 50 and are maintained at ground potential. The intermediate disks, namely the disks 58, 60, 62 and 64, are mounted upon a common electrically conducting support 65 which is electrically connected to the end plate 51 and maintained at cathode potential. The metallic disks are suitably separated by insulating spacers 66. In the shadow type of electron microscope, the lens system comprising the charged disks 58-64, inclusive, serves only to produce a wider divergence of the electron stream emanating from the point source at the tip of the cathode 53 and thus to produce a larger image upon the surface 55 for a predetermined source-to-screen length of the discharge vessel 49. Such an increased divergence, while desirable, is not essential in a shadow type microscope and, as indicated in the arrangement of Fig. 1, may be dispensed with.

It will be understood that the electron microscope illustrated in the drawings may serve either as a shadow type of microscope or as a lens type and that my invention is equally applicable to both types. If the cathode 53 has a finely pointed tip and the electrode 56 is in close proximity to the tip, the microscope will function as a shadow type, the electrostatic lens system serving to increase the divergence of the imaging electrons. On the other hand, if the cathode 53 does not act as a point source, due either to destruction of the tip or substitution of a thermionic type of cathode, the microscope may be used as a focusing type if the object-to-lens and lens-to-screen spacing is arranged in accordance with the well known general optical equation

$$\frac{1}{A} + \frac{1}{B} = \frac{1}{F}$$

where A equals the distance from the object to the one of the so-called principal planes of the lens, B equals the distance from the other principal plane of the lens to the screen, and F is the focal length of the lens.

In order to minimize the size of the electron microscope described above the last stages of magnification may advantageously be carried out by arranging a conventional light microscope 67 in position to view the electron-produced image on the screen 55.

Electron microscopes of the high vacuum type which are currently in use are commonly limited to a minimum lens element spacing of approximately one quarter of an inch at 50,000 volts and internal pressures of the order of 0.01 micron. Such spacing results in a minimum focal length of one quarter of an inch per lens, and a minimum source-to-screen length of approximately twelve inches for satisfactory magnification even when used in conjunction with a light microscope. According to my invention I propose to space apart the lens elements 58-64 by distances of the order of 50 mils at 50,000 volts so that a great many lenses may be positioned within a relatively short vessel. With such spacing to provide a plurality of lenses of short focal length, satisfactory magnification may be obtained with a source-to-screen length of the order of two to four inches. It will be evident that for operation at 25,000 volts, which is sufficient for the great majority of objects, the lens spacing at-

tainable will be so small that the limitations will be purely mechanical, while a source-to-screen length of as little as one inch does not appear unreasonable.

My invention also comprehends that a microscope of the above dimensions shall be operable with a significant amount of residual gas present, that is, under such poor vacuum conditions as have heretofore caused lens sparkover and other adverse positive ion effects in electron microscopes even with wide element spacing. By way of example, a discharge tube having an internal pressure of greater than 0.1 micron may be regarded as including a significant quantity of gas. Conversely, it is contemplated that by retaining conventional spacing and pressures my invention will make it possible to operate a microscope at greatly increased voltages thereby to obtain greater object penetration. Furthermore, the same means relied upon to provide the above innovations also precludes cathode tip destruction in the shadow type microscope having a pointed tip, even when operated at upward of 25,000 volts in a poor vacuum. These improved results are simultaneously attained, as will be explained more fully in the following, by the use of an energizing system, similar to that explained above with respect to Figs. 1 and 3, to limit the application of voltage to intervals within or approaching the range from a millisecond to millimicrosecond (10^{-3} to 10^{-9} seconds). By this means positive ion bombardment is substantially eliminated so that heating and destruction of the cathode destructive bombardment of the screen, and arc-over between the lens electrodes are all avoided.

The circuit for applying a pulse of voltage to the cathode structure or end plate 51 of the arrangement of Fig. 4 may be similar to that shown in connection with Fig. 1 and corresponding elements have been assigned like reference numerals.

It is emphasized that this portion of the circuit comprising the second spark gap 40, having main electrodes 41 and 42 and a discharge controlling auxiliary electrode 43, serves to limit the duration of the discharge during a period sufficiently short to avoid adverse positive ion effects of all types, and for terminating the discharge very soon after its initiation. The energization of electrode 43 is preferably correlated to that of the electrode 32 to assure that the gap 40 shall be triggered within a time of the order of a microsecond (10^{-3} to 10^{-9} seconds) after the breakdown of the gap 21. This is accomplished by energizing electrode 43 from a triggering circuit comprising the peaking transformer 44 and the associated circuit. If the values of the elements 47 and 48 are properly chosen and correlated, the voltage pulses impressed on electrode 43 will be slightly delayed with respect to the pulses impressed on electrode 52. Sparkover of the gap 40 obviously has the effect of grounding the cathode 51 and of making the continuation of a discharge from it impossible.

With a pulse discharge of the type described above and assuming the duration of each conductive interval of the microscope to be approximately within the range from 10^{-3} to 10^{-9} seconds, the destructive and space limiting effects of positive ion action are substantially eliminated. While I do not desire to be limited to any particular theoretical explanation, it is my present understanding that the markedly improved results obtainable with my pulse electron micro-

scope are attributable primarily to the fact that potential pulses of the order of time duration described prevent any positive ions present within the discharge tube from ever attaining any substantial velocity. It is generally understood that the mass and consequently the inertia of a positive ion is substantially greater than that of an electron. Consequently, while electrons may be emitted from the cathode and discharged upon the image-reproducing surface during each short conductive pulse, a pulse of the order of magnitude described is not sufficiently long to produce any substantial movement of a heavier positive ion or to provide it with any significant velocity. Subsequently, when the conductive pulse ceases, the ion quickly comes to rest and must again be accelerated to standstill by the next pulse. Accordingly, for all practical purposes the positive ions present in the discharge tube may be considered as stationary. In this way any positive ion action is substantially eliminated, since adverse positive ion effects are believed to be due largely to bombardment of the tube elements and the residual gas molecules by positive ions moving at a significant velocity.

Since the positive ions in my electron microscope are substantially stationary in space for all practical purposes, that is, they never attain a sufficient velocity to have a significant effect, the microscope is substantially independent of the degree of evacuation so far as positive ion effects are concerned. Furthermore, the structural limitations formerly imposed upon electron microscopes by positive ion bombardment are removed. There is no "mean free path" of effectively stationary positive ions, so that tube element spacing and evacuation are not controlled by this factor. Instead there is substituted as a limitation only the mean free path of electrons. This path is sufficiently large even under poor vacuum conditions to permit spacing of tube elements as close as mechanically possible. Indeed, it is even possible to retain clarity of image production to a point where the source-to-screen length of the tube approaches the mean free path of electrons. Then a tube of predetermined length need be evacuated only to meet the limitation, and conversely, a tube having a predetermined vacuum must have a length determined by the mean free path of electrons at such pressure. It will be understood that if the mean free path of electrons is less than the source-to-screen distance, the average imaging electron will encounter an obstacle before it reaches the screen, so that the images will not be clear. The relatively stationary character of the positive ions also removes voltage limitations heretofore imposed, so that microscopes having greatly improved penetrating power become possible by utilizing voltage of the order of hundreds of thousands of volts.

While I have shown and described my invention as applied to a particular system embodying various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electron microscope comprising an evacuated envelope which contains a cathode having a non-thermionic electron-emitting portion in the

form of a finely rounded point, means for supporting in close proximity to the said point an object desired to be examined, an electrode adapted when at high potential to draw electrons from the said point along divergent lines extending through the region of support of the object, and means for applying between the electrode and the cathode pulses of voltage of sufficient magnitude to assure penetration of the object by the electrons thus obtained from the cathode, said pulses being limited in duration to less than about 10^{-6} seconds, whereby excessive deterioration of the cathode point is prevented.

2. In vacuum discharge apparatus for producing in a selected imaging plane a magnified electron-optical image of an object desired to be investigated, the combination which includes a cathode having a non-thermionic electron-emitting portion in the form of a metal point with a radius of curvature at the tip of less than 10^{-3} centimeters, means for supporting the object to be investigated in close proximity to the cathode point and in a location between the point and the said imaging plane, and means for producing in the vicinity of the cathode point an intense electrostatic field of such strength and direction as to produce electrons from the point by field emission and to project such electrons through the object along divergent lines extending toward the imaging plane, said last-named means being operable to maintain the said field for time intervals limited to less than 10^{-6} seconds, whereby the cathode point is protected from destructive bombardment.

3. In vacuum discharge apparatus for producing in a selected imaging plane a magnified electron-optical image of an object desired to be investigated, the combination which includes a cathode having a non-thermionic electron-emitting portion in the form of a metal point with a radius of curvature at the tip of less than 10^{-3} centimeters, means for supporting the object to be investigated in close proximity to the cathode point and in a location between the point and the said imaging plane, electrode structure capable when at high potential of producing in the vicinity of the cathode point an electrostatic field adapted to project electrons from the point along divergent paths extending through the object toward the imaging plane, said structure being either inclusive of or in addition to the said object-supporting means, and an impulsing circuit connecting with the said electrode structure, said circuit including means for abruptly applying a high potential to the structure and for terminating the application of such potential in less than about 10^{-6} seconds.

4. In vacuum discharge apparatus for producing in a selected imaging plane a magnified electron-optical image of an object desired to be examined, the combination which includes a cathode having a non-thermionic emitting portion in the form of a finely rounded point, means for supporting the object to be examined in close proximity to the said point, and in a location between the point and the selected imaging plane, an electrode adapted when at high potential to draw electrons from the said point along divergent lines extending through the object and toward the imaging plane, said electrode being either inclusive of or in addition to the said object-supporting means, a circuit for applying between the cathode and the electrode pulses of voltage of sufficient magnitude to assure penetration of the object by the electrons thus ob-

tained from the cathode point, said pulses being of such limited duration as to avoid excessive deterioration of the cathode point, and an electron lens system between the said electrode and the imaging plane for producing in said plane a magnified replica of the cross-section pattern of the divergent electron stream proceeding from the cathode.

5. An electron microscope comprising an evacuated envelope containing a quantity of residual gas, a non-thermionic cathode mounted within said envelope and having an electron-emitting portion in the form of a fine point, means for supporting an object to be examined in close proximity to said point and in a location between said point and a selected imaging plane, an electrode adapted when at high potential to draw electrons from said point along divergent lines extending through said object and toward said imaging plane, and energizing means for applying between said cathode and said electrode periodic pulses of voltage of sufficient magnitude to ensure penetration of said object by said electrons, said pulses being of such short duration as to maintain positive gas ions formed by the resultant electron discharge effectively stationary in space thereby to avoid excessive deterioration of said cathode point by positive ion bombardment.

6. An electron microscope comprising an evacuated envelope containing a quantity of residual gas, a non-thermionic cathode mounted within said envelope and having an electron-emitting portion in the form of a fine point, means for supporting within said envelope an object to be examined in close proximity to said point and in a location intermediate said point and a selected imaging plane, an electrode adapted when at high potential to draw electrons from said point along divergent lines extending through said object and toward said imaging plane, and means for energizing said microscope comprising high frequency pulse generating means for periodically applying between said cathode and said electrode pulses of voltage of sufficient magnitude to ensure penetration of said object by said electrons and of a time duration of the order of one microsecond.

7. An electron discharge apparatus comprising an evacuated envelope containing a quantity of residual gas, a plurality of positive and negative electrodes positioned in closely spaced relation within said envelope, and energizing means for establishing an electron discharge within said envelope comprising means for applying between said electrodes pulses of voltage of such short duration that positive gas ions resulting from said discharge do not attain a sufficient velocity to reach a negative electrode within said envelope during the period of said discharge.

8. An electron discharge apparatus comprising an evacuated envelope containing a quantity of residual gas, a plurality of electrodes positioned in closely spaced relation within said envelope, said electrodes being spaced apart by distances of the order of 50 mils and said envelope containing surfaces which are at a negative operating potential with respect to one of said electrodes, and pulse generating means for impressing between said electrodes voltage impulses of sufficient magnitude to establish an electron discharge and of such short duration as to preclude movement of positive gas ions generated by said discharge to reach negative surfaces within said envelope during the period of said discharge.

9. An electron microscope comprising a discharge envelope containing a quantity of residual gas, a plurality of positive and negative electrodes positioned within said envelope and spaced apart by distances of the order of 50 mils, means for supporting within said envelope an object desired to be examined, and energizing means for establishing an electron discharge within said envelope comprising means for impressing between said electrodes voltage pulses of sufficient magnitude to ensure penetration of said object by the discharged electrons and of such short duration that positive gas ions resulting from said discharge do not attain sufficient velocity to reach negative ones of said electrodes.

10. An electron discharge apparatus comprising an evacuated envelope containing a significant quantity of residual gas, a plurality of electrodes positioned within said envelope, and energizing means for establishing an electron discharge within said envelope comprising pulse generating means for periodically impressing between said electrodes voltage pulses of such short duration that substantially none of the positive gas ions formed by said discharge reach any of said electrodes.

11. An electron discharge apparatus comprising an evacuated envelope containing a significant quantity of residual gas, a plurality of positive and negative electrodes positioned within said envelope and spaced apart by distances of the order of 50 mils, and energizing means for establishing an electron discharge within said envelope comprising means for impressing between said electrodes high voltage impulses of such short duration that positive gas ions formed by said discharge do not attain sufficient velocity to reach negative ones of said electrodes.

12. An electron microscope comprising a discharge envelope containing a quantity of residual gas, a cathode and at least one other electrode positioned in closely spaced relation within said envelope, means for supporting within said envelope an object desired to be examined, and means for rendering said cathode electron-emissive comprising means for applying between said cathode and another electrode pulses of voltage of sufficient magnitude to ensure penetration of said object by electrons emitted by said cathode and of a time duration of the order of one microsecond.

13. An electron microscope comprising a discharge envelope containing a quantity of residual gas, a plurality of electrodes positioned within said envelope and spaced apart by distances of the order of 50 mils, means for supporting within said envelope an object desired to be examined, and energizing means for establishing an electron discharge within said envelope comprising pulse generating means for impressing between said electrodes pulses of voltage of sufficient magnitude to ensure penetration of said object by the discharged electrons and of a time duration falling approximately within the range from 10^{-3} to 10^{-9} seconds.

14. An electron microscope comprising a discharge envelope containing a significant quantity of residual gas, a plurality of electrodes positioned within said envelope, means for supporting within said envelope an object desired to be examined, and energizing means for establishing an electron discharge within said envelope comprising high frequency pulse generating means for periodically impressing between said electrodes pulses of voltage of sufficient magni-

tude to ensure penetration of said object by the discharged electrons and of a time duration falling approximately within the range from 10^{-3} to 10^{-9} seconds, whereby positive gas ions resulting from said discharge are constrained to remain effectively stationary in space.

15. An electron microscope comprising a partially evacuated discharge envelope containing a significant quantity of residual gas at substantial pressure, means for supporting within said envelope an object desired to be examined, an electron emissive cathode and at least one other electrode positioned within said envelope and arranged when energized to establish a stream of electrons from said cathode through said object, and an electron-sensitive image-reproducing surface positioned in the path of said electron stream to provide an enlarged electron-optical image of said object, said image-reproducing surface being spaced from said cathode a distance of the same order of magnitude as the mean free path of electrons within said gas.

16. An electron microscope comprising a partially evacuated discharge envelope containing a significant quantity of residual gas at substantial pressure, means for supporting within said envelope an object desired to be examined, an electron emissive cathode and at least one other electrode positioned in spaced relation within said envelope and arranged when energized to establish a stream of electrons directed from said cathode through said object, said envelope containing surfaces which are at a negative operating potential with respect to said other electrode, an electron-sensitive image-reproducing surface in the path of said electron stream beyond said object thereby to provide an enlarged electron-optical image of said object upon said surface, said image-reproducing surface being spaced from said cathode a distance equal to less than the same order of magnitude as the length of the mean free path of electrons within said gas, and means for energizing said microscope comprising pulse generating means arranged to impress between said cathode and another electrode pulses of voltage of sufficient magnitude to ensure penetration of said object by said electrons and of sufficiently short duration to preclude the acquisition of sufficient velocity by positive gas ions generated by the resultant electron discharge to permit said ions to reach negative surfaces within said envelope.

17. An electron microscope comprising a partially evacuated discharge envelope containing a significant quantity of residual gas at substantial pressure, means for supporting within said envelope an object desired to be examined, an electron-emissive cathode positioned within said envelope to project toward said object a stream of electrons, an electron-emissive cathode within said envelope and arranged when energized to establish a stream of electrons directed from said cathode toward said object, an electrostatic lens system arranged in the path of said stream of electrons and comprising a plurality of lens electrodes spaced apart by a distance of the order of 50 mils, an electron-sensitive image-reproducing surface positioned in the path of said electron stream to provide an enlarged electron-optical image of said object upon said surface, said image-reproducing surface being spaced from said cathode a distance of the same order of magnitude as the length of the mean free path of electrons within said gas, and means for energizing said cathode without incurring adverse positive ion effects comprising high frequency pulse generating means arranged periodically to impress upon said cathode pulses of voltage of sufficient magnitude to ensure penetration of said object by said electrons and having a time duration of the order of one microsecond.

18. A high voltage electron discharge apparatus comprising an evacuated envelope containing a quantity of residual gas, a plurality of electrodes positioned in spaced relation within said envelope, and energizing means for establishing an electron discharge from one of said electrodes comprising means for impressing between said electrodes high voltage pulses of such short duration that positive gas ions formed by said discharge remain effectively stationary in space.

19. A high voltage electron microscope comprising a discharge envelope containing a quantity of residual gas, a plurality of electrodes positioned in spaced relation within said envelope, means for supporting within said envelope an object desired to be examined, and energizing means for establishing an electron discharge of high object penetrating value within said envelope comprising means for impressing between said electrodes high voltage pulses having a time duration of the order of one microsecond.

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