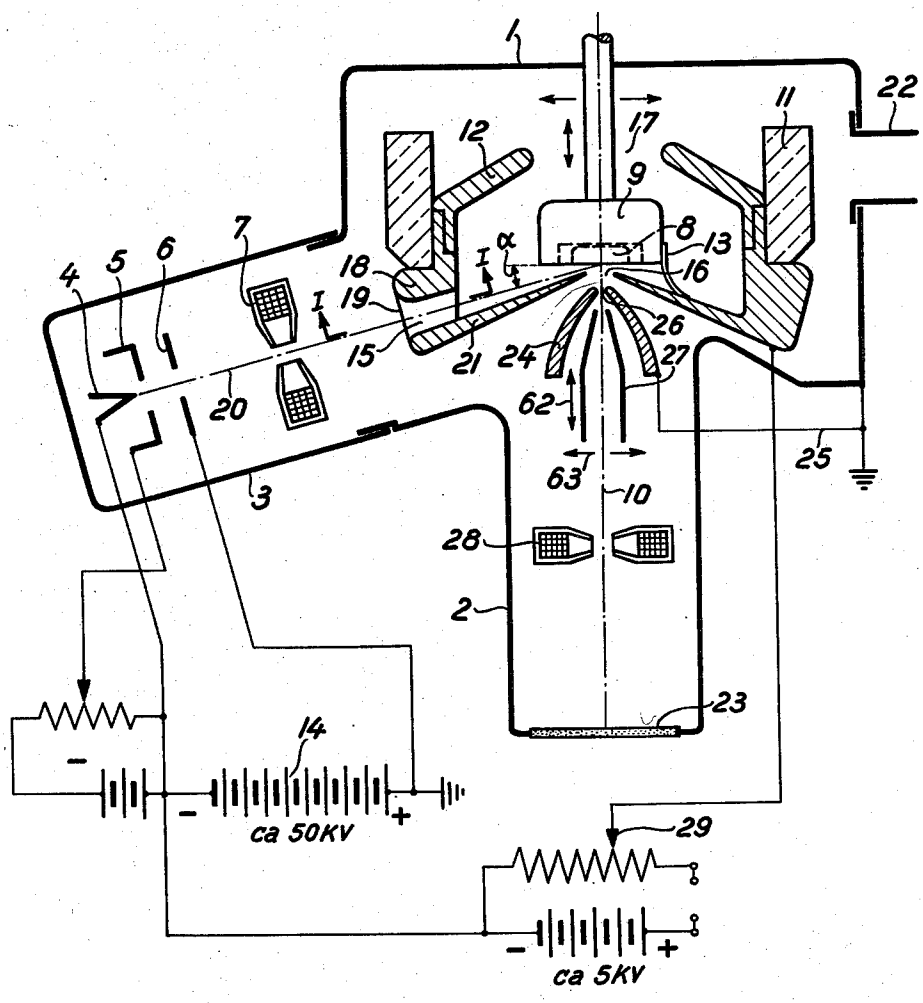
March 15, 1960 G. E. BARTZ ET AL 2,928,943

ELECTRONIC MICROSCOPE FOR TOP ILLUMINATION OF SURFACES

Filed Sept. 5, 1958 4 Sheets-Sheet 1

Fig. 1



INVENTORS
GUNTER ERWIN BARTZ
WALTER BILL

BY Toulmin & Toulmin
ATTORNEYS

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Filed Sept. 5, 1958 4 Sheets-Sheet 2

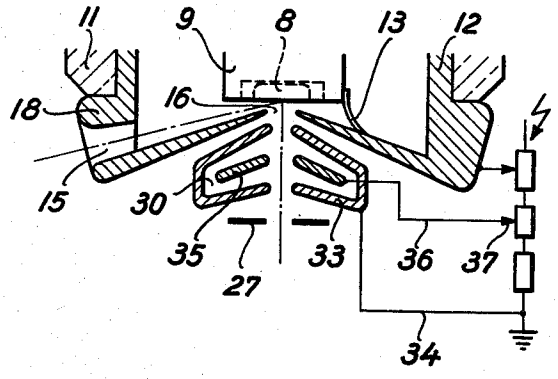


Fig. 2

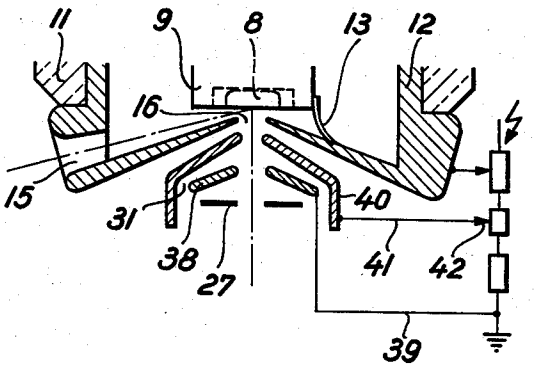


Fig. 3

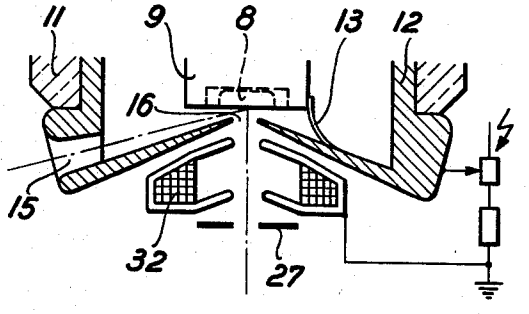


Fig. 4

INVENTORS
GUNTER ERWIN BARTZ
WALTER BILL
BY Toulmin & Toulmin
ATTORNEYS

March 15, 1960 G. E. BARTZ ET AL 2,928,943

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Filed Sept. 5, 1958

4 Sheets-Sheet 3

Fig. 1a

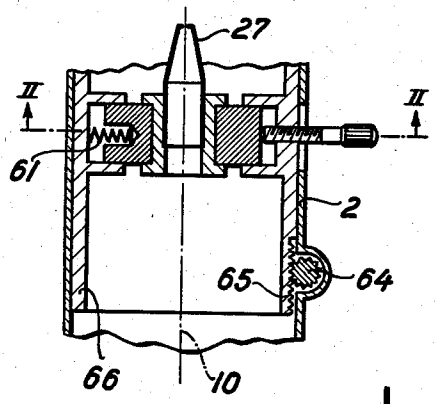
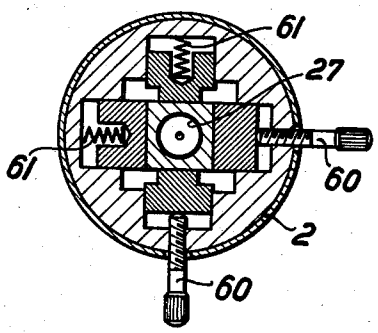


Fig. 1b



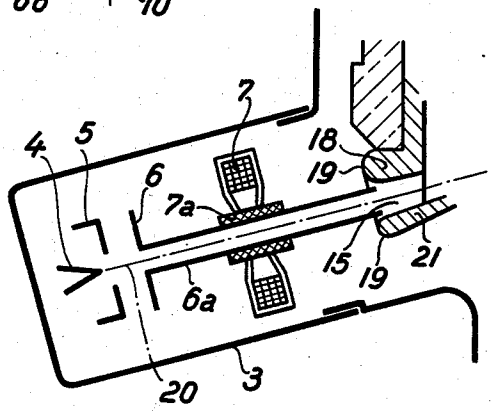


Fig. 5

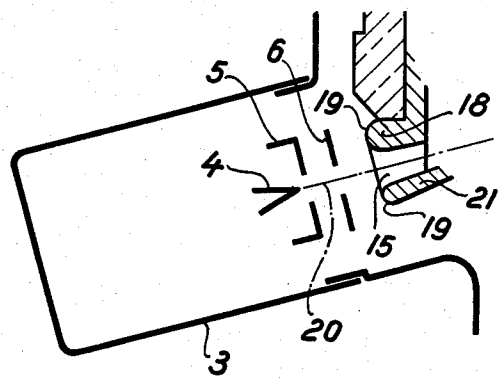


Fig. 6

INVENTORS
GUNTER ERWIN BARTZ
WALTER BILL

BY Toulmin & Toulmin
ATTORNEYS

March 15, 1960 G. E. BARTZ ET AL 2,928,943

ELECTRONIC MICROSCOPE FOR TOP ILLUMINATION OF SURFACES

Filed Sept. 5, 1958 4 Sheets-Sheet 4

Fig. 7

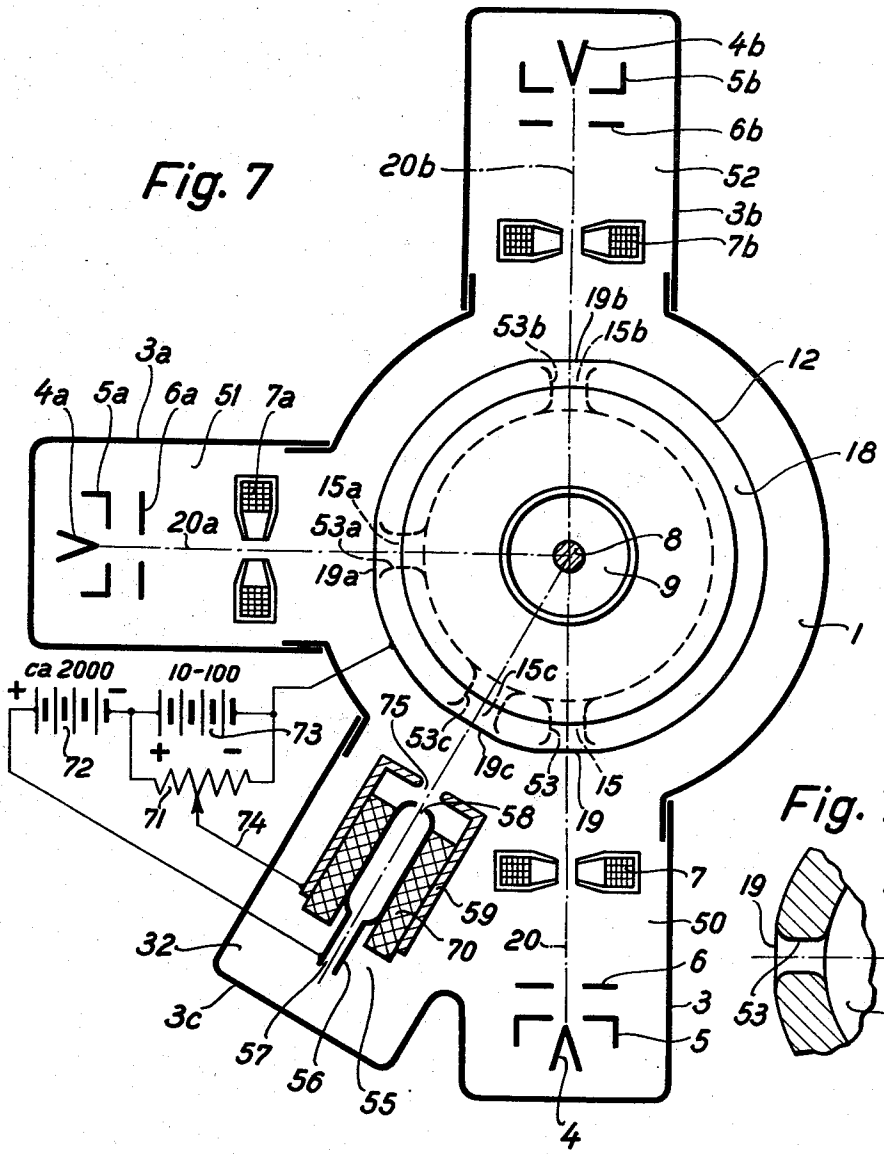


Fig. 7a

INVENTORS
GUNTER ERWIN BARTZ
WALTER BILL

BY Toulmin & Toulmin

ATTORNEYS

United States Patent Office 2,928,943 Patented Mar. 15, 1960

2,928,943

ELECTRONIC MICROSCOPE FOR TOP ILLUMINATION OF SURFACES

Günter Erwin Bartz, Dutenhofen, and Walter Bill, Naunheim, Germany, assignors to Ernst Leitz, G.m.b.H., Wetzlar, Germany

Application September 5, 1958, Serial No. 759,162

Claims priority, application Germany September 11, 1957

8 Claims. (Cl. 250—49.5)

This invention relates to an electronic microscope suitable for making surfaces of objects visible by means of top illumination.

It is already known in the art to make an object surface visible by means of electronic rays in which the surface itself is illuminated directly with beams of ions. The ions strike secondary electrons out of the illuminated surface of the object which are then conventionally accelerated and caused to reproduce images with the aid of electro-optical lens systems.

These known devices suffer from the drawbacks of causing a heavy charge load on the surface of the object. Furthermore the discharged ions accumulate on the surface in the form of material layers which lead to a filling in of depressions in that surface equal to a snowing-in effect, thus progressively hiding details of the original surface in the resulting image.

It is the object of our invention to avoid these and other drawbacks of the presently known apparatus, and to provide an electronic microscope for top illumination of surfaces, which is simpler both in construction and operation than the existing devices while being free in particular, from the snowing-in effect of ion beam microscopes, and subjecting the surface of the object only to a moderate load.

This object is achieved by the electronic microscope according to the invention which is adapted for forming direct images of the surface of an object by means of secondary electrons, and provided with a conventional electronic beam-operating system comprising an accelerating anode, which system is so disposed as to cause an electron beam to fall under an oblique angle on to the surface area of the object to be depicted, and which microscope is further provided with a shielding cage or can adapted for excluding electrostatic fields in its interior and having a plurality of openings and being rotation-symmetrical in shape and enclosing the object, while being at the same time centered about the optical axis of the secondary emission path serving to produce the image, and being at the same electrical potential as the object itself.

According to another feature, the objective system of the electronic microscope according to the invention is formed by the aforesaid shielding can and the object together with a ground-connected electrode disposed behind the can in the electronic path from the object to the image observation means, which latter is preferably a conventional fluorescent screen.

In other embodiments of the electronic microscope according to the invention, the aforesaid electrode forming part of the objective system is replaced by other lens means in the imaging path from the object to the image-producing screen means, which other means consist either of an electrostatic unipotential lens, or an electrostatic immersion lens, or a magnetic lens or lens system forming part of the objective system.

Furthermore, the electron microscope according to the invention may comprise an additional electron beam-

generating system and/or an adjustable ion-beam generating source, which ion source is almost, but not quite at the same potential as the object, and is so disposed in the device according to the invention that the direction of the ion beam approximately coincides with the direction of the primary electron beam directed towards the object.

The emitter system for generating the primary electron beam comprises, for example, an electron source, a Wehnelt cylinder and an accelerating anode. Such a system is, for instance, described in Manfred von Ardenne: Tabellen der Elektronenphysik, VEB Deutscher Verlag der Wissenschaften, Berlin (1956), vol. I, p. 131.

It is advisable to have the electron emitter system directed at an oblique angle toward the object.

The body of the shield can or cage enclosing the object and protecting the same against undesirable electrostatic fields is substantially symmetrical with regard to an axis of rotation which, preferably, is identical with the optical axis of the image-transmiting system formed by the paths of the secondary electronic beams, and is provided with a plurality of openings. Primary electrons are permitted to enter the shielding can by a first, lateral opening, while secondary electrons leave the can by way of another opening provided close to the object in the wall of the cage centered about the axis of symmetry of the latter. A third opening or bore in the cage wall serves for introducing and withdrawing the object from the can and for unimpeded displacement of the object carrier or holder.

In a similar manner, several independent illuminating systems for directing primary electron beams toward different portions of the object surface may be provided in the device according to the invention and, in this case, a correspondingly larger number of openings will have to be provided in the can wall, so that the object may be top-illuminated severally either at the same time, or in successive order.

The field-free space in the interior of the shield cage or can permits a straight-lined travel of the illuminating beam or beams. Furthermore, the can provides a reliable safeguard against discharges, for the high field intensity at the object which latter usually bears corners and/or edges, is only utilized at the spot or area under observation, and the danger of an electrical arc-over is substantially eliminated or at least greatly reduced. It is correspondingly possible to operate the microscope with extremely high field intensities, for instance in the order of 50 kilovolts/cm., which, of course, signifies a considerable increase in the resolving power of the emission microscope, since the latter increases in linear function with the field intensity at the place under observation.

The ejection of image-forming secondary electrons from the object by primary electrons instead of the conventionally used ions offers several advantages. First of all, the object rating is considerably less when irradiating the object with electrons instead of ions. Secondly, as has been mentioned above, the "snowing-in" effect is avoided.

Other advantages reside in the fact that a single high voltage source will suffice for providing voltage to the system, and that the angle of the incident primary beam relative to the object can easily be altered by changing the object voltage. Other advantages are of a vacuum-technical nature, it being possible to obtain an extremely pure vacuum in the interior of the electronic tube which could not be attained if an ion beam is directed into the interior of the apparatus.

On the other hand, when objects of electrically non-conductive or semiconductive materials are to be made visible, it may be desirable to prevent the object from

becoming electrostatically charged by spraying the same with slow ions.

In such cases, a source for producing a beam of slow ions (speeds ranging from about 10 to 100 volts), of the type described in C. Hailer: Wissenschaftliche Veröffentlichungen der Siemens Werke (1938), vol. 17, p. 115, may be used in the apparatus in addition to the electron beam-producing system. This ion-beam producing source should be provided with means for adjusting the intensity and direction of the beam, the latter to coincide approximately with that of the primary electron beam, and should be held approximately at object potential, as stated hereinbefore.

The invention will be still further explained with the aid of the accompanying drawings in which

Figure 1 is a schematical sectional view of an embodiment of the top-illumination electronic microscope according to our invention;

Figure 1*a* is a longitudinal sectional view of the micrometric means for adjusting the diaphragm **27** suitable for adjusting the object-holder **9**;

Figure 1*b* is a cross sectional view of the micrometric adjusting means taken along the lines II—II in Figure 1*a*;

Figure 2 is a partial sectional view of a somewhat different embodiment of certain electrode means used in the electronic microscope shown in Figure 1;

Figure 3 shows in partial sectional view another embodiment of the electrode means in the electronic microscope shown in Figure 1; and

Figure 4 illustrates a third embodiment of the electrode means in a partial sectional view of the electronic microscope according to the invention.

Figure 5 is a partial, schematical sectional view of a modification of the primary electron beam generating system in the electronic microscope of the present invention;

Figure 6 is a partial, schematical sectional view of yet another modification of the primary electron beam generating system in the electronic microscope of the present invention;

Figure 7 is a schematical, sectional view of another embodiment of the invention, similar to Figure 1, but showing another preferred embodiment of the top-illuminated electronic microscope of the present invention having a plurality of electron beam generating systems and being equipped with an ion beam generating system.

Figure 7*a* is a schematical, cross sectional view, taken along I—I of Figure 1.

More particularly, the embodiment of the electron microscope according to the invention as illustrated in Figure 1 comprises a microscope hull or casing **1** having a main tube **2** which is cocentrically arranged about the optical axis of the object-image path, and a lateral angular tube **3** which houses the primary electron beam generating system consisting of an electron emitting cathode **4**, a modulating (Wehnelt cylinder) electrode **5** and an accelerating anode **6**. In the path of the primary electron beam toward the approximate center of the casing **1**, there is proposed a condenser lens **7**, for instance of the type described, by Von Ardenne, supra. The object **8** under observation is borne by an object support or holder **9** which may be provided with the conventional means (not shown) for adjusting and measuring the exact position of the object **8** in casing **1**.

Axially symmetrical to the aforesaid optical axis, which is indicated by a phantom line at **10**, there is mounted in the interior of casing **1** an insulating block **11**, for instance in the form of an annular body of high tension insulating material, in which there is mounted a shield can **12**.

Can **12** is symmetrical to its axis of rotation which coincides with optical axis **10**, and is preferably made of stainless steel, and free from corners or edges and of a highly polished, completely smooth surface, whereby the formation of corona discharges is substantially suppressed.

Can **12** is electrically connected, on the one hand, by means of a number of sliding contacts **13** (only one of which is shown in Figure 1) with object **8**, and, on the other hand with a source of high voltage potential at **14**.

Openings **15**, **16** and **17** are provided in the wall of can **12**, of which opening **15** is provided in a neck portion **18** of can **12**, the front wall of which is somewhat flattened at **19** in a plane which is vertical to the optical axis **20** of the illuminating system (see Figure 7).

Opening **16** is provided in an inwardly curved or conical wall portion **21** of can **12** whereby the opening is located close to the surface of object **8** where the primary electron beam along axis **20** impinges on the latter.

This opening **16** is centered with extreme accuracy on the common optical axis through the subsequently described elements of the imaging system.

The further, larger opening **17** in the wall of can **12** opposite opening **16** serves for the introduction, withdrawal and unimpeded displacement of object holder **9** in any lateral direction, and for the evacuation of the interior of can **12**, which is effected together with the interior of casing **1** by means of a vacuum pump (not shown) connected to outlet pipe **22**.

At its free end main tube **2** bears a fluorescent screen **23** or similar means for making the electron-beam produced image of the top-illuminated object surface area visible.

An electrode **24** which is connected to ground via line **25**, is located in the path of the secondary electron beams from object **8** to the latter screen **23** along optical axis **10**. This electrode has a central opening **26** for passage of the secondary electrons, and is provided with adjusting means which permit the distance between the opening **16** of can **12** and the electrode to be altered.

A micrometrically adjustable or iris diaphragm **27** is disposed at the focal point of electrode **24** behind the latter as seen from the object **8**. Between the diaphragm **27** and fluorescent screen **23**, there is disposed an electronic lens **28** of known type which serves as a projective.

Such lenses are described, for instance, in Von Ardenne, op. cit., vol. I, p. 407, 412, 416.

The adjustment of diaphragm **27** can be effected with cross slide macrometric adjusting means known per se and shown, for example, in Figures 1*a* and 1*b*. The diaphragm **27** can be displace in the directions of arrow **63** by means of the adjusting screw **60** acting against a spring **61** and it can be moved in the directions of arrow **62** by means of the screw **64** engaging the ratchet portion **65** provided in the slidable sleeve **66** within the cylinder **2**.

The analogous micrometric adjusting means can be used for displacing the object-holder **9**.

The electronic microscope shown in Figure 1 operates as follows:

Primary electrons are emitted from the system of cathode **4**, modulated by electrode **5** and accelerated by anode **6**, and then focussed by condenser **7** in the direction toward object **8** along optical axis **20**.

A voltage, the so-called object voltage is applied at both the object **8** and shield can **12**, which is positive with regard to the potential of cathode **4** and can be taken from potentiometer **29** and varied, for instance, between 0 and 5000 volts.

Since the can is connected with potentiometer **29** having a voltage in the order of 2 kilovolts, whereas the anode **6** has a voltage in the order of 50 kilovolts (see Figure 1), the electrons of the primary beam have to travel against a negative voltage and are thus braked upon approaching opening **15** of can **12** down to a speed which corresponds to the positive value of the object voltage or "landing voltage" of the primary electrons on the object surface spot or area to be top-illuminated. In the space free from electrostatic field which exists in the interior of can **12**, the primary electron beam travels in a straight line toward the

aforesaid object spot or area. The primary electrons which impinge on this spot or area, eject from the same secondary electrons which travel substantially along optical axis **10**.

Together with can **12** being at even potential with object **8**, the normally grounded electrode **24** produces an axially symmetrical accelerating field, which grips through opening **16** of can **12** and accelerates the secondary electrons leaving the surface of the object from a speed of about 2 kilovolts up to 50 kilovolts. This acceleration is necessary in order to create an image and to obtain the requisite speed in order to create an image on screen **23**.

This accelerating field also causes a deflection of the illuminating primary electron beam in the vicinity of opening **16** in such a manner, that the angle of incidence α of the primary beam with the object surface becomes smaller.

A smaller angle of incidence is desirable whenever the surface of the object is comparatively planar, it is undesirable whenever the surface of the object is irregular and has indents and projections. In that case undesirably elongated shadows would be produced which can be avoided by choosing a greater angle of incidence. This can be done by changing the voltage of the voltage sources by means of the potentiometer **29**. The angle of incidence is much smaller by lowering the voltage at the potentiometer **29** and vice versa.

In case of substantially planar objects an object voltage in the range of 1000–2000 volts is chosen; in case of objects with more irregular surfaces the object voltage is to be in the order of 4000–5000 volts. In both instances the accelerating voltage is in the order of from 40–50 kilovolts. The angle of incidence α is in the order of 20°.

By selecting a suitable "landing voltage" and correspondingly adjusting the emission of primary electrons from the electron beam generating system **4**, **5**, **6**, it is, however, possible to provide for optimal conditions of illumination.

Can **12**, electrode **24** and the object **8** form together an electrostatic focussing lens which serves as an objective system and produces a real intermediary image. In the focus of the objective behind the latter, seen from the object, the iris diaphragm **27** is preferably provided for reducing aberrations occurring in the image. This diaphragm may have an inner diameter of about 5 to 20 microns. The real intermediary image produced by the objective is enlarged with the aid of the above-mentioned projective lens **28** and appears on the fluorescent screen **23**.

In the embodiment shown in Figure 2, the field-producing electrode **24** is replaced by an electrostatic unipotential lens **30**, in Figure 3 by an electrostatic immersion double aperture lens **31** and in Figure 4 by an iron clad magnetic lens **32**. In Figure 2, the electrode **33** of unipotential lens **30** is connected to ground via line **34**, while the electrode **35** is connected via line **36** to a potentiometer **37**, whereby the potential at electrode **35** can be varied by means of the potentiometer **37**.

In a similar manner, the electrode **38** of the double aperture lens **31** is connected via line **39** to ground, while the electrode **40** is connected via line **41** to potentiometer **42**.

The arrangement and operation of unipotential lenses in electronic microscopes is described in detail, for instance, in Von Ardenne, op. cit., vol. II, p. 802, double aperture lenses in H. Johannson, in Annalen der Physik (1933), vol. 18, p. 385 and magnetic lenses in Von Ardenne op. cit., vol. II, p. 803–805.

The electronic microscope of the present invention can also be equipped with a modified primary electron beam generating system as shown, for example, in Figures 5 and 6.

As shown in Figure 5, the anode **6** may have a tubular elongation **6***a* extending into the opening **15** of cage **12**. The condenser lens **7** is disposed around the tubular elongated portion **6***a* substantially in the middle thereof with an interposed insulating layer **7***a*.

Due to this arrangement, an even narrower pencil of primary electrons is created since exterior field influences are excluded. Consequently, the speed of the primary electrons is more even and hence the speed of the secondary electrons is also more even thereby creating a clearer image.

It is also possible to dispense with the condenser lens **7** by disposing the primary electron beam generating system **4**, **5**, and **6** close to the opening **15** of cage **12** as shown, for example, in Figure 6. In that case the cage **12**, the accelerating anode **6** and the Wehnelt cylinder **5** form an electro-optical system. The adjustment of cathode **4** can be effected with adjusting means of the type shown in Figures 1*a* and 1*b*.

According to another embodiment the electronic microscope of the present invention is equipped with a plurality of primary electron beam generating systems as, for example, three systems **50**, **51**, and **52** as shown in Figure 7. The casing **1** bears three cylinder portions **3**, **3***a*, **3***b*, housing a cathode **4**, **4***a*, **4***b*, and a Wehnelt cylinder **5**, **5***a*, **5***b*, an anode **6**, **6***a*, **6***b*, and a condenser **7**, **7***a*, **7***b*, respectively. The optical axis is designated with **20**, **20***a*, **20***b*, respectively. These axes pass through openings **15**, **15***a*, and **15***b* defined by the flattened front portions **19**, **19***a*, and **19***b* and the surfaces **53**, **53***a* and **53***b*. The object holder **9** is disposed within the cage **12**.

According to still another preferred embodiment the electronic microscope of the present invention is provided with an ion beam generating system **55**. This system is housed in a further cylinder portion **3***c* of the casing **1** situated as close as possible to one of the three cylinder portions **50**, **51**, or **52**. This ion source which is, of course, known per se, consists of a gas inlet pipe **56** with a hollow space inside. At the end opposite to the entrance **57** of the inlet pipe there is provided a small exit opening **58**. The gas discharge pipe is embedded in an insulating layer **70** within the electrode **59**. The gas inlet pipe is connected with the positive pole of a voltage source **72** of approximately 2000 volts, whereas the electrode **59** is connected with the terminal **74** of a potentiometer **71** which, in turn, is connected with the negative pole of the voltage source **72** and with the negative pole of a further voltage source **73** of approximately 100 volts. The negative pole of this second voltage source is also connected with the cage **12**.

This ion generating source operates as follows:

The gas leaving the small opening **58** of the gas inlet pipe **56** results in a gas discharge due to the voltage of about 2000 volts between the inlet pipe **58** and the electrode **59** which causes the gas to be ionized. The ions leaving the opening **75** of the electrode **59** are accelerated towards the object holder by the voltage in the range of 10 to 100 volts between the electrode **59** and the cage **12**. If a low accelerating voltage is chosen, for example 10 volts, the positive ions will cause a discharging of the object which is negatively charged by the beam of primary electrons, if the object consists of a non-conductor.

By choosing a high accelerating voltage, for example 100 volts, the ions will have an etching effect on the surface of the object, for example a metallic object. In this case the beam of electrons may be directed to the object only for a few seconds since otherwise too many ions would cover the object thereby producing the undesirable snow effect. The etching performed in such a manner offers great advantages over the etching done by means of acids since a much finer etching effect is obtained.

It will be understood that this invention is susceptible to modification in order to adapt it to different usages and conditions, and, accordingly, it is desired to compre-

hend such modifications within this invention as may fall within the scope of the appended claims.

What is claimed is:

1. An electronic microscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising means for producing primary electrons, anode means for accelerating said primary electrons, means for directing said primary electrons toward the object, and a shielding can enclosing said object and provided with openings for the entry of said primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can.

2. An electronic miscroscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising means for producing primary electrons, anode means for accelerating said primary electrons, means for directing said primary electrons at an oblique angle toward the object and a shielding can enclosing said object and provided with openings for the entry of said primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can.

3. An electronic miscroscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising means for producing primary electrons, anode means for accelerating said primary electrons, means for directing said primary electrons toward the object, a shielding can enclosing said object and provided with openings for the entry of said primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can; and electrode means intermediate said can and said fluorescent screen, said electrode means being grounded and constituting together with said can the objective system of the microscope.

4. An electronic microscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising means for producing primary electrons, anode means for accelerating said primary electrons, means for directing said primary electrons toward the object, a shielding can enclosing said object and provided with openings for the entry of said primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can; and electrostatic unipotential lens means intermediate said can and said fluorescent screen, said electrostatic unipotential lens means being grounded and constituting together with said can the objective system of the microscope.

5. An electronic microscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising means for producing primary electrons, anode means for accelerating said primary electrons, means for directing said primary electrons toward the object, a shielding can enclosing said object and provided with openings for the entry of said primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can; and electrostatic immersion lens means intermediate said can and said fluorescent screen, said electrostatic immersion lens means being grounded and constituting together with said can the objective system of the microscope.

6. An electronic microscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising means for producing primary electrons, anode means for accelerating said primary electrons, means for directing said primary electrons toward the object, a shielding can enclosing said object and provided with openings for the entry of said primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can; and magnetic lens means intermediate said can and said fluorescent screen, said magnetic lens means being grounded and constituting together with said can the objective system of the microscope.

7. An electronic microscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising a plurality of systems for producing beams of primary electrons, anode means for accelerating said primary electrons, means for directing said primary electrons toward the object, and a shielding can enclosing said object and provided with openings one each for the entry of one of said beams of primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can.

8. An electronic microscope for direct imaging of the surface of an object by means of secondary electrons ejected from said surface toward a fluorescent screen adapted for making the imaged object surface visible, and wherein the object and fluorescent screen are disposed along an optical axis of the microscope, comprising means for producing primary electrons, anode means for accelerating said primary electrons toward the object,

a shielding can enclosing said object and provided with openings for the entry of said primary electrons, for the passage of said secondary electrons from said object toward said fluorescent screen, as well as for the introduction, withdrawal and displacement of the object relative to said can, said can presenting rotation symmetry and being centered upon the aforesaid optical axis, and means for applying the same electrostatic potential to said object and said can, and an additional source of slow ions, means for applying to said ion source an electrostatic potential close to that of said object, said ion source being so arranged in the microscope that the direction of the ions produced thereby substantially coincides with

the direction of the aforesaid primary electrons, and comprising means for controlling the intensity, speed and direction of the ion emission.

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