Fig. 1

1. Method and apparatus for obtaining ultramicroscopic images in an ion microscope.

2. Sheets-Sheet 1

3. INVENTOR:

GUSTAV WEISSENBERG

4. BY

Richardson, David and Neider
METHOD AND APPARATUS FOR OBTAINING ULTRAMICROSCOPIC IMAGES IN AN ION MICROSCOPE

Gustav Weissenberg, Wetzlar (Lahn), Germany, assignor to Ernst Leitz G.m.b.H., Wetzlar, Germany

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The present invention relates to methods and apparatus for ultramicroscopy, and more particularly to methods and apparatus of this character in which ions are used for the formation of a magnified image.

It is well known in the art that the resolving power of ion microscopes is theoretically greater than the resolving power of electron microscopes. This is because of the fact that the mass of an ion is greater than that of an electron in a ratio of at least three powers of ten. However, the practical utilization of this higher resolving power when using ions has been rendered difficult by the same factor, i.e. the relatively large mass of the ions and also by the unavailability of any luminous screen or photographic material which is capable of withstanding the ion bombardment involved in the formation of the magnified ultramicroscopic image. At the same time, known ion microscopes, of course, the full useful magnification corresponding to the resolving power must be obtained.

Difficulties of this kind are avoided by the method and apparatus according to the invention the method being characterized by two steps. In the first step, a magnified image of the object is formed by means of ions on a mirror-finished metal plate which is preferably cooled to an extremely low temperature for instance by liquid air. When the image-forming ions impinge on the metal plate they change the charges thereof so as to form atoms. The distribution pattern of the atoms formed on the metal plate forms an invisible image of the object, a so-called latent image, on the metal plate. In the second step the metal plate is arranged as a cathode in an electron microscope and excited to produce electron emission so that an image of this cathode is formed by means of an electron optical system on a luminous screen or a photographic plate in a manner known per se in the art. The ion microscope may be arranged either as a transmission-type microscope or as a reflection microscope. In a particularly advantageous design, the ion microscope and the electron microscope are set up in such a manner that the polished metal plate is used both for forming an ion image and as a cathode without removing it from the vacuum. This may be accomplished, for example, by mounting the metal plate rotatably between an ion microscope and an electron microscope with their optical axes in alignment so that the polished surface is first presented at the image plane of the ion microscope for formation of the latent image. The plate is then rotated through 180° which brings the polished surface into position at the object plane of the electron microscope, whereafter it is excited to cause electron emission and the magnified electron image may be observed directly on a fluorescent screen or recorded on a photographically sensitized surface in conventional manner.

According to another embodiment of the invention, the ion microscope and the electron microscope may be arranged with their optical axes angularly inclined with respect to each other and with the polished surface of the metal plate obliquely inclined with respect to the optical axis of the ion microscope.

Accordingly, it is an object of the invention to provide an ion microscope of high resolving power in which an invisible ion image is formed on a retentive surface, the invisible image being reproduced for visual observation by electron emission, using either a fluorescent screen or a photographic film, as desired.

A further object of the invention is the provision of a cathode means in the form of a mirror finished metal plate upon which a latent image is formed by ion bombardment, the latent image being transformed into an electron image by activation of the plate to produce electron emission from its polished surface.

Still another object of the invention is the provision of a cathode plate of this character which is cooled during ion bombardment to prevent atom migration and which may be subsequently heated or otherwise activated to obtain electron emission therefrom.

Briefly, the invention comprises a source of ions, a lens system for directing the ions on or through the object to obtain an image, a further lens system for focusing a magnified ion image on a polished metal plate to obtain an invisible latent image, and an electron microscope in which the polished surface of the metal plate is arranged as a cathode at its object plane, together with means for activating the polished surface to obtain electron emission therefrom.

Other objects, features and advantages of the invention will become apparent upon reading the following specification together with the accompanying drawings forming a part hereof.

Referring to the drawing:

Figure 1 is a diagramatic sectional view of an embodiment of the invention, showing a reflecting ion microscope and an electron microscope having aligned optical axes and a rotatable metal plate or cathode;

Figure 2 is a diagramatic sectional view of a modified embodiment of the invention, showing an irradiating ion microscope and an electron microscope arranged at an angle to each other with the metal plate arranged at an inclination with respect to the optical axis of the ion microscope; and

Figure 3 is a diagramatic sectional view of a further embodiment of the invention, showing a reflecting ion microscope and an electron microscope having an axis inclined with respect to the axis of the ion beam from which an electron image is to be formed, the metal plate being activated to produce electron emission by ion bombardment.

Referring to Fig. 1, an evacuated vessel 1 is provided with a lateral extension 2. Disposed in the upper end of vessel 1 is an ion source 3 and a condenser lens 4. The object 5 is disposed near the outer end of the lateral extension 2. Ions emanating from source 3, after passage through the condenser lens 4, are deflected by deflecting field structure 6 through an angle of slightly less than 90° toward the object 5, a diverging or dispersion lens 7 being provided near the object 5. After reflection from the object 5, the ions pass again through the diverging lens 7 and deflecting field 6 and thence through one or more projection lenses 8 arranged in front of the polished surface of a metal plate 9. The metal plate 9 may be rotated at will by means of a knurled knob 10 disposed exteriorly of the envelope 1, the plate 9 being rotatably supported on a pivot pin 11 which extends through the wall of the evacuated envelope 1. The pivot pin 11 is formed of material having a high coefficient of thermal conductivity and is in thermal communication with suitable cooling means such as a supply of liquid air (not shown). An electric heater 12 is disposed in a cavity in the rear of
the polished surface of plate 9 and is supplied with current when it is desired to activate the polished surface as described in greater detail below. When the plate 9 is rotated through 180° on pivot pin 11, its polished surface is then located at the object plane of an electron microscope comprising a luminescent or fluorescent viewing screen 13 at the lower end of vessel 1, an objective lens 14, preferably of the immersion type, in proximation with plate 9, and a projection lens 15 intermediate the immersion lens 14 and viewing screen 13. It will be observed that the optical axis through members 3-4-8 of the ion microscope portion of the apparatus is in alignment with the optical axis through members 14-15-13 of the electron microscope portion. The operation of the apparatus is as follows: The ions emanating from the ion source 3 and subjected to post-acceleration in conventional manner are focussed by the condenser lens 4 into a beam of parallel rays which is laterally deflected by the deflecting field 6 towards the object 5. These ions are reflected from the object 5 in accordance with the varying ion-reflecting properties of different portions of its surface thereby modifying the reflected beam of ions in conformity with pictorial details of configuration of the object 5. The object 5 is at approximately the same potential as the ion source 3. Alternatively, there may be provided an electrically conductive surface at approximately the same potential as the ion source 3 and from which the ions are reflected. In such case, the electrically conductive surface will be superposed directly on the object 5 or located directly in front of the object and will present the same pictorial characteristics to an ion reflection standpoint to those characteristics of the object which are to be observed by means of the apparatus.

The reflected ions are accelerated toward the deflecting field 6 by the diverging lens 7. These reflected ions are then deflected in the deflecting field 6, this time toward the plate 9. An ion-image of object 5 or its associated conductive surface is produced on the polished surface of the plate 9 by the projection lens system 8. The plate 9 is maintained at a negative potential with respect to the ion source 3 and the object 5, it being assumed that the source 3 produces positively charged ions such as Cs ions, for example. These ions are attracted to the negatively charged surface of the plate 9 whereupon they are transformed into a deposit of atoms, the density of distribution of this atomic deposit forming an invisible latent image of the object 5. In order to prevent the loss of the atoms on the surface of plate 9, the plate is cooled to a low temperature as by liquid air. This cooling thus prevents loss of detail and preserves definition in the latent image.

After formation of the latent atomic image on plate 9, it is rotated through 180° by means of knob 10 so that its polished surface faces the objective lens 14 and is directed toward viewing screen 13, the polished surface being normal to the optical axis of the electron microscope portion of the apparatus. The plate 9 is then heated to electron emitting temperature by energization of heater 12. The polished surface of the plate 9 then operates as a cathode and the electron-optical system comprising electron lenses 14 and 15 produces a visible image on the viewing screen 13 in conventional manner. The plate 9 may be formed of metal such as tungsten, nickel or other electrode material which is adapted to be subjected to ion bombardment and activated to produce electron emission. By using ions, such as those of Cs having a low work factor, the latent image on plate 9 is readily converted into a visible image on the screen 13. It is to be understood, of course, that viewing screen 9 may be replaced by a suitable photographically sensitized surface if a permanently recorded image is desired. By suitably dimensioning the relative magnifications within the ion microscope and electron microscope portions of the apparatus, the higher resolving power of the ions may be fully utilized while at the same time, the disadvantages inherent in ion microscopes of conventional construction are avoided. In the modified embodiment of the invention shown in Fig. 2, the optical axes of the ion microscope and electron microscope portions of the apparatus are angularly inclined with respect to each other instead of being in alignment with each other as in the embodiment of Fig. 1. The envelope 22 contains an ion source 23. Ions from source 23 are focussed by a condenser lens 24 on an ion-translucient object 25. After passage through the translucent object 25, the ions are acted upon by a projection lens system 27, 29 so that a magnified image of object 25 is formed on the polished surface of a metal plate 30. Metal plate 30 is maintained at a suitably low temperature by means of a coolant, such as liquid air, supplied through a duct 32 which communicates with the interior of plate 30. The latent atomic image formed on plate 30 is reproduced on a viewing screen 35 by means of an immersion type objective lens 36 and a projection lens 37. The polished surface of plate 30 is inclined obliquely with respect to the optical axis 38 through members 24-25-29 of the ion microscope portion of the apparatus. The electron microscope portion of the apparatus is disposed in an extension tube of evacuated envelope 22 and its optical axis is normal to the polished surface of plate 30.

The invisible latent image formed by ion bombardment of plate 30 is activated by an electron source 40 and a condenser lens 41 which direct an energy-rich stream of electrons against the polished surface of plate 30. This electron stream is of sufficient intensity to excite the atoms formed thereon by the ion-image projection to a condition of secondary electron emission. The ion-target surface of plate 30 is thus caused to act as an image producing cathode in the electron microscope portion 35, 36, 37 of the apparatus without manipulation of the metal plate as in the case of the apparatus of Fig. 1. The secondary emission electrons are then accelerated by the immersion type objective lens 36 and projection lens 37 so that they strike the viewing screen 35 producing the desired enlarged image of object 25. The parallax effect caused by obliquity of the polished surface of plate 30 with respect to the ion stream along optical axis 38 may be readily corrected by means of compensatory astigmatism included in lens system 36-37.

Figure 3 shows a further embodiment of the invention as applied to a surface of plate 9. The plate is cooled to a low temperature so that the latent image is not destroyed. In this instance, the paths of travel of the incident and reflected ion beams define an angle with each other which is less than 180°. The optical axis of the electron-optical portion of the microscope is obliquely inclined with respect to the image-forming ion beam which impinges on the metal plate. As in the case of Fig. 2, the ion beam which forms the latent image strikes the polished surface of the metal plate obliquely and the optical axis of the electron microscope portion of the apparatus is normal thereto.

A stream of ions emitted from a source 51 is directed through a monochromatizing filter 52 which passes only ions having energy levels which lie within a narrow range. The selected ions then pass through a condensing lens 53 and a deflecting field structure 54 to the object 55, through a dispersion lens 56 being located in proximity to the object 55. The ions reflected from the object 55 pass back through the dispersion lens 56 and again through the deflecting field structure 54 to a series of magnifying projection lenses 57 which form an image on the polished surface of a low temperature metal plate 58. The electron microscope portion of the apparatus comprises an objective lens 60, a projection lens 61 and a viewing screen 62. The ions which are trapped and converted to atoms on the polished surface of plate 58 are activated to a state of secondary emission by bombardment with ions.
from a further ion source 63, these activating ions being focussed on the surface of plate 58 by a condenser lens 64. All of the apparatus is disposed within a common evacuated vessel.

When ions having an extremely small work function such as Cs, Rb, etc. are used, the electrode emission may be excited instead of by thermal emission or excitation to secondary emission by electron or ion bombardment, by irradiation with light and particularly ultraviolet light. The metal plate is illuminated during the image formation, by ions or with the filtered light from a mercury lamp, the ion exposure of the object being interrupted when there appears on the luminous screen an electron image of sufficient brightness.

If relatively heavy ions having a high work function are used, a bombardment with electrons or ions is preferred.

The ion-optical and electron-optical lenses and other elements used may be electrostatic and/or electromagnetic lenses or prisms. Furthermore, the individual parts shown in the embodiments may be combined with each other to form compound elements, if desired.

In order to erase or cancel the latent image on the metal plate, it is only necessary to heat the plate to an intense heat by means of the heater 12 until the image-forming atoms have been evaporated from its polished surface. The latent atomic image may also be removed by subjecting the polished surface of the plate temporarily to an unusually intense bombardment with atoms and/or electrons.

While there have been disclosed what are believed to be the best embodiments of the invention, it will be apparent to those skilled in the art that many changes and modifications may be made therein without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. The method of producing a visible ultramicroscopic image by ion bombardment of an object to be viewed, said method comprising the steps of: bombarding said object with ions traveling in optical paths to obtain an ion-image of said object; enlarging and focusing said image upon the polished surface of a metallic plate; exciting said surface to derive electron emission therefrom. Delepting said image; and directing said emitted electrons to utilization means for deriving an enlarged visible image of said object therefrom.

2. The method according to claim 1, wherein said exciting step is performed by heating said surface to a temperature at which electron emission occurs.

3. The method according to claim 1, wherein said exciting step is performed by bombardment of said surface with charged particles to obtain secondary electron emission therefrom.

4. The method according to claim 3, wherein said surface is bombarded with electrons.

5. The method according to claim 3, wherein said surface is bombarded with ions.

6. The method according to claim 1, wherein said object is bombarded with cesium ions and said polished surface is maintained at a negative potential for converting said ions to cesium atoms.

7. The method according to claim 1, wherein said ions are positively charged metallic ions, said method comprising the further steps of maintaining said surface at a negative potential for converting said ions to atoms, and cooling said surface to prevent migration of said atoms.

8. Microscopic apparatus of the class described, comprising in combination: an evacuated envelope; a source of ions disposed in said envelope; a metallic plate disposed in said envelope, said plate having a polished surface; ion-optical means arranged to direct ions from said source to said surface, said ion-optical means comprising means for directing said ions to and from an object to be viewed and forming an enlarged latent image of said object on said surface; means for activating said surface to cause electron emission therefrom for electronically reproducing said latent image; and electron-optical microscope means comprising objective lens means focussed on said surface for enlarging and reproducing said latent image during activation of said surface by said activating means.

9. Apparatus according to claim 8, wherein said source of ions produces positively charged metallic ions and in which said plate is maintained at a negative potential for converting said ions to atoms, said apparatus further comprising cooling means in thermal communication with said plate for reducing the temperature of said surface to prevent the migration of said atoms.

10. Apparatus according to claim 9, wherein said source of ions produces cesium ions.

11. Apparatus according to claim 8, wherein said activating means comprises heating means in thermal communication with said plate for heating said surface to a temperature at which electron emission occurs.

12. Apparatus according to claim 9, wherein said activating means comprises a source of electrons and electron-optical means for bombarding said surface with electrons from said source, the intensity of said bombardment being sufficient to cause secondary electron emission from said surface.

13. Apparatus according to claim 8, wherein said activating means comprises a further source of ions and further ion-optical means for bombarding said surface with ions from said further source, the intensity of said bombardment being sufficient to cause secondary electron emission from said surface.

14. Apparatus according to claim 8, wherein the optical axes of said ion-optical and said objective lens means are aligned in proximity to and at opposite sides of said plate, said apparatus further comprising revolving mounting means supporting said plate and permitting rotation of said plate through an angle of 180° for selectively presenting said surface either to said ion-optical system or to said objective lens means.

15. Apparatus according to claim 8, wherein said polished surface is normal to the optical axis of said objective lens means, the optical axis of said ion-optical system being angularly inclined with respect to said optical axis of said objective lens means for directing said ions obliquely against said surface.

16. Apparatus according to claim 15 further comprising astigmatic correction means included in said electron-optical microscope means for correcting for a parallax caused by said oblique direction of said ions against said surface.

17. Apparatus according to claim 15, wherein said activating means comprises a source of charged particles and means for directing said particles obliquely against said surface to produce secondary electron emission therefrom.

No references cited.