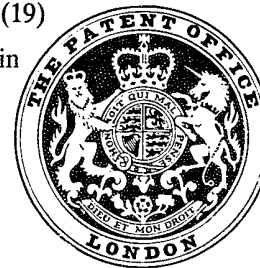


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(54) ELECTRON MICROSCOPE

(71) We PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED of Abacus House, 33 Gutter Lane, London, EC2V 8AH a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The invention relates to an electron microscope of the kind including an electron gun for generating an illuminating electron beam, an electron-optical condenser lens system for directing and concentrating said illuminating electron beam onto a region in an object plane to be occupied by an object during examination, and an image-forming electron-optical lens system arranged to form in an image plane, an electron image of an electron-illuminated part of an object located in said object plane.

High-resolution electron microscopes of the kind referred to are, however, difficult to focus with respect to the electron image formed in the image plane because an illuminating electron beam of relatively small effective aperture is normally employed, resulting in a large depth of focus. In such an electron microscope an attempt to increase the aperture of the illumination beam results in a corresponding increase in electron current density in the object plane, and this can lead to damage or destruction of the object under investigation.

British Patent Specification Number 687,207 describes an electron microscope in which an attempt is made to reduce this difficulty by superposing an alternating current component whose period is short compared with the visual persistence of the human eye, onto the focussing field of the condenser lens. This causes the focal point of the condenser lens to be oscillatorily displaced along the electron-optical axis of the microscope, and the microscope is set up

so that the illuminating electron beam is focussed at maximum aperture in the object plane at the point where the alternating and steady focussing fields add to form a peak value. The large aperture condition and high illumination intensity at this point provides a bright image with small depth of focus enabling a focussing adjustment to be readily carried out. Although the current density is high at this point, this condition only lasts for about a quarter of a cycle after which the illuminating electron beam is rapidly defocussed, greatly reducing the electron density at the object, and therefore the illumination intensity. Visual persistence enables the image to be observed despite the considerable fluctuation in intensity throughout the oscillatory cycle. The degree of reduction in object damage that can be achieved in this way is, however, limited for a given increase in aperture, and the choice of available exposure intensity is undesirably restricted. The varying brightness of the image can make the arrangement unsatisfactory for making a recording at a large aperture.

The invention has for an object to provide an improved electron microscope of the kind referred to.

According to the invention there is provided an electron microscope, including an electron gun for generating an illuminating electron beam, an electron-optical condenser lens system for directing and concentrating said illuminating electron beam onto a region in an object plane to be occupied by an object during examination, an image-forming electron-optical lens system arranged to form in an image plane an electron image of an electron-illuminated part of an object located in said object plane, and a device for providing an apparent enlargement of the aperture of the illuminating electron beam comprising an electron beam deflection assembly arranged

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along the path of the illuminating electron beam and capable of deflecting the electron beam initially away from the electron-optical axis of the microscope and then of directing the electron beam back towards said axis, and a deflection signal generator connected to supply deflection signals to said deflection assembly which cause the central axis of the illuminating electron beam to tilt about a point located in said object plane, said deflection signal generator being arranged to generate deflection signals which vary with time in a manner such that the tilt of the axis of the illuminating electron beam is scanned through a plurality of attitudes during an electron image integration period, as herein defined, so that the resultant integrated electron image has an appearance similar to that of an image formed using an illuminating electron beam of greater aperture than that of the said illuminating electron beam after concentration by said condenser lens system in the absence of a scanned tilt.

The attitude of the axis of the illuminating electron beam is to be understood to include both the angle of tilt with respect to the electron-optical axis of the microscope and the direction of tilt about that axis, either or both of which can be varied during a scan.

The electron image integration period is to be understood herein to mean the time taken to register or record an electron image for observation. In the case of visual observation on a luminescent phosphor screen, this will be determined by the persistence of vision of the eye of the observer or the decay factor of the phosphor whichever is the longer. In the case of a photographic record, the integration period will correspond to the exposure time.

In an embodiment of an electron microscope in accordance with the invention, the electron beam current is not altered when providing the effect of an apparent enlargement of the working aperture, the transverse dimension of the illuminating electron beam remains the same in the object plane, and there is substantially no axial shift of the region of focus of the illuminating electron beam. Viewed with respect to a plane transverse to the axis of the electron microscope and spaced from but adjacent the object plane, the illuminating electron beam can be caused to describe in said plane any desired scanning path about the electron-optical axis of the electron microscope. The transverse overall dimensions of this scanned region and the actual path scanned within said region, can be chosen substantially at will, provided that the tilting point is always situated in the object plane. Since the focussing of the beam by the condenser lens system is substantially unaltered by the process of tilting the beam, the illumination

intensity in the object plane can be maintained substantially constant, and the desired apparent coherence increase of the illuminating beam can be used during the making or studying of recordings.

In an embodiment of the invention a correction can be effected for the off-axis passage of the electron beam through an objective lens, by applying a correction signal, related to the degree of transverse displacement of the illuminating beam during tilt, to the excitation of the relevant image-forming lens.

An embodiment of an electron microscope in accordance with the invention will now be described by way of example, with reference to the accompanying drawing, the single figure of which illustrates an electron microscope embodying the invention. The drawing diagrammatically shows an electron microscope comprising an electron gun 1 which preferably comprises a field emission source 2 for generating an electron beam having a comparatively high density or a comparatively small cross-section. Adjacent the emission source 2 there is arranged an anode 3 and, proceeding in the direction of the electron beam, a succession comprising a beam alignment device 4, a condenser lens 5, a beam wobbler 6, an objective lens 7 comprising pole shoes 8, an object 9 comprising an object adjustment device 10, an intermediate lens 11, and a projection lens 12. An image space 13 of the electron microscope accommodates a camera 14 and a phosphor screen 15 which can be observed through a window 16. All electron-optical elements are accommodated in a housing 17 which includes in addition to the window 16, a passage 18 for applying the necessary potentials and a vacuum duct 19 provided with a connection 20 to a pumping device (not shown).

A deflection signal generator 21 for the wobbler 6 is constructed in an embodiment in accordance with the invention, to generate deflection signals which vary with time in a manner such that, during an electron image integration period, as herein defined, a scanning tilt movement about a point 22 in the object plane is imparted to an illuminating electron beam. The deflection signal generator is preferably also controlled in response to the high voltage to be applied; this is diagrammatically shown by means of a connection line 23.

A beam wobbler usually comprises two sets of electromagnetic coils whereby an electron beam is first deflected in known manner away from the electron-optical axis 24 of the microscope and subsequently deflected back again towards a given point on the electron-optical axis. The latter point on the electron-optical axis is referred to as the tilting point onto which the beam can be

directed from any direction within a conical defining surfacd. The scanning process can be understood by defining a notional plane transverse to the electron-optical axis and located between the second set of wobbler deflection coils and the object plane containing the tilting point. The intersection of the notional plane with the conical defining surface defines a cone shaped region within which the axis of the illuminating electron beam can be directed during a scan. The deflection signal generator can generate time varying deflection signals which cause the intersection of the electron beam axis to scan the circumference of the base of the cone-shaped region, causing the beam itself simply to describe the surface of the cone, or the beam may be deflected to scan systematically the whole of the base of the cone so that the beam axis is tilted to scan the whole of the interior of the cone-shaped region during a said image integration period.

The tilt scan defining surface or region need not be conical but may have any convenient shape, for example the shape of a pyramid, i.e. the scanned region in the notional plane may be rectangular. For reasons of symmetry, a circle or a rectangle is preferable for said scanned region. Notably in the case of a circle, the beam can follow a helical deflection path, for example, by utilizing two sine wave deflection generators, powered 90 degrees out of phase and both amplitude modulated by a ramp waveform, whilst in the case of a rectangle, the movement of the beam in the notional plane is that of a scanning beam, as in a television system, effected by means of a corresponding deflection generator assembly.

If the wobbler is actuated in this manner, the object is exposed, measured in time, with an apparent aperture which is given by the apex of the cone or pyramid and which may be made as great as, for example, 1000 times the aperture of the illuminating electron beam itself.

During this scanning beam deflection, the beam current is unaltered and the object illumination point is substantially undisplaced in the axial direction during an exposure. In a manner similar to that described in the said British Patent Specification 687,207, correction for spherical aberration can be effected. To achieve this it is merely necessary in an embodiment of an electron microscope in accordance with the invention, to control the appropriate lens, in this case, for example, the objective lens, in a manner dependent on the radial displacement of the tilted illuminating electron beam. By comparison with the correction applied in the known electron microscope, the electron beam in an electron microscope

embodying the invention will always remain narrow, but, when tilted, will not pass paraxially through an image-forming lens. Consequently, on the image forming basis of a paraxial beam path in the case of the undeflected electron beam, the spherical aberration which would otherwise occur due to the off-axis beam path through the lens, can thus be fully compensated. As a result of the addition of an adjustable control member to the deflection signal generator for the deflection device (wobbler), an embodiment of an electron microscope in accordance with the invention is caused to operate with a conical scan of the tilt direction about the electron optical axis with a presettable apex angle or a series of conical scans of different apex angles. Exposure during a said image integration period is also possible, in succession, from a plurality of different fixed directions tilted relative to the optical axis. As a result, the nature of the exposure can be adapted, for example, to particular properties of the object to be examined while maintaining an apparent increase in the illumination aperture.

WHAT WE CLAIM IS:-

1. An electron microscope, including an electron gun for generating an illuminating electron beam, an electron-optical condenser lens system for directing and concentrating said illuminating electron beam onto a region in an object plane to be occupied by an object during examination, an image-forming electron-optical lens system arranged to form in an image plane an electron image of an electron-illuminated part of an object located in said object plane, and a device for providing an apparent enlargement of the aperture of the illuminating electron beam comprising an electron beam deflection assembly arranged along the path of the illuminating electron beam and capable of deflecting the electron beam initially away from the electron-optical axis of the microscope and then of directing the electron beam back towards said axis, and a deflection signal generator connected to supply deflection signals to said deflection assembly which cause the central axis of the illuminating electron beam to tilt about a point located in said object plane, said deflection signal generator being arranged to generate deflection signals which vary with time in a manner such that the tilt of the axis of the illuminating electron beam is scanned through a plurality of attitudes during an electron image integration period, as herein defined, so that the resultant integrated electron image has an appearance similar to that of an image formed using an illuminating electron beam of greater aperture than that of the said illuminating electron beam after concentration by said condenser lens system

in the absence of a scanned tilt.

2. An electron microscope as claimed in Claim 1, wherein the electron gun comprises a field-emission source.

5 3. An electron microscope as claimed in Claim 1 or Claim 2, wherein said deflection signal generator is arranged to generate deflection signals which cause the axis of the illuminating electron beam to perform a
10 helical scan about the electron microscope axis during a said electron image integration period.

4. An electron microscope as claimed in Claim 1 or Claim 2, wherein said deflection
15 signal generator is arranged to generate deflection signals which cause the axis of the illuminating electron beam to perform a raster-like scan with respect to a notional plane transverse to the microscope axis and
20 spaced from said object plane, during a said electron image integration period.

5. An electron microscope as claimed in Claim 1 or Claim 2, wherein said deflection
25 signal generator is arranged to generate in succession a plurality of predetermined discrete deflection signals so as to illuminate the object in succession from a corresponding plurality of preselectable directions during a said electron-image integration period.

30 6. An electron microscope as claimed in Claim 1 or Claim 2, wherein said deflection signal generator is arranged to generate deflection signals which cause the axis of the illuminating electron beam to perform a
35 conical scan of selectable apex angle during a said electron image integration period.

7. An electron microscope as claimed in Claim 6, wherein said deflection signal
40 generator causes a series of said conical scans having a succession of apex angles to be performed.

8. An electron microscope as claimed in any one of the preceding claims, wherein
45 said image-forming electron-optical lens system includes an electron-optical correction device for spherical aberration, and wherein a correction signal is applied thereto dependent on a radial component relative to the
50 axis of the electron microscope, of the deflection signals applied to said deflection assembly from said deflection signal generator.

9. An electron-image-forming electron
55 microscope substantially as herein described with reference to the accompanying drawing.

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