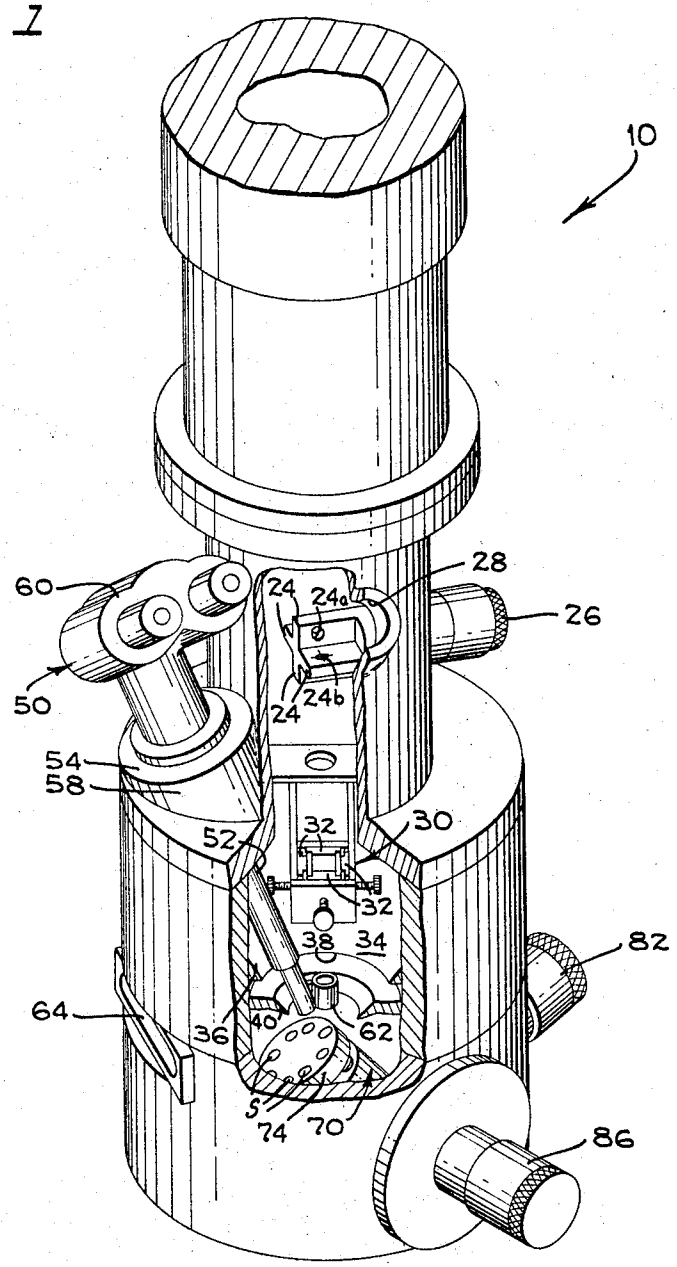
March 19, 1968 V. G. MACRES 3,374,349

ELECTRON PROBE HAVING A SPECIFIC SHORT-FOCAL LENGTH MAGNETIC LENS AND LIGHT MICROSCOPE

Original Filed Jan. 31, 1961 2 Sheets-Sheet 1

Fig. 1



INVENTOR.
VICTOR G. MACRES

BY Paul B. Eile

PATENT AGENT

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Fig-2

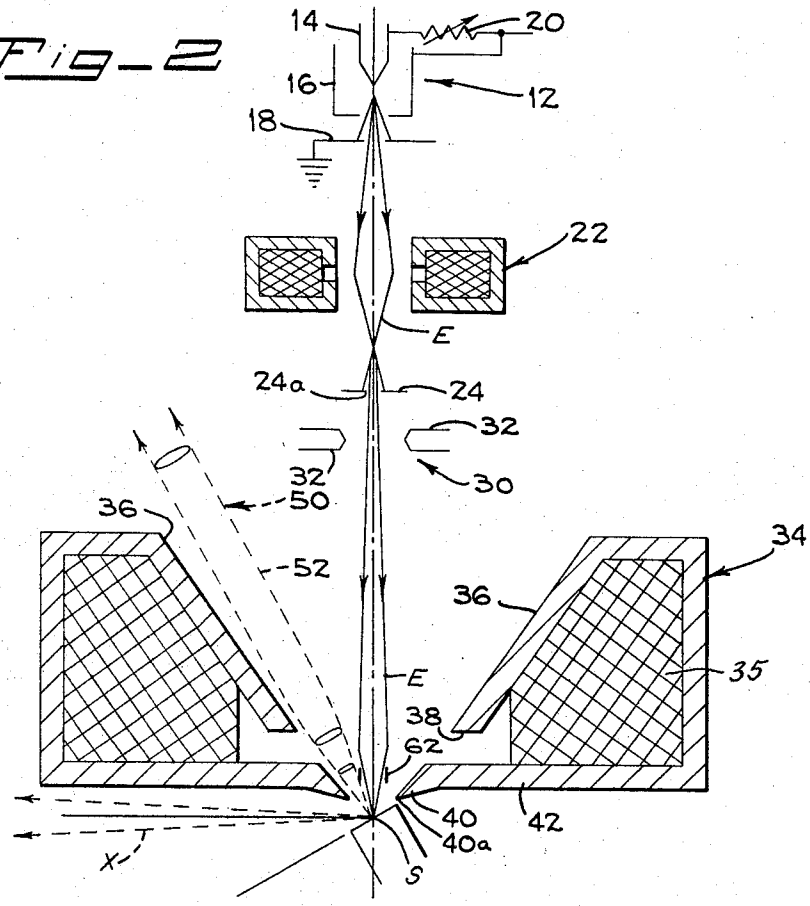
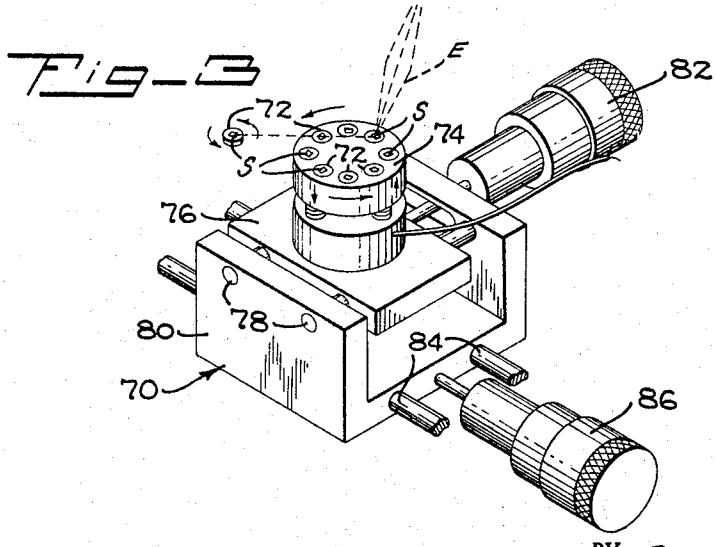


Fig-3



INVENTOR.
VICTOR G. MACRES

BY Paul B. Fike

PATENT AGENT

United States Patent Office 3,374,349
Patented Mar. 19, 1968

3,374,349

ELECTRON PROBE HAVING A SPECIFIC SHORT-FOCAL LENGTH MAGNETIC LENS AND LIGHT MICROSCOPE

Victor G. Macres, 3385 Louis Road,
Palo Alto, Calif. 94303

Continuation of applications Ser. No. 368,448, May 11, 1964, and Ser. No. 86,200, Jan. 31, 1961. This application Nov. 14, 1966, Ser. No. 594,275
4 Claims. (Cl. 250—49.5)

ABSTRACT OF THE DISCLOSURE

An electron probe including a support for a specimen to be probed, an electron beam directed at said specimen and focused thereon by an adjacent short-focal length lens, and a light microscope for observing the probed specimen.

The present application constitutes a continuation of applicant's prior applications, Ser. No. 86,200, filed Jan. 31, 1961, and Ser. No. 368,448 filed May 11, 1964, both applications having now been abandoned.

The present invention relates generally to electron optics, and more particularly, to electron probes for purposes of microscopic analysis, micro-machining, topical heat treatment or other application involving irradiation of a specimen or sample by a beam of high velocity electrons.

Since 1913 when Moseley determined the irradiation of materials by high velocity electrons produced X-radiation characteristic of the particular material being irradiated, many varied devices embodying such principle have been constructed for spectrographic analysis. For purposes of microscopic analysis, Hillier proposed the focusing of the electrons to a minute area on the irradiated material, and the utilization of such "microprobe" in conjunction with more or less conventional X-ray spectrographic equipment, this proposal being the subject of United States Patent No. 2,418,029. More recently, various microprobes have been constructed, primarily for application as a microscopic analytic tool, but with the concommitant realization that the electron irradiation of material could also be employed for other purposes such as micro-matching or topical heat treating of the irradiated material with but minor operational variations principally in the electron beam intensity.

In the practical construction of electron microprobes, for microscopic analysis or other purposes, serious performance limitations have appeared because of the necessity for certain practical design compromises. As a particular example, it is necessary in a practical electron microprobe not only to focus the electron beam at the desired point on the sample or specimen, but it is also highly desirable to provide for optical viewing of the irradiated specimen, and finally, it is necessary to provide for egress of the X-radiation emitted from the specimen or sample. Thus, it will be seen that not only an electron beam but light and X-radiation converge at a single microscopic area, and the obvious conflicting space requirements have necessitated certain of the mentioned design compromises of existing microprobe equipment. Among others, the following limitations have been noted:

(1) a long focal length of the objective electron lens resulting in excessive spherical aberration of the focused electron beam at the irradiated area of the specimen.

(2) Extremely complex reflecting optical systems that are not only expensive but are difficult to maintain in precise working order.

(3) Low "take-off" angle of the emitted X-radiation so that detection inaccuracies result.

Accordingly, it is a general object of the present invention to provide an electron probe capable of excellent electron focusing, enabling simple optical viewing, producing highly accurate X-ray detection when used for microscopic analysis, and generally facilitating both construction and operation.

It is a particular feature of the invention to provide an electron probe including an electron focusing lens of short focal length and a lens geometry such that spherical aberration is reduced to a practical minimum.

A related feature is the particular design of the electron focusing lens so that although its focal length is short, and the specimen to be radiated is consequently in physical proximity thereto, the specimen is positioned in a substantially field-free region.

Another related feature is the design of the electron focusing lens so that a simple, refractive-type light microscope can be accommodated enabling direct optical viewing of the specimen without, however, any interference with the electron beam or its focus.

Another feature of the invention relates to the support of the specimen or sample to be irradiated in a position such that good optical viewing is enabled and a relatively high angle of emergence of X-radiation is enabled to thus provide accurate X-ray detection.

Yet a further feature of the invention is to provide a specimen support or stage which can support a plurality of specimens for alternative movement into irradiation position.

A related feature is the provision of a fluorescent specimen on the specimen stage so that the characteristics of the focused electron beam can be visually indicated through utilization of the light optical system.

Yet another feature of the invention is the provision of a main housing arranged to accommodate the specimen stage, the light microscope and other units in a manner permitting ease of removal and also arranged to function as a mounting jig so that appropriate disposition is obtained upon reassembly.

These as well as other objects and features of the invention will become more apparent from a perusal of the following description of the accompanying drawing wherein:

FIG. 1 is a perspective view of an electron probe apparatus embodying this invention, parts thereof being broken away to illustrate interior details of construction,

FIG. 2 is a schematic diagram of the electron probe physically illustrated in FIG. 1, and

FIG. 3 is an enlarged fragmentary perspective view of the specimen stage included as an element of the FIG. 1 structure.

With reference to the drawings, the electron microprobe is housed within a generally tubular body **10** that is somewhat enlarged at its lower end, as shown in FIG. 1. At the upper end of the tubular body **10**, an electron gun is mounted to direct a beam of electrons substantially axially through the tubular body. Such electron gun is of conventional nature, being of the type employed in an ordinary electron microscope, and is thus not illustrated physically in FIG. 1, but is only schematically illustrated in FIG. 2. As so illustrated, the electron gun, generally indicated at **12**, includes a filament **14** which is suitably heated so as to emit electrons, a control grid **16**, and an appropriately formed anode **18** operating at a relatively high positive potential so as to effect acceleration of the emitted electrons into a generally pencil-like beam indicated at E. A suitable control indicated at **20** is provided so that the grid bias can be adjusted to provide the required electron source characteristics.

A toroidal magnetic beam-condensing lens **22** is mounted in axial alignment with and spaced relation to the electron gun **12** so as to focus and condense the beam of electrons E also in a manner normally employed in conventional electron microscopes so that further detailed structural or operational description is not warranted and such condensing lens is only illustrated schematically in FIG. 2.

The initially condensed electron beam E is thereafter collimated by an apertured plate **24** interposed in the beam path and preferably composed of brass or other non-magnetic material. The size of the aperture **24***a* in such plate **24** determines what portion of the beam E is transmitted therethrough and what portion is directed against the adjoining surface of the plate and thus stopped from further transmission. Preferably, as shown in FIG. 1, four distinct plates **24** are employed, each of which radiates from a central juncture point or hub so as to form a unitary structure which has the shape of a cross in transverse section. The multiple-plate structure is carried at the inner end of a member that extends through the wall of the tubular body **10**, is rotatably supported thereby, and has a suitable knurled handle **26** at its outer extremity enabling manual rotation of one or another of the plates **24** into beam-collimating position with its aperture **24***a* aligned with the axis of the tubular body **10**. Various size apertures **24***a* can thus be chosen for a particular microprobe operation, and if desired, one of the plates **24**, rather than being apertured, can have a small amount of fluorescent material placed on its surface and suitable cross-hair line indicia placed thereover, as indicated at **24***b* in FIG. 1. If such plate **24** is then brought into operative position on the axis of the tubular body **10**, a rough indication of the desired alignment of the electron beam E is visually apparent. So that this surface can be viewed easily by the operator, a suitable window **28** is mounted in the side of the tubular body **10**.

The collimated electron beam E in its continuing traverse downward through the tubular body **10** next passes through an electrostatic deflecting device generally indicated at **30** which includes adjustably-supported deflection plates **32** whose potential can be adjusted so as to maintain the electron beam symmetrically centered on its longitudinal axis, or can be varied to produce "scanning" of the beam across a specimen S.

As schematically illustrated in FIG. 2, the electron beam E thereafter continues in its traverse, diverging slightly in its advance, until it passes through a second magnetic objective electron lens, generally indicated at **34**, whose general purpose is to focus the beam into substantially a point at the surface of a specimen S supported therebeyond.

In accordance with the present invention, this magnetic objective lens **34** is formed to provide a short focal length, to permit optical viewing of the irradiated specimen S by a simple refractive-type light microscope, and to permit egress of the emitted X radiation. Like the magnetic condensing lens **22**, the magnetic objective lens **34** is of generally toroidal configuration including a coil **35** surrounded by a shield **36**. More particularly, the internal surface of the torus as formed by the core shield **36** tapers inwardly in the direction of electron motion so as to converge on the electron axis at an angle slightly greater than 30°. One pole piece **38** of the lens **34** is formed at the inner extremity of the shield **36** and the other pole piece **40** of the lens **34** is formed in tapered alignment therewith at the inner extremity of the lower core shield **42** that lies in a plane that is substantially perpendicular to the axis of the electron beam. Consequently, as can be readily visualized by reference to FIG. 2, the magnetic center of the lens **34** is located but a very short distance from its lowermost physical extremity.

As a result of the disposition of the magnetic center of the objective lens **34**, the mentioned speciment S to be irradiated can be positioned in relatively close proximity

thereto. In turn, the lens **34** can thus be designed to have a relatively short focal length. In practice, a focal length of 16 millimeters has been successfully utilized. Since it is known that spherical aberration of an electron optical system increases with an increasing focal length, it will be clear that in the present structure, it is reduced to a practical minimum.

The lower pole piece **40** of the magnet is provided with an inward and downward taper, as indicated at **40***a*, which serves to restrict the fringing fields of the magnetic lens **34** from the space occupied by the specimen S. Again, in practice, a restriction of the field to less than 10 gauss at the specimen has been obtained. In view of such magnetic field restriction, the specimen S can constitute a ferromagnetic material yet will not interfere to any appreciable degree with the proper focusing of the electron beam.

The described taper or internal convergence of the objective lens **34** permits the introduction of the tubular lens-supporting body **52** of an adjustable light microscope, generally indicated at **50**, in a manner such that the light optical axis intersects the electron optical axis at the point or minute area (approximately 1 micron diameter) of irradiation of the specimen S. As shown best in FIG. 1, the light microscope **50** is mounted as a unit on a circular plate **54** arranged for sealing juncture to the circular lip at the extremity of a cylindrical protuberance **58** projecting angularly from the tubular body **10** of the electron probe. When the plate **54** is secured in position by suitable bolts, conventional viewing binoculars **60** are available to the operator of the device, and the lens-supporting body **52** projects angularly inwardly toward the electron beam axis, the lower extremity of the tubular lens-supporting body terminating just shy of intersection with the moving electrons. The microscope incorporates a light source and illumination arrangement such that "critical" illumination can be realized so as to provide maximum contrast and thus allow the realization of the inherent resolution capabilities of the light optical microscope.

To avoid interference with the proper operation of the magnetic objective lens **34**, the tubular lens-supporting body **52** of the light microscope **50** is formed of brass or other non-magnetic material and preferably a small metallic cylindrical shield **62** is attached to the extremity of the light microscope body so as to isolate the electron beam and thus preclude the influence of electric charges which may accumulate on the non-conductive glass lens of the light microscope **50** which accumulation might otherwise produce a distorting effect on the electron focusing action. Preferably, the axis of the light optical system is approximately 30° relative to the electron beam axis and preferably, as shown, the specimen S is tilted so that its exposed surface lies in a plane perpendicular to the light optical axis so as to enhance optical viewing.

Such tilted position of the specimen S also enhances the accuracy of X-ray detection of associated spectrographic equipment when the electron probe hereinabove described is utilized for microscopic chemical analysis. More particularly, as shown in FIG. 2, even though the specimen S is located physically quite close to the magnetic objective lens **34**, a relatively large X-radiation emergence angle is obtainable. As shown at X in FIG. 2, X-radiation angles up to 35° or 40° are achievable, and as shown in FIG. 1, a suitable window **64** is positioned in the side of the body **10** to permit passage of the X-radiation to any associated spectrographic equipment. It may be mentioned that such spectrographic equipment forms no part of the present invention, in and of itself, and therefore is not described. However, conventional spectrographic equipment such as mentioned in the Hillier Patent No. 2,418,029 can be employed in association with the present electron probe apparatus when microscopic analysis is to be performed.

The specimen S is supported in the described angular disposition on a suitable stage **70** that is illustrated more

clearly in FIG. 3 and which generally is arranged to enable selection of specimens S and movement of a selected specimen into appropriate irradiation position. As shown, each specimen S can be mounted on a small disk **72**. In turn, a plurality of the small specimen disks **72** can be removably supported for rotation about their own axes on a plurality of seats peripherally located on a larger disk **74**. Suitable electrical and mechanical means are provided to raise and lower this larger disk **74** and also to rotate the same so that one or another of the specimens S can be brought into irradiation position. In turn, the rotatable large disk **74** is mounted for translatory motion with a table **76** slidably mounted on transverse bars **78** within the upstanding ends of a carriage **80** and under the control of a micrometer **82** that projects through the tubular body **10** of the device so as to enable the desired adjustment during operation. The mentioned carriage **80** is also mounted on bars or rails **84** for movement in a direction at right angles to the translatory motion of the described table **76** and is again under the control of a micrometer **86** that is manually accessible exterior of the tubular body **10**. To facilitate focusing of the electron beam E on the specimens S, one of the latter can be in the form of fluorescent material. Thus, for precision alignment of the electron beam E, the fluorescent specimen S can be brought into irradiation position and appropriately adjusted physically until by visual observation through the light microscope **50**, the desired electron optical focus thereon is obtained.

It will, of course, be understood that the tubular body **10** must be evacuated to approximately 10^{-4} millimeters of mercury and suitable vacuum equipment is accordingly connected thereto in a conventional manner which need not here be described. Also, it will be apparent that all junctures to the tubular body **10** must be appropriately sealed so as to maintain such vacuum during operation.

Quite obviously, various modifications and/or alterations can be made to the described structure without departming from the spirit of the invention. Accordingly, the foregoing description of one structure is to be considered as purely exemplary and not in a limiting sense; the actual scope of the invention is to be indicated by reference to the appended claims.

What is claimed is:

1. An electron probe which comprises means for forming an electron beam, means for supporting a specimen to be irradiated at a predetermined position on the axis of said electron beam, means including a short focal length magnetic electron lens disposed entirely between said beam forming means and the specimen for focusing said beam on the specimen, said electron lens having an

internal aperture of convergent configuration in the direction of electron motion for passage of the beam therethrough and a lens center closely adjacent the specimen, a light microscope supported for viewing of the irradiated specimen, said light microscope having an optical lens supporting tubular body of non-magnetic material projecting partially through the interior of said convergent electron lens aperture with its axis intersecting the axis of said electron beam at the surface of the irradiated specimen so that the light passes through the same lens aperture as the electron beam, and means to analyze and detect X-rays emitted from said specimen.

2. An electron probe according ot claim **1** which comprises an electron shield disposed between said electron beam and the terminal portion of said tubular light microscope body.

3. An electron probe according to claim **1** wherein said specimen-supporting means supports the specimen with its surface to be irradiated in a plane perpendicular to the axis of said light microscope.

4. An electron probe which comprises means for forming an electron beam, means for supporting a specimen to be irradiated at a predetermined position on the axis of said electron beam, the surface of the specimen being disposed at an acute angle relative to said beam axis, and means including a magnetic electron lens disposed entirely between said beam forming means and the specimen for focusing said beam on the specimen, said electron lens including a coil with a surrounding core shield terminating in pole pieces having an entirely internal convergent configuration in the direction of electron motion, and means to analyze and detect X-rays emitted from said specimen.

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WILLIAM F. LINDQUIST, *Primary Examiner.*

RALPH G. NILSON, *Examiner.*