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Liebl

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[54] **MICROBEAM PROBE APPARATUS**

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[58] **Field of Search** 250/309, 310, 311, 396, 250/398

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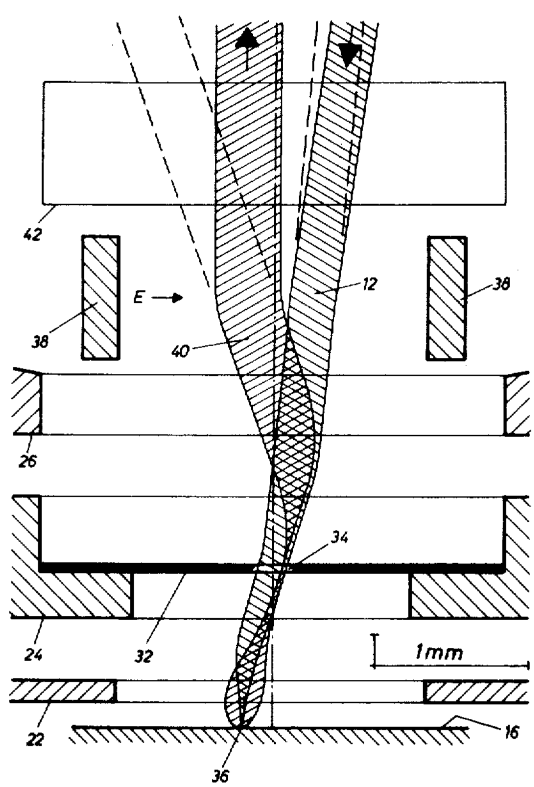
[57] **ABSTRACT**

The invention relates to a microbeam probe in which a test surface is subjected to an intense beam of ions or electrons and the resulting secondary particles are analysed. An apparatus is provided in which a common electrostatic lens of short focal length acts as an objective for the primary beam and also as a collecting lens for the secondary particles. The common lens comprises two rotationally symmetrical lenses of short focal length in series with an apertured diaphragm between them.

6 Claims, 4 Drawing Figures



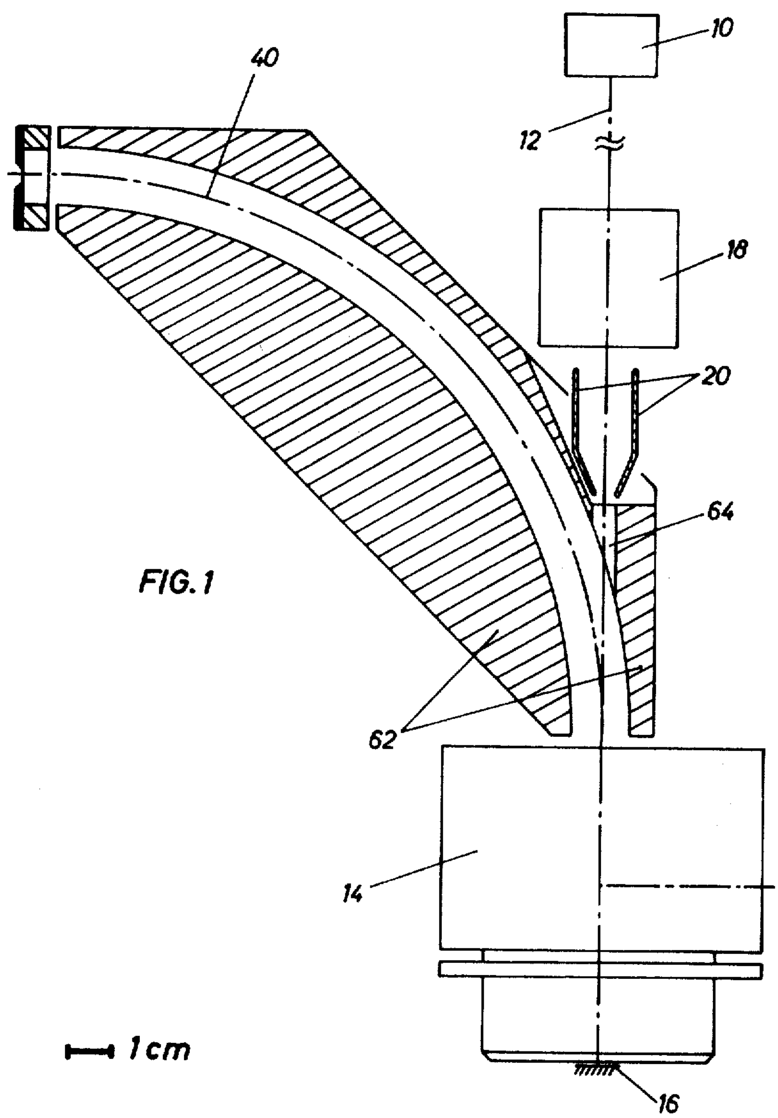


FIG. 1

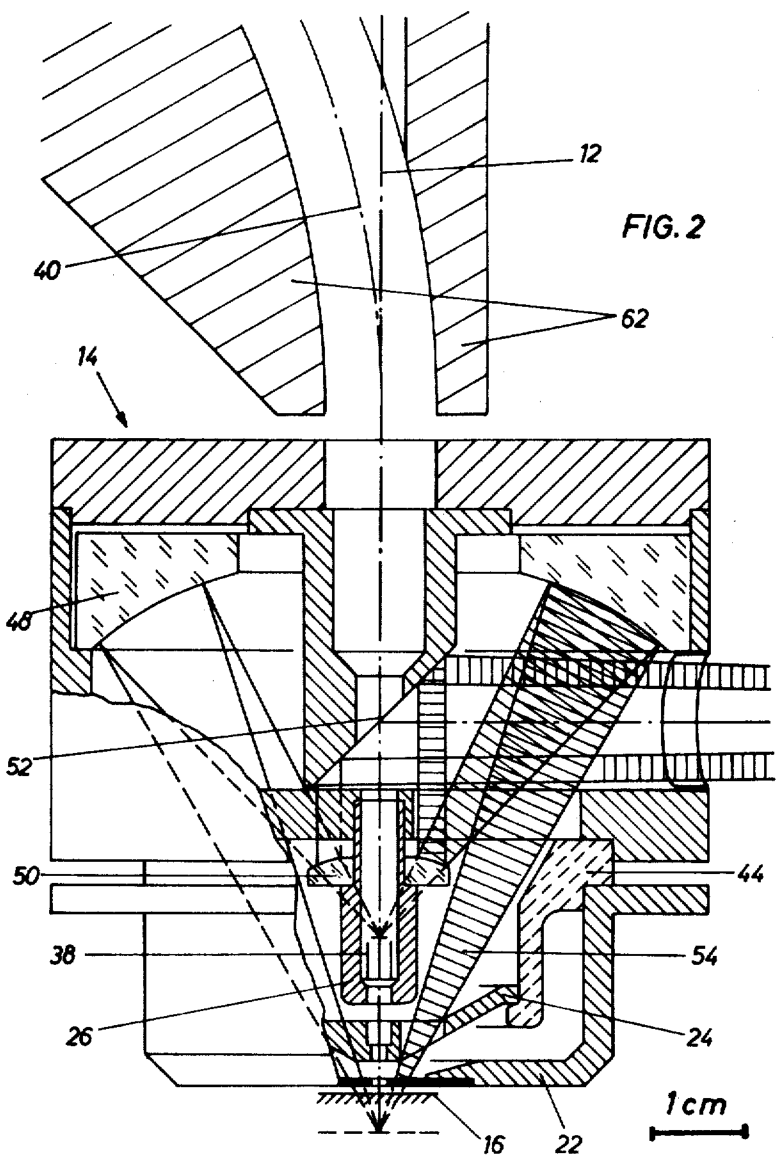


FIG. 2

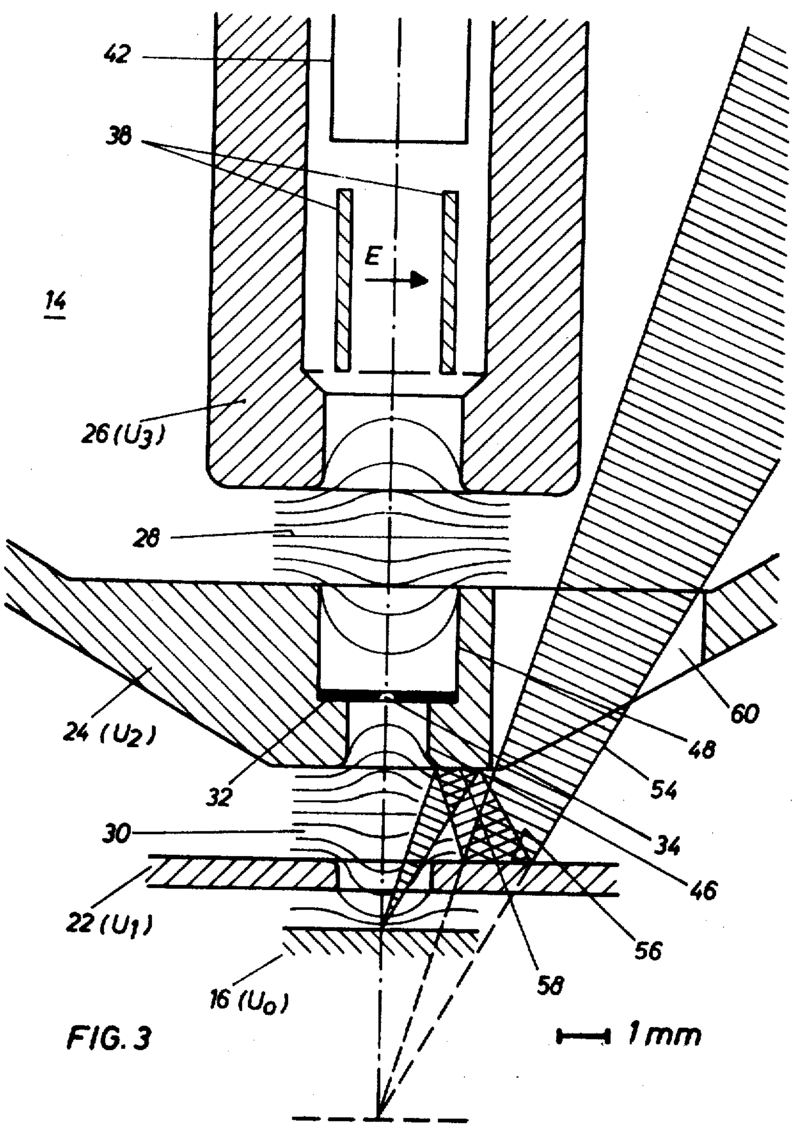
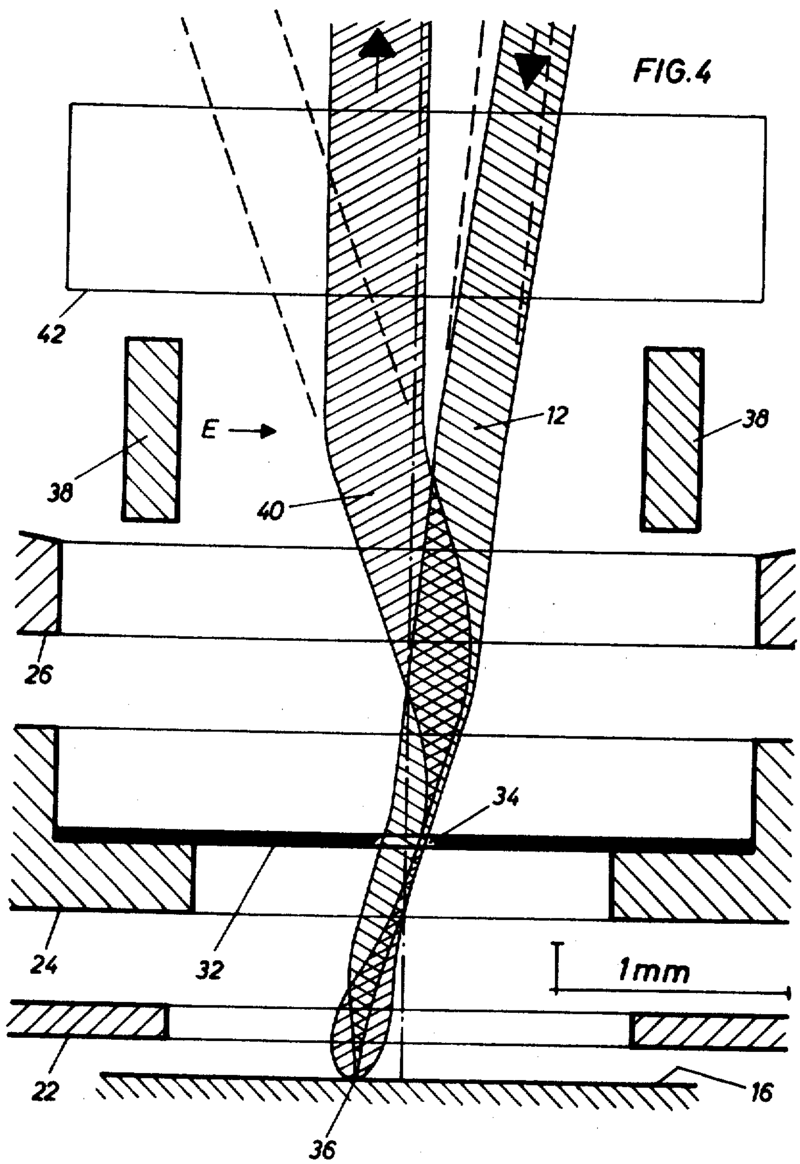


FIG. 3

FIG.4



MICROBEAM PROBE APPARATUS

The present invention relates to a microbeam probe, that is to say a device in which a desired portion (test field) of the surface of an object to be examined (test sample) is bombarded with an intensely concentrated beam of particles (electron beam or ion beam), and in which the secondary particles evaporated or otherwise released from the surface are delivered to an analyzing device, which consists in general of a mass spectrometer or the like. A microbeam probe usually includes a particle source, which delivers a substantially parallel, or possibly slightly divergent beam of primary rays (the angle of divergence being, for example, smaller than 5°, and preferably smaller than about 1°), an objective with at least one microbeam optical lens for focussing the primary bundle of rays upon a small test field of the surface to be investigated, and an electrode arrangement, whereby the secondary particles which are generated in the test field by the bundle of primary rays may reach the analyzing device.

In the known microbeam probes the secondary particles which are to be investigated are in general accelerated away from the test field in a lateral direction (that is to say along a path which forms an angle to the axis of the primary beam) (see, for example, German Offenlegungschrift 1,937,482). On this account the distance between the objective and the test sample, and therefore also the focal length of the objective, must be relatively large in order to allow space for accommodating the electrode arrangement of the secondary beam optical system, accelerating the secondary particles away from the test field and making it possible for these to be completely detected (quantitatively). On the other hand however it is desirable to make the focal length of the objective as small as possible, this being for two reasons. In the first place the degree of reduction achievable by the objective is the greater, the shorter is the focal length, this reduction being in fact the ratio of the diameter of the primary particle source, or of the region of smallest cross section of the bundle of primary rays (crossover point, intermediate focus) and the diameter of the test sample impinged upon by the primary beam. Secondly, in the case of a microbeam lens, in particular an electrostatic lens, its spherical aberration decreases with the focal length, that is to say as the focal length decreases the space angle increases, from which the primary particles can be focussed into a test field of desired diameter, and accordingly the greater becomes the current density in the test field.

Accordingly the present invention takes as its basic purpose the provision of a microbeam probe having an objective of substantially shorter focal length than that of the known microbeam probes without detracting from a comprehensive quantitative detection of the charged secondary particles and the transfer thereof into an analyzing device.

According to the present invention this problem is solved by a microbeam probe of the above mentioned type in which the objective comprises two rotationally symmetrical electrostatic lenses of short focal length arranged in series and an intervening apertured diaphragm; these lenses as well as the surface to be investigated being so dimensioned and arranged with respect to the energy of the beam of primary particles that this beam is focussed onto the test field by the combined action of the electrical fields of the objective — whilst

the diaphragm functions as an aperture diaphragm for the primary beam. At the same time the secondary particles generated in the test field are focussed in the aperture of the apertured diaphragm by the further lens constituted by the electrodes of the second lens of the objective and the conductive surface, and are also collimated by the first lens of the objective to form an at least substantially parallel beam of secondary particles, which latter beam leaves the objective in a direction which is substantially opposite to that of the bundle of primary rays, and between the primary beam source and the objective there is arranged a device for generating a deflecting field, which separates the primary beam from the secondary beam by virtue of the different acceleration voltages of the particles of these beams.

By the expression "lens of short focal length" there is to be understood preferably a lens whose focal length is of the same order of magnitude as the free diameter of the bored electrodes associated with the lens.

Therefore, in the microbeam probe according to the present invention the secondary particles are accelerated opposite to the direction of the primary beam and are delivered to the analyzing device by the same electrodes which also form the objective for the primary beam. Because an intermediate focus or crossover region of the secondary ray beam lies in the plane of the diaphragm defining the aperture of the primary beam, a high intensity of the secondary beam is ensured. The objective of the microbeam probe according to the present invention can have a focal length of 5 mm and less, whilst an objective focal length of less than 30 mm cannot be obtained with the known microbeam probes operating with secondary particle analysis. Having regard to the achievable reduction and the acceptable space angle, the microbeam probe according to the invention represents a substantial advance over the state of the art.

The microbeam probe is not restricted to a particular sign of the particles, but on the contrary, given suitable poling of the bias voltages, can operate with an electron beam as well as with a primary ion beam, and independently thereof can detect positive or negative secondary particles.

Further extensions and modifications of the invention are characterised in the subordinate claims.

A practical example of the invention will be explained in more detail with reference to the accompanying drawings, in which

FIG. 1 is a somewhat simplified, partly cut away, side elevation of the electrode system of a microbeam probe according to one practical example of the invention;

FIG. 2 is a sectional elevation of the objective and a portion of an adjacent spherical condenser of the microbeam probe according to FIG. 1 on an enlarged scale as compared thereto;

FIG. 3 is a still further enlarged cross sectional elevation of a part of the objective of the microbeam according to FIG. 1 and 2; and

FIG. 4 is a sectional elevation of a part of the objective of the microbeam probe according to FIGS. 1 to 3, somewhat expanded in the horizontal direction as compared with FIG. 3, and with an indication of the path of the primary beam and the secondary beam.

The electrode system represented in FIG. 1 is in practice arranged in an evacuable vacuum vessel, which is accessible through a lock, through which there may be introduced an object having the surface to be investigated. The electrode system contains a primary beam source **10** which is indicated only schematically, which can be designed in any known manner and which delivers a primary beam **12** of ions or electrons. The primary beam has a region of minimum cross section determined by the primary ray source or a crossover region (intermediate focus) of the primary beam, which by means of a microbeam optical objective, shown only schematically at **14** in FIG. **1**, is imaged upon a surface **16** of a test object which is to be investigated. The test field bombarded by the primary beam **12** can be scanned in known manner by two sets **18** and **20** of electrostatic deflecting plates effecting a raster type deflection over the surface to be investigated (like the motion of the electron beam over the picture screen of a television tube).

The objective comprises three mutually insulated bored electrodes **22, 24** and **26**, as may be seen particularly from FIG. **3**. The test surface **16** to be examined, which should be electrically conductive or coated with a conducting layer, is arranged closely adjacent under the bore of the electrode **22** at the object side. When using a primary ray beam consisting of ions, the electrode **26** is preferably placed at earth potential ($U_3 = 0$), the electrode **24** is placed at high voltage (for example $U_2 = -20$ kV), the electrode **22** at a relatively low voltage (for example $U_1 = -500$V) and the test surface **16** is placed at the potential which should correspond to the exit energy of the secondary particles (for example $U_0 = +1$ kV).

The potential values and signs given here as an example will apply when positive secondary particles are to be investigated.

The fields **28** and **30** here schematically represented between on the one hand the electrodes **26** and **24**, and on the other hand the electrodes **24** and **22**, function as condenser lenses. By suitable choice of the ratio of U_2 to the energy of the primary ray beam **12**, the result can be achieved that the primary ray beam is focussed upon the test surface **16** by the combined action of these two lenses **24–26** and **22–24**, as is represented in FIG. **4**. This condition can be achieved both for positive as well as for negative primary particles in the energy range between about 5 and 25kV. Between the two lenses there is situated within the relatively thick electrode **24** a short space which is free of field. In this position there is arranged an apertured diaphragm **32** with a fine opening **34**, which serves for defining the aperture of the primary beam **12**. The arrangement of the apertured diaphragm is most favourable at this position, because under the conditions of the raster type deflection of the primary beam the deviation of the beam path from the lens axis remains small in both lenses.

In respect of the secondary particles (that is to say ions in the example here considered), which proceed from the test fields **36** (FIG. **4**) impinged upon by the focussed primary beam, the conducting surface **16**, the electrode **22** and the electrode **24** function as an electrostatic lens in the form of a triode system, whose field can be so adjusted by suitable choice of potential of the electrode **22** that the secondary beam emitted from the test field **16** is focussed in a crossover region, which lies in the plane, that is to say the aperture **34**, of the diaphragm **32**. The magnitude of the aperture **34** determines the maximum possible exploration field of the

test surface **16**, that is to say the field under view. So long as one remains within this field of view, all of the secondary particles pass with adequate initial energies through the diaphragm **32**. In respect of the secondary ions, the field between the electrodes **24** and **26** functions as a retarding immersion lens, whose lower focal plane coincides with the plane of the apertured diaphragm **32**. Because the secondary beam has a crossover region at this position, the beam is formed by this lens into a parallel beam. By virtue of the raster type of deflection of the primary beam, there takes place a corresponding periodic angular deflection of this parallel beam. This can be removed, in respect of one deflection coordinate, by a electrical field E between the two auxiliary deflection plates **38** synchronised with the raster deflection, so that the emerging secondary beam **40** (FIG. **4**) only moves parallel to itself. The same applies for the other coordinate of the raster deflection, which is compensated by a field between auxiliary deflecting plates **42**.

It is possible to employ either positive or negative primary particles, and independently thereof positive or negative secondary particles can be brought out for analysis. The poling of the bias voltages at the electrodes **22** and **24** and the test surface **16** depends upon the sign of the secondary particles which are used. The poling is so selected that the secondary particles are accelerated between the surface **16** and the electrode **24**. When investigating positive secondary ions, the electrode **24** therefore receives a negative bias voltage with respect to the surface **16**, whilst in the case of investigation of negative secondary ions or secondary electrons, the electrode **24** must be positive with respect to the surface **16**. The condition that the primary beam must be focussed upon the test surface, permits of fulfilment in both cases and for primary particles of both signs (positive or negative ions, electrons), by suitable choice of the energy of the particles, that is to say the accelerating voltage.

From FIG. **2** it is clear how the objective can be constructed from the mechanical viewpoint. For the purpose of mutual electrical insulation of the metal parts forming the three electrodes **22, 24** and **26**, there is provided a single insulator **44**, which includes a flange-like portion, which mutually insulates the electrodes **22** and **26**, and an annular portion with an inwardly projecting edge, in which the electrode **24** is seated in an insulated manner. For the sake of clearness the leads to the electrodes are not shown. The effective portion of the electrode **22** has the shape of a comparatively thin plate (FIG. **3**), whilst the electrode **24** is comparatively thick. The bore of the electrode **24** has, at its object side, a cylindrical part **46** of smaller diameter and a contiguous portion **48** of larger diameter. At the step formed between the two parts **46** and **48** there is positioned the diaphragm **32** in the form of a disc. The electrode **26** has the shape of a tube, with a somewhat constricted end and contains the auxiliary deflecting plates **38, 42**. The objective may, as shown in FIG. **2**, contain a light microscopic device of the black screen type for observing the surface **16** under test. The observation device comprises, in a known manner, an annular concave mirror **48**, a convex mirror **50**, which includes a bore for the beam of particles, and a similarly bored deflecting mirror **52**. The path taken by the light beam **54** is shown in FIGS. **2** and **3**. The known observation devices of this type cannot however be directly employed in the presently described microbeam probe on account of the short focal length objective and the correspondingly small electrode spacing distances. Accordingly, in the presently described microbeam probe the light ray beam is deflected in the manner shown in FIG. 3 by means of two reflecting surfaces **56** and **58** which are either formed by the upper side of the electrode **22** and the under side of the electrode **24** respectively or are arranged upon said electrodes, so that the beam can pass from the concave mirror **48** through the aperture of the electrode **22.** The electrode **24** is provided with cavities **60** of ring sector shape for the light beam.

The separation of the primary beam **12** and the secondary beam **40** can be effected externally of the objective, for example, by means of a spherical condenser **62** (a condenser with plates in the form of portions of spherical surfaces), which deflects the secondary beam **40** emitted by the objective **14** out of the path of the primary beam **12,** which condenser may, for example, be the constituent part of a double focussing mass spectrometer (see for example German Offenlegungschrift 2,031,811). The outer plate of the spherical condenser **62** has a bore **64** proceeding in the direction of the objective axis, through which the primary beam **12** enters. Because the energy of the primary beam **12** is substantially greater than that of the secondary beam **40,** the primary beam suffers only a slight deflection in passing along the short length of path through the spherical condenser **62,** which deflection can be compensated by applying a suitable bias voltage to the pair of deflecting plates **20.**

The lens fields **28** and **30** (FIG. 3) operate upon the primary beam like a composite objective, which in the practical example here represented has a focal length of about 5 mm. The known types of microbeam probe, which work upon secondary particle analysis, have focal lengths of at least 30 mm. Thus the presently described microbeam probe represents a substantial technical advance as compared with the state of the art.

I claim:

1. A microbeam probe apparatus comprising an ion or an electron particle source (**10**) for producing an essentially collimated primary beam (**12**) of charged particles having a relatively high energy,

a charged particle objective system including first and second sets of electrodes (**26, 24—24, 22**) to produce first and second electrostatic lens fields of short focal lengths in first and second areas of space respectively, said fields being positioned to be transversed by the path of said primary beam **12** in the order named,

a diaphragm (**32**) having a fine aperture (**34**) positioned between said first and second areas of space,

a conductive surface (**16**) comprising a sample area to be investigated positioned in spaced relationship near said second set of electrodes on the side thereof, remote from said first set,

means for biasing said electrodes of said first and second sets, and said conductive surface to

a. produce first and second electrostatic lens fields which cooperate to focus said primary beam through said aperture (**34**) into a small spot on said sample area,

b. cause secondary charged particles, which emerge from said sample area under the action of said primary beam to accelerate towards said second set of electrodes, and be focused by said second lens field into a focus area within said aperture (**34**),

c. and collimate said secondary particles passing through said opening into a secondary beam (**40**) of relatively low energy traveling in a direction essentially opposite to that of said primary beam (**12**), and

deflecting means (**62**) acting on said primary and secondary beams to deflect said relatively low energy secondary beam (**40**) away from the path of said primary beam while leaving said relatively high energy primary beam essentially unaffected.

2. The apparatus according to claim **1** wherein said first set of electrodes comprises first and second apertured electrodes (**26, 24**) transversed by the path of the primary beam (**12**) in the order named; said second set of electrodes comprises said second electrode (**24**) and a third apertured electrode (**22**) transversed by the path of said primary beam **12** in the order named; said second electrode having a substantial thickness in the direction of said beam path to form a substantially field-free space within its aperture; said aperture diaphragm (**32**) being positioned within said field-free space.

3. Apparatus according to claim **1** wherein said first electrode (**26**) is of annular shape; said second electrode (**24**) has the form of a relatively thick plate which has a bore having a portion of large diameter facing said first electrode, and a contiguous annular portion of smaller diameter, and said third electrode (**22**) has the shape of an apertured relatively thin plate.

4. Apparatus according to claim **3** in which the apertured diaphragm (**32**) is positioned between the two cylindrical parts of the second electrode.

5. Apparatus according to claim **1** further including first deflecting means positioned to deflect the primary beam across said sample surface, and second, auxiliary deflecting means positioned near said objective system between said objective system and said first deflecting means to compensate for lateral shifts of said primary beam caused by said first deflecting means.

6. Apparatus according to claim **1** further comprising a light-optical system of the Schwarzschild type for observing said sample area of said surface; said light-optical system comprising a first reflecting surface (**56**) on the side of the third electrode (**22**) facing said second electrode (**24**), and a second reflecting surface (**58**) on the side of said second electrode (**24**) facing said third electrode (**22**) to deflect a light beam extending from said sample area to an observer.

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