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(54) ION MICROPROBES

(71) We, NATIONAL RESEARCH DEVELOPMENT CORPORATION, a British Corporation established by Statute, of Kingsgate House, 66—74 Victoria Street, London, S.W.1, 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:—

This invention relates to ion microprobes and is concerned with ion- and electron-optical arrangements for extracting ions from a specimen being examined. The extracted ions may be analysed in a mass spectrometer and the resultant signal may be used to form an image of an area of the specimen by scanning such area with the bombarding beam in a conventional manner.

In existing ion microprobes the design of the electron-optics is a compromise between on the one hand the need to shield the bombarding focused beam from the electrostatic field required for extraction of secondary ions so that off-axis deflection and astigmatism is minimised and on the other hand the requirement of efficient ion extraction. Furthermore existing designs enable only ions or electrons but not both to be extracted at any one time.

It is an object of the invention to provide an ion microprobe in which particles of both polarities can be simultaneously and efficiently extracted.

According to the invention an ion microprobe includes an ion extraction arrangement comprising two separate paths for ions and electrons diverging from a common point, a generally cone-shaped or pyramidal guard electrode surrounding each path, the apex angles of which guard electrodes are equal and coincide with the said point, said guard electrodes being positioned to lie tangentially to each other and to a planar surface including the said point, an aperture for said paths at the apexes of both guard electrodes, electrical connection between the guard electrodes for enabling the same potential to be applied to both guard elec-

trodes, means for generating electric fields within the guard electrodes oppositely polarised with respect to each other, and means for causing a focussed ion beam to strike the said point without suffering astigmatism.

Preferably a further generally cone-shaped or pyramidal electrode is provided inside the volume defined by each guard electrode coaxial with the extraction path therethrough the apexes of which further electrodes point in opposite directions to the apexes of the guard electrodes within which they are positioned and in which in operation equal and opposite potential differences relative to the potential of the guard electrodes are applied to the further electrodes, and the further electrodes are so positioned that the electric field patterns in the regions of the paths are similar but of opposite direction and there are no appreciable components of electric field non-parallel to either path.

In carrying out the invention the guard electrodes may be formed in a block of metal and material is removed from the block in a plane close to and parallel to the said planar surface so as to enable a specimen under examination to be positioned at the point of bombardment.

From a consideration of the geometrical relationship between the guard electrodes it will be appreciated that the semi-apex angle α of each guard electrode can have a maximum value of 45° and if the angle of the plane containing the two ion paths relative to the plane of the specimen is β then $\tan \alpha = \sin \beta$. A particular case of this relationship is when α is 45° in which case β is 90° and the plane containing the two ion paths is at right angles to the plane of the specimen and thus includes the normal at the point of bombardment. This particular arrangement is of special value since it enables the bombarding ion beam to be directed along one of the ion extraction paths and the electric field configuration enables the bombarding beam to travel in one direction while secondary electrons emitted from the point of bombardment will travel along the same

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path in the opposite direction. These secondary electrons can be readily separated from the bombarding beam by a suitable magnetic deflecting field. Positive ions emitted from the point of bombardment will travel along the other ion beam path.

It is desirable to be able to view the point of bombardment optically along the normal and this has been difficult to achieve in existing arrangements since any optical lens system of short working distance would disturb the field configuration. However, in embodiments of the invention a viewing arrangement can be incorporated by providing an optical axis along the normal to the point of bombardment. In the particular case where α is 45° and the two guard electrodes meet tangentially along the normal then a small amount of material can be removed along the line of the tangent by drilling a hole and inserting a suitable microscope objective lens in the optical path so formed. The removal of material for viewing does not appreciably disturb the electric field pattern.

In order that the invention may be more fully understood reference will now be made to the drawing accompanying this specification the single Figure of which illustrates in section an ion microprobe embodying the invention.

In the Figure a block 1 of a suitable metal has bored in it two cones 2 and 3 each having a semi-apex angle α equal to 45° . Cones 2 and 3 are positioned so that their apexes coincide and they both lie tangentially to a planar surface 4. Also they are tangential to each other along a line 5 which extends normally to surface 4 from the point 6 where the apexes of the two cones coincide. A thin layer of material is removed from surface 4 to enable a specimen 7 to be positioned at surface 4 so that the point 6 lies on the surface of the specimen. The geometry of the arrangement is such that the axis 8 of cone 3 and the axis 9 of cone 2 both lie in the same plane as the normal at point 6 and the angle between axes 8 and 9 is 90° . At the apexes of cones 2 and 3 small apertures 10 and 11 will appear to enable ions or electrons to pass to and from point 6 along paths coincident with 8 and 9.

Within cones 2 and 3 there are provided extraction electrodes 13 and 14 which are in the form of metal inserts insulated from the body 1 defining the cone-shaped guard electrodes 2 and 3. Metal inserts forming the guard electrodes 13 and 14 have similar shapes to each other and are preferably cone-shaped or pyramidal. Electrodes 13 and 14 are respectively positioned with their axes coincident with paths 8 and 9 and with their apexes directed oppositely to the apex of their associated guard electrode 2 or 3. In operation a potential of $+V$ relative to the guard electrodes is applied to extraction elec-

trode 13 and an equal and opposite potential $-V$ is applied to extraction electrode 14. The electric field patterns produced in this way are such that along the ion paths 8 and 9 there are no off-axis electric deflection forces but the field acts to extract positive ions axially along path 9 and negative ions and electrons along path 8. Furthermore owing to the symmetry of the geometry and the balanced electric fields it is possible to drill a hole along the normal 5 and insert in it a microscope objective lens 15 without appreciably disturbing the electric fields. It is thus possible to view the point of bombardment 6 without obstruction while the apparatus is being used.

In operation a focussed positive-ion beam from an ion gun lens 12 is aimed at point 6 and in the regions between electrode 13 and point 6 will experience an accelerating field which will have no asymmetric off-axis components and which will not in any way cause astigmatism or off-axis deflection provided the beam is directed along the axis of path 8. Electrons and secondary positive ions emitted from point 6 by the effect of the bombardment will be attracted along either path 8 or path 9 depending on their polarities. Positive ions emitted from point 6 will be attracted along path 9 and be accelerated through the initial region between the point of emission 6 and extraction electrode 14 by an electric field. After passing through extraction electrode 14 any suitable configuration of electrodes 17 can be provided in path 9 depending on the measurements that are desired to be made on the extracted ions. In general the extracted ions will be led to a mass spectrometer. As regards any secondary electrons emitted from point 6 in one mode of operation these will be attracted along path 8 in the opposite direction to the bombarding ion beam and after passing through electrode 13 they can then be separated from the bombarding ion beam by a suitable magnetic deflection field and be directed into a Faraday cup 16.

If desired the point of bombardment can be scanned by applying a suitable scanning field to the bombarding beam. The detected secondary electron current and the positive ion current detected in the mass spectrometer may be used to form scanning images simultaneously on the screens of two separate cathode ray tubes.

While in the arrangement shown in the Figure the guard electrodes have a semi-apex angle α of 45° it will be appreciated α can have a smaller value and the electrode assembly can be tilted so that the ion paths 8 and 9 are not co-planar with the normal at point 6. If the plane of the axes 8 and 9 is at an angle β relative to the bombarded surface then the value of β is given by the relationship $\tan \alpha = \sin \beta$. Furthermore although

in the Figure the bombarding ion beam is shown as coinciding with one of the extraction ion paths this is not essential and a separate path for the bombarding beam can be provided which may be in a plane other than the plane containing paths 8 and 9.

WHAT WE CLAIM IS:—

1. An ion microprobe including an ion extraction arrangement comprising two separate paths for ions and electrons diverging from a common point, a generally cone-shaped or pyramidal guard electrode surrounding each path, the apex angles of which guard electrodes are equal and coincide with the said point, said guard electrodes being positioned to lie tangentially to each other and to a planar surface including the said point, an aperture for said paths at the apexes of both guard electrodes, electrical connection between the guard electrodes, for enabling the same potential to be applied to both guard electrodes, means for generating electric fields within the guard electrodes oppositely polarised with respect to each other and means for causing a focussed ion beam to strike the said point without suffering astigmatism.

2. The ion microprobe as claimed in Claim 1 in which a further generally cone-shaped or pyramidal electrode is provided inside the volume defined by each guard electrode coaxial with the extraction path therethrough the apex of which further electrodes point in opposite directions to the apexes of the guard electrodes within which they are positioned and in which in operation equal and opposite potential differences re-

lative to the potential of the guard electrodes are applied to the further electrodes, and the further electrodes being so positioned that the electric field patterns in the regions of the paths are similar but of opposite direction and there are no appreciable components of electric field non-parallel to either path.

3. The ion microprobe as claimed in either one of the preceding claims in which the guard electrodes are formed in a block of metal and material is removed from the block in a plane close to and parallel to the said planar surface so as to enable a specimen under examination to be positioned at the point of bombardment.

4. The ion microprobe as claimed in any one of the preceding claims in which the means for causing a focussed ion beam to strike the said point includes an ion gun for directing an ion beam along one of said paths and means providing an axial accelerating field therealong.

5. The ion microprobe as claimed in any one of the preceding claims in which optical viewing means are provided along an axis normal to the said point.

6. The ion microprobe as claimed in any one of the preceding claims in which the semi-apex angles of the guard electrodes are 45°.

7. An ion microprobe substantially as described herein with reference to the accompanying drawing.

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