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[54] **ELECTRON PROBE APPARATUS USING AN ELECTROSTATIC FIELD TO CAUSE SECONDARY ELECTRONS TO DIVERGE**

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[51] **Int. Cl.**..........................**H01j 37/26,** G01n 23/00

[58] **Field of Search**........250/49.5 A, 49.5 C, 49.5 E, 250/49.5 PE

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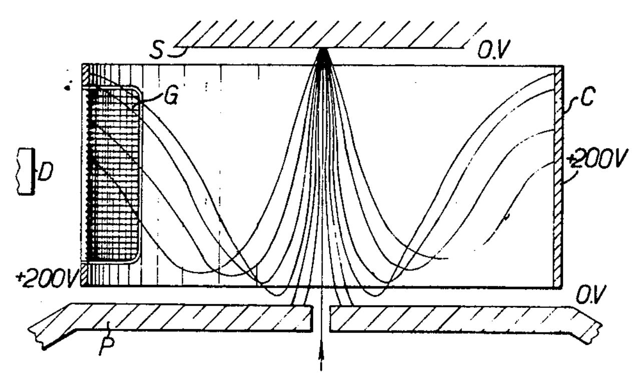
Attorney—Scrivener, Parker, Scrivener and Clarke

[57] **ABSTRACT**

In electron beam apparatus in which a probe-like beam of electrons impinges on a specimen surface and the resulting secondary electrons are detected to give information about the specimen surface topography or other properties such as electric potential or electrostatic or magnetic field, there is formed between the point of impact and the detector a field which modifies the trajectories of the secondary electrons, causing them to diverge and, in some cases, to be retarded. The field can be electrostatic, set up by a cylindrical shield-like electrode and an end electrode, with the detector set in a limited angular region of the wall of the shield.

9 Claims, 4 Drawing Figures



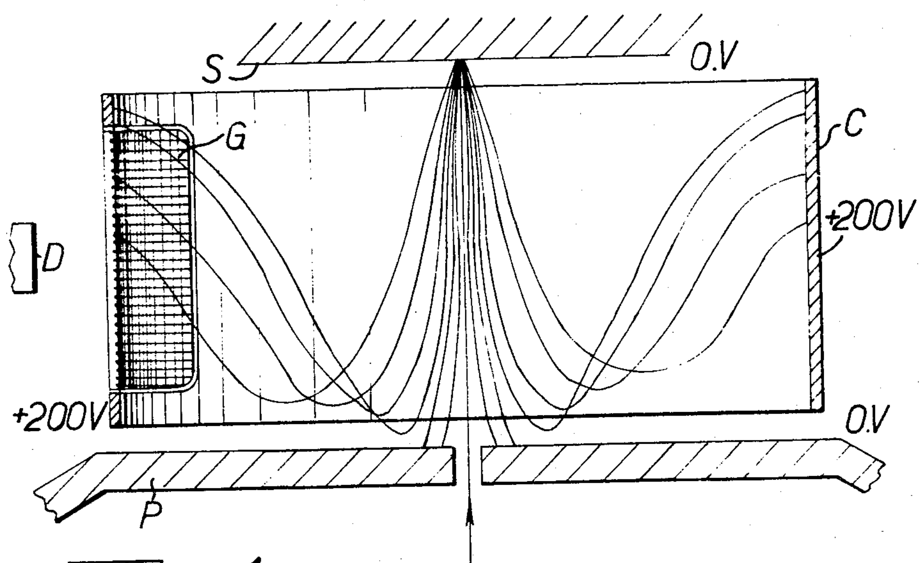


Fig. 1

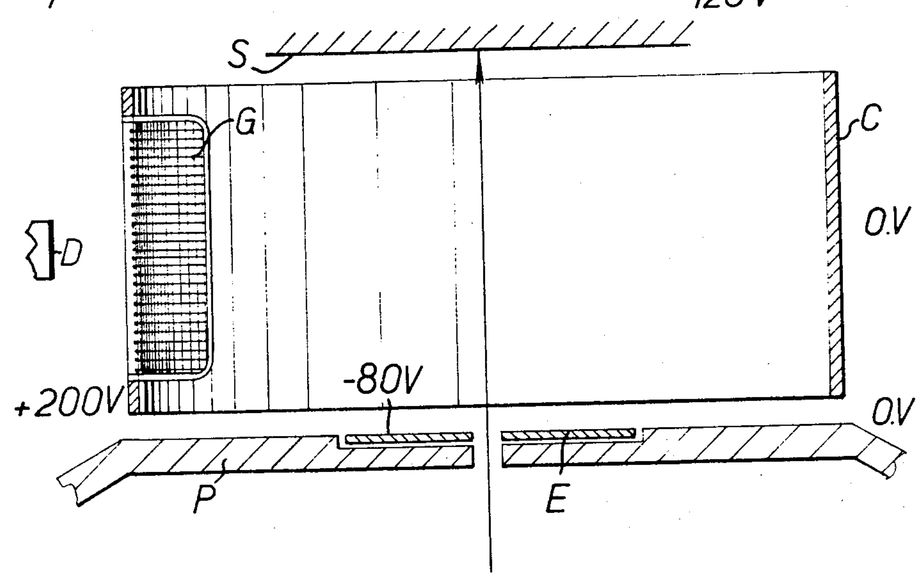


Fig. 3

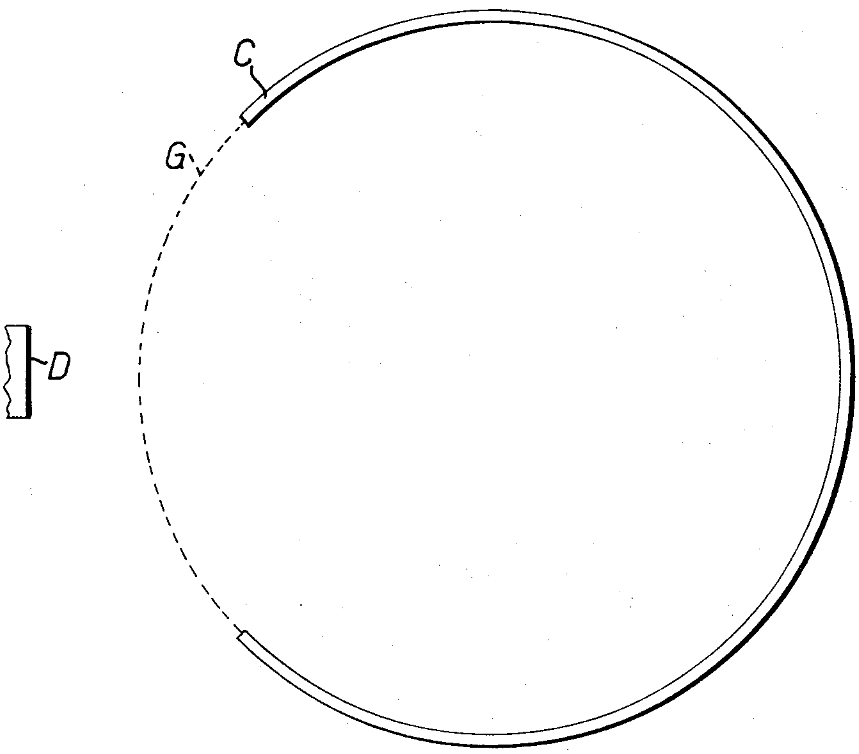


Fig. 2

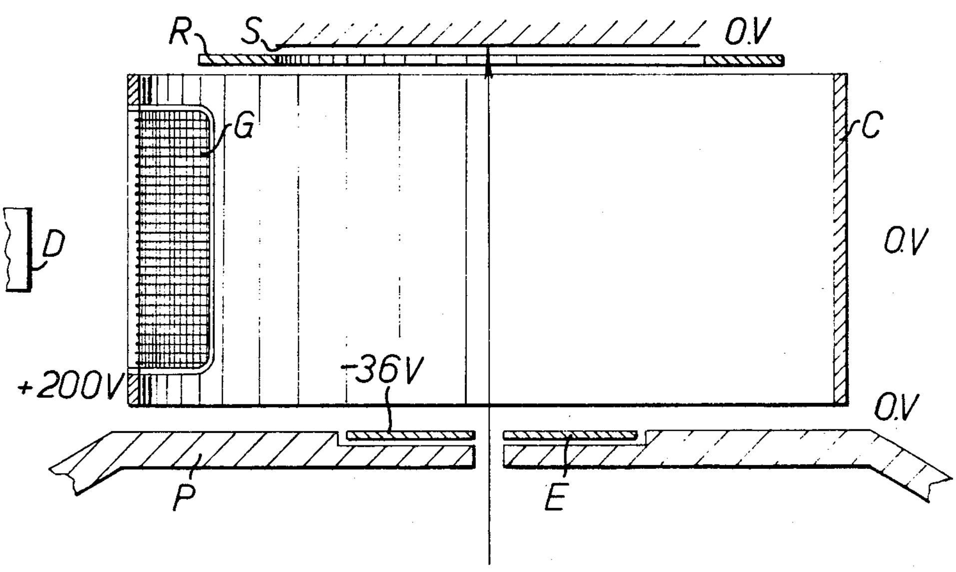


Fig. 4

ELECTRON PROBE APPARATUS USING AN ELECTROSTATIC FIELD TO CAUSE SECONDARY ELECTRONS TO DIVERGE

This invention relates to electron beam apparatus of the kind in which a finely focussed beam or probe of electrons is caused to impinge on the surface of a specimen under examination and one of the resulting effects, namely the number of secondary electrons given off by the specimen from the point of impact, is used to obtain information about the specimen surface. For example in the scanning electron microscope the beam is caused to scan a small region of the surface of the specimen in a raster and a signal obtained from collection of the secondary electrons control the brightness of the spot of a cathode ray tube scanned in synchronism with the electron beam, so that a two-dimensional image of the scanned region of the specimen surface is built up, the contrast in the image resulting from changes in the magnitude of the secondary electron signal as the beam passes from point to point of the surface.

Electron probe X-ray micro-analysers, in which primarily the X-rays emerging from that point of impact, may also include means for forming a contrast image from the secondary electrons. Furthermore it is not essential for the beam to be scanned laterally; instead the beam could be stationary while the specimen is moved, or both could be stationary, while some factor, such as the voltage on the specimen, or the potential difference across a junction in it, is varied.

In these known instruments the contrast in the image is derived primarily from the variations in the secondary emission coefficient at the point of impact, which variations result in a change in the rate of emission of electrons and a consequent change in the rate at which electrons enter the device (such as a scintillator) used for collecting them. The changes in secondary emission coefficient may be caused by surface topography, i.e., when the beam passes over bumps or pits or steps in the surface, since this alters the effective local angle of incidence of the beam, or they could be caused by a change in the nature of the material of the specimen, for example when it passes from a region of one element to a region containing another.

In all these cases it has been the standard practice to collect as many as possible of the available secondary electrons in the detecting device, usually by putting the detecting device at a substantial positive potential with respect to the specimen, so as to attract the electrons towards it. The positive potential on the detector creates an electrostatic field that is effectively like that of a convergent lens. It has also been known, for the same reason, to make the detector subtend a large solid angle at the point of impact, even as much as a hemisphere, but this is only possible with certain types of detector, and not with scintillators.

The present invention is based on appreciation of the fact that it is not necessarily the collection of the maximum secondary electrons in the detector that gives the greatest sensitivity. On the contrary, if too high a voltage is applied to the detector, it will collect almost all the secondary electrons regardless of the direction and so there will be no observable contrast resulting from electric or magnetic field distributions in or around the specimen surface.

According to the invention we propose to provide, in the region between the surface of the specimen and the detector, an electric or magnetic field that is such as to cause the electrons to diverge or spread out in their path from the point of impact to the detector, instead of simply being attracted in maximum number towards the detector. In this way, not only are differences in the direction of the emerging secondary electrons not masked, but on the contrary they are accentuated.

Where the specimen surface is perpendicular to the beam the divergence will be away from the axis of the beam. Where the specimen surface is inclined to the beam the divergence will normally be away from the normal to the specimen at the point of impact.

The field that causes the divergent trajectories of the electrons may be electrostatic or electromagnetic or partly one and partly the other, but a solely electrostatic field is easier to produce in a simple and controllable manner. In one preferred arrangement a cylindrical electrode is provided, with its axis coinciding with the axis of the beam and the detector is set in, or forms a part of, the cylindrical wall. A further electrode, in the form of a grid or a disc-like plate may be disposed in the face of the adjacent pole-piece of the final lens of the beam-forming system.

By causing the secondary electrons to diverge from the point of impact we reduce the number of electrons reaching the detector, as compared with known detector arrangements, but at the same time we can actually improve the contrast that results from small local effects at the specimen surface which are such as to cause the electrons to emerge preferentially in one direction rather than another. One such effect is simply that of topography, and the detector according to the invention is able to distinguish clearly between bumps and pits, as a face that is inclined towards the detector will appear bright and one that is inclined away will appear dark. Even comparatively shallow pits or undulations are revealed, whereas in conventional detectors the contrast produced by these is poor.

However, the most valuable effects which the detector according to the invention is able to observe are those due to potential contrast or due to electromagnetic fields in or near the specimen surface. The observation of potential contrast is particularly valuable in the examination of the behavior of semiconductors, integrated circuits and micro-circuit elements.

The influence of local electromagnetic fields is more complex as their components normal to the surface as well as those parallel to it will influence the path of the secondary electrons but by suitable placing of the detectors it is possible to discriminate between them. The invention makes it possible to examine for example magnetic domains on a microscopic scale, in magnetic materials or in recordings on magnetic tape.

The divergent electron trajectories caused by the electrostatic field of the electrode system of the detector in the preferred form of the invention need not be continuously divergent; they may have an initially convergent component. However, the overall effect is divergent. The field may be formed by two or more superimposed fields, and by varying the potentials on these electrodes and on the specimen it is possible to vary the mode of operation of the detector.

The invention will now be further described by way of example with reference to the accompanying drawings in which:

FIG. 1 illustrates diagrammatically a preferred form of the invention;

FIG. 2 is a plan view of the shield on a reduced scale;

FIG. 3 shows an alternative mode of operation of the detector of FIG. 1; and

FIG. 4 shows a third mode of operation.

In the drawings we have, for convenience, not illustrated the beam-generating or beam-forming and scanning equipment, as these can be of known form. The beam is assumed for convenience to be pointing vertically upwards and emerges through the outer pole-piece P of the final or objective lens, of the electromagnetic type in the version illustrated. It impinges on a small area (a few microns across) of a specimen S which, in the version illustrated, has its surface perpendicular to the beam. The impact of these primary electrons, which may have energies of the order of 20 KeV, causes the emission of low-energy secondary electrons, with energies of only a few electron volts. Their quantity is influenced by the nature of the material of the specimen (and also to some extent by the local topography) but their direction of emergence is influenced strongly by the local topography; furthermore, as they leave the specimen their trajectories are changed by any electrostatic or electromagnetic fields that are present close to the specimen surface. In known detectors these variations in trajectory would be lost in that the detector is designed to attract all the secondary electrons, or at least as many as possible, into the detector. In that arrangement shown in FIG. 1 we provide an electrode system that actually superimposes a field causing the paths of the individual electrons to diverge away from the electron-optical axis of the beam, so as to enhance the initial difference in trajectory.

We do this with a round cylindrical shield C having its axis coincident with that of the beam and extending axially substantially from the specimen surface to the pole-piece P. In a first mode of operation it is held at a potential between 200 and 500 volts positive with respect to the specimen surface, typically at 350 volts. The pole-piece P of the lens is at zero volts. A rotationally symmetrical electrostatic field is thereby produced, such that electrons which leave the specimen surface at an acute angle to the electron-optical axis are caused to diverge away from that axis and eventually reach the surface of the shield C. Thus any influence at the specimen surface which tends to pull the electrons to one side of the axis rather than the other will be accentuated and the electrons will reach one arcuate portion of the shield rather than the opposite portion.

The trajectories of some electrons of a particular energy (4 electron volts) emerging from the point of impact at different acute angles to the electron-optical axis are shown in the drawing. Those of higher or lower initial energies will have slightly different paths. Basically the specimen surface, the pole-piece P and the cylindrical shield C form a hollow cylindrical drum with its ends at 0 volts and its curved surface at a positive potential and the resulting electrostatic field is a rotationally symmetrical one with a saddle point at the center. At first the electrons, initially moving relatively slowly, have that component of their velocity which is parallel to the electron-optical axis increased by the field, so those electrons which were initially diverging anyway start to converge, but as they approach the pole-piece P they are retarded, the axial component of their velocity is reduced, ultimately to zero, and the positive potential on the shield C draws them outwards and actually reverses their axial component. The initial divergence of the electrons from the electron-optical axis, after a slight initial convergence, is thus enhanced to a substantial extent. Any asymmetry in the distribution of their trajectories on initially leaving the point of impact is therefore enhanced and if the electrons are emerging predominantly over a certain sector they will strike predominantly the corresponding sector of the shield C.

It will be understood that the shield need not be circular in cross-section. Moreover, the member P need not be the pole-piece itself but could be an earthed plate covering the pole-piece. Likewise the specimen may be covered by a flat disc-like earthed shield (with a small opening to expose that part of the specimen on which the beam impinges) to ensure predictable field conditions. However, the overall result could be achieved (though less predictably) with a specimen of small dimensions and no such earthed shield.

Set into, and flush with, the inner surface of the shield C is the gauze G that forms the entry cage for a detector D in the form of a scintillator; this gauze extends the greater part of the axial length of the shield and circumferentially it extends over an arc of, say, between 60° and 120°, and in a typical example it extends over 90°. The gauze is at the same potential as the shield C and thus does not upset the symmetry of the field.

The scintillator itself can be at the usual high potential of several kilovolts, and can lead through a light pipe to a photomultiplier (not shown) to produce an electrical signal proportional to the number of electrons passing through the gauze.

It will be evident that the detector D will pick up, and produce a signal from, those electrons which fall in that sector of the shield C which is occupied by the gauze. Thus any contrast due to asymmetry in the direction in which the electrons leave the point of impact on the specimen surface is observed as a change in signal strength in the detector D.

It will be also understood that, in addition to being sensitive to the direction of the electron paths, the detector arrangement according to the invention will still, like known detectors, show contrast due to differences in secondary emission coefficient.

The shield C will normally be of metal. All the components may have a thin coating of carbon to reduce the emission of spurious unwanted secondary electrons generated by the impact on them of high-energy primary electrons backscattered from the point of impact. Such a coating is particularly useful where the components are small in size.

Beyond the detector D we may use an energy analyser, known in itself, to obtain information about the quantities of electrons picked up in different energy bands.

In the apparatus illustrated in FIG. 1 the entry gauze or cage G of the detector extends the greater part of the axial length of the shield C. It would be possible, in a modification, to restrict it, preferably in an adjustable manner, so that only the electrons picked up over a selected part of the axial length of the shield enter the detector. This can be done by blanking off part of the gauze G. The signal in the detector will then represent the number of electrons of only certain energy/direction combinations.

The mode of operation shown in FIG. 1 is the simplest and the easiest to understand. It is suitable for observing topography of the specimen surface. For the observation of magnetic contrast we prefer to use a different mode, shown in FIG. 3. Here we have introduced a disc-shaped grid or plate A, recessed into the face of the pole-piece P but insulated from it, and we have also altered the relative potentials on the different components. For convenience the pole-piece remains at earth potential but the specimen is now at −120 volts. The shield is at earth potential. The plate A is, in a typical case, at −80 volts. Finally, the gauze G of the detector is at a positive potential, for example +200 volts.

A specimen containing magnetic domains may have a magnetic field close to its surface in any direction, i.e., having a component normal to the surface and having components in two directions parallel to the surface. The electrode system of FIG. 3 produces in effect two superimposed electrostatic fields having a divergent effect on the electron trajectories, one field being between the specimen surface and the plate A (which is 40 volts positive with respect to it), and the other field being between the specimen surface and the shield C (which is 120 volts positive with respect to it). It is only the components of the magnetic field parallel to the specimen surface that produce asymmetry of direction of the electron paths, and so this mode of operation is suitable for observing the components of magnetic field in this direction, not the component normal to the surface. It is also suitable for observing electric fields parallel to the specimen surface.

In the mode shown in FIG. 3 the detector gauze G is at a higher potential than the shield C and so introduces some asymmetry itself, but this has little influence on the important part of the field, namely at the specimen surface, and so although it does reduce directional contrast to some extent it is not serious.

In the two direction-sensitive modes of operation described above the detector is not sensitive to moderate changes in the energy of the electrons, and so potential contrast does not occur simultaneously with sensitivity to lateral electric and magnetic fields.

The third mode of operation, illustrated in FIG. 4, is particularly suitable for observing electric potential contrast. The electrode layout is the same as in FIG. 3, but the potentials are different. The specimen S and the shield C are now both at earth potential, as well as the pole-piece P, and the plate A is at a negative potential of variable value, being −36 volts in a particular example. The gauze G of the detector is again at +200 volts.

The resulting retarding field (since the plate A is now negative with respect to the specimen surface) removes almost all of the directional information from the signal, and although it causes the electrons to diverge, it is the retarding effect that is predominant. Contrast in electrical potential between different regions of the specimen surface scanned will produce changes in the electrical signal that are monotonic, i.e., there are no maxima or minima in the relationship (within the normal working range) and so there is a direct and continuous relationship between specimen surface potential and signal strength. By varying the potential on the electrode A we can control the symmetry of the relationship.

An additional ring-shaped electrode R, shown in broken lines in FIG. 4, may be introduced close to the specimen surface and can carry a negative bias to vary the shape of the relationship between the potential on the specimen and the signal in the detector, and thereby to improve the linearity of this relationship.

The mode shown in FIG. 4 is particularly suitable for observing the behavior of micro-circuits. With a linear signal characteristic, we can measure D.C. voltages and A.C. waveforms on a micro-circuit or circuit elements with only low distortion.

The beam need not impinge on the specimen surface normally, but on the contrary operation at any angle from 0° to 90° is possible, with the whole detector/shield system (including the scintillator) rotated. In this case a metal plate with a small hole or slot for entry of the electron beam will replace the pole-piece as the body defining that end of the divergent field region which is opposite the specimen. The disc-like insert will then be fitted in the center of this plate.

Although in the arrangements described the invention is used with an electron beam scanning a selected small region of the specimen surface in synchronism with a cathode ray tube display of the contrast signal, the invention could be used equally well with time-varying phenomena, using for example a stationary spot or a line scan in one dimension. Where the phenomenon varies in a regular periodic manner stroboscopic techniques may be employed; this is of particular value in examining alternating current waveforms at a selected point in the surface of a micro-circuit.

The fields that cause the electron trajectories to diverge and/or to be retarded have been shown as electrostatic in the examples described. However, they could be modified by the superposition of magnetic fields, produced by suitably placed permanent magnets or by electro-magnets. It is a general rule that effects which are obtainable electrostatically can also be obtained by the use of magnetic fields, although they may be less easy to design. It may even be possible to produce a wholly magnetic field to give the required divergent effect, effect by the use of two axially spaced toroidally wound electro-magnets replacing the shield C.

We claim:

1. Electron beam apparatus comprising means for generating a high energy beam of electrons, a specimen stage in the path of said beam, designed to receive a specimen for impingement thereon of said beam, and means for detecting secondary electrons emitted by and diverging from said specimen as a consequence of said impingement, wherein the improvement lies in the provision of guiding means for controlling the path of said secondary electrons from the specimen to the detecting means, said guiding means comprising an electrode structure creating a divergent electrostatic field in the path of said secondary electrons from said

specimen, said field being selected to cause said secondary electrons of a given energy and following different paths from said specimen to spread out to a greater degree than they would do in the absence of said field thereby increasing the mutual divergence of said paths so as to accentuate differences in the trajectories of said secondary electrons, said detecting means occupying only a fraction of the solid angle over which the secondary electrons which are subjected to the increased divergence are spread.

2. The electron beam apparatus of claim 1 wherein said guiding means comprise a hollow cylindrical shield, said shield being disposed with the axis thereof substantially normal to the surface of said specimen at the point of impingement of said beam.

3. The electron beam apparatus of claim 2 wherein said secondary electron detecting means are disposed in the wall of said shield occupying only a fraction of the surface area thereof.

4. The electron beam apparatus of claim 2 wherein said shield is at an electric potential which is positive with respect to said specimen.

5. The electron bean apparatus of claim 2 wherein said shield has a diameter greater than the axial length thereof.

6. The electron beam apparatus of claim 2 wherein said guiding means further comprise a disc-shaped electrode, said electrode being disposed with its axis coincident with the axis of said shield and being disposed at the opposite end of said shield from said specimen.

7. The electron beam apparatus of claim 6 wherein said electrode is at the same potential as said specimen.

8. Electron beam apparatus comprising means for generating a beam of electrons, a specimen stage designed to receive a specimen for impingement thereon of said beam, means for detecting secondary electrons emitted by said specimen as a consequence of said impingement and guiding means for said secondary electrons, said guiding means creating a divergent electrostatic field in the path of said secondary electrons from said specimen such as to cause said secondary electrons of a given energy to spread out, accentuating differences in the trajectories thereof, said guiding means comprising first a hollow cylindrical shield, said shield being disposed with the axis thereof substantially normal to the surface of said specimen at the point of impingement of said beam, secondly a disc-shaped electrode disposed with its axis coincident with the axis of said shield and at the opposite end of said shield from said specimen, and thirdly a ring-shaped electrode adjacent said shield and between said shield and said specimen, said ring-shaped electrode being at an electric potential which is negative with respect to said specimen whereas said first-mentioned disc-shaped electrode and said shield are at the same potential as said specimen, said means for detecting secondary electrons being disposed in the wall of said shield and occupying only a fraction of the surface area thereof.

9. A method of analyzing the secondary electrons emerging from the point of impact of an electron beam on a specimen, said method comprising the steps of subjecting said secondary electrons to a divergent field that acts to accentuate the different trajectories of secondary electrons of the same energy whereby said secondary electrons diverge from one another over a substantial solid angle, and detecting the secondary electrons over only a fraction of said solid angle.

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