

[54] **ELECTRON MICROSCOPES AND MICRO-ANALYSERS**

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[22] Filed: **Feb. 14, 1972**

[21] Appl. No.: **225,968**

[30] **Foreign Application Priority Data**

Feb. 12, 1971 Great Britain 4,604/71

[52] U.S. Cl. **250/398, 250/311**

[51] Int. Cl. **H01j 37/26**

[58] Field of Search 250/49.5 R, 49.5 A,
250/49.5 PE, 398

[56] **References Cited**

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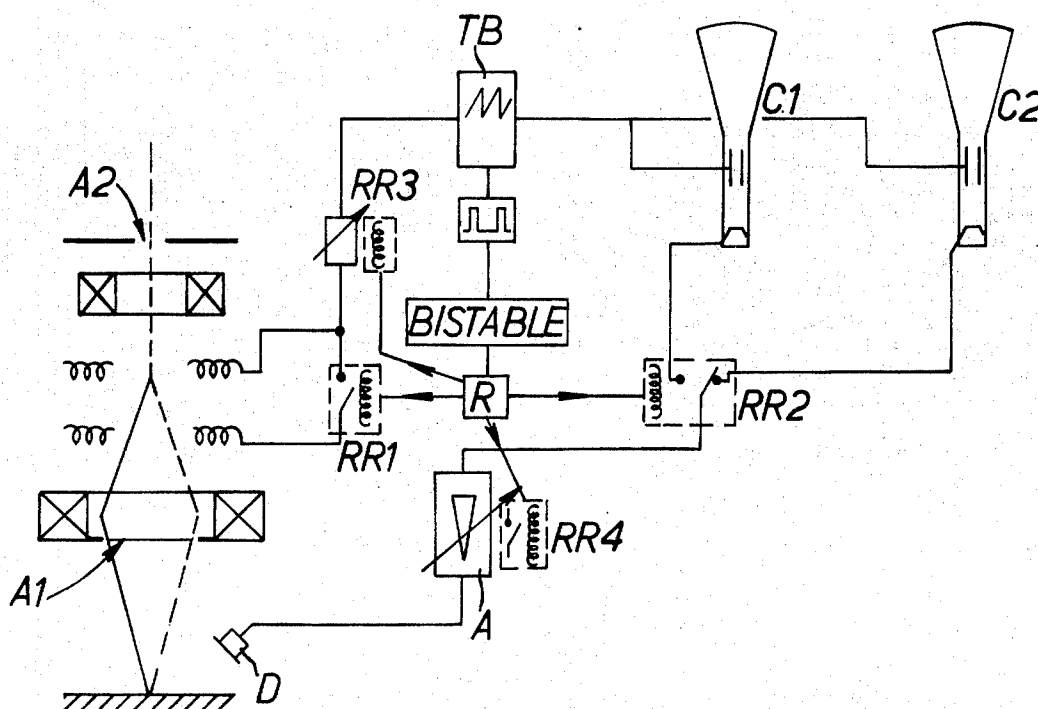
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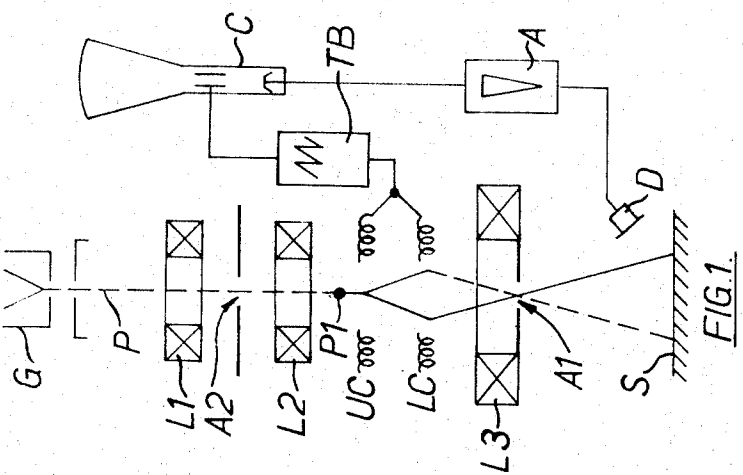
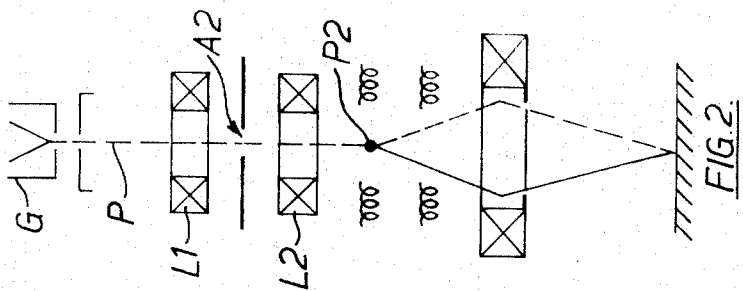
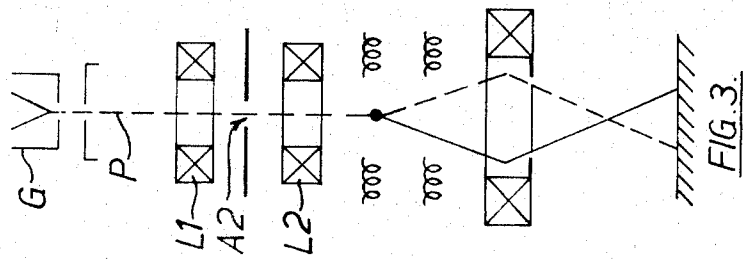
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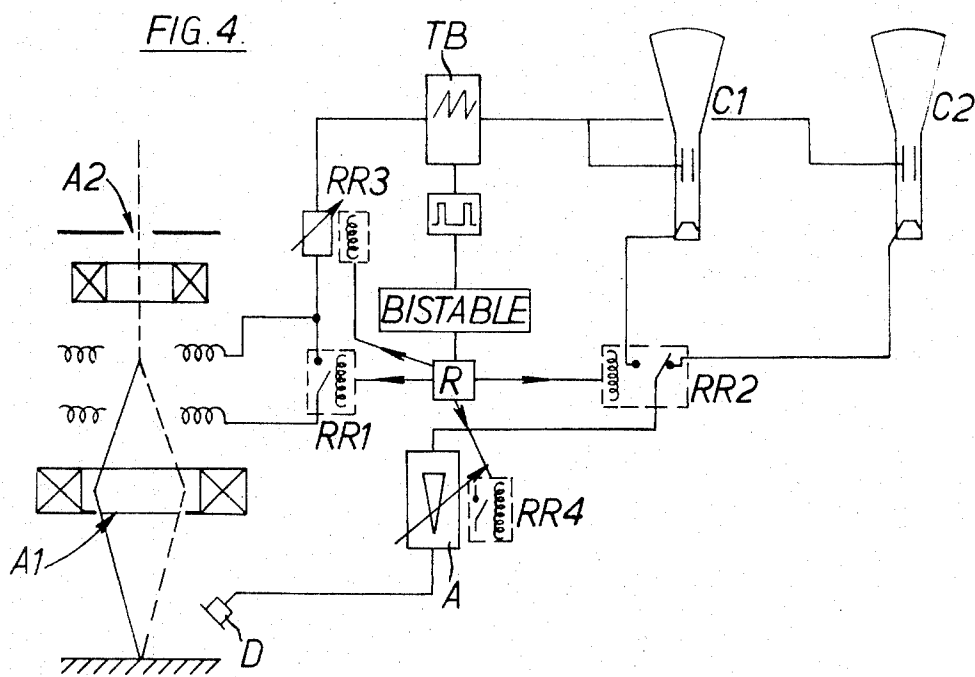
[57] **ABSTRACT**

In a scanning electron beam instrument also capable of being used to exhibit pseudo-Kikuchi (electron channelling) effects by causing the electron beam to rock angularly or spirally about a substantially fixed point on a specimen surface the electron beam is switched rapidly between the rocking (electron channelling) mode and the linear scanning (micrograph) mode to allow the simultaneous display of information derived from both modes.

8 Claims, 4 Drawing Figures







ELECTRON MICROSCOPES AND MICRO-ANALYSERS

The invention relates to scanning electron microscopes and X-ray micro-analysers in which a finely focussed beam or probe of electrons is caused to impinge on a specimen to be examined and is caused to scan a region of the specimen, while an electrical signal derived from the resultant effect on the specimen, for example from a detector of the emitted secondary electrons, back-scattered primary electrons, X-rays, or from the specimen current is used to control the brightness of the trace on the screen of a two-dimensional recorder, in particular a cathode-ray tube, which is scanned in synchronism with the scanning of the primary electron beam. Thus there appears on the screen of the cathode-ray tube an image of the scanned region of the specimen surface in terms of the effect on the specimen of the primary beam in producing secondary or back-scattered electrons, X-rays or specimen current.

Where the primary beam scans a small area of the specimen, for example 300 micrometres square, in a two-dimensional raster, the overall magnification of the microscope is the ratio of the dimensions of the image on the screen on the cathode-ray tube to the dimensions of the scanning raster. It is well-known to display two images on two cathode-ray tube screens simultaneously, for example one displaying the image derived from a detector of the X-rays, the other displaying an image derived from the secondary electrons. It has also been proposed in U.S. Pat. Specification No. 3,502,870, based on Japanese Application 42/42,790 and 42/42,792 to switch the scanning system acting on the primary beam, rapidly between two different amplitude levels, so that alternate small magnification and large magnification images are produced in rapid succession and they are displayed side by side on the screens of two cathode ray tubes, or on different halves of one screen. Thus one image shows a relatively large area of the specimen surface at low magnification, and the other image shows at much greater magnification a selected region within that area. In U.S. Pat. Specification No. 3,235,727 it has been proposed, in a scanning X-ray micro-analyser, to display simultaneously a two-dimensional image and an image from a slow line scan along a selected path on the specimen surface within the scanned area. Again this is achieved solely by control of the deflection circuits that control the scanning of the primary electron beam. Both in this case and in the case of the other U.S. Patent mentioned above, the means for controlling the formation and focussing of the primary electron beam are undisturbed.

In recent years it has been found by D.G. Coates (Phil. Mag. No. 16, page 1179, 1967) and others that so-called electron channelling effects are observable when a finely focussed electron beam is caused to impinge on the surface of a crystalline specimen at varying angles of incidence and the resulting back-scattered electrons are detected. This effect is analogous to the Kikuchi effect observed in transmission electron microscopes and has been called a pseudo-Kikuchi effect. It has been proposed to observe this effect by rocking the specimen about two orthogonal axes intersecting the axis of a fixed electron beam at the point of impact. However better results are obtained more effectively by Schulson and van Essen (J. Sci. Instruments 1969)

by leaving the specimen fixed and causing the beam to rock rhythmically about the point of impact. If the beam is rocked in two mutually perpendicular angular directions or in a conical path to sweep out a solid angle centred on the point of impact, and if the resulting back-scattered electron signal is used to control the brightness of the trace on a cathode-ray tube screen of which the beam is deflected in two perpendicular linear directions, or in a spiral scan, in synchronism with the angular deflection of primary beam, a two-dimensional pattern is obtained, displaying the electron channelling or pseudo-Kikuchi effect, and information about the crystal structure of the specimen at the point of impact can be deduced from this pattern.

It is possible to produce the required rocking primary beam by modification of a known scanning electron microscope one such arrangement described by van Essen, Schulson and Donaghay in *Nature*, Vol 225, No. 5235 pages 847-848. However a problem in the practical use of such an instrument is to identify the point of impact, or to select a particular point of impact for examination within a given region of the specimen surface.

According to the invention we now propose, in a scanning electron probe instrument, to switch the mode of operation of the primary electron beam rapidly back and forth between the normal two-dimensional raster scanning mode and the rocking, channelling-effect, mode and to display simultaneously and side by side (or even superimposed) the two images derived from these two modes. The switching may be done at any suitable frequency and most conveniently it is at the frame frequency, so that one complete two-dimensional frame is produced, to give an image of a selected area of the specimen, and this is followed by one complete angular scan with the beam sweeping out a solid angle centered on a fixed point of impact within that area.

It will be appreciated that in contrast to known twin-image displays, this is not merely a matter of altering the scanning; it is necessary to alter the mode of the primary beam. During one frame it behaves as a normal scanning electron microscope beam, then during the next frame it alters its behaviour and instead rocks about the point of contact on the specimen. This involves switching the current in at least one beam-deflecting or focussing coil, as will become apparent from the description below of two preferred embodiments.

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

FIG. 1 is a diagrammatic representation of a normal scanning electron microscope operating in the micrograph mode;

FIG. 2 shows the primary beam portion of the microscope of FIG. 1 operating in the beam-rocking or electron channelling effect mode;

FIG. 3 shows the instrument of FIG. 2 operating in a modified micrograph mode; and

FIG. 4 is a block circuit diagram showing a circuit for switching between the modes of FIGS. 1 and 2 or 2 and 3.

Referring first to FIG. 1, the normal scanning electron microscope comprises an electron gun G from which the emerging electrons are formed into a finely focussed beam or probe P by means of a system of elec-

tromagnetic or electrostatic lenses comprising, in the example shown, three electromagnetic lenses L1, L2 and L3. The lenses L1 and L2 form an image of the source at a point P1 and this is demagnified by the lens L3 to form a fine spot, only one or two micrometres in diameter, at the surface of the specimen. The beam impinges on the surface of a specimen S and the back-scattered electrons or secondary electrons are detected by a detector D which produces an electric signal dependent on their quantity. Alternatively the electron beam current flowing to the specimen itself is measured. An X-ray micro-analyser is similar except that the detector D is replaced by a detector of X-rays.

Two pairs of upper and lower scanning coils, of which the pair acting on only one plane are visible in FIG. 1 at UC and LC, cause the beam to scan over an area of the specimen in the manner of a television raster, this area being for example of 300 micrometres square, scanned in 300 lines, in a frame period which may last anything from a fraction of a second to several minutes (in the case of an X-ray micro-analyser). The purpose of using two pairs of coils UC and LC is to allow the beam, as it scans back and forth, to pass always through the small exit aperture A1 of the final lens L3. This aperture must be small to keep down the spherical aberration, and the short focal length allows insufficient room to place scanning coils below this aperture.

The deflection current for the coils UC and LC in each scanning direction is provided by a sawtooth waveform timebase generator TB. It will be understood that there will be one such generator for the frame scan and a second (not shown) for the line scan in a perpendicular direction. These generators also control the deflection in corresponding planes in a cathode-ray tube C, in which the brightness of the trace is controlled by the signal from the detector D. Thus there is produced on the screen of the tube C an image of the scanned region in terms of the secondary electrons, specimen current, X-ray signal or other effect.

To display the electron-channelling effect it has already been proposed to modify such an instrument by switching off the lower scanning coils LC, adjusting the lens current in the lenses L1 and L2 to shift the image of the electron source to a point P2 (FIG. 2) in the plane of the upper scanning coils UC and adjusting the current in the lens L3 as well so that the demagnified image of the point P2 is still at the specimen surface. Then when the beam is deflected away from the axis of the instrument (which is also the axis of the lens L3) by the coils UC it is refracted back onto the axis by the lens L3, so that the lens, as well as forming a focussing lens, also takes part in the scanning. Neglecting spherical and chromatic aberrations, the overall result is that the beam rocks back and forth about its point of impact on the specimen, as shown in FIG. 2. This forms the subject of British Patent Application No. 2829/70 and 32059/70 (cognate) and the corresponding U.S. Pat. Application No. 108,408 of von Essen et al now U.S. Pat. No. 3,702,398 German P 21 02 616.4 and Japanese 1528/71. To limit the angular divergence of the beam an aperture A1 is inserted above the scanning coils.

It will be understood that in the mode illustrated in FIG. 2 the beam will sweep out an angular raster over a square-section solid angle and the pattern produced on the screen of the cathode-ray tube C will display the

effects, on the secondary electron emission or other detected effect, of varying the angle of incidence of the beam on a given fixed spot of the specimen surface. In a modification described in the above-mentioned earlier application the angular scan is done conically rather than in a rectangular raster, for reasons connected with the correction of aberrations, and the display on the screen of the tube C can correspondingly be spiral. The total apex angle of the cone may be between 10° and 20°.

The present invention lies in switching rapidly back and forth between the micrograph mode, for example as shown in FIG. 1, and the electron-channelling mode, such as in FIG. 2, sufficiently rapidly to be able to display two continuous or apparently continuous images simultaneously on two screens. To make it simpler to switch between the two modes we preferably arrange that the first image is formed at the point P2 all the time, i.e., in the micrograph mode as well, and then the currents in the lenses L1 and L2 do not need to be altered. It is still necessary to switch the lower scanning coils LC on and off, and also to alter the value of the deflection current fed to these coils, as the angular deflection has to be much higher in the rocking mode than in the micrograph mode. The gain of the amplifier A of the signal from the detector may need to be changed. Also, of course it is necessary (unless one wants both images superimposed on one screen) to switch the output back and forth from one tube to the other.

A suitable circuit for doing all this is shown in block form in FIG. 4. There are two cathode-ray tubes C1 and C2. Although it would be possible, if desired, to switch between modes at the line scanning frequency, this switching is preferably done at frame frequency, so that a complete frame is scanned in one mode before switching to the other. If necessary, long-persistence screens may be used on the cathode-ray tubes to ensure maintenance of the images. A train of pulses from the flyback of the frame timebase generator TB acts to change over a bistable circuit B which, through a relay R if necessary, acts on reed relays RR1, RR2, RR3 and RR4 to switch on and off scanning coils LC, to direct the output of the detector D to the appropriate cathode-ray tube C1 or C2, to alter the scanning deflection current, and to alter the gain of the amplifier A. The aperture A1 remains in place but is large enough to allow the rocking mode of operation, and the resulting increased spherical aberration in the micrograph mode is accepted. The aperture A2 also remains in place in both modes.

Because of the aberrations mentioned above the electron beam will not, in the rocking mode, examine a spot of only the diameter of the ideally focussed probe, which is one or two micrometres; in practice the spot examined will be between 5 and 10 micrometres across. However, the electron channelling effect is adequately displayed and, by virtue of the fact that the micrograph; i.e., the two-dimensional image of a region of the specimen, and the electron-channelling pattern of a selected spot within that region are simultaneously displayed it is possible without difficulty to correlate the appearance and crystal structure. Moreover, as the user transverses the specimen table to examine a larger region of the specimen, for example searching for crystalline domains of a particular nature, the electron-channelling information in respect of the point which,

at any given instant, is at the centre of the field of view is being continuously presented to him. This reduces very greatly the risk of overlooking a domain of particular interest.

Normally the electron-channelling information will be that in respect of the point at the centre of the micrograph picture. However it will be understood that, by the provision of manually variable biasing controls which are switched into and out of the time base generator circuits in synchronism with the other switching, it would be possible to shift the electron-channelling spot at will to coincide with any desired region in the micrograph picture.

Although we have described above an arrangement in which the primary beam is switched over between the condition of FIG. 2 and substantially that of FIG. 1 an alternative arrangement now to be described with reference to FIG. 3 is simpler to put into practice and is in fact preferred. FIG. 3 shows the effect of taking the arrangement of FIG. 2 and, without altering anything else, increasing the current in the lens L3. This brings the point about which the beam rocks upwards above the specimen, and so at the specimen surface the beam does now scan a finite area. This effectively results in a straightforward micrograph mode of operation, equivalent to that of FIG. 1. It is true that not only the nodal point of the scanning but also the focus (or rather the circle of least confusion) of the lens is now no longer at the specimen surface, and so the lens is now operating in a partially de-focussed condition. However, although there is therefore some loss of picture quality as compared with the orthodox micrograph mode of FIG. 1, this is acceptable for the purpose of the invention, which is primarily to give the user a simultaneous general micrograph picture of the region in which he is examining the electron-channelling effects, and this loss is outweighed by the advantage of the FIG. 3 arrangement in simplicity of the changing over operation. The circuit for achieving the changeover can be like that of FIG. 4 except that fewer relays are needed. For example the relay RR1 could control the switching in and out of the additional current to the lens L3, and the relay RR2 could switch the detector signal between the two cathode-ray tubes C1 and C2. The switching will again normally be at frame frequency, so that there are alternate complete frames in the two modes, and the speed is limited only by the response time of the relays (which could be replaced by solidstate circuits if necessary) and by restrictions imposed by the inductance of the winding of the lens L3. In a typical case the current in the lens L3 for the electron-channelling mode of FIG. 2 is 600 milliamperes and has to be increased by 30 milliamperes to produce a micrograph scan, in the manner of FIG. 3, of about 300 micrometres amplitude, where the rocking scan is through a total angle of 10°.

A similar result to that of FIG. 3 could be achieved by reducing the current in the lens L3 instead of increasing it, and then the nodal point could fall below the specimen surface. However this is less satisfactory as the resulting micrograph image would then be a reversed one, in both directions, so effectively it could appear to have been turned through 180° about the electron-optical axis as compared with the orthodox micrograph image obtained by the system of FIG. 1, and this could be confusing.

It will be understood that, both in the version switching between the FIG. 2 mode and the FIG. 1 mode and in that switching between the FIG. 2 mode and the FIG. 3 mode, it would be possible to use spiral scanning instead of cartesian scanning, in fact the instrument could be provided with switches allowing selection of either form of scanning at will. A switch can also be provided to allow the micrograph mode or the channelling-effect mode of scanning to be held at will, i.e. to halt the switching-over sequence.

Although we have shown a single detector D used for both modes, it will be understood that there may be separate detectors, with separate amplifier channels leading to the respective cathode ray tubes. They may be of different form, for example one responding to back-scattered electrons and the other to some other effect. There may be additional detectors, for example one responding to X-rays, to display an image of the X-ray response, at a particular wavelength, of the scanned region.

We claim:

1. A scanning electron beam instrument comprising means for forming a beam of electrons and causing said beam to impinge on a suitably placed specimen surface in the path thereof, at least one device for detecting the effect on said specimen surface of the impact thereon of said beam, means for displaying the resulting information, first scanning control means acting on said electron beam and serving to deflect said beam laterally so as to scan linearly a finite region of said specimen surface, second scanning control means acting on said electron beam and serving to deflect said beam angularly about a fixed point on said specimen surface, whereby said beam rocks about said point, and repetitively operating switching means acting on said first and second scanning control means to make each of said control means operative in turn, said switching means acting also on said displaying means whereby information from said detecting device resulting from said linear scanning and said rocking are simultaneously displayed.

2. The instrument set forth in claim 1 including two of said detecting devices and two respective displaying means.

3. The instrument set forth in claim 1 wherein said switching means include means alternately directing information from a single said detecting device to each of two separate said displaying means.

4. The instrument set forth in claim 1 wherein said first and second scanning control means include some elements common to both means.

5. The instrument set forth in claim 4 wherein said first scanning control means comprise a time base generator and associated first and second axially spaced deflecting coils, and said second scanning control means comprise said time base generator and first deflecting coils and a focussing electromagnetic lens acting simultaneously as deflection means.

6. The instrument set forth in claim 5 wherein said switching means comprise firstly means for switching on and off said second deflecting coils and secondly means for altering the power of said first deflecting coils.

7. The instrument set forth in claim 4 wherein said first and second scanning control means comprise deflection means common to both control means, and means for acting on a part of said deflecting means to

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operate said part at two different levels, one in which said beam rocks about a point on said specimen surface, and a second in which said beam rocks about a point displaced along the axis of said beam from said specimen surface.

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8. The instrument set forth in claim 7 wherein said part of said deflecting means comprise an electromagnetic lens serving also as focussing means for said beam.

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