United States Patent [19]

Drayton et al.

[11] **3,795,808**

[45] **Mar. 5, 1974**

[54] **ELECTRON MICROSCOPES**

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[22] Filed: **May 17, 1972**

[21] Appl. No.: **254,133**

[30] **Foreign Application Priority Data**

May 18, 1971 Great Britain 15522/71

[52] **U.S. Cl.** **250/310,** 250/311

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

[58] **Field of Search** ... 250/49.5 A, 49.5 B, 49.5 PE, 250/310, 311

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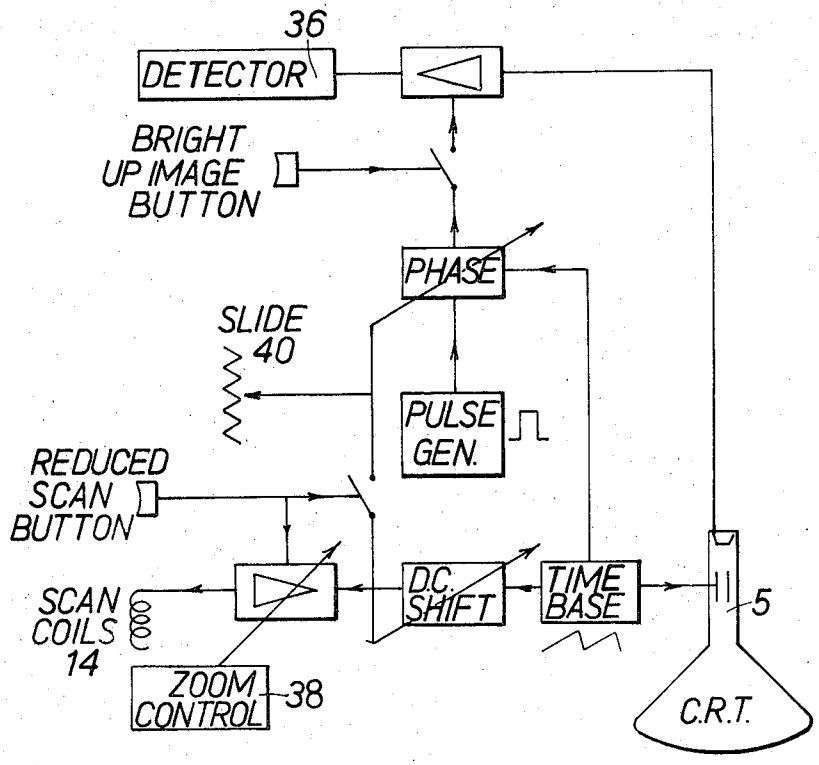
Primary Examiner—James W. Lawrence
Assistant Examiner—B. C. Anderson
Attorney, Agent, or Firm—Scrivener Parker Scrivener and Clarke

[57] **ABSTRACT**

In a scanning electron probe instrument such as a scanning electron microscope or X-ray micro-analyser the two-dimensional display of the image can have a manually controlled bright-up region or spot and the direct current signals which movement of this region generates can be switched in at will to the primary beam deflection to shift the scanning to the selected region without mechanically shifting the specimen; then by reducing the scanning amplitude automatically this region is magnified to fill the screen.

4 Claims, 11 Drawing Figures



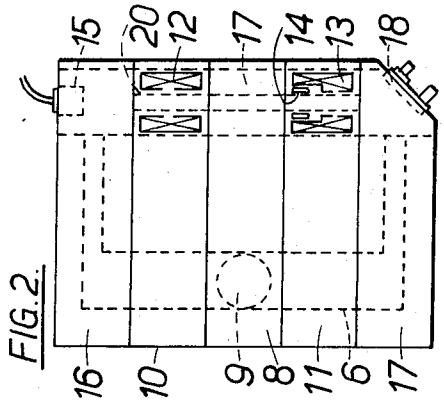


FIG.2.

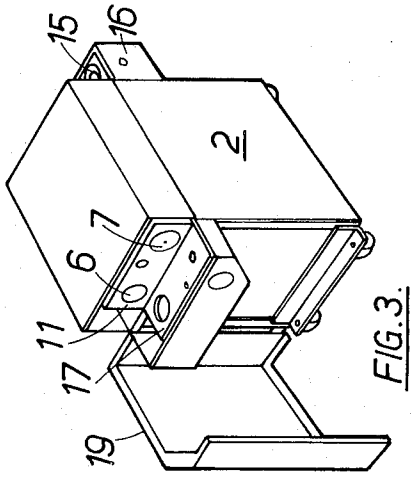


FIG.3.

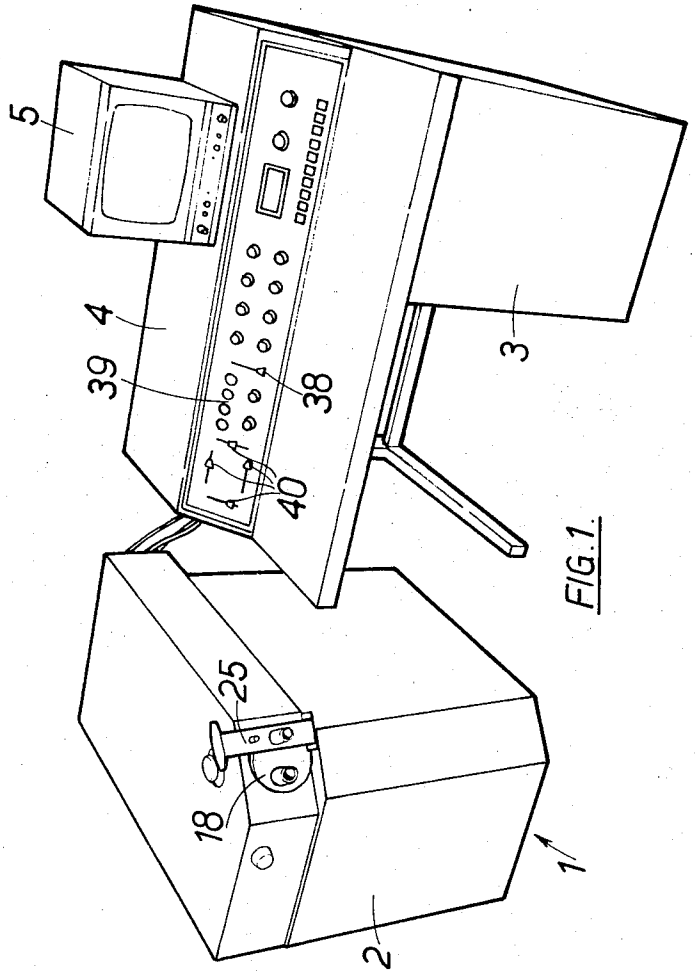
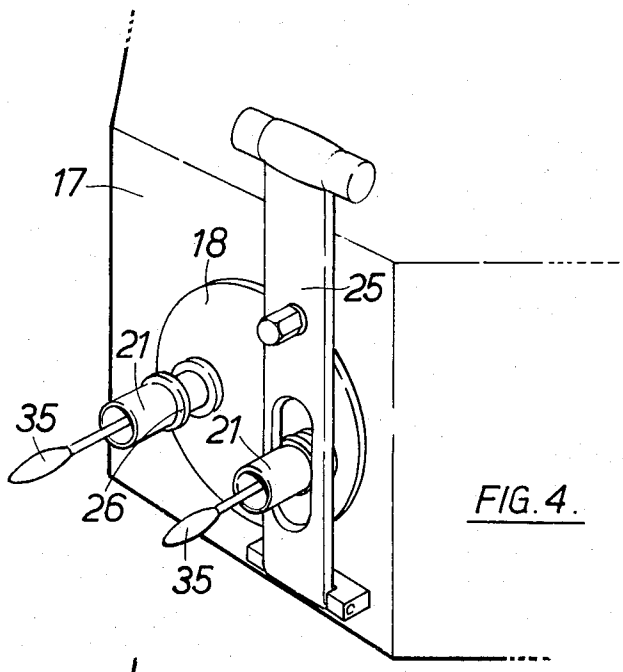


FIG.1.



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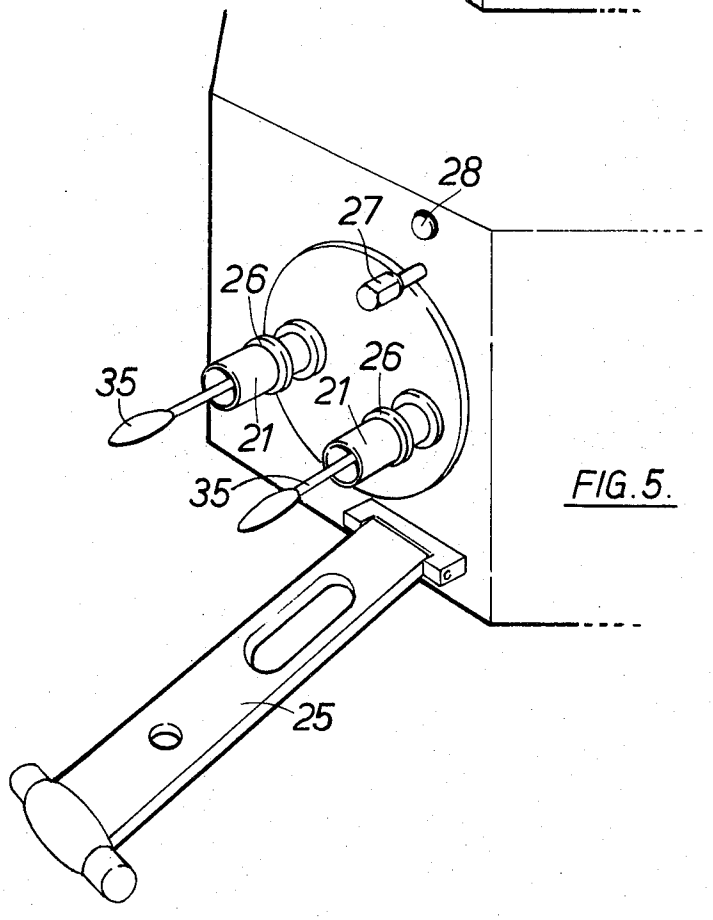

FIG. 5.

FIG. 6.

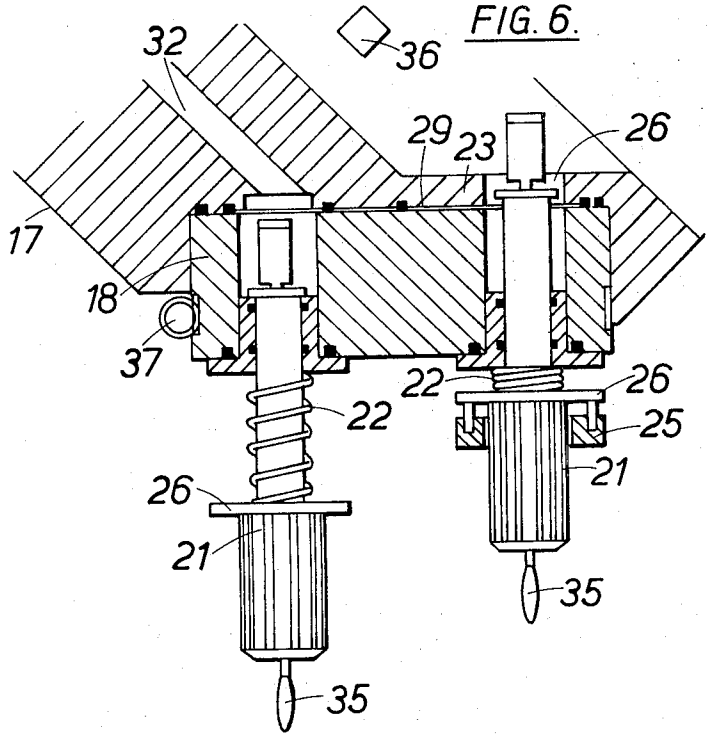
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FIG. 7.

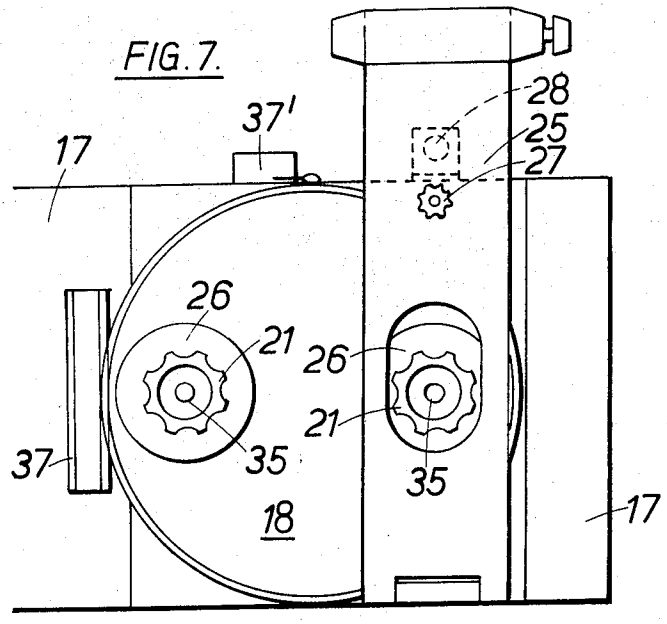
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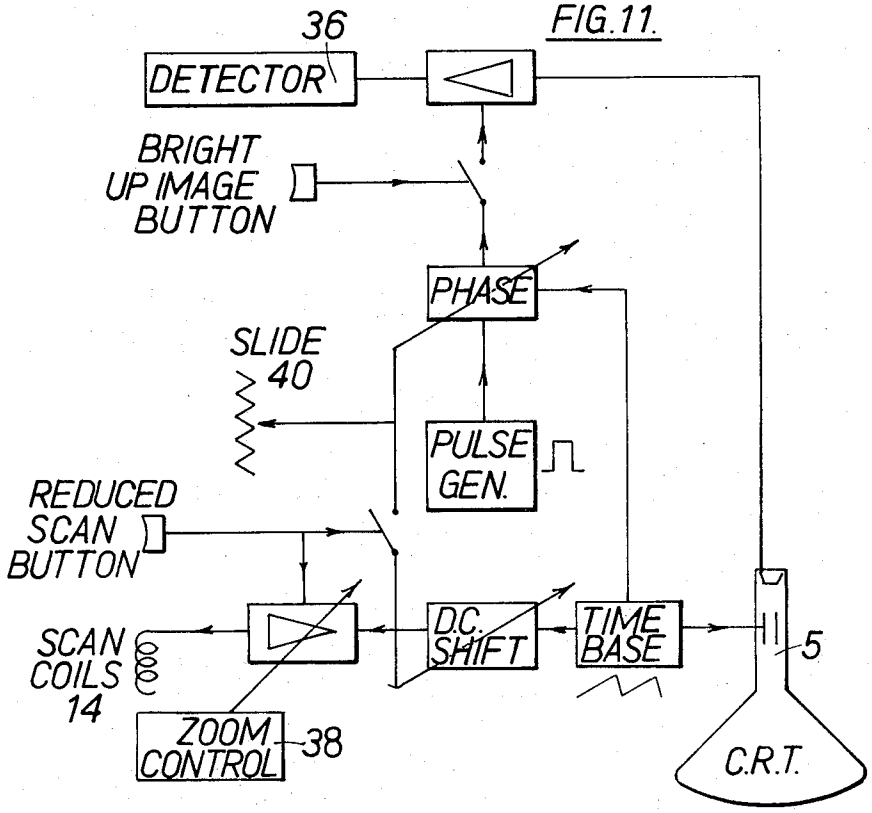
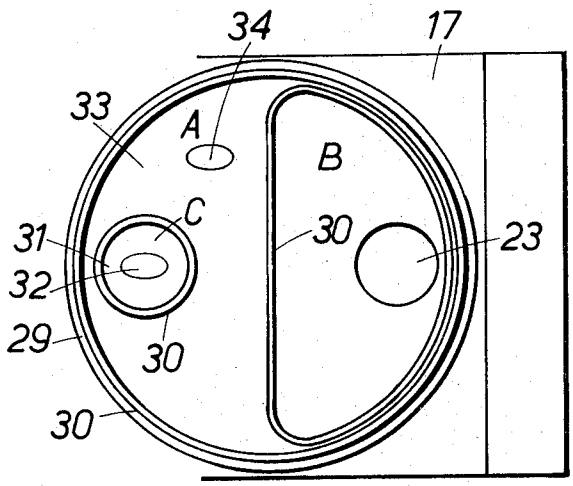
FIG.11.


36
DETECTOR
BRIGHT UP IMAGE BUTTON
PHASE
SLIDE 40
PULSE GEN.
REDUCED SCAN BUTTON
SCAN COILS 14
D.C. SHIFT
TIME BASE
5
C.R.T.
ZOOM CONTROL
38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A
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FIG.8.

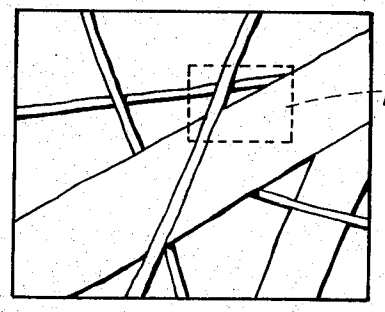

FIG.9.

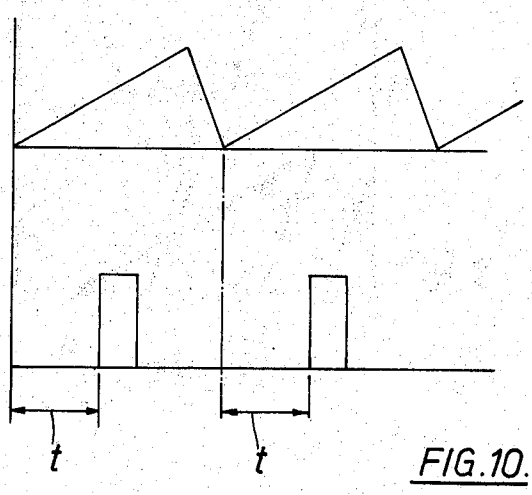

FIG.10.

ELECTRON MICROSCOPES

This invention relates to scanning electron microscopes and related electron beam instruments, in which a fine beam or so-called probe of electrons is focussed onto the surface of a specimen and is caused to scan a region of that surface, while the electron radiation or other radiation (for example X-rays) emanating from the point of impact on the specimen surface, or the electron current flowing to or from the specimen, is detected and used to modulate a recorder (such as a cathode ray tube) controlled in synchronism with the scanning movement.

Such instruments are now well-known, and various different models are available on the market, with various special features and with extra items of equipment available as accessories. However they are all, almost without exception, relatively sophisticated and expensive instruments, requiring skilled use and laboratory conditions. Particularly for routine laboratory checking of production articles, attempts have been made to simplify the changing of specimens, by the use of linearly moving or rotary specimen stages, but the changing of specimens has generally been an operation taking several minutes, involving the opening and closing or airlocks then followed by renewed pumping-out of the microscope column to restore the high vacuum, before the instrument is ready for use again.

Also in known instruments it is usual to be able to vary the magnification, either continuously or in steps, to enable a substantial area of the specimen surface (for example 1mm square) to be observed and then a selected region of interest within that area can be examined more closely at a larger magnification; however, for this purpose it is necessary to shift the specimen until the selected region is in the centre of the scanned area, and the originally viewed area is lost.

An aim of the present invention is to provide a scanning electron probe instrument, in particular a scanning electron microscope, which is low in cost and particularly simple to use, such as to be comparable with a conventional high quality optical microscope in outlay and ease of operation, whilst offering the known substantial advantages (such as high resolution and a very greatly increased depth of field) of electron microscopes over optical microscopes. In particular it is an aim of the invention to simplify and speed up the operation of specimen changing and another aim is to improve the ease with which a selected region of the scanned area can be examined in detail.

According to the invention there is provision in the scanning means to allow a selected region within a larger scanned area to be identified, for example by being displayed at increased brightness, and then for that region, regardless of its position in relation to the optical axis of the instrument, or in relation to the centre of the overall scanned area, to be scanned in detail, to fill the display screen, without shifting of the specimen. Thus after examining that region one can revert straight away to displaying the former area. Then another small region of the area can, if desired be examined in detail, and another, all the time without losing the overall picture.

Other features and advantages of the invention will be revealed by the following description of a preferred embodiment of the invention by way of example, taken

in conjunction with the accompanying drawings, in which:

FIG. 1 is a general view of the instrument, complete with display monitor;

FIG. 2 is a plan view of the microscope column assembly;

FIG. 3 shows the electron beam column opened up for cleaning or other attention;

FIG. 4 shows an external view of the specimen stage with the instrument in use;

FIG. 5 shows the specimen stage of FIG. 3 with the handle swung back to allow a specimen change;

FIG. 6 is a horizontal section through the specimen stage region of the instrument;

FIG. 7 is a view looking along the axis of rotation of the specimen table;

FIG. 8 shows the base of the recess that receives the table, to illustrate the positions of the different seals;

FIG. 9 illustrates diagrammatically a typical image with the 'bright-up' raster superimposed;

FIG. 10 is a set of graphs showing the waveforms necessary to achieve the 'bright-up';

FIG. 11 is a block circuit diagram of assistance in understanding the manner of introducing the 'bright-up' feature.

Referring first to FIG. 1 the instrument comprises basically a unit 1 comprising a base portion 2 in which is housed all the vacuum pumping equipment for the microscope column, with the column itself resting on top, and a unit 3 in the form of a console containing all the electronic circuits and having a desk portion 4 with the control knobs and dials. A standard 625-line 50 frames/second or 60 frames/second TV-type monitor 5, meeting CC1R standards is used to display the image of the scanned area and can be placed in any convenient position, such as on the console unit 3 as shown.

The electron microscope column has its electron-optical axis horizontal and is made up of five machined basically rectangular aluminium alloy blocks placed face to face. Each block has two main holes in it and placed so that when the five blocks are assembled together there are formed two spaced horizontal mutually parallel bores 6 and 7 (FIG. 2), one forming the microscope column and the other forming a vacuum manifold.

The centre block 8 is secured rigidly to the base portion 2 by four bolts and has an opening 9 in its lower face communicating with the vacuum pumping equipment (not shown). The two adjacent blocks 10 and 11 are each secured by bolts or studs to the centre block and one carries an electromagnetic condenser lens 12, whilst the other carries an electromagnetic final or objective lens 13, as well as vertical and horizontal scanning coils 14.

An electron gun assembly 15 is housed in an end block 16 which overhangs the base portion 2 and which is hinged along its lower edge to the adjacent block 10. This allows the block to be swung down, as shown in FIG. 3, to give immediate access to the gun for cleaning and in particular for replacement of the filament.

Similarly at the other end of the unit 1 a fifth block 17 carries a specimen stage 18 in the form of a rotatable disc mounted at 45° to the electron-optical axis in a face machined at the appropriate angle, and this block 17 can be hinged down for access to the specimen stage, after a door 19 in the base portion has been swung back as shown in FIG. 3.

A non-magnetic tube **20** extends down the centre of the bore **7** to define the actual microscope column. This tube may be of composite construction and the portion in the region of the scanning coils **14** is preferably of high-resistivity material such as a nickel alloy to avoid eddy current losses. As will be seen from FIG. **2** the vacuum manifold formed by the other bore **6** communicates with the pumping equipment through the opening **9** and communicates with the gun region in the one end block **16** and the specimen region in the other end block **17,** but the remainder of the bore **7** outside the tube **20,** in the centre three blocks, is sealed off from the vacuum and so the lenses **12** and **13** and the scanning coils **14** can be at atmospheric pressure.

It will be understood that the various blocks are sealed together in a vacuum-tight manner, for example by O-rings (not shown) around the bores and if necessary by the provision of a locating spigot on the one block-co-operating with a recess in the adjacent block. By the use of blocks machined from solid material we obtain an exceptionally rigid structure and are therefore able to mount the whole electron microscope with its axis horizontal, which would not be possible in most orthodox constructions, because of the deflection problems that would arise. In a known manner the filament of the electron gun assembly is mounted in gimbals to allow it to be adjusted so that its apex is exactly on the electron-optical axis, despite thermal distortion.

Referring now to FIG. **4** to **8,** the specimen table **18** is in the form of a rotatable disc of PTFE received in a recess machined in the oblique face of the block **17** and sealed into it by O-rings. Its outer face is open to atmosphere and it has two openings at diametrically spaced points to receive two specimen stages **21** with their axes parallel to its axis of rotation. The left-hand position is that in which the holder can be withdrawn by hand and replaced by a fresh one and the right-hand position is the operative position. A spring **22** (FIG. **6**) around each stage urges the stage into a partially retracted position in which its operative end clears an internal wall **23** in the block **17** to allow rotation of the disc **18.** To advance the specimen to the viewing position, in which it protrudes through an aperture **24** in the wall, as shown in FIG. **6,** a handle **25** is swung up manually from the position shown in FIG. **5** to that shown in FIG. **4,** engaging a collar **26** on the specimen stage and urging it inwards against the spring loading. The handle is retained in place by a detent **27** which can moreover be screwed in and out by hand to alter the axial position of the specimen stage, and hence of the specimen itself in the microscope column. As well as mechanically locking the specimen holder against inadvertent movement while in the advanced position, the handle **25** simultaneously (as an added safety precaution) covers a push-button **28** (FIG. **5**) used to initiate rotation of the disc.

That face **29** (FIG. **6**) of the interior of the recess in the block *k*17 which mates with the inner face of the disc is divided by O-rings **30** (FIG. **8**) into three regions; a first region **31,** to which the stage **21** is exposed in the specimen-changing position is open to atmosphere when the stage is removed and replaced by another. But when a stage has been placed in the disc **18** at this position the user can press a button to connect the region through a passage **32** (FIG. **6**) to the pumping equipment, which pumps the region down (so-called "roughing-down") to a partial vacuum of, for example 10^{-2} torr (mm of Hg). This can be taking place as soon as a specimen stage, with a new specimen in it, has been placed in the disc and while the specimen at the diametrically opposite position is still undergoing examination.

A second region **33** of the face **29** of the recess is permanently connected through a passage **34** to the vacuum pumping equipment, and is capable of being evacuated down to the same vacuum level as the interior of the microscope column. The third region is that formed by the interior of the microscope column and is maintained at a vacuum of 10^{-6} torr.

Each specimen stage incorporates a central 'joystick' lever **35** pivoted within the stage by a stiff gas-tight ball-type universal joint and carrying the specimen on its free inner end. The outer end is formed as a handle, allowing the specimen to move laterally in any direction. The whole stage **21** can also be rotated about its own axis to rotate the specimen while it is under examination. With the axis of the stage intersecting the electron-optical axis, this means that rotation occurs about the electron-optical axis, regardless of the angular position of the lever **35** within the stage **21,** and the specimen is thus rotated about the centre of the field of view without upsetting the choice of the region selected, by the lever **35,** for viewing.

The block **17** contains an electron detector **36** of known kind, for example a scintillator, picking up secondary electrons emitted by the specimen under the impact of the electron beam. There may also be provision for detecting the X-rays that are emitted and because the specimen is inclined at 45° to the electron beam it is possible to use a high take-off angle up to 50°. In addition provision may be made, if desired, for measuring the specimen current in a known manner.

When it is desired to change the specimen, assuming the new specimen now to be examined has already been inserted at the left-hand position and has been pumped down to 10^{-2} torr, the handle **25** is swung down, allowing the specimen that has just been examined to withdraw through the wall **23.** The button **28** is now exposed and is pressed by the user to start an electric motor (not shown) which drives a worm gear **37** (FIG. **7**) to index the disc **18** round in a clockwise direction through 180°, the movement being halted automatically by a microswitch **37'**. This movement is arranged to take about 35 seconds, and during the course of it the specimen moves from the region **31** to the region **33,** where it is further evacuated and, although the small quantity of air carried into the region **33** with the specimen stage reduced the high vacuum in that region, the stage is in practice at a vacuum of about 10^{-4} torr before it reaches the region of the interior of the column. Thus by the time the specimen reaches the column it is already at a relatively high vacuum and only a negligible quantity of air is admitted to the specimen chamber at each specimen change. This quantity is quickly removed by the continuous pumping that is being performed on the column and so the specimen is ready for immediate examination.

Meanwhile the specimen that has just been examined is now in the changing position and can be removed.

It will be understood that there may be the usual interlocks and warning lights or buzzers to prevent incorrect use, for example over-hasty specimen changing before the required vacuum levels have been reached.

In a modification there could be more than one intermediate region like the region **33.** Also it could be arranged that the indexing movement of the disc **18** could be intermittent, pausing for a specified time, or until a specified vacuum level has been reached, with the specimen at the or each intermediate position.

By the arrangement described it is possible to change a specimen completely in only about 40 seconds, in contrast to known electron microscopes which require anything from 3 to 10 minutes. It is important to note that a second specimen to be viewed next is already being partially pumped down at the changing station even while one specimen is being viewed.

We will now described what we call the 'bright-up' feature with reference to FIGS. **9, 10** and **11.** FIG. **10** shows a typical region of a specimen as displayed on the screen of the cathode ray tube at relatively low magnification. It will be understood that the horizontal and vertical (X and Y) time base deflection systems of the cathode ray tube are synchronised with those of the primary electron beam and the brightness of the c.r.t. trace is controlled by the signal from the detector **36.** The magnification is controlled by varying the amplitudes of the saw-tooth deflection signals fed to the coils **14,** and it is important to observe that the smaller these signals are, the greater is the magnification. In the preferred embodiment the magnification is continuously variable in each of two ranges by a 'zoom' control **38** on the desk **4,** and the actual magnification is indicated by a digital display **39.** The accelerating voltage applied to the electron beam is variable in steps from 1KV to 25KV and as this affects the magnification the digital display is automatically compensated for changes in accelerating voltage.

Depending on the magnification, the area of the specimen scanned may be anything from 10mm square (X20 magnification) down to about 20 microns (micrometres) square (X10,000 magnification). Normally one will start by inspecting a substantial area of the specimen at low magnification, selecting the area by manually shifting the specimen by the use of a joystick control. Then within this area one will see a region that deserves closer examination. Unless this region happens to be already in the centre of the displayed area, in orthodox instruments it is necessary to bring this region onto the electron-optical axis by shifting the specimen itself in the X and Y directions as required, before the magnification can be increased to allow more detailed examination of the selected region; if this were not done, then merely to increase the magnification alone (by reducing the scanning amplitudes) would send the selected region off the screen altogether. Moreover as soon as one moves the specimen, one has lost the previously scanned larger area, and cannot easily re-locate it, for example to remind one of the relationship between the selected region and the area in which it is situated.

In contrast to this the present invention allows easy selection, within a scanned area, of a particular region at a larger magnification without permanently losing the image of that area. For this purpose we superimpose on the normal brightness control of the c.r.t. trace a square-wave pulse of predetermined duration during each of a predetermined number of lines, so as to result in a small rectangular region B (FIG. **9**) appearing brighter than the rest. In the preferred embodiment this rectangular area is one quarter of the width and height of the overall image. Thus the pulse length is one quarter of the time taken to scan a single line and it is gated to occur in each of one quarter of the total number of lines. By the provision of appropriate direct current shift signals under the control of slides **40** on the desk **4** it is possible to control the phase of the pulses in relation to the line scan and the gating of the pulses in relation to the frame scan, and thereby to shift the position of the bright-up region B to any desired part of the image.

The electronic circuits required for achieving this will be readily understood by those skilled in the art. FIG. **10** shows an outline the manner in which it is achieved in the line scan, and it will be understood that the frame scan corresponds. The top line shows the saw-tooth line scan signal in relation to time. The second line shows the bright-up pulse applied to the brightness control of the cathode ray tube, which is to be superimposed on the continuously varying signal from the detector **36.** The manually operated slide varies a d.c. signal that alters the time t between the start of the line and the start of the pulse, to control the position of the bright-up region.

In normal use the bright-up region B is not present. It is introduced by pressing a button labelled 'Bright-up Image' on the control desk **4.** Then the region B is shifted by the use of the slides **40** to cover a region that appears to be of particular interest.

Then the user presses another button labelled 'Reduced Scan' and this automatically applies direct current bias signals to the scanning coils **14** (or to auxiliary d.c. shift coils, not shown) controlling the primary electron beam and the values of these bias signals are determined by the setting of the slides **40,** so that now, regardless of the overall position of the specimen in relation to the true electron optical axis of the instrument, the scan becomes centered on the region B. At the same time the scanning amplitude is reduced by a factor of four, thereby increasing the magnification by this amount, and so now the region B fills the c.r.t. screen. The zoom control **38** remains connected, and can now be used to increase the magnification still further if desired.

At any time the user can return to the original image by releasing the 'Reduced Scan' button. He can then, if he wishes, press the 'Bright-up Image' button again and use the slides **40** to select another region within this area for closer examination in the same way as before.

We are aware that it has previously been proposed to apply direct current shifts to the scanning coils of a scanning electron microscope but these have only been small and have been merely for correction purposes or to provide a fine electrical shift on top of the existing coarse mechanical shift of the specimen itself, or to align the centre of the scanned area exactly with the electron-optical axis. In contrast to this, in the present case the d.c. shift may be many times the scanning amplitude of the bright-up image.

As indicated earlier our d.c. shift signals could be applied to separate coils rather than to the existing scanning coils **14.** The important thing to observe is that the magnitudes of these shift signals are derived automatically from the positioning, by the user, of the bright-up region B in the image displayed. In a modification the bright-up region B could be in the form of a spot rather than a complete rectangle. Also its position could be controlled by a form of joystick control rather than by

separate X and Y slides. Although spots controlled by joysticks are known in themselves, these have previously only been for identifying or pointing out certain regions, not for controlling subsequent operation of the instrument.

FIG. 11 illustrates in block circuit diagram form, the relationship between the different components necessary for providing the 'bright-up' feature.

We claim:

1. A scanning electron probe instrument comprises means for generating a beam of electrons, a specimen stage adapted to receive a specimen at a position in the path of said beam, detecting means adapted to detect the effect of impact of said beam on said specimen, means for deflecting said beam laterally, a time base generator connected to said deflecting means and adapted to cause said beam to scan an area of the surface of said specimen, two-dimensional image display means, said display means being fed from said time base generator whereby to form an image synchronised with said beam, a connection between said detecting means and said display means such as to modulate said display means to produce an image of the scanned area of said specimen surface in accordance with the effect of the impact thereon of said beam, means for producing a local region on said image of different brightness from the remainder of the area of said image, said local region still being derived from the same said detector means as the remainder of said image, and differing from the remainder of said image only in the brightness thereof manually controlled means for shifting the position of said local region at will, and switchable means for shifting the main centre of deflection of said beam to a region of said specimen corresponding to said region of the image in accordance with the manually selected position of said manually controlled means.

2. The instrument set forth in claim 1 including scan-reducing means operable simultaneously with said switchable shifting means and acting on said deflecting means to reduce the area of specimen surface scanned and thereby increase effective magnification on shifting of said mean centre.

3. The instrument set forth in claim 1 wherein said local region comprises a rectangular area of similar shape to said image.

4. The instrument set forth in claim 3 wherein said display means comprise a cathode ray tube screen and said detecting means modulate the brightness of said screen, and wherein said local region is formed by a rectangular area on said screen of increased brightness in relation to the mean brightness of said image.

* * * * *