

- [54] **ELECTRON MICROSCOPE**
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[22] Filed: **Feb. 3, 1972**

[21] Appl. No.: **223,382**

Related U.S. Application Data

- [63] Continuation of Ser. No. 73,117, Sept. 17, 1970,
abandoned.

[52] U.S. Cl. **250/311, 250/307, 250/398**

[51] Int. Cl. **H01j 37/26, G01n 23/22**

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

[56] **References Cited**

UNITED STATES PATENTS

3,351,755 11/1967 Hasler 250/49.5
3,191,028 6/1965 Crewe 250/49.5

FOREIGN PATENTS OR APPLICATIONS

156,251 8/1962 U.S.S.R. 250/49.5

OTHER PUBLICATIONS

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[57] **ABSTRACT**

The application describes improved techniques for correcting an output detection signal from an electron microscope for aberrant variations in the electron beam produced by the microscope. The preferred embodiment comprises a monitor assembly for producing a reference signal proportional to the magnitude of the electron beam and a correction circuit for varying the magnitude of the detection signal in response to variations in the reference signal. The monitor assembly may comprise a diverting assembly for diverting a portion of the electron beam from its normal path to produce a flow of diverted electrons and a transducer assembly for producing a signal proportional to the number of diverted electrons so that a reference signal is produced. The correction circuit may comprise logarithmic amplifiers, a subtraction circuit, and an anti-logarithmic amplifier for producing a signal which corresponds to the ratio of the detection signal and the reference signal. This corrected signal may be used to drive a cathode ray tube display of the specimen.

4 Claims, 4 Drawing Figures

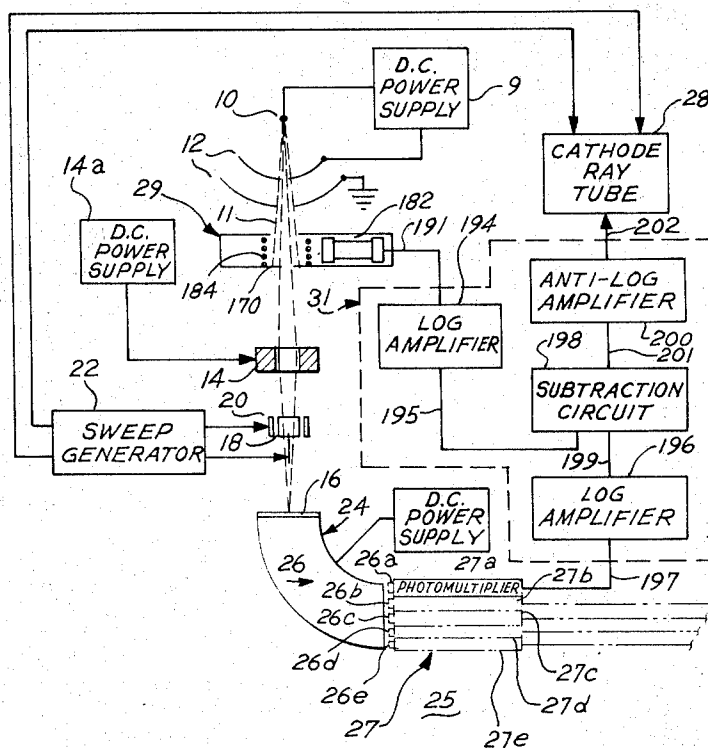


Fig. 1

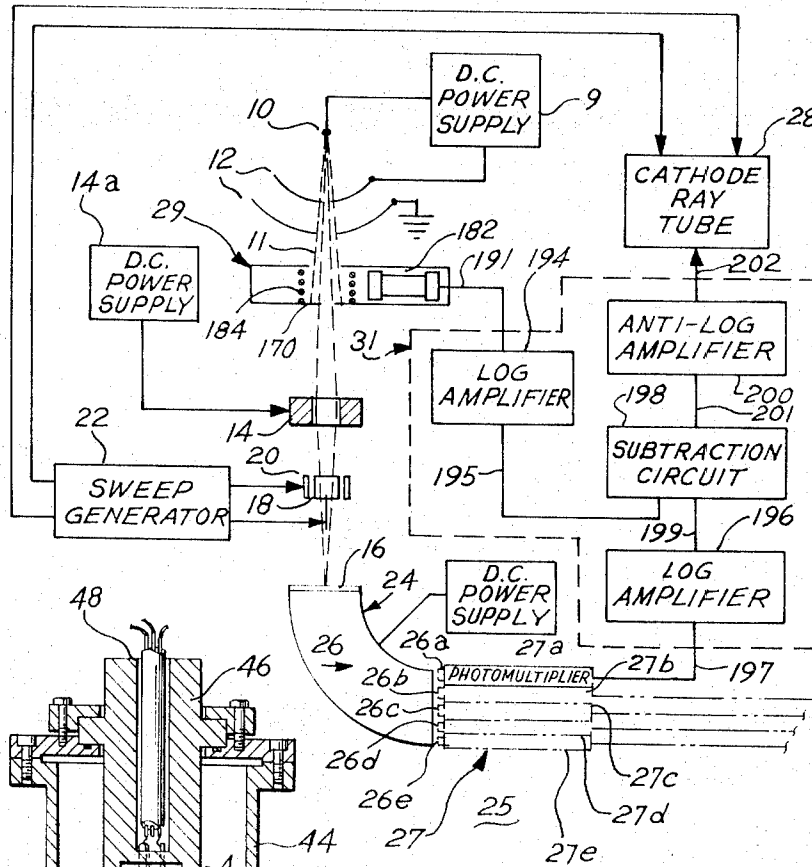
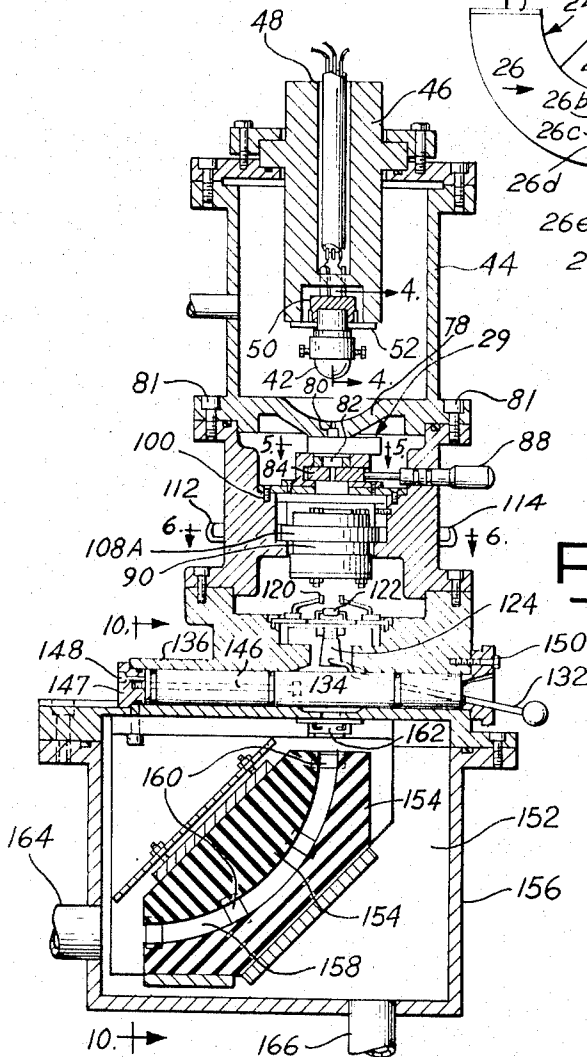


Fig. 2



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Fig. 3

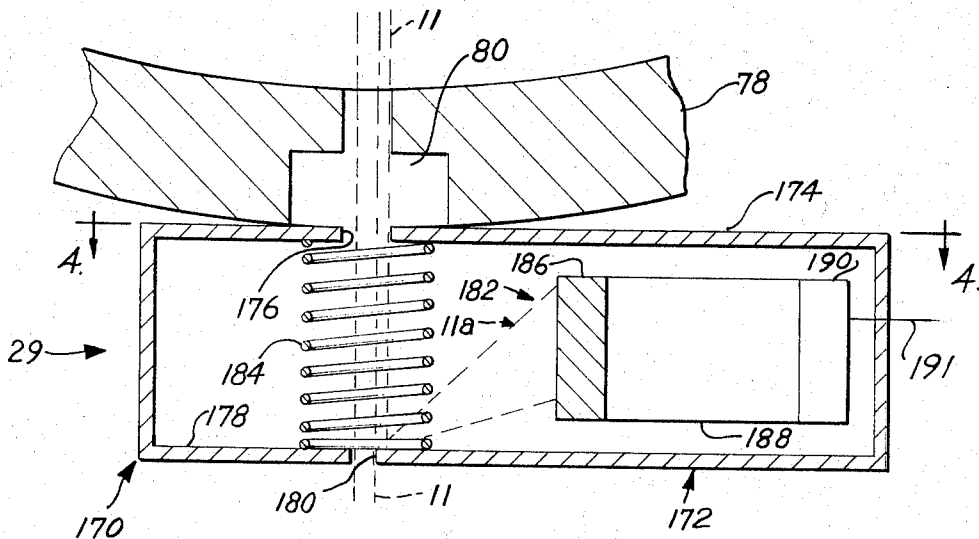
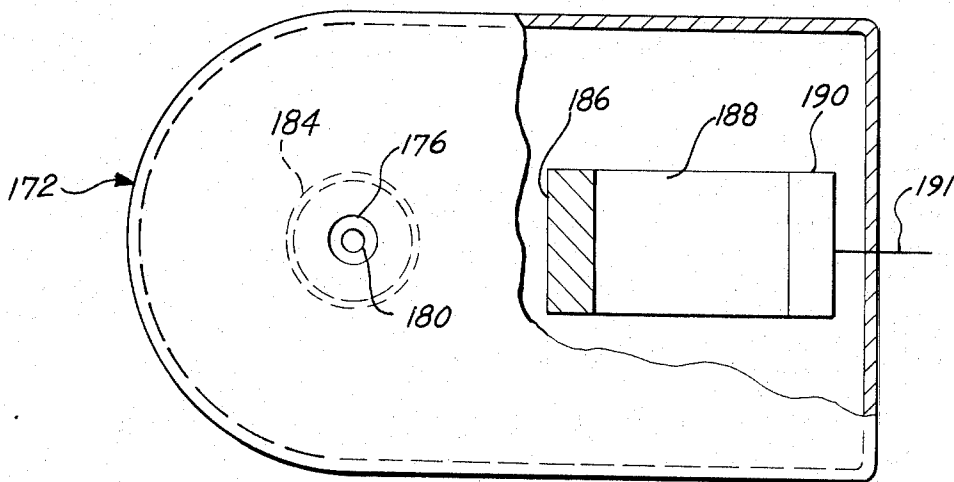


Fig. 4



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ELECTRON MICROSCOPE

RELATED APPLICATION

This is a continuation of U. S. Pat. application Ser. No. 73,117, entitled "Electron Microscope," filed Sept. 17, 1970 in the name of Albert V. Crewe, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to electron microscopes, and more particularly relates to the correction of variations in an output detection signal from the electron microscope due to variations in the electron beam.

Those skilled in the art recognize that scanning electron microscopes provide an important tool by which scientists may examine extremely small particles of matter. One such scanning electron microscope which has proved to be particularly useful is described in my U. S. Pat. No. 3,191,028, issued June 22, 1965. Although this microscope offers a number of advantages and features over analogous prior art microscopes, experience has shown that it does not always produce an extremely high quality micrograph unless it is evacuated to a pressure of about 10^{-10} Torr. If the microscope is only evacuated to a higher pressure (e.g., 10^{-8} Torr), experience has shown that the intensity of a detection signal derived from the transmission of electrons from a specimen is subject to objectionable fluctuations. These fluctuations, in turn, cause the quiescent electron current of the display oscilloscope to fluctuate. The fluctuations cause numerous horizontal streaks on the resulting micrograph. The situation is generally tolerable when working at low magnifications because the contrast in the micrograph is high owing to the presence of such objects as grid wires or other artifacts of very high or very low signal level. When working at high magnification, however, the field of view is generally limited to low contrast specimens so that any fluctuation of current is objectionable.

The applicant has discovered that the reason for the current fluctuation is that the electron emission from the tip of the source of electrons is subject to periodic variations. These variations are generally caused by gas molecules that arrive at the tip and change local conditions to enhance or decrease the current over small regions of the total emission pattern. If one of these regions is on the axis of the microscope, the net effect is a substantial change in the intensity or current density of the electron beam which flows from the tip. The variations are particularly noticeable when a field emission tip is employed to increase the resolution of the microscope.

Of course, it is possible to control the fluctuations of the electron beam by decreasing the ambient gas pressure. At pressures of 1×10^{-10} Torr, the fluctuations are by no means as severe as at 1×10^{-8} Torr, but they still exist and can ruin a portion of the micrographs. Moreover, in order to evacuate the microscope to 10^{-10} Torr, expensive and complicated evacuation apparatus is required. In addition, the apparatus must be operated for long periods of time in order to attain the desired evacuation pressure.

SUMMARY OF THE INVENTION

The applicant has discovered that the above-described variations in the intensity of current density of the electron beam may be corrected by providing a

monitor assembly for producing a reference signal proportional to the magnitude of the electron beam and by also providing a correction means for varying the magnitude of the detection signal in response to variations in the reference signal.

In a preferred embodiment of the invention, correction of the detection signal is achieved by producing a signal corresponding to the ratio of the detection signal and the reference signal. In this embodiment, the monitor assembly comprises apparatus for diverting a portion of the electron beam from its normal path to produce a flow of diverted electrons and comprises a transducer for producing a signal proportional to the number of diverted electrons. This signal corresponds to the reference signal which is used by the correction means to correct the detection signal.

The advantages of the above-described invention are at once apparent. By using the ratio of the reference and detection signals, fluctuations in the electron beam have no significant effect on the signal which is used to produce the micrograph. Thus, micrographs of high quality can be produced even if the microscope is operated at pressures which cause fluctuations in the current density of the electron beam. As a result, the electron microscope may be operated at relatively high pressures (e.g., 10^{-8} Torr), to produce micrographs having a quality and resolution heretofore unattainable except by much more complicated and expensive means. Since improved micrographs can be produced at higher microscope pressures, less sophisticated evacuation apparatus can be used. As a result, there is a significant decrease in the amount of time necessary to reduce the pressure within the microscope to operable levels. For example, most microscopes can be evacuated to about 10^{-8} Torr in a couple of hours, whereas the time required to evacuate the same microscope to about 10^{-10} Torr is generally measured in days of time.

DESCRIPTION OF THE DRAWINGS

These and other advantages and features of the present invention will hereinafter appear for purposes of illustration, but not of limitation, in connection with the accompanying drawings, wherein like numbers refer to like parts throughout, and wherein:

FIG. 1 is a schematic drawing of a preferred form of the present invention as it is employed with an exemplary scanning electron microscope of the type described in U. S. Pat. No. 3,191,028 (Crewe — June 22, 1965);

FIG. 2 is a cross-sectional view of a preferred form of monitor means made according to the present invention as it is employed in the exemplary microscope shown in FIG. 1;

FIG. 3 is an enlarged, fragmentary, cross-sectional, partially schematic view of the monitor means, together with additional apparatus shown in FIG. 2; and

FIG. 4 is a fragmentary top plan view taken along line 4—4 of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2, an exemplary scanning electron microscope which may be used in connection with the present invention comprises a DC source of power 9 that provides a source of potential for a field emission point source of electrons 10 that produces an electron beam 11. The electron beam is accelerated by

electrodes 12 toward focusing magnets 14 that are controlled by a DC power supply 14a. The focusing magnets focus the electron beam into a spot a few angstroms (A) in diameter on the surface of a thin specimen 16. Deflection electrodes 18 and 20 are disposed between the specimen and the focusing magnets and are responsive to voltages from a sweep generator 22 of a cathode ray tube display device 28. The sweep generator and deflection electrodes cause the electron spot to sweep over the surface of specimen 16 in a predetermined pattern.

A momentum analyzing spectrometer 24 is mounted after the specimen 16 and is adjusted to separate electrons transmitted through the specimen 16 into discrete energy levels thereof. A scintillation detector 26 comprising detectors 26a-26e is coupled to a photomultiplier 27 comprising photomultiplier tubes 27a-27e. Those skilled in the art will appreciate that scintillation detector 26 and photomultiplier 27 comprise detection apparatus for producing a detection signal corresponding to the flow of electrons from specimen 16. In addition, it will be recognized that spectrometer 24 may be arranged so that electrons of all energy levels are received by detector 26a. Alternatively, each of the detectors 26a-26e may be connected to photomultiplier tube 27a, so that the signal produced thereby corresponds to the electrons transmitted at all energy levels. Additional features of the exemplary electron microscope may be understood with reference to U.S. Pat. No. 3,191,028 wherein like numbers refer to like parts of FIGS. 1 and 2.

Referring to FIGS. 1-4, a preferred form of the present invention intended for use in connection with the above-described exemplary scanning electron microscope basically comprises a monitor assembly 29 and a correction circuit 31. More specifically, monitor assembly 29 comprises a diverting assembly 170 and a transducer assembly 182.

Referring to FIGS. 3 and 4, diverting assembly 170 comprises an enclosed metal box 172 having an upper surface 174 that defines an aperture 176 having a 200 micron diameter. As shown in FIG. 2, the monitor assembly is located between elements 80 and 82 of the electron microscope described therein. Box 172 also has a lower surface 178 that defines an aperture 180 having a 100 micron diameter. As shown in FIG. 3, apertures 176 and 180 are concentric and have a center line located approximately in the middle of electron beam 11.

Transducer assembly 182 comprises a metal coil 184 that surrounds the electron beam between upper and lower surfaces 174, 178. The transducer assembly also comprises a scintillator 186, a light pipe 188, and a photomultiplier 190 schematically arranged as shown. Those skilled in the art will appreciate that electrons striking the scintillator are converted to light which is transmitted to photomultiplier 190 by light pipe 188. Photomultiplier 190 produces a reference signal proportional to the magnitude of electron beam 11, which is transmitted over a conductor 191.

It should be noted that metal coil 184 is an important element. Absent such a device, the electric field from the voltage on the remaining portions of the transducer assembly would deflect and produce serious astigmatism in the electron beam. If possible, the metal coil should be biased at ground potential. However, if it is necessary to place a voltage on the coil, great care

should be taken to shield any insulators from the electron beam.

Referring to FIG. 1, correction circuit 31 comprises a ratio circuit for producing a corrected signal corresponding to the ratio of the detection signal and the reference signal. This ratio circuit comprises logarithmic amplifiers 194 and 196, a subtraction circuit 198, and an antilogarithmic amplifier 200 connected as shown by conductors 195, 197, 199 and 201. Those skilled in the art will appreciate that amplifier 200 produces a corrected signal corresponding to the ratio of the detection signal and the reference signal. The corrected signal is conducted over a conductor 202 to provide a video information signal by which a micrograph display may be produced on cathode ray tube 28. Elements 194, 196, 198 and 200 are well-known to those skilled in the electronic arts, and may be made and used by such individuals based on the present disclosure.

The preferred embodiment operates as follows. Electron beam 11 passes through aperture 176 into diverting assembly 170. Since aperture 180 is smaller than aperture 176, a portion of the electron beam strikes the surface 178 in the area around aperture 180. The electrons which strike this area are diverted from their normal path to produce a flow of diverted electrons 11a. Some of these electrons strike scintillator 186 and are converted to light rays in a well-known manner. The light rays are then conducted along light pipe 188 and are converted to a corresponding reference signal by photomultiplier 190. The reference signal is transmitted over conductor 191. As previously mentioned, the reference signal is proportional to the magnitude of the diverted electrons which are, in turn, proportional to the magnitude of the electron beam 11.

Electron beam 11 is then focused onto specimen 16 by focusing magnets 14 and is scanned over the surface of the specimen by deflection electrodes 18, 20. The resulting flow of electrons from specimen 16 is detected by detection apparatus 25 in order to form a detection signal on conductor 197. As previously mentioned, photomultiplier 27a, to which log amplifier 196 is connected, normally produces a signal proportional to the flow of electrons at a particular energy level. However, as previously described, photomultiplier 27a may be modified to produce a signal proportional to the flow of electrons at all energy levels. Alternatively, each of the detectors 26a-26e and photomultipliers 27a-27e may be connected with a correction circuit, such as circuit 31, and a cathode ray tube to individually display the electrons transmitted at various energy levels.

The detection signal on conductor 197 is conducted to logarithmic amplifier 194 that produces a first signal on conductor 199 corresponding to the logarithm of the detection signal. At the same time, the reference signal is conducted to logarithmic amplifier 194 that produces a second signal on conductor 195 corresponding to the logarithm of the reference signal. The first and second signals are then conducted to subtraction circuit 198 that produces a remainder signal on conductor 201 corresponding to the difference between the first and second signals. The remainder signal is then conducted to an antilogarithmic amplifier 200 which produces a corrected signal on conductor 202 corresponding to the antilogarithm of the remainder signal. The corrected signal corresponds to the ratio of the detection and reference signals. The cor-

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rected signal is then used as a video information signal by which a micrograph display may be produced on cathode ray tube 28.

Those skilled in the art will recognize that the techniques described herein are merely exemplary of the preferred practice of the invention which is defined by the appended claims.

What is claimed is:

1. In an electron microscope comprising an electron source for producing an electron beam and comprising detection means for producing a detection signal corresponding to the flow of electrons from a specimen placed in the electron beam, improved apparatus for limiting variations in the detection signal due to variations in the electron beam comprising:

monitor means for producing a reference signal having a magnitude determined by the magnitude of the electron beam, said monitor means comprising means for isolating an electric field produced by the monitor means from the electron beam; and correction means for producing a corrected signal corresponding to the ratio of the detection signal and the reference signal, whereby the corrected signal is free from changes in signal magnitude due to variations in the electron beam.

2. Apparatus, as claimed in claim 1, wherein the correction means comprises:

a first logarithmic amplifier for producing a first signal corresponding to the logarithm of the detection signal;

a second logarithmic amplifier for producing a sec-

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ond signal corresponding to the logarithm of the reference signal;

a subtraction circuit for subtracting the second signal from the first signal to produce a remainder signal; an antilogarithmic amplifier for producing a corrected signal which corresponds to the antilogarithm of the remainder signal; and

electronic means for instantaneously displaying an image corresponding to the corrected signal at electronic speed.

3. Apparatus, as claimed in claim 1, wherein the monitor means comprises:

a first metal surface that defines a first aperture through which the electron beam is directed;

a second metal surface that defines a second aperture smaller than the first aperture through which a portion of the electron beam may pass, whereby a portion of the electrons in the electron beam are diverted by the area of the second metal surface surrounding the second aperture;

a porous metal structure that surrounds the electron beam between the first and second metal surfaces;

a scintillator for receiving diverted electrons and for converting the diverted electrons to light;

a light pipe connected to the scintillator; and

a photomultiplier responsive to the light transmitted by the light pipe.

4. Apparatus, as claimed in claim 3, wherein the porous metal structure comprises a coil.

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