United States Patent

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[72] Inventor Albert V. Crewe
Palos Park, Ill.
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[73] Assignee The United States of America as represented by the United States Atomic Energy Commission

[54] **DETECTOR SYSTEM FOR A SCANNING ELECTRON MICROSCOPE**
7 Claims, 4 Drawing Figs.

[52] U.S. Cl. .... 250/49.5 A, 250/49.5 E, 250/49.5 AE
[51] Int. Cl. H01j 37/28
[50] Field of Search .... 250/49.5 A, 49.5 E, 49.5 PE, 49.5 AE

[56] References Cited
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OTHER REFERENCES
Denbigh et al.; Journal of Scientific Instr.; Vol. 42, No. 5, May, 1965, pp. 305-311;

Primary Examiner—Anthony L. Birch
Attorney—Roland A. Anderson

ABSTRACT: In an electron microscope transmitted electrons are detected according to whether they are unscattered, elastically scattered or inelastically scattered by the specimen. The elastically scattered electrons are further separated according to the magnitude of the scattering. Signals from the separate detectors can be used separately or combined as desired to enhance the information obtained from a specimen.

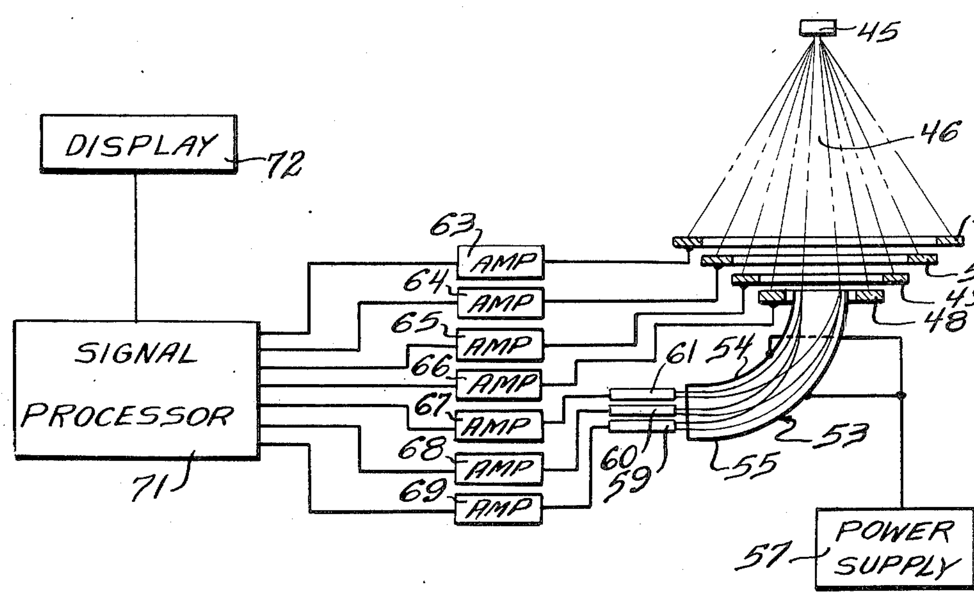


FIG-1

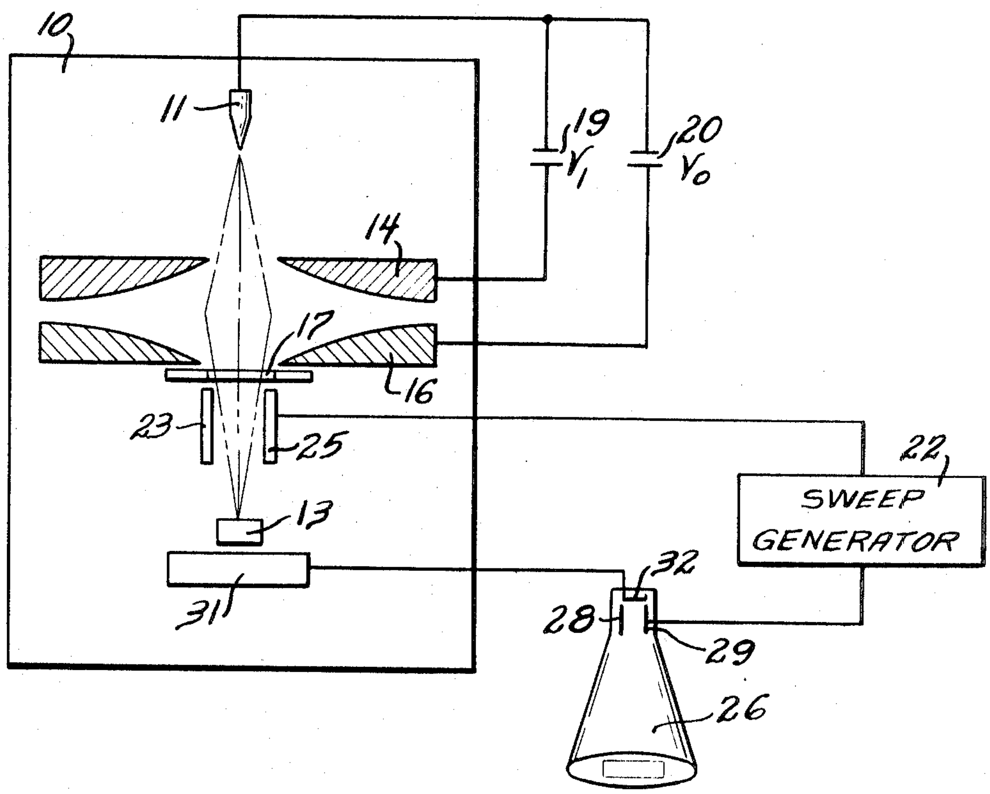
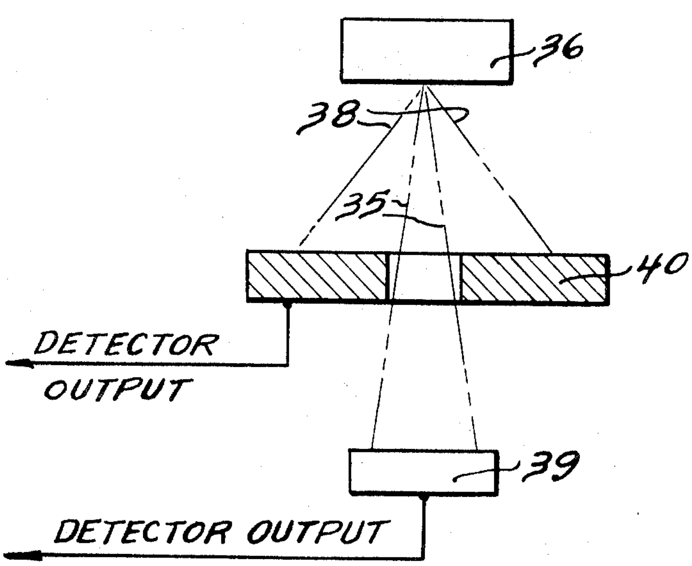
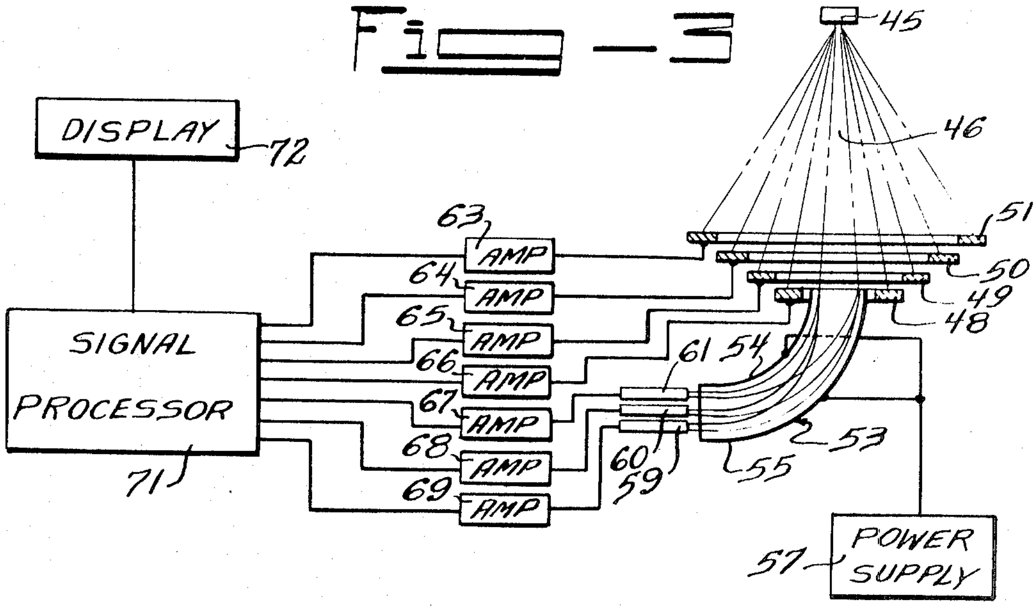


FIG-2



Inventor
Albert V. Crewe
[signature]
Attorney

Fig-3



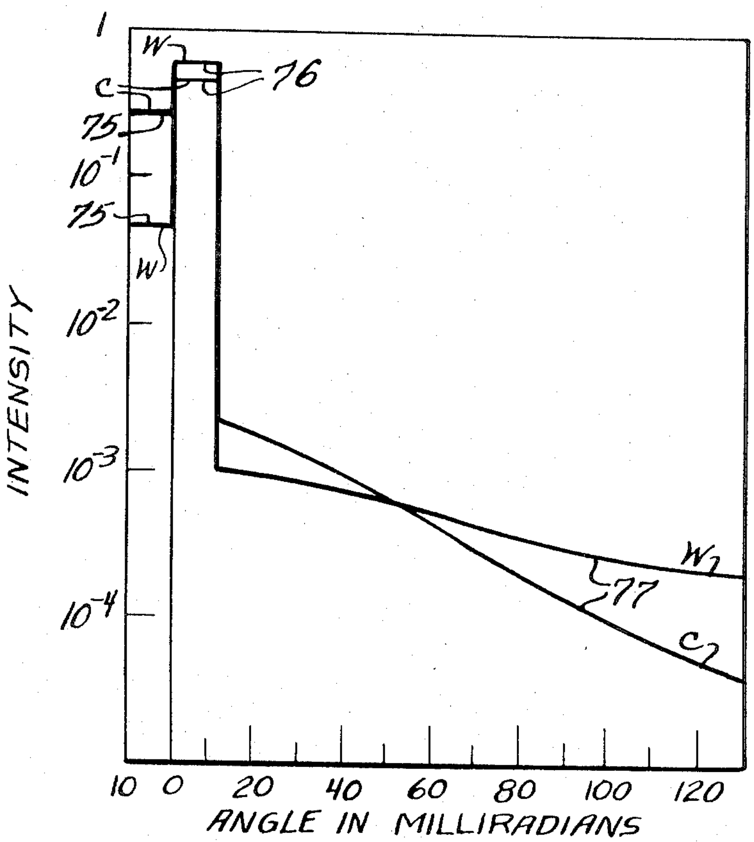


Fig-4

Inventor
Albert V. Crewe

Attorney

DETECTOR SYSTEM FOR A SCANNING ELECTRON MICROSCOPE

CONTRACTUAL ORIGIN OF THE INVENTION

The invention described herein was made in the course of, or under, a contract with the UNITED STATES ATOMIC ENERGY COMMISSION.

BACKGROUND OF THE INVENTION

In the scanning electron microscope a small focused spot of electrons is scanned across the specimen being observed. Any physical effect caused by the incident beam can be detected and displayed as an intensity variation on a synchronously scanned display oscilloscope. The area scanned may be rectangular, as in a television picture, or it may be any other shape which is desirable.

The electrons transmitted by the specimen can be divided into three groups: those elastically scattered, those inelastically scattered and those that are unscattered. In prior art electron microscopes the transmitted electrons have been detected without separation or they have been separated by energy content before detection. Thus the elastically scattered and unscattered electrons have not been separated before detection and information about the specimen has been lost.

It is therefore an object of this invention to provide an improved detection system for a scanning electron microscope.

Another object of this invention is to provide an electron microscope wherein the transmitted electrons are separated according to whether they are elastically or inelastically scattered or are unscattered before detection.

Another object of this invention is to provide an electron microscope wherein the elastically scattered electrons are separated according to the degree of scattering before detection.

SUMMARY OF THE INVENTION

In practicing this invention a detector for a scanning electron microscope is provided which separately detects the elastic electrons, the inelastic electrons and the unscattered electrons. The inelastic electrons are deflected through only a very small angle and thus remain in the cone of illumination of the beam after it leaves the specimen together with the unscattered electrons. An annular detector permits the inelastic and unscattered electrons to pass through a hole therein to a separate detector where the electrons are separated according to energy; that is, no energy loss—unscattered electrons; energy loss—inelastic electrons. The elastic electrons are deflected outside the cone of illumination and are detected by the annular detector. A series of annular detectors can be provided to measure the intensity of the transmitted elastic electrons vs. degree of deflection. The signals from the various detectors can be combined as desired to provide information about the specimen.

DESCRIPTION OF THE DRAWINGS

The invention is illustrated in the drawings, of which:

FIG. 1 is a drawing of a scanning electron microscope;

FIG. 2 is a drawing of the detection system of this invention;

FIG. 3 is a drawing of another embodiment of the detection system of this invention; and

FIG. 4 is a curve showing the output from the detection system of this invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, there is shown a schematic and block diagram of a scanning electron microscope. The microscope includes a vacuum chamber 10 in which the microscope elements are positioned. An electron source 11, which may consist of a field emission tip, provides electrons which are focused on specimen 13. Anodes 14 and 16 act to accelerate and focus the electrons through aperture 17 to specimen 13. Power supplies 19 and 20 are connected to anodes 14 and 16, respectively, to provide the required voltages for electron acceleration and focusing.

The electron beam which impinges on specimen 13 is focused to as small a spot as possible. Therefore, in order to illuminate the desired area of the specimen, the beam is scanned over this desired area in a manner similar to a TV scan. Sweep generator 22 provides scanning voltages to deflection plates in the microscope (represented by deflection plates 23 and 25). The voltages on the deflection plates act to move the electron beam across the specimen in a desired manner.

Sweep voltages from sweep generator 22 are also applied to the deflection plates of CRT 26 (represented by deflection plates 28 and 29). The sweep voltages applied to the CRT 26 are in synchronism with the sweep voltages applied to the electron microscope so that the electron beam in the CRT 26 traces a raster on the face of the tube as the specimen 13 is scanned.

A detector 31 placed beneath specimen 13 receives electrons transmitted through the specimen. Detector 31 is coupled to cathode 32 of CRT 26 to modulate the intensity of the electron beam in CRT 26 according to the electrons received by detector 31. The modulated electron beam forms a picture on the face of CRT 26 representative of the specimen being observed.

The electrons which reach the plane of detector 31 comprise three components, those elastically scattered, those inelastically scattered or energy loss electrons, and the unscattered electrons. The elastically scattered electrons have a very wide angular distribution and most of them reach the plane of detector 31 outside of the cone of illumination. The inelastic electrons are scattered according to the energy loss involved in the inelastic event. Since the majority of the energy loss events are in the range 0–40 volts and the energy of the incident electrons is several tens of kilovolts, the scattering angle is very small—a milliradian or less. The unscattered electrons fill the cone of illumination and the intensity of this component is the intensity of the original beam minus the elastic and inelastic electrons.

These three groups of electrons can be separated from one another so that they can be separately used. Referring to FIG. 2, there is shown a detection system which can separate the three groups of electrons. The cone of illumination 35 from specimen 36 passes through a hole in annular detector 40. If the hole in detector 40 is just large enough to allow the illuminating cone 35 to pass through, it will detect the elastically scattered electrons which are outside the cone of illumination 35. The elastically scattered electrons are within cone 38 and outside of the cone of illumination 35. The electrons in the cone of illumination and which pass through the hole can be physically separated into unscattered electrons and inelastically scattered electrons by detector 39. The operation of detector 39 in separating the unscattered electrons and the inelastically scattered electrons will be described in a subsequent portion of the specification.

In FIG. 3, there is a detailed drawing of detectors suitable for use in this electron microscope system. The cone of illumination 46 passes through a series of annular detectors 48 to 51 into an electrostatic spherical analyzer 54 of conventional design. Analyzer 54 includes electrodes 54 and 55 which are connected to power supply 57. Power supply 57 acts to develop an electric field between electrodes 54 and 55 to deflect electrons which enter the analyzer. The amount of deflection is determined by the energy of the electrons. Thus, with the field adjusted so that the unscattered electrons strike detector 59, the inelastic electrons which have lost energy will strike detectors 60 and 61. While three detectors are shown, any number (two or greater) may be used, consistent with the requirements of the system. Detectors 59, 60 and 61 may be, for example, scintillation detectors or silicon surface barrier detectors.

The elastically scattered electrons from specimen 45 fall outside the cone of illumination 46 and are detected by the annular detectors **48** to **51**. Detectors **48** to **51** may be, for example, silicon surface barrier detectors. Each of the detectors **48** to **51** detect the electrons which are elastically scattered at different angles.

The signals from each of the detectors **48** to **51** and **59** to **61** are amplified in amplifiers **63** to **69**. The amplified signals are combined in a desired manner in signal processor **71** and displayed by display unit **72**. The signals may be displayed as a television like picture, as photographs, as graphs or in other known ways.

Different specimens will partition the electrons in different ways so that in some cases it will be preferable to use one of the signals while in other cases a combination of the signals would be used. If the three signals are denoted by A (unscattered electrons), A* (inelastically scattered electrons) and B (elastically scattered electrons), a signal of the form:

$$\frac{A+xA^*+yB}{A+A^*+B}$$

would be useful. A suitable electronic signal processor could be used to perform this function. The signal processor would have two controls for controlling the values of x and y (where x and y can assume positive or negative values) to develop the contrast of interest to the microscopist.

Consider, for example, a specimen consisting of alternating areas of 50 A of carbon and 5 A of tungsten. A plot of the elastic, inelastic and unscattered electrons as a function of the spatial distribution of the electrons on the detector aperture plane is shown in FIG. 4. The cone of illumination of 10 milliradians and the inelastic electrons are shown within the 10 milliradian section of the plot as curves **75**. The unscattered electrons are also shown within the 10 milliradian section of the plot (separated from the inelastic electrons) as curves **76**. The elastic electron intensity is plotted as a function of the angular distance from the cone of illumination as curves **77**. The tungsten contrast is small and negative for the unscattered electrons, positive and larger for the inelastic electrons and either positive or negative for the elastically scattered electrons depending upon the angle of observation.

Picture contract can therefore be enhanced as desired depending on the choice of the electron groups which are used. If the ratio of the inelastic electrons to the elastic electrons is used, the picture contrast is proportional to 25/Z, where Z is the atomic number of the element. This signal is substantially independent of the thickness of the specimen so that "noise" which is caused by thickness variations is reduced and specimen detail due to different atoms is enhanced. In another example the signal from the elastically scattered electrons below 50 milliradians (the crossover point) could be subtracted from the signal above 50 milliradians to increase contrast. The resulting signal would then be particularly sensitive to the relative thickness of the carbon and the tungsten. The contrast of a particular area could be enhanced by choosing the dividing line between the positive and negative signals from a series of detectors such as **48** to **51** (FIG. 3).

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A detector system for examination of a specimen by an electron microscope having a source of electrons for irradiating the specimen, the microscope acting to focus the electrons on a spot on the specimen and further to scan the focused spot of electrons over the specimen, the irradiating electrons after passing through the specimen developing into groups of unscattered, inelastically scattered and elastically scattered electrons, substantially all of the unscattered and inelastically scattered electrons forming a cone of illumination with substantially all of the elastically scattered electrons being outside of the cone of illumination, including in combination, first detection means positioned to receive only electrons outside of the cone of illumination and to detect all said received electrons and to develop a first output signal representative of all of said received and detected electrons said first output signal being representative of the elastically scattered electrons only, and utilization means coupled to said first detector means for utilizing said first output signal.

2. The detector system of claim **1** further including, second detector means positioned to reject electrons outside of the cone of illumination to detect at least one of the groups of inelastically scattered and unscattered electrons in the cone of illumination and to develop a second output signal representative of the group of electrons detected, said utilization means being coupled to said second detector means for utilizing said second output signal.

3. The detector system of claim **2** wherein, said second detector means includes third detector means for detecting said inelastically scattered electrons and to develop a third output signal representative of the inelastically scattered electrons detected, and fourth detector means for detecting said unscattered electrons and to develop a fourth output signal representative of the unscattered electrons detected, and utilization means coupled to said third and fourth detector means for utilizing said third and fourth output signals therefrom.

4. The detector system of claim **3** wherein, said first detector means includes an opening therein substantially the size of the cone of illumination of said inelastically scattered electrons and said unscattered electrons, said first detector means being positioned to permit electrons in said cone of illumination to pass through said opening and to detect electrons outside of said cone of illumination, said third and fourth detector means being positioned to detect electrons within said cone of illumination.

5. The detector system of claim **4** wherein, said first detector means includes a plurality of first detectors, each of said first detectors being positioned to detect electrons outside of said cone of illumination and scattered at an angle different from the angle of scatter of the electrons detected by any other of said second detectors.

6. The detector system of claim **5** wherein, each of said plurality of first detectors is in the form of an annular ring detector, said plurality of annular first detectors being positioned concentrically to detect electrons scattered to different angles outside of said cone of illumination.

7. The detector system of claim **6** wherein, said third and fourth detector means comprise a spherical analyzer, said spherical analyzer being positioned to receive said electrons within said cone of illumination and to separate the same according to the energy thereof, said fourth detector means being positioned to detect unscattered electrons, said third detector means including at least one third detector positioned to detect inelastically scattered electrons.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,626,184 Dated December 7, 1971

Inventor(s) Albert V. Crewe

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

On cover page, change the Appl. No. from "168,020" to --16,802--.

Column 3, line 41, change "contract" to --contrast--.

Column 4, line 12, after "electrons" insert a comma.

Column 4, line 18, after "illumination" insert --and to receive electrons in the cone of illumination--.

Signed and sealed this 30th day of May 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents