United States Patent [19]

Hashimoto et al.

[11] **3,914,606**

[45] **Oct. 21, 1975**

[54] **ELECTRON DETECTOR**

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[30] **Foreign Application Priority Data**

Mar. 12, 1973 Japan 48-28724

[52] **U.S. Cl.** **250/305;** 250/282

[51] **Int. Cl.**[2] **H01J 39/00**

[58] **Field of Search** 250/305, 306, 440, 282

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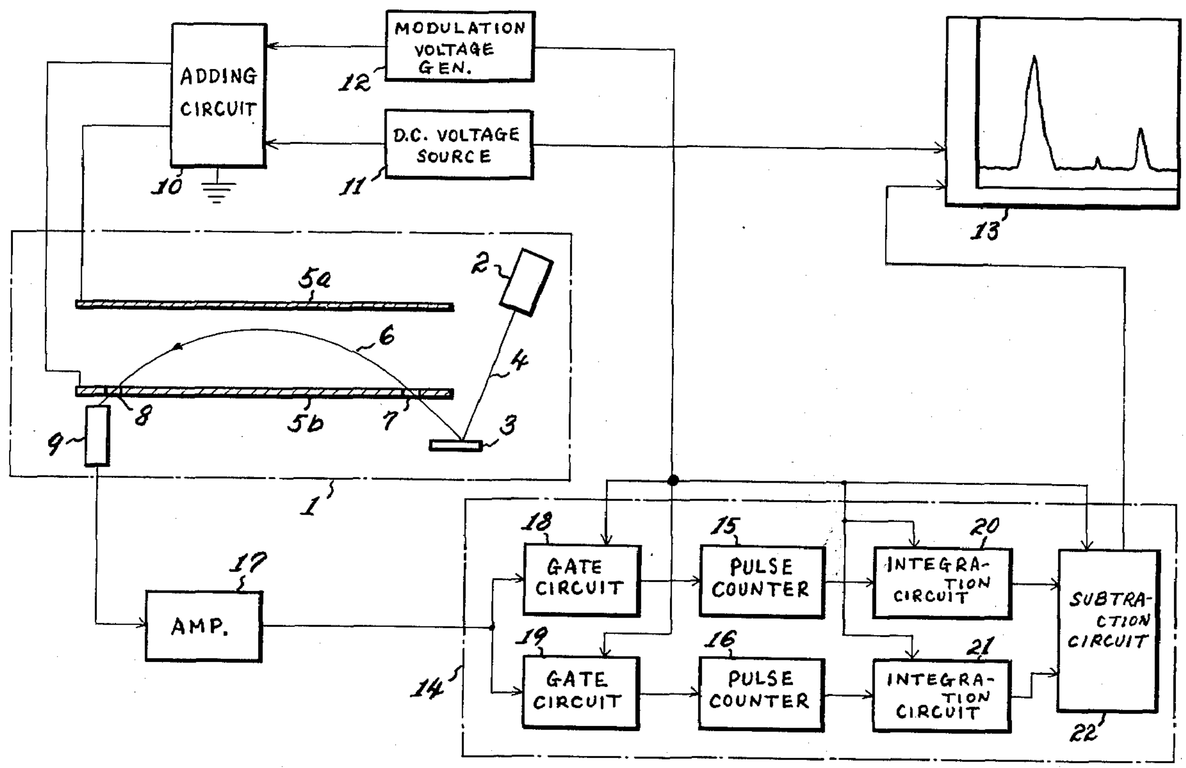
Primary Examiner—James W. Lawrence
Assistant Examiner—D. C. Nelms
Attorney, Agent, or Firm—Webb, Burden, Robinson & Webb

[57] **ABSTRACT**

A device for measuring electron densities at a given energy level in an electron beam or the like having strong background noise, for example, in the detection of Auger electric energy spectrums. An electron analyzer passes electrons at the given energy level and at the same time or ad seriatum electrons of at least one adjacent energy level. Detecting means associated therewith produce signals indicative of the densities of the electrons at each energy level and combine these signals to produce a signal indicative of the density of the electrons of the given energy level absent background noise.

8 Claims, 21 Drawing Figures



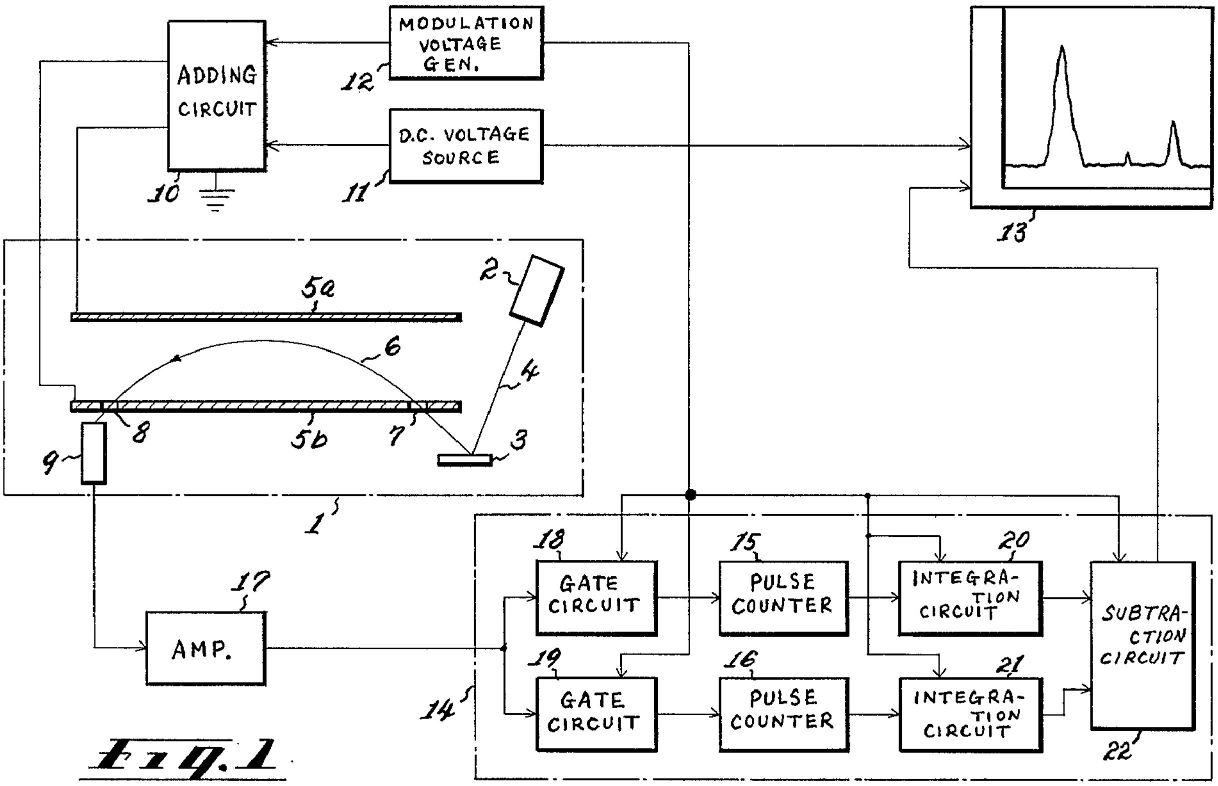


Fig. 1

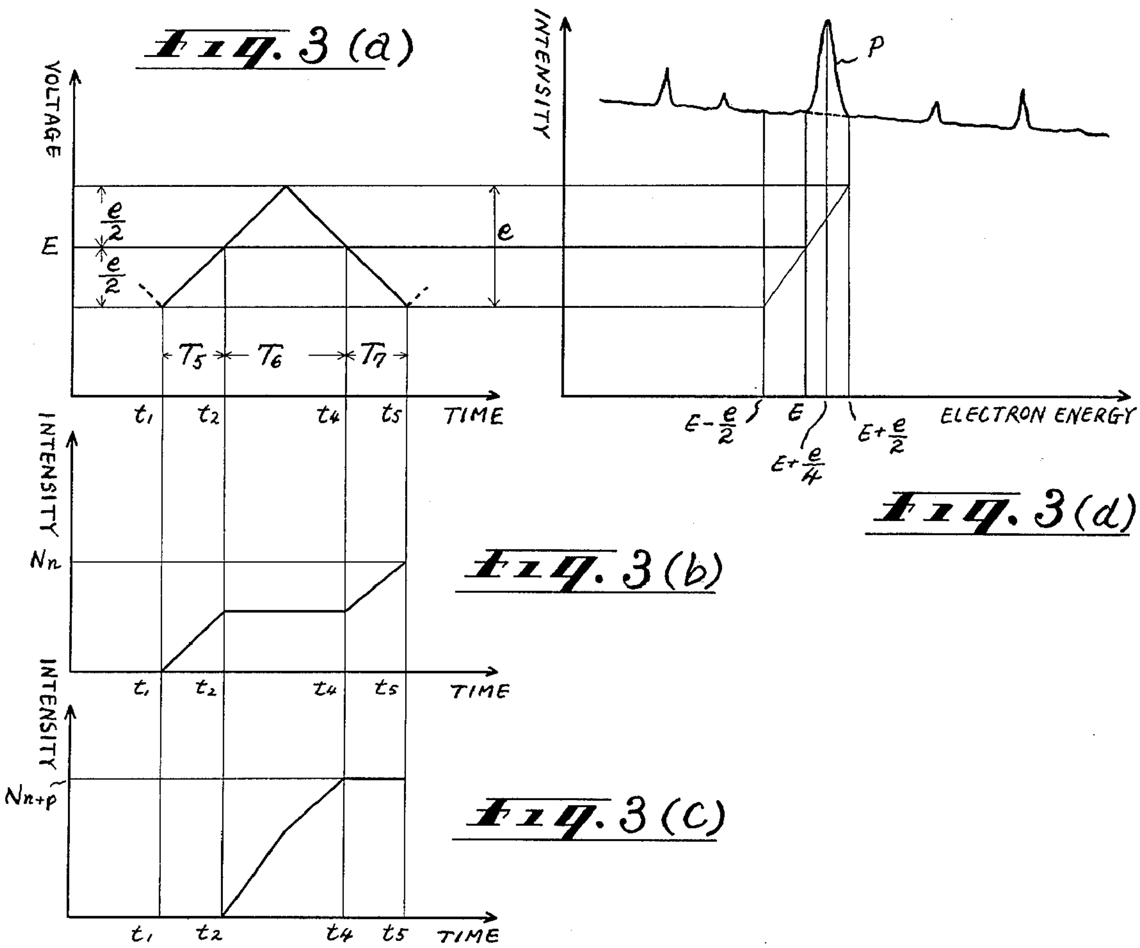


Fig. 3(a)

Fig. 3(b)

Fig. 3(c)

Fig. 3(d)

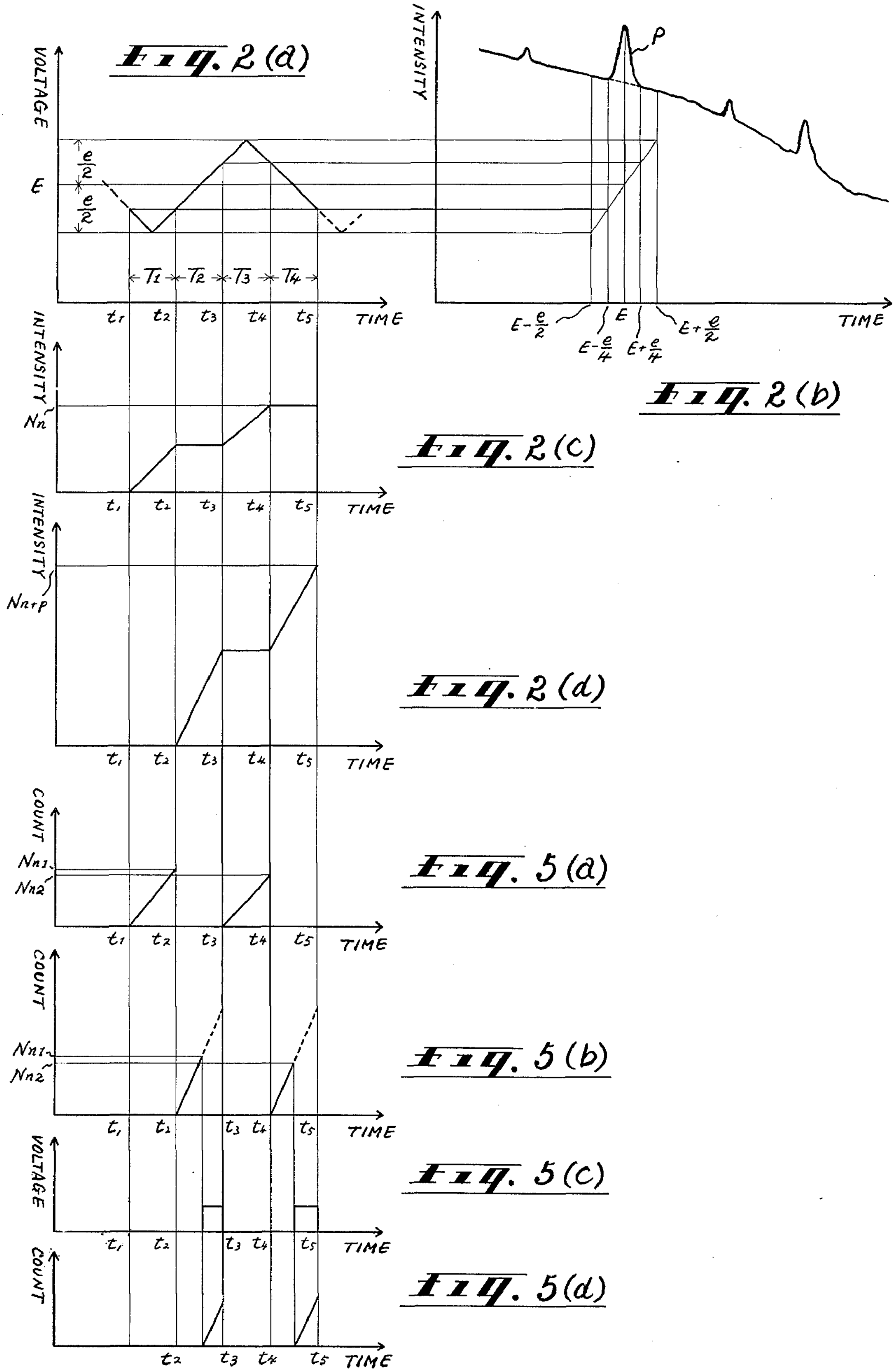


Fig. 2(a)

Fig. 2(b)

Fig. 2(c)

Fig. 2(d)

Fig. 5(a)

Fig. 5(b)

Fig. 5(c)

Fig. 5(d)

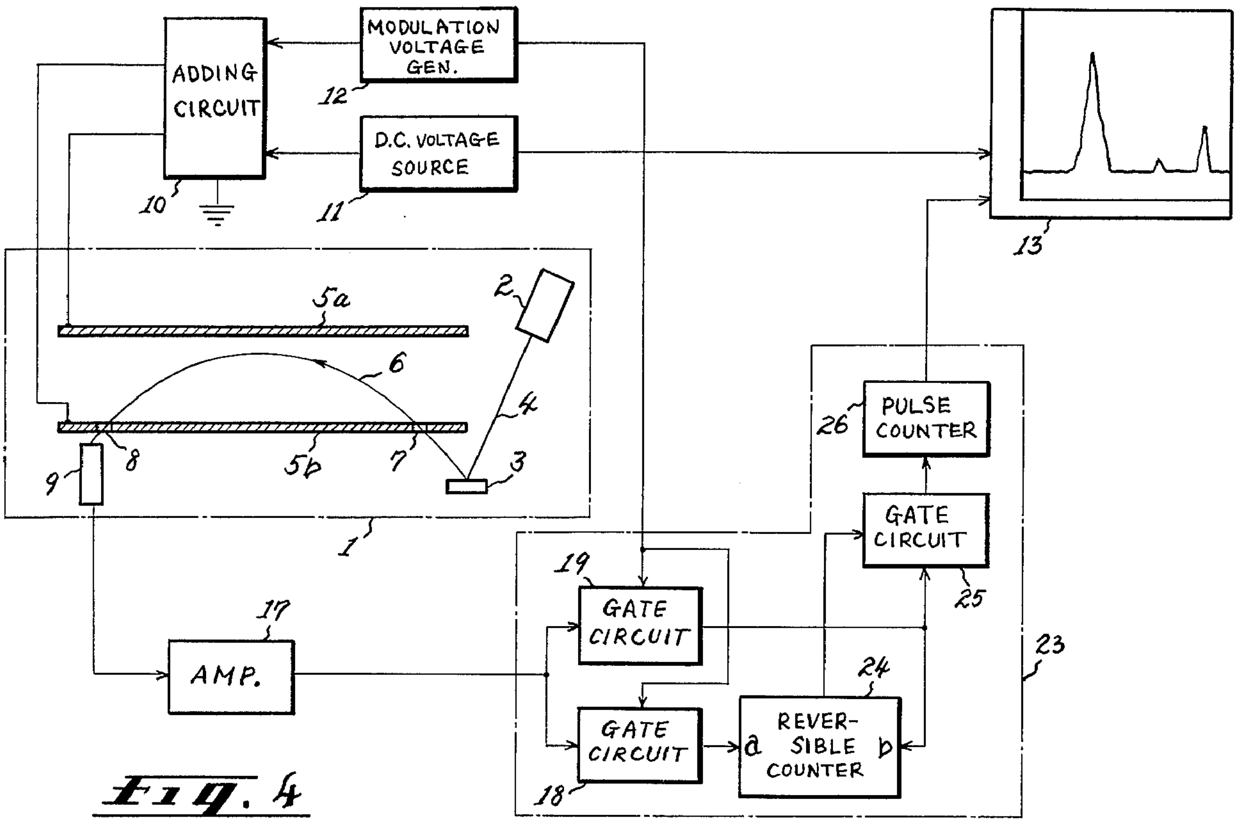

MODULATION VOLTAGE GEN.
ADDING CIRCUIT
D.C. VOLTAGE SOURCE
PULSE COUNTER
GATE CIRCUIT
GATE CIRCUIT
GATE CIRCUIT
REVERSIBLE COUNTER
AMP.
a
b
1
2
3
4
5a
5b
6
7
8
9
10
11
12
13
17
18
19
23
24
25
26

Fig. 4

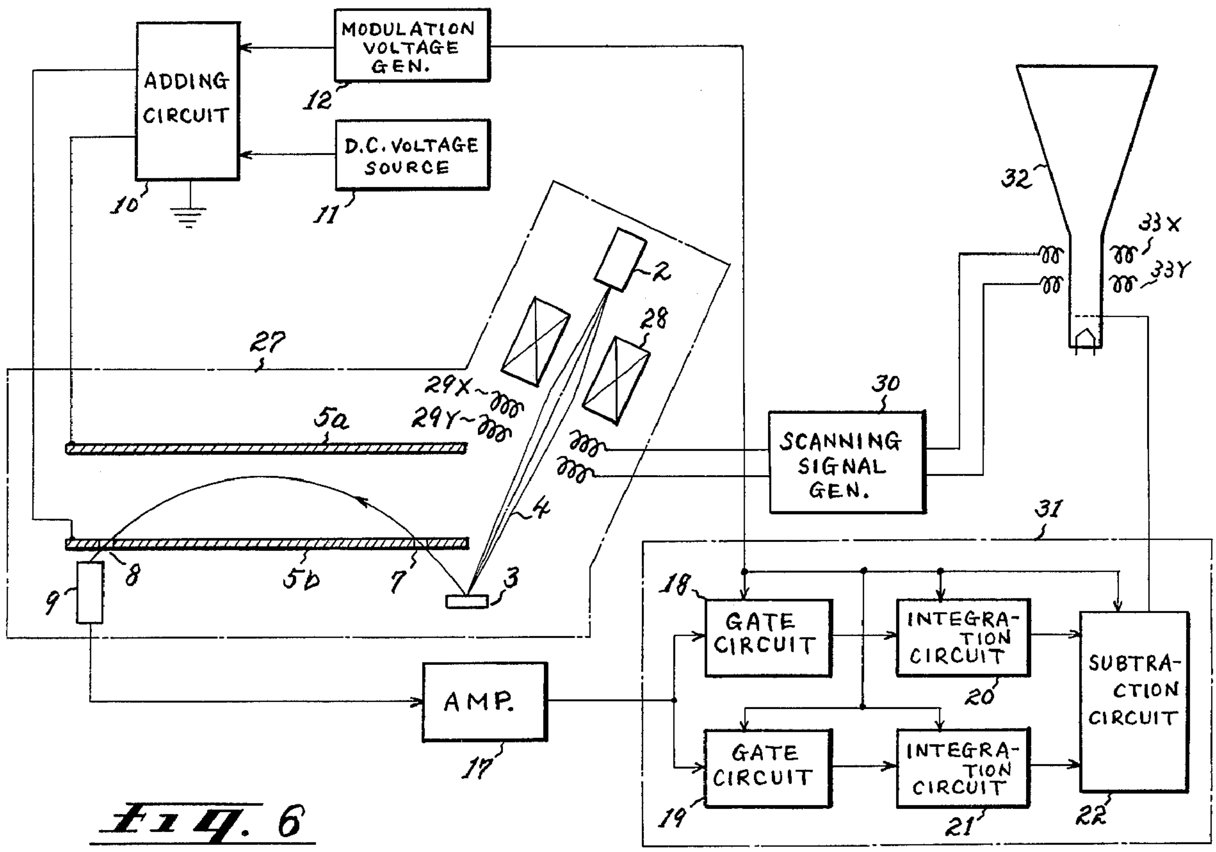

MODULATION VOLTAGE GEN.
ADDING CIRCUIT
D.C. VOLTAGE SOURCE
SCANNING SIGNAL GEN.
AMP.
GATE CIRCUIT
INTEGRATION CIRCUIT
GATE CIRCUIT
INTEGRATION CIRCUIT
SUBTRACTION CIRCUIT
2
3
4
5a
5b
7
8
9
10
11
12
17
18
19
20
21
22
27
28
29X
29Y
30
31
32
33X
33Y

Fig. 6

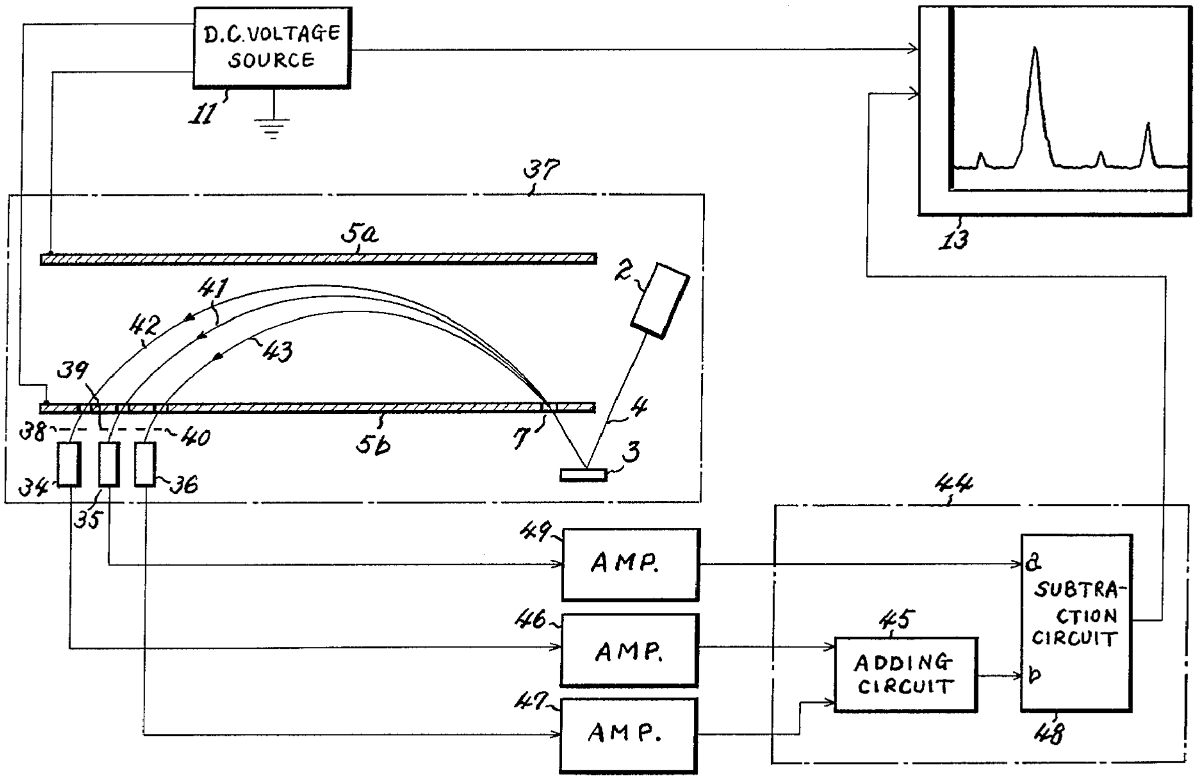

D.C. VOLTAGE SOURCE
11
13
37
5a
2
41
42
43
39
4
38
40
5b
7
3
34
35
36
44
49
AMP.
a
SUBTRACTION CIRCUIT
46
AMP.
45
ADDING CIRCUIT
b
47
AMP.
48

Fig. 7

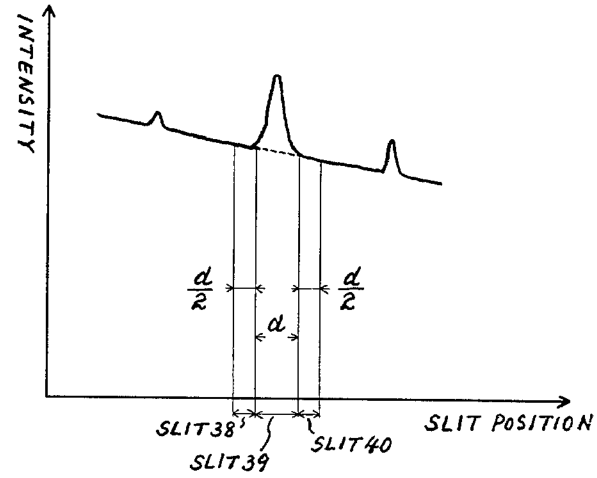
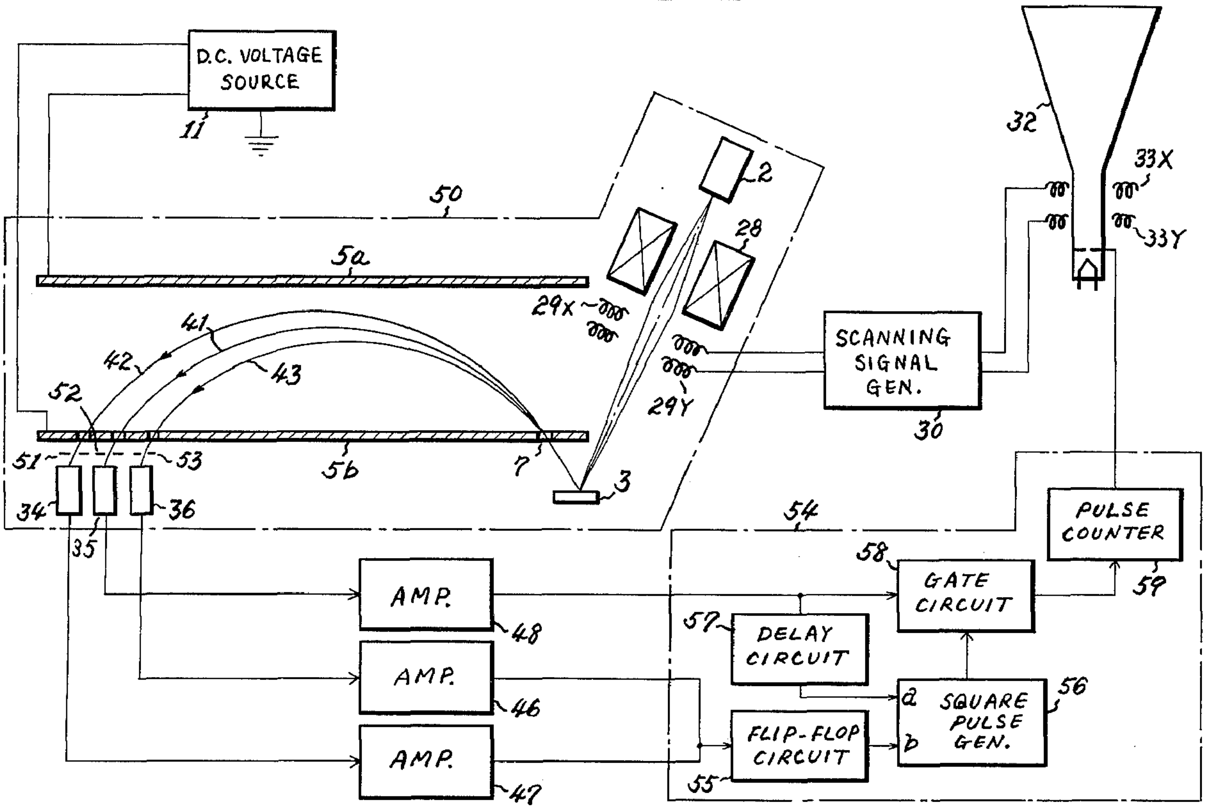

INTENSITY
d/2
d
d/2
SLIT 38
SLIT 39
SLIT 40
SLIT POSITION

Fig. 8

Fig. 9


D.C. VOLTAGE SOURCE
11
50
5a
41
42
43
52
51
53
5b
7
3
2
28
29X
29Y
34
35
36
SCANNING SIGNAL GEN.
30
32
33X
33Y
54
PULSE COUNTER
59
58
GATE CIRCUIT
57
DELAY CIRCUIT
SQUARE PULSE GEN.
56
a
b
FLIP-FLOP CIRCUIT
55
AMP.
48
AMP.
46
AMP.
47

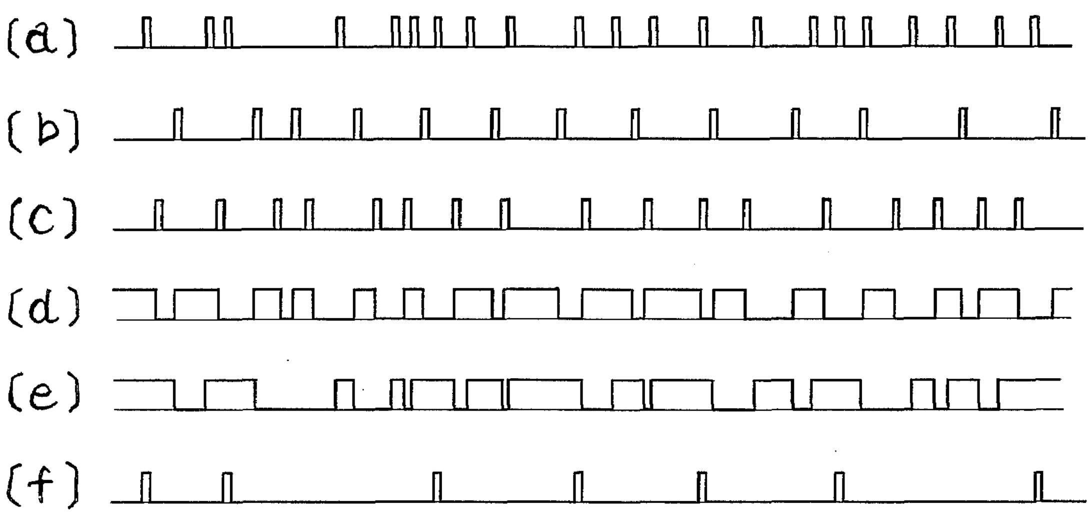

(a)
(b)
(c)
(d)
(e)
(f)

Fig 10

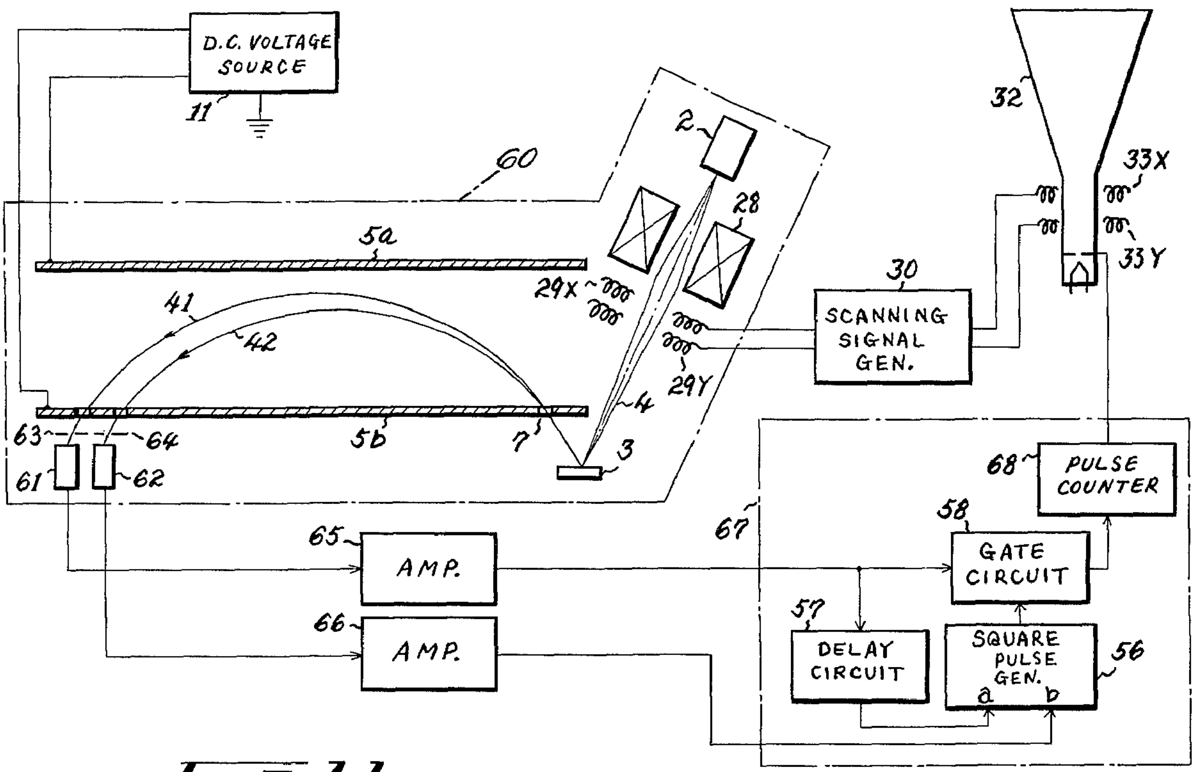

D.C. VOLTAGE SOURCE
11
60
2
28
5a
41
42
29X
29Y
4
5b
7
3
63
64
61
62
30
SCANNING SIGNAL GEN.
32
33X
33Y
68
PULSE COUNTER
67
58
GATE CIRCUIT
65
AMP.
66
AMP.
57
DELAY CIRCUIT
SQUARE PULSE GEN.
a
b
56

Fig. 11

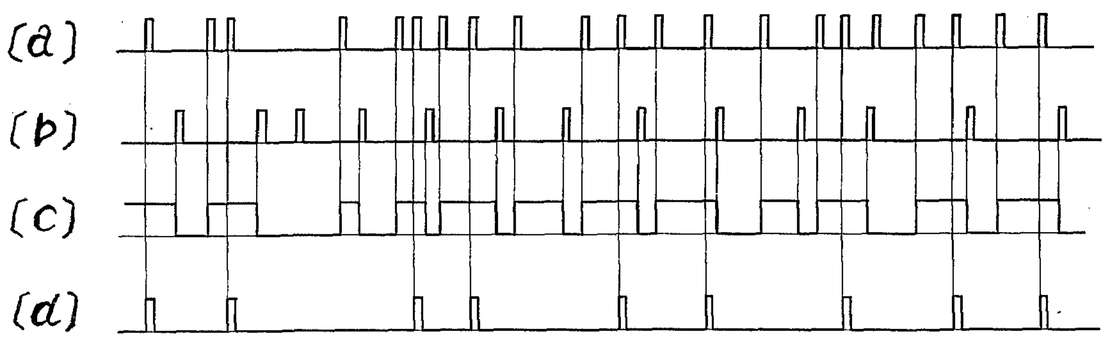

(a)
(b)
(c)
(d)

Fig. 12

ELECTRON DETECTOR

This invention relates to an analyzing device for measuring weak signals detected along with a large amount of background noise.

To investigate substances existing in the thin layer immediately below the specimen surface, the utilization of the so-called Auger electron energy spectrum, obtained by irradiating the specimen with primary electrons or X-rays, is most desirable. However, with conventional type energy devices Auger electrons are detected or analyzed along with secondary (or photo) electrons and backscattered electrons, all of which are ejected from the specimen simultaneously.

Moreover, the density of the Auger electron energy spectrum is much weaker than that of the photo electron energy spectrum in that the former spectrum embodies a considerable amount of background noise, thus making it difficult to accurately measure the Auger electron energy spectrum with the apparatus presently available.

In an attempt to overcome this problem, a method was devised and incorporated in some conventional type analyzing devices whereby the output signal of the electron energy analyzer is differentiated, said differentiation being based on the fact that the change in strength of the background noise is much smaller than that of the Auger electrons. However, in this method, the detected input signal must be sufficiently strong to provide an analogue input signal for the lock-in amplifier. Accordingly, especially when the analyzer output signal is pulsed, intergration must be carried out for some time which makes Auger electron energy measurement quite time consuming. As a result, it is impossible to observe rapid changes in the specimen with time; for example, when the specimen temperature is increased linearly with time. Another drawback with this method is that, since only the change rate of the input signal is measured, the measurement accuracy of the Auger electron density is not of a high order and thus, it is impossible to analyze substances lying immediately below the specimen surface quantitatively.

Accordingly, an advantage of this invention is to provide an analyzing device for measuring the density of the Auger electron energy spectrum peaks more precisely.

Another advantage of this invention is to provide an analyzing device capable of observing the change in the Auger electron spectrum peak height when the specimen temperature is varied with time.

A still further advantage of this invention is to provide an analyzing device for precisely measuring the density of the Auger electron energy spectrum peaks even when the detected signal is pulsed.

Briefly according to this invention, a typical analyzer device is provided with additional means for detecting a plurality of signals obtained by the electron energy analyzing means, such that said signals respectively correspond to the successive values of the electron beam energies and a function of at least one of said signals is subtracted from one of the other said signals by a processing circuit network.

Additional features and advantages of this invention will become more readily apparent by reading through the following detailed description in conjunction with the accompanying drawings of which:

FIG. **1** is a block schematic showing one embodiment of the analyzing device according to this invention,

FIGS. **2** and **3** are diagrams for explaining the operation of the embodiment shown in FIG. **1**,

FIG. **4** is a block schematic showing one embodiment of the analyzing device according to this invention,

FIGS. **5**(*a*), (*b*), (*c*) and (*d*) are diagrams for explaining the operation of the embodiment shown in FIG. **4**,

FIGS. **6** and **7** are schematics showing the embodiments according to this invention,

FIG. **8** is a diagram for explaining the operation of the embodiment shown in FIG. **7**,

FIGS. **9** and **11** are schematics showing the embodiments according to this invention, and

FIGS. **10** and **12** are diagrams for explaining the operations of the embodiments shown in FIGs. **9** and **11** respectively.

Referring to FIG. **1**, an electron energy analyzer section **1** incorporates an electron gun **2** for irradiating a specimen **3** with a primary electron beam **4.** Two electrostatic electrodes **5***a* and **5***b* separate electrons **6** emanating from the specimen **3** according to energy. Electrons **6** including Auger electrons and secondary electrons emanating from said specimen pass through an input slit **7** of the electrode **5***b* and are subjected to the electric field existing between the electrodes **5***a* and **5***b*. Thus, the trajectory of the electrons is determined according to the energy of electrons so that only electrons having an energy properly corresponding to the electric field strength are able to pass through the output slit **8** for subsequent detection by an electron detector **9.**

An adding circuit **10** determines the electric field strength, the output terminals of said adding circuit being connected to the two electrodes **5***a* and **5***b*. A D.C. voltage source **11** and a modulation voltage generator **12** are connected to the input terminals of the adding circuit **10.** A recorder **13** records the output voltage of the D.C. voltage source **11** together with the processed output signal of the analyzer section **1.**

FIG. **2**(a) shows the output of the adding circuit **10** during a micro lapse of time. In the figure, the modulation voltage, i.e. the output of the modulation voltage generator **12,** has a width e. The output voltage E of the D.C. voltage source **11** varies at a much slower rate than the output of the generator **12.** Timing signals, t_1 to t_5, are supplied by the generator **12** to a circuit network **14.**

In the embodiment shown in FIG. **1**, since the electrons detected by the detector **9** are few in number, the detector output signal is pulsed. Accordingly, the circuit network **14,** in this case, incorporates two pulse counters **15** and **16.** The processing sequence is as follows. The output signal of detector **9,** after being amplified by an amplifier **17,** enters pulse counters **15** and **16** via gate circuits **18** and **19.** The two pulsed signal components, after being pulse counted, then enter integration circuits **20** and **21** the respective outputs of which are subtracted by a subtraction circuit **22** prior to being fed into the recorder **13.** In this case, the subtraction circuit **22** generates zero signal when the subtraction value becomes minus.

FIG. **2**(*b*) shows the energy distribution of the electrons detected by the detector **9.** The ordinate indicates the density of the detected electrons and the abscissa indicates the energy of the detected electrons which is proportional to the output voltage of the adding circuit **10.** As shown for the particular position during sweep shown in FIG. 2b, the output voltage corresponding to peak P equals E and the modulation voltage width e includes peak P, the peak spread equalling E − (e/4) and E + (e/4). The background noise level near peak P is shown as E − (e/2) and E + (e/2), the outer limits of the modulated signal for the given sweep position.

Timing signals generated by modulation generator **12** control the gate circuit **18** so as to pass the input signal during time intervals T_1 and T_3. Accordingly, the output of the integration circuit **20** is as shown in FIG. **2**(*c*). The final counting value Nn shown in FIG. **2**(*c*) corresponds to the intensity background noise surrounding peak P. Moreover, when the background signal varies linearly as shown in the figure, Nn also corresponds to the density of the background signal component of the spread of peak P.

The remaining timing signals generated by generator **12** control the gate circuit **19** so as to pass the input signal during the time intervals T_2 and T_4. Accordingly, the output of the integration circuit **21** is as shown in FIG. **2**(*d*). In this case, the final counting value Np+n corresponds to the density of peak P plus that of the background signal component included in the peak spread.

Incidentally, the t_5 timing signal operates the subtraction circuit **22**, and more or less simultaneously, resets integration circuits **20** and **21**.

It will be apparent from the above that the output of the subtraction circuit **22**, which is recorded by the recorder **13**, represents the density corresponding to the peak signal itself.

FIGS. **3**(*a*), (*b*), (*c*) and (*d*) are graphical illustrations for explaining an operation mode of the embodiment shown in FIG. **1** which differs from that heretofore described. In this case, the generator timing signals are generated at intervals t_1, t_2, t_4 and t_5 as shown in FIG. **3**(*a*), where time interval T_6 equals the sum of time intervals T_5 and T_7. In this mode, the gate circuit **18** is controlled so as to pass the input signal during time intervals T_5 and T_7 while the gate circuit **19** is controlled so as to pass the input signal during time interval T_6. Accordingly, the output of the integration circuit **20** appears as shown in FIG. **3**(*b*) and that of the integration circuit **21** appears as shown in FIG. **3**(*c*). In other respects, this operation mode is identical to the former as explained in the aforegoing. Although the timing pattern of the generated signals in FIG. **3**(*a*) is simpler than that in FIG. **2**(*a*), peak measurement accuracy is not as good. However, when background noise surrounding the peak is almost constant or varies very gradually as shown in FIG. **3**(*d*), it is possible to obtain sufficient accuracy to ensure effective peak measurement.

FIG. **4** is a block schematic showing another embodiment of the analyzing device according to this invention in which the circuit network **23** is different from that described in FIG. **1**. In this embodiment, the modulation voltage generator **12** generates tming signals at instances t_1, t_2, t_3, t_4 and t_5, as shown in FIG. **2**(*a*), so as to control gate circuits **18** and **19**. The output (shown in FIG. **5**(*a*)) of the gate circuit **18** is supplied to input terminal a (normal) of a reversible counter **24**, and the output (shown in FIG.**5**(*b*)) of the gate circuit **19** is supplied to input terminal *b* (reversible) of said counter. Input pulses fed into the terminal a are counted and memorized, and then subtracted from the input pulses fed into the counter via terminal *b*. When the reversible counter **24** becomes zero or the number of pulses fed into terminal b excess the number (Nn_1, Nn_2) of pulses fed into terminal a, the counter **24** generates signals as shown in FIG. **5**(c), said signals being fed into the gate circuit **25** so as to open it. As a result, the output of the gate circuit **19** is fed to a counter circuit **26** via the gate circuit **25** only during the time when the pulses passing through the gate circuit **19** are much larger than the pulses passing through the gate circuit **18**. Accordingly, the output signals shown in FIG. **5**(*d*) correspond to the peak density value itself as in the case of the prior embodiment.

FIG. **7** is a block schematic showing another embodiment of the analyzing device according to this invention. In this embodiment, the modulation voltage generator **12** has been dispensed with and three electron detectors **34, 35,** and **36** are used instead of one. In an analyzer section **37**, the three detectors are arranged adjacently and below three slits **38, 39** and **40.** Electrons having slightly different energies are focussed by the electric field existing between the electrodes **5**a and **5**b so as to pass through said three slits. The electron trajectories **41, 42** and **43** are determined by the output of the D.C. voltage source **11.** Accordingly, the position of the slits corresponds to the energy of the electrons focussed at the slits.

In FIG. **8,** the abscissa indicates the slit position and the ordinate indicate the density of the electrons passing through the respective slits. Electrons corresponding to the spectrum peak P are focussed to the center of the slit **39** having a slit width d, and electrons corresponding to the background noise enveloping the spectrum peak P are focussed at the center of slits **38** and **40** each having a slit width (d/2). Accordingly, when the background noise component contained in the spectrum varies linearly as shown in FIG. **8,** the net density of the spectrum peak P is obtained by subtracting the sum of the outputs of the detectors **34** and **36** from the output of the detectors **35.**

This subtracting process is effected by the circuit network **44.** The analogue output of the detectors **34** and **36** are fed into the input of the adding circuit **45** via amplifiers **46** and **47,** and the added output of the adding circuit **45** is fed into the input terminal b of the subtraction circuit **48.** At the same time, the analogue output of the detector **35** is fed into the input terminal a of the subtraction circuit **48** via amplifier **49.** After subtraction (*a*—*b*), the output signal of the subtraction circuit **48** is fed into the recorder **13** and recorded together with the output signal of the D.C. voltage source **11** which is varied continuously. In this case, the subtraction circuit **48** generates zero signal when the subtraction count value (*a*—*b*) becomes minus. Thus, the net energy spectrum peaks of the electrons emanating from the specimen are recorded.

FIG. **9** is a block schematic showing another embodiment of the analyzing device according to the invention. In analyzer section **50** of this embodiment, the three detectors **34, 35** and **36** are characterized in that their outputs are pulsed and the three slits **51, 52** and **53** are of the same width. Accordingly, the construction of the circuit network **54** is different from that of the previous embodiments. The output of amplifiers **46** and **47** are as shown in FIG. **10**(*b*) and (*c*) respectively, and both outputs are fed into the same input terminal of a flip-flop circuit **55** in the circuit network **54.** The number of output pulses of the circuit **55** is equal to the mean number of the output pulses of the amplifiers **46** and **47** as shown in FIG. **10**(*d*). The output of the circuit **55** is fed into the input terminal b of a square pulse generator **56**. And another input terminal a of the generator **56** is fed with the output pulses (shown in FIG. **10**(*a*)) of the amplifier **48** via delay circuit **57** which slightly delays its input pulses. The square pulse generator **56** generates square pulses as shown in FIG. **10**(*e*) by using the input pulses from terminal a as rise signals of square pulses and by using the input pulses from terminal *b* as fall signals of square pulses. And a gate circuit **58** is controlled so as to pass the input pulses only during the time when the square pulses are fed from the generator **56**. As a result, the number of input pulses fed into a pulse counter **59** equals the difference between the pulse number from the detector **35** and the mean pulse number from the detectors **34** and **36**. Namely the output of the pulse counter **59** corresponds to the net energy spectrum peak strength of the electron beam. And this output is fed into the brightness control grid of the cathode-ray tube **32**.

Additionally, the specimen **3** is scanned with the electron beam **4** by means of scanning coils **29**X and **29**Y complete with their signal generator **30** as same as the embodiment shown in FIG. **6**. Consequently, the scanning image of Auger electrons having specific energy is displayed on the screen of the cathode-ray tube **32**.

FIG. **11** is a block schematic showing the other embodiment according to the invention. This embodiment shown in FIg. **9** in that number of the detectors is two in analyzer section **60**. This embodiment having two detectors is effective only when the energy spectrum background noise of the electrons is constant or nearly constant.

In an analyzer section **60**, two electron detectors **61** and **62** are arranged adjacently and below two slits **63** and **64** each having same slit width. The output pulses of the detectors **61** and **62** are amplified by amplifiers **65** and **66** and processed by a circuit network **67** so as to subtract the pulses of the output of the amplifier **66** from that of the amplifier **65**. Output of the amplifier **65** is split and one output is fed into the gate circuit **58** and another output is fed into the input terminal a of the square pulse generator **56** via delay circuit **57** which slightly delays its input signal. Input pulses of the gate circuit **58** are as shown in FIG. **12**(*a*). The output of the amplifier **66** is shown in FIG. **12**(*b*) and is fed to the input terminal b of the generator **56**. The square pulse generator **56** generates square pulses, as shown in FIG. **12**(*c*), using input pulses of the terminal a as rise signals of the square pulses and by using input pulses of the terminal b as fall signals of the square pulses. And the gate circuit **58** is controlled so as to pass the input pulses only during time when the square pulses are fed from the generator **56**. Accordingly, the number of input pulses of a pulse counter **68** is equal to the difference between the number of output pulses of the detector **61** and that of the detector **62** as shown in FIG. **12**(*d*).

FIG. **6** is a block schematic showing another embodiment of the analyzing device according to this invention. In the analyzer section **27** of the embodiment, the primary electron beam **4** is focussed on the surface of a specimen **3** by a condenser lens **28** and is made to scan the specimen surface by means of scanning deflecting coils **29**X and **29**Y which are energized by a scanning signal generator **30**. The detector **9**, in this case, is designed to detect electron density directly. Accordingly, the circuit network **31** does not require any counting circuits.

During the operation of the analyzing device according to this embodiment, the output voltage of the D.C. voltage source **11** is maintained at a constant value corresponding to the desired energy spectrum peak of the Auger electrons emanating from the specimen. Such being the case, the output of the detector **9** depends on the position at which the specimen surface is irradiated by the primary electron beam. The output signal of the detector **9**, thus dependent, is amplified by the amplifier **17** and processed by the circuit network **31**. After which, the signal is supplied to the brightness control grid of a cathode-ray tube **32**. Deflection coils **33**X and **33**Y are energized by the generator **30** which also energizes scanning coils **29**X and **29**Y as previously mentioned. In this way, a scanning Auger electron image is displayed on the screen of the cathode-ray tube **32**.

We claim:

1. A device for detecting signals indicative of the density of electrons of given energy level absent background noise in an electron beam having high background noise for all energy levels comprising:

a. analyzing means for discretely passing electrons of the given energy level and at least one different adjacent energy level,

b. detecting and integrating means associated with said analyzer for detecting the electrons passed by said analyzer and producing a first signal indicative of the density of electrons of the given energy level and at least one second signal indicative of the density of the electrons of at least one different adjacent energy level,

c. processing means for subtracting a function of the at least one second signal from the first signal to provide a signal indicative of the density of electrons of the given energy level absent background noise.

2. A device according to claim **1** in which the conditions of the analyzing means are swept such that an electron energy spectrum is produced.

3. A device for detecting an electron energy spectrum of an electron beam having strong background noise at all energy levels comprising:

a. analyzing means for spatially dispersing and separately focussing electrons according to their respective energy levels and passing electrons of one energy level at a time,

b. control means for modulating the conditions of the analyzer with an alternating signal periodically varying the energy level of the electrons passed by the analyzer about a detecting energy level which is slowly and continuously swept,

c. detection and integration means associated with said analyzing means and synchronized with said alternating signal for detecting electrons passed by said analyzer producing a first signal indicative of the density of electrons of the detection energy level and producing at least one second signal indicative of the density of the electrons in at least one different adjacent energy level,

d. processing means for subtracting a function of at least one second signal from the first signal to provide a signal indicative of the density of the electrons at the detection level absent background noise and thereby producing a spectrum as the detection level is swept.

4. A device according to claim **3** in which the control means modulates the analyzer symmetrically about the detection level and the detection and integration means detects a first signal indicative of the density of the electron level during two periods including the instances in which the analyzer passes electrons at the detection level and detects second signals during periods when the first signals are not being detected.

5. A device for displaying a scanning image of the Auger electrons comprising:

a. means for irradiating a specimen with a focussed primary electron beam so as to cause the specimen to eject Auger and other kinds of electrons from the specimen,

b. scanning means for scanning said primary electron beam over the specimen,

c. analyzing means for spatially separating and separately focussing the electrons according to their respective energies,

d. means for periodically detecting the output of the said analyzing means during a background noise detection period and during a background noise and spectrum signal detection periods, said detection means being synchronized with said control means,

e. subtraction means for subtracting output of said analyzing means during the background noise detection period from the output of said analyzing means during the background noise and spectrum signal detection period, and

f. display means for displaying a scanning image brightness modulated by the output signal of said subtraction means, said display means being synchronized with the scanning means.

6. A device for detecting a signal indicative of the density of electrons of given energy level absent background noise in an electron beam having high background noise for all energy levels comprising:

a. analyzing means for spatially separating and separately focussing the electrons according to their respective energies,

b. detecting means comprising a plurality of detectors for producing a signal indicative of the density of the electrons focussed by said analyzing means on said detectors, said detectors being located adjacently such that their signals are indicative of the densities of the electrons at adjacent energy levels, and

c. processing means for subtracting a function of the signal indicative of the density of electrons at adjacent energy levels from the signal indicative of the given energy level to provide a signal indicative of the density of electrons of the given energy level absent background noise.

7. A device according to claim **6** in which the detecting means comprises three adjacent detectors for detecting different adjacent energy levels in which the processing means subtracts a function of the signal from the detectors detecting the high and low energy levels from the signal of the other detector.

8. A device for displaying a scanning image of the Auger electrons of a given energy level comprising:

a. means for irradiating a specimen with a focussed primary electron beam causing the specimen to eject Auger and other kinds of electrons from the specimen,

b. scanning means for scanning said primary electron beam over the specimen,

c. analyzing means for spatially dispersing and separately focussing the electrons dislodged from the specimen according to their respective energy levels,

d. detecting and integrating means comprising a plurality of adjacent detectors for detecting the electrons focussed by said analyzing means providing signals indicative of the density of the electrons of the given and adjacent energy levels,

e. processing means for subtracting a function of the signals indicative of the given energy levels from a signal indicative of the adjacent energy levels to provide a signal indicative of the electron density of electrons of the given energy level absent background noise,

f. display means synchronized with said scanning means for displaying the scanning image brightness modulated by the output of said processing means.

* * * * *