

[54] **ELECTRON DETECTOR**  
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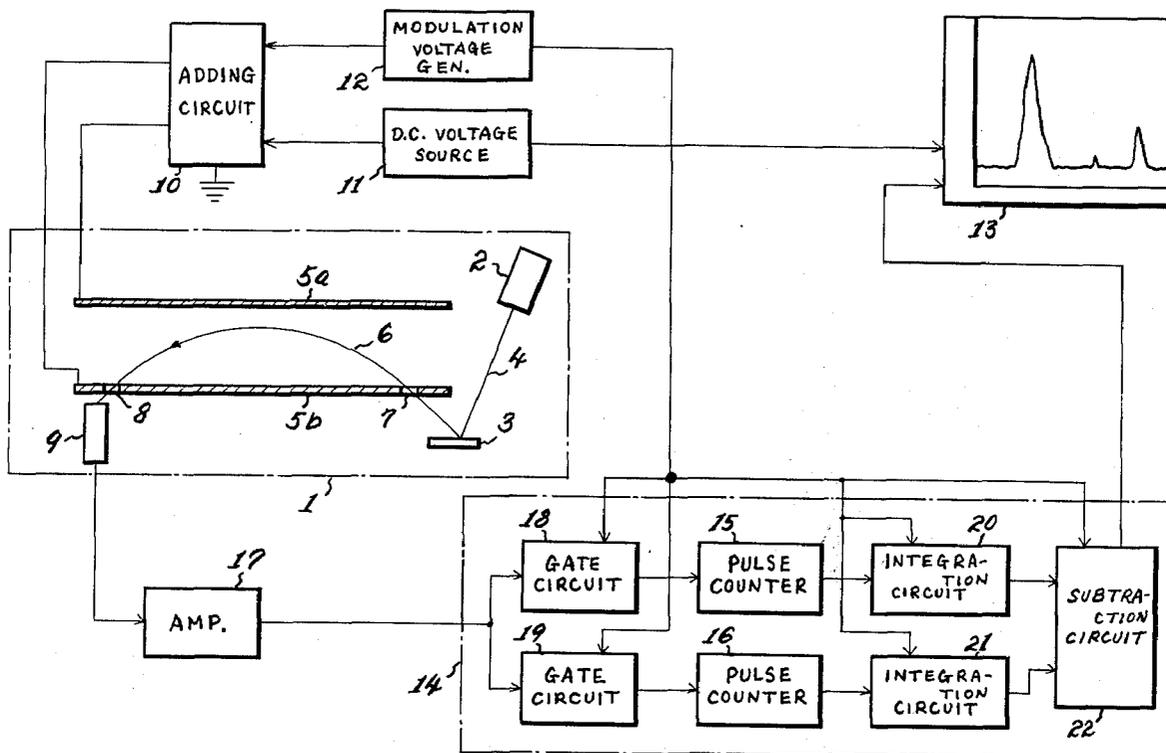
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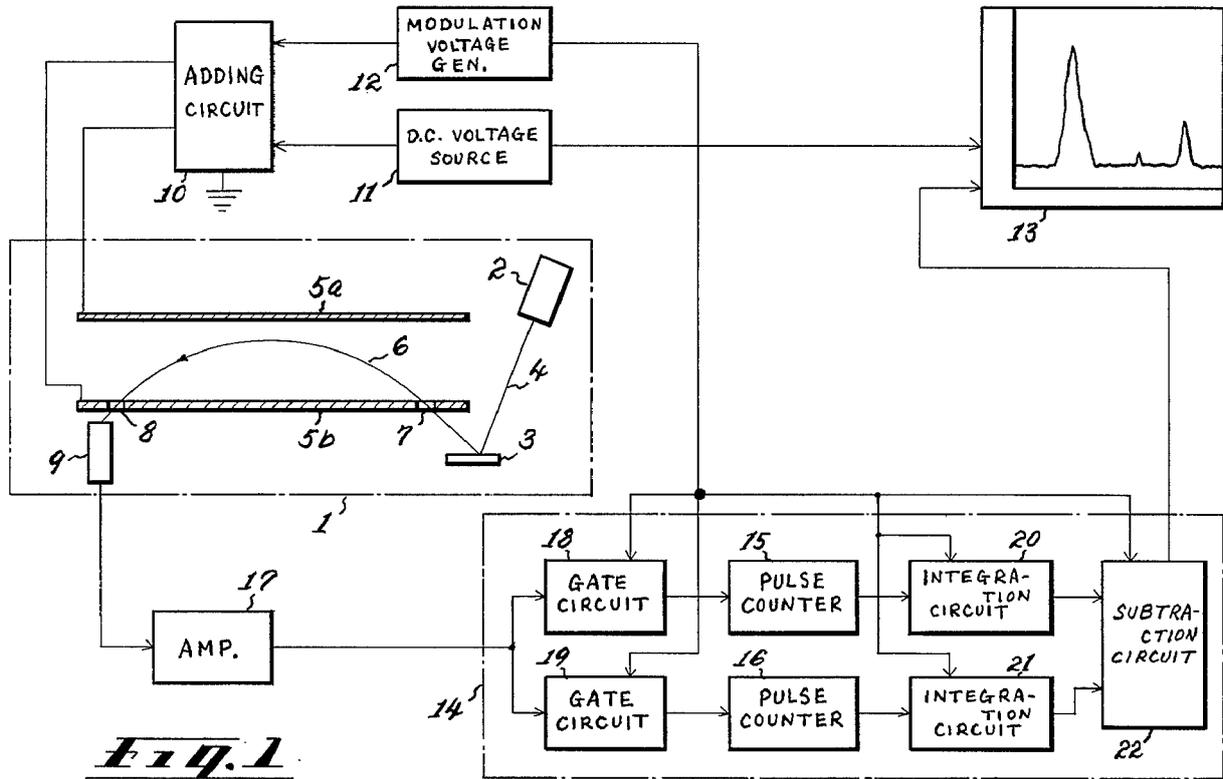
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 [51] **Int. Cl.<sup>2</sup>** ..... **H01J 39/00**  
 [58] **Field of Search** ..... 250/305, 306, 440, 282

[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.

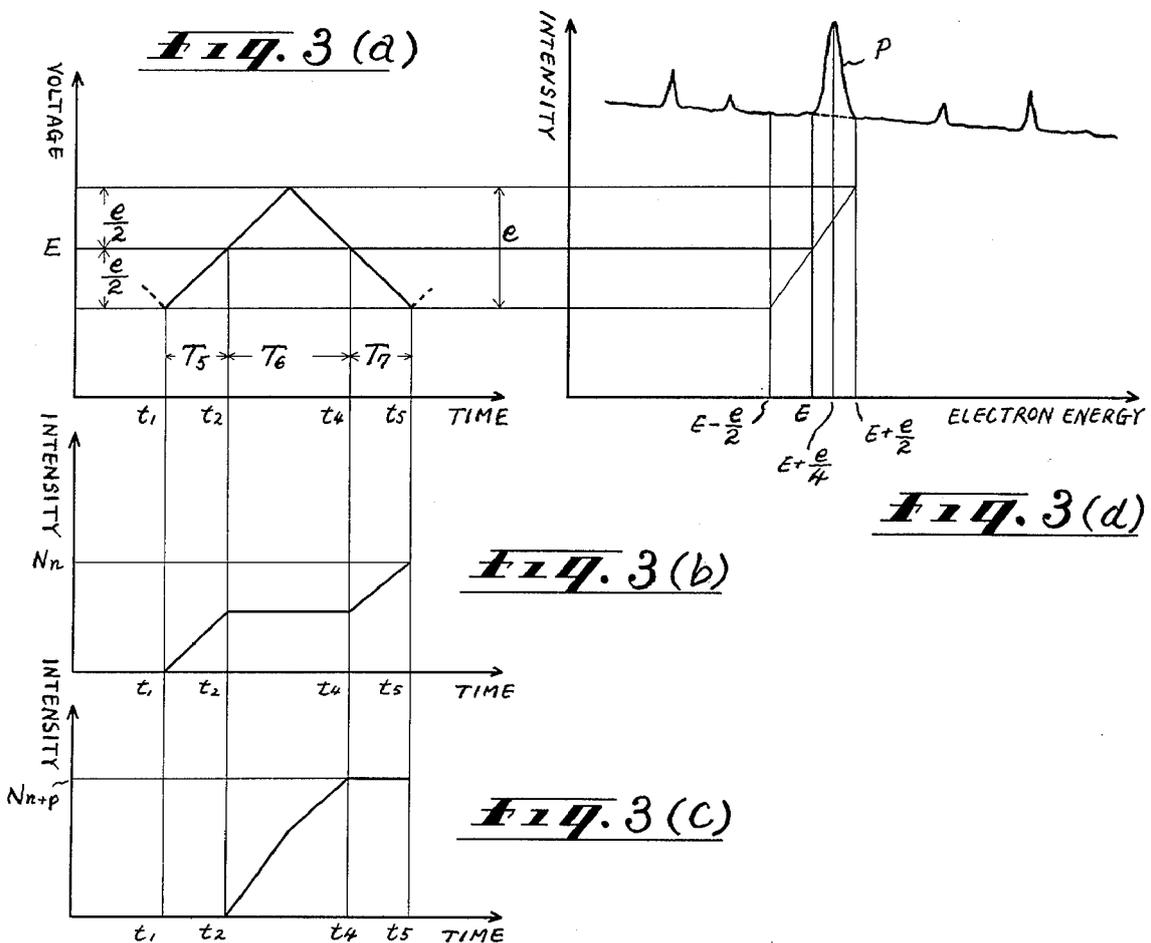
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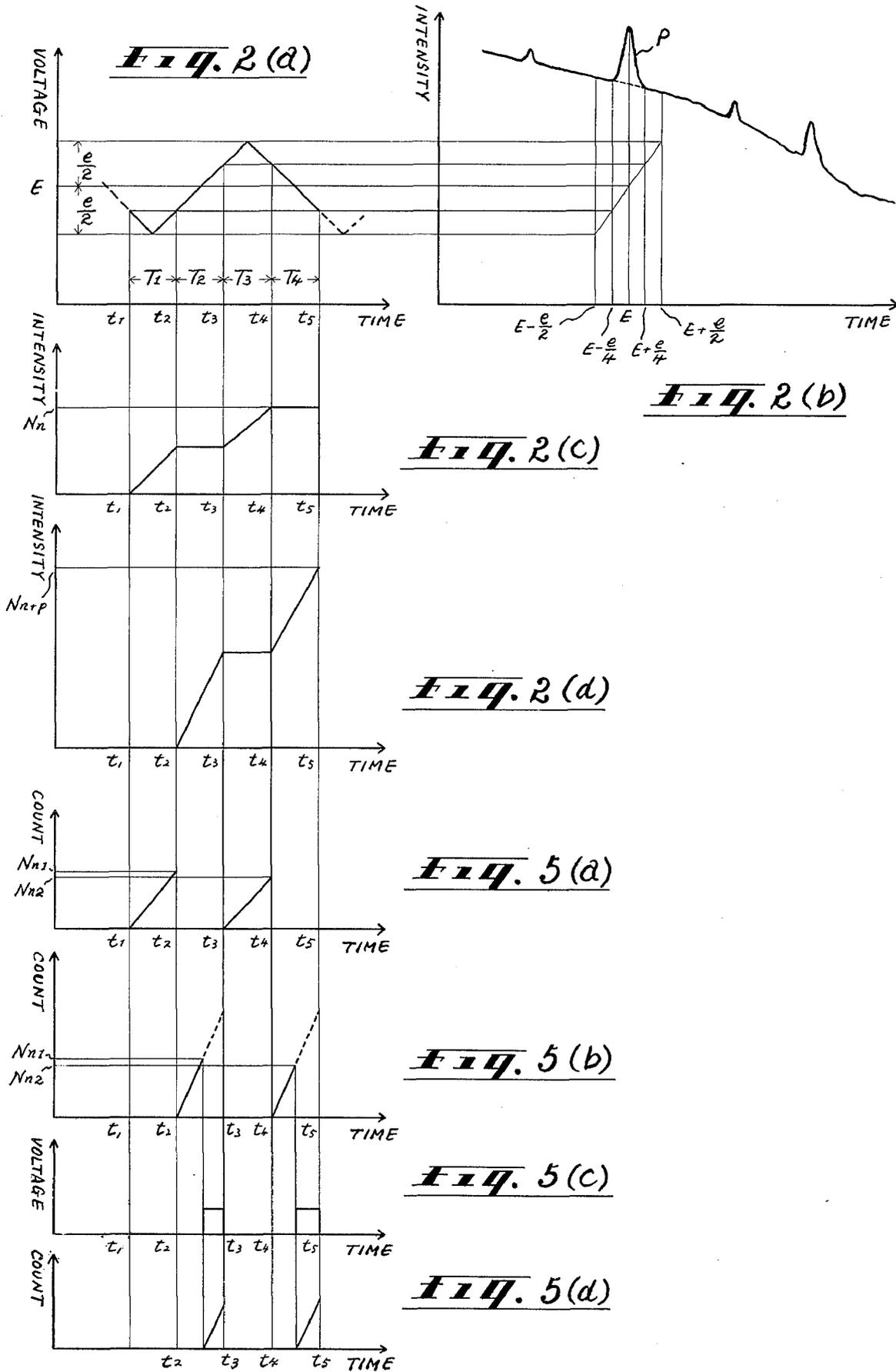
**8 Claims, 21 Drawing Figures**

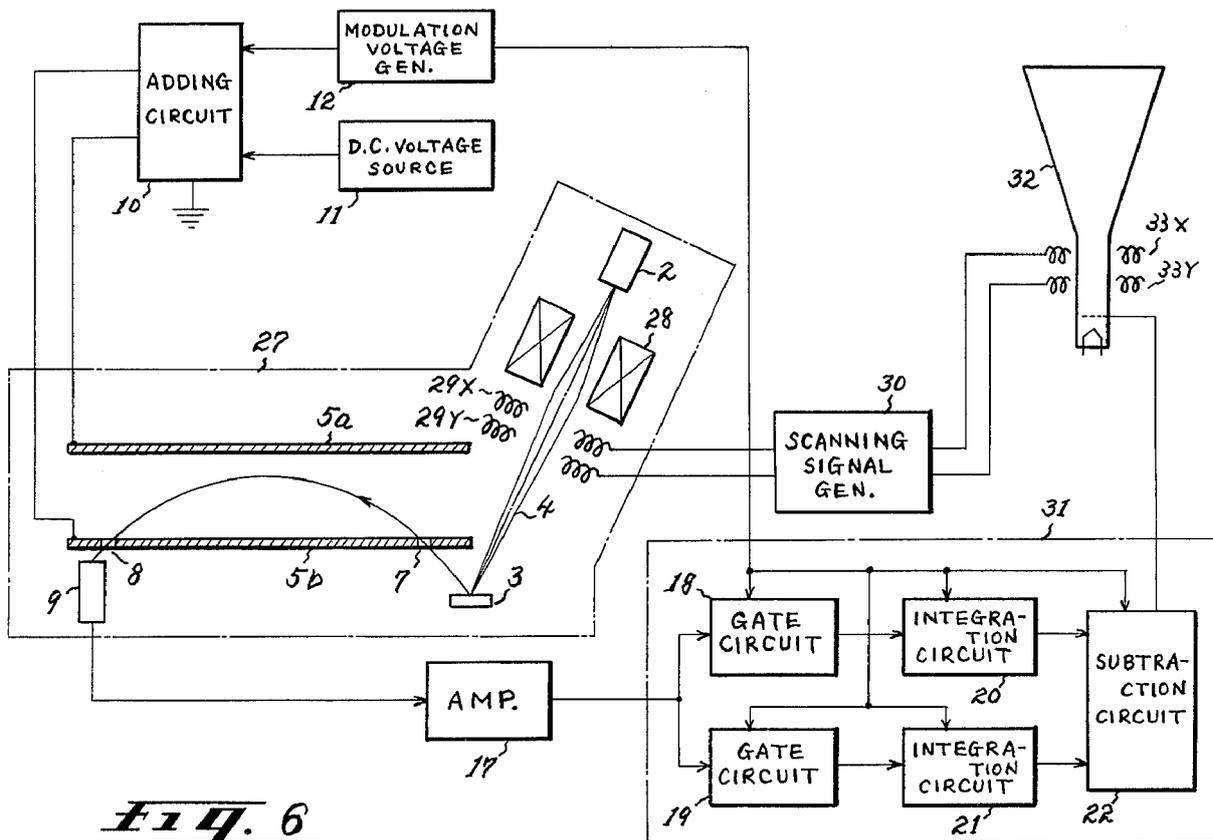
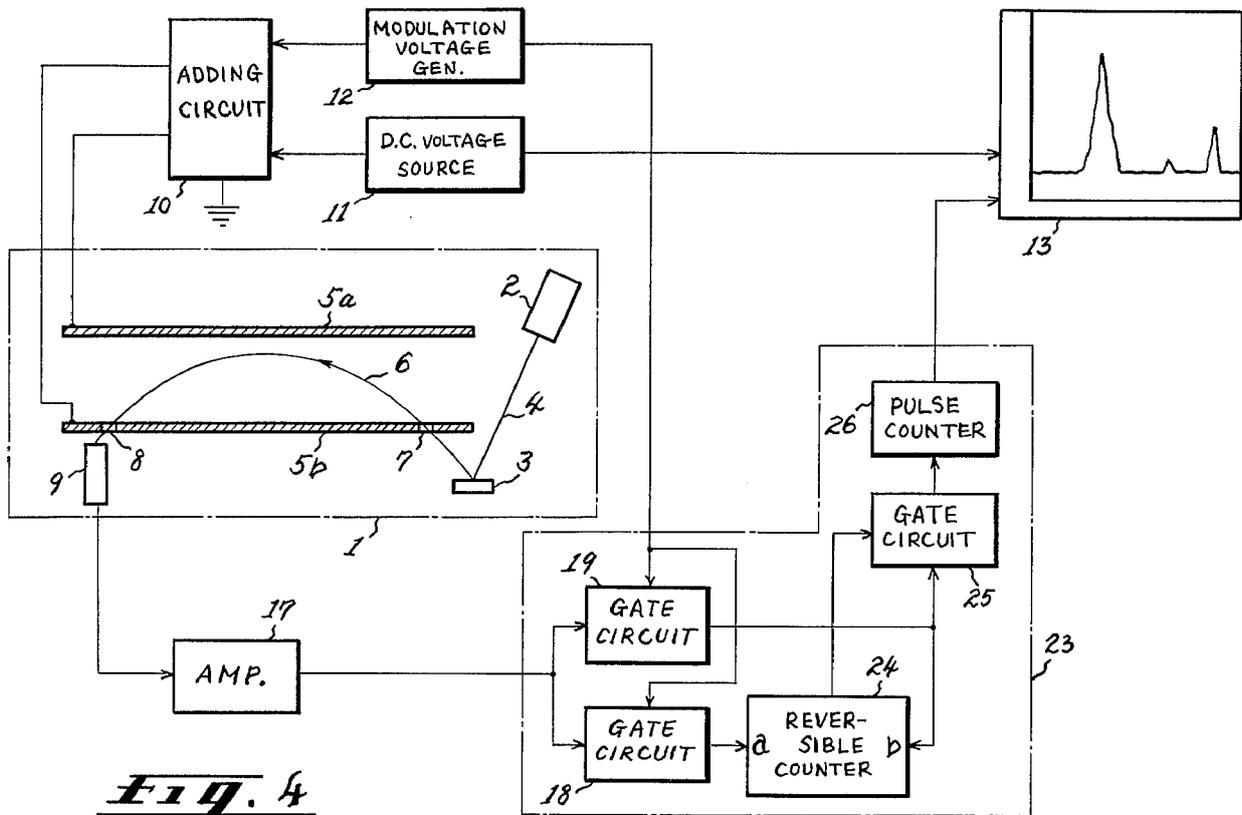


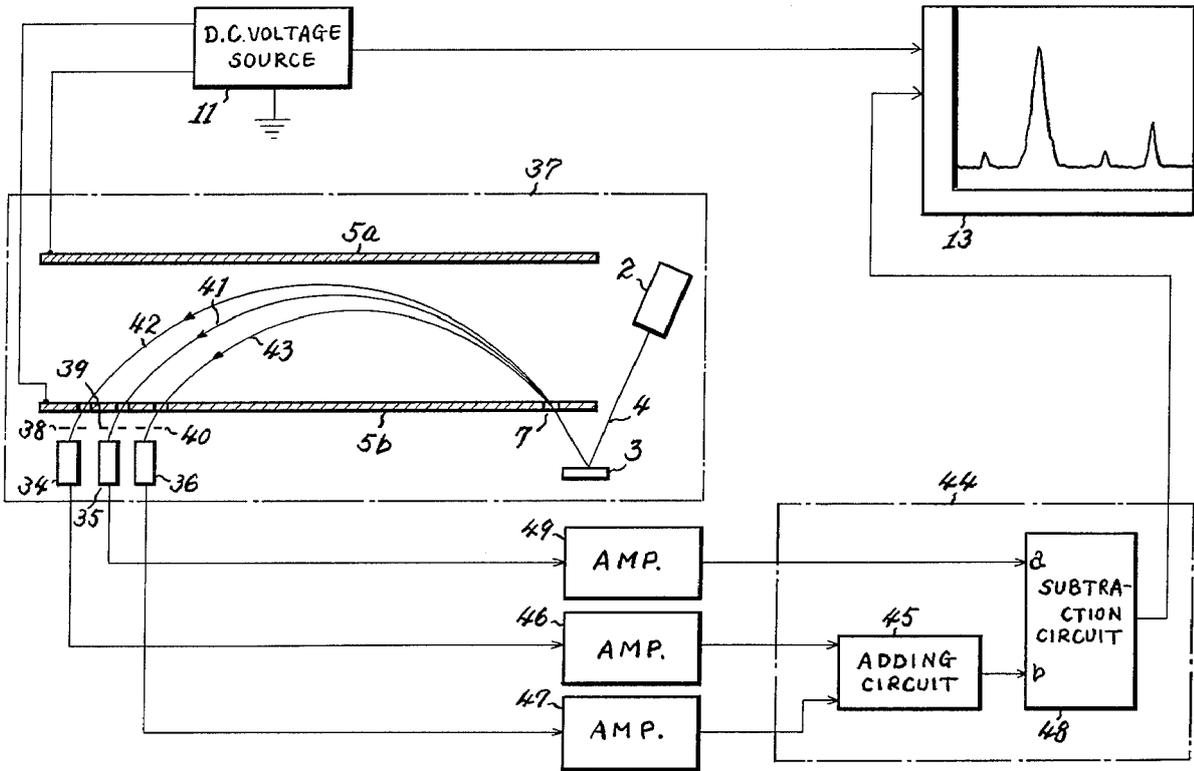


**Fig. 1**

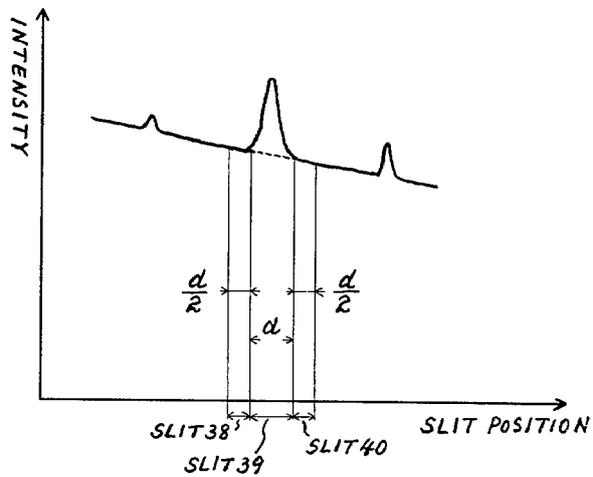






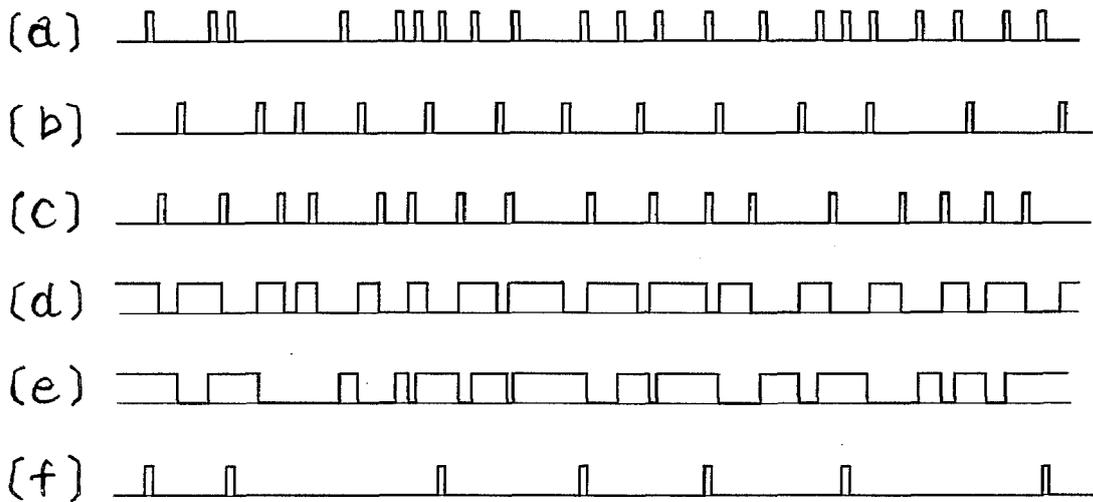
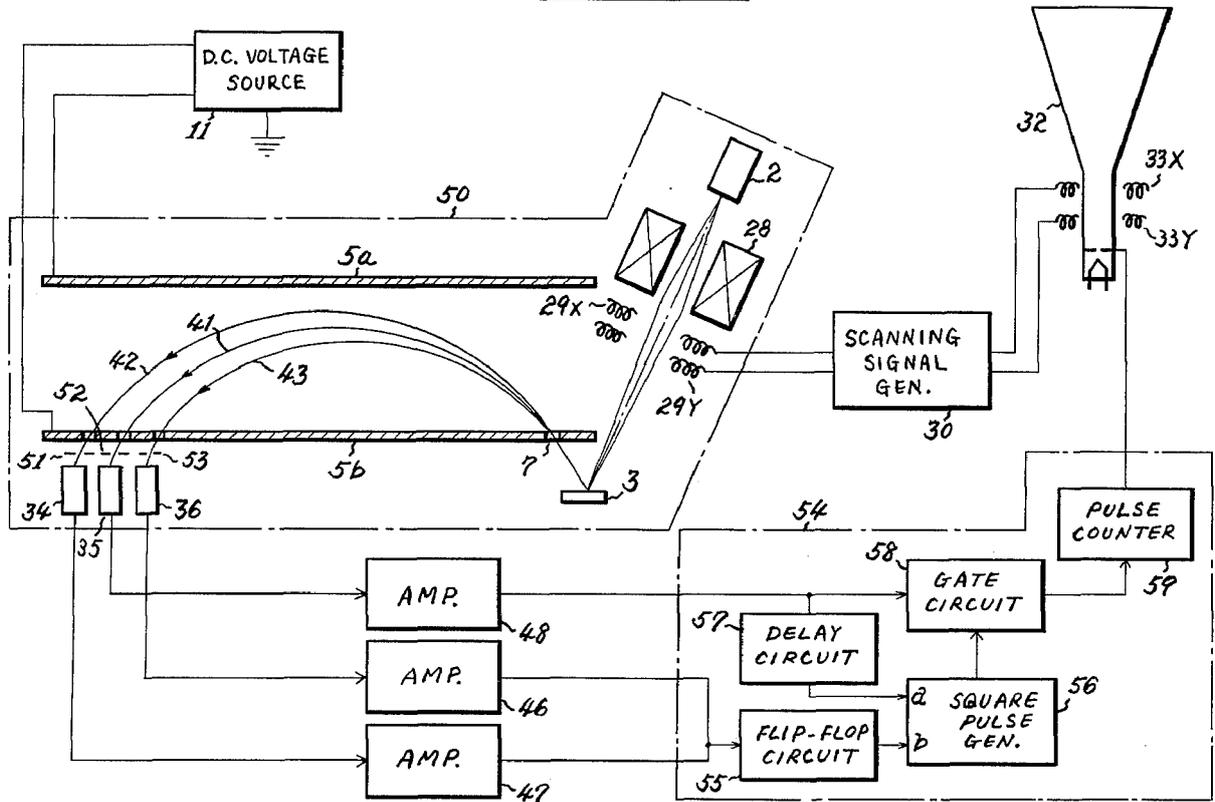


**Fig. 7**

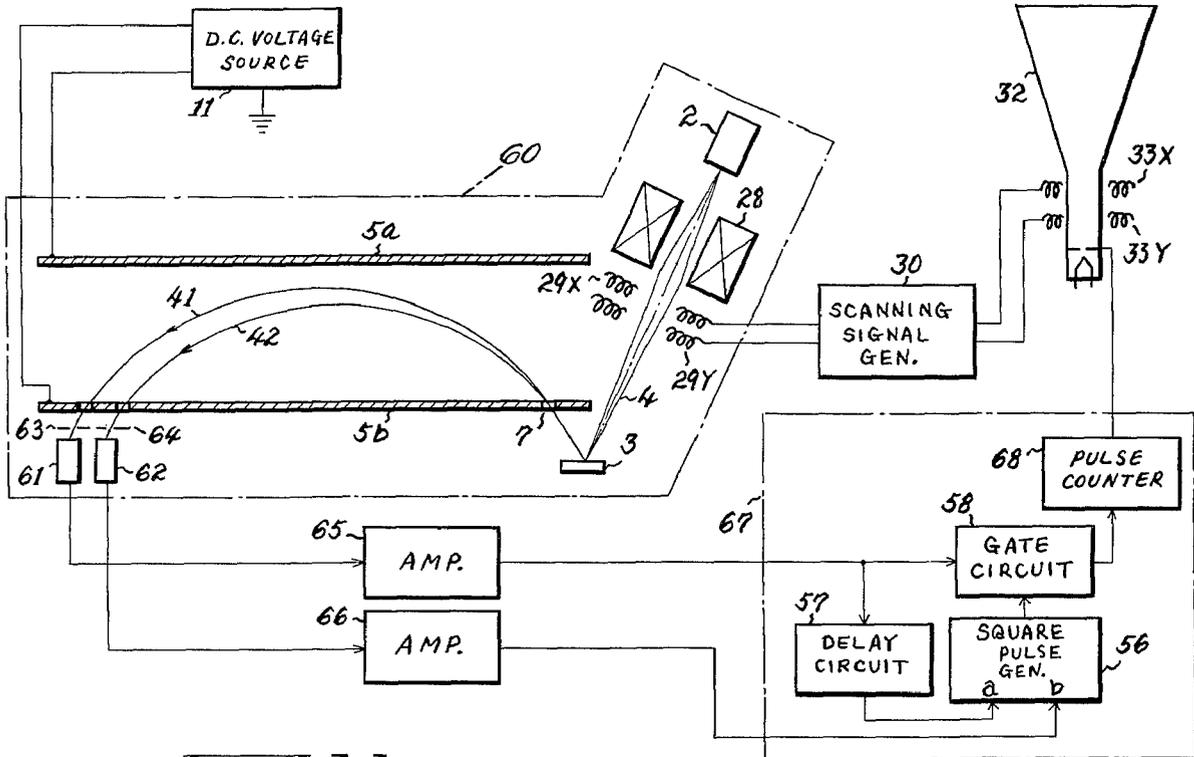


**Fig. 8**

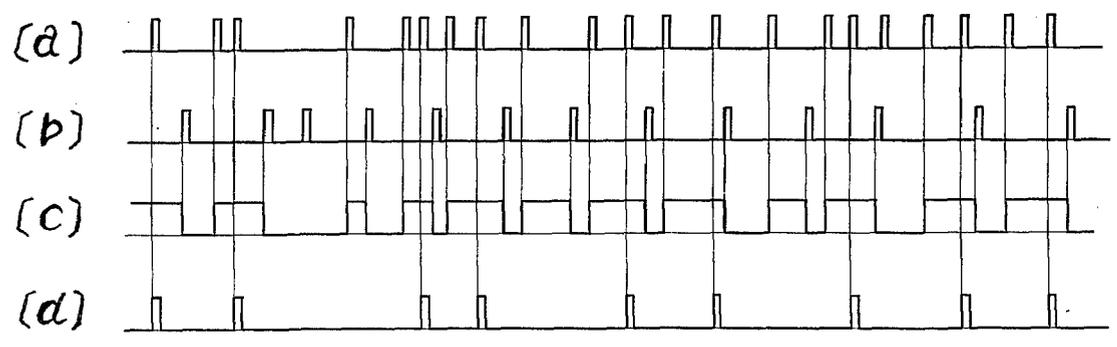
**Fig. 9**



**Fig. 10**



**Fig. 11**



**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 5a and 5b 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 5b and are subjected to the electric field existing between the electrodes 5a and 5b. 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 5a and 5b. 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 foregoing. 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 timing 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 5a and 5b 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 29X and 29Y 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 29X and 29Y 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 33X and 33Y are energized by the generator 30 which also energizes scanning coils 29X and 29Y 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.

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