

Nov. 30, 1965

KEN-JI KAZATO ETAL
ELECTRON MICROSCOPE WITH MEANS FOR TREATING
AND OBSERVING SPECIMENS

3,221,133

Filed April 2, 1963

9 Sheets-Sheet 1

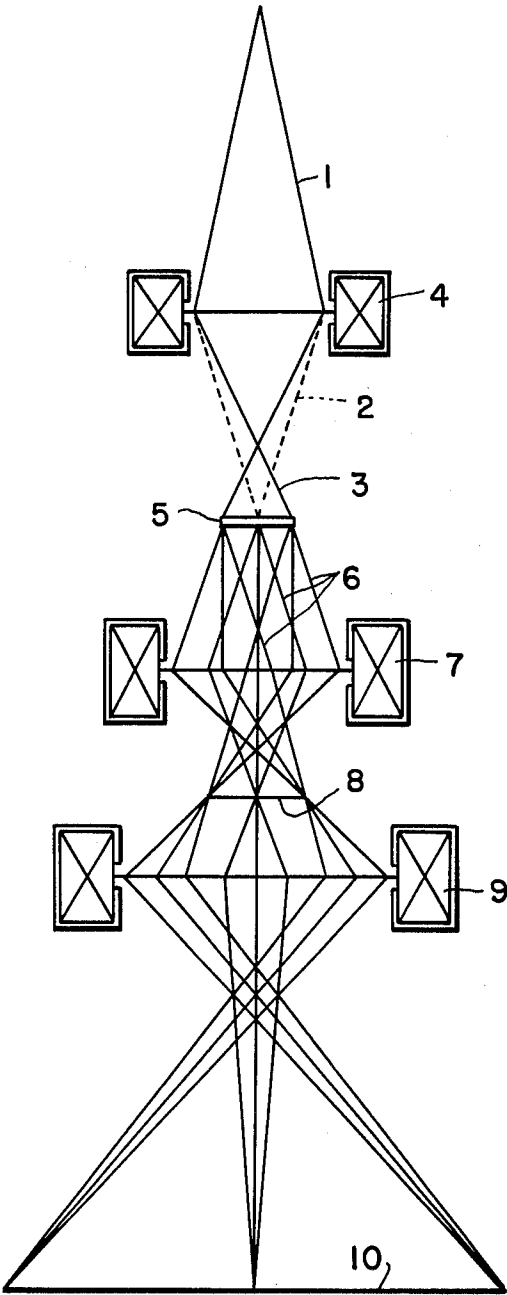


Fig. 1

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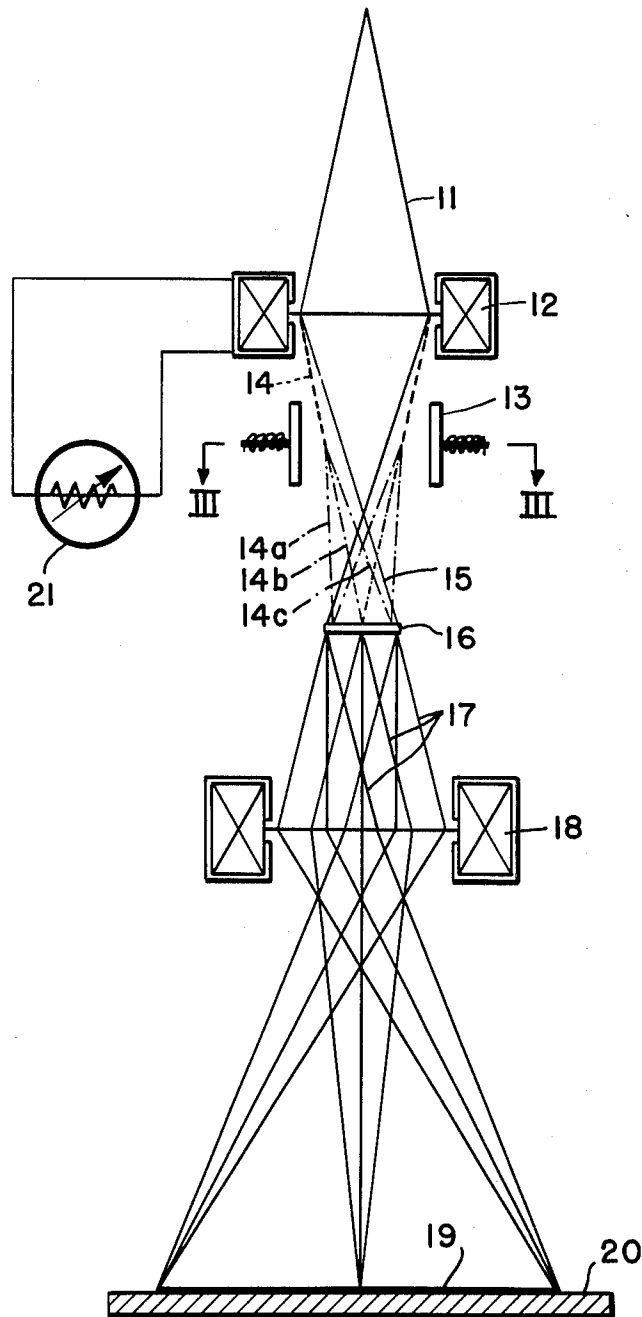


Fig.2

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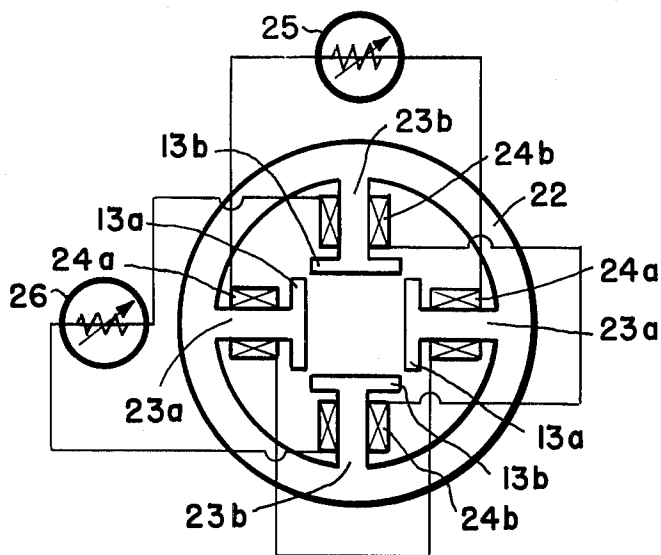


Fig. 3

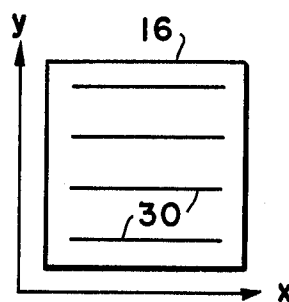


Fig. 5

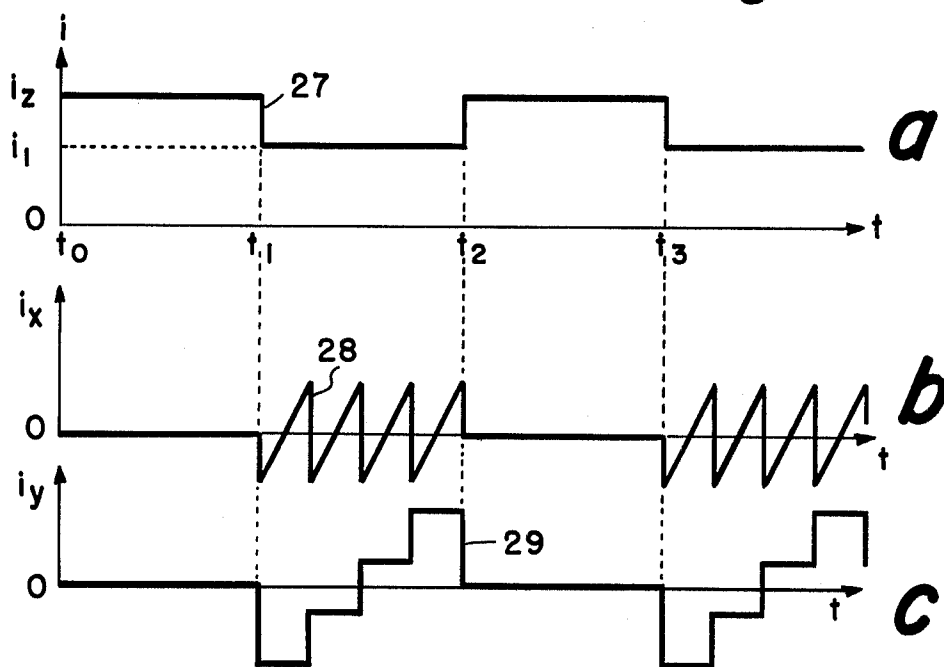


Fig. 4

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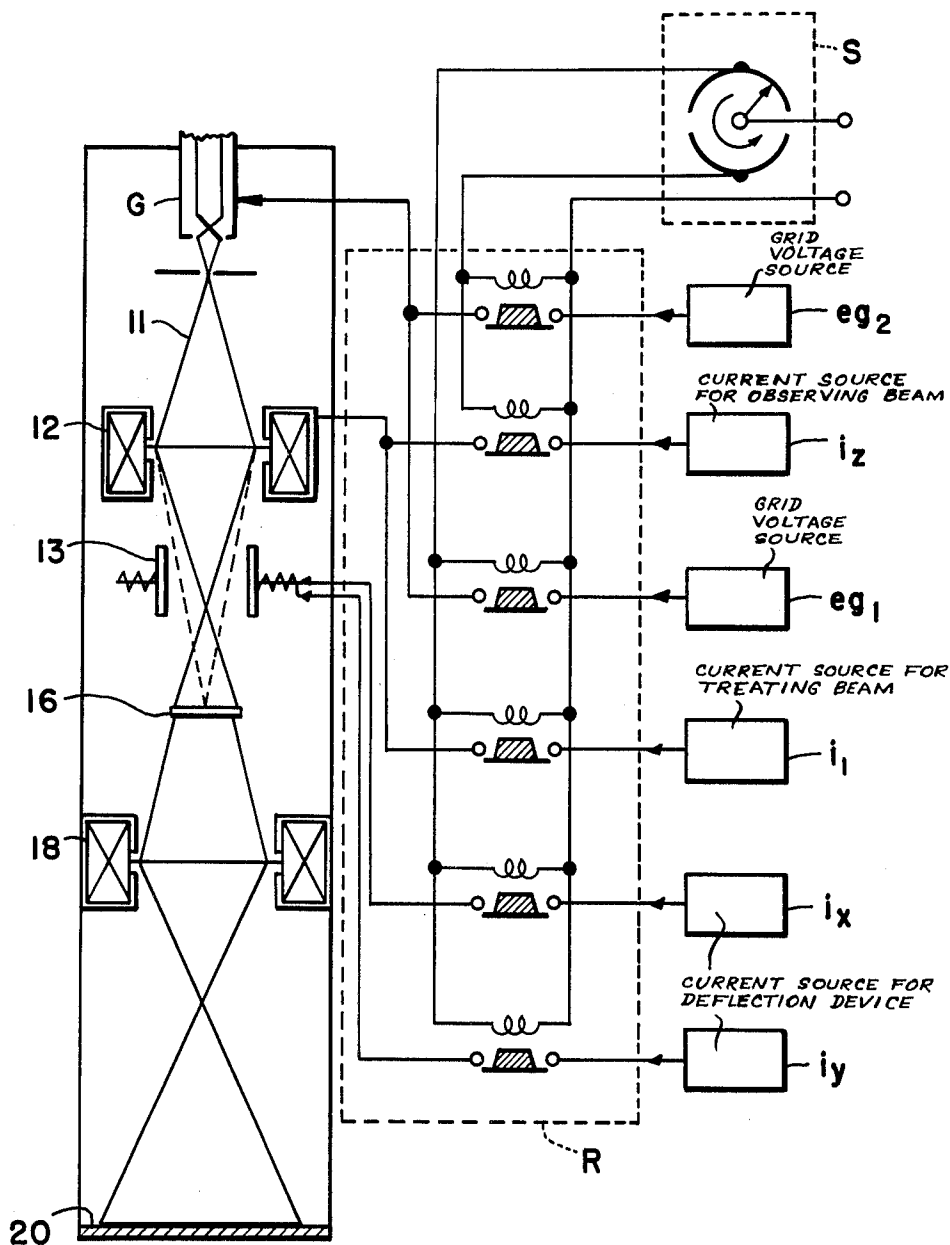


Fig.6

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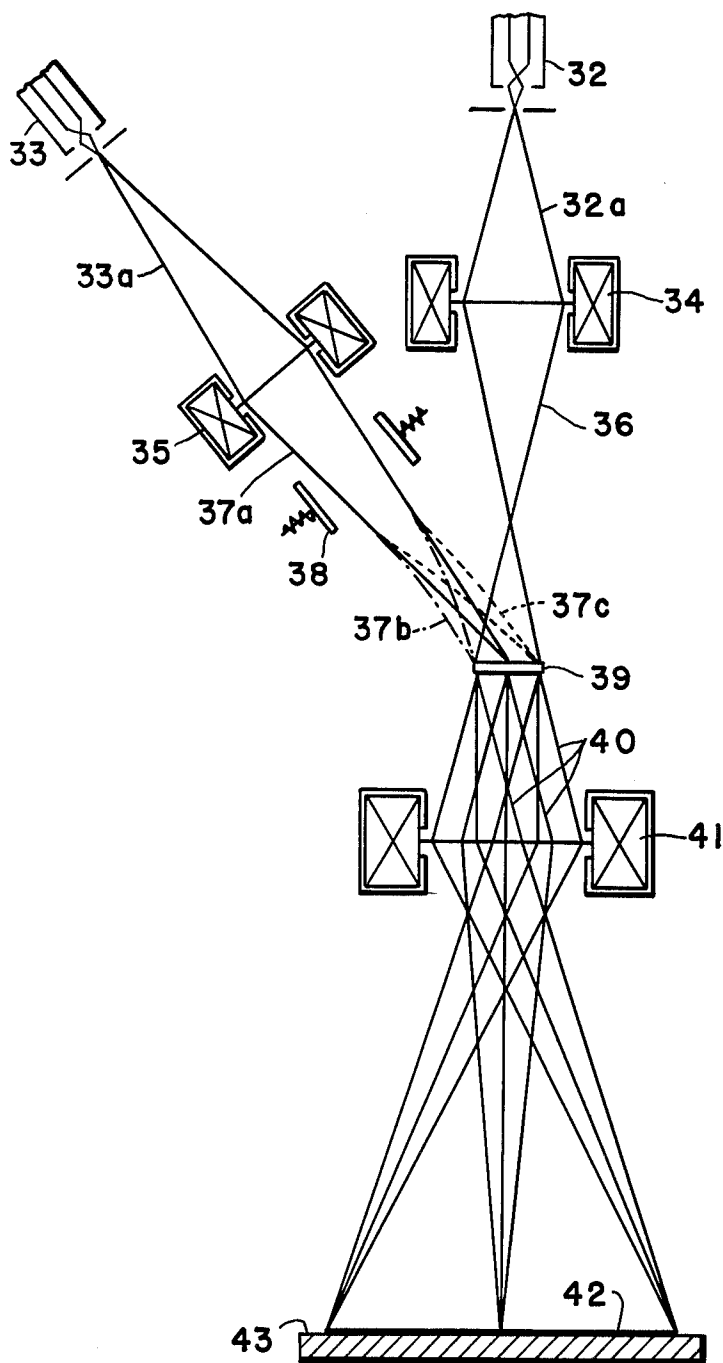


Fig. 7

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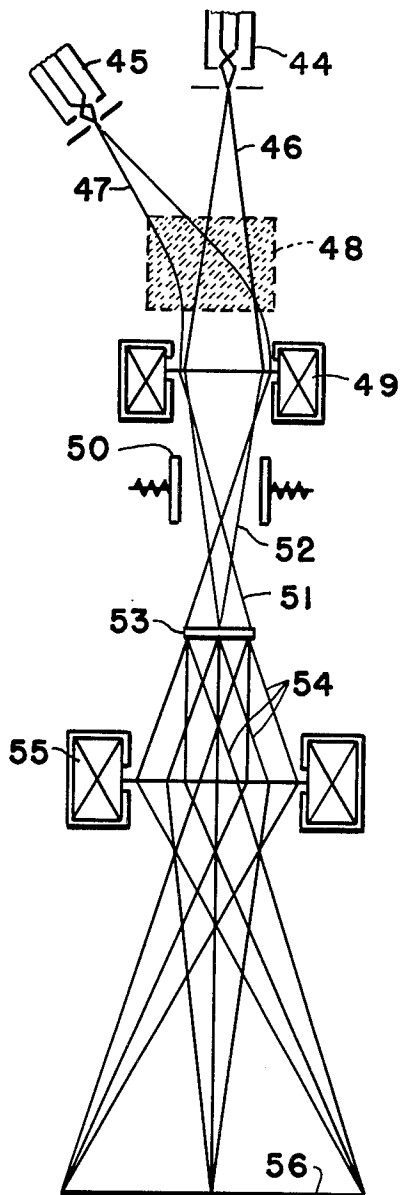


Fig. 8

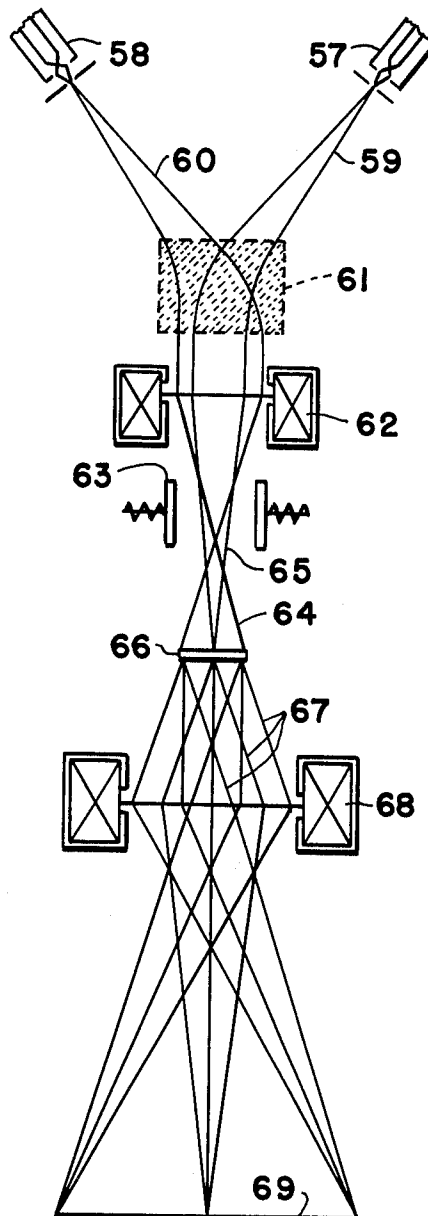


Fig. 9

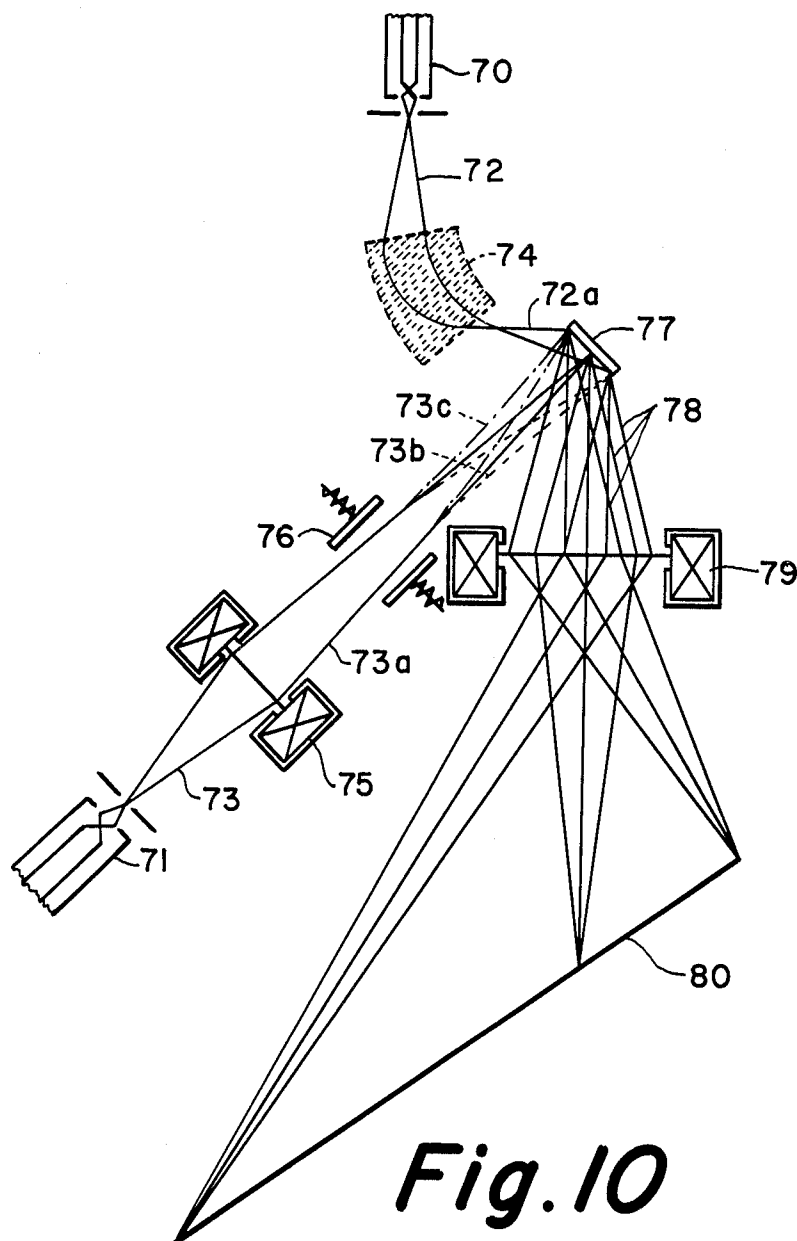
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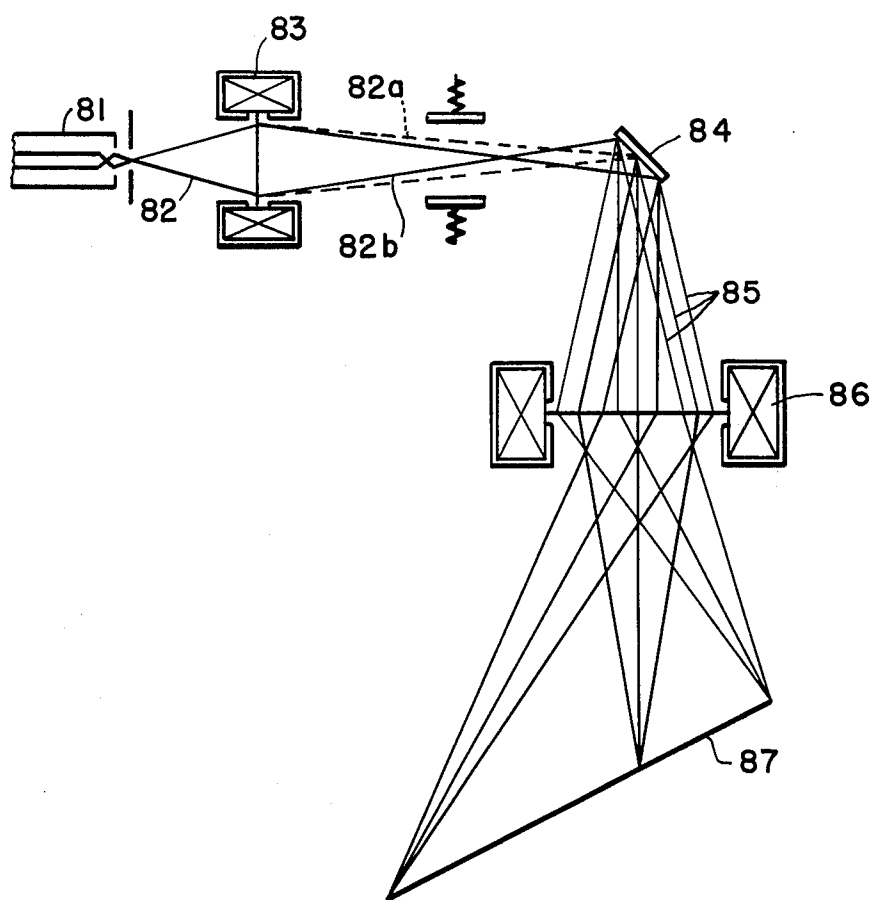


Fig. II

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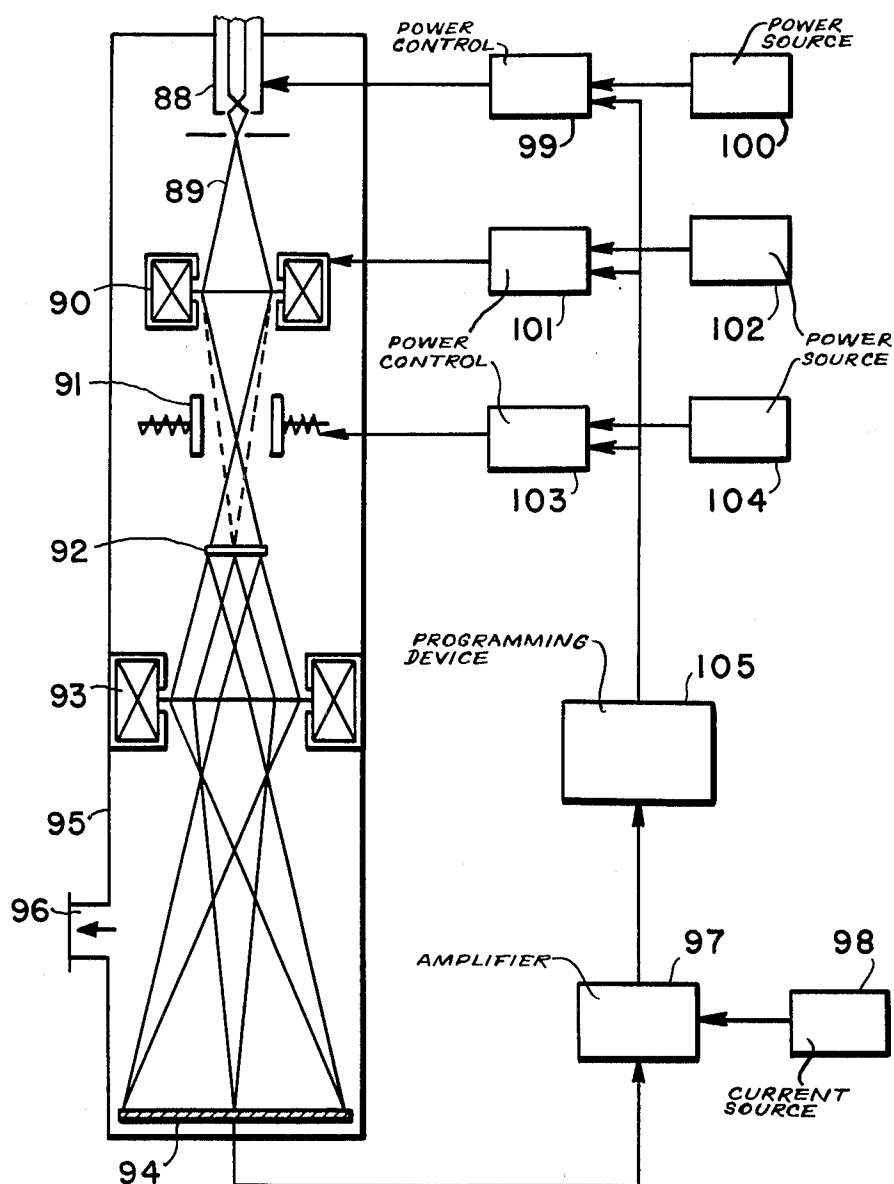


Fig. 12

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ELECTRON MICROSCOPE WITH MEANS FOR TREATING AND OBSERVING SPECIMENS

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7 Claims. (Cl. 219-69)

This application relates to an electron microscope or the like which may be used for treating a specimen, in addition to observing it. The treating beam produces a change in the shape of a specimen by removing portions thereof. Thus, it may be used to groove, cut or bore the specimen, and it is particularly useful for producing miniaturized electronic parts, such as resistors, by grooving metal films in accordance with a master design. The treating beam can also be used for the manufacture of synthetic fiber nozzles, shadow masks for color televisions, etc.

In our electron microscope, the focal length of a magnetic condenser lens is changed by varying the amount of current which is applied to the lens. By changing the focal length of the condenser lens, electrons emitted from an electron gun are switched from a beam used to observe the specimen to a beam used for treating the specimen. The switching of the beam of electrons from one type to another can be done automatically by suitable electronic circuits, and the specimen can be observed while it is being treated.

The foregoing operation is carried out when the specimen is sufficiently thin to transmit an electron beam. It is also possible to observe a magnified image of the specimen by means of an electron beam reflected from the specimen or by means of particles emitted from the specimen.

The image formed by the microscope can be directed onto a vidicon tube, and that tube will transmit a signal to an electronic circuit which programs the operation of the treating beam.

In the accompanying drawings, we have shown certain presently preferred embodiments of our invention in which:

FIGURE 1 is a diagram illustrating the principles of our invention;

FIGURE 2 is a diagrammatic illustration of one embodiment of our invention;

FIGURE 3 is a section along the line III-III of FIGURE 2;

FIGURE 4 is a graph showing the relationship with respect to time of the various control currents which affect the operation of the microscope;

FIGURE 5 is a plan view of a treated specimen;

FIGURE 6 is a schematic diagram showing an electric circuit for controlling the operation of a microscope embodying our invention;

FIGURES 7 to 11, inclusive, are diagrammatic illustrations of various modifications of our invention; and

FIGURE 12 is a block diagram of a circuit for programming and controlling the operation of a microscope.

Referring to FIGURE 1, an electron beam 1 emitted from an electron gun (not shown) produces either a treating beam 2 or an observing beam 3 depending upon the current supplied to a magnetic condenser lens 4.

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When the beam is acting as a treating beam, the current to the condenser lens 4 is adjusted so that the point of minimum cross section of the beam falls on the surface of the specimen. When the beam acts as an observing beam, the focal length of the condenser lens is adjusted so that the point of minimum cross section of the beam is above the specimen 5, and the beam uniformly illuminates the surface of the specimen. The focal lengths of the condenser lens can also be adjusted so that the point of minimum cross section of the observing beam is below the specimen 5.

The observing beam 3 is transmitted through the specimen 5 and forms beams diagrammatically illustrated at 6 which pass through a magnetic objective lens 7 which focuses them into a first magnified image 8. The beams then continue through a magnetic projection lens 9 and form a second magnified image 10 which may be observed on a fluorescent screen.

The treating beam 2 is focused so that the point of minimum cross section of this beam falls on the surface of the specimen 5 and can be used for grooving, cutting or boring the specimen 5 by electron bombardment. The spot where the treating beam strikes the surface of the specimen is also focused to form an image which can be observed, and thereby the treating beam 2 can be measured and controlled.

It will be understood that, as in conventional electron microscopes, the spaces through which the electron beams travel are maintained under a high vacuum (in the order of 10^{-4} mm. of mercury) so that the beams are not deflected by gas particles in these spaces.

Referring to FIGURE 2, an electron beam 11 generated by an electron gun (not shown) is shifted from a treating beam 14 to an observing beam 15 and back again by varying the current supplied to a magnetic condenser lens 12 in the same manner as described with reference to the treating beam 2 and observing beam 3 of FIGURE 1. In the device shown in FIGURE 2, the beams 14 and 15 are used to treat and observe a specimen 16. An electron beam 17 transmitted through the specimen is focused by an objective lens 18 to form a magnified image 19 on a fluorescent screen 20.

The microscope shown in FIGURE 2 also has a beam deflecting device 13 which will be later described with reference to FIGURE 3. The deflecting device operates only when the treating beam 14 also operates, and is used to make the treating beam 14 scan the surface of the specimen 16.

FIGURE 3 shows the electromagnetic deflection device 13. It comprises oppositely disposed magnetic pole pieces 13a and 13b mounted on cores 23a and 23b. Coils 24a and 24b are mounted on the cores and are supplied with current from power sources 25 and 26. A circular iron yoke 22 carries the cores 23a and 23b and provides a magnetic return path for the magnetic circuit.

Referring to FIGURE 2, the electron beam 14 passes through the deflection device 13 in a direction at right angles to the magnetic fields formed by the pole pieces 13a and 13b, and when current is supplied to the coils 24a and 24b, the beam is deflected an amount proportional to the magnetic field, which in turn, is proportional to the amount of current supplied to the coils. By varying the direction and intensity of the magnetic field created by the deflection device 13, the treating beam 14 can be moved across the surface of the specimen 16.

FIGURE 4 is a series of graphs showing the variations in current to the lens 12 and the coils 24a and 24b which will produce the parallel grooves or slits 30 in the specimen 16 as illustrated in FIGURE 5. In FIGURE 4, time is plotted along the abscissa, and the current is plotted along the ordinate of the graph. FIGURE 4 (a) shows how the current i supplied to the condenser lens 12 varies with time. During the time period from t_0 to t_1 , an exciting current i_2 is supplied to the lens 12, and the observing beam 15 uniformly illuminates the surface of the specimen. At time t_1 , an exciting current i_1 is fed to the coil 12, and the electron beam is converted to the treating beam 14, and the treatment continues until time t_2 . For the time period t_2 to t_3 , the observing beam 15 again illuminates the surface of the specimen 16.

FIGURE 4 (b) shows the supply of current i_x to the deflection coils 24a during the same time periods which were referred to with respect to the current supplied to the coil 12. As shown during the time periods t_1 to t_2 , and after t_3 , a current having a sawtooth wave form 28 is supplied to the coils 24a. During the time periods t_0 to t_1 and t_2 to t_3 , when the electron beam 11 is switched to an observing beam 15, no current is supplied to the deflecting coil 24a.

FIGURE 4 (c) shows the variations in the current i_y applied to the deflection coils 24b. During the period t_1 to t_2 and that following the period t_3 , current in stepped wave form 29 is supplied to the deflection coils 24b. As shown in FIGURE 4 (b), no current is supplied to deflecting coils 24b when the electron beam 11 is acting as an observing beam 15.

During the time periods when the electron beam 11 is switched to treating beam 14, the magnetic pole pieces 13a and 13b are actuated by the sawtooth wave current shown in FIGURE 4 (b) and the stepped wave form shown in FIGURE 4 (c), the successive positions of the treating beam 14 as deflecting being shown as 14a, 14b and 14c in FIGURE 2.

During the treatment periods, for example, during the period t_1 to t_2 , the specimen under treatment can be observed by cutting off the current to the deflection device 13 and changing the current to the lens 12 so that the electron beam acts as an observing beam. It is also possible to continuously observe the treating process on the specimen by shortening the intervals of time, i.e., t_0 to t_1 , t_1 to t_2 , etc., and by switching the beams with sufficient rapidity that a continuous image appears on the fluorescent screen 20 due to persistence of vision which is characteristic of the human eye.

FIGURE 6 shows diagrammatically a circuit whereby the electron beam 11 can be changed from a treating beam to an observing beam and back again, and the deflecting device may be timed to act on the treating beam, both with sufficient rapidity that the process can be continuously observed due to persistence of vision. In FIGURE 6, the six small blocks at the right side of the figure represent voltage and current sources which are connected to the electron gun, condenser coil 12 and the deflecting device 13. Block eg_2 is a source of grid voltage for the electron gun G, and block i_2 represents the source of current for the lens 12 when the beam is acting as an observing beam. Block eg_1 is the source of grid voltage for the electron gun, and block i_1 represents the source of current for the lens 12 when the beam is acting as a treating beam. Blocks i_x and i_y represent the sources of current for the beam deflection device when it is in operation. Each source of voltage or current is connected through an electromagnetic relay to the component of the microscope which it is to supply, the several relays being designated by the general reference letter R in FIGURE 6. The several relays are controlled by a switch S so that voltages and currents can be supplied to the operative components in proper sequence to change

the electron beam from a treating beam to an observing beam and to deflect the beam when it is acting as an observing beam. If the switch S is operated at a speed to cause the relays to shift the beam from one type to another as fast as individual frames of a motion picture film are passed through a projector, then the image seen on the fluorescent screen 20 will appear to be continuous due to persistence of vision.

FIGURE 6 shows a mechanically actuated circuit for shifting the voltage and currents. The currents and voltages could be shifted by conventional electronic circuits as well.

In the foregoing description of the operation of the microscope shown in FIGURE 2, the electron beam has been changed from a treating beam to an observing beam by changing the focal length of the condenser lens 12. The same result can be obtained by varying the accelerating voltage supplied to the accelerating grid of the electron gun.

The scanning range of the treating beam when shifted by the electrical deflecting device 13 is relatively limited, and, therefore, if a number of identical shapes are to be formed following a master copy, a mechanical shifting device can be used to move the specimen 16 under the path of the treating beam.

FIGURE 7 shows a modification of our invention in which two electron guns 32 and 33 are used instead of a single gun. The electron gun 32 produces an electron beam 32a which passes through a condensing lens 34 and forms an observing beam 36 which uniformly illuminates the surface of a specimen 39. The electron gun 33 produces an electron beam 33a which passes through condensing lens 35 and forms a treating beam which is shown in three positions, 37a, 37b and 37c, it being shifted by the deflection device 38. The electron beam 40 transmitted through specimen 39 is focused by a projection lens 41 to form a magnified image 42 on a fluorescent screen 43. By using two electron guns, it is possible to treat and observe a specimen such as the specimen 39 at the same time.

FIGURE 8 shows a further modification of our invention in which two electron guns 44 and 45 are used. In this embodiment, the accelerating voltage of the electron gun 44 is set higher than the accelerating voltage of the electron gun 45. The two electron beams 46 and 47 emerging from the gun 44 and 45, respectively, pass through a magnetic field which flows in a direction perpendicular to the plane of the drawing and is represented by the shaded area 48. Because the accelerating voltage for the electron beam 47 is less than that for the beam 46, the magnetic field 48 curves the beam 47 but does not affect the beam 46. Both beams pass through a condensing lens 49, which likewise affects the beam 47 more than the beam 46, so that the beam 47 is focused in advance of the specimen and uniformly illuminates the surface of the specimen 53. The beam 46 from the gun 44 is focused so that its area of smallest cross section is on the surface of the specimen 53 and thereby forms a treating beam 52 which is subjected to the deflecting device 50 which operates in the same manner as the deflecting device 13 shown in FIGURE 2. Electron beam 54 transmitted through the specimen 53 is focused by the projection lens 55 to form a magnified image 56 of the specimen 53.

The arrangement shown in FIGURE 8 has the advantage that the treating beam 52 is projected directly along the optical axis of the condenser lens 49 onto the specimen 53, thereby avoiding astigmatism of the lens 49 and increasing the intensity of the energy of the treating beam on the surface of the specimen 53.

FIGURE 9 shows a further modification of our invention in which two electron guns 57 and 58 produce two electron beams 59 and 60, which are oppositely

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charged with respect to each other. The two beams 59 and 60 are curved by a magnetic field which flows in a direction at right angles to the plane of the drawing, and which is represented by the shaded area 61 in FIGURE 9 so that the two beams 59 and 60 pass through a condensing lens 26. In the arrangement shown in FIGURE 9, the electron beam 59 forms a treating beam 65, and the beam 60 forms an observing beam 64. The observing beam 64 is transmitted through the specimen 66 and forms beams 67, which are focused by the projection lens 68 to form an enlarged image 69 of the specimen 66. The microscope shown in FIGURE 9 has a deflection device 63 which controls the treating beam 65 in the same manner as the deflection device 13 shown in FIGURE 2.

A microscope embodying our invention can also be used to treat and observe the treatment of specimens which are too thick to transmit electron beams. This is done by observing the image of particles emitted or reflected from the specimen being treated. FIGURE 10 shows one arrangement whereby this may be accomplished. Two electron guns 70 and 71 produce electron beams 72 and 73, respectively, the electron beam 72 being used for observation, and the beam 73 being used for treatment. The beam 72 is passed through a magnetic field which extends in a direction transverse to the plane of the drawing, and which is represented by the shaded area 74. The field 74 curves the beam 72 so that it strikes the surface of the specimen 77 at an angle less than 90° to the surface and illuminates the entire area of the surface. A beam 78 of particles reflected or emitted by the specimen 77 is focused by a reflector lens 79 to form a magnified image 80 of the surface of the specimen.

The beam 73 generated by the electron gun 71 is focused by the condensing lens 75 so that the area of minimum cross section of the beam impinges upon the surface of the specimen 77. The beam 73 is deflected by the deflecting device 76, which is similar to the deflecting device 13 of FIGURE 2, so that the beam follows the paths indicated by the reference numbers 73a, 73b and 73c in FIGURE 10.

FIGURE 11 shows a modification of the device shown in FIGURE 10 for treating and observing the treatment of specimens too thick to transmit electron beams. In the arrangement of FIGURE 11, an electron gun 80 transmits an electron beam 82 which is transformed into a treating beam 82a or an observing beam 82b by a condensing lens 83 in the same manner as described with reference to the embodiment shown in FIGURE 2. Alternatively, the observing and treating beams can be formed by changing the accelerating voltage of the electron gun 81.

A beam of particles reflected or emitted from a specimen 84 form a beam 85 which is focused by a projection lens 86 to form an enlarged image 87 of the specimen 84.

When our microscope is used in production, it is desirable to automatically control the movement and effect of a treating beam as it scans a specimen. FIGURE 12 is a block diagram of a circuit whereby this automatic control may be obtained. FIGURE 12 shows a microscope similar to that shown in FIGURE 1 in which a single electron gun 88 emits an electron beam 89 which is focused by a condensing lens 90 to form a treating and observing beam, the treating beam being caused to scan a specimen 92 by a deflecting device 91. The observing transmitted through the specimen 92 is focused by a projecting lens 93 onto a vidicon tube 94. All of the foregoing apparatus are placed in a vacuum chamber 95 which is exhausted through an outlet 96 to obtain the vacuum requisite for operation of the microscope.

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In the circuit shown in FIGURE 1, a power source 100 supplies current to the electron gun through the control 99 which regulates the accelerating voltage applied to the gun. Circuit 101 regulates the supply of current from the source 102 to the condensing lens 90, and circuit 103 regulates the supply of power from the source 104 to the beam deflecting device 91.

Signals generated by the vidicon 94 pass to an amplifier 97 supplied by a current source 98. Amplified signals from the amplifier 97 are passed to a programming device 105. Signals received by the vidicon 94 in response to an image projected onto it control the operation of the programmer 105, and thereby affect the operation of the microscope to continue the program or to repeat some or all of the portions of the program.

In the various embodiments of our invention which have been described, the condenser lens and the deflection devices described have been of the electromagnetic type. Our invention can also be accomplished with condensing lens and deflection devices which are of the electrostatic type. Also, in the various embodiments of our invention which have been described, an electron beam is used to observe and treat the specimen. In accordance with our invention, other forms of charged particle beams can be used, for example, an ion beam.

While we have described certain presently preferred embodiments of our invention, it is to be understood that it may be variously embodied within the scope of the appended claims.

We claim:

1. An electron microscope for treating and observing specimens comprising,

(A) a single source of electrons,

(B) means for focusing electrons from said source into a treating beam which strikes the surface of a specimen at the point of minimum cross-section of the beam to produce a change in the shape of said specimen by the removal of portions thereof and alternately into an observing beam which uniformly illuminates the surface of the specimen for forming an image thereof,

(C) means for magnifying said image, and

(D) means for observing said magnified image.

2. An electron microscope as described in claim 1 in which said source comprises one electron gun and in which said focusing means includes a condensing lens and means for varying the current supplied to said lens.

3. An electron microscope as defined in claim 1 in which said source comprises one electron gun and in which said focusing means includes means for varying the accelerating voltage supplied to an accelerating grid in said electron gun.

4. An electron microscope as defined in claim 1 and including deflecting means to cause the treating beam to scan the surface of the specimen.

5. An electron microscope as defined in claim 1 and including time mechanism to automatically cause the treating beam and the observing beam to impinge on the specimen alternately.

6. A electron microscope as defined in claim 5 and including means to deflect the treating beam to scan a surface of the specimen and means to render the deflecting means operative only when the treating beam impinges on the surface of the specimen.

7. An electron microscope as defined in claim 1 in which the treating beam moves across the surface of the specimen and which has a photoelectric screen on which said magnified image is projected and a circuit whereby voltage signals generated by the impingement of the image on the screen control the focusing of said observ-

ing and treating electron beams and the movement of the treating beam across the surface of the specimen.

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10 RALPH G. NILSON, *Primary Examiner*.

FREDERICK M. STRADER, *Examiner*.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,221,133

November 30, 1965

Ken-ji Kazato et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 66, for "obserserving" read -- observing --
column 3, line 37, for "deflecting" read -- deflected --;
column 5, line 6, for "26" read -- 62 --; line 70, after
"observing" insert -- beam --; column 6, line 1, for "FIGURE 1"
read -- FIGURE 12 --; line 18, for "electronmagnetic" read --
electromagnetic --; line 25, for "out" read -- our --; same
column 6, line 64, for "A" read -- An --.

Signed and sealed this 20th day of September 1966.

(SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents