United States Patent [19]

Yanaka et al.

[11] **3,852,597**

[45] **Dec. 3, 1974**

[54] **METHOD AND APPARATUS FOR OBSERVING A LOW MAGNIFICATION ELECTRON MICROSCOPE IMAGE**

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[73] Assignee: **Nihon Denshi Kabushiki Kaisha,** Tokyo, Japan

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[21] Appl. No.: **359,669**

[30] **Foreign Application Priority Data**

May 22, 1972 Japan 47-50594

[52] **U.S. Cl.** **250/311,** 250/307, 250/396

[51] **Int. Cl.** **H01j 37/26**

[58] **Field of Search** 250/310, 311, 396, 398, 250/307

[56] **References Cited**

UNITED STATES PATENTS

2,494,442	1/1950	LePoole	250/396
2,802,110	8/1957	Kazato et al.	250/311
3,090,864	5/1963	Takahashi et al.	250/311
3,359,418	12/1967	Bahr et al.	250/396
3,374,346	3/1968	Watanabe	250/396
3,560,781	2/1971	Riecke	250/396
3,629,575	12/1971	Emmasingel	250/396
3,715,582	2/1973	Akahori et al.	250/396

Primary Examiner—Archie R. Borchelt
Assistant Examiner—B. C. Anderson
Attorney, Agent, or Firm—Webb, Burden, Robinson & Webb

[57] **ABSTRACT**

A method and apparatus for observing a low magnification wide field, low aberration electron microscope image characterized in that the objective lens is not used, the focal length of the final stage condenser lens is adjusted so as to focus a crossover image on an aperture located near an intermediate lens and the position of the specimen is kept fixed regardless of magnification range.

5 Claims, 5 Drawing Figures

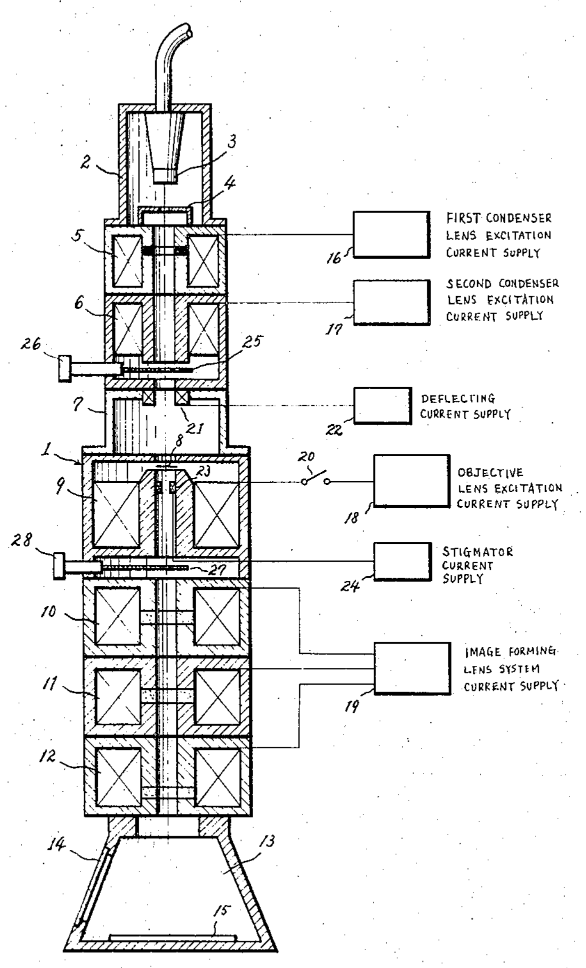
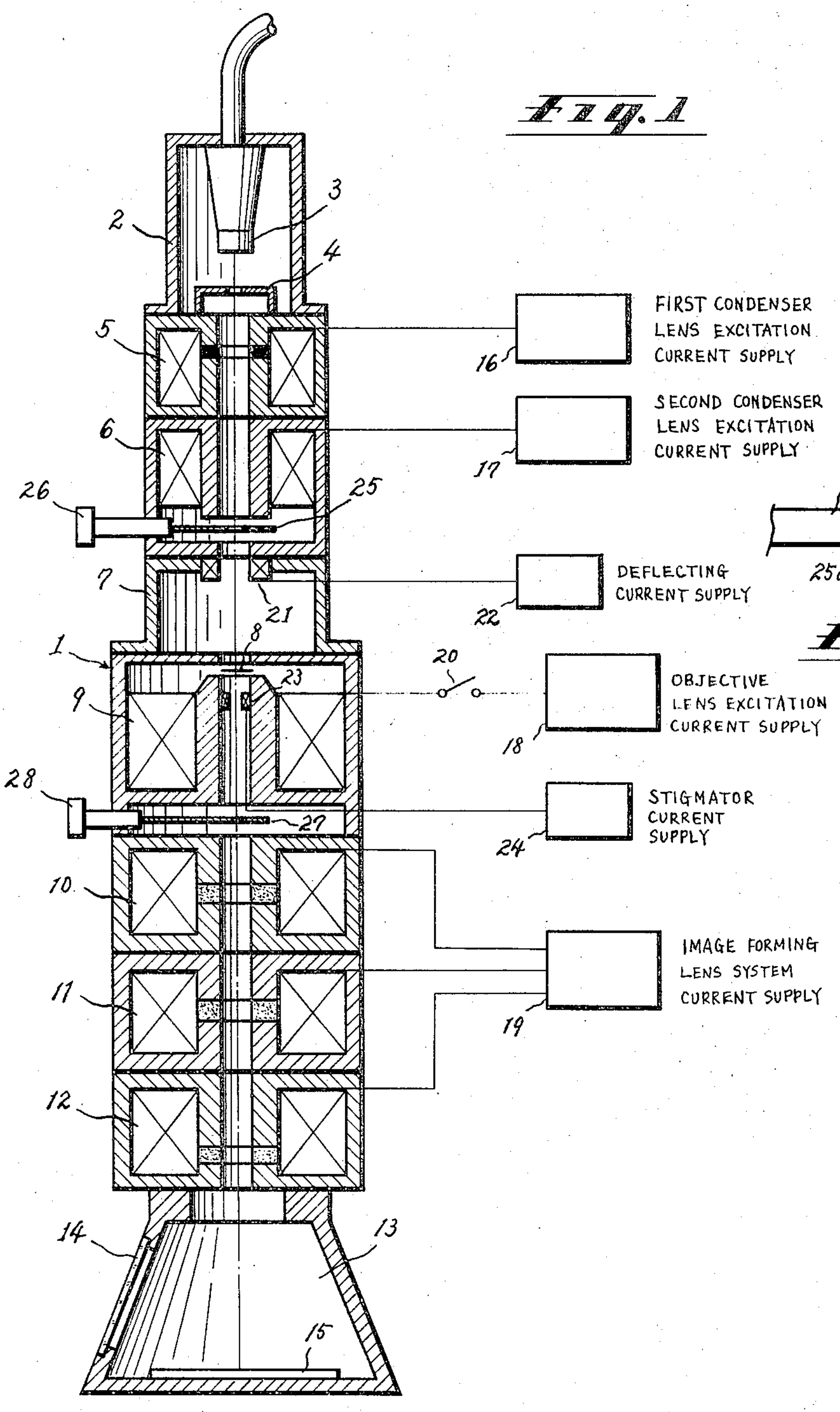


Fig. 1


FIRST CONDENSER LENS EXCITATION CURRENT SUPPLY
SECOND CONDENSER LENS EXCITATION CURRENT SUPPLY
DEFLECTING CURRENT SUPPLY
OBJECTIVE LENS EXCITATION CURRENT SUPPLY
STIGMATOR CURRENT SUPPLY
IMAGE FORMING LENS SYSTEM CURRENT SUPPLY
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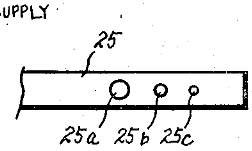
25
25a
25b
25c

Fig. 2

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3,852,597

SHEET 2 OF 2

Fig. 3

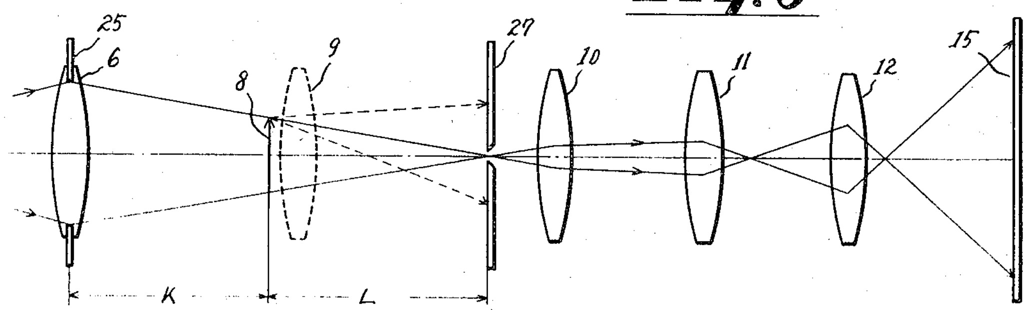
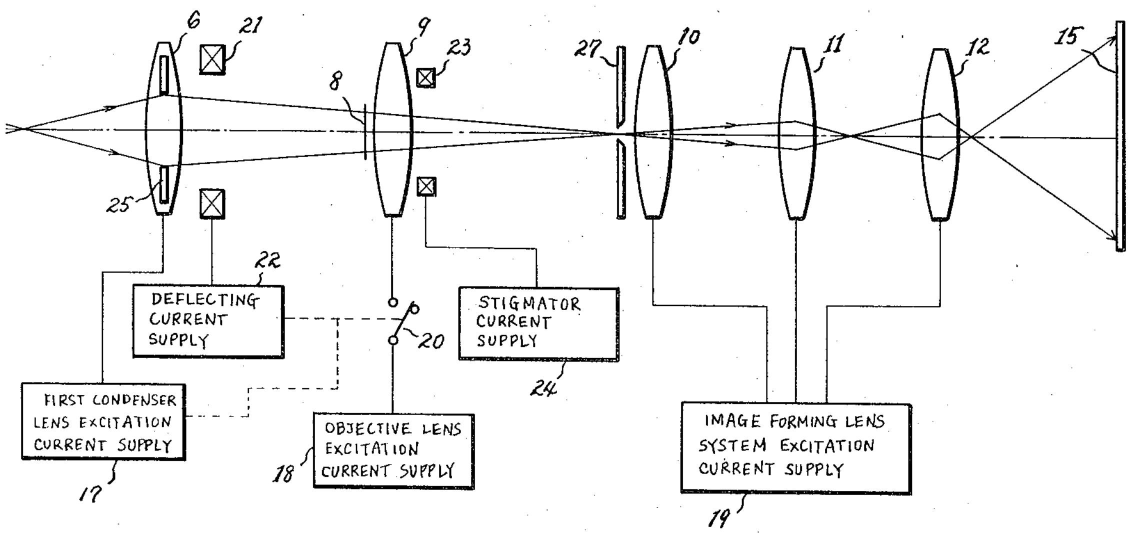


Fig. 4



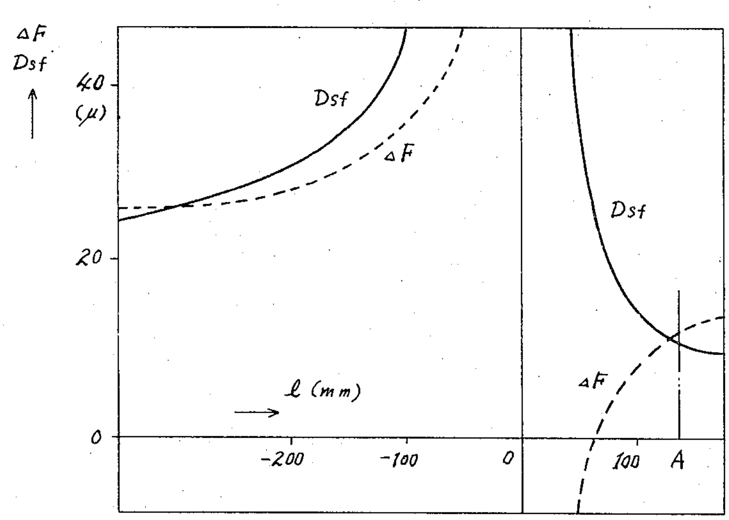


Fig. 5

METHOD AND APPARATUS FOR OBSERVING A LOW MAGNIFICATION ELECTRON MICROSCOPE IMAGE

This invention relates to a method and apparatus including an electron microscope for observing a low magnification image having high resolving power.

When observing a low magnification image with an electron microscope, the specimen is usually placed some little distance from the objective lens in order to increase the focal length and thereby widen the field of view, and also to enhance image contrast.

However, since the diameter of the objective lens aperture controls the field of view as well as the image contrast, the use of a small diameter objective lens aperture for enhancing image contrast has the disadvantage of restricting the field of view. For instance, if a 20 micron diameter aperture is used when observing an image magnified 1000 times, the diameter of the image on the photographic film or fluorescent screen is only about 20mm. Even if a larger aperture is used at the sacrifice of contrast, the diameter of the image will only be 100mm at most, which corresponds to a field of view of about 100 microns. This is not sufficient for practical purposes. Again, if in order to enlarge the field of view, it is necessary to extend the focal length more than a specified amount, the specimen would have to be placed outside the objective lens pole gap which would cause the image forming electron beam to become prone to the effects of external magnetic field fluctuations. As a result, image resolving power would be adversely affected.

Further, since a portion of the image forming electron beam passes through the peripheral area of the intermediate lens magnetic field in order to enlarge the electron beam image, the image formed by the electron beam becomes distorted and blurred due to intermediate lens field (off-axial) aberration.

Thus, in utilizing the method according to the present state of the art, it is necessary to take several tens of photographs at a comparatively high magnification, for example 5,000 times, and join them together to make a composite picture of the image having the required field of view. However, due to inherent image distortion, it is difficult to fabricate a sequential composite picture. Another problem of consequence, especially when using vulnerable specimens, is the vulnerability of the specimen to irradiation damage in view of the extended irradiation time necessary to complete the photographing of a series of photographs.

It should be pointed out in passing that U.S. Pat. No. 3,629,575 describes a method for observing a low magnification image whereby the objective lens energizing current is adjusted to a fixed value lying outside the normal control range in order to shift the focal plane of the objective lens facing the image from the contrast intensifying diaphragm to the objective-limiting diaphragm. However, in this method, due to the weak objective lens excitation current, lens aberration is appreciable making it impossible to obtain a low magnification image having the required amount of resolving power.

It is, therefore, an object of this invention to provide a method and apparatus capable of displaying a high contrast, wide field, low aberration image.

Another object of this invention is to make the field of view of the low and high magnification images correspond by preventing the specimen from moving during image observation.

These and other advantages of this invention will become apparent by reading the following description in conjunction with the accompanying drawings in which:

FIGS. 1 and 2 are schematic diagrams showing the electron microscope according to this invention;

FIG. 3 is a schematic diagram showing the electron beam path of the microscope optical system shown in FIG. 1 incorporating the method according to this invention;

FIG. 4 is a schematic diagram showing the electron optical system, complete with power circuits, of a practical embodiment of this invention; and,

FIG. 5 is a diagram showing the aberration features of electron optical system according to this invention.

Referring to FIG. 1, a microscope column 1 comprises a chamber 2 containing an electron gun 3, an anode 4, first and second condenser lenses 5 and 6, a specimen chamber 7 containing a specimen 8, an objective lens 9, first and second intermediate lenses 10 and 11, a projector lens 12 and a viewing chamber 13 complete with a viewing window 14 and a fluorescent screen 15. Excitation current supply sources 16, 17, 18, 19 are provided for the various lenses. A switch 20 is arranged between the objective lens 9 and its excitation current supply source 18. A deflecting coil 21 is arranged above the sample and has an associated deflecting current supply source 22. A stigmator coil 23 for the objective lens is associated with current supply source 24. A condenser lens aperture plate 25 is held by a supporting means 26. The aperture plate is provided with three apertures, 25*a*, 25*b*, and 25*c*, as shown in FIG. 2. A contrast aperture plate 27 is held by a supporting means 28.

FIG. 3 shows the electron beam path of the microscope optical system shown in FIG. 1 incorporating the method according to this invention. Although a four stage image forming lens system is used in the embodiment as shown, five or more stages or three stages are, of course, applicable. The specimen 8 is placed in the magnetic flux gap between the pole pieces of the objective lens as in the case of high magnification image observation. Although the incorporation of the method according to this invention does not necessarily means that the position of the specimen cannot be changed, it is, in the interests of low and high magnification image correspondence, to keep the specimen fixed. The aperture plate 27 is used for enhancing image contrast and can be used as a field limiting aperture in the conventional electron microscope.

In order to observe or photograph a low magnification wide field image according to this invention, the objective lens current is first of all switched off. Next, the second condenser lens aperture plate is positioned so that the largest aperture 25*a* having a diameter of 0.5mm or more aligns with the beam path and the contrast aperture plate 27 is similarly inserted in the electron beam path by means of the supporting means 28. The axis of the electron irradiating lens system including the final stage condenser lens 6 and the axis of the first intermediate lens 10 are then mutually aligned by means of the deflecting coil. The condenser lens excitation current is adjusted so as to form a crossover image on the aperture plate 27. Finally, the first intermediate lens current is adjusted so as to produce a specimen image on the image source point of the second intermediate lens **11.** By so doing, a low magnification wide field image is displayed on the fluorescent screen **15.**

FIG. **4** shows the electron optical system, complete with power circuits, of a practical embodiment utilizing the method according to this invention. In this embodiment, the supply source **22** of the deflecting coil **21** is controlled by the switch **20.** When the switch **20** is disengaged, the axis of the electron beam irradiating lens system is automatically aligned with the axis of the first intermediate lens **10** by means of the deflecting coil **21**; and when the switch **20** is engaged in order to observe an ordinary magnification image, the axis of the electron beam irradiating system is automatically aligned with the axis of the objective lens by means of the deflecting coil **21.** The current supply source **17,** which supplies excitation current to the condenser lens **6** so as to form a crossover point image on the aperture plate **27** when the switch **20** is disengaged, is interlocked with the switch **20.** Incidentally, by interlocking the switch **20** with the image forming lens system current supply source **19** which controls an image magnification, it is possible to facilitate the observation of a low magnification image utilizing the method according to this invention. In this case, the switch **20** is disengaged automatically when the image magnification decreases to below, let's say 1,000 times (or 2,000 times or 3,000 times if desired) by controlling the current supply source **19.**

The field of view of the low magnification image thus obtained is determined by the following equation,

$$a = L \cdot b/K + L$$

where a is the diameter of the observed specimen area, b is the diameter of the aperture **25,** K is the distance between the aperture **25** and the specimen **8** and L is the distance between the specimen and the contrast aperture **27.** Since $K \approx L$, a is roughly $b/2$. Thus, by utilizing a 0.5 mm diameter condenser lens aperture, a field of view of approximately 250 microns is obtained, a great improvement on the 100 micron field of view obtained with the conventional method.

Referring to image contrast, the intensity of the contrast depends on the aperture angle α_o at which the electrons transmitted through the specimen pass through the contrast aperture **27** and the quantity of electrons scattered by the specimen which are blocked by the aperture plate **27,** as shown by the broken lines in FIG. **3.** The aperture angle α_o is given by $\alpha_o + C/L$, where C is the diameter of the aperture **27.** Thus, if C is 20 microns, the aperture angle α_o will be 10^{-4} rad. or smaller depending on the value of L which is roughly 100 mm to 300 mm in conventional electron microscopes. This compares very favorably with the aperture angle utilizing the method as practiced by the present state of the art which is about 10^{-2} rad.; at best 10^{-3} rad. assuming a very small diameter contrast aperture is used.

In addition to enhanced image contrast, an aperture angle in the order of 10^{-4} rad. or smaller, as compared with an aperture angle in the order of 10^{-3} rad. or larger, proportionally reduces the various aberrations, since spherical aberration is proportional to α_o and axial chromatic aberration is proportional to α_o. Moreover, diffraction aberration can be discounted when the aperture angle is 10^{-4} rad. or smaller, due to its negligible proportions.

Image blurring caused by image field curvature and field astigmatism is also proportional to α_o and, since the electron beam passes near the optical axis of the first intermediate lens, the various aberration coefficients are minimized.

Now, under the condition that the electron beam having an angle α with respect to the optical axis passes at a distance X_o from the optical axis, through the specimen, the blurring factor ΔF due to field chromatic aberration and the over fringe width Dsf due to the defocus factor caused by image field curvature and field astigmatism are given as follows based on Glaser's "Blenden Freien System" of calculation.

$$\Delta F = (Cv \cdot X_o + CF \cdot \alpha) \cdot \Delta\gamma/\nu$$

$$Dsf = [3.2\bar{\lambda} \cdot K\{X_o^2(2Ca + Da) + 6Fa \cdot X_o \cdot (\alpha \cdot K - \lambda \cdot X_o) + 3Ba(\alpha \cdot K - \lambda \cdot X_o)\}]^{1/2}$$

where $\bar{\lambda}$ is the wavelength of the electron beam, λ and K are parameters, Ba, Ca, Da, Fa, Cv, Cf are the various aberration coefficients and V and ΔV are the electron accelerating voltage and its fluctuation factor respectively. Here, the angle α is given by $\alpha = -X_o/l$ by utilizing the distance l between the specimen and the crossover point image.

FIG. **5** shows the values of ΔF and Dsf with respect to l. In the figure, A indicates the position $l = L$ at which the contrast aperture plate is placed. Under the condition that the crossover point image is formed on said aperture, Dsf and ΔF are very small.

Finally, the axial astigmatism of the first intermediate lens is adequately corrected by the objective lens stigmator **23** without the need for fitting an additional intermediate lens stigmator.

Having thus described the invention with the detail and particularity as required by the Patent Laws, what is desired protected by Letters Patent is set forth in the following claims.

We claim:

1. A method for observing a low magnification image using a typical electron microscope having an electron beam condenser lens system including one or more lenses, and a projector lens system including an objective lens and one or more intermediate lenses arranged in sequential order along the optical axis of the microscope, an imaging means and means for adjusting the excitation current to the lens comprising the steps for:

A. keeping the specimen arranged between the objective lens magnetic gap fixed;

B. disconnecting the objective lens excitation current;

C. replacing the final stage condenser lens aperture by an aperture having a diameter of at least 0.5mm;

D. inserting a contrast aperture in the electron beam path adjacent the intermediate lens on the object side thereof;

E. adjusting the current in the condenser lens system so as to form a focal point at the contrast aperture; and,

F. adjusting the current in the projector lens system to focus a low magnification image on the imaging means.

2. In an electron microscope incorporating:

A. a condenser lens system including at least one condenser lens and associated excitation current sources;

B. a projector lens system including an objective lens and at least intermediate lenses and associated excitation current sources;

C. an imaging means;

the improvement comprising:

D. a switching means arranged between the objective lens and its associated excitation current supply source for disconnecting the excitation current;

E. means for replacing the final stage condenser lens aperture with an aperture having a diameter at least 0.5mm;

F. means for placing a contrast aperture in the electron beam path adjacent the intermediate lens on the object side thereof;

G. first means for adjusting the condenser lens excitation current so as to form a focal point on the contrast aperture when observing a low magnification image; and,

H. second means for adjusting the current in the projector lens system to focus a low magnification image on the imaging means.

3. An electron microscope as described in claim 2 characterized in that said first means for adjusting the condenser lens excitation current is interlocked with said switching means.

4. In an electron microscope incorporating:

A. a condenser lens system including at least one condenser lens and associated excitation current sources;

B. a projector lens system including an objective lens and at least one intermediate lens and associated excitation current sources;

C. an imaging means;

the improvement comprising:

D. a switching means arranged between the objective lens and its associated excitation current supply source for disconnecting the excitation current;

E. means for replacing the final stage condenser lens aperture with an aperture having a diameter of at least 0.5mm;

F. means for placing a contrast aperture in the electron path adjacent the intermediate lens on the object side thereof;

G. first means for adjusting the condenser lens excitation current so as to form a focal point on the contrast aperture when observing a low magnification image;

H. a deflecting means located below the final stage condenser lens, the excitation current source supply of said deflecting means being interlocked with said switching means so as to align the electron beam with the optical axis of the intermediate lens; and,

I. second means for adjusting the current in the projector lens system to focus a low magnification image on the imaging means.

5. In an electron microscope incorporating:

A. a condenser lens system including at least one condenser lens;

B. a projector lens system including an objective lens and at least one intermediate lens;

C. an imaging means;

the improvement comprising:

D. a switching means arranged between the objective lens and its associated excitation current supply source for disconnecting the excitation current;

E. means for replacing the final stage condenser lens aperture with an aperture having a diameter of at least 0.5mm;

F. means for placing a contrast aperture in the electron beam path adjacent the intermediate lens on the object side thereof;

G. first means for adjusting the condenser lens excitation current so as to form a focal point on the contrast aperture when observing a low magnification image; and,

H. second means for adjusting the current in the projector lens system to focus a low magnification image on the imaging means, said second means being interlocked with said switching means so as to cut off the objective lens excitation current when observing a low magnification image.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,852,597 Dated December 3, 1974

Inventor(s) Takashi Yanaka and Kohei Shirota

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

Column 3 Line 51, -- + -- should read -- = --.

Column 4 Line 25, The dash (-) after the equal sign should be deleted.

Signed and sealed this 18th day of February 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks