

April 1, 1947.

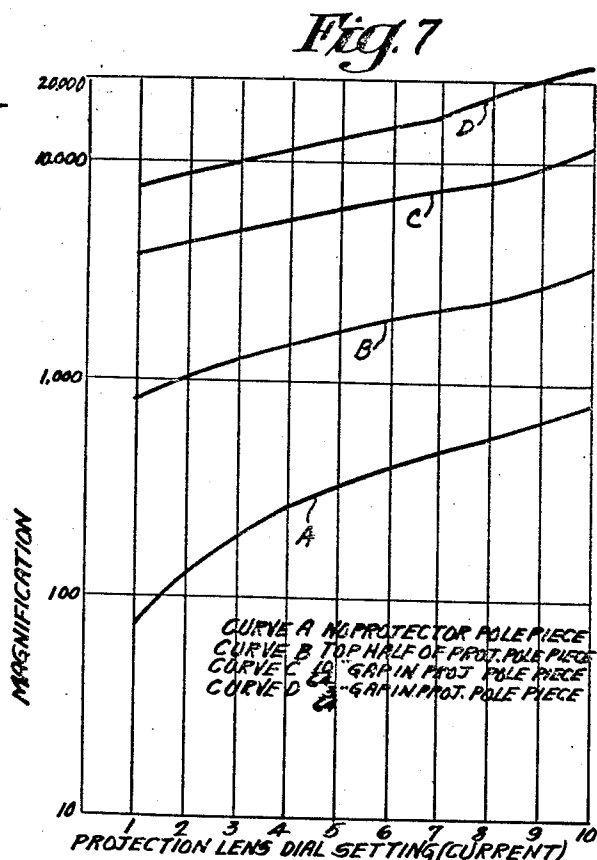
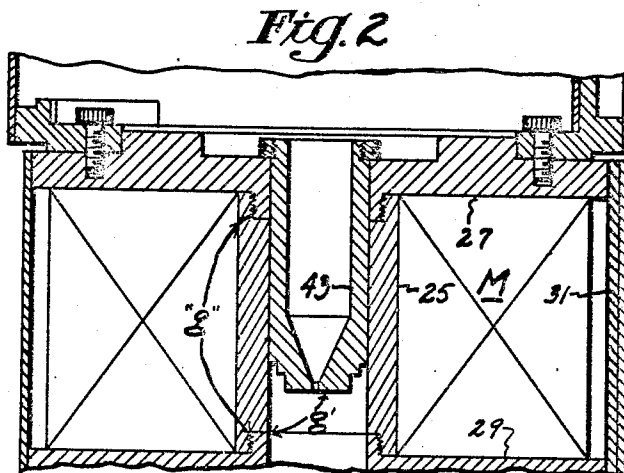
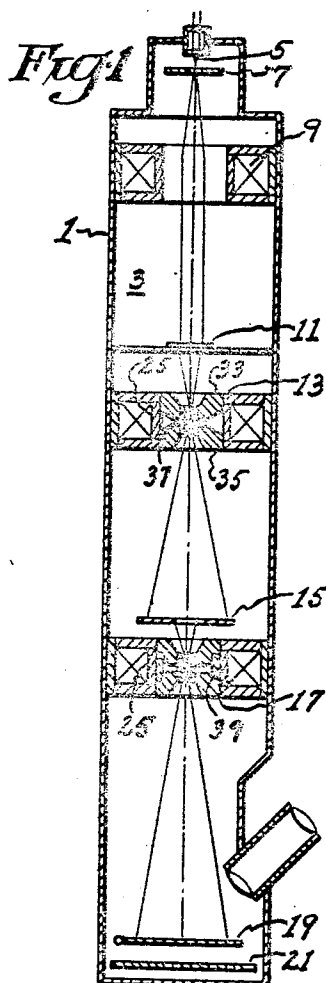
P. C. SMITH

2,418,432

MAGNETIC ELECTRON LENS SYSTEM

Filed May 1, 1944

2 Sheets-Sheet 1



INVENTOR.
 Perry C. Smith
 BY
 C. D. Huska
 ATTORNEY

April 1, 1947.

P. C. SMITH

2,418,432

MAGNETIC ELECTRON LENS SYSTEM

Filed May 1, 1944

2 Sheets-Sheet 2

Fig. 3.

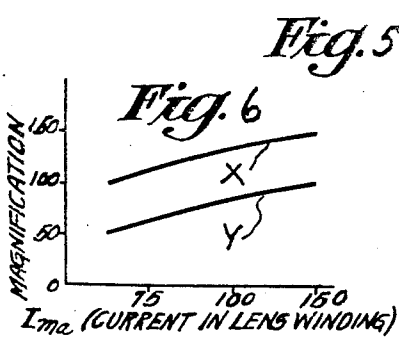
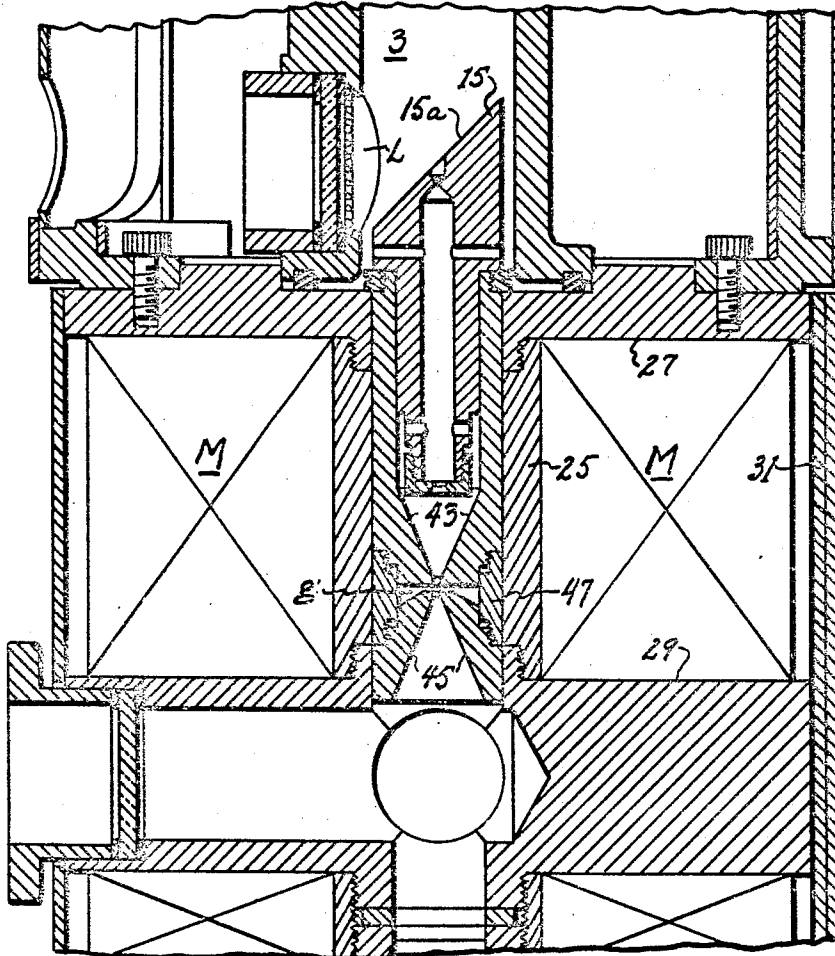


Fig. 5

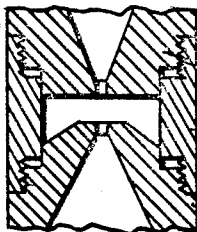
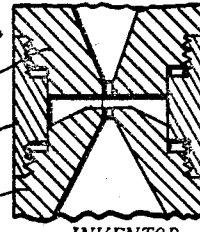


Fig. 4



INVENTOR.
Perry C. Smith
BY *CD Ruska*

ATTORNEY

UNITED STATES PATENT OFFICE

2,418,432

MAGNETIC ELECTRON LENS SYSTEM

Perry C. Smith, Moorestown, N. J., assignor to
Radio Corporation of America, a corporation
of Delaware

Application May 1, 1944, Serial No. 533,521

7 Claims. (Cl. 250—49.5)

1

This invention relates to electron lens systems and particularly to improvements in magnetic lenses for use in electron microscopes and analogous instruments.

In bacteriological and other research work involving microscopy it is frequently desirable to compare an electron micrograph of a specimen with a photomicrograph of the same or another specimen. For best results the comparison should be made between micrographs of the same magnification. While the magnification of present day magnetically focused electron microscopes can be altered, over a limited range, simply by varying the current applied to the focusing coils, the changes in magnification thus produced are not sufficient to provide a series of images within the order of magnification of a conventional light microscope. Nor is it always practical to achieve a desired range of magnification by altering the object-to-lens spacing, since such an adjustment, if carried to the extreme, changes the angle of illumination of the specimen and results in a distorted image.

Accordingly, the principal object of the present invention is to provide a magnetically focused electron microscope capable of an extremely wide range of magnification (such, by way of example, as from 100 or less to 20,000 or more diameters), and this too without excessive distortion or aberration effects.

Another and related object of the invention is to provide an electron microscope having numerous discrete yet overlapping ranges of magnification, and one wherein the said discrete ranges of magnification can be accurately achieved in a facile manner.

Another important object of the present invention is to provide an electron microscope having the high resolving power common to such instruments and one which shall nevertheless possess the large field of view and the various powers of magnification of a conventional light microscope.

The present invention is predicated upon an appreciation of the fact (heretofore unrecognized or, if recognized, not utilized) that the magnifying power of a magnetic lens, of the type incorporating a gap in the path of the magnetic flux, is a function of the length (as distinguished from the diameter) of said gap. Accordingly, the present invention contemplates an improved magnetic lens or lens system of the general character described and wherein means are provided for changing the effective length of the magnetic gap or gaps therein.

The variables heretofore utilized in achieving

2

variable magnification in an electron microscope of the magnetic-lens type are: (a) object-to-lens spacing, (b) the energizing current applied to the magnet coils, and (c) the diameter of the lens aperture. The present invention teaches that if these variables be fixed, then the longer the gap in the magnetic lens, the lower its magnifying power. The utilization of this "fourth variable" in an electron-optical system incorporating two or more magnetic lenses ensures an extremely wide range of magnification; so wide in fact, that for most practical applications, it is seldom necessary to resort to a change in the length of the gap in more than one lens. However, it is to be understood that wherever necessary or desirable, more than one lens in a given instrument may be varied in accordance with the principle of the invention.

Certain preferred details of construction together with other objects and advantages will be apparent and the invention itself will be best understood by reference to the accompanying drawings wherein:

Figure 1 is a partly diagrammatic longitudinal section of a magnetically focused electron microscope which will be referred to in explaining the principle of the invention.

Figure 2 is an enlarged longitudinal section of a magnetic lens incorporating a single part of a multi-part pole-piece assembly within the invention.

Figure 3 is a similar view of the same lens including a complete assembly of pole-pieces.

Figures 4 and 5 are enlarged fragmentary sectional views of the pole-piece assembly of Fig. 3 but including spacing elements of different sizes.

Figure 6 is a graph illustrative of the magnifying power of a single lens having spacers of different sizes between its pole pieces, and

Figure 7 comprises a series of curves indicative of the discrete yet overlapping ranges of magnification of a magnetic lens system within the invention.

In Fig. 1 of the drawings there is shown an electron microscope, indicated generally at 1, comprising an evacuable chamber 3 containing a thermionic cathode 5, an anode 7, a condenser coil 9, a specimen support 11, an objective lens 13, an intermediate apertured member 15, a projection lens 17, a pivoted fluorescent screen 19 and a photographic plate holder 21, all arranged in spaced relation in the order named, along the central axis of the chamber 3. In this more or less standard microscope assembly, the electrons from the cathode 5 emerge from the

apertured anode 7 in the form of a beam and are directed upon and through the specimen (which may be assumed to be transparent) by the condenser coil 9. The electron image of the specimen is then magnified by the lines of force within the conduit of the objective coil 13 and projected onto the intermediate apertured member 15. (As in standard practice, and as shown in Fig. 3, this intermediate part 15 may include an inclined fluorescent surface 15a for translating the intermediate electron image into an optical image which may be observed through a glass lens L, provided for the purpose, in the wall of the chamber 3.) The central portion of the electron beam or image passes through the aperture in the intermediate metal piece 15 and is in turn magnified by the magnetic field of the projection lens 17 and this magnified image is projected either upon the fluorescent screen 19 or, if the said screen is raised, upon the photographic plate 21.

Referring now to both Figs. 1 and 2, it is standard practice to enclose the coil M of a magnetic lens in a casing comprising a hollow brass core or conduit 25 through which the electrons pass, and a circular soft iron shell made up of annular "top" and "bottom" plates 27, 29, respectively, and an outer wall 31. Since brass is a non-magnetic material, the hollow conduit 25 comprises a "gap" in the magnetic path 27, 29, 31 about the coil M. It is well known that the diameter of this gap is one of the factors which determines the magnifying power of the lens and it is standard practice to make the effective diameter of the gap as small as possible to ensure maximum magnification. This is usually done (referring now to Fig. 1) by providing the interior of the brass conduit 25 with a pair of spaced apart apertured pole pieces 33 and 35 which are maintained in rigid permanent alignment as by means of a brass or other non-magnetic insert 37 or collar 39. (Such a rigid pole piece assembly is shown in U. S. P. 2,292,877 to James Hillier.)

The present invention is not especially concerned with the diameter of the conduit or conduits through which the electrons pass in their journey from the cathode to the fluorescent screen or other target but, as previously indicated, contemplates a pole piece assembly which operates to alter the effective axial length of the "gap" ("g," Fig. 3) in the magnetic circuit about each lens coil. This is achieved in accordance with the invention by the provision of a pole piece assembly made up of a number of separable parts including "top" and "bottom" magnetic pole pieces 43 and 45 (see Fig. 3) and a number of interchangeable non-magnetic collars 47, 47a, 47b, etc. of different length dimensions (cf. Figs. 4 and 5) for setting the spacing or "gap" between the said pole pieces.

While it is entirely practical to achieve any desired degree of magnification simply by selecting a spacer of the proper size for the pole pieces, it is not always necessary to use all of the elements of the pole piece assembly. That is to say, referring now to Fig. 2, the effective length of the gap *g*, and hence the magnification of the lens, may be set simply by using a single pole piece in the lens assembly. In this case, since the pole piece 43 is constituted of a magnetically permeable material (e. g. soft iron) and is in contact with the top plate 27, it extends the conductive path for the magnetic flux toward, but not to, the bottom plate 29 and, as indicated at

g', reduces the effective length of the gap between the said plates 29 and 31.

In some cases (as when an extremely low magnifying power is required) both pole pieces may be omitted from either or both the objective or projection lenses. In such a case, if the current applied to the coil M is of a fixed value, the magnification of that particular lens is determined by the diameter and length of the brass conduit 25, or gap *g*. It is usually preferable, however, to employ at least one pole piece, say the "top" piece, in each lens and to make the central aperture in all of the pole pieces of both lenses of the smallest possible diameter, whereby when a spacer of minimum length is provided between the pole pieces of a given lens the said lens will exhibit its highest possible degree of magnification (at any given magnetizing current).

Since, as previously set forth, the magnification of a magnetic lens can be altered over a limited range by varying the current applied to its magnet coil, it is seldom necessary to provide more than two or three different-sized pole piece spacers to achieve a very wide range of magnification. This is especially true when the lens system comprises two or more magnetic lenses in series, since, in this event, the overall magnification of the system is the product of the magnification of the several lenses.

Figure 6 shows the magnification of a single lens with but two different-sized spacers. In this case, one spacer was designed to establish a gap of $\frac{3}{64}$ " between the pole pieces and the other a gap of $\frac{10}{64}$ ". The performance of these two differently spaced pole piece assemblies is indicated by the curves X and Y respectively, which show that the range of magnification of the assembly incorporating the shorter of the two spacers exhibit a range of from 100 to 150 diameters when the current applied to the magnet coil was varied over a certain range, whereas the same assembly employing the longer of the pole piece spacers exhibited a range of from approximately 50 to 100 diameters.

Figure 7 shows a family of curves indicative of the performance of the lens system of an electron microscope wherein the spacing between the pole pieces of the objective lens (13, Fig. 1) was fixed and the two spacers referred to in connection with Fig. 4 were employed for altering the gap between the pole pieces of the projection lens (17) only.

Curve A shows the overall magnification of both lenses when both pole pieces (and the spacer) of the projection lens were removed from the brass conduit 25 in which they are normally seated. In this case the magnification was of the order of from about 75X to 800X, as determined by the energizing current applied to projection coil M (the current applied to the condenser and objective coils being fixed). With the "top" pole piece 43 in position within the lens conduit 25 (as shown in Fig. 2), the magnification of the instrument was increased over the range of 800X to about 1400X, as shown by curve B. Curve C shows that the use of the complete pole piece assembly, including the large (i. e. $\frac{10}{64}$ " gap) spacer extended the range still further, i. e. from about 1400X to about 12,000X, while curve D shows that the substitution of the smaller (i. e. $\frac{3}{64}$ " gap) for the larger spacer in the pole piece assembly increased the range of the microscope to about 22,000 diameters.

It will now be apparent that the present invention provides an improved electron lens sys-

5

tem for electron microscopes and one having numerous discrete, yet overlapping ranges of magnification and one wherein the said discrete ranges of magnification can be accurately achieved in a facile manner.

What is claimed is:

1. Method of changing the range of magnification of an electron lens of the type including a magnet and a gap in the path of the flux of said magnet through which electrons travel in their journey from a source to a target, said method comprising altering the physical length of said gap.

2. Method of changing the range of magnification of an electron lens of the type including a pair of spaced apart pole pieces and a magnet for energizing said pole pieces, said method comprising changing the spacing between said pole pieces.

3. Method of changing the range of magnification of an electron microscope of the type comprising an evacuable chamber containing a plurality of magnetic lenses arranged in series, and each including a pair of spaced apart pole pieces between which said electrons pass, said method comprising altering the spacing between the pole pieces of at least one of said magnetic lenses.

4. An electron lens comprising means defining a conduit through which electrons are adapted to pass, a magnet about said conduit for influencing the trajectories of said electrons, said conduit being constituted of a non-magnetic material and comprising a gap in the magnetic path between the poles of said magnet, and means for altering the effective length of said gap, whereby to alter the path of said flux, the trajectories of said electrons, and hence the magnification of said lens.

5. An electron microscope comprising an evacuable chamber containing a conduit through which electrons pass from a source to specimen and thence to a target, a magnet disposed about said conduit intermediate said specimen and said

6

target, a portion of the wall of said conduit adjacent to said magnet being constituted of non-magnetic material and comprising a gap traversed by the flux of said magnet, and means for altering the effective length of said gap and hence the magnification of said electron microscope.

6. An electron lens comprising means defining a conduit through which electrons are adapted to pass, a magnet about said conduit for influencing the trajectories of said electrons, said conduit being constituted of a non-magnetic material and comprising a gap in the magnetic path between the poles of said magnet, and means comprising a single pole piece adapted to be received within said conduit for extending one terminal of said gap in the direction of the other terminal of said gap.

7. A pole piece assembly for a magnetic lens comprising, an upper magnetic-metal pole piece and a lower magnetic-metal pole piece, and plurality of discrete interchangeable non-magnetic metal members of different length dimensions each adapted to engage and to support said pole pieces in a differently spaced relation determined by said different length dimensions.

PERRY C. SMITH.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,233,286	Marton	Feb. 25, 1941
2,243,403	Von Ardenne	May 27, 1941
2,356,535	Ruska	Aug. 22, 1944
2,209,669	Von Borries, et al.	July 30, 1940

OTHER REFERENCES

"A Compact High Resolving Power Electron Microscope," by Zworykin & Hillier, reprinted from the Journ. of Applied Physics, Dec. 1943, page 668. (Copy in Div. 54.)