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Electrostatic Electron Microscopy. III

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This article, the final one of a series on the design of electrostatic electron microscopes, contains a description of an instrument which illustrates the principles previously discussed. The microscope described is believed to be the first constructed with the object of providing the greatest of simplicity in construction, operation, and maintenance with the design parameters balanced to give a particular range of resolving power. The range chosen is about ten times the light microscope. The instrument is permanently aligned and utilizes external photography. The over-all size and weight of the instrument, as well as the number and complexity of components, are materially less than previously described instruments.

INTRODUCTION

THE previous articles of this series[1,2] have pointed out some of the factors to be considered in designing an electron microscope with electrostatic electron-optical components. These principles will now be illustrated by the description of a sample instrument. This instrument was constructed, for one thing, as a test of the usefulness of the electrostatic lens approach for a large portion of the field of electron microscope application. However, there was another and equally important objective which led to the choice of the design parameters. It was to construct an instrument which would give a particular resolving power range with the maximum of simplicity in manufacture, operation, and maintenance.

The range chosen was about ten times superior to the light microscope or a resolving power of about 200A. This was regarded as a field of microscopy of tremendous importance and one whose secrets are not more likely to be discovered quickly by a wider range instrument (which entails many complexities in achieving its performance) than by a radically simplified instrument whose operation and construction are everywhere balanced for this particular range.

Unlike previously described electron microscopes, no element of simplification was ruled out because it might affect the resolving power. Simplification and resolving power were balanced in an effort to have no part of the instrument "over-designed."

CHIEF DESIGN CHARACTERISTICS

The resulting instrument has the following basic characteristics of design:

(1) The electrons are accelerated and focused by a single, unregulated voltage.

(2) An imaging system of three electrostatic lenses is built into one compact cartridge. The total electron source to fluorescent screen distance is only eleven inches.

[1] C. H. Bachman and Simon Ramo, J. App. Phys. **14**, 8 and 69 (1943).

[2] C. H. Bachman and Simon Ramo, Phys. Rev. **62**, 494 (1942).

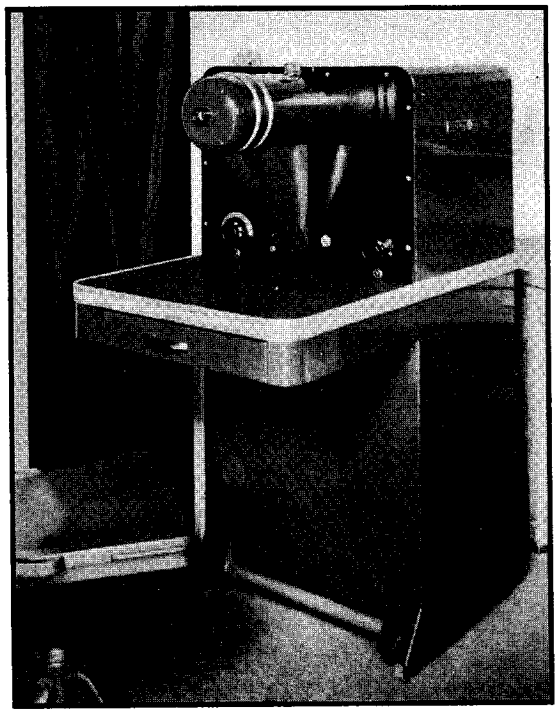

FIG. 1. The General Electric simplified electron microscope.

(3) The electron lenses are of unvarying focal length. Variation of magnification is obtained by conventional interchange of glass light-optical lenses which form the last magnification stage of the instrument. If desired, the electronic magnification may be shifted in range by the removal of one electron lens or the variation of electron lens positions.

(4) The short electron path resulting from the use of a multiple lens electron-optical system in combination with a stage of light-optical magnification makes it possible to align the lenses permanently.

(5) The above factors result in an unusually small electronic chamber. It can be re-evacuated to operating conditions in about two minutes after insertion of a new specimen. This, and the external photography technique, which a final light-optics stage facilitates, eliminate the need for specimen and photographic film insertion locks. Change of voltage or filament current or replacement of the filament itself requires no attention of any kind to the electron-optical system.

(6) The vacuum system consists of a single, small, rough-vacuum pump and an air-cooled, oil-diffusion, high vacuum pump. No special facilities are required and the instrument can be operated wherever 110-volts, 60-cycle power is available.

(7) The aforementioned characteristics result in a relatively small instrument both in weight and physical dimensions. The microscope is mounted on castors and can easily be moved from place to place.

MICROSCOPE COMPONENTS

Figure 1 shows the simplified microscope as it appears ready for visual observation of specimens. Figure 2 shows in cross section the arrangement of components. The electronic chamber is mounted horizontally above the desk-like portion of the instrument so that an operator seated before the instrument will find the fluorescent screen image conveniently located before his eyes. The controls are at his finger tips; they permit adjustment of accelerating voltage, brightness (filament current), specimen position, and connection of the chamber with the vacuum pumping system. The electronic chamber will be discussed in more detail later.

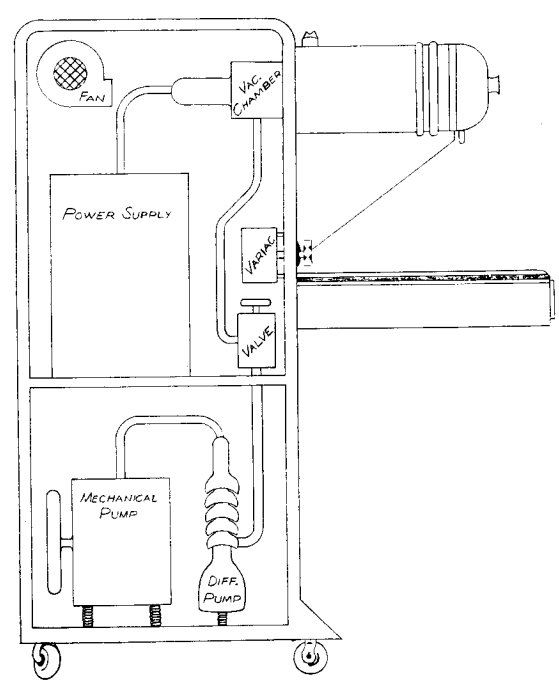

FIG. 2. Arrangement of microscope components.

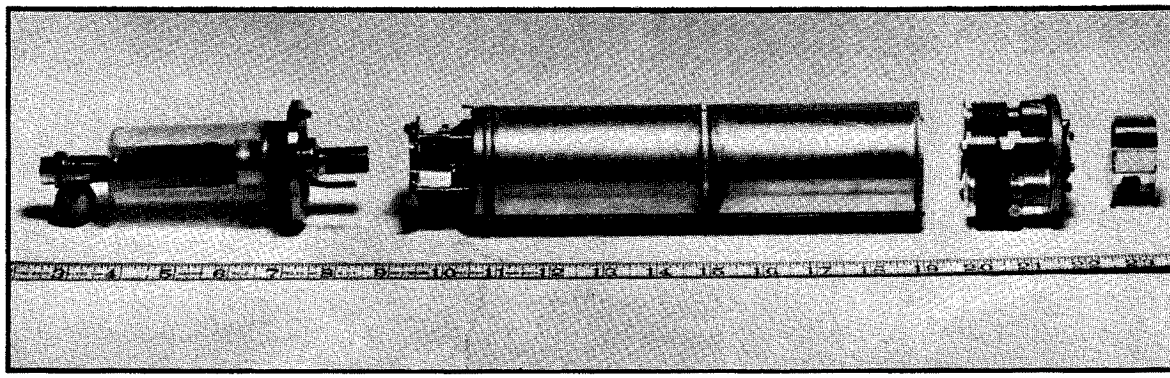

FIG. 3. Electron-optical components.

The electronic chamber is connected to the oil diffusion pump by copper tubing through the vacuum valve. The conventional method of maintaining the high vacuum required in the microscope calls for continuous operation of two pumps in series. Some form of "diffusion" pump is ordinarily used to reach the "fine" vacuum and this is "backed up" with a mechanical pump which furnishes the "rough" vacuum. Both types of pumps are available in a wide range of capacities. Of the two common types of diffusion pumps, oil and mercury, the oil pump is better suited to the microscope application since back diffusion of mercury vapor into the evacuated chamber (a phenomenon inherent in all diffusion pumps) may result in injurious reactions. Also low vapor pressure oils are available which make unnecessary the use of cold traps and water cooling required by mercury pumps.

The fore pump used is a Welch Duo Seal, 21 liters per minute capacity. It has been mounted on a vibration proof suspension. This pump backs up a two-stage oil diffusion pump of Distillation Products, Inc., design. This type was selected because of its fractionating column, self-cleaning feature, and because it lends itself to air cooling. The Cenco vacuum valve used contains no rubber gaskets, the seating arrangement being a hardened cone which is pushed against an edged brass seat. There is an offset in the glass tube between pump and valve which aids in condensing any back diffused oil vapors.

The power supply consists of a conventional half-wave rectifier and a 3-volt transformer for heating the microscope filament and is completely self-contained in the oil tank. A two-wire, shielded cable brings the filament supply to the gun connectors at the high voltage negative to ground. High potential and filament current are each controlled by a Variac in the transformer primary. Voltage can be varied smoothly from a very low value up to about 35 kv.

ELECTRON-OPTICAL COMPONENTS

Figures 3 and 4 show further details of construction of the electron-optical components of

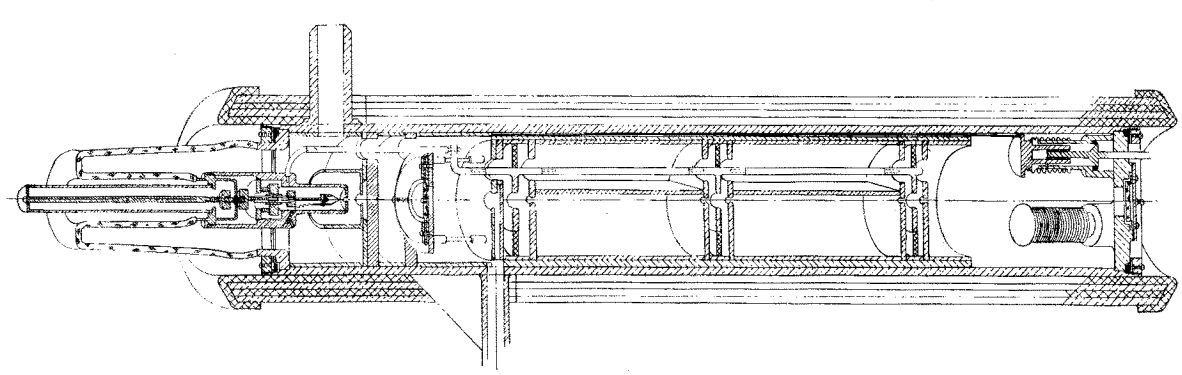

FIG. 4. Cross-sectional sketch of electronic chamber.

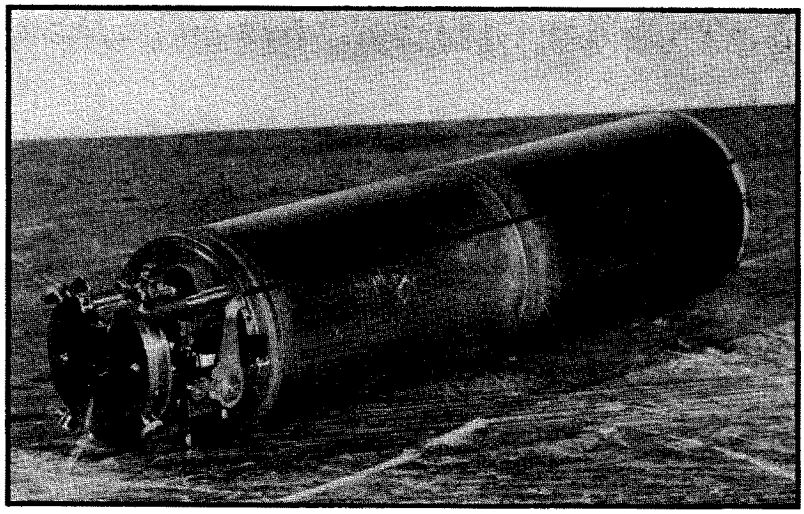

FIG. 5. Specimen manipulator and lens cartridge.

the instrument. The electron gun is a cylindrical shell containing a filament holder which can be adjusted for centering and spacing with respect to the microscope axis. The end cap screws off and the filament can then be replaced easily. This gun shell screws onto a thimble which is sealed to the re-entrant glass insulator, the other end of this being sealed to a ring which seats in the end of the vacuum chamber. The hairpin tungsten filament can be adjusted with respect to the aperture in the end cap by means of side screws and heating current is brought to it by a co-axial arrangement of tubing and rod as shown. A polished anode cup follows next along the axis and this serves to draw the electrons from the filament, through the end cap aperture; some of them pass through the aperture in the anode and move down the microscope axis at anode velocity. Magnetic shielding disks are placed following the anode to shield the magnetic field due to the filament current from the specimen region.

Before reaching the specimen, the beam is further limited by means of an aperture in a molybdenum disk mounted on the manipulator. This aperture is of such diameter that it subtends a solid angle of about 10^{-5} radian at the sample and it is so arranged that it can be adjusted for careful centering on the axis of the lens units. This adjustable aperture, the specimen manipulator, and the lens system are all part of a compact unit (Fig. 5) which can be assembled and checked for alignment before insertion in the vacuum chamber.

The manipulator provides three directions of motion, all at right angles, and each independent of the others. Two are used for scanning the object, the third for moving it into best (focused) position in front of the fixed focal length lenses. The motions are carried by three sets of ways provided with miniature balls and retainer pins.

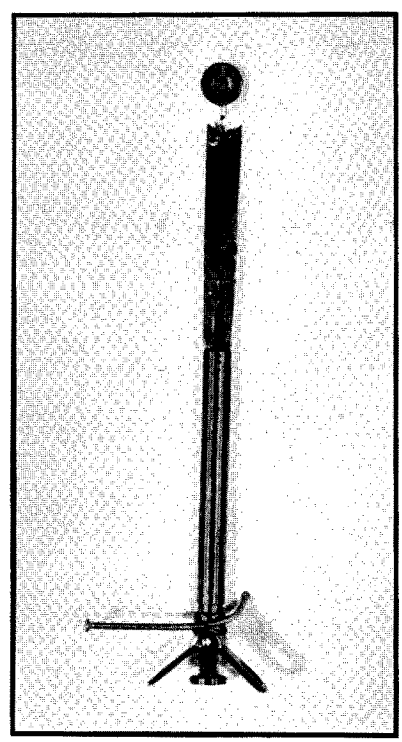

FIG. 6. Specimen holder and insertion rod.

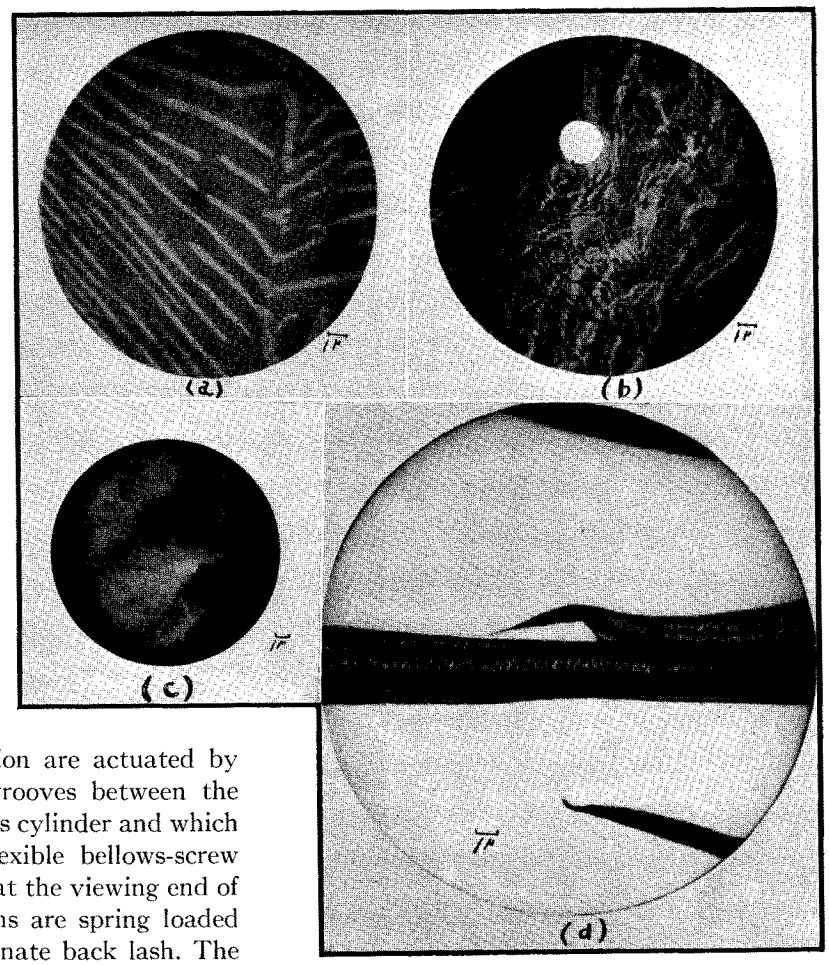

FIG. 7. Sample micrographs: (a) Formvar replica of metallographic specimen of carbonyl iron; (b) Formvar replica of metallographic specimen of 1-1 carbon steel, oil quenched; (c) recrystallized NaCl; (d) detail of fringe along edge of mosquito wing.

Levers controlling the motion are actuated by push rods which slide in grooves between the vacuum cylinder and the lens cylinder and which are, in turn, pushed by flexible bellows-screw devices set in the end plate at the viewing end of the microscope. The motions are spring loaded at the manipulator to eliminate back lash. The lever-screw combination gives to the scanning motion a total ratio about equivalent to 300 TPI screw. The focus motion has about half this value.

The object to be viewed (assumed to be suspended, in the conventional electron microscope manner, in holes of a small disk of fine mesh metal) is first mounted on a holder whose handle is several inches long (Fig. 6). The object holder is then inserted through the hole in the top of the vacuum chamber until it slips into the carrier provided on the manipulator where it is held snugly by a compression spring. The handle is allowed to rest on the side of the insertion tube and does not restrict the object as it is moved about.

Each electron lens consists of three disks with rounded apertures. The center disk is insulated and held at the cathode potential by means of a side rod assembly (Fig. 4) which leads from the gun along one side of the vacuum chamber through holes in the various other elements in the chamber and touches the outer edge of each center electrode. This side rod system must be kept sufficiently far from the axis so as not to introduce substantial cross electric fields in the lens. All lens plates are highly polished and are held in good alignment by the fit of their outside diameters in the containing cylinder. Spacing along the axis is accomplished by cylindrical spacers, and in assembling the unit, disks and spacers are stacked in the proper order in the containing cylinder. Though in practice one will probably most often choose to vary magnification by changing the external, light-optics stage, the electronic magnification is easily varied by changing spacers. Such a variation in electronic magnification, since it occurs ahead of the fluorescent screen, will probably serve in practice mainly to shift resolving power range (see below).

The fluorescent screen is deposited on a small

glass disk which is held on the end plate of the electronic chamber by a seat and gasket arrangement. In order to achieve desirable optical magnification of the image without introducing limits due to particle size of the fluorescent material, pin holes, and diffusion of light and electrons, techniques for laying thin and unusually uniform screens have been worked out. In general, in order to make the exposure time as short as possible for a given over-all magnification, it is desirable to choose the lowest electronic magnification possible. If the electronic magnification falls too low, the screen will, however, commence to limit resolving power.[1] This is why it will sometimes be desirable to alter the electronic magnification in accordance with changes in desired resolving power.

OPERATION OF INSTRUMENT

Though the limits of this instrument have not yet been completely determined, a number of micrographs have been taken, a few of which are reproduced in Fig. 7. All recordings to date have been made with about from 3000 to 7000 or 8000 diameters total magnification, of which about seven times was in the last (light-optics) stage. Under these conditions, a quick appraisal of the general structure of the specimen is possible by direct viewing of a large field directly on the fluorescent screen at magnifications often used in a light microscope. Any particular area may then be examined at several-fold more magnification by the insertion of a wide field eyepiece. This light-optical arrangement is a very efficient light gatherer and with the flat field of the eyepiece offers little chance of eye strain when used over long periods.

For photographing, the eyepiece is slipped from its holder and a simple camera is substituted. The photographs of Fig. 7 were taken with a simple camera using a single lens (Bausch and Lomb special design). Focus on the fluorescent screen can be pre-set and the camera locked in place if desired.

It will be noted that no special pre-exhaust chamber and vacuum locks are necessary either for photography or specimen replacement. The use of external photography completely removes one problem; and in the case of specimen insertion, the volume of the whole chamber is so small that a period of only three minutes is necessary to change specimens and be back in operation.

CONCLUSIONS

The extreme simplicity of design and construction would lead one to expect almost complete absence of care on the part of the operator. Such has indeed been the case. The limits of the general technique—unregulated voltage; multistage electrostatic lenses acting as a "booster" for a light-optics stage; external photography—are not yet known. However, the general performance of this sample instrument has led the authors to believe that the technique is well suited to the range of electron microscopy for which the instrument was designed.