

## II. ELECTRON OPTICS

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#### A. MODULAR PROGRAMMABLE ELECTRON BEAM SYSTEM FOR SPOT IRRADIATION IN SURFACE RESEARCH

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##### 1. Introduction

The reasons for developing a modular programmable electron beam system for spot irradiation in surface research have been set forth by King and Weaver.<sup>1</sup> The main reason is that the possibility exists for high-specificity binding sites for molecules, and thus it should be possible to stain cold surfaces with neutral molecules and then desorb the bound stain molecules with short pulses of highly localized heat or desorb them directly by electron stimulated desorption (ESD).<sup>2</sup> Broadly stated, the design goal is to maximize the current density that is available over a large range of voltage in a small scannable spot. Silver (see Sec. I-B) has calculated the dissipated energy density necessary to desorb small neutral atoms and molecules from biological material. The current density required in the probe is a strong function of the spot diameter because of thermal conduction in the specimen. For a 3  $\mu\text{m}$  spot diameter at 10 kV, 0.3 A/cm<sup>2</sup> is sufficient to desorb weakly bound molecules; in a 500  $\text{\AA}$  spot, 500 A/cm<sup>2</sup> is needed.

These values were recognized as being within the performance specifications for commercially available scanning electron microscope (SEM) systems, but because of the need for several such SEM systems to be used as blocks in larger research systems in our laboratory, the cost of buying and modifying commercial SEM equipment was prohibitive. The decision was thus made to design and build in-house the simplest possible modular system to do the required jobs. The resultant system is all-electrostatic and capable of forming spots down to a 3- $\mu\text{m}$  diameter at working distances of a few centimeters. The instrument is now being used to desorb neutrals with the programmable spot.

Operation of the electron beam system in a low-voltage mode for low-energy electron surface studies is also possible. A 1.5 kV, 3  $\mu\text{m}$  beam with a spot size of

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approximately 25  $\mu\text{m}$  (formed without lens apertures) has been used in the scanning mode to obtain scanning desorption micrographs and scanning Auger micrographs of the surfaces of silicon crystals. In a nonscanning mode the beam is being used for selected-area surface analysis by measurement of Auger electron spectra, electron energy-loss spectra, and ESD phenomena. This application is described in the report by H. F. Dylla (Sec. I-A) on the scanning desorption molecule microscope (SDMM).

### 2. General Design Aspects

To be compatible with other building-block apparatus in our laboratory, such as ionizers, detectors, manipulators, etc., it was necessary to specify that the output end of the electron beam system fit into a cylindrical volume 4" diam (max) and 5" high (max) with focused spot position approximately 2" beyond the final deflector set. Furthermore, it was necessary to devise a universal flange not only to support the electron beam modular system in a horizontal or vertical position and provide for vacuum sealing but also to allow electrical feedthrough and shielding facilities. These considerations, as well as the overriding necessities of flexibility in use and operator safety, fairly well circumscribed the mechanical design. The electron optical design was based upon the need to control both spot size and electron flux over a wide range, and to program movement for the spot. To keep the system simple, we decided to have only two modules: an electron source module, and an electron control module. Figure II-1 summarizes the general design aspects.

### 3. Electron Source Module

The electron source module is an electron gun designed to use either a thermionic V-filament or a Schottky thermionic field-enhanced (TF) point emitter. The advantages of the point emitter over the V-filament are decreased source size and increased maximum cathode current density, both by a factor of five to ten (see Dylla, Sec. I-A). The disadvantages of the point emitter over the V-filament are in the mechanical problems of fabrication, cathode-anode spacing, and alignment onto the axis of an optical system. With either a V- or a point filament, a choice of grid caps is available.

The telefocus grid cap<sup>3</sup> requires only one bias potential (negative) relative to the cathode and is useful primarily for selecting an axial crossover for the primary electron beam when current into the crossover is of secondary interest to the position of crossover. The telefocus grid cap is thus of most use when the electron source module is to be used alone, e.g., to deliver a stationary collimated flood beam onto a relatively large specimen.

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The Braucks grid cap<sup>4</sup> requires two bias potentials (one positive, one negative) with

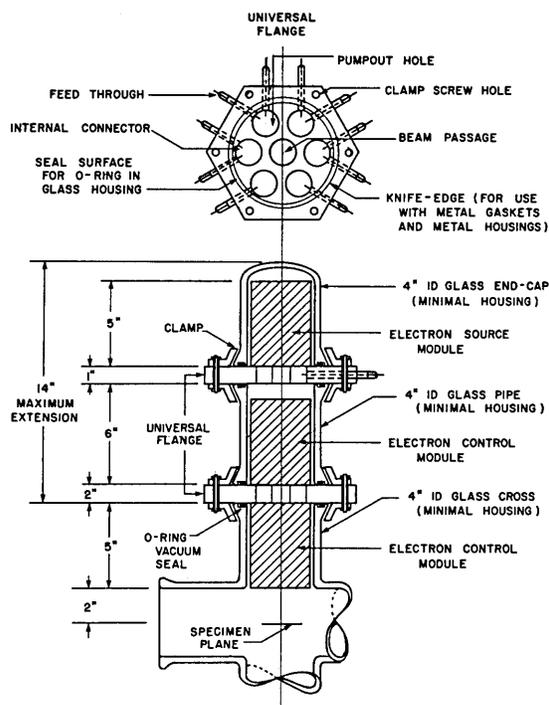


Fig. II-1. Modular programmable electron beam system for spot irradiation in surface research, showing the assembly for double deflection SEM operation.

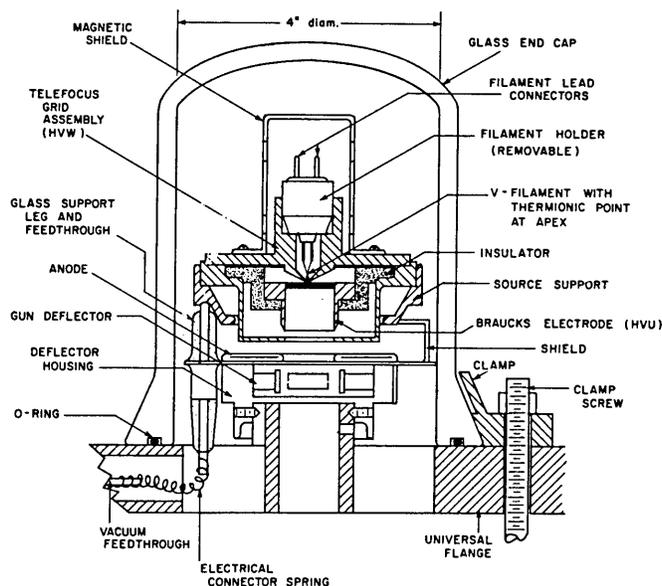


Fig. II-2. Electron source module with TF point and Brauck's cap.

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respect to the cathode and allows control of the intensity in the directed beam and of the position of the crossover. In general, within the design parameters, an increase in the negative bias HVW causes a decrease in spot size, while an increase in the positive bias HVU causes an increase in spot current density. The Braucks cap is primarily of use when the beam is to be acted upon by one or more control modules. Figure II-2 shows the electron source module equipped with a TF point and a Braucks cap. The anode and gun-deflector set are invariant parts of the electron source module.

### 4. Electron Control Module

The electron control module is a unitary lens + deflector package (Fig. II-3). Its design was derived by requiring that within the mechanical limitations described here, the identical control module should be usable singly (as an objective lens) or doubly (as a condenser + objective electron optical column). Flanked on one side by a single deflector set and on the other by a double deflector set, the lens is a fully symmetric

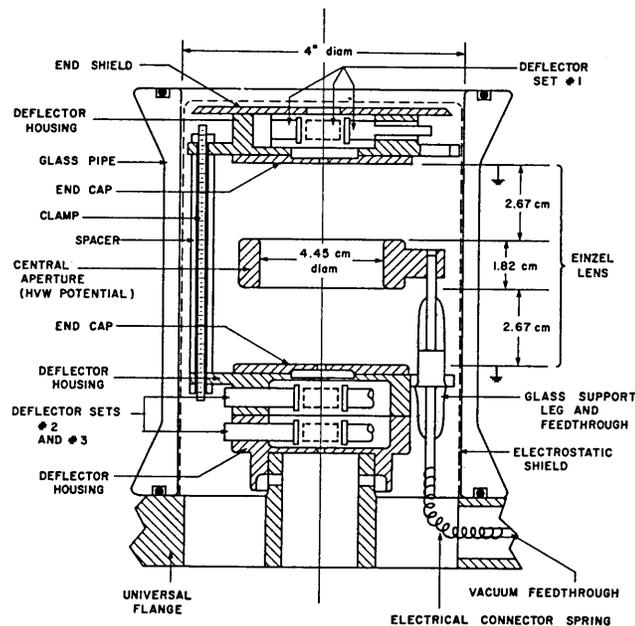


Fig. II-3. Electron control module.

electrostatic Einzel type, designed optimized at the following specifications:

- Type: electrostatic Einzel, fully symmetric
- Focal length: 5.33 cm
- Throw from objective mid-plane: 9 cm (max)
- Working distance: 5 cm nominal

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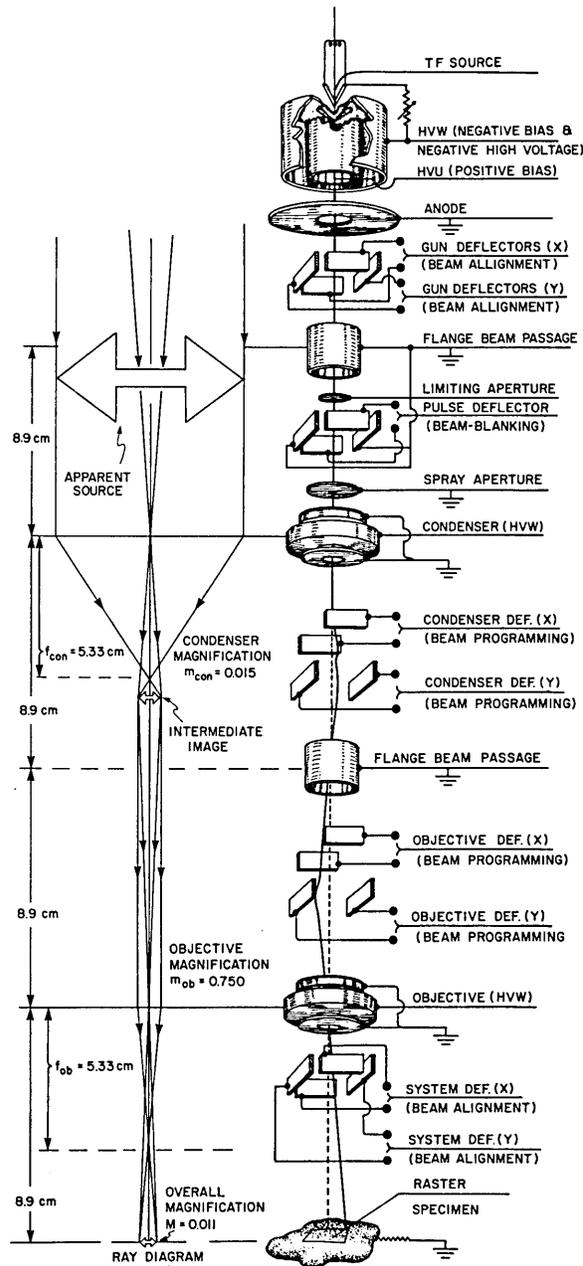


Fig. II-4. Use of the modular, programmable electron beam system in the SEM mode. One TF point electron source module is used with 2 electron control modules back-to-back. Control modules operate at HVW potential on the lens.

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Relative spherical aberration:  $3.5 (C_s/f)$

Relative chromatic aberration:  $2.5 (C_c/f)$

The aberration coefficients,  $C_s$  and  $C_c$ , are minimal for this type of lens.<sup>5</sup>

### 5. Programmable Beam System Use

Depending upon their assembly, the electron control module and the electron source module allow 12 possible systems ranging from a naked fixed-beam gun to a scanning electron microscope (SEM) system made up of gun, condenser lens, objective lens, and 5 sets of deflectors. In the SEM system, two-dimensional double deflection is possible, which allows raster formation at the specimen with minimum distortion in the spot because the beam itself always passes through the center of the lens used as the objective (Fig. II-4). Telecentric stops and other apertures may be placed in the system as shown.

In one version of the scanning desorption molecule microscope, the programmable beam system for spot irradiation is used to heat a microvolume of biological material and evaporate sodium and potassium, which are ionized and detected. In these experiments, the sample is mounted on a thick (25  $\mu\text{m}$ ) platinum ribbon so that no beam current is transmitted. SEM images using either absorbed or backscattered current are routinely used to position and tune up the beam. This will be described more fully in the doctoral thesis research of B. R. Silver. For these experiments, a useful beam has been obtained between 4 kV and 10 kV, with currents of 0.1-1.0  $\mu\text{A}$  into a spot of

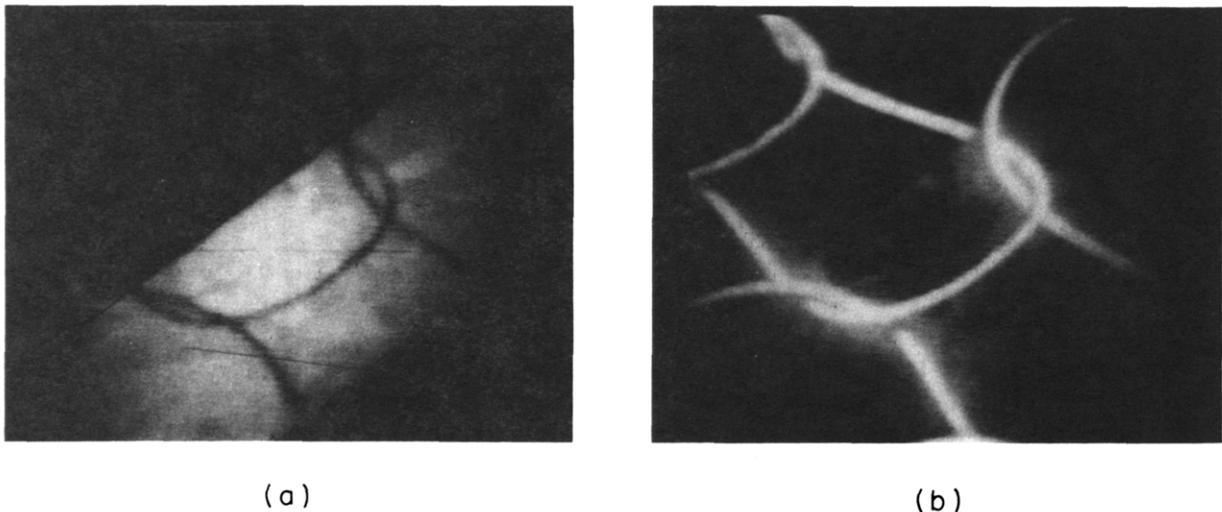


Fig. II-5. SEM image of platinum ribbon (1mm wide) behind a woven tungsten grid. (a) Current absorbed in ribbon. (b) Backscattered current.

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approximately 3  $\mu\text{m}$ , the design value. The spot diameter is estimated from the image of a woven tungsten grid. Typical operating values are HVW 6.0 kV, filament current 2.2 A, bias resistor 3  $\text{M}\Omega$ , HVU 170 V, dc deflection for gun alignment  $\approx \pm 50$  V, absorbed current in specimen 0.5  $\mu\text{A}$ , spot diameter  $\approx 3$   $\mu\text{m}$ . Starting from any given setting for 3- $\mu\text{m}$  resolution, the specimen current in general may be increased by decreasing the bias resistor, increasing HVU, or adjusting gun alignment, if the resulting broader spot is acceptable. A typical SEM image is shown in Fig. II-5.

References

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