SURFACE PROPERTIES OF THERMIONIC ELECTRODES

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I. Introduction

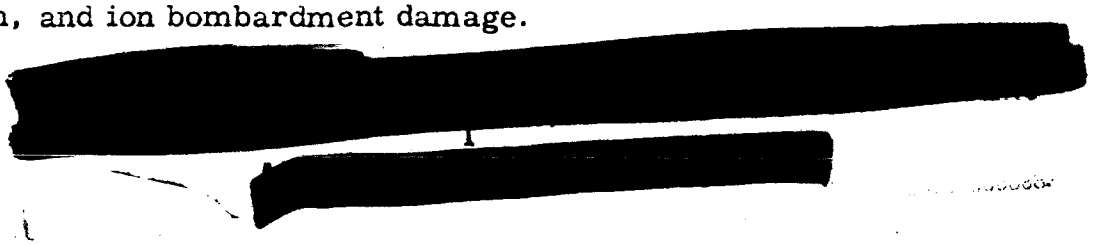
The primary objective of this research program is to investigate, both experimentally and analytically, the surface processes affecting the performance of thermionic energy converters. The first part of the program will be devoted to the development of an experimental apparatus that is based on the unique combination of several conventional components.

1. An ultrahigh vacuum chamber capable of attaining the conditions for maintaining clean surfaces for extended periods ($\sim 10^{-10}$ mm Hg).
2. A single-crystal refractory metal test specimen of known orientation and surface structure.
3. A molecular-beam device for depositing alkali metals upon the test surface at a known rate.
4. An electron gun and the necessary auxiliary equipment for measuring the work function (contact potential) of the test surface by means of the retarding-potential technique.[1,2]

With this apparatus we plan to determine the variation of work function with coverage (i.e., the number of alkali-metal atoms adsorbed on the test surface) and with surface temperature. We shall attempt to investigate several different combinations of alkali and refractory metals. We believe that these experimental data are needed in order to verify and improve the existing theoretical models of this interaction.[3,4]

The next part of the program will be concerned with the effects of additives (e.g., O_2, F_2, and H_2) on the thermionic properties of the test surface with varying alkali-metal coverage. This study is motivated by the fact that certain additives may be used to obtain substantial increases in the power output of thermionic energy converters.[5-7] Only minor modifications of the apparatus will be necessary to conduct these tests.

The main attribute of the apparatus described above is that it enables one to conduct detailed investigations under experimental conditions that are both well defined and controlled. As a result, the accuracy and reliability of the data should be exceptional. Another attribute of the apparatus is that it is appropriate for studying other problems, such as surface ionization, condensation probability, electron reflection, secondary emission, and ion bombardment damage.



II. Apparatus

A general description of the experimental apparatus is presented below. We shall explain the main features of the retarding-potential technique that is used to measure changes in the work function of the test specimen.

The current-voltage plot for an ideal planar diode* is illustrated in Fig. 1. It is assumed that the emitter work function, ϕ_1, is greater than the collector work function, ϕ_2, and back emission from the collector is negligible. Notice that while the emission current, I, is constant in the saturation region ($V < \phi_1 - \phi_2$), it decreases exponentially in the retarding region ($V > \phi_1 - \phi_2$). The quantity ($\phi_1 - \phi_2$) is called the "contact potential."

Let us assume that the collector work function decreases when a foreign substance (e.g., cesium) is allowed to adsorb upon its surface. If the experiment is designed so that the emitter work function remains constant, the contact potential will increase from ($\phi_1 - \phi_2$) to ($\phi_1 - \phi_2'$), and the current-voltage plot is now represented by the dotted curve in Fig. 1. The two curves are parallel in the retarding region because their slopes are independent of the collector work function. It is obvious that the change in the contact potential is equal to the change in the collector work function, $\Delta\phi_2$. Thus, we may determine $\Delta\phi_2$ by measuring the change in applied voltage, V, which is required to maintain the current at an arbitrary constant level, as shown in Fig. 1.

The primary feature of this experiment is the use of a simple feedback apparatus which automatically changes the applied voltage so as to maintain the current at a constant level. Thus, a simple measurement of V provides us with the desired data of $\Delta\phi_2$ as a function of gas coverage. A schematic diagram of the circuit is shown in Fig. 2. The circuit within the dashed box represents a Kiethley 600A Electrometer operating in the "fast" (feedback) mode. With the electrometer first in the "normal" mode (no feedback) and with no gas adsorption, the crystal and guard ring are biased to give a current that is well into the retarding region of the I-V curve (point A, Fig. 1).

*The "ideal planar diode" has been discussed in detail by Houston and Webster.[8] A uniform work function, no space charge, and zero back-emission are assumed.

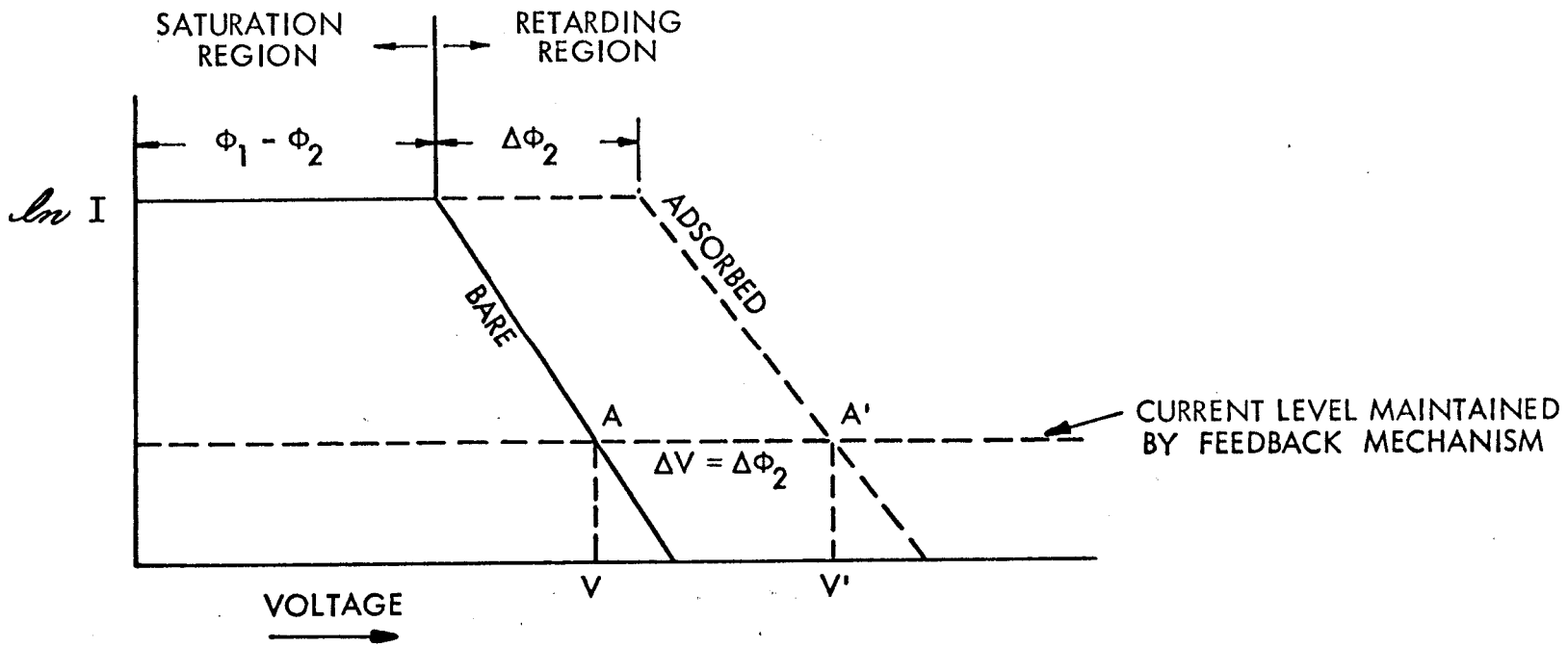


Fig. 1. Schematic of retarding potential technique.

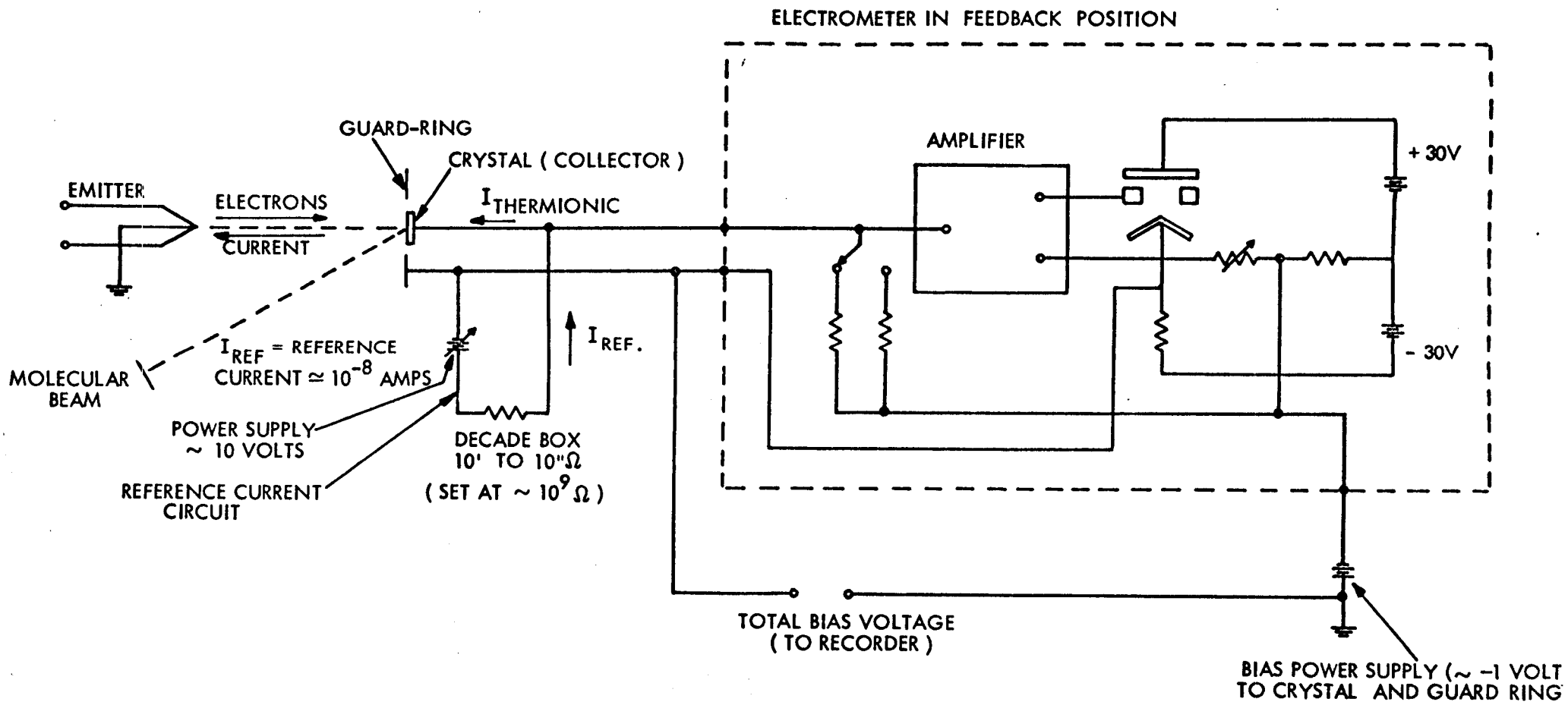


Fig. 2. Schematic of measurement circuit showing feedback system.

The reference circuit is then used to supply an equal and opposite current to make the meter reading zero. With zero-current input the meter is then switched to operate as shown in Fig. 2. If the crystal (the collector) is exposed to a molecular beam of cesium, the work function of the surface will decrease and cause the electron current to increase. This leads to a net current in the meter and a voltage drop, equal to the work-function change, across the amplifier. To compensate for this drop, a current flows in the feedback loop so that the voltage of the amplifier is changed by $\Delta\phi_2$, the work-function change. This voltage also alters the potential of the crystal and guard ring, so the net effect is that the thermionic current is retarded back to its original value, as shown in Fig. 1.

Figure 3 is a schematic diagram of the electron gun and crystal circuits. The electron gun is a standard commercial item, except that the oxide cathode has been replaced by a directly heated tantalum filament. The filament is held at ~2300°K and is run space-charge-limited in order to reduce fluctuations. As shown, the control unit is equipped with a reference circuit to supply deflection voltages to a recorder. These are then correlated to actual deflections and, if desired, the entire surface can be surveyed with the electron beam. The "can" serves to give a field-free region near the crystal and also has some focusing effects. The crystal is cleaned by employing electron bombardment to heat it to high temperatures.

Figure 4 is a diagram of the placement of the components, and an external view is presented in Fig. 5. The vacuum chamber, 18 inches in diameter and 36 inches deep, is evacuated by means of Varian Vac Sorb, Vac-Ion, and titanium getter pumps. Copper gaskets are used throughout. After a 250°C bakeout, the system pressure falls to the 10^{-11} torr range. All of the experimental apparatus is mounted on the lid for easy removal. Current and voltage leads are taken out through standard feedthrough flanges. The cesium molecular beam and the oxygen and hydrogen beam arrangements also have been flange-mounted for ease of installation. The cesium beam features an outer cooling shell to condense excess cesium. The oxygen and hydrogen leaks are commercially available devices acting as semipermeable membranes when heated. The beams are equipped with an ionization gauge for pressure measurement. The electron gun and

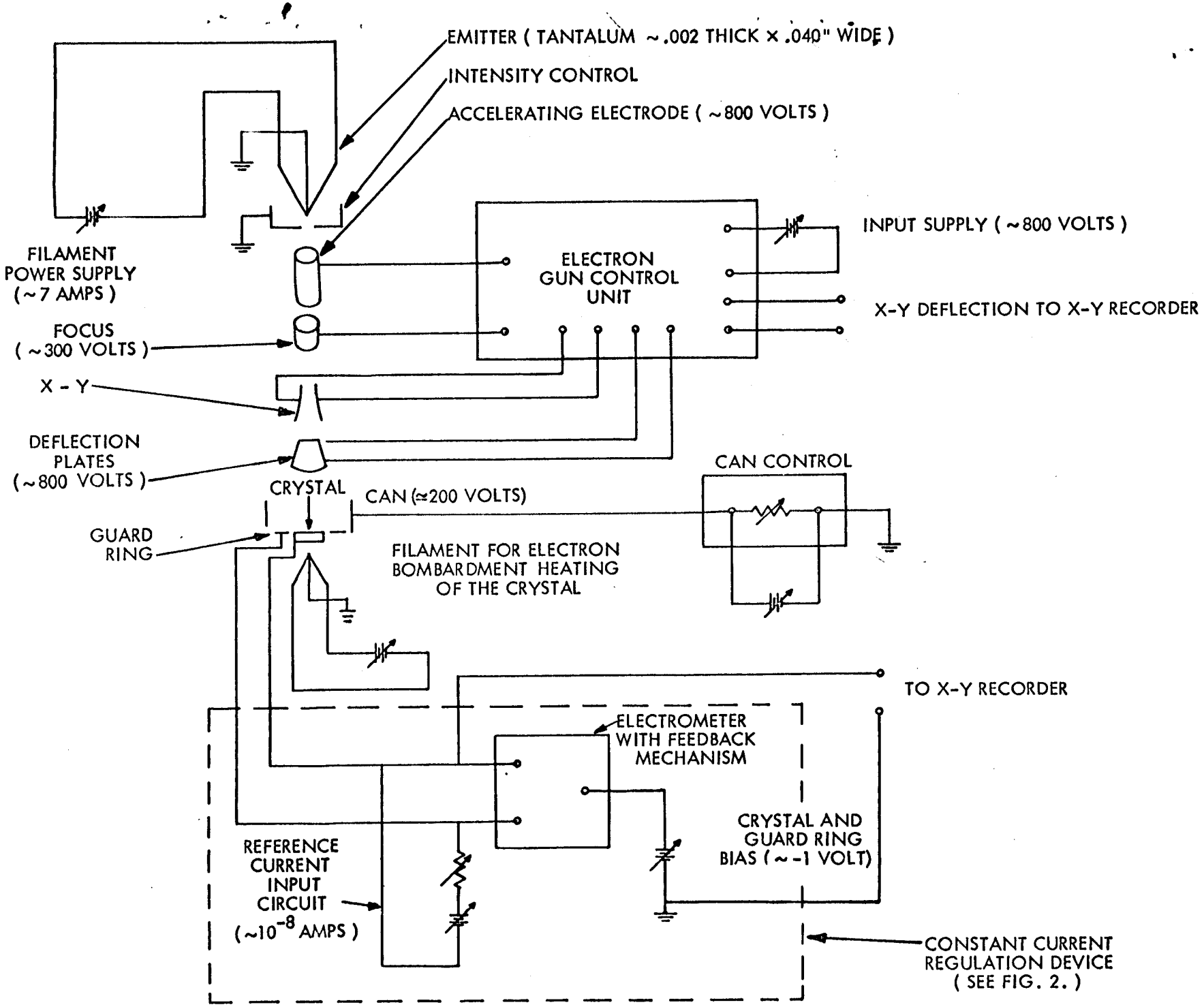


Fig. 3. Schematic of control and measurement circuits.

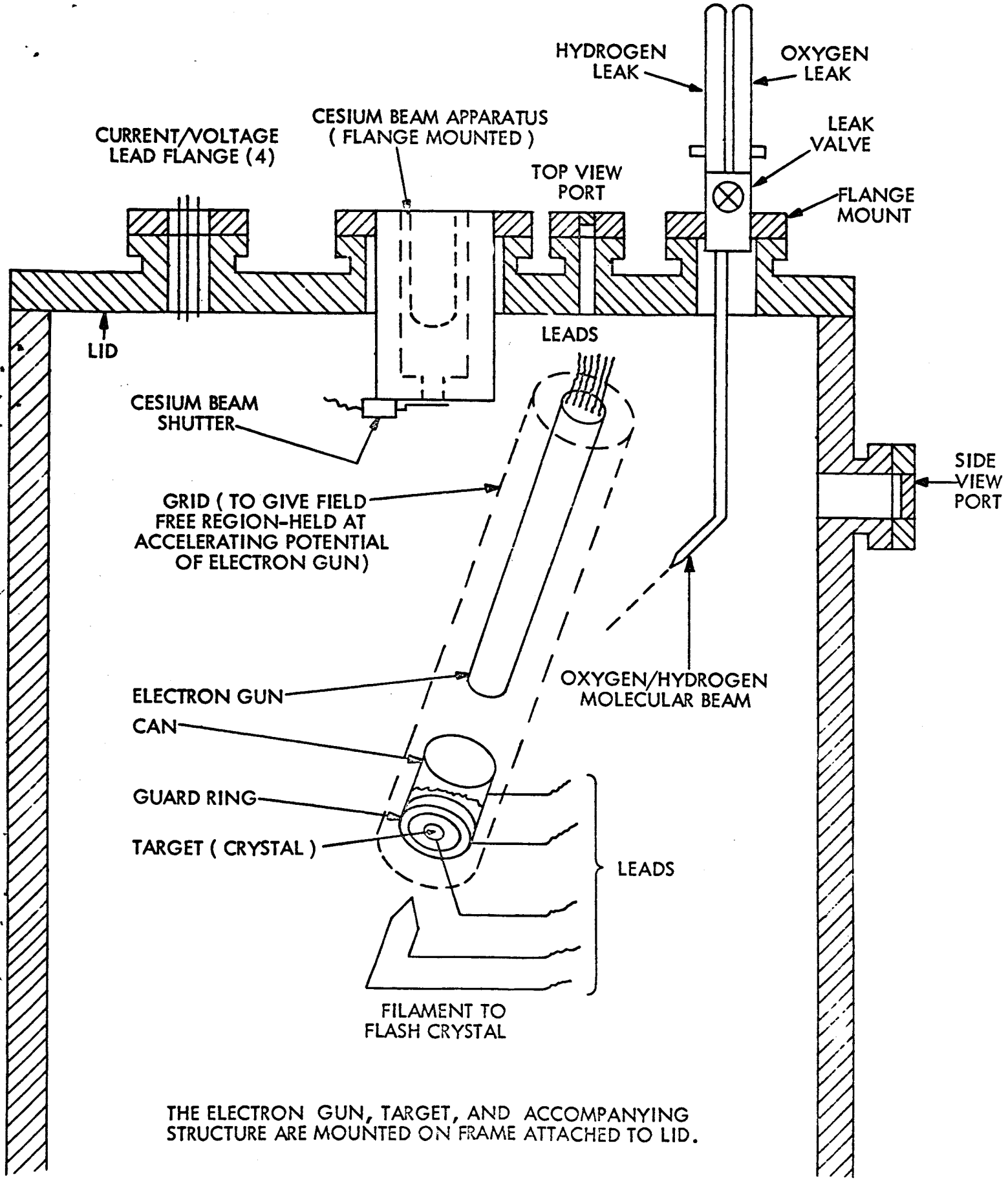


Fig. 4. Schematic of apparatus inside Varian system.

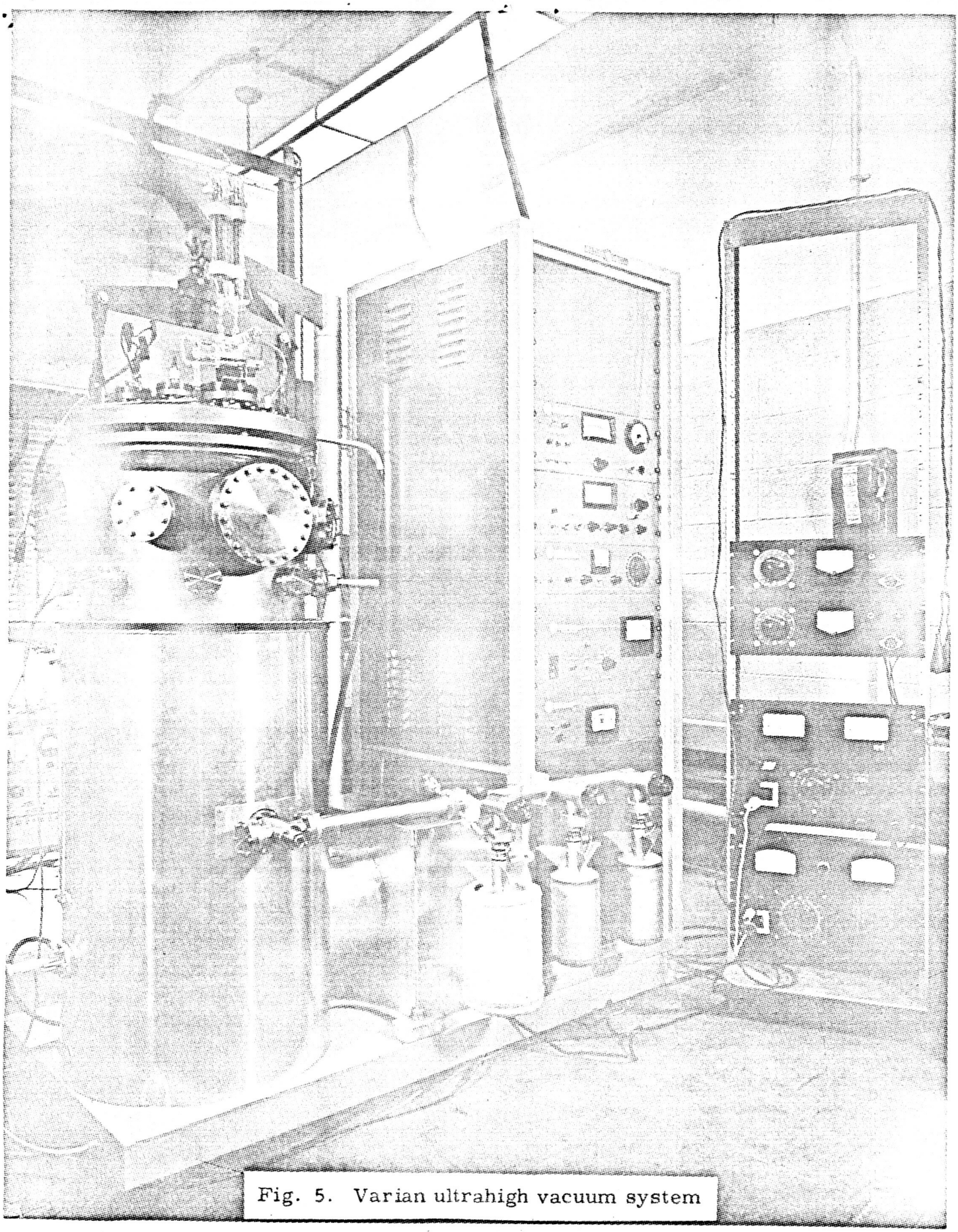


Fig. 5. Varian ultrahigh vacuum system

target apparatus are mounted on a frame attached to the lid. The electron optics require the use of a grid, held at the electron gun accelerating potential, surrounding the electron path. The grid, while providing a field-free region, still allows passage of the molecular beams.

The system is provided with two viewing ports, one at the top and one on the side. When crystal temperatures, during flashing, become too high for thermocouple measurement, it is possible to use an optical pryometer at one of these ports.

Alignment of the system is relatively easy, since the gun and target are mounted to allow translation and rotation. The system is quite adaptable and flexible, since many more ports are still available for any additions that may be required in the future.

III. Present Status and Future Schedule

All of the components described above have been designed and built. The circuits, electron gun, crystal heater, and vacuum system have been tested. We plan to assemble the cesium beam and perform preliminary runs within the next two months.

References

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