AIR FORCE INSTITUTE OF TECHNOLOGY

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A DESIGN AND EVALUATION

OF AN ION IMPLANTATION SYSTEM

GE/EE/70-20

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by

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Preface

The purpose of this project was to redesign a bakeable sputtering apparatus and examine its capabilities as an ion implantation system.

Assembly and modification of the machine, as well as the repair of several of the electronic components, consumed most of the time available for this project.

The system is now operational, and several recommendations for further work (which I could not complete due to time limitations) are contained in Chapter VI.

I wish to express my appreciation to the many people without whom the successful fabrication of this machine would not have been possible. Special recognition should be given to the following individuals: Mr. Eugene H. Miller of the Air Force Materials Laboratory (MATE) whose resourcefulness was invaluable, Mr. Donald A. Smith who spent countless hours of his off-duty time working on this project, Mr. Gordon Nichols who helped design and fabricate many of the special jigs and electrical and mechanical accessories, Mr. Millard Wolfe and the personnel of the AFIT school shops for their patience and help in fabricating many special components of the apparatus, Mr. Bryan Hill of the Air Force Avionics Laboratory (AVTA) who was my Laboratory Sponsor, Mr. Wayne Chase of Systems Research Laboratories who taught me a great deal about high-vacuum systems, and Dr. Robert Hengehold of the AFIT Physics Department (AFIT-SE) for his timely suggestions. My appreciation is

also extended to Prof. J. Lubelfeld, my Faculty Advisor, for his faith and guidance in this project. I wish to acknowledge my wife's patience and understanding throughout this difficult period.

Stephen P. Plusch

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Abstract

A machine originally designed as a bakeable, monoenergetic sputtering apparatus was redesigned for use as an ion implantation system. Engineering modifications produced a virtually oil-free high-vacuum system. The base pressure of the system (unbaked) in its present configuration is 1×10^{-8} Torr. A 0.8-μA, 6.5-keV nitrogen ion beam was obtained. The machine, after modifications, was studied to determine its feasibility as an ion implantation system. If beam voltages greater than 10 kV are used, the machine will be suitable to perform small-area implants (areas $\approx$ 0.5 cm^2) with dopants available in gaseous form (non-corrosive) ranging in energy from 10 to 30 keV.

A DESIGN AND EVALUATION OF AN ION IMPLANTATION SYSTEM

I Introduction

Background Information

The successful fabrication of p-n junctions in semiconductor materials depends upon the precise control of minute quantities of dopant elements. The electrical properties of these p-n junctions are determined by the concentration and distribution in depth of the dopants (donors and acceptors). These dopants are normally introduced into the semiconductor material by one of the following conventional methods: (1) growing the semiconductor crystal from a mixture containing a specified amount of the desired impurity, (2) diffusing the desired impurity into the semiconductor crystal lattice thermally, (3) alloying the desired dopant with the semiconductor substrate, or (4) introducing the dopant into the semiconductor during epitaxial growth of the parent material upon the existing crystal lattice.

Recently, "ion implantation," a unique method of introducing dopants into semiconductor materials, has been shown to have great potential. When a semiconductor crystal lattice is bombarded by a beam of high-energy ions, the host material will lose some of its atoms by sputtering, but the lattice will retain a significant fraction of the incident ions. The ions remaining in the semiconductor crystal are said to have been implanted.

In the implantation process, ions generated in a source are accelerated through a potential of typically 25 to 300 kV, mass analyzed for beam purity, focused, swept for uniformity, and allowed to impinge on the surface of a semiconductor substrate. The depth to which the ions are implanted (typically between 100 and 10,000 Å) depends primarily upon the incident energy (non-channeling direction) of the ions. The total number of implanted ions is a function of the ion beam current and the exposure time.

Among the more important advantages of ion implantation are the following: (1) dopants which have not been used in the past because of problems with limited solubility or dissociation can be introduced easily into the crystal lattice, (2) impurity distributions which differ significantly from those possible by conventional techniques may be selectively produced, (3) materials may be doped which are difficult or impossible to dope by usual methods, and (4) very shallow uniform layers and, therefore, very high resistivities may be obtained. The ion implantation technique is not without its disadvantages. Crystal damage effects and post-implant electrical activity are important problems which are under intensive research at the present time.

The equipment required for an ion implantation system is as follows: (1) an ion source capable of producing the desired ions, (2) an electrostatic acceleration and focusing system capable of producing a well-focused beam of the desired energy, (3) a mass analyzer to produce a highly pure beam of a single species of the desired ionization state, (4) a target chamber, (5) a clean high-vacuum pumping system, and (6) suitable instrumentation.

A simplified arrangement of an ion implantation system is shown in Fig. 1.

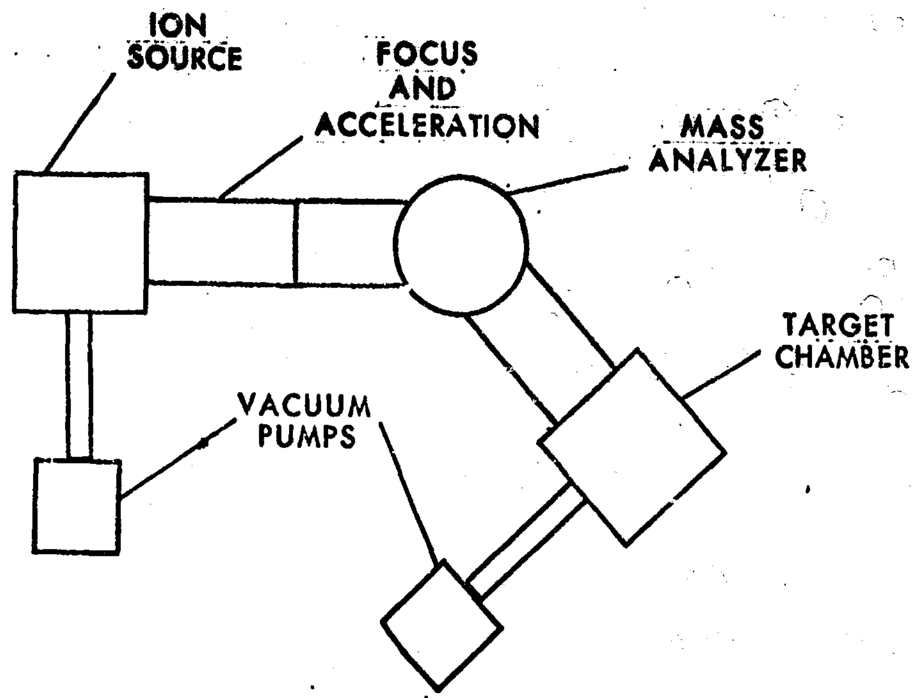


Figure 1

Simplified Diagram of a Typical Ion Implantation System

A system with these basic components (originally designed in 1963 by Radiation Dynamics, Inc. as a bakeable sputtering apparatus and modified by Systems Research Laboratories, Inc.) was available in completely disassembled form in the AFIT-AFML Cooperative Laboratory in Bldg. 125 at Wright-Patterson Air Force Base, Ohio.

The thesis problem was to reassemble the machine, locate and repair any vacuum leaks, test and repair associated electronic equipment, obtain an ion beam of a convenient species, and determine the feasibility of the machine as a high-vacuum ion-implantation system.

Approach to the Problem

Initially, it was realized that a large number of diverse problems would have to be solved in order to obtain useful results. Equipment, jigs, and accessories would have to be fabricated to meet the power, vacuum, cooling, and electronic requirements of the machine.

The machine was modified and assembled, vacuum leaks were found and repaired, electrical and electronic components were tested and repaired, and an ion beam was obtained. The characteristics of this beam are given in Chapter V. In addition, laboratory facilities were modified to meet the water and power needs of the machine.

Thesis Organization

Two primary tasks were involved in the solution of this problem: (1) modification and construction of the machine, which included obtaining high-vacuum conditions and insuring proper operation of associated electronic equipment, and (2) determination of the operating characteristics and potential of the machine.

A description of the final configuration of the apparatus is presented in Chapter II. The assembly and modification process is described in Chapter III. Operating characteristics and procedures are given in Chapter IV. The results and conclusions of this endeavor are included in Chapter V. Since numerous further investigations and modifications, that could not be made by the author due to the obvious constraints, are possible, a number of recommendations for further study and possible modifications are presented in Chapter VI.

Projected Capabilities

The capabilities of this machine are best illustrated by comparing it to systems of similar construction. Several such systems are described in the literature (Refs 1:1539, 2:16, and 3:7-10). Each of these systems has a gaseous ion source, ion accelerating and focusing assembly, mass analyzer, beam deflection assembly, and a target chamber.

These systems are capable of producing singly ionized ions of nitrogen (N^+), arsenic (As^+), phosphorus (P^+), and boron (B^+) (other ions may be generated also) with energies from 0 to approximately 100 keV. These systems are capable of uniform implants over relatively large areas (approximately one square inch). These systems are quite versatile and useful in many ion implantation applications.

The ion beam machine, when compared to these three systems, is limited in two respects: (1) no provision exists for sweeping the target to obtain uniform implants, and (2) the maximum energy obtainable, at present, is approximately 30 keV. A beam deflection assembly, outlined in Chapter VI, may be added to the system. The maximum energy available may be increased to approximately 60 keV, as described in Chapter VI.

The ion beam machine is presently capable of performing implants over small areas (approximately one square centimeter) where energies below 30 keV are required.

Areas of research in which this ion implantation system would be useful include: (1) characterization of implanted layers in single-crystal silicon (10 to 50 keV) (Refs 5:37-43 and 10:49-66), (2) formation of silicon-nitride (dielectric) films (10 keV) (Ref 5:71-75), and (3) p-n junction formation in materials other than silicon [silicon carbide (SiC), gallium arsenide (GaAs), etc.] (10 to 50 keV) (Ref 10:87,88). This machine would also be useful for fabrication of: (1) high-value ion-implanted resistors (30 to 55 keV) (Ref 9), (2) diodes (10 to 80 keV) (Ref 10:68-70), (3) avalanche diodes (60 keV) (Ref 10:73), (4) particle detectors for nuclear instrumentation (2 to 80 keV) (Ref 10:73,74), and (5) MOSFET's (20 to 50 keV) (Ref 10:87,88). It should be noted that many useful implants may be made with energies less than 50 keV.

II. Ion Implantation Apparatus

This chapter gives a detailed description of the ion beam machine in its present state. Subsequent sections describe the functional parts of the equipment, beginning with the ion source and terminating at the target.

General Description

This machine is capable of producing mass analyzed beams of positive, singly ionized ions ranging in mass from hydrogen to krypton and in energy from 10 to 30 keV. Beams approximately 0.5 cm in diameter with current densities to 500 $\mu A/cm^2$ are possible. Some of these specifications are the same as those of the original machine (Ref 6:7). (Many of the specifications of the original machine are no longer valid due to redesign.)

The ion beam machine is evacuated to a nominal pressure of 2×10^{-8} Torr by a 500-1/s ion pump located at the base of the target chamber. A separate 8-1/s ion pump is located on the source chamber and evacuates it to a pressure of approximately 1×10^{-7} Torr before the source is placed in operation. Pumping the source to a low pressure removes contaminants from the source chamber and thus reduces the probability of generating unwanted ion species.

In the present configuration the ion beam is accelerated to its final energy in a single stage as it emerges from the ion source.

The mass analyzing magnet has cadmium pole pieces 7 in. in diameter and is capable of producing a uniform field of approximately 10,000 G in the 1 1/2-in.-wide mass analyzing section between the pole pieces.

In the present configuration, there are no slits or apertures which would insure mass separation of the beam.

A partial sectional view of the ion beam machine is shown in Fig. 2, and a drawing of the system is shown in Fig. 3. Photographs of the system with associated control unit, power supplies, and instrumentation are shown in Figs 4 and 5. Figure 6 is a close-up of the system from the source to the target chamber. A close-up of the source end is shown in Fig. 7.

Since the power supplies and other electronics are supporting equipment, they are described separately in Appendix A.

Ion Source

The ion source is a low-voltage-arc source of the duoplasmatron type (Ref 12:540). The source is shown schematically in Fig. 8.

A tungsten dispenser cathode (see Appendix B) supplies electrons which are attracted to the intermediate electrode (z-electrode) and anode by a potential of approximately 60 V. As the electrons proceed from cathode to anode, they ionize the intermediate gas (nitrogen in this configuration) and form a plasma. The intermediate electrode and the anode form the pole pieces of the arc-focusing magnet. The action of the intense inhomogeneous magnetic field produced by this magnet and the electrostatic action of the intermediate electrode (maintained at a potential slightly more positive than the filament) cause the plasma to be compressed and increase the efficiency of the source. The ion beam is extracted from the plasma through a 0.356-mm (0.014-in.) aperture in the center of the anode by the electrostatic action of the extractor electrode. A low-voltage-arc source of this nature operates with a gas

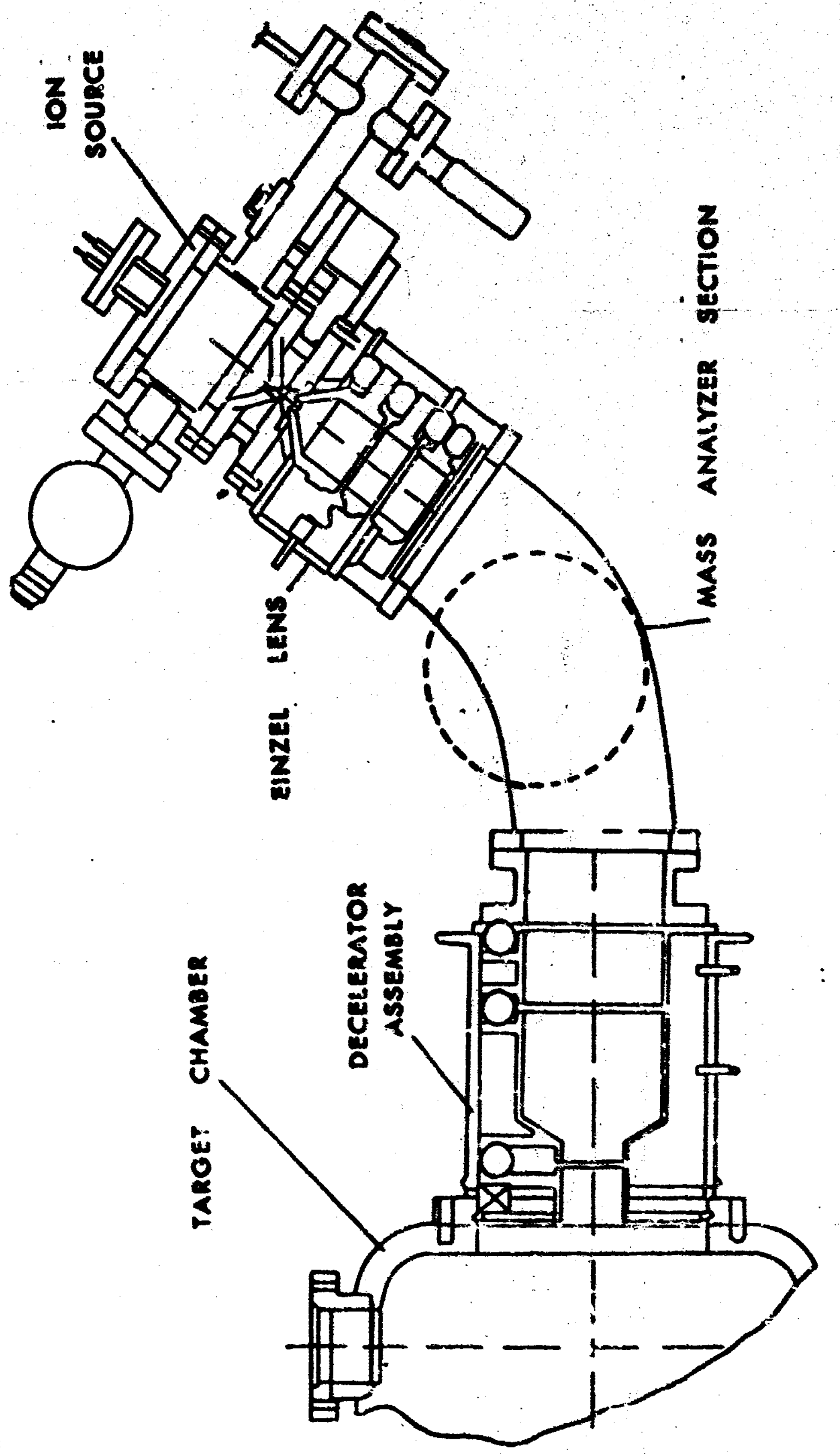


Figure 2. Partial Sectional View of Ion Beam Machine

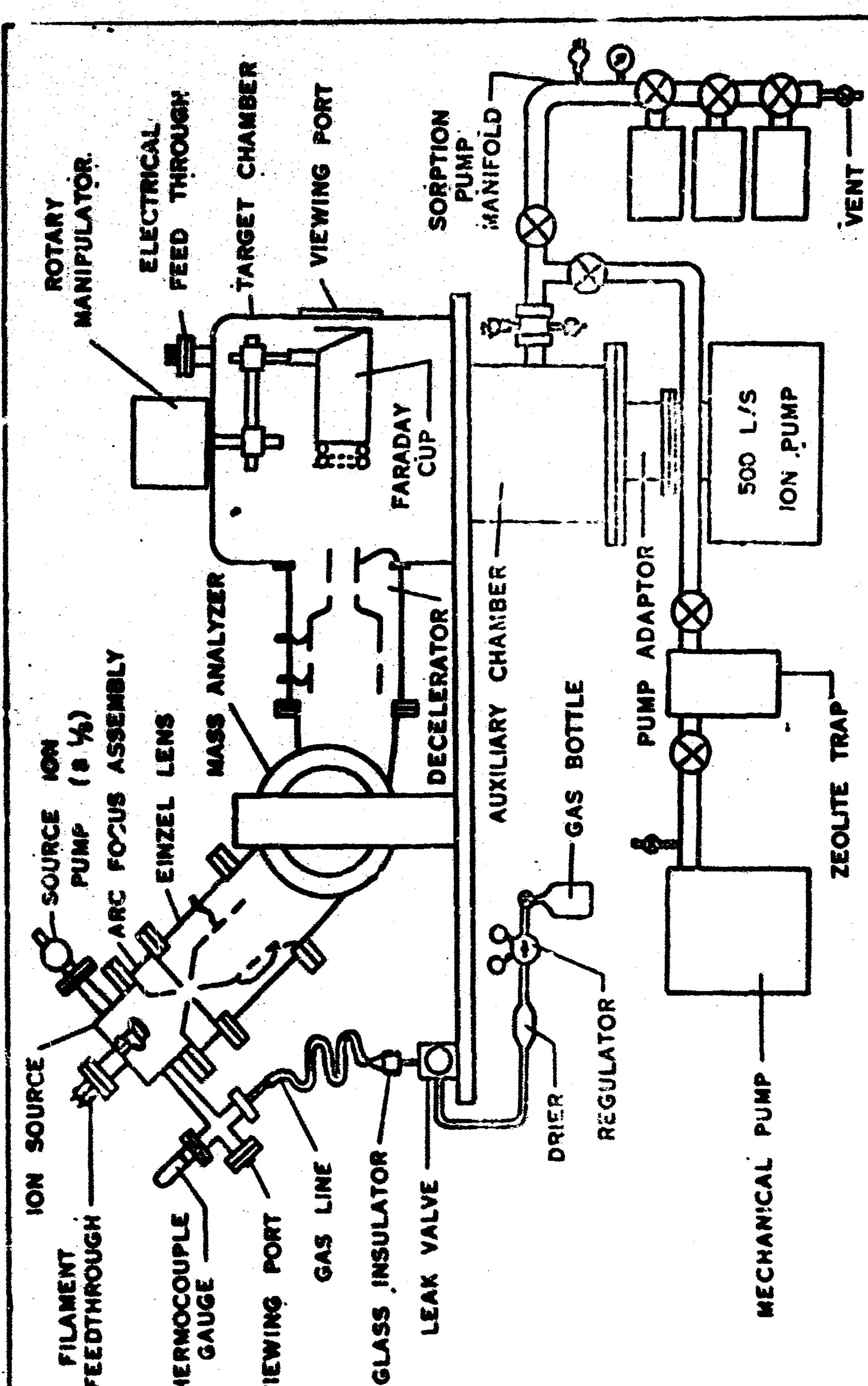


Figure 3. Drawing of the Ion Beam Machine

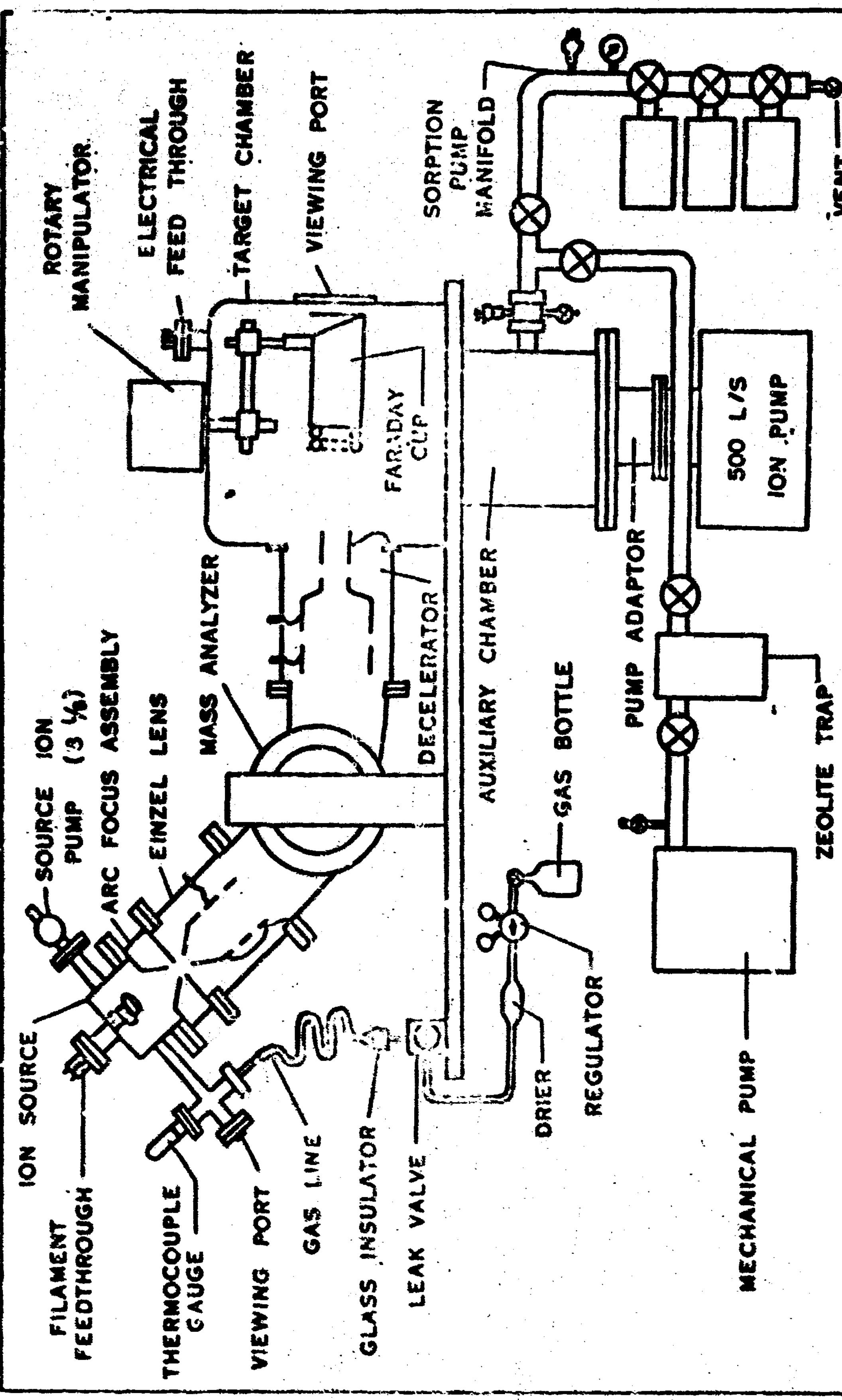


Figure 3. Drawing of the Ion Beam Machine

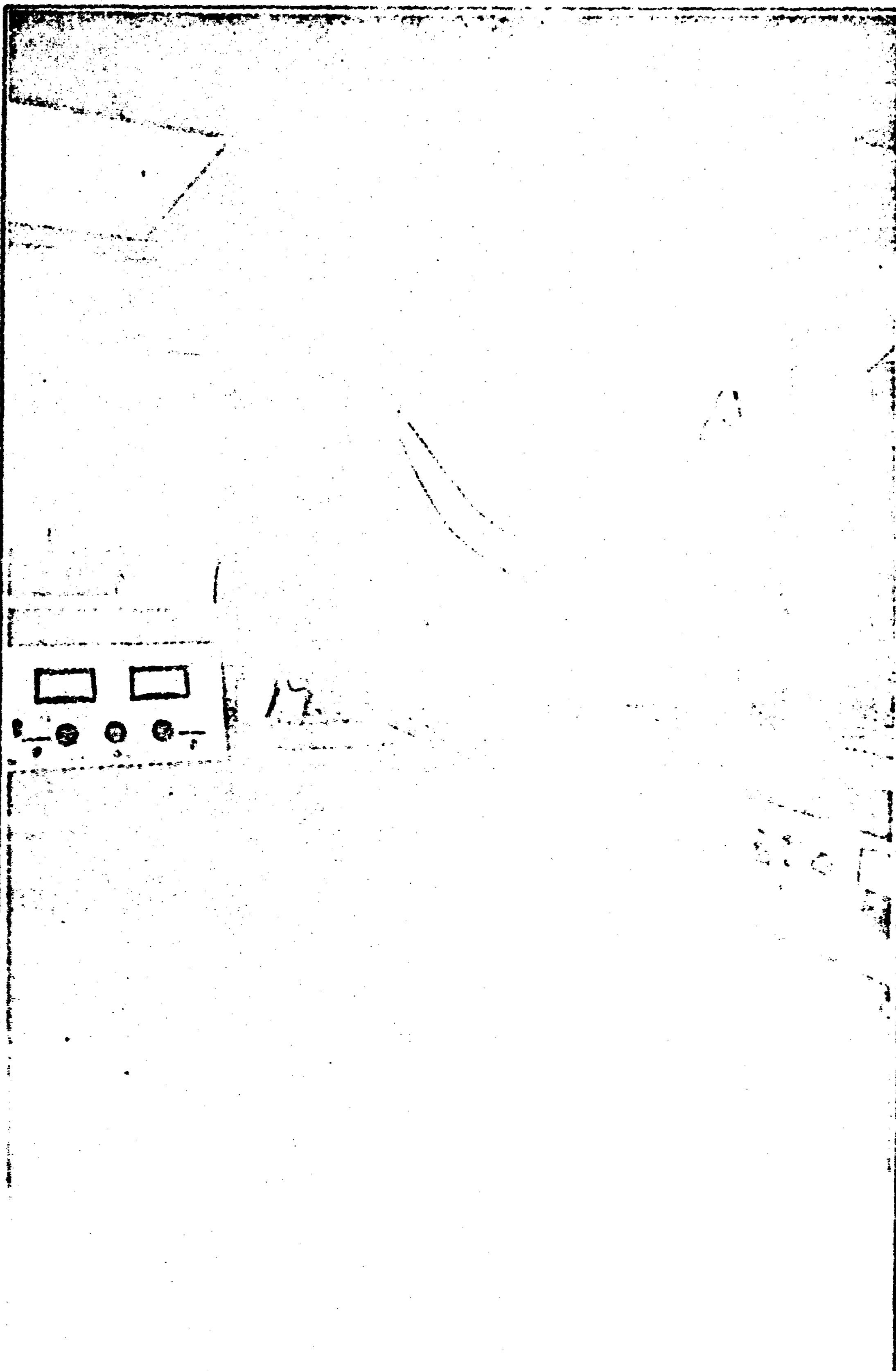
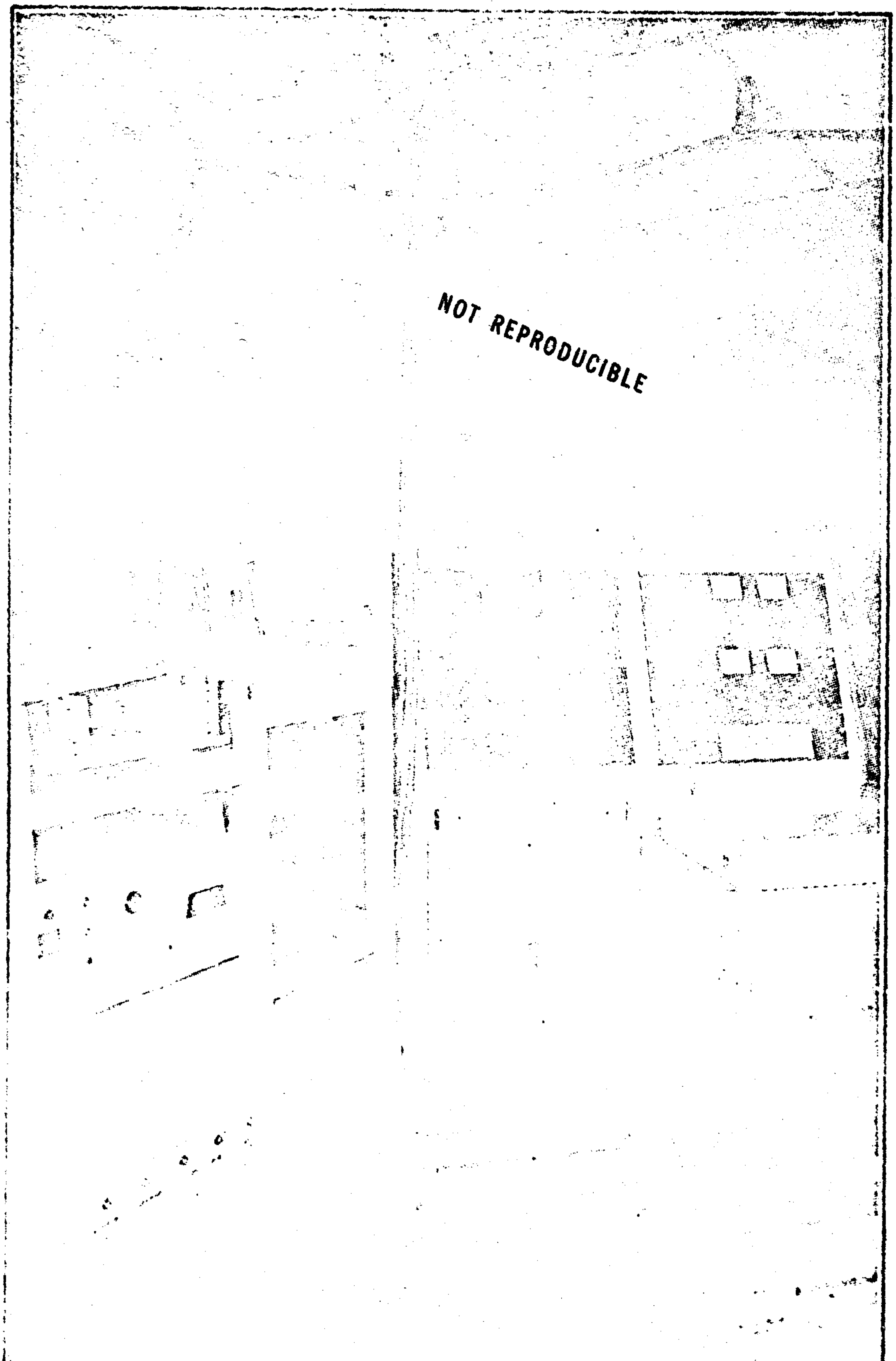


Figure 4. Ion Implantation [illegible]



[illegible] (Right Half)

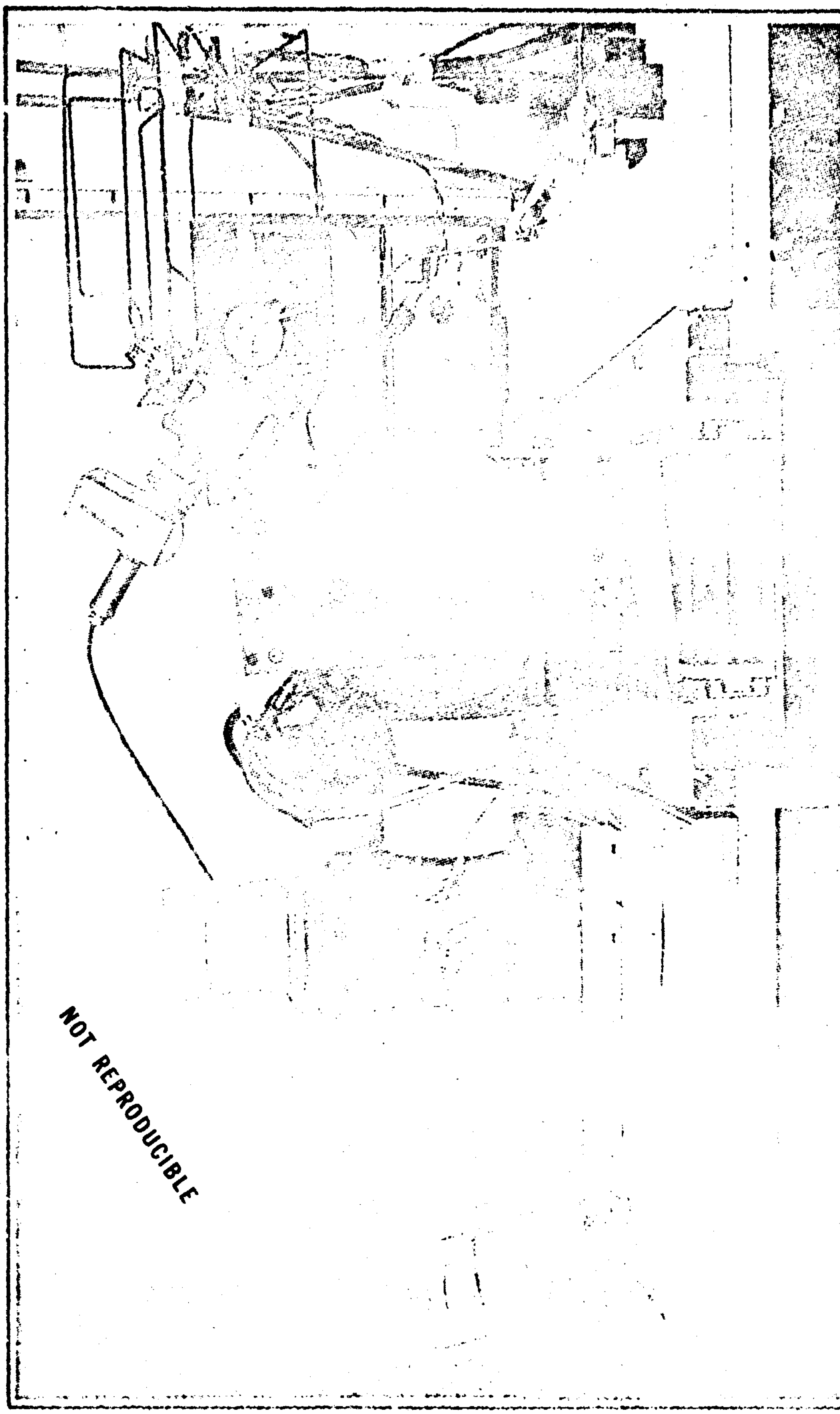


Figure 6. Ion Implantation System (Source to Target Chamber)

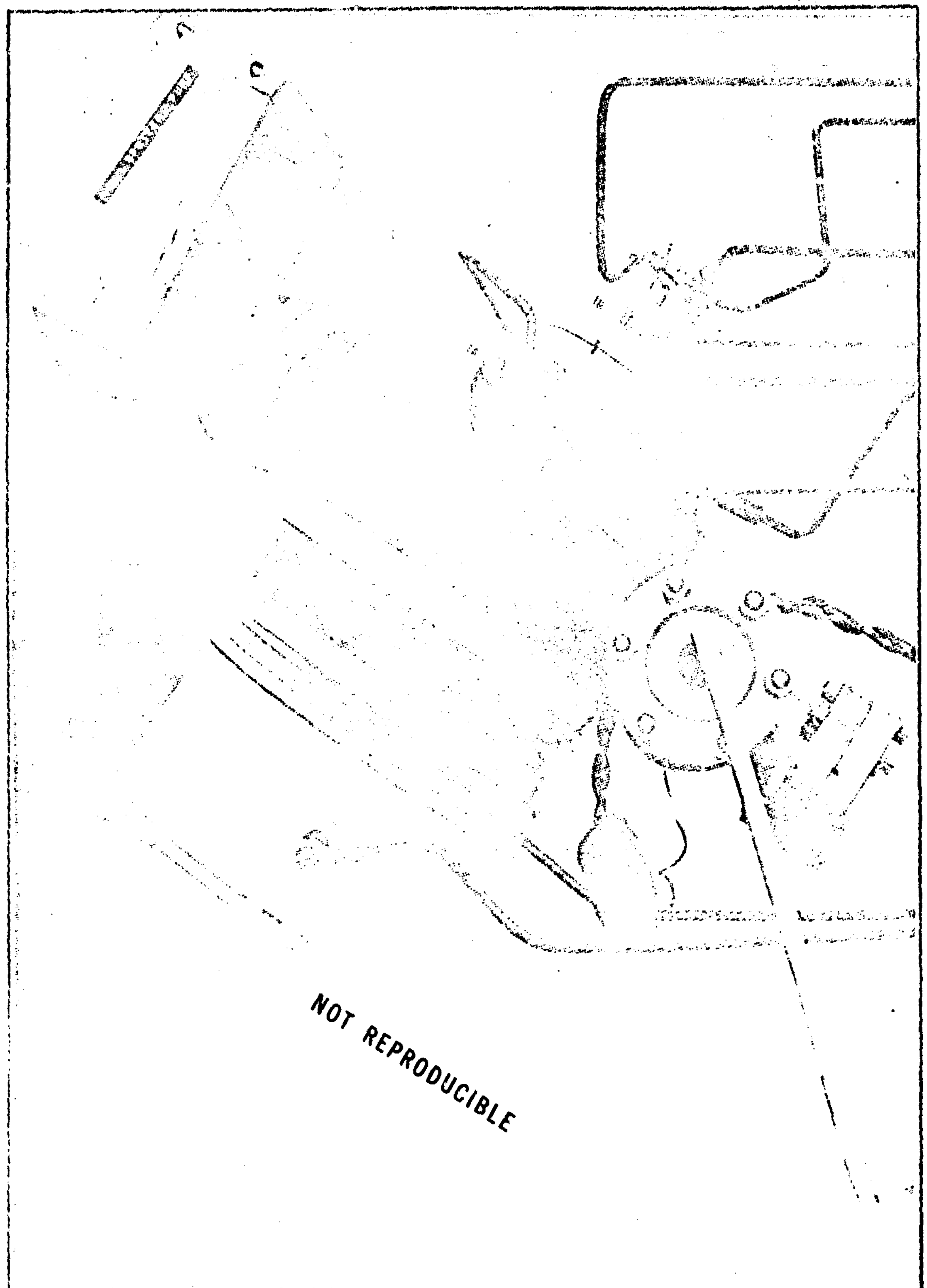


Figure 7. Ion Implantation System (Source End)

pressure in the range 1 to 2.5 × 10^{-1} Torr. This source is capable of producing beams of positive ions from a wide variety of elemental and

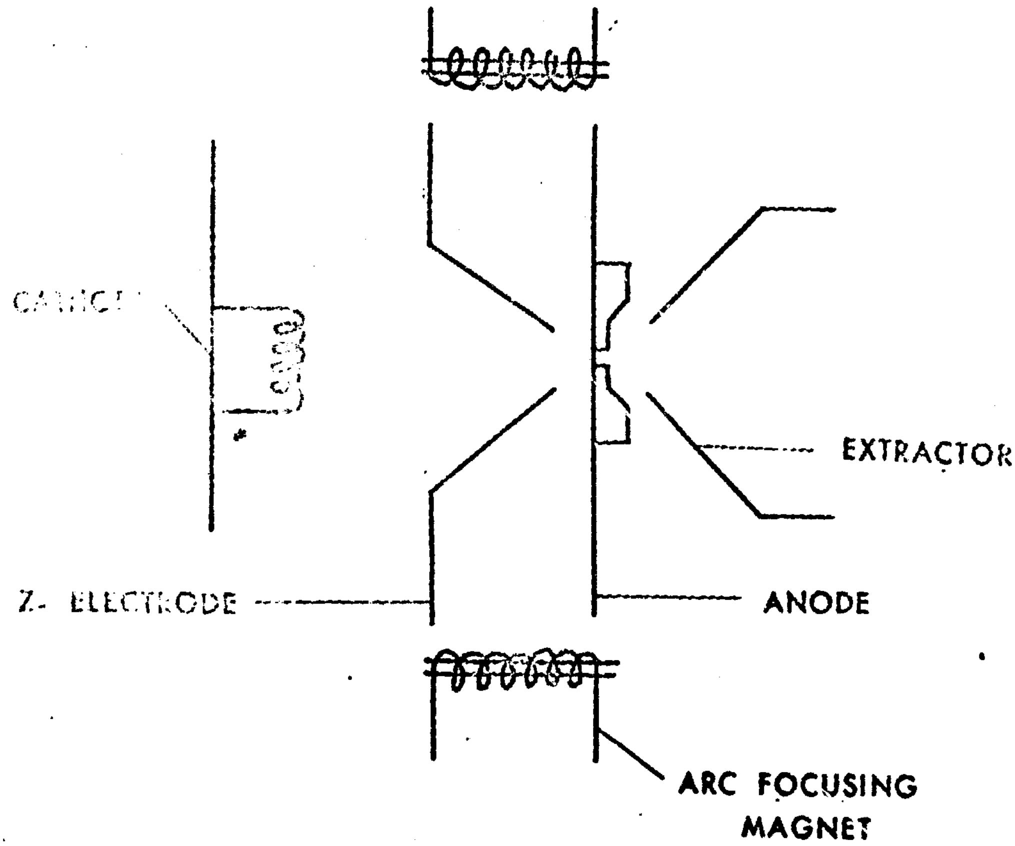


Figure 8

Schematic Drawing of Ion Source

compound gases such as arsine (AsH_3), phosphine (PH_3), boron trichloride (BCl_3), nitrogen (N_2), etc., which are useful dopants for various semiconductors.

Beam-Focusing Assembly

The ion beam is extracted from the aperture in the anode of the source by the electrostatic action of the extractor electrode (L_1) of the electrostatic lens system. When the ion beam emerges from the source, the high-energy ions are rapidly diverging. In order for the beam to be propagated through the rest of the system, it must be focused. A schematic drawing of a portion of the ion source and the lens system is shown in Fig. 9. The ion source is attached on the

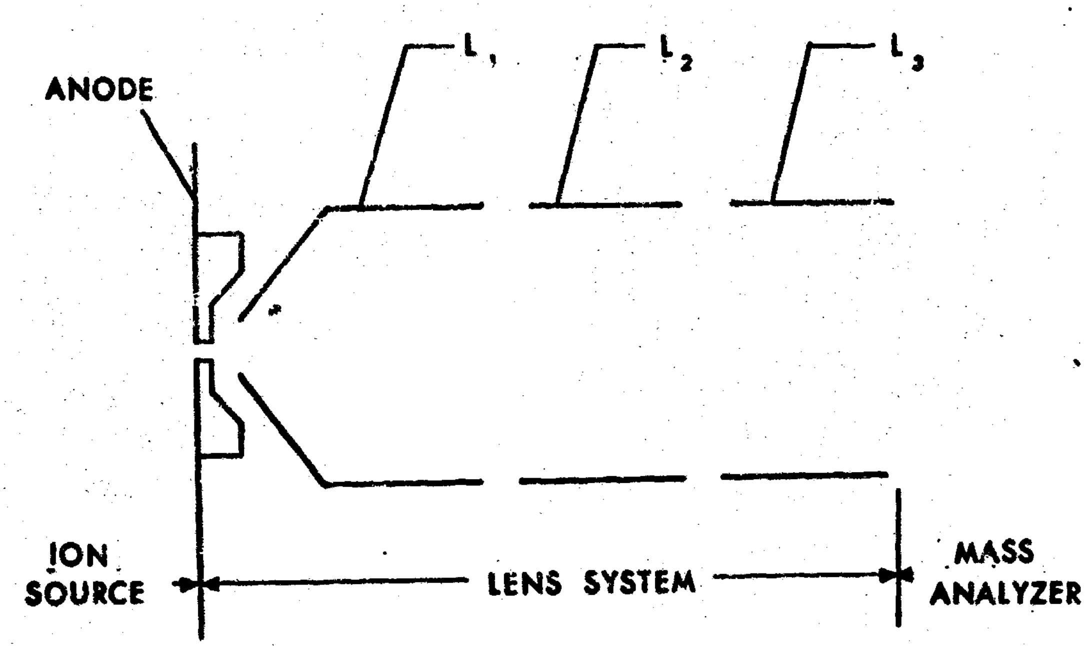


Figure 9

Schematic Drawing of Beam-Focusing Assembly

left, and the inlet flange of the mass analyzer is attached on the right. The lens consists of cylindrical stainless-steel electrodes whose inside diameter is 1 15/16 in. The electrodes are separated by gaps of 0.156 in. Electrostatic lenses are formed at the gaps between the electrodes. In this configuration the anode is held at +10 to 25 kV, and the extractor (L_1) and the third electrode (L_3) are grounded. The voltage applied to the center electrode (L_2) is variable, and it controls the focal length of the lens system. This particular lens arrangement is called an einzel or unipotential lens. The lens voltage applied at L_2 is adjusted such that the focal point of the lens is at the correct position at the entrance to the mass analyzer.

Deceleration Assembly

Since the desired beam energy for ion implantation in most cases is 10 keV or greater, the deceleration assembly in the present configuration is used only as a drift space. Possible future uses for this assembly are discussed in Chapter VI.

Target Chamber

The target chamber is a 1-cu-ft stainless-steel chamber with three quartz viewing ports, vertical and horizontal rotary motion feedthroughs, and four standard 2 3/4-in. ultra-high-vacuum flanges to which electrical feedthroughs, ionization gauges, and various other fittings may be attached. In the present configuration, one quartz viewing port is in line with the beam at the rear of the chamber, two quartz windows are perpendicular to the beam at the entrance of the target chamber, and two ionization gauges and two electrical feedthroughs are mounted on the standard flanges.

A Faraday cup is attached to the vertical rotary-motion feedthrough by a universal mounting bracket which permits the cup to be positioned at any location and at any desired angle in a horizontal plane within the target chamber. The present Faraday cup is for measuring total beam currents, and it consists of a closed stainless-steel cylinder with two insulated grids as shown in Fig. 10. The grids consist of stainless-steel wire screens insulated from the cup and from each other by glass insulators. The grids may be biased highly negative to prevent the escape of secondary electrons generated by the high-energy ion beam impinging on the cup.

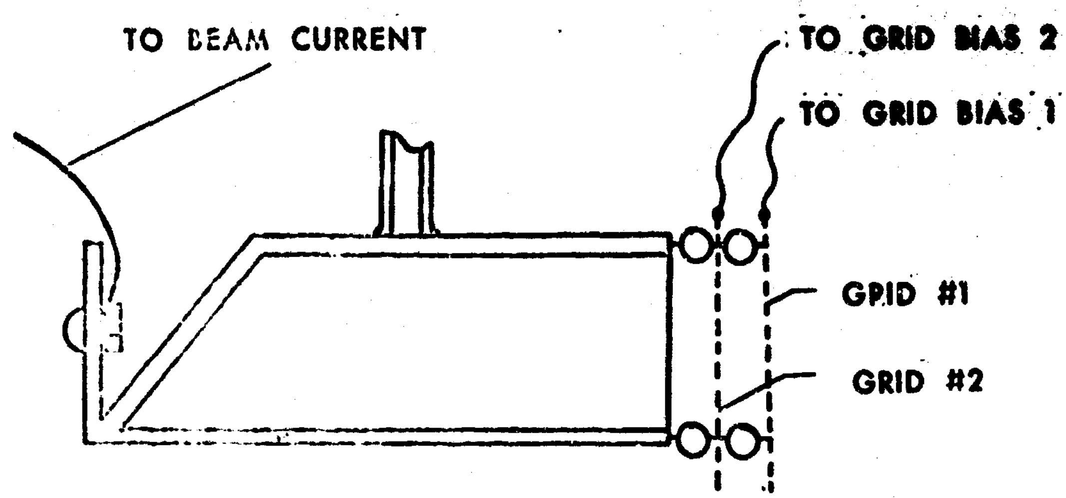


Figure 10

Faraday Cup for Total Beam Current Measurements

A quartz viewing plate is attached to the horizontal rotary motion feedthrough by a lever arm which permits the viewing plate to be raised to a position directly in front of the last decelerator electrode at the entrance of the target chamber. This viewing plate provides a single detector for the presence of an ion beam. At low current densities ([illegible]) the quartz glows blue; at higher beam currents it becomes incandescent. This quartz indicator has several advantages because the quartz (1) has a very high melting point, (2) can detect current densities from 10 $\mu A/cm^2$ to 50 mA/cm^2, and (3) can provide qualitative information about the shape of the beam because its glow or image is well defined.

III. Assembly and Modification

The first task prior to assembling the machine was to examine the previous configuration to determine whether it was compatible with the new facility in Bldg. 125. It was necessary to modify both the laboratory facilities and the machine as the system was assembled. The modifications and the assembly procedure are outlined below.

Preliminary Planning

In the previous configuration of the ion beam machine, the high vacuum was maintained by a 6-in. oil diffusion pump having a mechanical forepump, a cold-water chevron baffle, and a liquid-nitrogen cold trap. Water and power requirements for this configuration are shown in Table I.

A single 208-V, 1-ϕ, 20-A electrical circuit was available in the laboratory. Arrangements were made to have the following additional electrical circuits installed: (1) one 110/220 V, 1 ϕ, 30 A, and (2) two 208 V, 3 ϕ, 6.2 kVA/ϕ. An enclosure for a 208-V, 3-ϕ, Δ-Y transformer with multiple outlets was fabricated to provide 208-V, 3-ϕ, Y-connected power.

A recirculating water system was available in the laboratory, but its capacity was insufficient to satisfy the cooling requirements of both the ion beam machine and the existing laboratory equipment. After a special study, the necessary alterations to increase the capacity of the recirculating water system were determined.

During this planning stage, I studied various ion implantation systems at Hughes Research Laboratories, Malibu, California; Stanford

Electronics Laboratory, Stanford University, Stanford, California; and the production facility at Hughes, Newport Beach, California. The

Table I

Electrical and Water Requirements for Ion Beam Machine

Component	Requirement
Electrical	
Analyzing Magnet	208 V, 3 ϕ, Y-connected, 5 kVA/ϕ
Console	208 V, 3 ϕ, Δ-connected, 5 kVA/ϕ
Diffusion Pump	115 V, 1 ϕ, 17 A
Mechanical Pump	220 V, 1 ϕ, 8 A
Miscellaneous	115 V, 1 ϕ, 45 A
Water	
Analyzing Magnet	5 to 7 gpm, 80°F max, 75 psig max
Diffusion Pump	0.5 gpm, 60 to 70°F max

information gained while studying these systems was very valuable in providing an overall view of the problem.

In this initial phase it became apparent that serious difficulties could arise if oil-diffusion pumps, even well trapped, were used to evacuate the system. A surface film of vacuum pump oil would almost certainly form on the interior of the target chamber and on lens surfaces. If the ion beam were to hit surfaces contaminated in this manner, a charge would accumulate and persist due to the dielectric properties of the oil. The presence of such charge would violate the fundamental assumption that all electrostatic lens surfaces are equipotential. The result of the accumulation of charge would be a drift in beam intensity and position. As the beam drifted, it would strike new areas causing instabilities detrimental to the implantation process. This oil problem could be alleviated by the installation of titanium, getter-ion type pumps.

A 500-l/s getter-ion pump was available in the laboratory, but the flange on the ion pump was not compatible with the flange on the auxiliary chamber. An adapter spool was designed and plans were submitted for its fabrication. A possible delay time of two to three months was anticipated for fabrication of this ion pump adapter; therefore, I decided that the system should be assembled with the diffusion pump until the new adapter was available.

The machine was assembled in three phases: (1) mechanical assembly to insure completeness and proper placement of system components, (2) disassembly and cleaning, and (3) final assembly, leak testing, and electrical checkout.

Mechanical Assembly

For the placement of system components, refer to Fig. 3. Early examination of the major system components revealed that the seals between the cold-water chevron baffle and diffusion pump, the cold-water chevron baffle and liquid-nitrogen trap, the diffusion-pump adapter and auxiliary chamber, and the auxiliary chamber and target chamber were diamond-cross-section, copper crush rings. The mechanical arrangement of this configuration is shown in Fig. 11.

This type of seal was necessary in the previous configuration because the system was to be bakeable; however, it was difficult to obtain a reliable seal without applying a great deal of torque to the flange bolts (greater than 100 ft-lbs). In the present configuration,

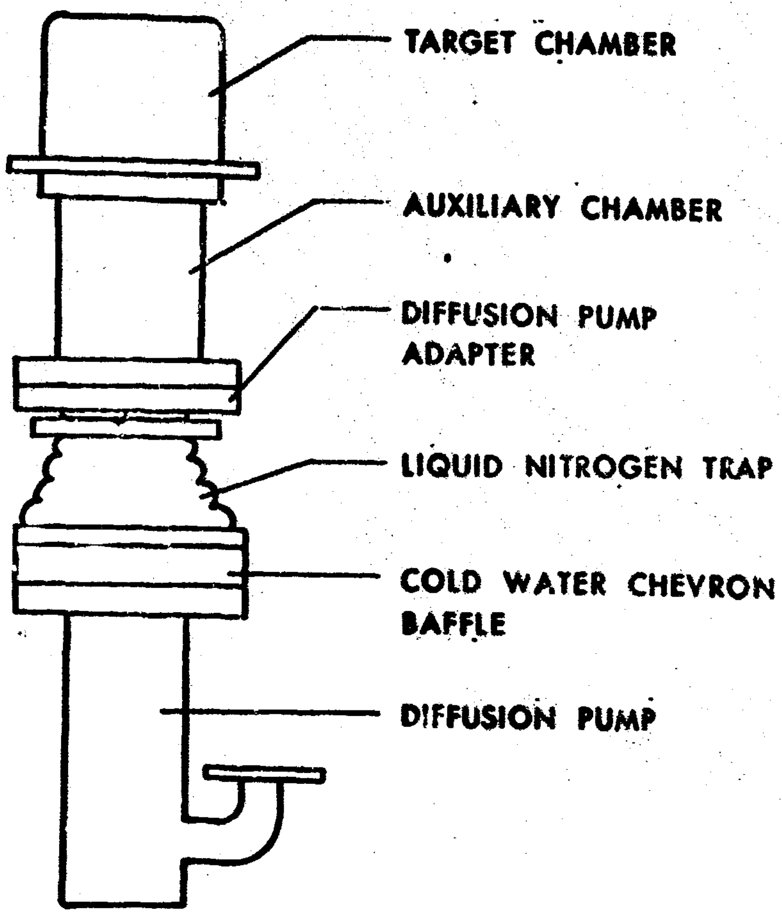


Figure 11

Mechanical Arrangement of Vacuum Pumping Components in Previous Configuration

the system need not be bakeable; therefore, these seals were replaced with aluminum-reinforced viton gaskets for increased reliability.

Since the target chamber is the basic unit of the system, it was installed in the aluminum framework first. To lend stability to the system, the auxiliary chamber was secured to the bottom of the target chamber. The decelerator and mass analyzer sections were then bolted to the target chamber. To align the target chamber properly, it was first necessary to install the mass-analyzer pole-piece framework and pole pieces. Extreme caution was observed when working with the framework and pole pieces since they are extremely heavy (total 800 lbs) and unwieldy. The sliding mechanism (Ref 2:8-14) was secured to prevent accidental slippage during framework and pole-piece installation. When the magnet framework and pole pieces were in place, the target chamber was aligned in such a way that the mass-analyzer section fit properly between the magnet pole pieces. The einzel lens with the arc-focus assembly (anode-intermediate electrode section) attached was bolted to the mass-analyzer section. The next step was to attach the source chamber to the arc-focus assembly. The arc-focus assembly consists of two metal flanges separated by a ceramic insulator. Originally, the ceramic section was secured to the flanges by ceramic-to-metal brazed seals. In the past these seals could not be made leak free as called for in the design. A leak-free seal had been obtained finally (Ref 2: 14, 18) through the use of epoxy and a spring-loaded suspension system. When the machine was dismantled, moved to its present location, and stored, this section was probably weakened. A new insulated suspension system was designed and fabricated to support the source chamber, and the aluminum framework above the support table was strengthened. While the source was being remounted on the machine, the weakened seals failed. Before proceeding with the assembly of the machine, it was necessary to repair the arc-focus assembly. Repair of this section is covered in Appendix C.

Because of the delay encountered in the repair of the arc-focus assembly and early receipt of the ion pump adapter, mechanical installation of the ion pump was begun. The ion pump and ion-pump adapter (approximately 400 lbs) were too heavy to hang unsupported from the aluminum framework. A stand was designed and fabricated to support them from below. Adjustable legs were fitted to the ion pump so that it could be aligned with the base of the auxiliary chamber.

The rotary motion feedthroughs, gauges, electrical feedthroughs, and ports were attached to the target chamber.

All remaining components necessary for final assembly were on hand. The components which required alignment were installed and checked. Mechanical assembly was completed with the exception of the installation of the source which was being repaired, and of other items which would not be installed until the final assembly phase.

Disassembly and Cleaning

The machine was disassembled; all components and associated fittings were carefully identified to speed final assembly. (The pole pieces and frame of the mass-analyzer magnet were left intact.)

The source chamber, einzel lens, and decelerator assembly were completely disassembled. All the fittings attached to the target chamber were removed.

With disassembly complete all components--flanges, fittings, etc.--which would ultimately be in contact with the interior of the vacuum system (with the exception of thermocouple gauges, ion pumps, rotary motion feedthroughs, and roughing-system components) were cleaned individually, in the following manner: (1) rough cleaned with trichloroethylene, (2) vapor degreased in trichloroethylene (three times), (3) hand cleaned with lint-free cloths in acetone and methanol.

<u>Final Assembly, Leak Testing, and Electrical Checkout</u>

The target chamber was reinstalled on the support table. The components were bolted together in the order listed in Table II. The types of seals between the components are also listed in Table II. The following description supplements the information given in this table. The viton gasket is an aluminum, reinforced polymer gasket. The gold seal is a continuous gold "O" ring made of high-purity, 0.040-in.-diameter gold wire. The copper seal is a flat OHFC copper gasket used with "con-flat" ultra-high-vacuum flanges.

At that point the arc-focus assembly was not yet repaired; therefore, the open end of the mass-analyzer section was capped with a blank flange.

To install the 500-l/s ion pump, the ion-pump stand was placed beneath the auxiliary chamber, and the ion pump was carefully moved onto it. The ion pump adapter was then bolted to the ion pump, and the ion-pump-adapter flange and the flange on the base of the auxiliary chamber were carefully aligned. The viton gasket was inserted, the pump was raised into position with the adjustable legs, and the adapter and chamber were securely bolted together. The load was distributed evenly on each pump leg to prevent unnecessary stresses. The ion pump, ion-pump adapter, and stand are shown in Fig. 12. The roughing vacuum system was then attached to the 2 3/4-in. flange on the auxiliary chamber. The roughing vacuum system was modified previously to make it compatible with the ion-pumped system. The roughing system consists of a mechanical pump, vent valve, bakeable zeolite trap with isolation

Table II

Component Assembly and Flange Seal Types

Components	Seal
auxiliary chamber/target chamber	viton
decelerator/target chamber	gold wire
mass-analyzer section/decelerator	" "
einzel lens/decelerator	" "
rotary motion feedthroughs/ target chamber	" "
viewing ports/target chamber	" "
ionization gauges/target chamber	copper
electrical feedthroughs/ target chamber	"
blank flange/einzel lens	gold wire
ion-pump adapter/ion pump	copper
ion-pump adapter/auxiliary chamber	viton
thermocouple gauge/source chamber	copper
viewing port/source chamber	"
gas line/source chamber	"
8-1/s ion pump/source chamber	"
filament feedthrough/source chamber	"
arc-focus assembly/einzel lens	gold wire
arc-focus assembly/source chamber	" "

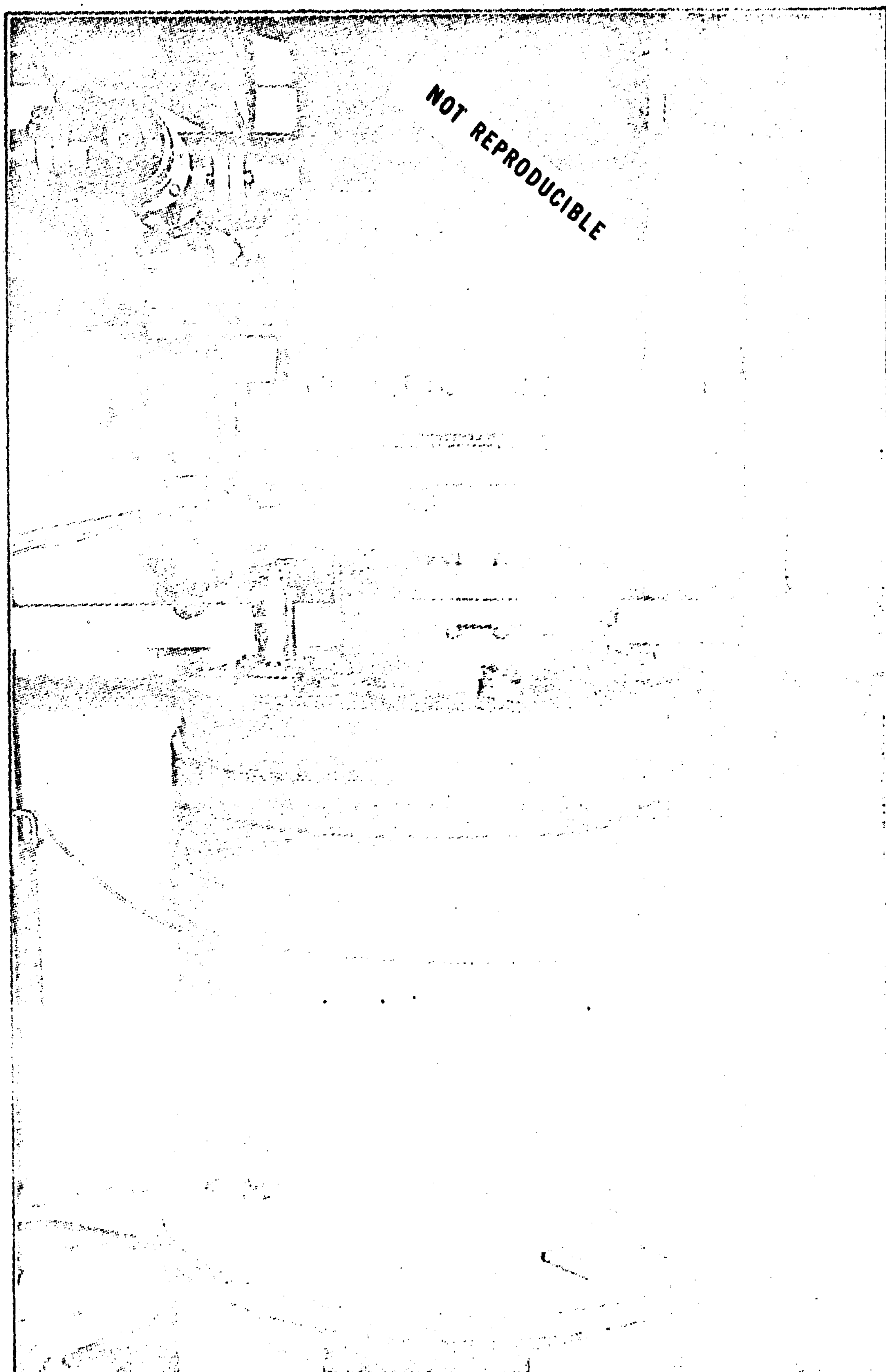


Figure 12. Photograph of Modified Vacuum Pumping System

valves, sorption-pump station with three sorption pumps, pressure gauges, and high-vacuum isolation valves as shown in Fig. 3.

The system was then rough pumped down to a pressure of 300 mTorr with the mechanical pump. At this pressure the mechanical pump was valved off and the first sorption pump (which had been cooled) was op[illegible] [illegible] of 27 mTorr was attained. The sorption pump was [illegible] the system pressure rose rapidly indicating that t[illegible] [illegible]. Leaks were found at the decelerator/target [illegible] [illegible] mass-analyzer section flanges. The leaks were [illegible] tightening the flanges. The system then attained a [illegible] approximately 1 mTorr. At this pressure the ion pump was [illegible] the sorption pump was valved off. With the ion pump i[illegible] the system reached a base pressure of 2×10^{-8} Torr.

Th[illegible]-focus assembly, source chamber, and einzel lens were as[illegible] during the repair process; therefore, the need for the [illegible] suspension system was obviated, and instead a support was fa[illegible] and installed under the mass-analyzer section to relieve th[illegible] decelerator assembly.

[illegible] was removed from the mass-analyzer section. The [illegible]-einzel lens assembly was attached to the mass-[illegible] gauge, viewing port, [illegible] ion pump, [illegible] feedthrough were attached to the ion-source [illegible] process.

[illegible] pumped with the mechanical pump to a pressure [illegible] then sorption pumped to approximately 1 mTorr. [illegible], and it pumped the system to a pressure of [illegible] that no significant leaks were present in the source-chamber assembly and that the arc-focus assembly had been repaired satisfactorily.

The gas-feed assembly--which consists of a source gas bottle, pressure regulator, drier, leak valve, glass insulator tube, and a length of stainless-steel tubing--was fabricated and attached to the source chamber.

During the installation of the gas-feed assembly, the universal Faraday [illegible] was designed and fabricated. This assembly was attached to the vertical rotary motion feedthrough in the target chamber. The Faraday cup was connected to the electrical feedthroughs. A mechanical arm was designed and fabricated to position the quartz indicator; this assembly was attached to the horizontal rotary motion feedthrough in the target chamber.

The mechanical assembly was then complete, and the system was pumped down. It reached a base pressure of 2×10^{-8} Torr, indicating that there were no significant leaks in the system.

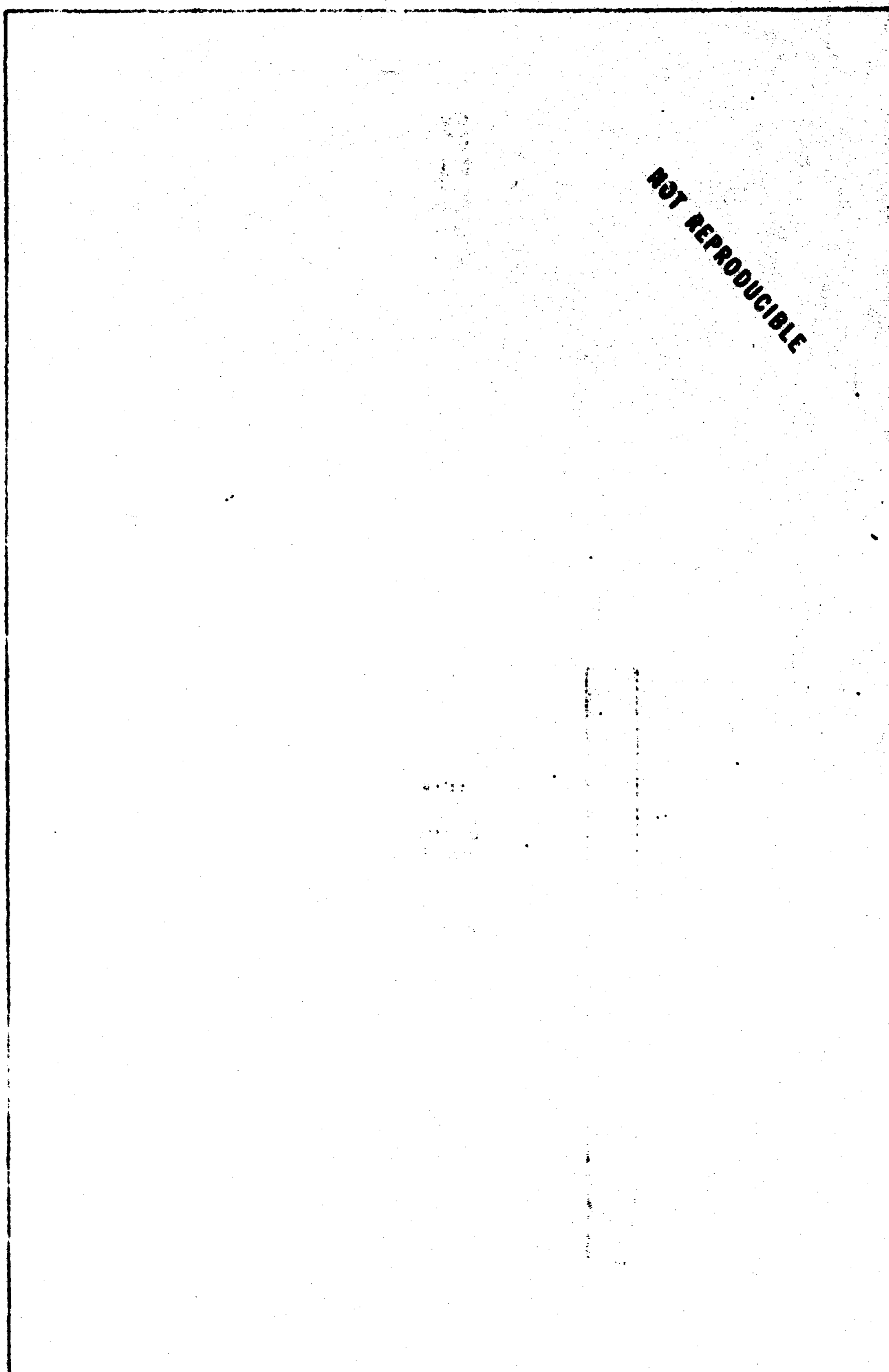
With mechanical assembly completed and high vacuum attained in the system, the cathode was prepared for installation. The system was vented to atmospheric pressure, and the filament electrical feedthrough was removed. The cathode had been stored in a vacuum-sealed glass container to prevent [illegible] and deterioration. The cathode was removed from the container. Platinum and platinum + 10% rhodium wires (thermocouple) were spot-welded to the emitting surface, and the cathode was mounted (by the heater leads) onto the filament electrical feedthrough. The thermocouple wires were then attached to the filament electrical feedthrough. The electrical feedthrough, with cathode and thermocouple attached, was reinstalled in the tee of the source chamber.

The system was pumped down to 2×10^{-8} Torr. Nitrogen gas was admitted to the system through the gas-feed line to remove the air and any impurities which might have entered when the system was at atmospheric pressure.

The power supplies and associated instrumentation where then connected to the various system components. A check of the system revealed that all of the power supplies and instrumentation were functioning normally.

Initial attempts at obtaining an arc were hampered by the apparent lack of sufficient emission (electrons) from the filament. I found that in the original set-up of the system, before it was brought to Bldg. 125, the emitting surface of the cathode was not connected electrically to the filament supply (electrical zero with respect to the anode and intermediate electrode). As a result the gas ionization efficiency was reduced, and the filament had to be operated at abnormally high currents (approximately 10 A) to obtain an arc. To remedy this, the emitting surface was connected to the filament by placing an external jumper from one leg of the filament to one leg of the thermocouple. The performance of the source was improved; an arc could be maintained with a filament current of approximately 6 A.

The first attempts to obtain a beam failed because arcing occurred across the glass insulator in the gas-feed assembly. This problem had not been encountered by the original designers since, as the records indicate, the machine had never been operated in this configuration (i.e., at positive beam potential). The length of the glass insulator was increased from 2 3/4 in. to 36 in. with the addition of the specially designed insulator shown in Fig. 13. This modification enabled the author to succeed in obtaining a nitrogen ion beam in the system. The characteristics of this beam are given in Chapter V.



[illegible] Line Insulator

IV. Operating Characteristics and Procedures

This chapter is divided into two main sections: (1) electronic circuitry and typical parameter values, and (2) operating procedures. The purpose of the chapter is to provide guidelines for the operation of the ion beam machine.

Electronic Circuitry and Typical Parameter Values

Electronic Circuitry. The power supplies and instrumentation are described in Appendix A. A schematic drawing of the machine with its associated electronic circuitry is shown in Fig. 14.

The cathode is an indirectly heated type described in Appendix B. Power is supplied to the cathode heater by a 0 to 26 V, 12-A alternating ac current supply. The cathode temperature is monitored by a platinum-versus-platinum + 10% rhodium thermocouple which is spot-welded to the emitting surface. A temperature calibration chart for the thermocouple is given in Appendix B (Ref 7:22,23). A plot of temperature-versus-input power and voltage is also contained in Appendix B (Ref 13). The operation of the filament seemed to agree more closely with the plot of temperature-versus-input power and voltage.

The anode potential is supplied by a [illegible] V, 0 to [illegible] A arc power supply. When the source is operating properly, the intermediate electrode is held at a potential of a few volts positive with respect to the filament (varies with arc current) by the [illegible] dropping resister which is connected to the arc supply.

The intermediate electrode current and voltage are monitored by meters on the control console.

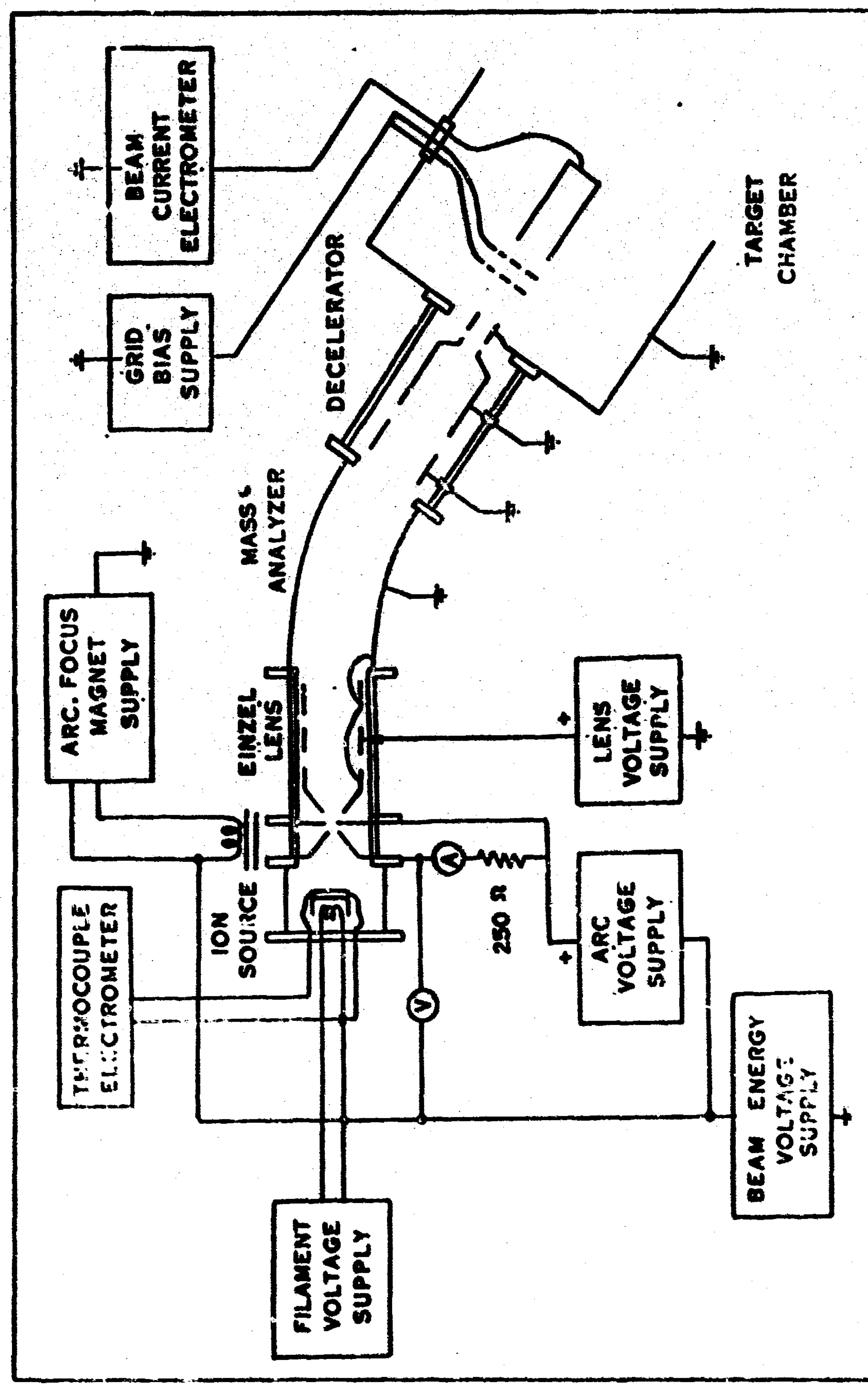


Figure 14. Ion Beam Machine Electronic Configuration

The arc-focus magnet is energized by a 0 to 200 V, 4 A dc power supply.

The pressure in the source chamber is monitored by a 0 to 1000 mTorr thermocouple gauge (control unit is in the control console).

The arc, arc focus, and filament power supplies, the intermediate-electrode monitor, and the thermocouple-gauge control unit are referenced to the beam potential. Since all the source electronics are referenced to the beam potential, the entire ion source is at a positive with respect to ground by an amount equal to the desired beam potential. This allows the mass-analyzer section, decelerator, and target chamber to be grounded for safety and maximum flexibility.

The beam-energy and einzel-lens voltages are supplied by 0 to 30 kV, 10 mA, filtered, dc power supplies.

Grid bias for the Faraday cup is supplied by a 0 to 300 V dc power supply.

<u>Typical Operating Parameter Values</u>. Operating parameters of the ion beam machine were observed during its operation in the present configuration. These nominal values are intended to serve as a guide in the operation of the system. Any changes made to the system can alter these values considerably. The parameters (for nitrogen source gas) are shown in Table III. The values of these parameters [illegible] with a beam potential of 6.5 kV and an einzel-lens voltage of [illegible] kV.

The values of the remaining parameters (beam voltage, lens voltage, analyzing-magnet current, etc.) are not typical and are discussed in Chapter V.

Table III

Typical Parameter Values for Ion Beam Machine

Parameter	Typical Value	Units
source gas	nitrogen	--
source-gas pressure	180 to 220	mTorr
filament voltage	10 to 11	V
filament current	6 to 7	A
intermediate-electrode voltage	30 to 50	V
intermediate-electrode current	130 to 150	mA
arc-focus-magnet voltage	9 to 15	V
arc-focus-magnet current	1 to 2	A
anode voltage	50 to 60	V
anode current	1 to 2	A
target-chamber pressure	5×10^{-7}	Torr
Far[illegible]-cup grid bias	-100	V

Operating Procedures

The following operating procedures which evolved throughout the study and operation of the system are recommended. (For component location, refer to Fig. 3.)

Atmospheric Pressure to High Vacuum

1. Insure that all valves in the system are closed and that all ports and flanges have been tightened securely.
2. Insure that all electronics are off, with the exception of the thermocouple gauges.

3. Fill the Dewars of two of the sorption pumps with liquid nitrogen (insure that the corks on the sorption pumps are in tight); wait 40 minutes (refill the Dewars as necessary). Note: The mechanical pump is used for leak checking only when it is apparent that there are gross leaks in the system. The trap must be well baked and the system must not be pumped below 300 mTorr with the mechanical pump.
4. Open the sorption-pump manifold valve of the first sorption pump slowly, but fully. Open the sorption-pump-manifold-to-auxiliary-chamber valve very slowly to avoid having liquid nitrogen boil out of the sorption-pump Dewar. Monitor the pressure with the roughing-pressure thermocouple-gauge indicator in the panel below the ion-pump control unit.
5. Wait for the system pressure to drop to 500 mTorr (approximately fifteen minutes). Refill the sorption-pump Dewar as needed. Valve off the first sorption pump at the manifold.
6. Open the valve on the second sorption pump. Turn on main power switch #2 on the laboratory wall (insure that the high-voltage power supplies are off). Turn on only the circuit breaker on the low-voltage side of the control console. Adjust the current set knob on the source-pressure thermocouple-gauge control unit on the console to 121 mA. Monitor the system pressure on this gauge. When the pressure has dropped to approximately 1 mTorr, start the 500-l/s ion pump in accordance with its operating instructions (Ref 3:2-11). When the pump has started, close the sorption-pump-manifold-to-auxiliary-chamber valve. Secure the sorption pumps.

7. The system pressure should drop to approximately 1×10^{-7} Torr (measured at ion pump) within one hour after the 500-1/s pump is started (assuming that the system has no significant leaks). Note: The ionization gauges are used to measure target-chamber pressure only when increased accuracy is desired.
8. When the system pressure reaches approximately 5×10^{-7} Torr, start the 8-1/s source-chamber ion pump in accordance with its operating instructions (Ref 4:5-6). The pressure (from log scale on pump-control unit) in the source chamber should drop to approximately 5×10^{-7} Torr in one hour.

System Operation at High Vacuum

1. System pressure should be at least 1×10^{-6} Torr prior to continuing with these instructions.
2. Turn on the source-cooling air blower and the analyzing-magnet cooling water.
3. Depress the filament-supply ON button (current control should be in extreme counterclockwise position).
4. Slowly increase filament current in small amounts (1 to 2 A) until the operating temperature is reached (approximately 10.5 V at 6.0 A on power-supply meters). The filament will outgas as it is heated; keep the pressure in the source chamber below 1×10^{-5} Torr while the filament is heating.
5. When the filament operating temperature is reached and outgassing has stopped (as indicated by decreasing source-chamber pressure), turn off the 8-1/s source-chamber ion pump.
6. Filament emission should be checked at this time. Depress the ON button on the arc supply (voltage control would be in

extreme counterclockwise position). Raise the arc voltage to approximately 50 V; the intermediate-electrode current should be approximately 5 to 10 mA. If filament emission is not apparent, follow the filament activation procedure in Appendix B. When activation is complete, return the filament supply to normal settings and repeat this step. Should the filament fail to activate, check and replace it if necessary.

7. Open the source-gas bottle. Adjust the gas-pressure regulator to approximately 10 psi.
8. Return the arc-supply control to the fully counterclockwise position. Open the precision leak valve and adjust the source-gas pressure to the desired value (50 to 400 mTorr, depending upon the source gas used).
9. Check the current setting on the source-pressure thermocouple gauge (121 mA); adjust the gas pressure if necessary.
10. Raise the arc-supply voltage control until the arc strikes (50 to 100 mA intermediate-electrode current). Continue to raise the arc-voltage control until the intermediate-electrode current peaks (300 to 400 mA). Continue to increase the arc-voltage control; a point will be reached when the intermediate-electrode current will drop sharply accompanied by a simultaneous rapid increase in arc-supply current (anode current). When this occurs, adjust the arc supply quickly for the desired arc current (approximately 60 V). Check the source-gas pressure immediately and adjust it as necessary to maintain the desired pressure. Obtaining a steady arc is an art and will require patience and practice. If the arc is extinguished

(intermediate electrode and arc supply current drop to zero), reduce the arc voltage to zero (wait several minutes) and repeat the procedure beginning with Step 8. If the intermediate electrode current peaks and then drops to zero, the gas pressure may be improperly set or the filament emission may be insufficient to maintain the arc. Check the filament emission (raise slightly if necessary) and/or try a different source-gas pressure.

11. Once a continuous arc and stable operating conditions have been obtained, depress the ON button of the arc-focus-magnet supply and adjust the magnet current to its normal operating value (1 to 2 A).

12. Energize the Faraday-cup grid-bias supply and set the bias at - 100 V.

13. Insure that the coarse-current control on the analyzing-magnet power supply is in the extreme counterclockwise position. Depress the ON button and adjust the coarse-current control to the approximate setting (Ref 2:28-32).

14. Insure that the voltage control of the high-voltage power supplies (beam energy and lens voltage) are in the extreme counterclockwise position. Turn on the circuit breaker for the high-voltage section of the console; turn on the safety key switch.

15. Slowly raise the beam voltage to the desired value. HAZARDOUS POTENTIALS NOW EXIST ON THE SOURCE END OF THE MACHINE. Check the arc operating parameters and adjust as necessary (arc parameters may change as an ion beam is extracted from the source).

16. Raise the lens voltage to the approximate operating value.

17. If the operating parameters are reasonably correct, the beam-current micro-ammeter should indicate the total beam current.

18. Adjust the following parameters to obtain maximum beam current:

    (1) Mass-analyzer-magnet current

    (2) Lens voltage

    (3) Arc current

    (4) Arc-focus-magnet current

    (5) Source-gas pressure.

19. All operating conditions must be checked at short intervals due to the extreme line-voltage fluctuations which occur in the electrical circuits in the laboratory.

20. If the beam should stop, do the following as <u>safely</u> and quickly as possible: (1) reduce both high-voltage power supplies to zero, (2) set the arc supply to zero, (3) close the precision gas-leak valve, (4) set the analyzing-magnet current to zero, (5) set the arc-focus-magnet current to zero, and (6) begin again at Step 8.

21. If the 500-l/s ion pump should trip off at any time, accomplish Step 20 immediately and, in addition, reduce filament current to one-half of its operating value; wait two minutes, and reduce filament current to zero. Begin energizing the system again beginning at Step 1 of this section.

<u>Securing System Electronics</u>. Carry out Step 20 of the previous section. In addition, turn off all supplies mentioned in Step 20, reduce the filament current slowly to zero, close source-gas bottle, shut off mass-analyzer-magnet cooling water when the pole pieces are

cool, turn off the high-voltage safety switch, turn off the high- and low-voltage section circuit breakers, turn off main power switch #2 on the laboratory wall, turn off Faraday-cup grid-bias supply, and turn off source-cooling air blower when the source chamber is cool. Start the 8-1/s ion pump and insure that 500-1/s ion pump is operating properly.

Venting the System to Atmospheric Pressure

1. Insure that all power supplies are de-energized and make sure the filament is cool.
2. Turn off both ion pumps if one or both are on.
3. Attach a gas line from the gas phase connection on the liquid-nitrogen Dewar to the vent valve on the auxiliary chamber. Remove as much air from the nitrogen line as possible before attaching it to the vent valve.
4. Open the sorption-pump-manifold-to-auxiliary-chamber valve so that chamber pressure may be monitored on the Bourdon pressure gauge in the sorption-pump manifold.
5. Open the vent valve and admit nitrogen slowly to prevent creating a vacuum in the nitrogen Dewar. Watch the pressure gauge and close the vent valve when the pressure is zero inches of mercury or zero psi. DO NOT PRESSURIZE THE SYSTEM.

V. Results and Conclusions

The characteristics of the vacuum system and the ion beam are discussed in this chapter. The results are analyzed and som conclusions presented.

Vacuum System Characteristics

A major problem in the assembly of this machine was the attainment of high vacuum. As a result of the modifications discussed in Chapter III, a vacuum system was obtained with a base pressure (without baking) of less than 1×10^{-8} Torr. This ultimate vacuum exceeds the projected requirements of the system. The 500-l/s ion pump handles the gas load (neutral gas escaping from the anode orifice) satisfactorily with nitrogen as the source gas. The pressure in the target chamber rises to approximately 7×10^{-7} with the source in operation, with an arc current of 1 A and source gas pressure of 220 mTorr. This target chamber pressure is sufficiently low to prevent the ion beam from being adversely affected and to make target contamination insignificant. The system is virtually oil free.

Ion Beam Characteristics

A nitrogen ion beam was obtained in the system; the characteristics of the beam and the operating condition of the system are presented in Table IV. The beam current was maximized by adjusting the following parameters: (1) arc current, (2) arc-focus-magnet current, (3) einzel-lens voltage, (4) source-gas pressure, and (5) mass-analyzing-magnet current.

Table IV

Characteristics of the Nitrogen Ion Beam and Operating Conditions of the System

Parameter	Value	Units
source gas	nitrogen	--
source-gas pressure	190	mTorr
filament voltage	10.75	V
filament current	6.8	A
intermediate-electrode voltage	45	V
intermediate-electrode current	145	mA
arc-focus-magnet voltage	10	V
arc-focus-magnet current	1.05	A
anode voltage	56	V
anode current	1.25	A
beam energy	6.5	keV
einzel-lens voltage	5.3	kV
analyzing-magnet current	1.0	A
beam current	0.8	μA
Faraday-cup bias	-100	V

The maximum beam potential was limited to 6.5 kV by arcing which occurred through the gas-feed-line insulator (source end of gas line at positive b[illegible], precision leak valve at ground--earth ground--potential). [illegible] nitrogen gas at 200 mTorr formed a low-resistance path, ionized, and overloaded the beam-voltage power supply. Originally the glass insulator was 2 3/4 in. long and breakdown occurred at 700 V. The breakdown voltage was increased to approximately 7 kV by installing the redesigned insulator shown in Fig. 13. This problem was not apparent at the outset because as far as can be ascertained, the system had never been operated in this configuration before (Refs 3 and 4). This problem could not be completely solved because of the time limitation, but proposed solutions are presented in Chapter VI.

The beam-energy power supply current was excessive (800 μA) for the beam current obtained (0.8 μA). This phenomenon is explained by the fact that at low extraction voltages, the ion beam diverges rapidly and the whole beam does not pass through the aperture in the extraction electrode. A large fraction of it impinges upon the extraction electrode causing current in the beam-potential (extractor) circuit. (This current is the sum of the ionic current and the secondary electron current.) This phenomenon decreases with increasing extractor voltage until the whole beam passes through the extractor aperture (Ref 10:144-145). When sufficient extraction voltage is obtained in this system (i.e., when the gas-feed problem is solved), the beam current available in the target chamber should increase markedly.

At times the low-voltage arc was unstable and difficult to initiate and maintain. Increasing the filament temperature and, consequently, its electron emission, seemed to alleviate this condition. Operating the filament at these increased temperatures is inconsistent with good engineering practice. It is apparent that either the anode-to-cathode distance is too large or the cathode electron emission is insufficient.

This problem should be studied in detail to improve the performance of the source.

Solutions for these and other less significant problems are discussed in the following chapter.

Performance as an Ion Implantation System

The machine in its present form has the essential components to perform small area implants of dopants which may be derived from elemental or compound non-corrosive gases. When the restriction on the maximum beam potential has been eliminated by the incorporation of one of the modifications discussed in Chapter VI, the machine will perform satisfactorily as an ion implantation system.

VI. Recommendations

In addition to the many modifications which the system has undergone, other possible modifications--some necessary, some desirable--have come to light. The following items are presented which would increase the usefulness of the ion beam machine as an ion implantation system. Th recommendations are divided into two classes: (1) necessary and (2) desirable.

Recommendations (Necessary)

1. The most significant problem is the limited beam potential. Two courses of action are advisable at the present time: (1) install a glass frit (porous glass filter) in the glass insulating section of the gas-feed line and (2) float the entire gas-feed system at the beam potential. Since it is desirable for the precision gas-leak valve to be grounded for safety and ease of control, the solution utilizing the glass frit should be attempted first.
2. The repair of the arc-focus assembly should be considered only a temporary solution since the presence of epoxy in the system poses potential problems. This assembly should be replaced with a properly designed ceramic and metal section of similar, but improved, construction.
3. Instabilities noted in the arc when the source was in operation indicate that improvement of the cathode and associated components is necessary. A study should be conducted to

determine the optimum filament or cathode type, the correct filament spacing, and the optimum source geometry.

4. The electrical system (line voltage) in the laboratory suffers from fluctuations and transients which cause the system to be unstable. A three-phase constant-voltage transformer or solid state regulator should be installed in the incoming 208-V feeder for the laboratory. The capacity of this regulating device should be sufficiently large to provide regulated power for all equipment in the laboratory.

5. The characteristics of the beam should be examined closely once the beam-voltage problem has been alleviated. The following characteristics of the beam should be determined accurately: (1) beam intensity ($\mu A/cm^2$) vs beam energy (keV), (2) beam intensity ($\mu A/cm^2$) vs source pressure (mTorr), arc current (A), arc-focus-magnet current (A), and mass-analyzing-magnet current (A), and (3) beam-current-density spatial distribution at the target.

Recommendations (Desirable)

1. Two high-vacuum valves should be installed in the system. If it were possible to isolate the 500-l/s ion pump from the rest of the system, the auxiliary and target chambers could be brought to atmosphere without securing the ion pump. An additional high-vacuum valve should be installed between the decelerator assembly and the target chamber; the target chamber could then be brought to atmosphere without interrupting the beam. It is desirable that the beam be interrupted as little as possible since a significant amount of

time is required to obtain a stable beam. If the latter valve is installed, it will be necessary to alter the pumping system since it must handle the neutral gas load while the source is isolated.

2. A universal target holder should be designed and incorporated into the target chamber. It should have the following characteristics: (1) it should have three degrees of freedom (preferably adjustable from outside the target chamber), (2) it should accept various types of semiconductor wafers, (3) it should be insulated from the target chamber up to 30 kV (1×10^{-4} Torr), and (4) it should be possible to heat it to 800°C or cool it to liquid-nitrogen temperature.
3. An automatic pressure controller should be installed to maintain the source gas at a predetermined setting. This will free the operator from this time-consuming operation.
4. A deflection assembly should be installed between the einzel lens and the entrance to the mass-analyzing section which would be capable of aligning the beam vertically and horizontally. Proper alignment of the beam at the entrance to the mass-analyzing section will insure the most efficient mass separation.
5. The decelerator-assembly electrodes could be removed and a beam-scanning assembly installed in their place. This assembly would consist of vertical and horizontal deflection plates to which variable dc and ac signals could be applied for positioning and sweeping the beam. In this manner, uniform implants could be obtained over a much larger area.

6. The following modifications to the source are proposed to increase the efficiency of the system: (1) the anode-aperture diameter could be reduced to a value consistent with the required beam intensity which would reduce the neutral-gas load on the system, (2) the 250-Ω resistor in the intermediate-electrode circuit could be replaced with a 0 to 375-Ω potentiometer which could be used to further optimize the source performance, and (3) the arc-focus magnet could be replaced with a more conventional concentrically wound type consisting of approximately 1000 turns of #20 wire wound on a Teflon spool.

7. Finally, the implantation energy range of the system could be extended to approximately 50 keV by replacing the electrical feedthroughs in the target chamber with the ultra-high voltage type (up to 25 kV at 1×10^{-4} Torr) and by operating the target at a potential of up to 25 kV negative with respect to the target chamber.

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Appendix A

Power Supplies and Instrumentation

General

The power supplies associated with the ion beam machine were designed initially to allow a great deal of flexibility in the operation of the machine.

Console

The console power supplies are divided into two sections: (1) low voltage (left side) and (2) high voltage (right side). The input power is 208 V, 3 ϕ, Δ-connected. Each section is protected by a separate circuit breaker.

The low-voltage section is electrically isolated from the line (by a 1:1, 30 kV isolation transformer) and from the cabinet in order that it may float at the high voltage (beam energy supply up to 30 kV). The controls for the low-voltage section are isolated from the front panel by insulating shafts to prevent hazardous voltages from being applied to these controls.

The following components are located in the low-voltage section (left half) of the console: (1) arc supply (0 to 200 V, 0 to 4 A dc), (2) arc-focus-magnet supply (0 to 200 V, 0 to 4 A dc), (3) filament (cathode) supply (0 to 26 V, 0 to 12 A ac), (4) intermediate-electrode dropping resistor (250 Ω), (5) intermediate-electrode monitor (0 to 500 mA dc and 0 to 200 V dc meters), and (6) thermocouple-gauge control unit.

The high-voltage section of the console has a safety key switch in addition to the circuit breaker to prevent the high-voltage supplies from being energized accidentally. The high-voltage section (right half) has two 0 to 30 kV, 0 to 10 A dc power supplies. These supplies are also isolated from the line by the 30 kV isolation transformer. In addition, several safety interlocks are included in the high-voltage section. The high-voltage power supplies cannot be energized unless their controls are set for zero voltage (extreme counterclockwise position). There is a door interlock, and the high-voltage outputs are automatically grounded when the high-voltage section safety key switch is in the OFF position. Both high-voltage power supplies are equipped with adjustable overload trips. The high-voltage supplies are very versatile; they may be used to provide 0 to 30 kV positive or negative, independent of each other. Extreme care should be exercised when using the control console.

Faraday-Cup Grid-Bias Supply

This supply may be any 0 to 200V, 0 to 10 mA dc supply.

Analyzing-Magnet Power Supply

This power supply is designed to provide continuously regulated current to the electromagnets. Controls provide for coarse and fine adjustment of the magnet current from 0 to 50 A dc. Before this power supply is energized, the cooling water for the magnets must be turned on.

Thermocouple Gauges

The roughing pressure in the sorption-pump manifold, in the auxiliary chamber, and in the source chamber is monitored by three thermocouple gauges calibrated to read pressures from 0 to 1000 mTorr.

Ionization Gauges

The target chamber pressure can be monitored by either of two ionization gauges installed in the chamber. The controller for the ionization gauges is in the auxiliary-equipment rack to the left of the target chamber.

Electrometer

The thermocouple voltage may be measured by an electrometer or potentiometer. Throughout the operation of the machine in this study the beam current was measured by a Millivac electrometer, Model MV852A.

Appendix B

Tungsten Dispenser Cathode Characteristics

The following technical bulletins and graphs describe the operation of the tungsten dispenser cathode.

NOTE!!! This sheet for Engineers and Supervisors

TECHNICAL BULLETIN - #106

TUNGSTEN DISPENSER CATHODES

I. Handling and Care of Cathodes.

a) Porous tungsten with a formula of barium oxide dispersed throughout the matrix is the essential form of these dispenser cathodes. Because BaO will absorb moisture and vapors, the cathodes are packed to minimize exposure and to keep out dust and other undesirable impurities. To insure optimum performance, cathodes should not be exposed to atmospheric conditions for more than 48 hours. Keep in a partial vacuum of 10^{-3} torr or better. If cathodes are not sealed in glass when received, immediately transfer to a vacuum of 10^{-3} torr or better. Blisters may occasionally occur on the surface due to too rapid heating after inadvertent exposure to moisture during assembly and handling. These blisters may be avoided by a slower rate of heating.

b) Dispenser cathodes have been run between 800°C and 1250°C depending upon the customer's objective. However, it is more customary to run them between 1025°C and 1225°C. At these temperatures, saturated DC emission of 3 and 9 a/cm² can be expected.

II. Activation and Use.

The following suggestions are based on a glass diode structure. They are offered as a guide only. Time, temperature and processing are subject to some changes for large tubes and tubes using ceramic-metal structures.

a) Bake tube for one hour at 450°C. Cool. Vacuum should be better than 10^{-6} torr at this point.

b) Raise cathode temperature slowly to 1190°C_b and hold for 5 minutes. Measure temperature on tungsten emitter.

c) Outgas anode by induction heating. 900°C_b for 10 minutes. Reduce E_f to prevent cathode from exceeding 1190°C_b.

d) With anode cool, set cathode temperature to 1150°C_b. Apply DC anode voltage slowly to 50 volts across .025" spacing. Emission current should flow immediately and be sufficiently stable for tube to be transferred to aging and life rack in ½ hour.

e) Partially flash getter and seal off diode.

f) Finish flashing getter. Put tube on test.

g) Activation should be complete in from ½ to 4 hours with the cathode at 1150°C_b. Anode voltage is optional.

h) A vacuum of 10^{-7} to 10^{-8} torr is better than 10^{-5} to 10^{-6} torr with respect to reducing adverse effects on emission during operation.

S P E C T R A - M A T , I N C .

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Materials for Electronics and Aerospace Industries.
Electron and Ion Sources. Special Components.
Research, Development and Production.

October 1969 TB 106

[illegible] SPECTRA-[illegible]MAT, INC.

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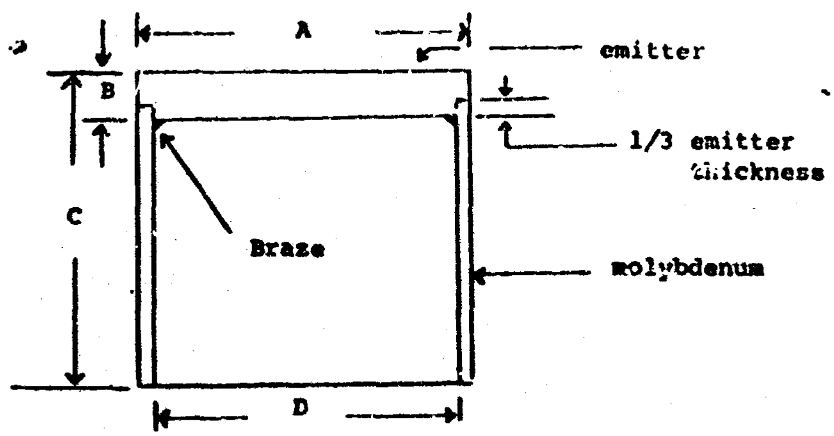
Standard Cathode Types

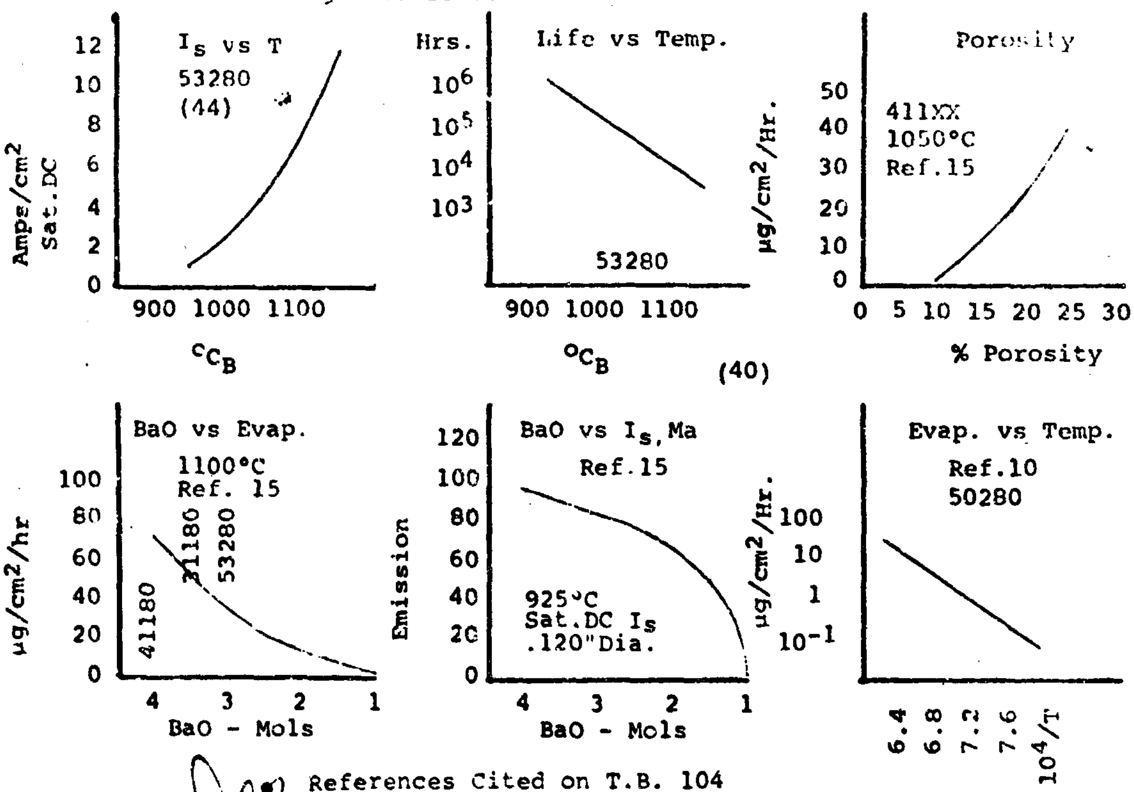


Cathode [illegible]	Dimensions (inches)			
	A± .001	B± .002	C± .005	D± .001
Std. 1[illegible]	.134	.040	.285	.116
Std. 20[illegible]	.200	.040	.300	.170
Std. [illegible]	.[illegible]50	.[illegible]40	.[illegible]	.[illegible]20
Std. 3[illegible]	.300	.040	.400	.270
Std. [illegible]0	.400	.050	.450	.[illegible]0
Std. 50[illegible]	.500	.050	.500	.[illegible]50
Std. 600	.600	.075	.600	.540
Std. 750	.750	.075	.750	.[illegible]
Std.1000	1.000	.100	1.000	.940

TECHNICAL BULLETIN - #105
TUNGSTEN DISPENSER CATHODES

Tungsten dispenser cathodes, in general, consist of a porous matrix with a formula of barium oxide dispersed uniformly throughout. They have been operated between 800°C and 1250°C depending upon the application. Some generalized curves taken from the literature or experience are shown below to illustrate certain key parameters.

It is apparent that custom-tailored cathodes, which can trade one property for another, can have significant advantages over a standard cathode for some applications. For example, choice of processing or design can move properties up or down on the curve or even displace a curve to the right or left.



References Cited on T.B. 104

SPECTRA - MAT, INC.

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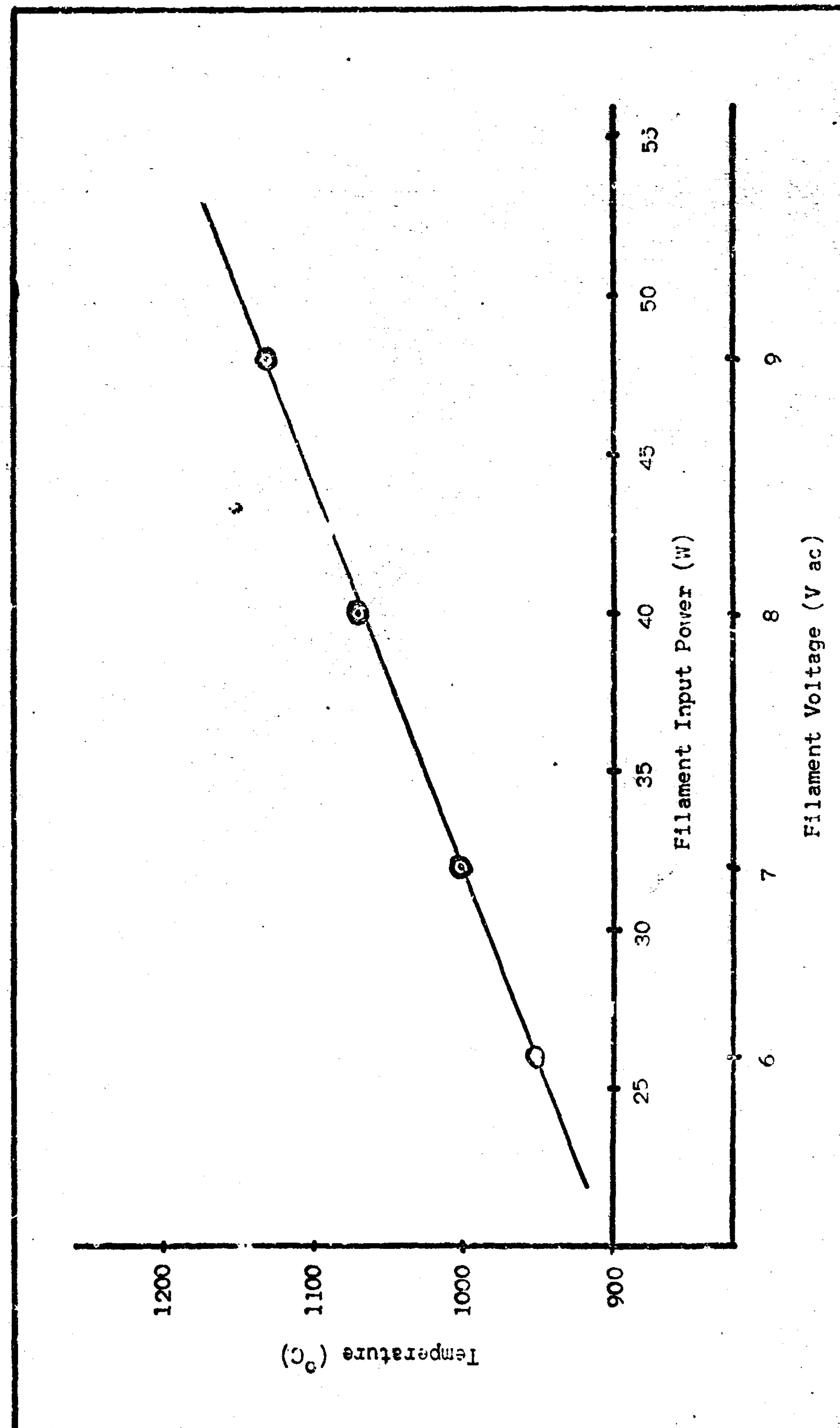

Figure 15. Cathode Operating Characteristics (Ref 13)

PLAT. vs. PLAT. +10% RHODIUM THERMOCOUPLE

Degrees Centigrade — Reference Junction 0° C.

°C	0	1	2	3	4	5	6	7	8	9
					Millivolts					
600	5.224	5.234	5.244	5.254	5.265	5.275	5.285	5.295	5.306	5.316
610	5.326	5.336	5.346	5.357	5.367	5.377	5.388	5.398	5.408	5.418
620	5.429	5.439	5.449	5.459	5.470	5.480	5.490	5.501	5.511	5.521
630	5.532	5.542	5.552	5.563	5.573	5.583	5.593	5.604	5.614	5.624
640	5.635	5.645	5.655	5.666	5.676	5.686	5.697	5.707	5.717	5.728
650	5.738	5.748	5.759	5.769	5.779	5.790	5.800	5.811	5.821	5.831
660	5.842	5.852	5.862	5.873	5.883	5.894	5.904	5.914	5.925	5.935
670	5.945	5.956	5.967	5.977	5.987	.998	6.008	6.019	6.029	6.040
680	6.050	6.060	6.071	6.081	6.092	6.102	6.113	6.123	6.134	6.144
690	6.155	6.165	6.176	6.186	6.197	6.207	6.218	6.228	6.239	6.249
700	6.260	6.270	6.281	6.291	6.302	6.312	6.323	6.333	6.344	6.355
710	6.365	6.376	6.386	6.397	6.407	6.418	6.429	6.439	6.450	6.460
720	6.471	6.481	6.492	6.503	6.513	6.524	6.534	6.545	6.556	6.566
730	6.577	6.588	6.598	6.609	6.619	6.630	6.641	6.651	6.662	6.673
740	6.683	6.694	6.705	6.715	6.726	6.737	6.747	6.758	6.769	6.779
750	6.790	6.801	6.811	6.822	6.833	6.844	6.854	6.865	6.876	6.886
760	6.897	6.908	6.919	6.929	6.940	6.951	6.962	6.972	6.983	6.994
770	7.005	7.015	7.026	7.037	7.047	7.058	7.069	7.080	7.091	7.102
780	7.112	7.123	7.134	7.145	7.156	7.166	7.177	7.188	7.199	7.210
790	7.220	7.231	7.242	7.253	7.264	7.275	7.286	7.296	7.307	7.318
800	7.329	7.340	7.351	7.362	7.372	7.383	7.394	7.405	7.416	7.427
810	7.438	7.449	7.460	7.470	7.481	7.492	7.503	7.514	7.525	7.536
820	7.547	7.558	7.569	7.580	7.591	7.602	7.613	7.623	7.634	7.645
830	7.656	7.667	7.678	7.689	7.700	7.711	7.722	7.733	7.744	7.755
840	7.766	7.777	7.788	7.799	7.810	7.821	7.832	7.843	7.854	7.865
850	7.876	7.887	7.898	7.910	7.921	7.932	7.943	7.954	7.965	7.976
860	7.987	7.998	8.009	8.020	8.031	8.042	8.053	8.064	8.076	8.087
870	8.098	8.109	8.120	8.131	8.142	8.153	8.164	8.175	8.187	8.198
880	8.209	8.220	8.231	8.242	8.254	8.265	8.276	8.287	8.298	8.309
890	8.320	8.332	8.343	8.354	8.365	8.376	8.388	8.399	8.410	8.421
900	8.432	8.444	8.455	8.466	8.477	8.488	8.500	8.511	8.522	8.533
910	8.545	8.556	8.567	8.578	8.590	8.601	8.612	8.623	8.635	8.646
920	8.657	8.669	8.680	8.691	8.702	8.714	8.725	8.736	8.747	8.759
930	8.770	8.781	8.793	8.804	8.815	8.827	8.838	8.849	8.861	8.872
940	8.883	8.895	8.906	8.917	8.929	8.940	8.951	8.963	8.974	8.986
950	8.997	9.008	9.020	9.031	9.042	9.054	9.065	9.077	9.088	9.099
960	9.111	9.122	9.134	9.145	9.157	9.168	9.179	9.191	9.202	9.214
970	9.225	9.236	9.248	9.260	9.271	9.282	9.294	9.305	9.317	9.328
980	9.340	9.351	9.363	9.374	9.386	9.397	9.409	9.420	9.432	9.443
990	9.455	9.466	9.478	9.489	9.501	9.512	9.524	9.535	9.547	9.559
1000	9.570	9.582	9.593	9.605	9.616	9.628	9.639	9.651	9.663	9.674
1010	9.686	9.697	9.709	9.720	9.732	9.744	9.755	9.767	9.779	9.790
1020	9.802	9.813	9.825	9.837	9.848	9.860	9.871	9.883	9.895	9.906
1030	9.918	9.930	9.941	9.953	9.965	9.976	9.988	10.000	10.011	10.023
1040	10.035	10.046	10.058	10.070	10.082	10.093	10.105	10.117	10.128	10.140
1050	10.152	10.163	10.175	10.187	10.199	10.210	10.222	10.234	10.246	10.257
1060	[illegible]	10.281	10.293	10.304	10.316	10.328	10.340	10.351	10.363	10.375
1070	10.387	10.399	10.410	10.422	10.434	10.446	10.458	10.469	10.481	10.493
1080	10.505	10.517	10.528	10.540	10.552	10.564	10.576	10.587	10.599	10.611
1090	10.623	10.635	10.647	10.658	10.670	10.682	10.694	10.706	10.718	10.729
1100	10.741	10.753	10.765	10.777	10.789	10.801	10.812	10.824	10.836	10.848
1110	[illegible]	[illegible]	[illegible]	10.896	10.907	[illegible]	10.931	10.943	10.955	10.967
1120	[illegible]	10.991	11.003	11.014	11.026	11.038	11.050	11.062	11.074	11.086
1130	11.098	11.110	11.122	11.133	11.145	11.157	11.169	11.181	11.193	11.205
1140	[illegible]	[illegible]	[illegible]	[illegible]	11.265	11.277	[illegible]	[illegible]	11.312	11.324
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.671	11.683
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.803
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.911	11.923

Figure 16. Thermocouple Calibration Chart (600 to 1199°C) (Ref 7:22)

PLAT. vs. PLAT. +10% RHODIUM THERMOCOUPLE
Degrees Centigrade — Reference Junction 0° C.

°C	0	1	2	3	4	5	6	7	8	9
	Millivolts									
1200	11.935	11.947	11.959	11.971	11.983	11.995	12.007	12.019	12.031	12.043
1210	12.055	12.067	12.079	12.091	12.103	12.115	12.127	12.139	12.151	12.163
1220	12.175	12.187	[illegible]	12.212	12.224	[illegible]	12.248	12.260	12.272	12.284
1230	12.296	12.308	12.320	12.332	12.344	[illegible]	12.368	12.380	12.392	12.404
1240	12.416	12.428	12.440	12.452	12.464	12.476	12.488	12.500	12.512	12.524
1250	12.536	12.548	12.560	12.573	12.585	12.597	12.609	12.621	12.633	12.645
1260	12.657	12.669	12.681	12.693	12.705	12.717	12.729	12.741	12.753	12.765
1270	12.777	12.789	12.801	12.813	12.825	12.837	12.849	12.861	12.873	12.885
1280	12.897	12.909	12.921	12.933	12.945	12.957	12.969	12.981	12.993	13.005
1290	13.018	13.030	13.042	[illegible]	[illegible]	[illegible]	13.090	13.102	13.114	13.126
1300	13.138	13.150	13.162	13.174	13.186	13.198	13.210	13.222	13.234	13.246
1310	13.258	13.270	13.282	[illegible]	13.306	[illegible]	13.330	13.342	13.354	13.366
1320	13.378	13.390	13.402	13.414	13.426	13.438	13.450	13.462	13.474	13.486
1330	13.498	13.510	13.522	[illegible]	[illegible]	13.558	13.570	13.582	13.594	13.606
1340	13.618	13.630	13.642	13.654	13.666	13.678	13.690	13.702	13.714	13.726
1350	13.738	13.750	13.762	13.774	13.786	13.798	13.810	13.822	13.834	13.846
1360	13.858	13.870	13.882	13.894	13.906	13.918	13.930	13.942	13.954	13.966
1370	13.978	13.990	14.002	14.014	14.026	14.038	14.050	14.062	14.074	14.086
1380	14.098	14.110	14.122	14.133	14.145	14.157	14.169	14.181	14.193	14.205
1390	14.217	14.229	14.241	14.253	14.265	14.277	14.289	14.301	14.313	14.325
1400	14.337	14.349	14.361	14.373	14.385	14.397	14.409	14.421	14.433	14.445
1410	14.457	14.469	14.481	14.493	14.504	14.516	14.528	14.540	14.552	14.564
1420	14.576	14.588	14.600	14.612	14.624	14.636	14.648	14.660	14.672	14.684
1430	14.696	14.708	14.720	14.732	14.744	14.755	14.767	14.779	14.791	14.803
1440	14.815	14.827	14.839	14.851	14.863	14.875	14.887	14.899	14.911	14.923
1450	14.935	14.946	14.958	14.970	14.982	14.994	15.006	15.018	15.030	15.042
1460	15.054	15.066	15.078	15.090	15.102	15.113	15.125	15.137	15.149	15.161
1470	15.173	15.185	15.197	15.209	15.221	15.233	15.245	15.256	15.268	15.280
1480	15.292	15.304	15.316	15.328	15.340	15.352	15.364	15.376	15.387	15.399
1490	15.411	15.423	15.435	15.447	15.459	15.471	15.483	15.495	15.507	15.518
1500	15.530	15.542	15.554	15.566	15.578	15.590	15.602	15.614	15.625	15.637
1510	15.649	15.661	15.673	15.685	15.697	15.709	15.721	15.732	15.744	15.756
1520	15.768	15.780	15.792	15.804	15.816	15.827	15.839	15.851	15.863	15.875
1530	15.887	15.899	15.911	15.922	15.934	15.946	15.958	15.970	15.982	15.994
1540	16.006	16.017	16.029	16.041	16.053	16.065	16.077	16.089	16.100	16.112
1550	16.124	16.136	16.148	16.160	16.171	16.183	16.195	16.207	16.219	16.231
1560	16.243	16.254	16.266	16.278	16.290	16.302	16.314	16.325	16.337	16.349
1570	16.361	16.373	16.385	16.396	16.408	16.420	16.432	16.444	16.456	16.467
1580	16.479	16.491	16.503	16.515	16.527	16.539	16.550	16.562	16.574	16.586
1590	16.597	16.609	16.621	16.633	16.645	16.657	16.668	16.680	16.692	16.704
1600	16.716	16.727	16.739	16.751	16.763	16.775	16.786	16.798	16.810	16.822
1610	16.834	16.845	16.857	16.869	16.881	16.893	16.904	16.916	16.928	16.940
1620	16.952	16.963	16.975	16.987	[illegible]	17.010	17.022	17.034	17.046	17.058
1630	17.069	17.081	17.093	17.105	17.116	17.128	17.140	17.152	17.163	17.175
1640	17.187	17.199	17.211	17.222	17.234	17.246	17.258	17.269	17.281	17.293
1650	17.305	17.316	17.328	17.340	17.352	[illegible]	17.375	17.387	17.399	17.410
1660	17.422	17.434	17.446	[illegible]	[illegible]	17.481	17.492	17.504	17.516	17.528
1670	17.539	17.551	17.563	17.575	[illegible]	[illegible]	17.610	[illegible]	[illegible]	17.645
1680	17.657	17.668	[illegible]	[illegible]	17.704	17.715	17.727	[illegible]	[illegible]	[illegible]
1690	17.774	17.785	17.797	[illegible]	17.821	[illegible]	17.844	[illegible]	[illegible]	[illegible]
1700	17.891	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1710	18.008	18.019	18.031	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.113
1720	18.124	18.136	[illegible]	[illegible]	18.171	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1730	18.241	18.253	[illegible]	[illegible]	[illegible]	[illegible]	18.311	[illegible]	[illegible]	[illegible]
1740	18.358	[illegible]	18.381	[illegible]	18.404	[illegible]	18.427	[illegible]	[illegible]	[illegible]
1750	18.474	18.486	18.497	[illegible]	18.520	[illegible]	[illegible]	[illegible]	[illegible]	18.579
1760	18.590	18.602	18.613	[illegible]	18.637	[illegible]	[illegible]	18.672	[illegible]	[illegible]

Figure 17. Thermocouple Calibration Chart (1200 to 1769°C) (Ref 7:23)

Appendix C

Repair of the Arc-Focus Assembly

The arc-focus assembly initially consisted of two stainless-steel flanges separated by a ceramic insulator. The ceramic insulator had metal compatible with kovar embedded in it. Kovar rings were brazed into the flanges, and the ceramic insulator was brazed to each flange. The assembly failed at these brazed seals.

This assembly had leaked and failed previously (Ref 4:14). A seal was finally obtained through the use of low-vapor-pressure epoxy (Ref 4:16).

One side of this assembly failed again as explained in Chapter III. Low-vapor-pressure epoxy was applied to the ceramic insulator and to the stainless-steel flange. The assembly was pressed together and allowed to cure. This attempt failed because the epoxy cracked.

The assembly was heated to 500°F to break down the remaining epoxy. At this point both seals failed. The flanges and the ceramic seal were cleaned and prepared for another attempt.

It was decided that bolting the assembly to the machine after the epoxy had cured strained the epoxy excessively. In this second attempt, the flanges were bolted, with gold wire seals in place, to the einzel lens and to the source chamber prior to the application of the epoxy. A special jig was designed and fabricated to hold this assembly while the repair was effected. Structural epoxy was used in lieu of the low-vapor-pressure type. The source chamber was placed in the jig with the filament (cathode) flange down. Epoxy was applied to the flange on the source chamber (the groove outside the kovar ring was filled) and to the ceramic insulator (which had previously been roughed up with coarse sandpaper). The ceramic insulator was placed upon the flange and weighted to hold it securely in place. The epoxy was allowed to cure for more than twenty-four hours. When this epoxy had cured, epoxy was applied to the other side of the ceramic insulator and to the flange on the einzel lens. The einzel lens and flange were placed upon the insulator, and the epoxy was allowed to cure for more than twenty-four hours.

When the epoxy was thoroughly cured, the unit containing the source chamber, arc-focus assembly, and einzel lens was ready for installation on the ion beam machine. Since these components were assembled as a unit, no excessive strain was applied to the arc-focus assembly during its installation.

Unclassified

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

A machine originally designed as a bakeable, monoenergetic sputtering apparatus was redesigned for use as an ion implantation system. Engineering modifications produced a virtually oil-free high-vacuum system. The base pressure of the system (unbaked) in its present configuration is 1×10^{-8} Torr. A 0.8-μA, 6.5-keV nitrogen ion beam was obtained. The machine, after modifications, was studied to determine its feasibility as an ion implantation system. If beam voltages greater than 10 kV are used, the machine will be suitable to perform small-area implants (areas ≈ 0.5 cm^2) with dopants available in gaseous form (non-corrosive) ranging in energy from 10 to 30 keV.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Solid-State Physics						
Ion Implantation						
Ion Bombardment						
Particle Accelerator Techniques						
Ion Accelerator						
Ion Beams						

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