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DEVELOPMENT, CONSTRUCTION AND TESTING OF AN ULTRAHIGH VACUUM D.C. SPUTTERING SYSTEM

By George Horn and Paul Gould

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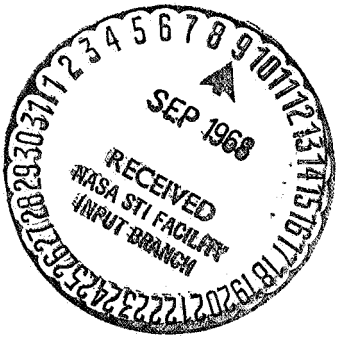

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SUMMARY

An ultrahigh vacuum system was developed to create state of the art environment for a pair of direct current sputtering electrodes. The objective of the design was such that it would provide the best cleanliness available with modern techniques in a vacuum system at a reasonable pumping speed. When such system backfilled with the sputtering gas media, it would produce results reproducible to a great extent by eliminating parameters of film production due to contaminant background. Thus, in design the following approach was taken. Two diffusion pumps in series were to provide the pumping speed with mechanical roughing pump backing. To eliminate contaminant back diffusion, the roughing pump had an in-line electrostatic trap while the two diffusion pumps each had in-line liquid nitrogen traps. The main diffusion pump was fitted with an optically dense freon 12 cooled baffle. The low leakage rate of the system was assured by using all metal gasket seals. The metal seals, in addition, provided the possibility of a high temperature bake on the system.

The above vacuum system providing the background, the high voltage sputtering electrodes had to be designed such that they would not themselves degrade the environment. They were ceramic, pure silver braze, and stainless steel 316L construction. The anode heatable to 800°C while the cathode was water cooled. The anode was adjustable to provide for gap variations, leveling, and tilt for X-ray studies on the film.

INTRODUCTION

The three basic parameters of ultrahigh vacuum are leak rate, pumping speed, surface phenomenon. It is a well established fact that the straight kinetic theory of ideal gases does not provide us with valid predictions about the behavior of the

ultrahigh vacuum system, although very good results are obtained with the same theory in high vacuum practice. In terms of the above three parameters, then ultrahigh vacuum can be defined as that portion of the low pressure scale where surface phenomena become the dominant parameter. It should be observed that this third parameter is not called surface outgassing since it has been proved that values of the above are very small in terms of the achievable pressures (say 10^{-11} torr), and that empirical approximations of the past are not valid. If surface outgassing rates are measured in an ultrahigh vacuum by providing a high artificial leak rate on such system, the values obtained will be several decades higher than ones obtained without the leak rate. Thus the role of surfaces is highlighted by an increased residence time of molecules in the ultrahigh vacuum system that leak in through artificial or natural leaks. Extended pumpdown times thus made early investigators believe in an unnaturally high surface outgassing rate. Although these gases pumped away do come from the surfaces, they don't originate there. Their source is the real leak.

In terms of pumpdown times, this means that in otherwise equal vacuum systems the one having a decade lower leak rate will achieve a decade lower pressure in the same allotted time as the other would achieve a decade higher, as it is borne out by experience. Thus it should be kept in mind that when system pressures of 10^{-9} to 10^{-10} are desired, they can elegantly be obtained without bakeout by reducing the leak rate of the system, and all within the normal pumpdown times. Naturally, bakeout can always help some, but in most cases it offers very small returns for a significant effort. Design philosophy should thus provide bakeout for the sake of the specimen, but otherwise allow low leak rates for ease of operation.

As far as the "pumping speed" parameter is concerned, in ultrahigh vacuum design it has been proven as early as 1962 that such characteristic of the diffusion pump stays constant in the molecular flow range.

In summary, then, the combination of low leak rate component designs and high conductivity pumping ports achieve the desired performance.

The net pumping speed at the sputtering device will be a function of the pump speed and the conductance of the intervening components between the pump and the chamber, which will then determine the working pressures which can be maintained while the sputtering electrode is heating. This led to the choice of a high speed pump, and the combining of the trapping requirements into a high conductance component.

The operation of the anode at 600-700°C and at vacuum of 1 x 10-9 torr imposed a material selection problem due to diffusion of gases through the metal at these temperatures (since the anode is of hollow construction). This can impair the purity of the gases inside the system and the total pressure. These diffusion rates can be demonstrated, in order of magnitude, following the basic diffusion equation:

$$q = - DA \frac{dc}{dx}$$

which, for vacuum systems where wall of chamber is diffusion medium, becomes:

$$Q = C - {}^{B}/_{T}$$

q gas flow μ liter/min/cm^2 for 1 mm thickness

C and B are constants of particular metal gas systems

The above equation can yield diffusion rates, however, only if its constants for the particular metal gas system are known.

Lacking such knowledge, heavy reliance was made on empirical experience.

Several materials or alloys were considered for the purpose. With this material selection step one seeks low diffusion constants versus good leak-tight weldability for vacuum. For instance, 304 stainless steel provides excellent welding (leak-tight, reliable) properties for vacuum fabrication. Its approximate overall diffusion or leak rates measured in Ilikon chambers at 700°C would provide, for the present configuration, values of 0.5 x 10-6 torr liter/sec. The pumping speed needed to keep 1 x 10-9 torr pressure at equilibrium (in order of magnitude):

$$S = \frac{0.5 \times 10^{-6} \text{ torr liter/sec.}}{10^{-9} \text{ torr}} = 5 \times 10^{2} \text{ liter/sec.}$$

Thus, we reach an acceptable leak rate.

Taking one step further, materials of improved diffusion rates can be found, however these leak rates can never be reduced to zero. Also, desired fabrication properties would be sacrificed. Thus, we combined a stainless steel selection and argon backfill of the electrode to eliminate ionic diffusion and

other than argon contaminant in the system.

When selecting high voltage feedthroughs to carry the normal 5 KV operating voltage into the vacuum chamber, with 10 KV breakdown capability, the natural selection is the ceramic to kovar type. However, the exceptional operating temperatures impose caution on design. Such feedthroughs utilize metal to ceramic vacuum brazed seals. The highest temperature brazing alloy must be selected to guarantee vacuum integrity during continuous operation. The anode post will always conduct heat from the anode to the seals. Highest temperature brazing compounds have melting points at 950°C, and these joints then should not be operated higher than 350°C continuously. Shorter bakeouts are allowed. Thus, anode posts should be of low thermal conductivity material and preferably cooled on the atmospheric side.

DESCRIPTION OF EQUIPMENT

General

This system consists of a sputtering chamber and an ultra-high vacuum pumping system capable of attaining a vacuum of 10^{-11} torr in the sputtering chamber, and the sputtering electrodes. A 5 KVA power supply required for sputtering operations was not supplied as a part of the system. Figure 1 is a block diagram of the system showing the location and interconnection of the vacuum components, Figure 2 is an overall view of the system, and Figure 3 a close-up view of the chamber with the electrodes visible through the viewing windows.

Sputtering Chamber

The sputtering device is essentially a high vacuum, thin film sputtering chamber with a water cooled cathode, a heated anode, and various pass-thrus for optical viewing, instrumentation, and gas insertion. Glow discharge is achieved by applying high voltage dc power across the cathode and anode. Wherever possible, all materials are non-magnetic, copper-free stainless steel, type 304, for weldability and cleanliness. Small amounts of kovar are used in the glass-metal seals.

The sputtering chamber consists of an 18-inch ID by 14-inch high main cylinder having a top and bottom cover plate consisting of a flange and a standard ASME dished head upon which are mounted the ports and pass-thrus. The entire chamber is constructed of polished (No. 4 finish inside) type 304 nonmagnetic, copper-free stainless steel. All bolts used for flanges are of nonmagnetic stainless steel, also. Small amounts of kovar metal

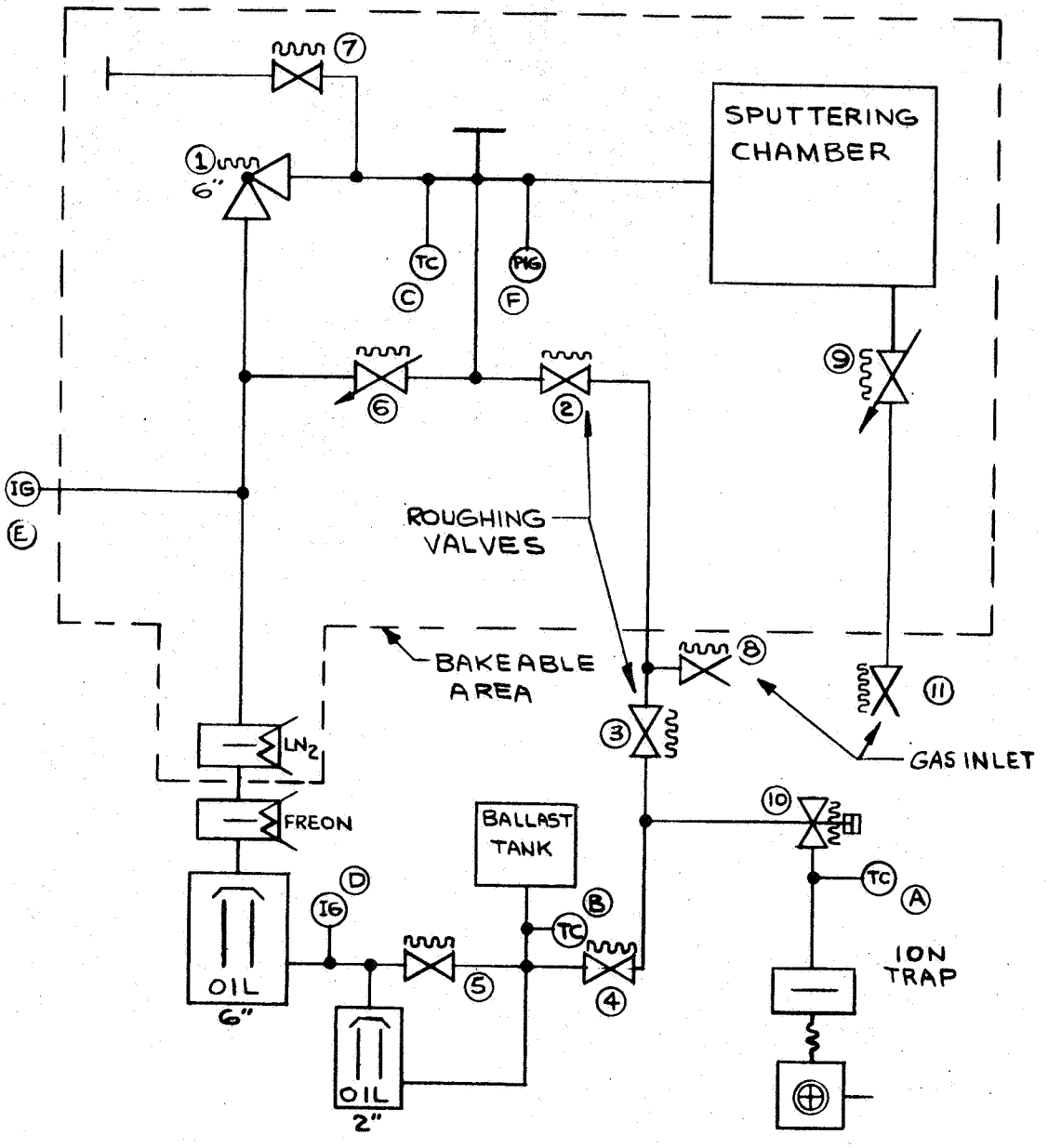

Figure 1. System Block Diagram

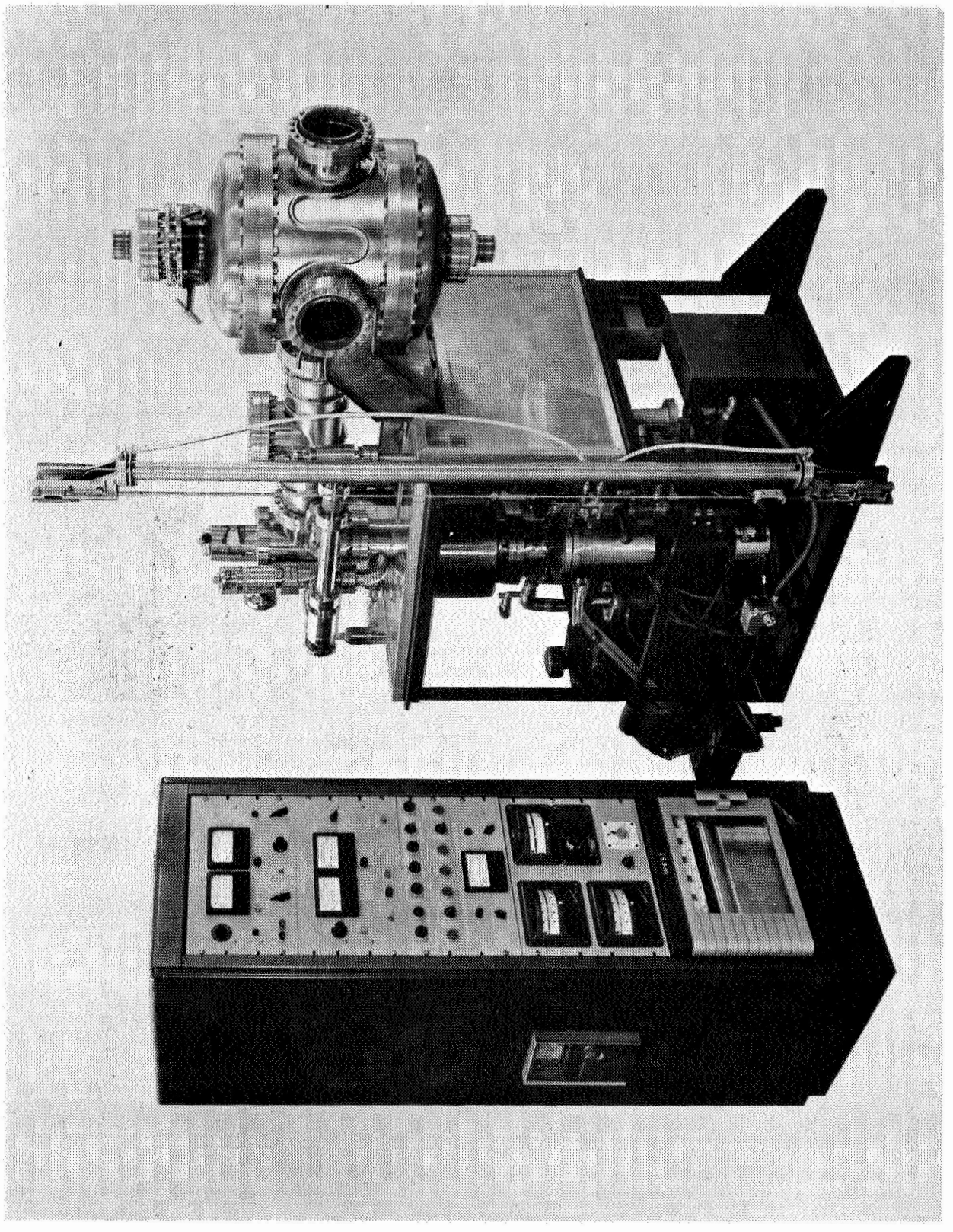

Figure 2. An overall view of the system and controls from the front or working side

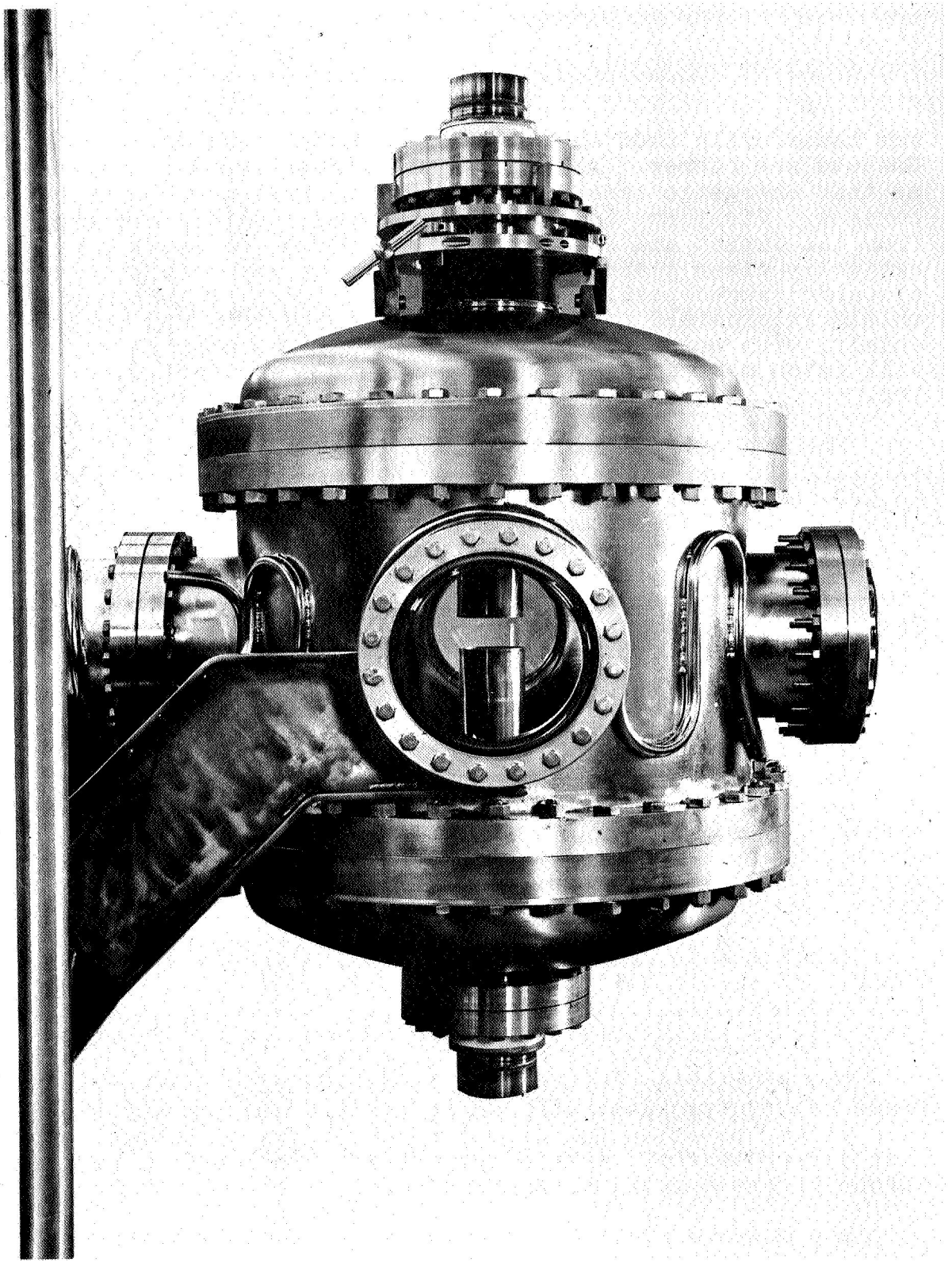

Figure 3. A closeup view of the sputtering chamber which shows the electrode tips visible through a viewing port

are necessarily used in the glass-to-metal seal construction. Gaskets are copper. All nonstainless steel metals are shielded so that energetic ions must undergo at least one bounce before contact. Viewports (glass-to-metal construction) are protected from ion impact and from sputtered material collection by a thin optically clear glass insert which can be removed for cleaning or discarded economically. A 26 gauge polished stainless steel shield is provided to fit inside the sputtering chamber. This shield, with necessary cut-outs for windows, electrodes, etc., will catch most of the sputtered material and facilitate cleaning.

The two pairs of main chamber flanges are of Ilikon design, allowing the use of either an elastomer O-ring, or a copper wire (0.080-inch diameter OFHC annealed) compression ring, interchangeably. The elastomer section makes use of an undersized dovetail groove to ensure that a small amount of elastomer will be trapped between the mating flanges allowing a large sealing force to be applied and preventing displacement during opening. The $2\frac{1}{4}$-inch thickness of a flange pair allows ample uniform sealing force for either type of seal.

The anode cover plate of the chamber, in addition to the anode, contains three copper-sealed $2\frac{1}{2}$-inch flanges. Two are blank; the third contains a 3-pair straight-through kovar tube-to-glass type thermocouple pass-thru. On the cathode cover plate, in addition to the cathode, there is a 4-inch blank port arranged at an appropriate angle to the anode tilt limit, a blank $2\frac{1}{2}$-inch diameter port, and a $1\frac{1}{2}$-inch diameter port on which the variable leak is attached. The anode and cathode covers are interchangeable.

The variable leak is a bakable Granville-Phillips Type 203, capable of smooth variation from less than 1×10^{-10} st.cc sec to a rate greater than 100 st.cc sec. This valve is easily adaptable to an automatic pressure control in the future.

The sputtering chamber is braced and supported onto the main frame by adjustable struts, as is the tee section and the 6-inch main valve, to allow for slight movement due to thermal expansion during bakeout, and to prevent application of a bending torque to the 6-inch vacuum flanges.

The cathode plate has a cathode 2-inches in diameter fixed through the center, plus a pass-thru port with a manually-controlled leak valve continuously variable from 100 cc/sec to 10-10 cc/sec. The leak valve is flanged to the pass-thru port and is connected to a flexible stainless steel hose of a length that allows displacement of the cathode cover within the vertical lift limits without disconnecting the gas line. The cathode cover has a 4-inch blanked-off port in line with the anode tilt

limits, for future planned experiments.

The sputtering end of the cathode is internally water cooled. It has a removable stainless steel plate capable of accepting a sputtering disc 2-inches in diameter, with a 1/8-inch high lip and three screws to secure the disc. The interface of the plate and the cathode body provides positive thermal and electrical conductivity by means of meshing radiators. The entire length of the cathode protruding into the chamber is shielded by a metal ground shield. A 1/8-inch air gap is maintained uniformly between the cathode and ground. The breakdown voltage of the cathode is 10 KV dc. Ceramic insulators are used to provide high-voltage isolation. The outer end of the cathode includes a standard fitting for cooling water, and a standard electrical terminal for the high-voltage power supply.

The cooling water supply, in order to provide the electrical isolation required for the cathode, uses a recirculated insulating medium, deionized water, with a counter flow heat exchanger and tap water as the secondary coolant. Deionized water, produced by bypassing a small percentage of the coolant through a mixed bed demineralizer and returning it to the reservoir, proved to be the most practical coolant with regards to efficiency and non-toxic properties and ability to be removed before or during the system bakeout without problems.

The anode plate (Figures 4 and 5) has an anode 2-inches in diameter mounted through the center, an instrumentation pass-thru with six connections for thermocouple lead-ins (chromel alumel), and two $2\frac{1}{2}$-inch diameter blanked-off ports. Gaskets are copper, inaccessible to the energetic ions. The anode is mounted in a bellows assembly so as to be adjustable vertically $\pm\frac{1}{2}$-inch and tiltable approximately 15 degrees to line up with the 4-inch port in the cathode cover. The working end of the anode is a removable pure molybdenum plate and has spring clips capable of holding 5/8-inch diameter wafers. The interface of the plate and anode body provides positive thermal and electrical conductivity by meshing radiators. The anode is hollow and has an internal heater capable of producing 25°C to 800°C controlled and recorded to ± 2°C. Necessary thermocouples, controls, and isolated power supply for the heater assembly were provided. The anode from the upper end of the bellows to within 1/16-inch of the work end is shielded by a metal ground shield. A 1/8-inch air gap is maintained uniformly between the anode and ground. The breakdown voltage of the anode insulation is 10 KV dc. Ceramic insulators are used to provide electrical isolation. The outer end of the anode includes a standard electrical connection for the high-voltage power supply. The anode and cathode plate assemblies of the chamber are interchangeable if desired.

Figure 4. An exterior view of the anode cover supported on the hoist yoke, showing the argon shield and electrical feedthroughs

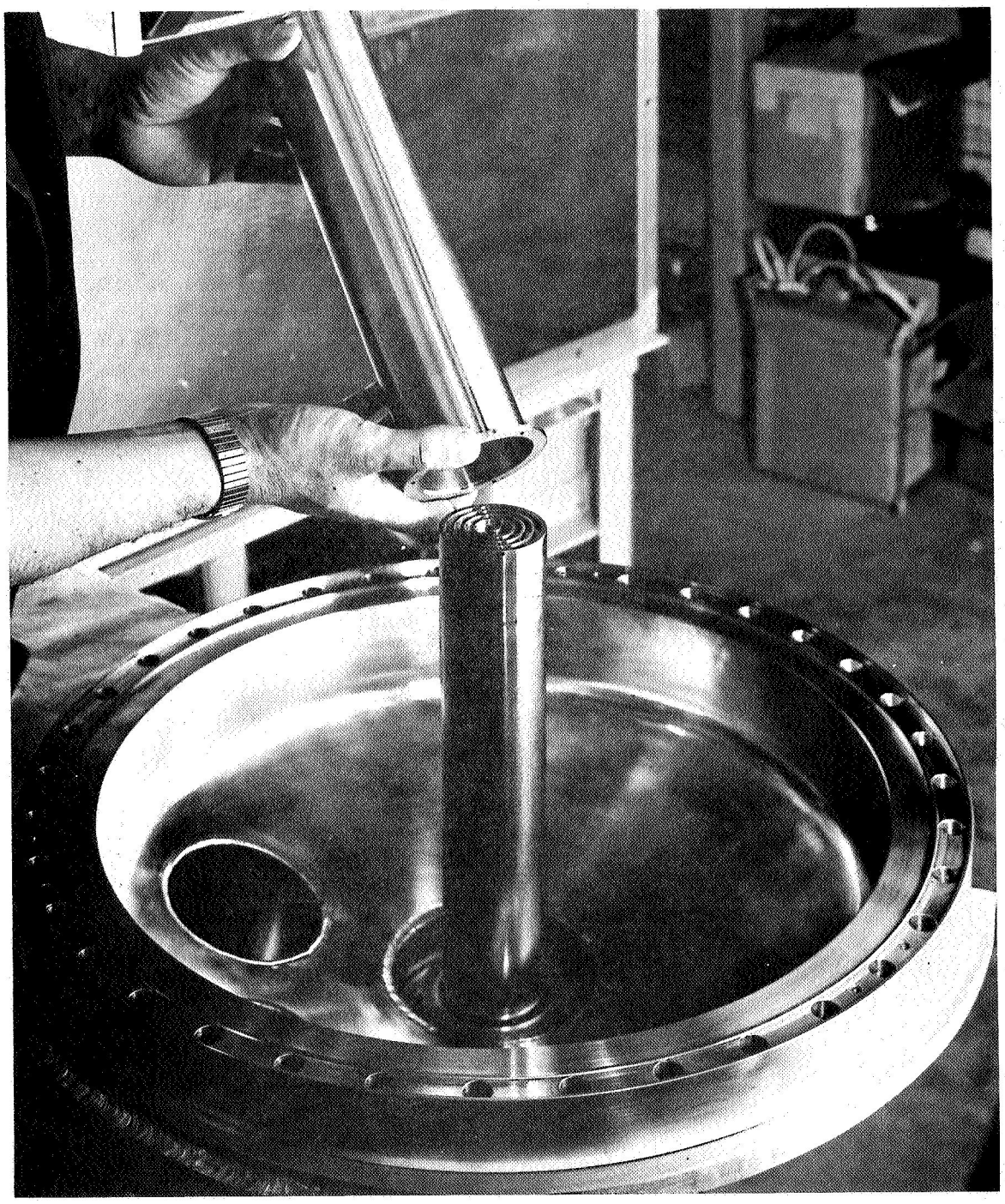

Figure 5. An interior view of the anode showing the ground ion shield being assembled, and the meshing thermal radiators below the end plate

For greater detail of the construction problems encountered in making the anode and cathode electrodes, reference should be made to the drawing of the electrodes (Figure 6) and various photographs (Figures 7 and 8) taken during the construction and after completion and testing.

The shell of the electrodes, the end caps and the shields were constructed of 316L stainless steel as dictated by the design restraints, and were assembled without trouble. Likewise, the outer flange connectors, the anode tilt mechanism and bellows, and the outer shield assemblies (all 304 stainless steel) were fabricated and mated without incident, and as originally proposed.

The remaining items in the total electrode assemblies, the ceramic to metal unit, is necessary for electrical isolation of the electrode ends from the grounded chamber. The specifications required that the cathode be capable of isolation as well as the anode.

The necessary shape and size of these ceramic pieces required that they be custom manufactured, but the ceramic to metal joint was of standard type. The subcontractor for the manufacture of these parts, Ceramaseal, Inc., chose a copper-silver eutectic braze to join the ceramic to the kovar metal which, in turn, Ilikon welded to the remainder of the assembly. Although only two pieces were needed, three were ordered from Ceramaseal, and four were started in production.

Of the three units delivered to Ilikon, two were mated to the waiting electrode pieces and installed on the system, which was then operative, and pumped down. After lengthy testing for vacuum capability, during which they underwent several mild bake-outs, it was determined that both ceramic units had small leaks (approximately 1×10^{-8} st.cc/sec each), one in the kovar metal and one in the brazed joint. After confirming these findings on a helium mass spectrometer, these pieces were removed by machining, the third available ceramic piece was assembled, and a fourth piece was ordered. The third and, several weeks later when delivered to us, the fourth piece were found to have leaks in the brazed joint.

At this point, with 100% failure for this batch, discussions were initiated with Ceramaseal engineers to determine the direction to take. They decided that the basic design was not at fault, but that the braze, due to a combination of events (temperature, humidity, etc.) during the firing, was not satisfactory and that a new batch of four using a pure silver braze would be tried. Of this group, two were found to leak, and two were successfully mated to the remainder of the electrodes and performed as originally desired.

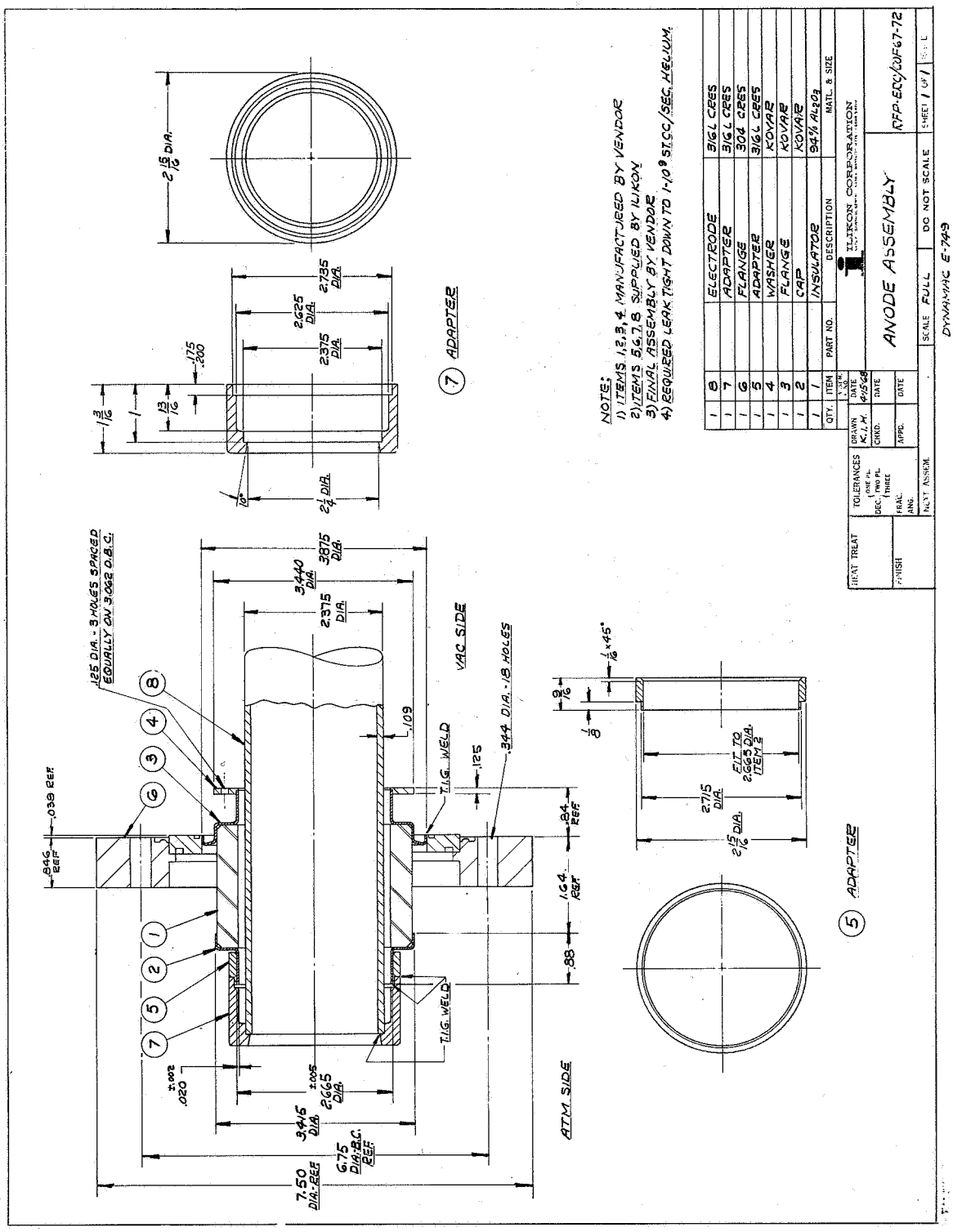

Figure 6. Drawing of electrode design used

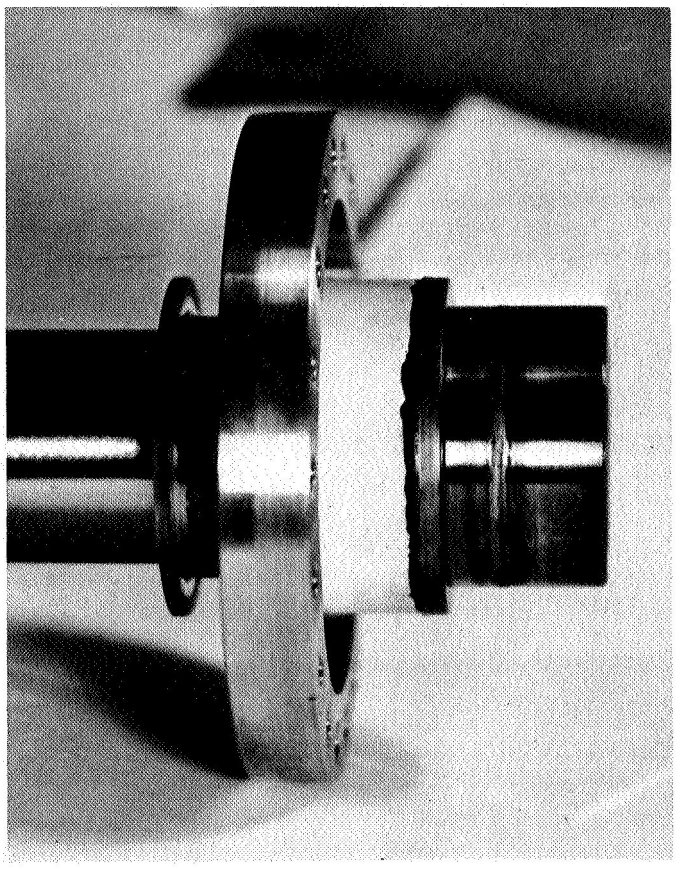

Figure 7. Side view of ceramic feedthrough during initial construction. Note glyptal plugging leak on brazed joint.

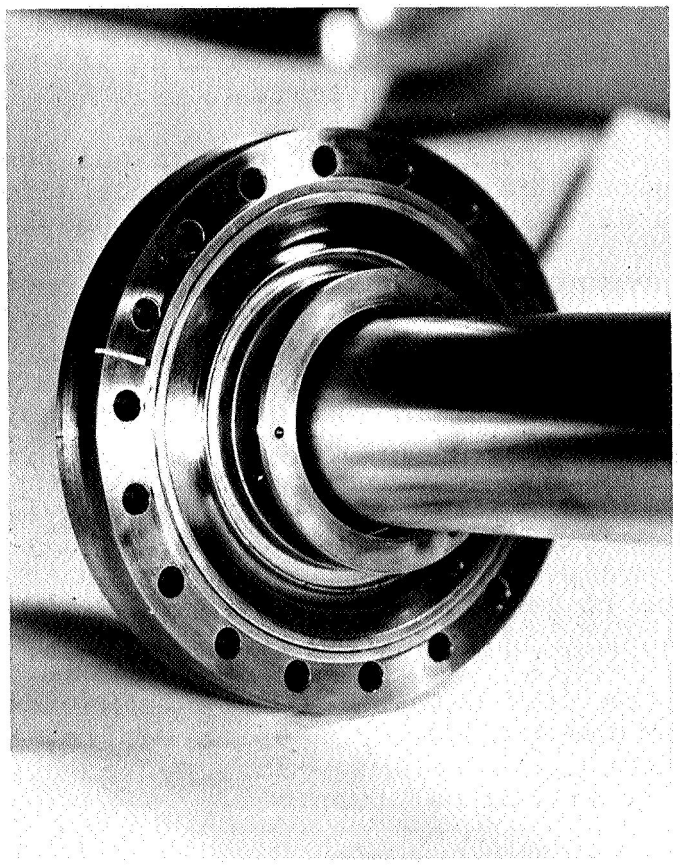

Figure 8. Interior view of same electrode as in Figure 7, during construction

To attain the desired level of vacuum in the sputter chamber the pumping cycle is performed in two basic steps: (1) a "rough" evacuation of the chamber and vacuum system using the mechanical pump, and (2) pumpdown to ultimate vacuum using the diffusion pump. Bakeout may be added, as a third step, to force out contaminants which would otherwise be slowly released into the system, thus preventing it from attaining its ultimate vacuum or extending the pumping time required.

In addition to roughing, the mechanical pump provides the necessary forepressure for operation of the diffusion pumps (vacuum at the discharge of the diffusion pumps). After the mechanical pump has roughed the entire system, it is valved off from the high vacuum portion of the system, pumping only on the diffusion pumps. The diffusion pump heaters are then turned on and the pumpdown cycle continues into the high vacuum range. A foreline trap at the suction of the mechanical pump reduces migration of mechanical pump sealing oil into other portions of the system.

The mechanical pump is a Welch Model 1397B, 15 cfm, two-stage, vented pump. Although it is dynamically balanced, rubber shock mounts were provided to further reduce the lowest frequency vibrations, and it is connected to the foreline by means of a metal bellows.

The foreline trap adjacent to the mechanical pump suction is a Bendix-Balzer Vacuum Model 1B 36 ion baffle, complete with power supply and water cooling. This prevents any contamination of the system by mechanical pump oil.

The system has two separate lines for pumping: one is used for rough pumping the system to the 4×10^{-2} torr range with the mechanical pump; the other is used for pumping to the ultrahigh vacuum range with the diffusion pumps. Valving is provided to isolate the diffusion pumps from the roughing line while the chamber is being pumped.

After a rough vacuum of approximately 4×10^{-2} torr has been achieved in the chamber, the roughing line is valved-off and the 6-inch main valve is opened to attain the ultimate vacuum of 3 x 10-11 torr. This operation can be completed within 12 hours of pumping on the system. An auxiliary valved line bypasses the 6-inch main valve to connect the chamber with the diffusion pump during the sputtering operation. When sputtering, the 6-inch valve is closed, and the valve in the bypass line is opened to maintain an adequate flow of argon through the system while maintaining a pressure of approximately 1×10^{-1} torr on the back side of the diffusion pump. The flow of argon is adjusted by opening the variable leak in the argon line and by properly throttling the bypass line valve. A third valve allows gases to flow into a mass spectrometer for sampling purposes.

The 6-inch main valve and the chamber are connected by a 6-inch tee. The open side of the tee, provided for future experimentation, has a 6-inch blanked-off flange.

The main diffusion pump is an NRC NHS-6, 6-inch, 1500 liters per second pump with a stainless steel body. This pump (modified by Ilikon) is capable of 5 x 10-12 torr operation on a properly constructed system, and has more than sufficient pumping speed for this application, since additional pumping capacity would be of limited advantage when the conductance of the other system components is considered. The pump was modified by the removal of the rubber-sealed cold cap water cooling lines (found to be a source of gas load) and the oil drain and fill plugs. The cap has been integrated into the cold trap as described further in this section. This pump has been further modified by the addition of a copper sealed (Conflat type) 8-inch ID top flange in place of the standard flange.

A 2-inch NRC Model HS-2, 285 liters per second diffusion pump with cold cap, a small receiver and a thimble type liquid nitrogen trap are placed in the backing line between the 6-inch diffusion pump and the mechanical pump. The receiver (approximately 10-liter volume) is attached to the top of this pump, and has a full-opening top cover which contains a liquid nitrogen trap. Rubber seals are used in this area, since pressures in the 10^{-8} torr range can easily be attained with their use. A Nottingham type hot cathode gauge is mounted on the side of the receiver. A valve allows bypassing the 2-inch pump during rough-down. This additional diffusion pump provides better purification of the oil in the main pump, and better control of oil backstreaming during start-up and shut-down of the main diffusion pump.

The cold trap, of Ilikon design, has an 8-inch exit flange to mate with the diffusion pump and a 6-inch entrance flange to mate with the 6-inch main valve. The overall diameter of the trap is 14 inches, thus providing an excellent baffling capability while giving a large net conductance. The lower section contains an optically dense, freon-cooled copper plate and the freon-cooled diffusion pump cold cap (normally only water cooled). This added cooling enhances the baffling efficiency of the cold cap since re-evaporation from its top surfaces is greatly reduced. Above the freon-cooled section, and in the same oversized duct, is an optically dense liquid nitrogen trap, again oversized for best conductance. This portion of the trap includes a positive anti-migration barrier to ensure total oil backstreaming below detectable levels. The flanges of the trap (and all flanges exposed to ultrahigh vacuum) are of the sexless, copper gasket type.

The cooling lines are of permanent welded design, allowing bakeout of the nitrogen-cooled portion. A heating mantle is provided for baking this portion to about 400°C when desired. The cold trap has an integral extended top neck to allow connection of the bypass line and hot cathode gauge directly below the 6-inch main valve seat, but above the nitrogen trap, thus avoiding the influence of a nitrogen surface on the gauge reading.

The freon compressor is 1/3 hp capacity, water-cooled, and expands directly into the area of the trap being cooled, thus eliminating the need for exchange fluids and pumps. Such arrangements have been used in Ilikon laboratories for many years without maintenance problems. During testing of the system, it was requested that all possible vibration be eliminated, and therefore the freon compressor was removed from the chamber support frame to the floor, and flexible lines were substituted for the copper feed line to the trap. These steps substantially reduced the vibration transmitted to the chamber.

The 6-inch main isolation valve is of Granville-Phillips manufacture. It is bakable to 425°C and seals by means of a low-torque copper gasket - knife edge mating, thus contributing no organic gas load to the system. Likewise, the three 2-inch bakable valves are of the same manufacture and design (gold seal) as well as the two interconnecting bellows which allow expansion of the 2-inch lines during bakeout. All of these valves have low torque sealing features for easy operation. They have stainless steel bellows and bodies and are provided complete with necessary parts for baking.

The bypass lines are 2-inch nominal size to allow greater versatility and greater pumping speed for future requirements (such as the mass spectrometer flange). They are of stainless steel and copper gasket construction, including the bellows sections.

The bakable valves are ultrahigh vacuum valves utilizing standard copper flange gaskets and gold seal gaskets. The valves are bakable to 425°C.

The high vacuum foreline valves are standard O-ring sealed type with Viton seals. These valves are not bakable.

The gauges provided on the system consist of three thermocouple gauges, two hot cathode ionization gauges, and one cold cathode ionization gauge. The thermocouple gauges have a range from 10^{-3} torr to 1 torr and are located at the diffusion pump exit, above the mechanical pump, and at the 6-inch tee. The hot cathode, Nottingham type gauges have a range between 10×10^{-4} torr and 1×10^{-11} torr, and are located above the liquid nitrogen traps of each diffusion pump. The cold cathode gauge

operates in the range between 10 x 10^{-5} torr and 1 x 10^{-13} torr, and is located at the 6-inch tee. Controls for these gauges are located in the system control rack.

In addition to the gauge controls, the system control rack contains the heater controls and all controls essential for system and sputtering device operations. It is a console arrangement of electronic packages with enough cable to locate the rack anywhere within an 8-foot radius of the sputtering device.

Bakeout of the system down to the top of the main cold trap is accomplished by the two-part aluminum-fiberglass oven with wall mounted strip heaters. Two West Instrument Company indicating-temperature controllers (Model J) monitor and control the bakeout ovens. A 0 to 10 hour timer controls the bakeout time. The two sections plug into receptacles provided on the system frame, and may be rolled into position by one man. The table top is of asbestos board composition covered with a polished aluminum sheet. It provides efficient infra red reflectance from the internal resistance heaters, ensuring uniform system temperatures.

The liquid nitrogen cold trap can be baked out also by means of a lace-up heating mantle provided. This is not required during normal usage.

For ease of operation, a hoist, attached to the support frame, is capable of raising or lowering either the top or bottom door of the chamber and swinging the door onto an adjacent table or cart. The attaching arm is in the form of a U-shaped yoke, with bolts and mating holes in each chamber door.

INITIAL TEST RESULTS

After the initial difficulties suffered with the leaking ceramic to metal seals on the electrodes, the ultrahigh vacuum system was performing according to plan. Tests conducted after a preconditioning bakeout and air release could be summarized as follows:

1) Ultimate pressure - 3.2 x 10^{-11} torr (G.E. gauge).

2) Ultimate pressure without liquid nitrogen in traps - 4.3 x 10^{-10} torr (Nottingham gauge).

3) Pumpdown to ultimate without bakeout - about 18 hours average.

4) Pumpdown to ultimate with bakeout - 14½ hours - heat up and cool down of chamber requiring all the above time.

5) Bakeout temperatures - 400°C very uniform (±3°C at extremes).

During the performance testing of the electrodes, the anode tip was found very gassy. During the very first heat up, pressures in the chamber rose to the high 10-7 torr range at 700°C operation. Such gas evolution rate (approximately 2 x 10-5 torr liter/sec) was very unreasonable to assume as diffusion through the hot anode tip, especially since calculations (see Introduction) yielded rates several decades lower. Therefore, it was assumed that the source of such gas was - one, surface outgassing of surrounding chamber walls and components that in the process heated up by radiative heat exchange and two, bulk material outgassing of the heated anode block. Each of the above should, however, prove temporal and thus a conditioning period of anode bake was initiated. The total number of hours at 600°C, then 800°C and finally 900°C of the anode tip exceeded 16 hours before pressures in the lower 10-9 torr range were achieved in the chamber while the anode was at 700°C. Not before such pressures were reached could any gas diffusion through the anode tip be observed. (It should be noted that this lengthy outgassing procedure could have been avoided by preheating the anode tip in vacuum at 1000°C.) The following performance parameters were noted:

1) Heat up time of anode tip to 700°C - 24 minutes.

2) Heat up time of anode tip to 800°C - 37 minutes.

3) Maximum anode tip temperature - 950°C.

The sputtering tests were conducted using glass substrates and germanium as media. The following parameters were observed at 2 inch electrode separation and 200 μ argon pressure:

1) With 1.5 KV, 0.15 ampere is drawn by the discharge.

2) With 4.8 KV, 0.48 ampere is drawn by the D.C. discharge.

Discharge pattern and stray discharge are shown in the following series of photographs (Figures 9 and 10).

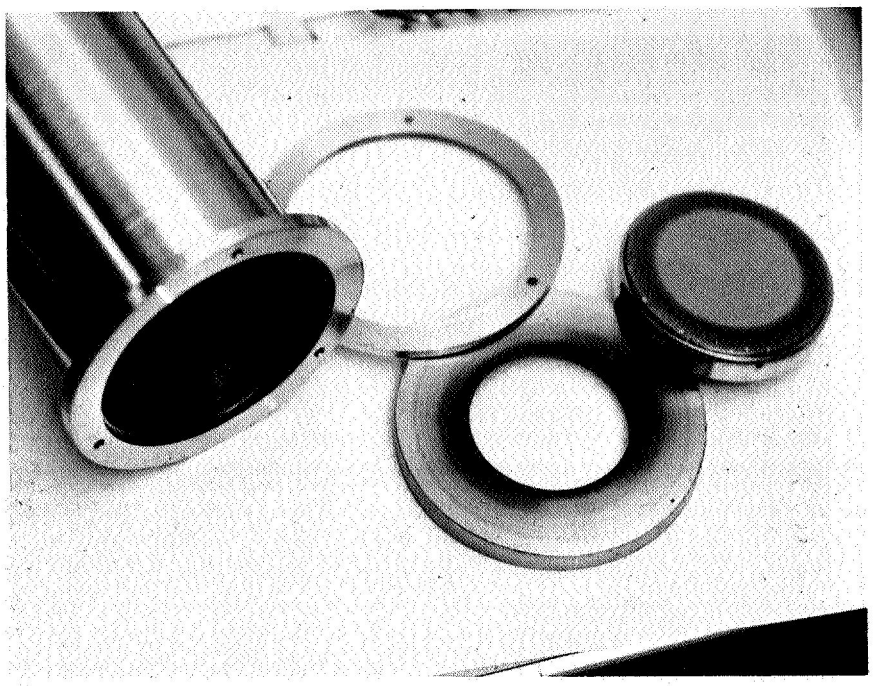

Figure 9.

THE DISASSEMBLED CATHODE AFTER SEVERAL HOURS OF SPUTTERING

From left to right - cathode shield, spacer ring for shield flange, cathode cover, germanium cathode and holder.

Note center of germanium eroded and the deposit on the grounded cover plate.

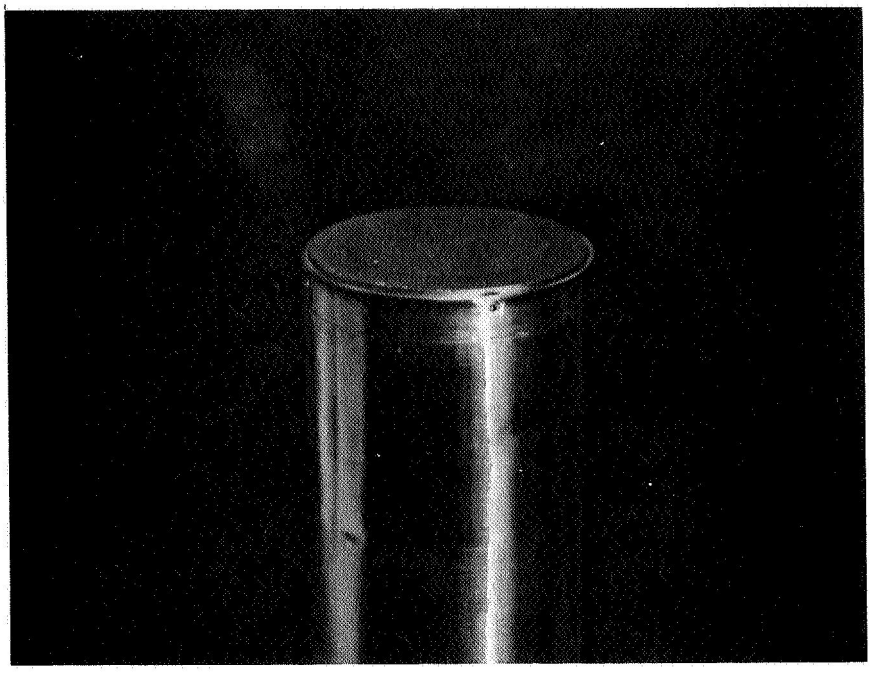

Figure 10.

THE DISASSEMBLED CATHODE AFTER SEVERAL HOURS OF SPUTTERING

Germanium cathode and holder mounted on the cathode tip.

Note sign of stray discharge around top edge.

NEW TECHNOLOGY APPENDIX

After a diligent review of the work performed under this contract, no new innovation, discovery, improvement or invention was made.