FINAL REPORT ON PHOTO CURRENT SUPPRESSOR GAUGE DEVELOPMENT

W. L. Schuemann

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1. Introduction

A type of ionization gauge called the photo current suppressor gauge has been developed at the Coordinated Science Laboratory of the University of Illinois during the past three years. This gauge is capable of effectively suppressing the photoelectric current (x-ray current) from the ion collector, thereby considerably extending the range of ionization-type gauges. Simple suppressor gauges have a limitation similar to the x-ray limit of the Bayard-Alpert gauge at 1×10^{-13} Torr. Slightly more complicated suppressor gauges probably would not be limited by an x-ray effect above 1×10^{-16} Torr, though this has not been experimentally verified. These gauges have a higher sensitivity than typical inverted gauges, are only slightly more complicated, and can use the same power supplies and electrometers.

2. Review of X-Ray Effects in Ionization Gauges

Readings of the Bayard-Alpert gauge,[1] the most widely used instrument for measuring pressure in ultrahigh vacuum systems are not linear with pressure in the vicinity of 1×10^{-10} Torr and lower because of a photoelectron current from the collector. This current is due to collector bombardment by soft x-ray photons released at the grid when

[1] R. T. Bayard and D. Alpert, Rev. Sci. Instr. 21, 571 (1950).

it is struck by the ionizing electrons. Metson[2] and Dalke-Schutze[3] have designed gauges which suppress this photoelectron current by the utilization of a fourth electrode placed between the ionization region and collector at such a potential as to prevent photoelectrons from leaving the collector. Their gauges are limited in the measurement of very low pressures by two factors: (1) low sensitivity and (2) a photoelectric current which flows from the suppressor electrode to the collector as the result of x-ray bombardment of the suppressor electrode.

Previous papers on the suppressor gauge being developed at CSL have described the first working model[4] and a later version, the model 19 gauge,[5] which has been used in our laboratory for several years. Redhead and Hobson[6] have described their version of the suppressor gauge and developed methods for modulating the ion current in order to make pressure measurements in the low 10^{-15} Torr region possible. This paper enumerates the important considerations in the design of suppressor gauges and describes the model 46 suppressor gauge which represents a considerable improvement mechanically and economically over previous suppressor gauges.

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[2] G. H. Metson, Brit. J. Appl. Phys. 2, 46 (1951).

[3] W. E. Dalke and H. J. Schutze, 20th Annual Conference on Physical Electronics, M.I.T., Cambridge, Mass., 26 March 1960.

[4] W. C. Schuemann, Transactions on the Ninth National Vacuum Symposium (The Macmillan Company, 1962), 428.

[5] W. C. Schuemann, Rev. Sci. Instr. 34, 700 (1963).

[6] P. A. Redhead and J. P. Hobson, Fundamental Problems of Low Pressure Measurement Conference, Teddington (Middlesex) England (Sept. 1964).

3. General Principles of Suppressor Gauges

The suppressor gauge consists of two regions separated by a shield as shown in Fig. 1. The filament and grid in the ionization region are similar in arrangement to those of a Bayard-Alpert gauge except for the addition of a small grid cap which closes the bottom of the grid. These electrodes are at their usual potentials of +50 and +200 volts, respectively. The shield is at ground potential and has three functions: (1) It shields the suppressor ring, which forms the retarding field for photoelectrons, from all x-rays coming directly from the grid region. Thus it prevents the creation of a large photoelectric current which otherwise could flow from the suppressor to the collector. (2) Together with the grid, the shield forms an electrostatic lens which both accelerates and focuses the ions to the collector. (3) The shield, along with the platinum bright coating on the glass, protects the ion drift region and collector against variations in wall potential which would change the sensitivity of the gauge, or reduce its ability to suppress the photocurrents, and against electrostatic noise pickup by the collector from the ionization region, or from outside of the gauge. Operation of the gauge is accomplished using standard ionization gauge supplies plus a small battery or high voltage supply for the suppressor voltage.

4. Design Considerations for Suppressor Gauges

4.1 Sensitivity

In a gauge intended for measuring very low pressures, it is desirable to have as high an ion current as possible while not

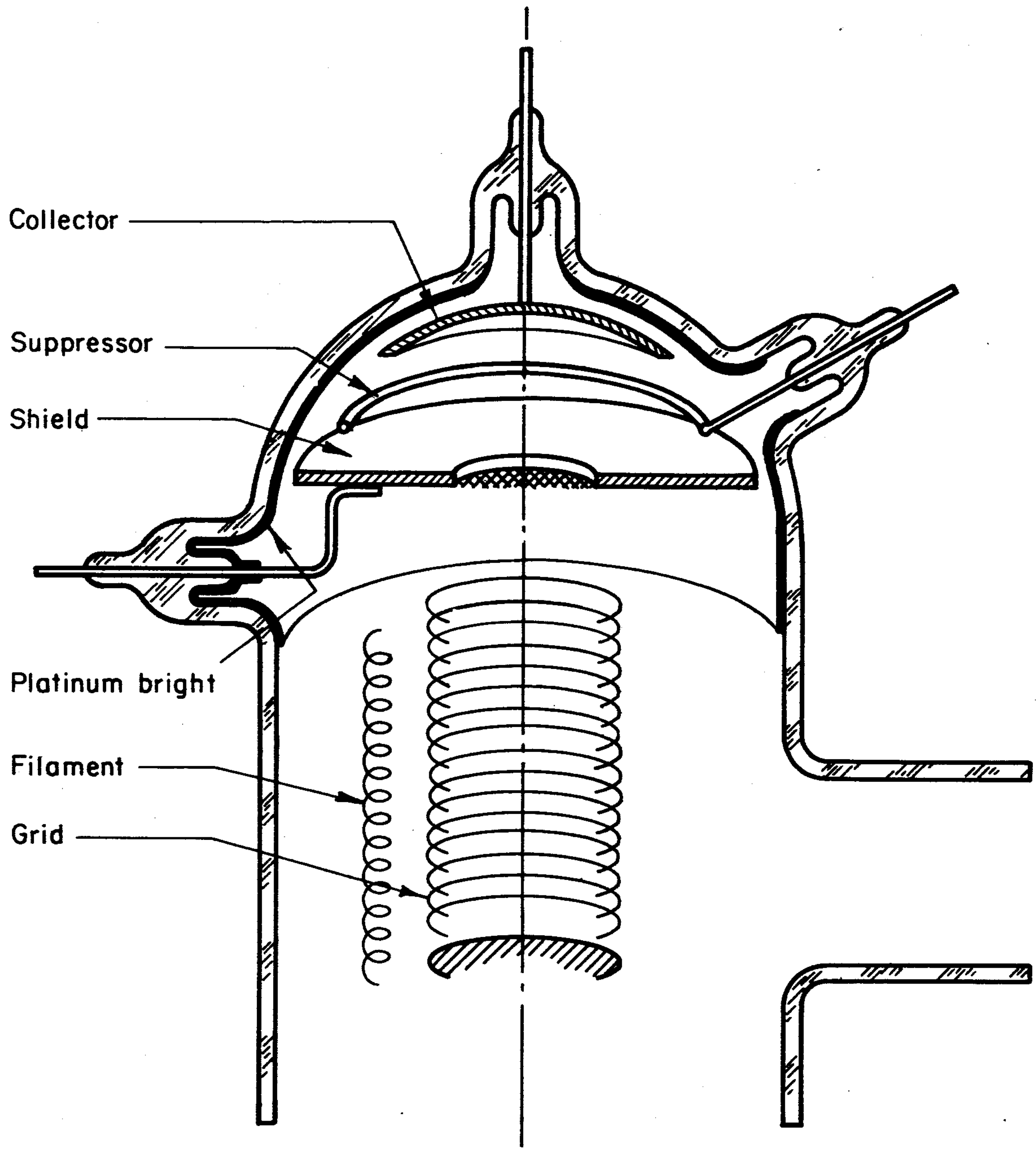

Fig. 1. Scale Cross-section of the Model 46 Suppressor Gauge.

introducing excessive pumping speeds or ionizing electron currents. Considerations such as grid volume, grid geometry, and the collection efficiency for ions therefore become important. Tests involving the geometry shown in Fig. 1 showed that 50% of the ions were accelerated into a 1/4 inch circle at the center of the shield and that all of the ions were focused into a 3/8 inch circle. After passing through the shield, the outer edges of the beam diverge rapidly, but 50% of the total ion current will still be captured inside of a 5/16 inch circle several grid diameters away from the grid, indicating a rather good collimation for half of the ions coming from the grid. As will be shown later, the rather good collimation of half of the ion current makes possible the design of a suppressor gauge which would probably be able to measure much lower pressures than the gauge being described here.

4.2 Primary and Reflected X-Ray Effects

We will define the ejection of photoelectrons from the collector by photons coming directly from the ionization region as the primary x-ray effect. The ejection of photoelectrons from the suppressor ring by photons, reflected from the collector and parts of the shield and which subsequently impact on the suppressor ring, will be referred to as the reflected x-ray effect. The primary photoelectron current from the collector, when the suppressor is grounded (no suppression), corresponds to a pressure of 7×10^{-11} Torr for the gauge in Fig. 1. This unsuppressed x-ray current varies with the size of the hole in the shield, distance of the collector from the grid, distribution of electron impacts on the grid, etc. The reflected photoelectric current, with the suppressor negative, corresponds to about 1 X 10^{-13} Torr. This current varies with the size of the hole in the shield; the size, shape, and distance from the shield of the collector; and the size, shape, and position of the suppressor ring. In most designs the surface area of the suppressor is the most important parameter. The primary x-ray effect will result in a negative current from the collector, adding to the positive ion current flowing to the collector, while the reflected x-ray effect will result in a negative current to the collector, subtracting from the ion current.

The major feature of this type of gauge is that the primary x-ray current can be suppressed to a value small compared to the ion current by means of a retarding field in front of the collector. The effectiveness of the suppression is a function of the size, shape, and distance from the shield of the collector; of the size, shape, position, and voltage of the suppressor ring; and of any electric fields which either penetrate into the collector region from the grid region or originate on the glass walls of the collector region due to charging of the glass. In the model 46 gauge, the opening in the shield is covered with a fine mesh to isolate the collector region from fields originating in the grid region, and all glass surfaces in the collector region are covered with platinum bright which is grounded to the shield, thereby eliminating the effects of any stray electric fields. It is also necessary to realize that the suppression field is defocusing for ions, and that the collector must be sufficiently large that all ions are captured even at the highest suppressor voltages.

The majority of photoelectrons from the collector probably have energies of less than 10 volts. The number of photoelectrons which have higher energies decreases rapidly with increasing energy, though the exact distribution is not known. Since it is not necessary to suppress all of the photoelectric current but only a sufficient fraction such that the photoelectric current remaining is small compared to the ion current being measured, it should be obvious that the suppression field and hence the suppressor voltage necessary for sufficient suppression will become larger as the pressure and hence the ion current is reduced. For the model 46 suppressor gauge, if it is specified that the photoelectric current must be less than 5% of the ion current at a given pressure, this voltage is about -1000 V. at 1×10^{-13} Torr, -500 V. at 1×10^{-12} Torr, and -200 V. at 1×10^{-11} Torr. Of course, the voltage does not have to be varied with pressure but merely chosen sufficiently large to guarantee suppression at the lowest anticipated pressures. About -600 V. has been found to be optimum.

4.3 Oscillations in Suppressor Gauges

The model 19 suppressor gauge, in use at our laboratory for several years, showed a strong tendency toward oscillation, characterized by a negative collector current when the pressure was below 10^{-11} Torr. The oscillation was very persistent, was enchanced by making the suppressor voltage more negative, and showed time constants for the growth or decay of the oscillation after the suppressor voltage was changed. This strange behavior was found to be due to wall potentials in the grid region going negative with the suppressor voltage, thereby making the potential distribution in the grid region very favorable for electron cloud oscillations. The train of events started at a small exposed wire lead which supplied the suppressor its potential. In the model 19 gauge, the exposed lead is adjacent to the grid and hence was bombarded by soft x-rays. The majority of the resulting photoelectric current, of about 1×10^{-11} A., from the lead went to the glass walls of the gauge where it was neutralized by ions made outside the grid. When the pressure fell into the low 10^{-11} Torr region, the ion current became smaller than the photoelectric current, and the glass walls were then driven negative to near the potential of the suppressor. This allowed strong electron cloud oscillations to exist which were able to give surprisingly large numbers of electrons enough energy to penetrate through the shield opening and the suppression field to the collector. Since the glass walls went negative with the suppressor voltage, the oscillations became stronger as the suppression was increased. This explains why the electrons coming from the grid region could not be prevented from reaching the collector by making the suppressor more negative. Obviously, the solution to this problem is to place the suppressor lead above the shield as shown in Fig. 1, thereby removing it from the grid region.

As a side experiment it was observed that the wall potentials in Bayard-Alpert gauges at 10^{-10} Torr and lower would vary anywhere from 10 volts negative of the filament voltage to several volts negative of the collector voltage. In the latter case, the Bayard-Alpert gauge collector current went negative. Changes in residual magnetic field, pressure, temperature, and electron emission current sometimes caused large immediate variations in the wall potential. Negative collector currents were always eliminated by making contact with the metallic film on the glass wall and making it positive with respect to the collector.

4.4 Data from Suppressor Gauges

Two types of data (other than pressure measurements) can be obtained from a suppressor gauge. The first is illustrated in Fig. 2. This figure shows curves of collector current versus suppressor voltage. The data was taken at 10 mA. emission current and each individual curve represents data taken at a constant pressure. These curves illustrate that as the suppressor voltage is increased, the photoelectric component of the collector current is gradually suppressed until the collector current becomes constant. This final constant collector current is the ion current to the collector. As described earlier, it can be seen that lower pressures require higher suppressor voltages for complete suppression.

The second type of data is illustrated in Fig. 3. This figure shows curves of collector current versus the voltage between the grid and filament. All of these curves were taken at the same pressure of 1.3×10^{-11} Torr and at 10 mA. emission current. Each

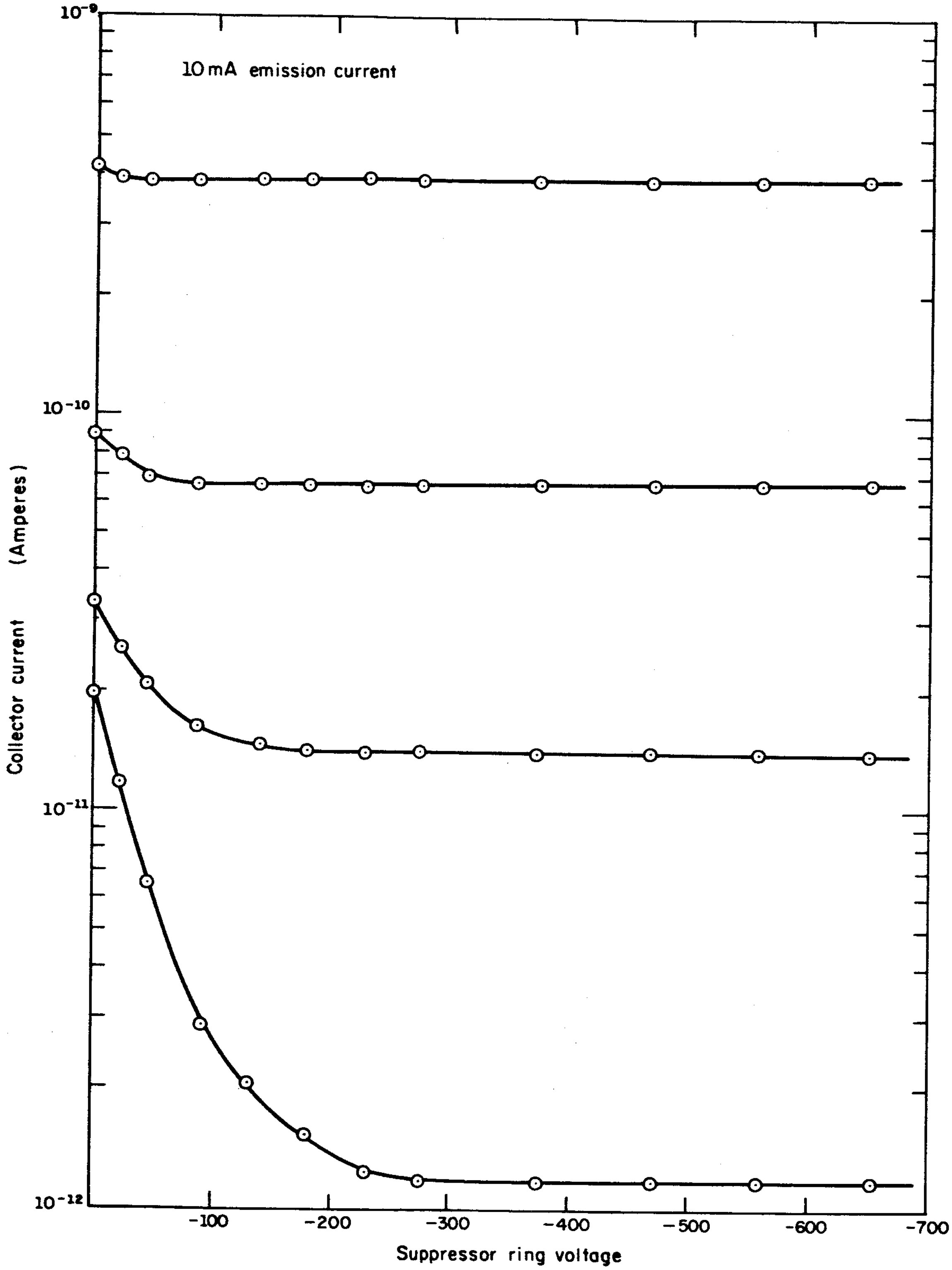

Fig. 2. Collector Current versus Suppressor Voltage, at Several Pressures, for the Model 46 Gauge.

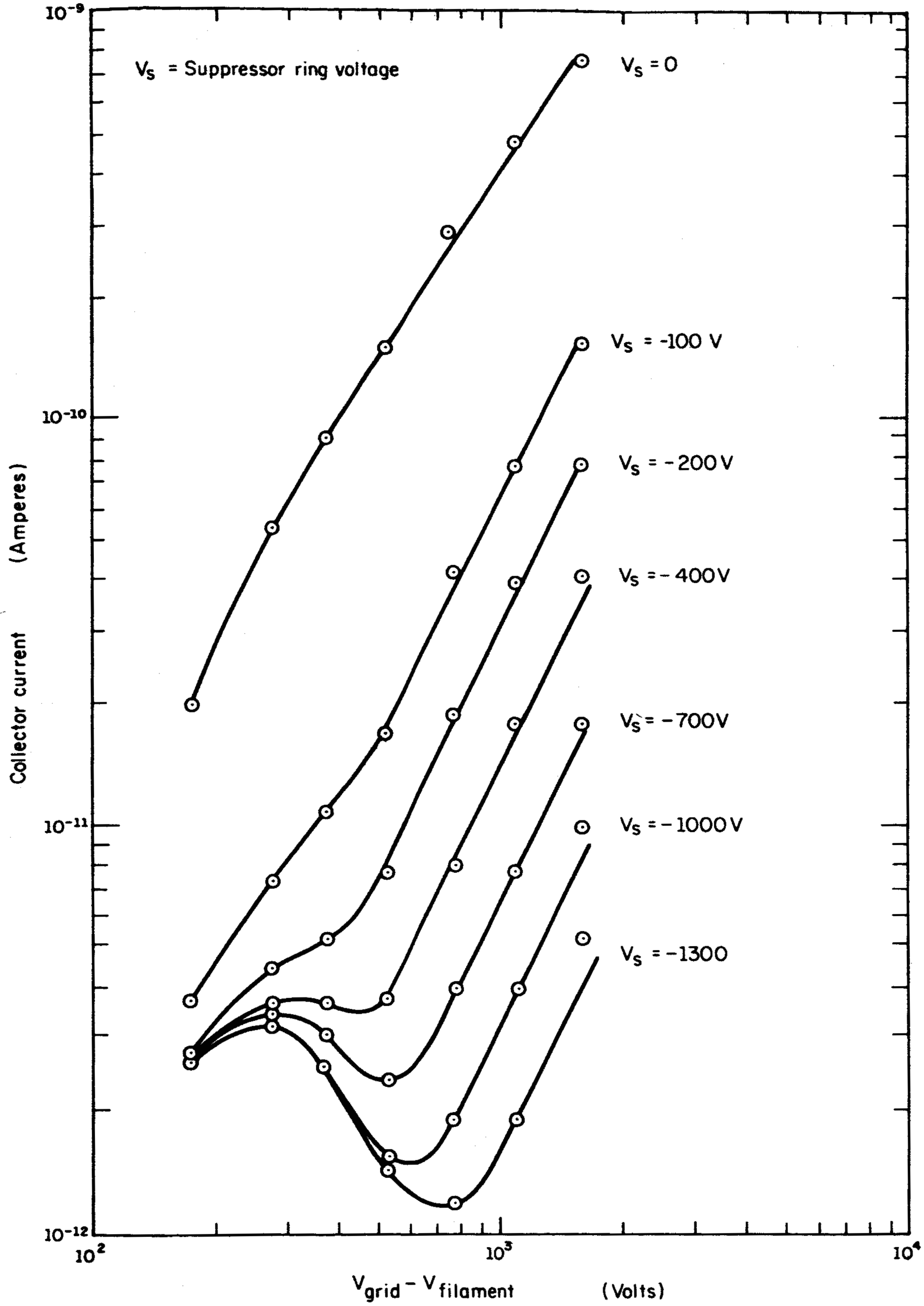

Fig. 3. Collector Current versus Grid Voltage, at Several Suppressor Voltages, for the Model 46 Gauge.

individual curve corresponds to data taken at a constant suppressor voltage. With the suppressor voltage at zero we see that the common x-ray curve, of the type familiar from measurements on Bayard-Alpert gauges, is obtained. For very large suppressor voltages we can eliminate the photoelectric current from the collector and are left with something resembling a probability of ionization curve. For intermediate values of suppressor voltages, we see that the suppression of the photocurrent can be maintained until the energy of the x-rays and, hence, the energy of the photoelectrons becomes sufficiently large that the photoelectrons are able to penetrate the suppression field and escape from the collector in sufficiently large numbers to cause the collector current to increase rapidly with grid voltage.

The type of curve shown in Fig. 2 is easy to obtain and is an excellent way of determining if the gauge and its associated electronics are performing properly. This data cannot be obtained if strong Barkhausen oscillations exist in the gauge. When they exist it is possible for electrons from the grid region to reach the collector when the suppressor voltage is less than about 100 volts. This is not normally a problem since the suppressor is always more negative than this in normal operation.

The main value of the curves shown in Fig. 3 is that for each suppressor voltage, the curve can be extrapolated back to normal grid voltage to determine at what pressure that particular suppressor voltage will begin to exhibit marginal suppression characteristics.

5. Model 46 Design Features

The gauge shown in Fig. 1 was evolved after it was decided to make a suppressor gauge that was easier and cheaper to manufacture than the model 19 gauge and which would eliminate the oscillation problem. The gauge in final form is simply a modification of a commercially available Bayard-Alpert gauge. The sensitivity of the gauge is 27 $Torr^{-1}$. The low pressure limit of the gauge is in the low 10^{-13} Torr region and the gauge is highly linear to pressures considerably higher than those at which an inverted gauge departs from linearity. The high pressure linearity is probably due to the lack of any high ion space charge such as exists in an inverted gauge around the collector at high pressures. This gauge also has the desirable feature that the collector is completely surrounded by a grounded conductor which considerably simplifies the ion current measuring problems due to the elimination of electrostatic noise.

5.1 Model 46 Construction Outline

Construction starts by opening up a commercial Bayard-Alpert gauge near the press. The original collector is removed from the envelope and two additional openings are made in the top of the envelope; one for the suppressor and one for the shield. The platinum bright coating is then painted on and fired to 650°C for a few minutes. The collector and suppressor ring are then inserted into the envelope and their feedthroughs sealed in. The shield with a small wire finger for making contact with the platinum bright is then inserted and its feedthrough sealed in. The bottom of the gauge's grid is then closed by spotwelding a small circular grid to the grid's four support wires. The tube is then sealed back together and is ready for service.

5.2 Operation of Suppressor Gauges

In normal operation, the shield is always grounded, the filament is at approximately +50 V. and the grid is at approximately + 200 V. During outgassing of the grid, the shield is left grounded and the pressure in the gauge can be monitored if the suppressor voltage is high enough. Normal operation in our laboratories is at 3.7 mA. emission current while an outgas is performed at between 100 and 150 watts. It has never been found necessary to outgas either the shield or collector to reach low pressures. They are apparently sufficiently outgassed by thermal radiation during the grid outgas.

Sparkers used for leak checking should not be touched to the shield feedthrough as the connection between the shield and platinum bright may be burned away.

If oscillations are present in the tube, the collector current may become negative if the suppressor is near ground due to electrons gaining enough energy in the grid region to go through the hole in the shield and impact on the collector. At normal suppressor voltages, this effect is never seen, because the electrons are unable to penetrate through the retarding field formed by the suppressor.

6. Outline for a Super Suppressor Gauge

In a gauge as outlined above, the reflected x-ray limit is approximately one thousandth of the unsuppressed primary x-ray limit. As long as the reflected photons reach the suppressor after one reflection, the lower limit of the gauge cannot be improved without adversely affecting one of the other characteristics of the gauge. Any geometry which would lower the reflected x-ray limit would also have to incorporate improved primary x-ray current suppression in order to keep the suppressor voltage within reason at lower pressures. The gauge shown in Fig. 4 satisfies both conditions, though the sensitivity will be reduced to 5 $Torr^{-1}$. By thinking about all the possible paths photons from the grid could follow, it will be seen that the only place on the suppressor where a photon can impact after one reflection is on the half of the suppressor near the shield. Any resulting photoelectron can only go to the shield and therefore never affects the collector current. The half of the suppressor near the collector can only be struck by photons after two reflections and therefore the reflected x-ray current, which can reach the collector in this case, should be approximately one millionth of the unsuppressed primary x-ray current. It should also be noted that the suppressor in this geometry is much larger than in the model 46 gauge and hence able to exercise considerably more control over the primary x-ray current. Several gauges of this type have been built and their characteristics

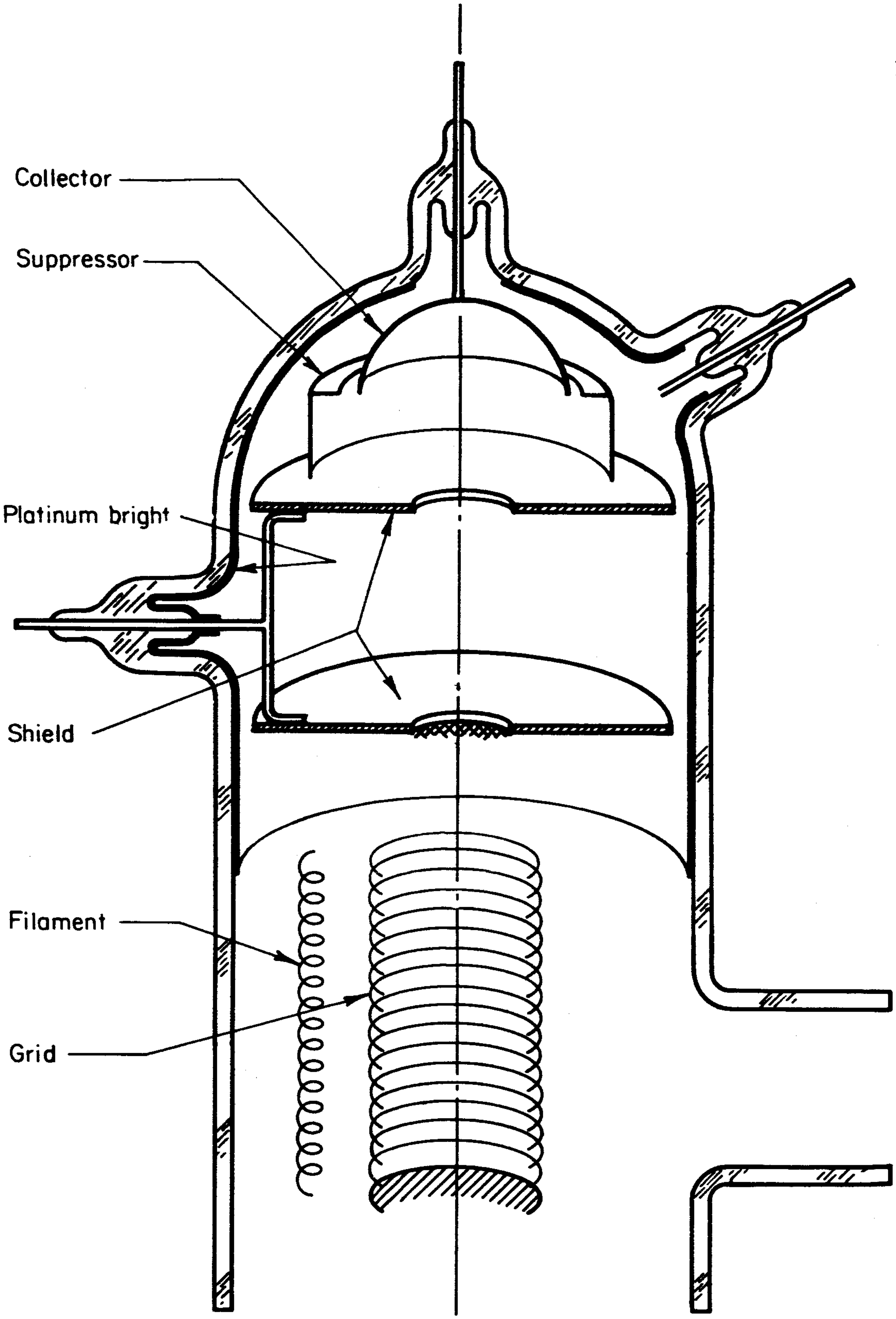

Fig. 4. Scale Cross-section of the Model 45 Suppressor Gauge.

are better than simpler suppressor gauges. At the present time our laboratory is unable to measure their ultimate x-ray limitation and has no plans to develop this version of the gauge.

7. Detailed Construction Information for the Model 46 Suppressor Gauge

The model 46 suppressor gauges made at CSL have been converted from Westinghouse type 5966 Bayard-Alpert gauges and is shown in Fig. 5. These tubes are opened by our glassblower at the base of the tube where the press was originally sealed in. The press is then removed and the opening at the lower end of the envelope is widened to make it possible to insert the shield later. The original collector is then removed from the envelope and a short 12 mm glass tube glassed on to make it possible to install the collector feedthrough later without heating the main envelope. At a point 45° down and another at 90° down from the collector, holes are blown and additional short 12 mm glass tubes are added to take the suppressor and shield feedthroughs. At this time we usually change the pumping lead from 1/2 inch to 1 inch. A coating of platinum bright is then painted on the inside of the hemisphere, which forms the end of the envelope, and 1/4 inch into the hole which will hold the suppressor. The coating should go under the edge of the collector but no closer to the collector than necessary to minimize any possibility of a leakage resistance between the platinum bright and the collector. The envelope is then annealed at $650^{\circ}C$ which also fires the platinum coating. This unusually high annealing temperature is necessary in order to prevent the platinum coating from subsequently being lifted off the glass by condensed water vapor during glass blowing.

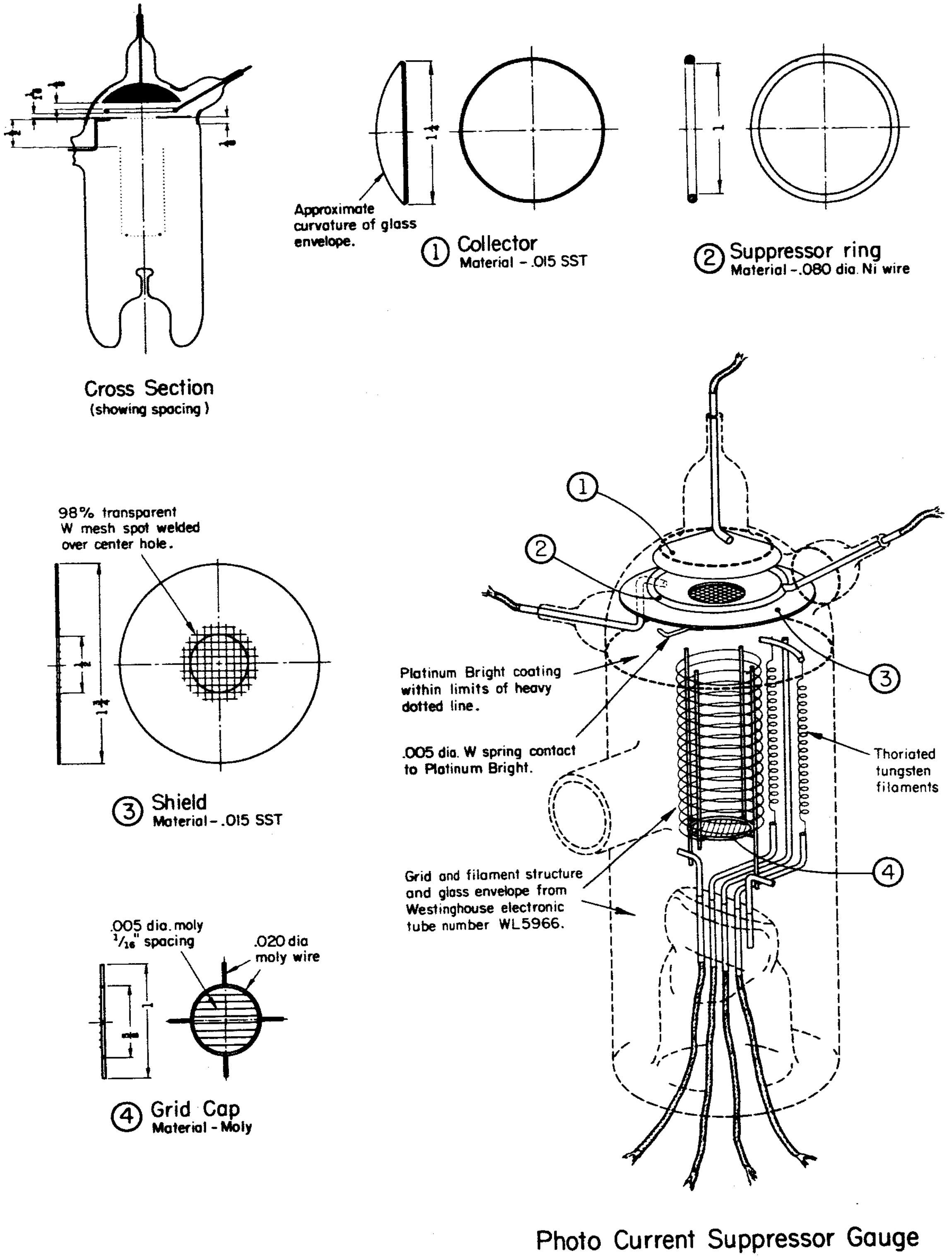

Fig. 5 Assembly drawing of Model 46 photo current suppressor gauge.

The collector is made from a disc of .010 inch stainless sheet 1-3/8 inch in diameter. It is made concave by pressing it into a lead block with a formed aluminum bar. The suppressor ring is a .080 inch nickel wire formed into a 1 inch I.D. circle. The shield is a 1-3/4 inch disc of .015 inch stainless sheet with a 1/2 inch hole in the center. Across the hole is spot-welded a 98% transparent woven tungsten mesh. On the outer perimeter of the shield, a 3/4 inch piece of .005 tungsten wire is spotwelded and bent in such a way as to make a light contact with the platinum bright coating on the envelope when the shield is installed. The feedthroughs for the collector, suppressor, and shield are standard .040 inch nickel to .030 inch tungsten to koolgrid wire type. The feedthroughs are appropriately formed and spotwelded to each piece.

An aluminum bar has been machined which fits loosely into the envelope, its top resting against the hemispherical end, which holds the collector in position for sealing in its feedthrough. A second aluminum bar, which rests against the collector, positions the suppressor for sealing in its feedthrough. The collector has a 1/16 inch gap between it and the envelope and the top of the suppressor is 1/8 inch from the plane defined by the edge of the collector. The shield is then installed and positioned by the flat end of another machined aluminum bar a distance of 1/16 inch from the lower edge of the suppressor by a small pin which extends from the bar through the mesh to touch the collector. This completes the work on the envelope.

The circular grid is constructed of a .020 inch moly wire circle with a 5/8 inch O.D. Across this are spotted .005 inch moly wires on 1/16 inch spacings. Then, four .020 inch moly wires are weld 90° apart on the ring which extend out radially for 3/16 inch. This ring is then welded to the four support wires on the 5966 grid just at the lower end of the grid winding. The reason why all four support wires are tied together is to prevent the unsupported two from warping the grid out of shape during a hard outgassing. If this happened, then the x-ray characteristics or sensitivity of the gauge might change. Some 5966 grid support wires extend above the upper end of the grid winding a considerable distance, and they should be clipped off close to the winding. All that remains to be done is to position the grid 1/2 inch from the shield, center the grid on the hole in the shield, and close up the envelope.

8. Summary and Conclusions

A relatively simple ionization vacuum gauge for measuring down to 10^{-13} Torr has been developed. The gauge has been used successfully by several experimenters both in CSL and other laboratories in the low 10^{-12} Torr region. Its cost in quantity would be little more than a standard inverted gauge while it can measure pressures hundreds of times lower. Because of the compatability of existing ion gauge supplies, electrometers, and measurement techniques, I believe that the suppressor gauge offers the most promise for making it possible for vacuum research people, the vast majority of whom now use Bayard-Alpert gauges, to develop the know-how for reliably obtaining pressures in the 10^{-11} and 10^{-12} Torr region.

9. Acknowledgments

I wish to express my appreciation to Bill Lawrence and Dale Coad for their patience with me and their initiative and craftsmanship in building many, many gauges and systems; to Will Prothe, Don Lee, and Harry Tomaschke for many of the solutions to difficult problems which appeared in the development of the gauge as well as their continuous encouragement; and especially to Dr. Danial Alpert for the wisdom and good judgment, both technical and personal, which was always forthcoming when needed.

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13. ABSTRACT

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