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FEASIBILITY STUDY OF THIN FILM TUNNEL CATHODES

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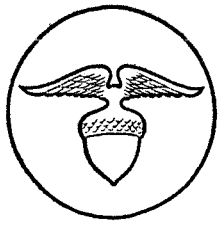

Arthur D. Little, Inc.

FEASIBILITY STUDY OF THIN FILM TUNNEL CATHODES

by

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ABSTRACT

Two types of deterioration in thin film tunnel cathodes were identified by direct transmission electron microscopy. Sputtered gold over sputtered bismuth oxide was investigated extensively as a thin cover metal film. The experimental evidence strongly suggests that electron emission in tunnel cathodes is through many small holes in the cover metal, rather than by any direct hot electron transport process through the cover metal.

ACKNOWLEDGMENT

I would like to acknowledge the contributions of Dr. Paul E. Doherty in developing and applying the electron microscope observation techniques used in this study. Dr. John Miles and Gaetano Lombardo contributed much useful discussion as well as laboratory assistance. Francis Galligani assisted in much of the sample preparation.

The assistance of Misses Jacqueline Pynn and Matilda Shamlian in preparation of the manuscript is gratefully acknowledged.

DONALD L. SULLIVAN

LIST OF FIGURES

I. INTRODUCTION

As a result of the first phase of this study, we concluded that an Al-Al_2O_3-Pt/Pd structure was a promising thin film tunnel cathode which was, however, subject to a partially reversible deterioration. The two major objectives of this second phase were to determine the exact nature of the deterioration and to develop techniques for minimizing it.

In Sections II-B and II-C, we summarize our observations of the physical aspects of deterioration in cathodes using evaporated platinum and gold as cover metals. In Section III we describe the search for a better, more stable cover metal film, which led us to the surprising conclusion that as one makes the thin cover metal film more structurally sound the electron emission efficiency drops. In Section IV we examine the implications of this discovery in the light of present theories of electron tunnel emission. Recommendations for experiments to positively identify the emission process are presented in Section V.

II. OBSERVATION OF TUNNEL CATHODE DETERIORATION

A. TECHNIQUE

The primary diagnostic technique that we have used is direct transmission electron microscopy of the cathode structures at various stages in their operating lifetimes. A glass substrate is first coated with a thin layer of plastic (4% parlodion in amyl acetate), applied by medicine dropper. Subsequent stripping of the plastic from the substrate seems to be facilitated by rubbing a minute amount of silicone onto the substrate with a clean cloth before applying the plastic. The solvent is allowed to evaporate overnight, after which the cathode is built up in the usual manner on top of the plastic. Cathodes made in this manner behave electrically the same as those deposited directly onto glass. After testing, selected areas of the plastic plus cathode are carefully floated off of the glass and onto an electron microscope specimen grid. The plastic is then dissolved in amyl acetate vapor and the specimen is ready for observation. Since the total device thickness can be made less than 1000 Å, it will be translucent to a 50-75 kilovolt electron beam.

A technique that sometimes successfully strips cathodes directly from glass is to carefully dip the edge of the area to be stripped into a weak sodium hydroxide solution. The sodium hydroxide will slowly work its way under the cover metal to dissolve the aluminum. There is some evidence that the oxide floats free along with the cover metal. The specimen is picked up from the liquid surface on a specimen grid, rinsed by floating for a few minutes in distilled water and is then ready for observation.

Initial observations were made on cathodes using platinum as a thin cover metal. After observing that gold covered cathodes deteriorated in much the same way as platinum covered cathodes, we switched to gold as a cover metal because of the relative ease of preparation of gold films with reproducible structures.

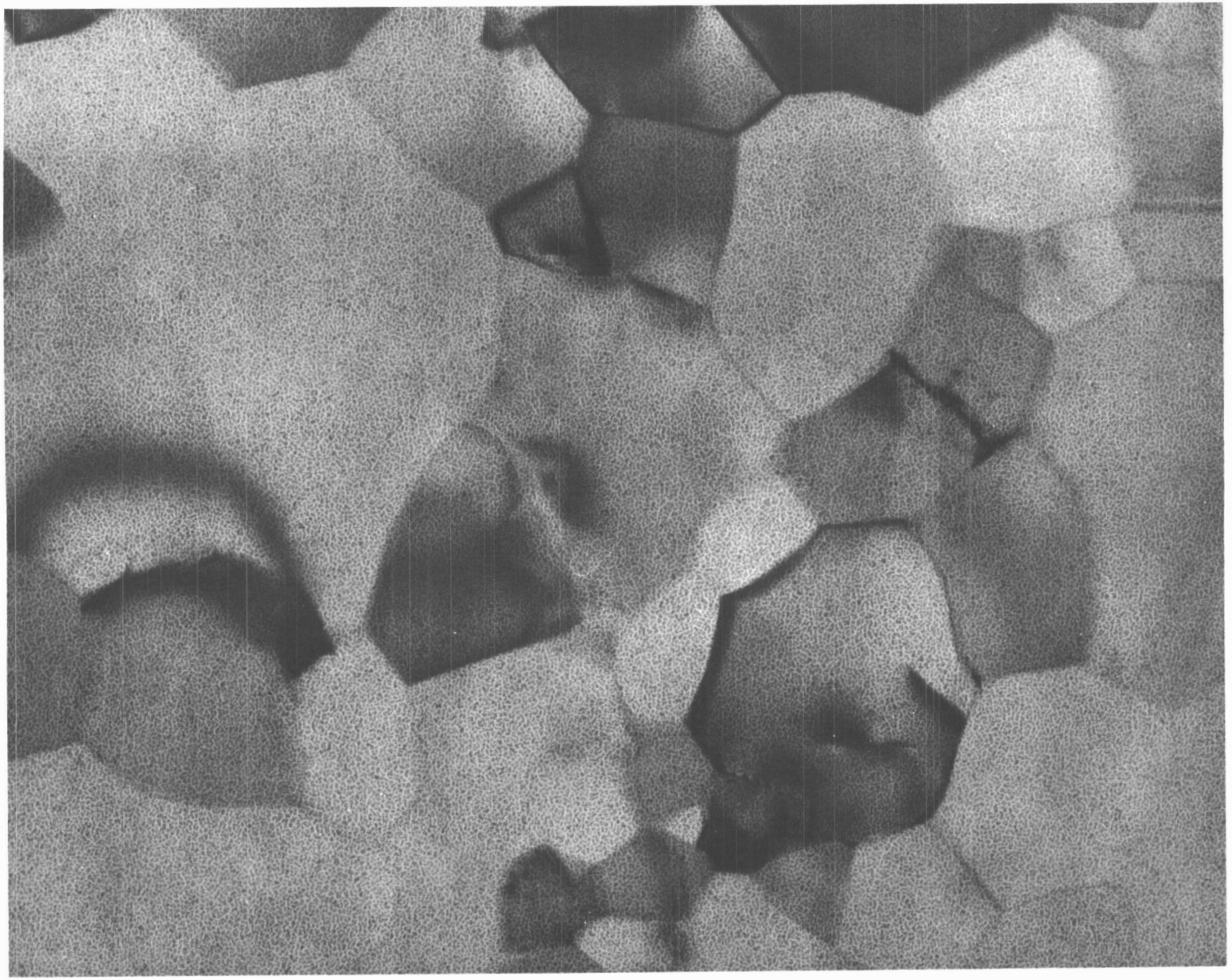


FIGURE 1 TRANSMISSION ELECTRON MICROGRAPH OF Al–Al_2O_3–Pt DEVICE

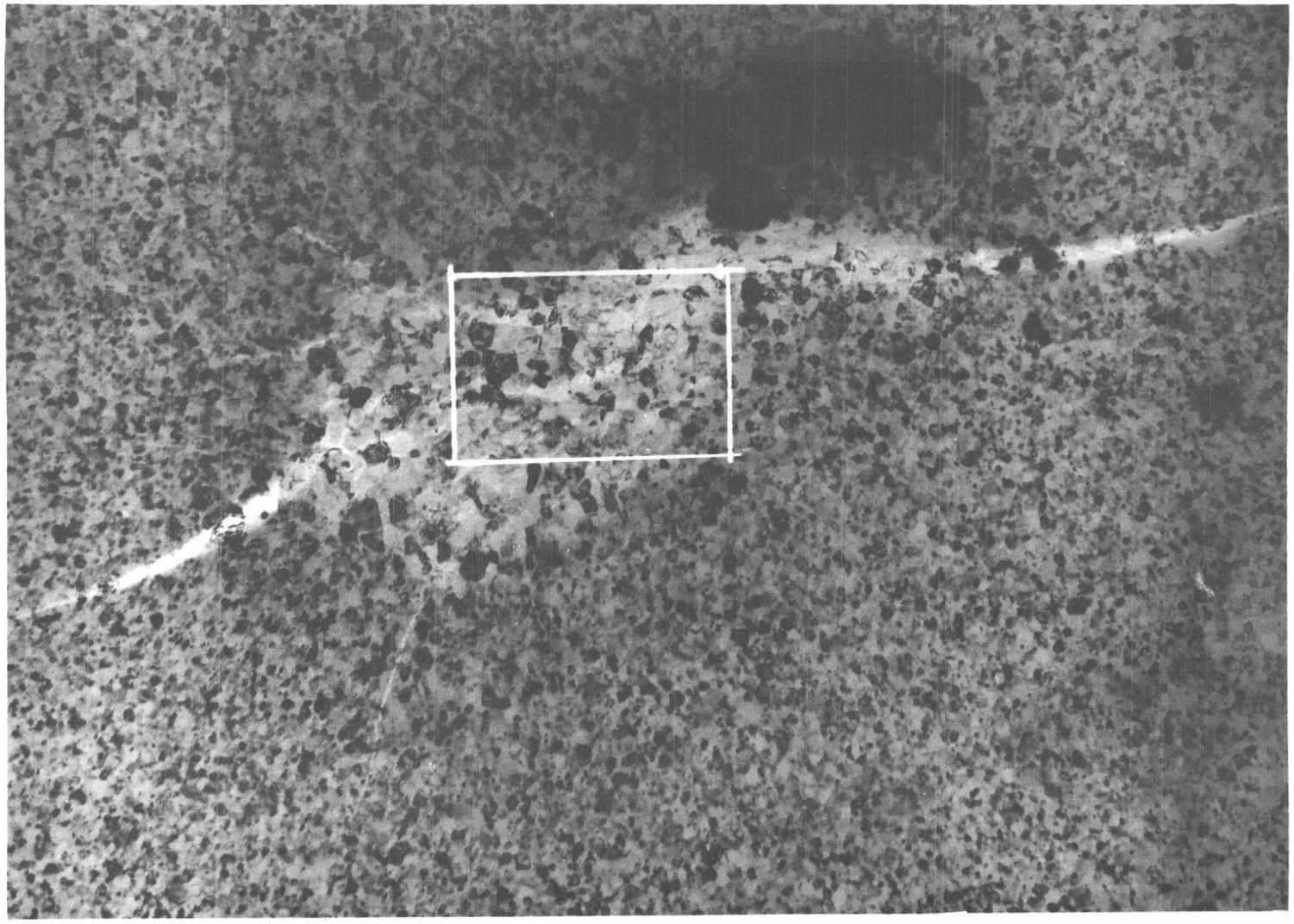
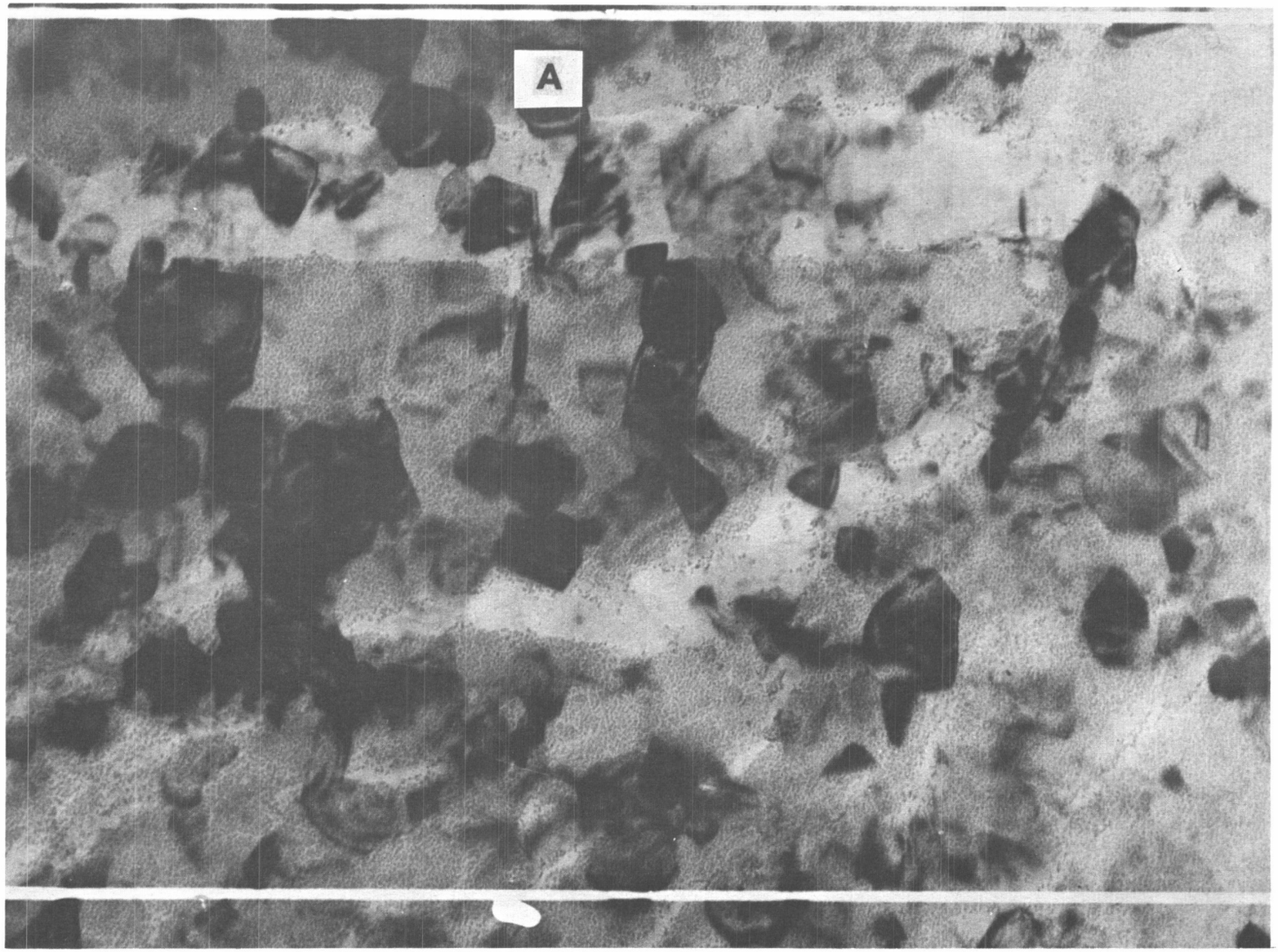


FIGURE 2 DAMAGED AREA OF Al–Al_2O_3–Pt CATHODE WITH THIN Pt COVER METAL



1000 Å

FIGURE 3 ENLARGED VIEW OF AREA OUTLINED IN FIGURE 2

B. $Al-Al_2O_3-Pt$ CATHODES

Figure 1 is an exceptionally clear picture of an $Al-Al_2O_3-Pt$ cathode at a magnification of 165,000. The evaporated aluminum film has a grain size averaging several thousand Angstroms. The aluminum oxide, being structureless, is invisible. The platinum is clearly visible as a discontinuous film with a particle size of about 50 Angstroms. It has been shown by electron diffraction that the small particles are platinum. Platinum films with this island type of structure typically have sheet resistivities of 10^3-10^4 ohms per square.

Two distinct types of deterioration have been identified. The first type appears to occur in cathodes which have a cover metal thin enough to be almost or actually discontinuous, and consists of rupture of the platinum film, aluminum oxide film or both, plus a migration of platinum across the cathode surface, probably under the influence of local heating. Figure 2 shows a disturbed area of such a cathode and covers about 0.3% of the total active cathode area. Figure 3 is an enlarged view of the area outlined in Figure 2. The cathode contained many similar areas, in some of which the aluminum film had blown out completely. In this particular area the aluminum is almost intact, but the significant increase in aluminum crystallite size in the damaged area demonstrates clearly that there has been severe heating in that area. The two bright streaks in the lower left and upper right of Figure 2 are actual cracks in the aluminum film.

We believe that the faint boundary seen at "A" in Figure 3 is the edge of the aluminum oxide film which has cracked because of its inability to expand along with the heated aluminum. This boundary can be traced for several inches along both sides of the cleared area at "A" because the platinum has migrated away from many places along the boundary. Migration of this type is known to take place in many materials at temperatures far below the bulk melting temperature. Migration in a particular direction is the result of a negative temperature gradient in that direction.

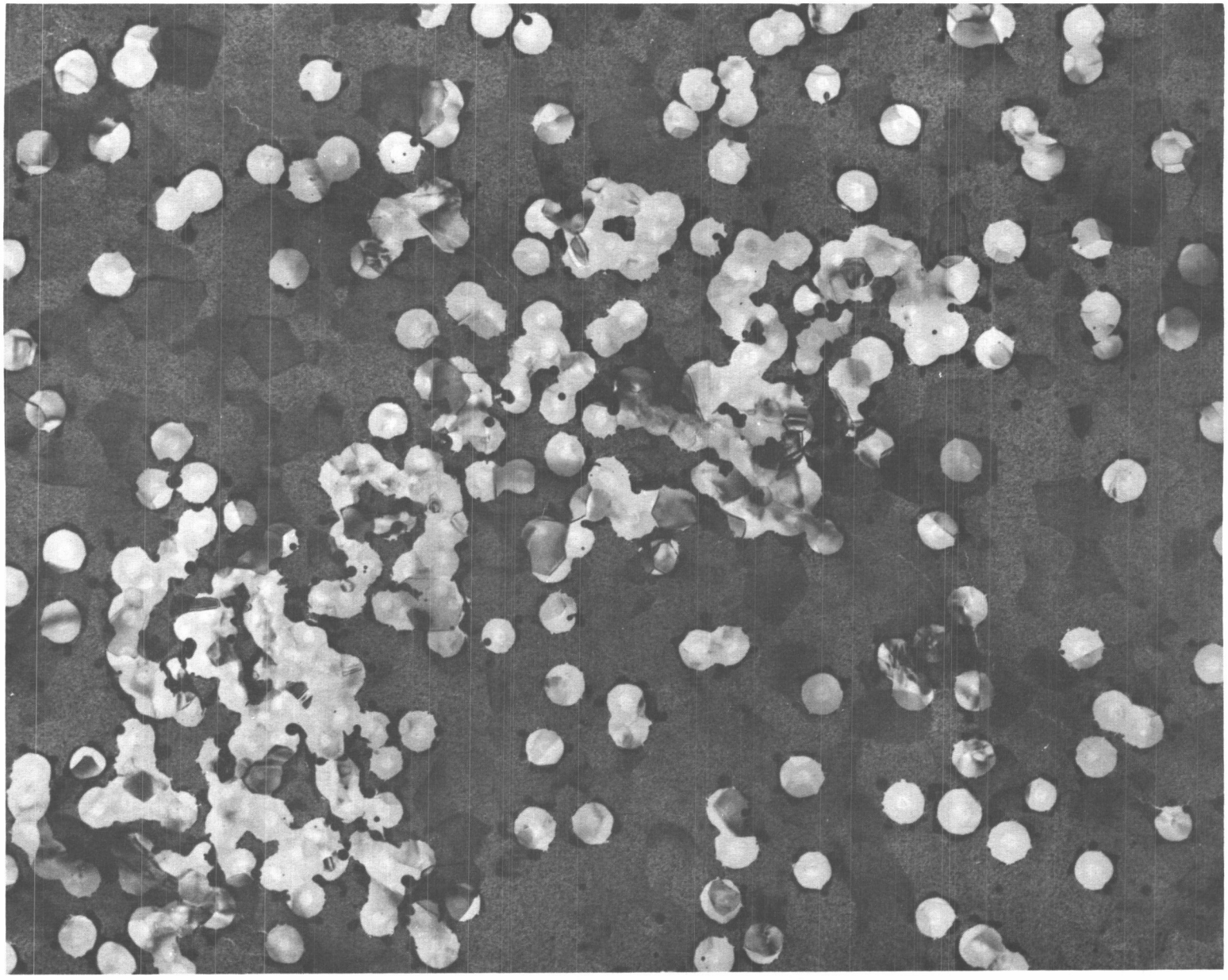
The destination of the migrating platinum is not always obvious, but one can see in Figure 2 subtle variations in average density in and near the damaged area. On closer examination of the areas of increased density, the platinum film is found to be more tightly packed, i.e., it has fewer voids than in the lighter areas.

We postulate that the dielectric has failed at some point in the damaged area and that the electrostatic energy stored in the dielectric in a region surrounding the point is dissipated at the breakdown point and in the high resistance platinum film around the breakdown point. The resulting temperature rise and thermal gradients are responsible for the platinum diffusion and aluminum grain growth.

The second type of deterioration occurs in cathodes whose cover metal is thick enough to be continuous, or nearly so. Figure 4 is illustrative of this type of deterioration in which localized breakdowns in the dielectric cause small areas of the platinum to melt or vaporize, disrupting the aluminum below and sometimes causing shorts in the oxide remaining at the edges of the holes. Metal, probably platinum, solidifies at the edges of the holes. The damaged areas are small and well defined because there is little joule heating in this thicker, more highly conductive platinum film. The energy stored in the nearby dielectric is therefore dissipated almost entirely at the breakdown point.

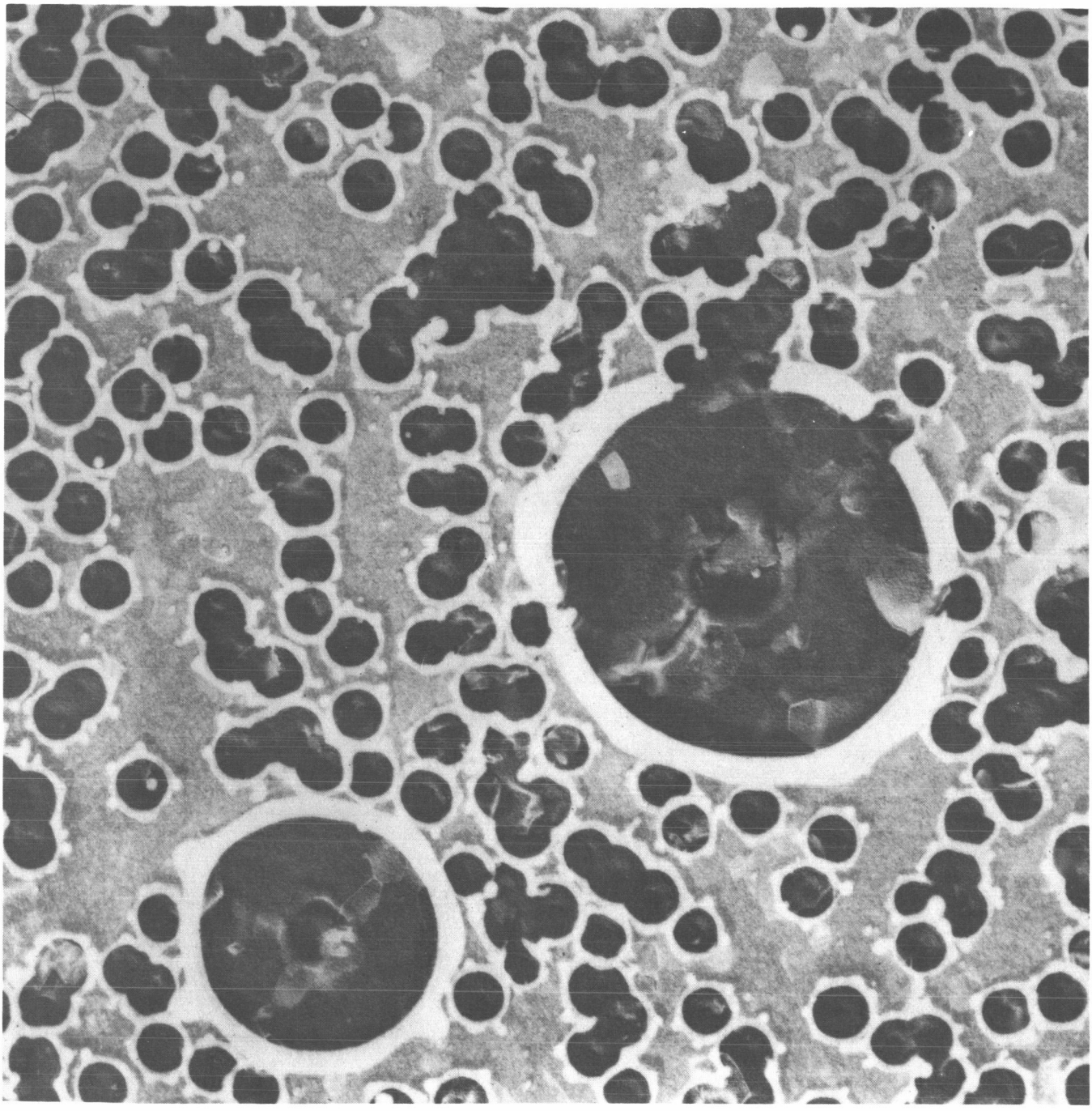
In the center of each hole one can see a light colored area about one-third the diameter of the hole. In addition many of the holes contain a small dark spot in the center of the light area. To aid in the interpretation of Figure 4, we took the specimen grid carrying the cathode shown in Figure 4 and shadowed it with about 100 Å of platinum at an angle of 18 degrees from the plane of the film. The length of the shadows cast by any topographical feature is thus about three times the height of that feature. Figure 5 shows a different area, after shadowing, of the cathode shown in Figure 4. We have photographically reversed Figure 5 so that areas in the shadow of objects projecting from the plane of the original cathode, and which receive no platinum in the shadowing process, have the dark appearance of ordinary optical shadows. In Figure 5 the "illumination" appears to come from the bottom of the picture. Note, however, that this simulation of ordinary illumination applies only to topographical features of the cathode. The usual electron transmission characteristics have been inverted so that light areas in the picture represent opaque areas in the cathode and vice versa.

In the center of the large hole is a crater about 2500 Å across and projecting from the crater is a droplet of material, presumably aluminum, frozen while still being ejected from the crater. The smaller holes have only a small crater and no drop. There are two reasons for deducing that the objects in the small holes are craters rather than hills. First, they show up light in Figure 4 and dark in Figure 5 implying a local reduction in aluminum density or thickness. Second, they cast no shadows, and the shadowing material, which appears light in Figure 5, has deposited on the upper side of the object. If the object were a hill rather than a crater, the shadowing material would deposit on its near, or lower side.



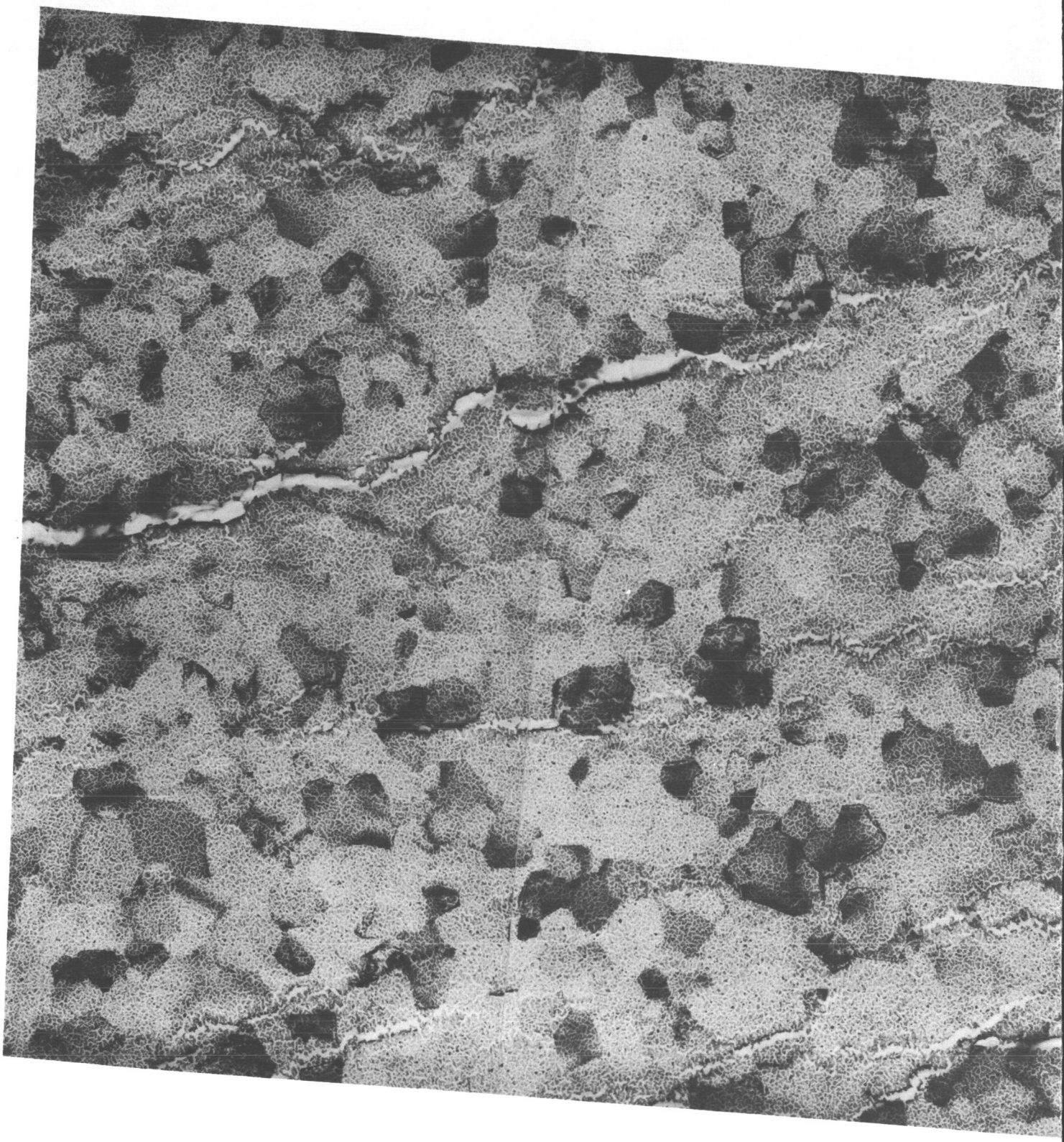
1000 Å

FIGURE 4 DAMAGED AREA OF Al–Al_2O_3–Pt CATHODE WITH THICK Pt COVER METAL



2000 Å

FIGURE 5 CATHODE OF FIGURE 4 AFTER SHADOWING WITH PLATINUM AT AN ANGLE



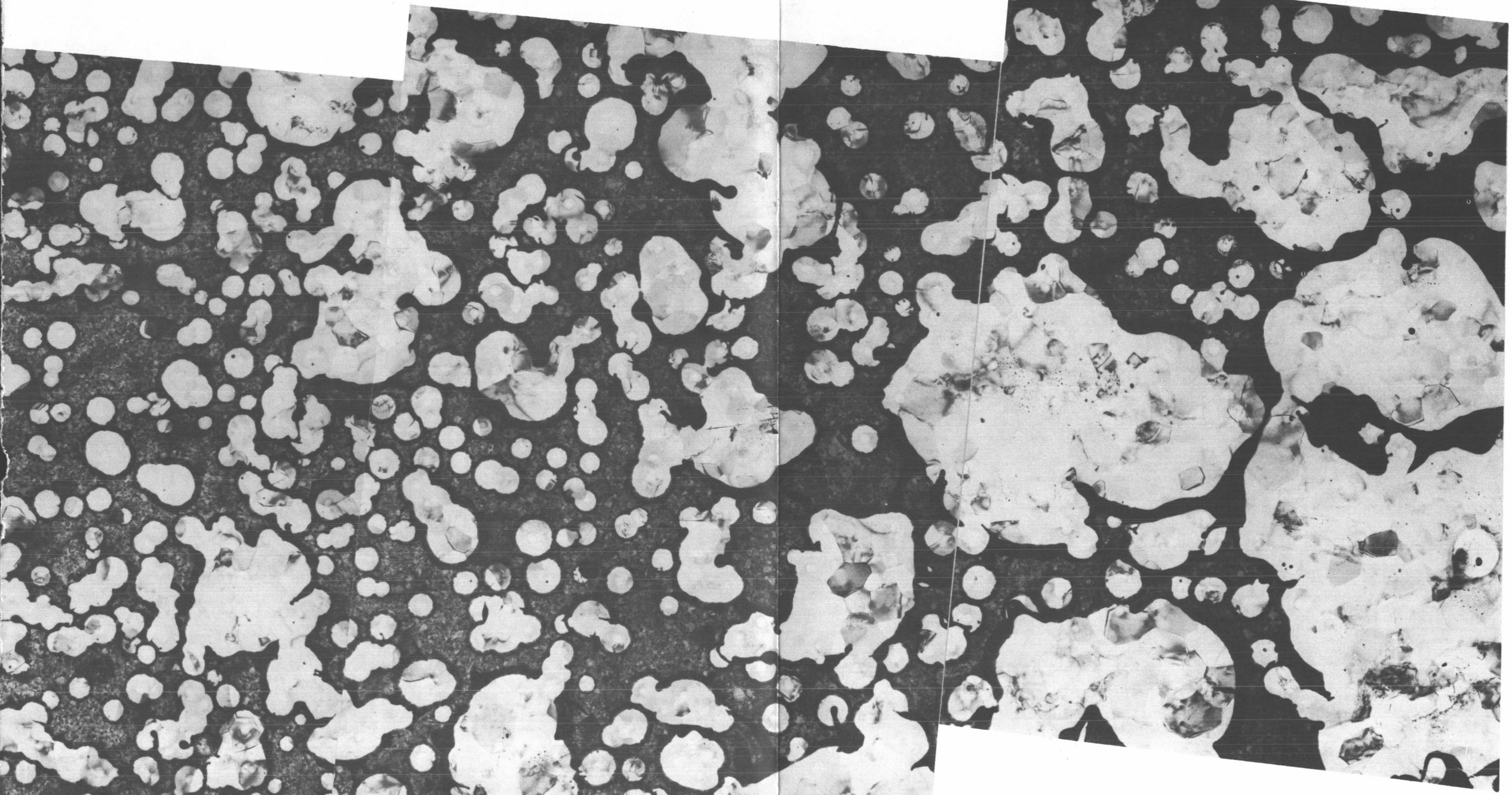
FOLDOUT FRAME 1

FOLDOUT FRAME 2

1.0μ

FOLDOUT FRAME 3

FIGURE 8 ELECTRON MICROSCOPE PHOTOGRAPH OF CATHODE CH–4 AT EDGE OF GOLD BAR



FOLDOUT FRAME 4

FOLDOUT FRAME 5

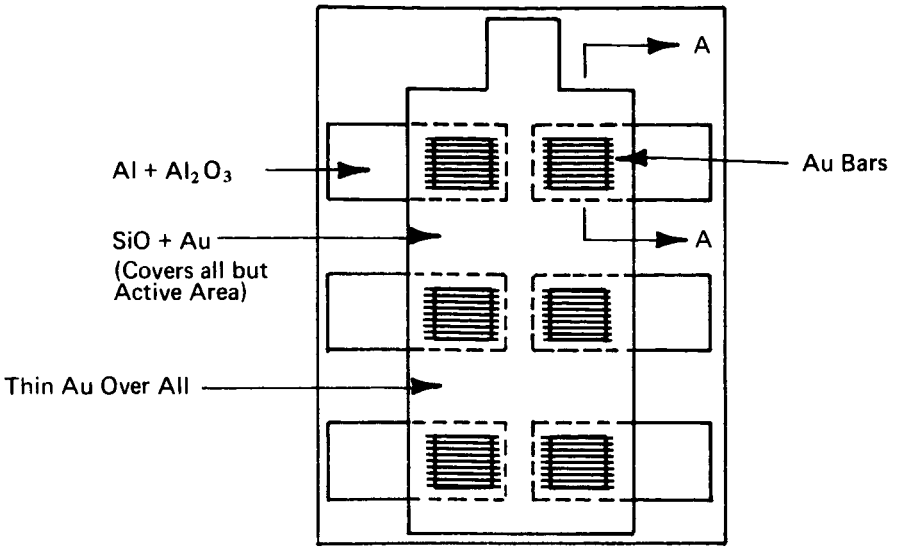
C. $Al-Al_2O_3-Au$ CATHODES

Deterioration almost identical to that described above is found in cathodes using gold as a thin cover metal. One version of such a cathode is illustrated in Figure 6. The object of this design was to utilize the thinnest cover metal film possible, and to help overcome the voltage drops due to large waste currents in the cover metal a set of thicker metal bars .005" wide and .010" on centers was laid down on top of the cover metal.

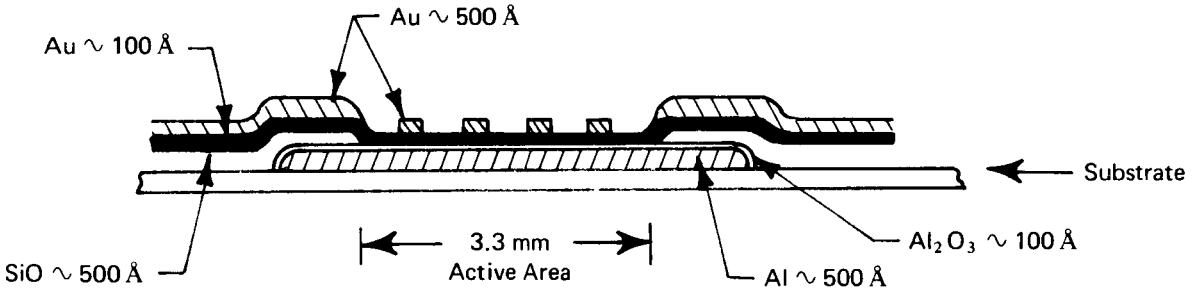
Figure 7 illustrates the electrical characteristics of cathode number CH-4 which was constructed according to the above plan. Figure 7a shows that when first tested the cathode emitted 1.7 microamps for a diode current of 200 microamps, an efficiency of just under one percent. After several minutes of operation for a total of about 2000 pulses, the characteristics had deteriorated to those shown in Figure 7b, the efficiency having dropped to about 0.04%. Figure 8 shows a 7 x 30 micron area of cathode CH-4 after photograph 7b had been taken. The area of the photograph is at the edge of one of the thick gold bars and its relation to the structure is sketched in Figure 6c. In Figure 8 the axis of the gold bar makes an angle of 60-70° with the long dimension of the photograph. On the left is the thin gold seen against the background of aluminum crystallites. Its average thickness is estimated to 100 Å, and it consists of a series of disconnected islands of gold. The center section of the photograph is the penumbra of the shadow cast by the metal mask used during vacuum deposition of the gold bars. In this region the thickness of the gold bar increases from zero to about 500 Å and the voids between gold crystallites disappear. The right side of Figure 7 is taken through the full 500 Å thickness of the gold bar.

The gold migration on the left side of Figure 8 takes place in filaments which are roughly perpendicular to the thick gold bar. Dark areas along one side or the other of these filaments show where the gold has gone. There does not appear to be any migration along the axis of the filament, which is the direction one would expect waste current to flow in the thin gold cover metal. Therefore it seems reasonable to assume that the driving force for the gold is a thermal rather than electric field or electromigration effect. The presence of the filament implies a nonuniform heating of the gold by the waste current which would tend to follow paths of lowest resistance. There are no obvious irregularities, either in the thin gold layers on unused cathodes or in the underlying aluminum film in Figure 8 to account for the uneven current distribution.

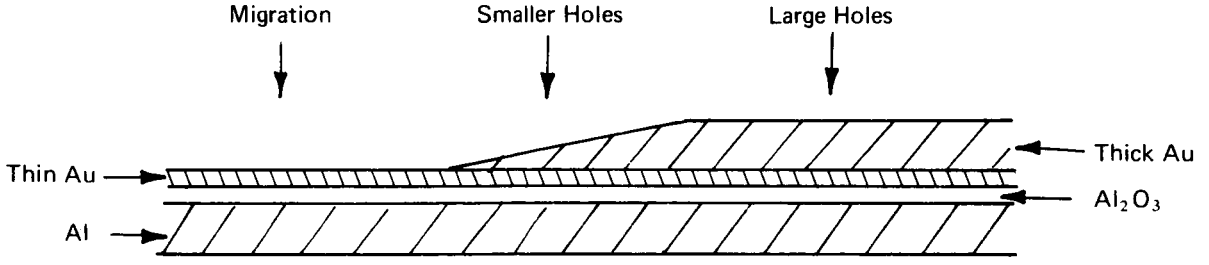
Toward the center of Figure 8 the localized dielectric breakdown begins, the extent of the damage increasing with the thickness of the gold bar. We believe that the large linear component of diode current shown in Figure 7b is flowing through myriads of leakage paths at the edges of the holes where the insulator has been disrupted. The apparent



a. Plan View

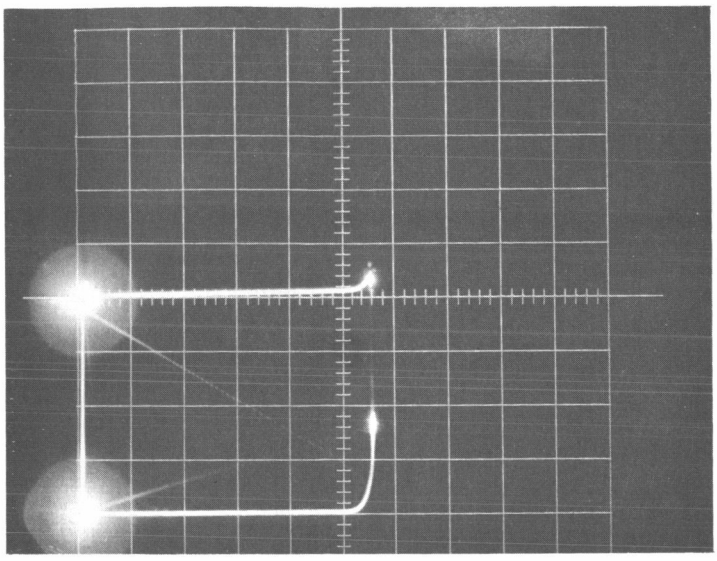


b. Cross Section A-A

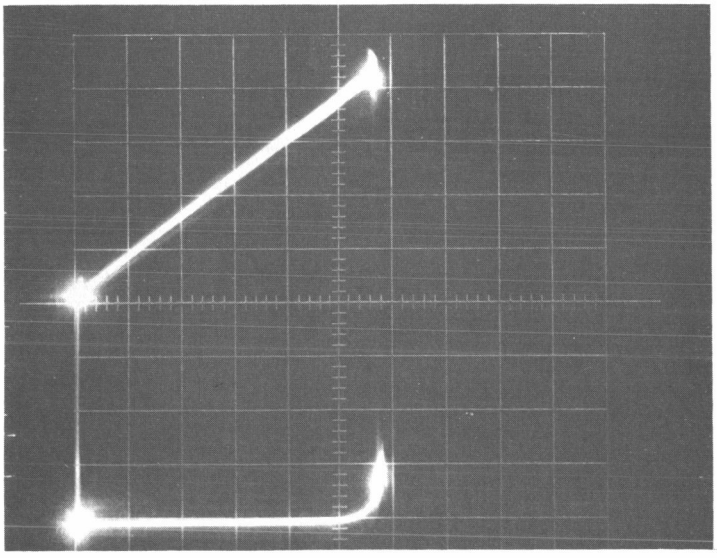


c. Magnified View of Section A-A
(At the edge of a 500 Å gold bar, showing area covered in Figure 8.)

FIGURE 6 EXPERIMENTAL TUNNELING COLD CATHODE CH–4



a. Initial Characteristics



b. After 2000 Pulses

Key to (a) and (b): $\uparrow I_D$ 500μa/cm
$\uparrow I_e$ 1μa/cm
$\underset{\rightarrow}{V_D}$ 2v/cm

FIGURE 7 ELECTRICAL CHARACTERISTICS OF CATHODE CH–4

recovery of these cathodes under baking, reported under the previous contract, could easily have been due to oxidation of the shorting metal if it was aluminum, or to migration and agglomeration of the shorting metal if it was gold.

For reasons which are set forth in Section IV, we now suspect that emission in this type of cathode takes place mostly around the edges of holes in the cover metal; that new holes are formed as the testing proceeds while the emission from existing holes decays. When the area available for new holes vanishes, as it has almost done on the right side of Figure 8, the cathode is defunct.

III. ATTEMPTS TO PREVENT DETERIORATION

As a result of the above observations on deterioration and the current theory of tunnel emission as a hot electron process requiring a very thin cover metal film, we made two approaches to the problem of supplying proper operating potentials to that area of the cathode that was considered to be the source of electron emission, namely the thin cover metal area. The first approach was to place an additional thickness of insulation under the metal bars so that higher potentials could be applied to the device terminals without causing dielectric breakdown under the bars. The second approach was to make the higher terminal voltages unnecessary by improving the sheet conductivity of the cover metal without decreasing its transparency to hot electrons.

The extra insulator under the bars was applied by evaporating silicon monoxide through a set of masks containing slits .002" wider than the bars. Proper mask alignment was difficult but was achieved by moving to a vacuum system with better mechanical features. A total of ten such cathodes was made. The first couple of cathodes made this way showed some promise since their lifetime was 4-5 times greater than the average of about 2000 pulses. However, subsequent attempts to duplicate this performance failed, and we conclude that the intial improvement was the result of some extraneous circumstance. It was observed that, even though the registration of the extra insulator and the bars was perfect, there was always some residual dielectric breakdown at the very edge of the bars. The reason for this behavior is not understood.

Attempts to improve the conductivity of the cover metal film included methods for enhancing the nucleation of evaporated films and deposition by cathodic sputtering. A total of seven cathodes was made in the nucleation series. Carbon, manganese or chromium was deposited on top of the aluminum oxide in an almost invisible layer and the gold or platinum condensed on top in the usual fashion. There was no measurable difference in performance or structure between these cathodes and others prepared without the added "nucleating" material. The same was true for cathodes cooled to liquid nitrogen temperatures during cover metal deposition.

It is known that certain metal oxides, notably bismuth oxide, have the ability to enhance the conductivity and stability of suitably deposited thin gold films. Gillham, Preston and Williams[1] describe a series of experiments whereby gold films on the order of 100 Å thick can be made to exhibit nearly bulk conductivity by sandwiching the gold between thin layers of bismuth oxide. Both the gold and the bismuth oxide were sputtered, the gold in pure argon and the bismuth oxide from a bismuth cathode in an oxygen-argon mixture. These gold films were reported to be highly resistant to the agglomeration usually caused by heating. The authors report that bismuth oxide/gold/bismuth oxide structures could be heated to 400°C with an actual improvement in conductivity and that bismuth oxide/gold structures could stand up to 200°C without adverse effects.

These properties of good conductivity and thermal stability seemed ideal for our purpose so we performed a series of experiments to see whether the necessary amount of bismuth oxide could be included in our structures without an adverse influence on the electron emission efficiency.

Sputtering was accomplished in the fixture sketched in Figure 9 which was designed to confine the glow discharge to the upper surface of the cathode. The cathode is a blank of pure aluminum 30 x 40 x 5 mm, cleaned by etching in a weak sodium hydroxide solution and thoroughly rinsing in distilled water. The blank is coated by vacuum deposition of either gold or bismuth at a system pressure of 2-5 x 10^{-6} torr. The bismuth is sputtered in a premix of 3% oxygen in argon which is kept flowing through the system by a mechanical roughing pump. The gold is sputtered in pure argon. The discharge voltage was usually kept at about 600 volts and the pressure regulated to keep the upper boundary of the cathode dark space halfway between cathode and substrate. This was achieved at gas pressures of 70-120 microns for the oxygen-argon mix and 100-160 microns for the pure argon, and gave current densities that could be varied around a nominal 1-2 milliamps/cm^2 by small changes in the discharge voltage. The fixture geometry which led to these operating pressures was not a good choice since the sputtering yield of metals is very pressure sensitive in this range of pressures.[2] The result was a poor correlation between discharge parameters and film sheet resistance. For better sputtering rate control a pressure of 20-50 microns would have been more desirable but would have required cathode-anode spacings of 2-3 cm and correspondingly higher voltages.

The range of discharge currents and sputtering times to be investigated was determined empirically. Bismuth oxide sputtering times less than 20 seconds or more than 60 seconds at 1 milliamp/cm^2 generally gave a higher resistivity in the subsequently sputtered gold films. Gold sputtering times less than 15 seconds at 1 milliamp/cm^2 usually led to discontinuous, high resistance films. Additional gold films were sputtered at higher voltages and lower pressures; others were sputtered at higher current densities for shorter times. No clear trends in cathode performance resulted from these variations. Twenty-nine cathodes were made in this series with sputtered gold cover metal films.

Most of these cathodes using sputtered films had the sort of nonlinear I-V characteristics associated with current transport through insulators. However, only four had any detectable ($>10^{-8}$ amps) electron emission, and of these four only one survived long enough for accurate measurements of its electrical characteristics. The initial efficiency of this last cathode, P47, was 1 x 10^{-5}, operating at 14 volts. Careful electron microscopic observation of these four cathodes revealed that all had cover metal films which were physically porous. Cathode P47, which had the greatest emission, had a completely discontinuous cover metal film consisting of particles 20 to 40 Å in diameter with similar spacing. Four careful attempts to duplicate the deposition conditions of cathode P47 re-

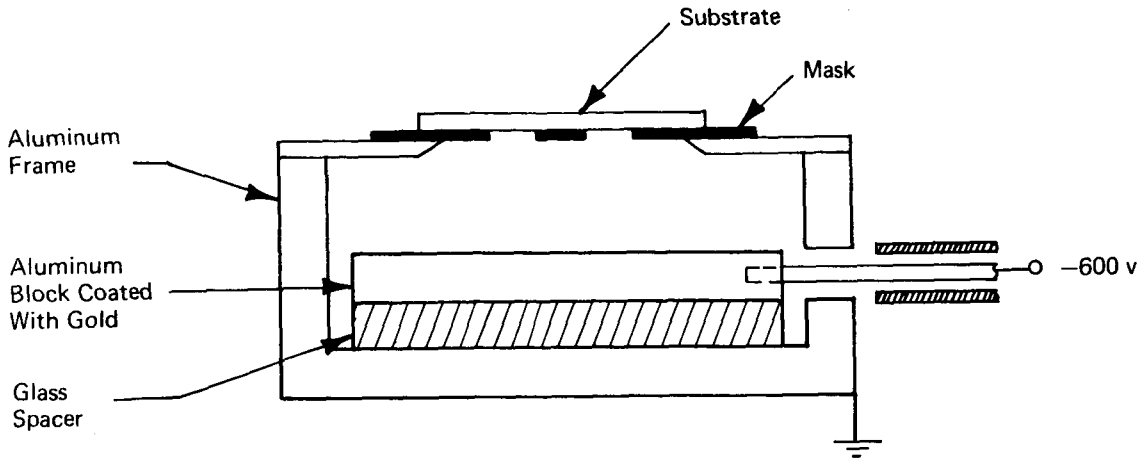


FIGURE 9 SPUTTERING FIXTURE

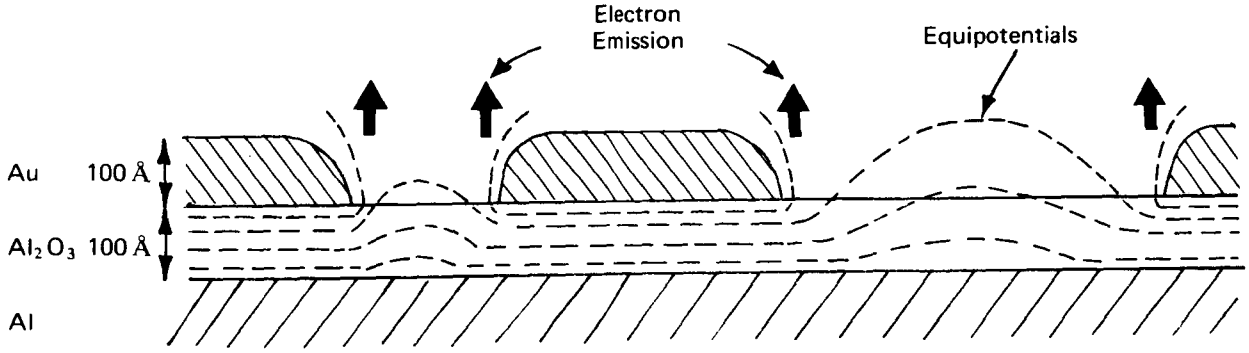


FIGURE 10 GEOMETRY OF EMISSION THROUGH HOLES

sulted in devices with no emission. The next best cathode, P37, whose initial efficiency was about 10^{-6} at 15 volts had a lacy cover metal film wherein the gold particles were interconnected but with many irregular holes of 200-400 Å size covering at least half of the total area. The other two cathodes, P45 and P46, whose emission was just barely detectable had cover metal films that were almost completely continuous, that is, had much smaller voids, occupying less than one percent of the total area.

Of the devices that showed no detectable emission, numbers P59b and P60b were examined carefully in the electron microscope and found to have no voids at all in the cover metal film. Both gold cover metal films were a pale yellow to yellow-green in transmission, also indicative of a continuous rather than agglomerated structure. The sheet resistance of P59b was 4.2 ohms/square. Using the method of Gillham et al[1], which empirically relates resistivity and thickness of gold films sputtered onto bismuth oxide under conditions almost identical to ours, we infer a thickness of about 220 Å for the gold cover metal of P59b. White light transmission of 50% through the thin gold only of P59b is also consistent with gold thickness on the order of 200 Å. The hot electron theory of tunnel emission and previous experimental results[3] predict that a 200 Å cover metal film should give a cathode with an efficiency on the order of 10^{-4}. No emission was observed, although the apparatus is capable of detecting efficiencies as low as 10^{-6}.

In summary, our attempts to improve cathode performance by creating an extremely thin, yet physically continuous gold cover metal film have led us in exactly the opposite direction. In the next section, we speculate on the reasons for this behavior and describe some additional experiments.

IV. EVIDENCE FOR EMISSION THROUGH HOLES

The fact that greater physical continuity in the cover metal film leads to a decrease in emission efficiency suggests that electron emission from this type of cathode may not result from hot electrons passing through the cover metal, as the present tunnel emission theories predict, but rather from electrons passing through voids in an otherwise continuous cover metal film. The primary purpose of the cover metal film would then be as an equipotential surface to maintain high fields at the surface of the insulator, from which the electrons are actually being emitted. Figure 10 illustrates how such an emission process might work and also shows how the size of the holes could influence the emission efficiency. The highest fields on the insulator would be just at the edge of the hole. At a distance away from the edge three times the insulator thickness, the electric field will be down by an order of magnitude.[4] If the emission process is due to high fields at the surface of the insulator, emission is going to occur primarily at the edge of the hole, and the rest of the hole is waste area. The optimum cover metal film would then be a high conductance film with a great many 200-300 Å diameter holes.

With this in mind we made another group of 8 cathodes, again using evaporated gold as a cover metal because of its natural tendency to form voids, but aiming for a film structure like that just to the left of center of Figure 8 where the gold film is continuous around the voids and thick enough to have a good sheet conductance.

At this time we also made a new set of evaporation masks which allowed us to measure the cover metal sheet resistance without opening the vacuum system. The cover metal sheet resistance on these cathodes ranged from 7 to 50 ohms/square. The most stable emission was from those with the lowest resistance but in no case was the initial efficiency greater than 10^{-4}. The interesting thing about this group of cathodes is that most of them did not emit when they were first made. In addition they initially had a large ohmic diode current such as one might expect from a number of isolated shorts through the insulator. However, if they were pulsed with gradually increasing voltages, the shorts would eventually be cleared, weakest first, the diode current would drop to normal, and emission would begin.

Electron microscopic observation of some of these cathodes revealed that the cover metal films were continuous until they had been tested, after which they contained holes of the sort shown in Figure 4. Cathodes which had been operated for a longer period had more holes than those operated for short periods. In terms of the emission process suggested above, these observations imply that emission requires the holes generated by the short clearing, or forming process. As the testing proceeds, new holes are formed and the existing ones begin some unknown process of deterioration. The net effect of this creation and deterioration of emission sites is usually a decline in emission, although we have

observed on a few occasions that the emission temporarily improved from its initial value before its final decline. Cathode P47, for instance, after some initial forming increased its efficiency from 2×10^{-4} to 5×10^{-4} after about 20,000 pulses in 30 minutes, dropping off to 5×10^{-5} after 16 hours and 60,000 more pulses. If, after the emission efficiency has declined to, say, ten percent of its initial value, the drive voltage is increased a few tenths of a volt, the emission can be restored to its initial value, or greater, after which it begins to decline again. The reason for this behavior probably lies in the variation of dielectric breakdown strength over the cathode area. During the forming process and testing at the first voltage, the weakest points in the dielectric break down, creating emission sites which then decay. When the applied voltage is increased, new areas break down, the number depending on the increase in voltage and the inhomogeneity of the dielectric. This effect can be observed on the shiny gold surface as a haziness which becomes more prominent as the deterioration proceeds. Eventually the cathode looks like the right-hand side of Figure 8, no new holes can be formed and the emission declines permanently.

This forming process was not observed in cathodes having continuous sputtered gold cover metal films. This implies that the sputtered bismuth oxide dielectric is more homogeneous than the plasma formed aluminum oxide. If so, the dielectric breakdown would probably be more catastrophic since larger areas would break down simultaneously. Some support for this conclusion can be drawn from optical microscopic observation of such films after testing, which shows that the breakdown areas are dendritic in shape rather than circular and are on the order of hundreds of microns long rather than tenths of microns in diameter.

In summary, we have found what appears to be a strong correlation between electron emission in thin film tunnel cathodes and the presence of holes, either natural or caused by testing, in the cover metal film. Since this discovery occurred at the very end of the program, we have not been able to demonstrate conclusively that electrons are emitted through holes in the cover metal film. However, the evidence is sufficient to allow a strong plausibility argument for such an emission process. In the following section we outline the experiments we believe to be necessary to identify the emission process unequivocally.

V. RECOMMENDATIONS

Tunnel cathode studies to date, including ours, have been based on the assumption of a hot electron emission process. Attempts to combat the deterioration observed experimentally have been influenced by the same assumption. We feel that the present study has cast sufficient doubt upon that assumption to justify a fresh appraisal of the emission process. Only when this process has been positively identified will it be possible to conduct an efficient search for the decay mechanism.

The first step should be a repetition, in somewhat greater detail and with more stringent controls than were feasible in the present program, of the comparison between sputtered and evaporated gold cover metal films with and without holes. Gold film thickness would be monitored by a crystal rate monitor and correlated with sheet resistance measurements. Sputtering fixtures would be redesigned to allow operation at lower pressures for reduced sensitivity of sputtering rate to gas pressure. Electrical test procedures would be revised to allow the recording of more complete life histories. Electron microscope observations would be made of every cathode. This comparison should not require more than eight or ten cathodes in all. Its main purpose would be to refine the cathode fabrication process so as to take advantage of techniques developed in the present study. In this way a more consistent group of cathodes can be made available for the next step, which is to locate the source of electron emission directly by imaging the cathode in a high resolution emission microscope. Instruments of this type have been reported with resolution capability on the order of 250 Å.[5] If, as we suspect, electrons are emitted from holes in the cover metal film, this resolution should be adequate to prove it.

Although emission microscope development seems to be concentrated in Europe at present, we would hope to find an instrument available in the United States. In either case we would prefer arranging for the use of an existing instrument rather than constructing our own. It might be desirable, however, to construct an emission microscope with more modest capabilities for use in preselecting cathodes for detailed observation in a more powerful machine. Detailed design and construction factors of this type of instrument are readily available in the literature, and we believe that a simple but useful emission microscope can be made at modest cost.

A detailed study of the decay phenomenon does not seem justified until the observations proposed above have led to some firmer conclusions about the nature of the emission process.

VI. REFERENCES

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