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David B. Snyder
Lewis Research Center
Cleveland, Ohio

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DISCHARGES ON A NEGATIVELY BIASED SOLAR CELL ARRAY IN A CHARGED PARTICLE ENVIRONMENT

David B. Snyder

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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SUMMARY

The charging behavior of a negatively biased solar cell array when subjected to a charged particle environment is studied in the ion density range from 200 to 12 000 ions/cm^3 with the applied bias range of -500 to -1400 V. The profile of the surface potentials across the array is related to the presence of discharges.

At the low end of the ion density range the solar cell cover slides charge to from 0 to +5 volts independent of the applied voltage. No discharges are seen at bias voltages as large as -1400 V. At the higher ion densities the cover slide potential begins to fluctuate, and becomes significantly negative. Under these conditions discharges can occur. The threshold bias voltage for discharges decreases with increasing ion density. A condition for discharges emerging from the experimental observations is that the average coverslide potential must be more negative than -4 V. The observations presented suggest that the plasma potential near the array becomes negative before a discharge occurs. This suggests that discharges are driven by an instability in the plasma.

INTRODUCTION

It is well known that if an unilluminated shorted solar cell array is biased sufficiently negative in the presence of a plasma, it will exhibit arc discharges (refs. 1 to 3). The trigger mechanism for these discharges is not yet understood. This work continues to study this effect. The current working hypothesis (ref. 3) is that when the electrical field strength between the solar cell cover slides and the interconnects becomes too great, a discharge may occur. The electric fields will be roughly proportional to the potential difference between the interconnects and adjacent cover slides, and the distance over which most of the change in potential occurs.

As an alternative hypothesis, the author assumed that the gradient of the potential causes the attracted positive ions to be focused on the interconnects, and that the size of the region over which the potential changes may vary, changing the efficiency with which ions are collected at the interconnects. Eventually, over microseconds, this current might become great enough to overload the power supply, resulting in an apparent discharge.

In this paper, both these hypotheses are examined taking into account the potentials observed on the biased solar array. A shorted biased solar array is subjected to a plasma where the ion density is low enough that the profile of the potential along the surface of the array changes on a time scale of seconds to minutes. The profile of the potential along a portion of the array is monitored by sweeping an electrostatic voltage probe across the array at five minute intervals. Discharges are detected by a probe that is capacitively coupled to the back of the array. With this apparatus the conditions under which discharges do and do not occur can be investigated, and the charging behavior of the cover slides can be discussed with respect to these discharges.

The observations reported here do not support either of these preliminary hypothesis, which assume that a discharge arises from the electric fields on the array. Instead the plasma itself may be responsible for the discharge.

EXPERIMENT

The objective of this work is to measure the profile of the potential across a biased solar array and to determine its response to a plasma environment. Of special interest is the behavior under conditions where discharges occur. The experimental apparatus is pictured in figure 1. Its essential parts are a plasma source, a solar array, plates to monitor the environment, and an electrostatic probe to read the potential along the surface of the array. The vacuum chamber is 1 m diameter x 2 m long. It uses ion pumps and a turbopump to reach a base pressure of under 10^{-6} torr. During these experiments, with the plasma source on, the pressure was in the range of 4 to 10×10^{-6} torr, the lower pressure corresponding to lower ion densities.

An electron bombardment ionizer is used as the plasma source. It uses a hot filament to generate electrons. The electrons are accelerated to about 50 V to ionize nitrogen gas as it flows into the vacuum system. Current through a coil concentric around the ionization chamber generates a magnetic field to increase the effective path length of the electrons in the gas, increasing the plasma density.

Limited plasma measurements were obtained during the experiments. To improve confidence, plasma characteristics under similar conditions were obtained later using a 1200 cm^2 plate as a Langmuir probe. The electron temperatures are about 1 eV; the plasma potentials are about +10 V; and the ion densities range from 200 to 12000 cm^{-3}. These parameters should be regarded as order of magnitude estimates.

The array segment (fig. 2) used in this work was originally constructed for the SPHINX satellite. It has previously been used for electron beam stimulated discharge studies (refs. 3 and 4). It is constructed from 24, 2 cm x 2 cm solar cells connected in series and forming a 6 x 4 array. The interconnects are 1 mm wide silver strips running along the edge of each cell and have four flat wires forming the connections to the following cell. The gap between cells for these connections are 0.2 to 0.5 mm wide. The surfaces of the cells are protected by fused silica cover slides, 0.15 to 0.25 mm thick. The cover slides do not extend over the main metal strip. The base for the array is a fiberglass printed circuit board. A sheet of kapton separates the array and base. On the back of the base, a 2.5 cm radius copper disk has been etched and covered with kapton. This back plate serves as a probe capacitively coupled to the array, providing a measurement of changes in the array's potential. The bias voltage was applied to the interconnects with a Spellman RHR-20PN60/RVC power supply. This power supply can provide voltages to 20 kV and current up to 3.3 mA (ref. 5).

During a typical run data is taken for 1920 seconds and stored at 0.5 second intervals by a MINC-23 computer with an A/D converter. At 300 second intervals the noncontacting Trek electrostatic voltage probe is swept across the array. This probe reads a voltage by nulling the electric field between itself and area being investigated. It was close enough to the array, about 0.75 mm, to average the potential over an area of about 1.6 mm^2. The probe takes 120 sec to sweep down the array, during which its position and voltage are recorded. During the following 180 sec, until the next probe sweep, the pressure was monitored. The electrostatic probe returns to its base position over a ground reference plate during the first 60 sec of this period.

Discharge transients were detected using the back plate probe. The capacitance of the back plate to the solar array is 65 pF, and to ground is 616 pF. A fast test pulse was used to determine the characteristics of the system. This causes the cable to ring at 15 to 20 MHz, consistent with the 4.4 m cable length from back plate to a Biomation 610B transient recorder. But the transient recorder has an internal high frequency limit of 2.5 MHz. The 50 ohm cable is terminated with 50 ohms at the transient recorder, but is open at the back plate. This arrangement measures rate of change of the average voltage on the array. During discharges, the arc current exceeds the current limit of the power supply and the power supply does not succeed in maintaining the bias voltage at the discharge site on the solar array. The signal shown in figure 3 is characteristic of discharges that appear as arcs on the array. The time of appearance of this signal is used as the time of discharging. The discharge times were recorded and the wave form of the discharges, i.e., the current to the back plate, were recorded by the transient recorder.

RESULTS

Three sets of data were obtained; one for low ion density (pressure $4x10^{-6}$ torr, ion density about 200 cm^{-3}), one for a medium density (pressure $6x10^{-6}$ torr, ion density about 8000 cm^{-3}), and one for a high ion den- sity (pressure $8x10^{-6}$ torr, ion density about 12 000 cm^{-3}). A summary of the data obtained is shown in table 1.

At low ion densities, bias voltages of -600 to -1400 V were applied. No discharges occurred. The typical behavior electrostatic voltage profile across the array is shown in figure 4. Figure 4(a) illustrates the profile across the array at various times, while figure 4(b) shows the behavior of two particular cells. When the biasing voltage is initially applied, both the interconnects and the cover slides go to the applied potential, i.e. the cover slides have no net charge. The cover slides then slowly accumulate positive charge, approaching a slightly positive potential. The potential of the surrounding kapton changes relatively rapidly due to its lower capacitance to the interconnects. On the array itself, the central cover slides charge rapidly, with those cover slides closer to the plasma source charging more rapidly. This effect is probably related to the array's vertical orientation in the tank. When the array is vertical the door of the tank is about 1 m in front of it and the center charges most quickly. In a horizontal orientation, the edges of the array charge most rapidly with the wall of the tank being about 0.4 to 0.5 m above the array. This behavior is apparently a consequence of the relevant characteristic lengths of the plasma being of the same order of magnitude as the dimensions of the tank. This particular charging feature is not expected in space.

The cover slides tend to charge to a slightly positive potential, +4 to +10 V. They simply charge to the plasma potential. At high bias voltages, fluctuations in potential across the array appear and tend to get more pronounced at higher biases, as seen in table 1. These fluctuations suggest that the local plasma potentials near the array are becoming non-uniform.

As shown in figure 5, at higher ion densities the behavior of the cover slide potential is substantially different. Initially the cover slides rapidly charge to a slightly positive potential (the plasma potential). But the cover slides then slowly become negative, and the potential across the array begins to fluctuate. At higher negative biases and higher ion densities, the average cover slide potential is more negative, and the fluctuations become more substantial. This is demonstrated in table 1, where the high standard deviations indicate significant variations in potential across the array. Under these conditions discharges can occur.

The fluctuations in potential across the array may be used to identify sites associated with discharges. In figure 5, the potentials of the two cover slides at 2 and at 4 cm became increasingly negative between 300 and 900 sec. After a discharge at 1189 sec this feature disappeared, indicating that the discharge occurred near this region of the array.

In several cases discharges occurred while the electrostatic probe was measuring the surface potential. From these cases (fig. 6) it is apparent that the cover slides attain nearly the interconnect potential at the time of the discharge, then recharge to ground. Since not all the features in the potential profile are changed, the discharge is apparently a local effect.

DISCUSSION

Figures 7 and 8 illustrate the shape of the potential profile in the vicinity of an interconnect under conditions which do not (fig. 7) and do (fig. 8) cause discharges. Figure 7 shows the measured voltage profile at an interconnect at low ion density for biases of both -800 and -1400 V for low ion density, i.e., conditions where no discharges were detected. The spatial resolution of the electrostatic probe is poor compared to the size of an interconnect,and the distances between positions where the potentials are read are long compared to the width of the interconnects. However, data from separate probe sweeps, are found to be consistent with each other. Data from separate sweeps can be aligned by calculating the position of the negative peak from the curvature at the three most negative points. When aligned in this way, the data constructs a consistent view of the potential in the region of the interconnect. In fact, there are no measurable differences between the two profiles when the -800 V profile is normalized to the -1400 V profile using an appropriate scaling factor of 14/8.

Figure 8(a) shows the profile at an interconnect biased to -1000 V under conditions where discharges were detected. The primary difference between profiles obtained at different times is that the average potential of the cover slides shifts. In figure 8(b) the data points for this case are superimposed and compared to the profile when no discharges are seen. The primary difference between these two sets of data is due to the cover slide potentials.

The hypothesis proposed by Stevens et al., (ref. 3) that discharges are related to the potential gradient between the cover slides and the interconnects, is not supported by this work. At low ion densities no discharges are seen even though the cover slide potentials reach ground and the bias is very negative. In contrast, under discharge-prone conditions, discharges are more likely to occur when the cover slides are at a substantial negative potential rather than when their potentials are near ground or slightly positive. The electric fields do not appear to change significantly. The spatial resolution of the measurement is millimeters, so this observation is not conclusive. In fact, these measurements show that the electric field is above 10^6 V/m. But because the cover slides are more negative, and the change in voltage less under conditions where discharges occurred than when they did not, the hypothesis is not supported.

Similar conclusions are drawn with respect to the other hypothesis advanced here, that focusing of the attracted ions in the vicinity of the interconnect is important to the discharge mechanism. Changes in the surface potentials near the interconnects would permit the ion focusing characteristics of the interconnect to change. At low ion densities, the profile of the potential in the region of the interconnects does not change with bias voltage, within the resolution of the experiment.

In cases where discharges occur the behavior is less conclusive. Figure 8 illustrates the data for a case where discharges occur. The shape obviously changes, yet the variations are primarily due to shifts in the cover slide potential. The width of the interconnect region does not change significantly. If the potential profile does change, it is only over distances as small, or smaller than the interconnect width. Therefore the size of the region over which focusing may change is small. This work produced no evidence that ion focusing in the region of the interconnect is important to discharging.

What this data does indicate is happening is that discharges occur when the average cover slide potential is more negative than -4 V, regardless of bias voltage. Figure 9 shows the average cover slide potential as well as its standard deviation at various interconnect biases, for different plasma conditions. In addition the number of discharges seen in a half-hour run is shown for those cases where discharges occurred. This average is determined by the ion density and the bias voltage. Except for the single case of a discharge at -600 V, all discharges occur when some cover slides are negative.

The charged particle environment in the vicinity of the array becomes negative under conditions when discharges can occur. The current to the grounded sensor becomes negative, and the cover slide potential becomes negative by several tens of volts locally. Two reasons are suggested for this behavior. The increase in negative charge density could be due to secondary electron emission from ion collisions with the array, or it could indicate that interconnects at high negative biases have more of an influence on the shape of the sheath near the array at high densities that at low densities, and that the shape of the sheath has an important role in the occurrence of discharges.

The second suggestion seems to be the more likely of the two. The electron emission cannot be from the cover slides, since they approach a roughly equilibrium potential. This emission could occur only in the vicinity of the interconnects which would limit the amount of emission available for a discharge. Also since the secondary electron yields for ions on metals are low, ion collection should not induce significant electron emission. An instability in the plasma, however, might be able to access the large amounts of charge from the plasma used in a discharge.

CONCLUSIONS

The data collected in this work has been examined in an effort to identify the mechanism initiating discharges on biased solar arrays in a plasma. The evidence submitted does not support either of the two hypotheses examined. The potential gradient in the vicinity of the interconnect is not directly responsible for discharges. At very low plasma densities, biases as large as -1400 V do not result in discharges even though the cover slides charge slightly positive. With a resolution on the order of millimeters, the distance over which the potential changes with no discharges resulting was no different than the distance for cases which result in discharges. In addition, the electric field in the vicinity of the interconnects was greater when no discharges were seen than when they were seen.

Focusing of attracted ions probably does not play an important role in the initiation of discharges. Again, the shape of the potential profile in the vicinity of the interconnect does not change appreciably, on a scale of millimeters, between conditions which produce discharges and those which do not.

It appears, that both the plasma and dielectric surfaces play important roles in the initiation of discharges. Before discharges occur, the cover slides on the array become negative. This indicates that changes in the plasma sheath are taking place, which in turn suggests that the plasma itself is playing an important role in the appearance of discharges on high voltage arrays. The plasma is not simply supplying charge to the process but may be driving the discharges.

Further work needs to be done to verify these observations. First, the work needs to carried out under better controlled and monitored conditions. The fluctuations in the cover slide potentials should be observable at lower bias voltages at higher plasma densities. In addition, theoretical work should be done to discover if plasma instabilities can exist under these conditions.

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TABLE 1.

Bias, V	Pressure 10^{-6} torr	Cover slide, V	Discharges
Low ion density (about 200/cm^3)			
-600	3.70	2.5±0.9	0
-800	3.30	3.9±1.2	0
-1000	4.40	4.5±1.6	0
-1200	3.50	3.7±1.2	0
-1400	4.10	2.3±5.4	0
Medium ion density (about 8000/cm^3)			
-600	6.15	18.2±4	1
-800	6.45	10.9±6	0
-900	6.15	3.6±6	0
-1000	5.80	-3.1±11	0
-1100	5.65	-8.0±15	1
High ion density (about 12 000/cm^3)			
-500	8.05	8.3±11	0
-600	8.00	6.3±16	0
-700	7.60	-4.5±19	0
-800	8.35	-17.5±20	2
-900	7.90	-16.4±25	4
-1000	8.00	-31.4±28	4
-1100	7.70	-3.3±14	2

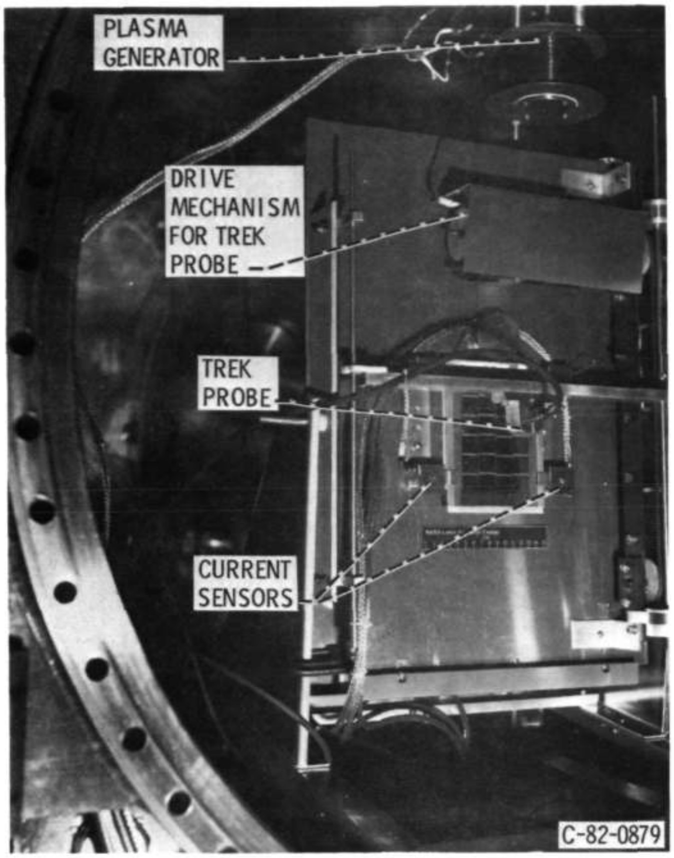


Figure 1. - Tank arrangement.

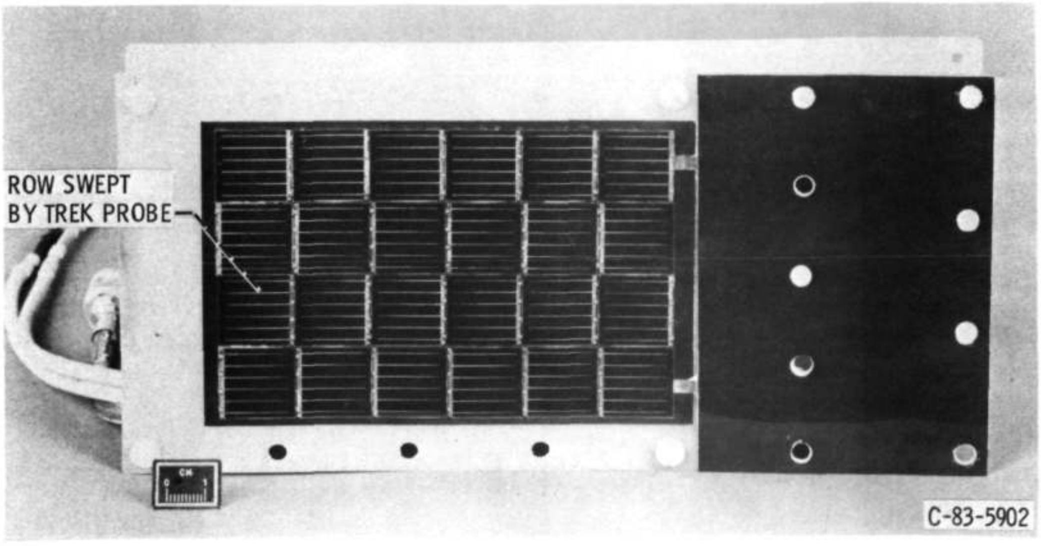


Figure 2. - Solar array.

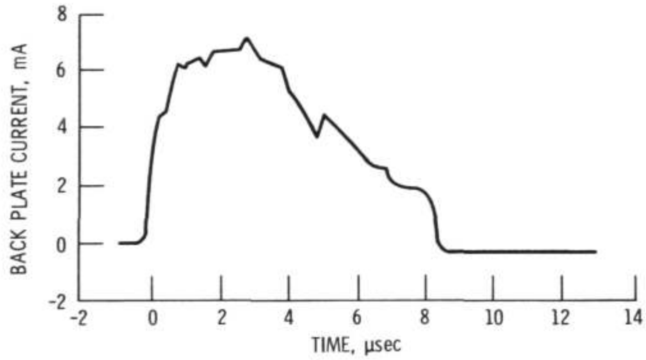
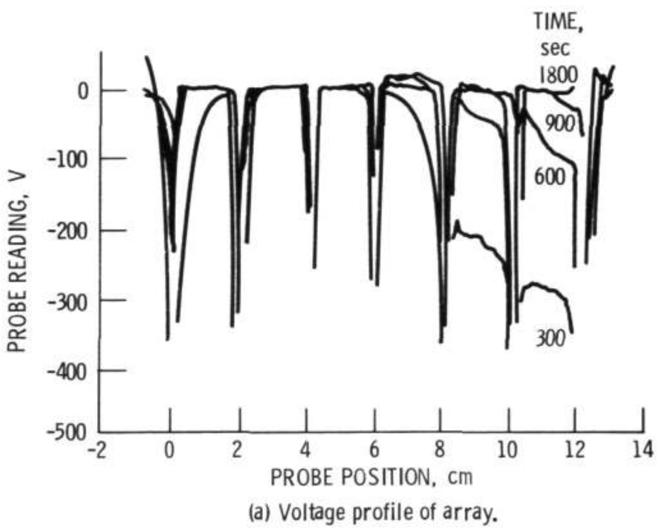
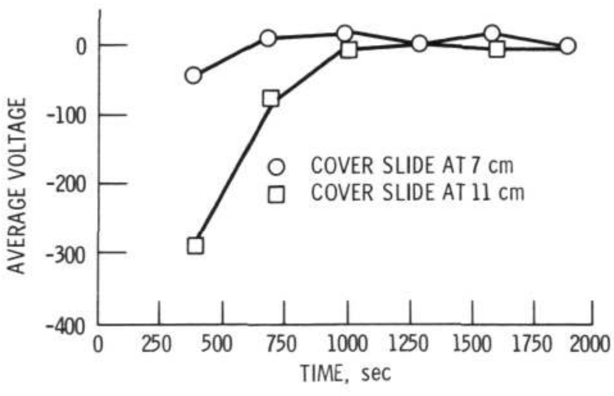


Figure 3. - Back plate response to a discharge. Bias, -800 V; ion density, 12 000 cm^{-3}.

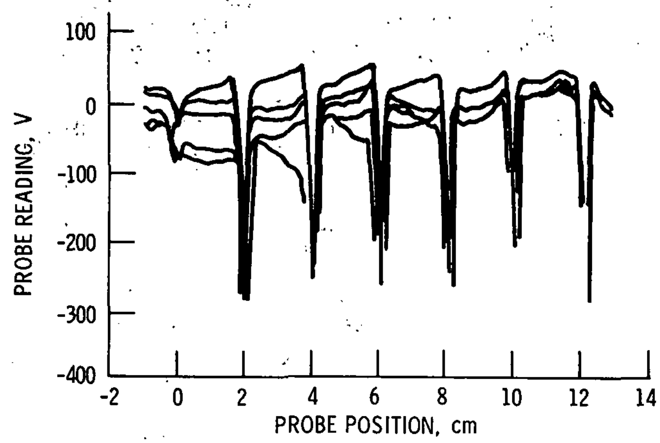


(a) Voltage profile of array.



(b) Average voltage of individual cover slides as function of time.

Figure 4. - Cover slide behavior at low ion density. Bias, 1400 V; ion density, 200 cm^{-3}.



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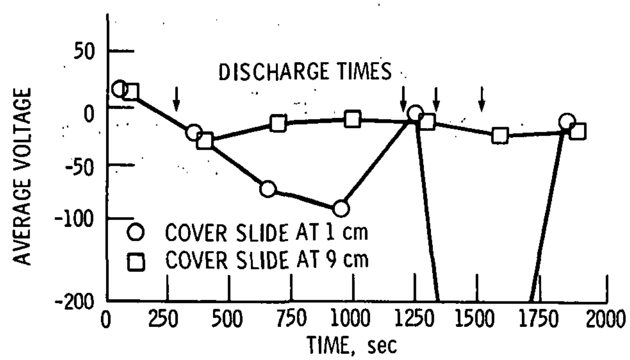
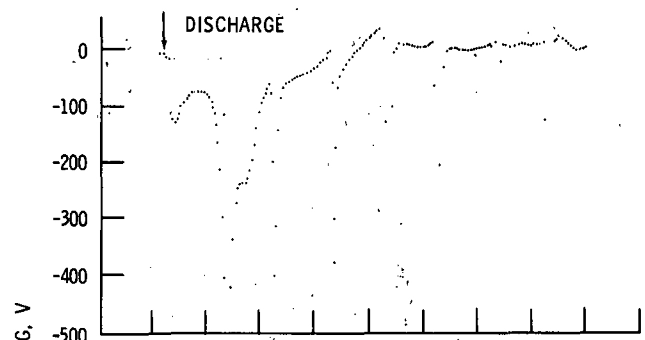
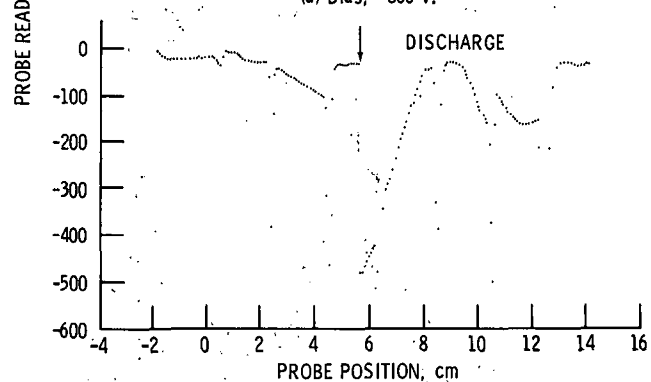


(b) Average voltage of individual cover slides as function of time.

Figure 5. - Cover slide behavior under conditions that allow discharges. Bias, -1000 V; ion density, 12 000 cm^{-3}.



(a) Bias, -800 V.



(b) Bias, -1000 V.

Figure 6. - Cover slide behavior during a discharge. Density, 12 000 cm^{-3}; 0.5 sec per point.

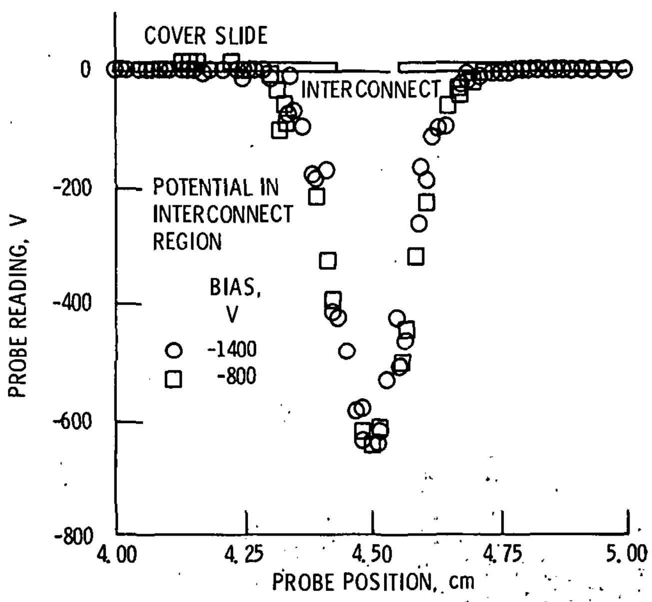


Figure 7. - Profile of potential in vicinity of an interconnect at low ion density. Ion density, 200 cm^{-3}; 800 V reading scaled by 14/8.

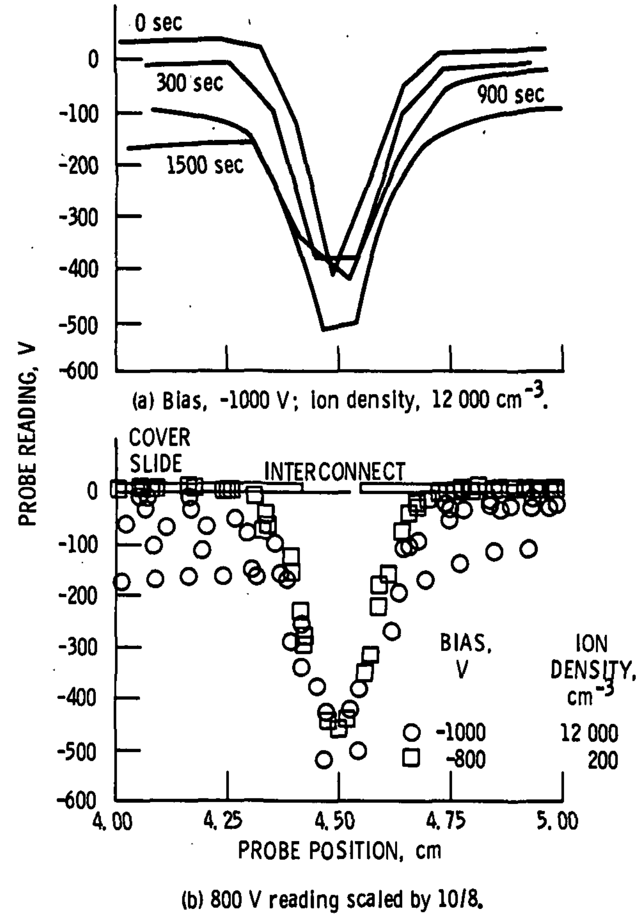


Figure 8. - Profile of potential near an interconnect under conditions where discharges can occur.

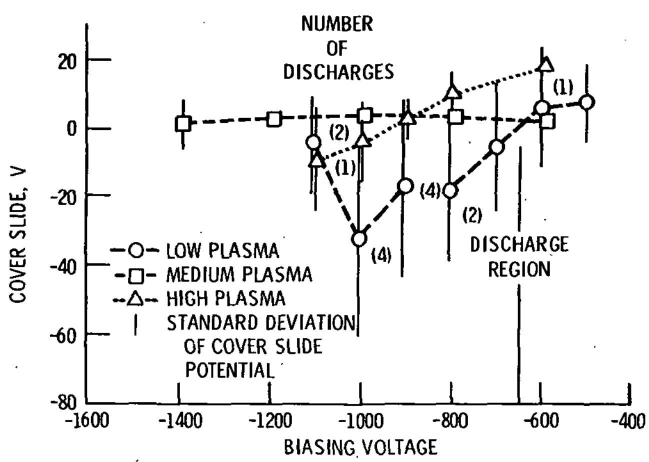


Figure 9. - Summary of average cover slide potentials.

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16. Abstract

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