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

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

At the low end of the ion density range the solar cell coverslides charged to 0 to 5 V independent of the applied voltage. No discharges were seen at bias voltages as large as -1400 V. At the higher ion densities the coverslide potential began to fluctuate and became significantly negative. Under these conditions discharges can occur. The threshold bias voltage for discharges decreased with increasing ion density. A condition for discharges emerging from the experimental observations was 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 studied this effect. The current working hypothesis (ref. 3) is that when the electrical field strength between the solar cell coverslides and the interconnects becomes too great, a discharge can occur. The electric fields will be roughly proportional to the potential difference between the interconnects and adjacent coverslides and the distance over which most of the change in potential occurs.

As an alternative hypothesis, I 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 can 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 and result in an apparent discharge.

In this study, both of these hypotheses were examined, taking into account the potentials observed on the biased solar array. A shorted, biased solar array was subjected to a plasma where the ion density was low enough that the

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profile of the potential along the surface of the array changed on a time scale of seconds to minutes. The profile of the potential along a portion of the array was monitored by sweeping an electrostatic voltage probe across the array at 5-min intervals. Discharges were detected by a probe that was capacitively coupled to the back of the array. With this apparatus the conditions under which discharges do and do not occur was investigated. The charging behavior of the coverslides is discussed with respect to these discharges.

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

EXPERIMENT

This work was undertaken 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 (fig. 1) consisted essentially of 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 was 1 m in diameter by 2 m long. It used 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 4×10^{-6} to 10×10^{-6} torr, the lower pressure corresponding to lower ion densities.

An electron bombardment ionizer was the plasma source. It used a hot filament to generate electrons. The electrons were accelerated to about 50 V to ionize nitrogen gas as it flowed into the vacuum system. Current through a coil concentric with the ionization chamber generated a magnetic field to increase the effective path length of the electrons in the gas and thus increase the plasma density.

Limited plasma measurements were obtained during the experiments. To improve confidence, plasma characteristics under similar conditions were obtained later by using a 1200-cm^2 plate as a Langmuir probe. The electron temperatures were about 1 eV; the plasma potentials were about 10 V; and the ion densities ranged from 200 to 12 000 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 been used for studies of electron-beam-stimulated discharges (refs. 4 and 5). It was constructed from twenty-four 2-cm by 2-cm solar cells connected in series and forming a 6x4 array. The interconnects were 1-mm-wide silver strips running along the edge of each cell and had four flat wires forming the connections to the following cell. The gaps between cells for these connections were 0.2 to 0.5 mm wide. The surfaces of the cells were protected by fused silica coverslides, 0.15 to 0.25 mm thick. The coverslides did not extend over the main metal strip. The base for the array was a fiberglass printed circuit board. A sheet of Kapton separated the array and base. On the back of the base, a 2.5-cm-radius copper disk had been etched and covered with Kapton. This back plate served as a probe capacitively coupled to the array and measured 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 to 3.3 mA (ref. 6).

During a typical run data were taken for 1920 sec and stored at 0.5-sec intervals by a MINC-23 computer with an analog/digital converter. At 300-sec intervals the noncontacting Trek electrostatic voltage probe was 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 took 120 sec to sweep down the array, during which time its position and voltage were recorded. During the following 180 sec, until the next probe sweep, the pressure was monitored. The electrostatic probe returned to its base position over a ground reference plate during the first 60 sec of this period.

Discharge transients were detected by using the back-plate probe. The capacitance of the back plate to the solar array was 65 pF, and to ground it was 616 pF. A fast test pulse was used to determine the characteristics of the system. This caused the cable to ring at 15 to 20 MHz, consistent with the 4.4-m cable length from back plate to a Biomation 6108 transient recorder. But the transient recorder had an internal high-frequency limit of 2.5 MHz. The 50-ohm cable was terminated with 50 ohms at the transient recorder but was open at the back plate. This arrangement measured rate of change of the average voltage on the array. During discharges the arc current exceeded the current limit of the power supply, and the power supply did 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 was used as the time of discharging. The discharge times were recorded and the waveforms 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 of 4×10^{-6} torr; ion density of about 200 cm^{-3}), one for a medium density (pressure of 6×10^{-6} torr; ion density of about 8000 cm^{-3}), and one for a high ion density (pressure of 8×10^{-6} torr; ion density of about 12 000 cm^{-3}). The data obtained are summarized in table I.

At low ion densities, bias voltages of -600 to -1400 V were applied. No discharges occurred. A typical electrostatic voltage profile across the array is shown in figure 4. Figure 4(a) illustrates the profile across the array at various times; figure 4(b) shows the behavior of two particular cells. When the biasing voltage was first applied, both the interconnects and the coverslides went to the applied potential (i.e., the coverslides had no net charge). The coverslides then slowly accumulated positive charge and approached a slightly positive potential. The potential of the surrounding Kapton changed relatively rapidly because of its lower capacitance to the interconnects. On the array itself the central coverslides charged rapidly, with those coverslides closest to the plasma source charging most rapidly. This effect was probably related to the array's vertical orientation in the tank. When the array was vertical, the door of the tank was about 1 m in front of it and the center charged most rapidly. In a horizontal orientation, the edges of the array charged most rapidly, with the wall of the tank being about 0.4 to 0.5 m above the array. This behavior was 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 coverslides tended to charge to a slightly positive potential, 4 to 10 V. They simply charged to the plasma potential. At high bias voltages fluctuations in potential across the array appeared and tended to get more pronounced at higher biases, as shown in table I. These fluctuations suggest that the local plasma potentials near the array are becoming nonuniform.

At higher ion densities the behavior of the coverslide potential was substantially different (fig. 5). Initially the coverslides charged rapidly to a slightly positive potential (the plasma potential). But the coverslides then slowly became negative, and the potential across the array began to fluctuate. At higher negative biases and higher ion densities, the average coverslide potential was more negative, and the fluctuations became more substantial. This is demonstrated in table I, 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 can be used to identify sites associated with discharges. The potentials of the two coverslides at 1 and 3 cm (fig. 5(a)) became increasingly negative between 300 and 900 sec. After a discharge at 1189 sec this feature disappeared, an indication 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 coverslides attained nearly the interconnect potential at the time of the discharge and then recharged to ground. Since not all of the features in the potential profile were changed, the discharge was apparently a local effect.

DISCUSSION

The shapes of the potential profile near an interconnect are shown under conditions that 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 (i.e., conditions where no discharges were detected). The spatial resolution of the electrostatic probe is poor compared with the size of an interconnect, and the distances between positions where the potentials are read were long compared with the width of the interconnects. However, data from separate probe sweeps were consistent with each other. Data from separate sweeps could 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 constructed a consistent view of the potential in the region of the interconnect. In fact, there were no measurable differences between the two profiles when the -800-V profile was normalized to the -1400-V profile by 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 was that the average potential of the coverslides shifted. In figure 8(b) the data points for this case are superimposed on and compared with the profile when no discharges were seen (-800 V). The difference between these two sets of data was primarily due to the coverslide potentials.

The hypothesis proposed by Stevens et al. (ref. 4) that discharges are related to the potential gradient between the coverslides and the interconnects is not supported by this work. At low ion densities no discharges were seen even though the coverslide potentials reached ground and the bias was very negative. In contrast, under discharge-prone conditions, discharges were more likely to occur when the coverslides were at a substantially negative potential rather than when their potentials were near ground or slightly positive. The electric fields did not appear to change significantly. The spatial resolution of the measurement was millimeters, so this observation was not conclusive. In fact, these measurements show that the electric field was above 10^6 V/m. But because the coverslides were more negative, and the change in voltage less under conditions where discharges occurred than when they did not, the hypothesis was not supported.

Similar conclusions were drawn with respect to the other hypothesis advanced here, that focusing of the attracted ions near 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 near the interconnects did not change with bias voltage, within the resolution of the experiment.

In cases where discharges occurred (fig. 8), the behavior was less conclusive. The shape obviously changed, yet the variations were primarily due to shifts in the coverslide potential. The width of the interconnect region did not change significantly. If the potential profile did change, it was only over distances as small as, or smaller than, the interconnect width. Therefore the size of the region over which focusing could change was small. This work produced no evidence that ion focusing near an interconnect is important to discharging.

These data do indicate that discharges occurred when the average coverslide potential was more negative than -4 V, regardless of bias voltage. Figure 9 shows the average coverslide potential as well as its standard deviation at various interconnect biases, for different plasma conditions. In addition the number of discharges in a half-hour run is shown for those cases where discharges occurred. This average was determined by the ion density and the bias voltage. Except for the single case of a discharge at -600 V, all discharges occurred when some coverslides were negative.

The charged-particle environment near the array became negative under conditions where discharges can occur. The current to the grounded sensor became negative, and the coverslide potential became 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 could not be from the coverslides, since they approached a roughly equilibrium potential. This emission could occur only near the interconnects, and this 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 have 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 near an interconnect was not directly responsible for the discharges. At very low plasma densities, biases as large as -1400 V did not result in discharges even though the coverslides charged slightly positive. With a resolution of the order of millimeters, the distance over which the potential changed with no discharges resulting was no different than the distance for cases that resulted in discharges. In addition, the electric field near 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 near the interconnect did not change appreciably, on a scale of millimeters, between conditions that produced discharges and those that did not.

Both the plasma and dielectric surfaces seemed to play important roles in the initiation of discharges. Before discharges occurred, the coverslides on the array became negative. This indicated that changes in the plasma sheath were taking place, which in turn suggested that the plasma itself was playing an important role in the appearance of discharges on high-voltage arrays. The plasma was not simply supplying charge to the process but might have been driving the discharges.

Further work needs to be done to verify these observations. First, the work should be carried out under better controlled and monitored conditions. The fluctuations in the coverslide 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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3. Grier, Norman T.: Experimental Results on Plasma Interactions with Large Surfaces at High Voltages. NASA TM-81423, 1980.

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5. Snyder, D. B.: Environmentally Induced Discharges in a Solar Array, IEEE Trans. Nucl. Sci., vol. 29, no. 6, Dec. 1982, pp. 1607-1609.

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TABLE I. - DATA OBTAINED

Bias voltage, V	Pressure, torr	Coverslide, voltage, V	Number of discharges
Low ion density (about 200 cm^{-3})			
-600	3.70×10^{-6}	2.5±0.9	0
-800	3.30	3.9±1.2	
-1000	4.40	4.5±1.6	
-1200	3.50	3.7±1.2	
-1400	4.10	2.3±5.4	↓
Medium ion density (about 8000 cm^{-3})			
-600	6.15×10^{-6}	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	8.05×10^{-6}	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

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Figure 1. - Tank arrangement.

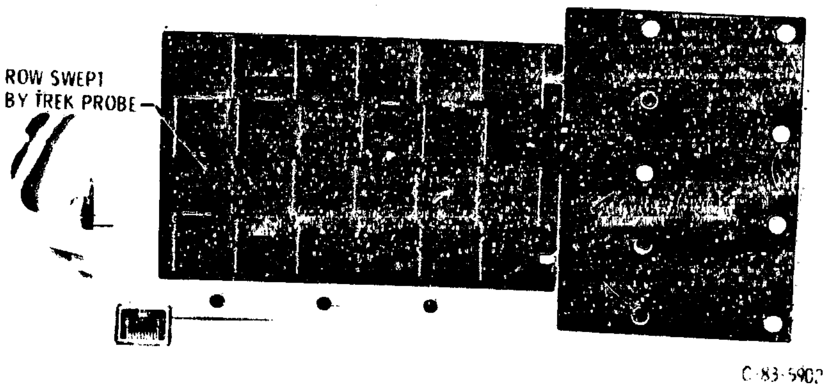


Figure 2. - Solar array.

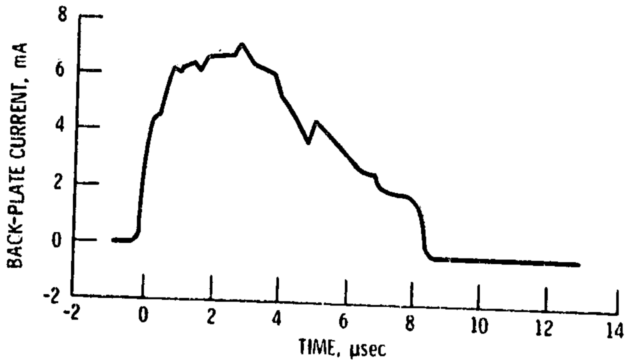
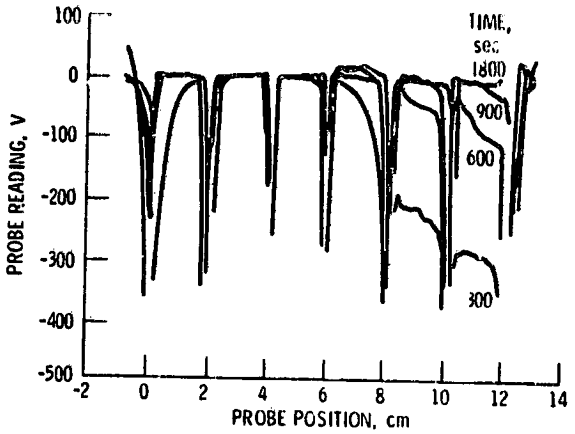
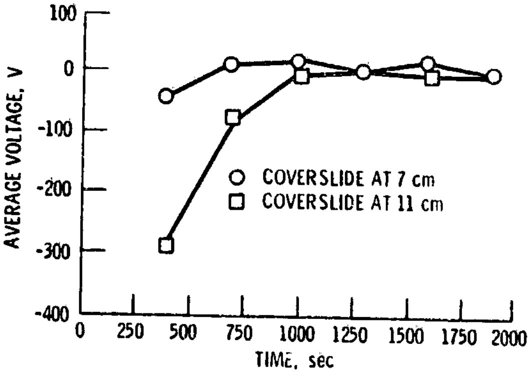


Figure 3. - Back-plate response to a discharge. Bias, -800 V; ion density, 12 000 cm^{-3}.



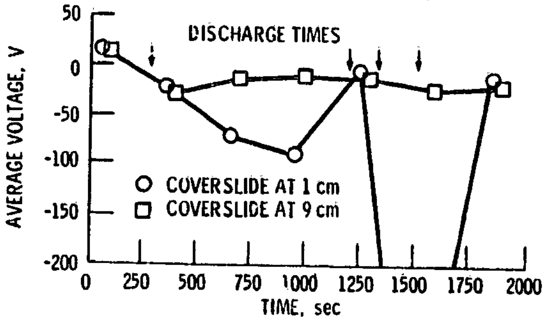
(a) Voltage profile of array.



(b) Average voltage of individual coverslides as function of time.

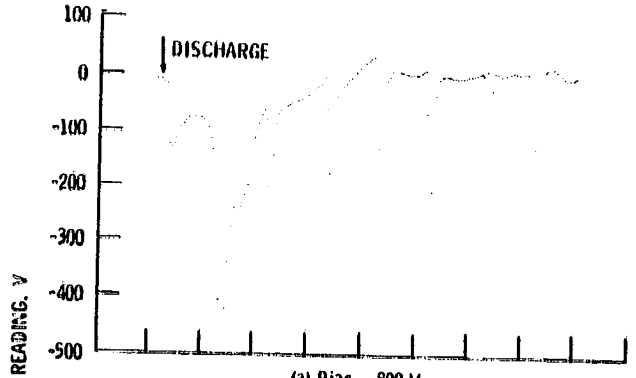
Figure 4. - Coverslide behavior at low ion density. Bias, 1400 V; ion density, 200 cm^{-3}.

(a) Voltage profile of array.

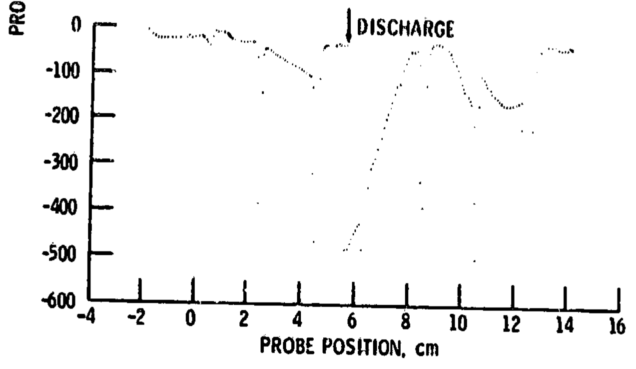


(b) Average voltage of individual coverslides as function of time.

Figure 5. - Coverslide 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. - Coverslide behavior during a discharge. Density, 12 000 cm^{-3}; 0.5 sec per point.

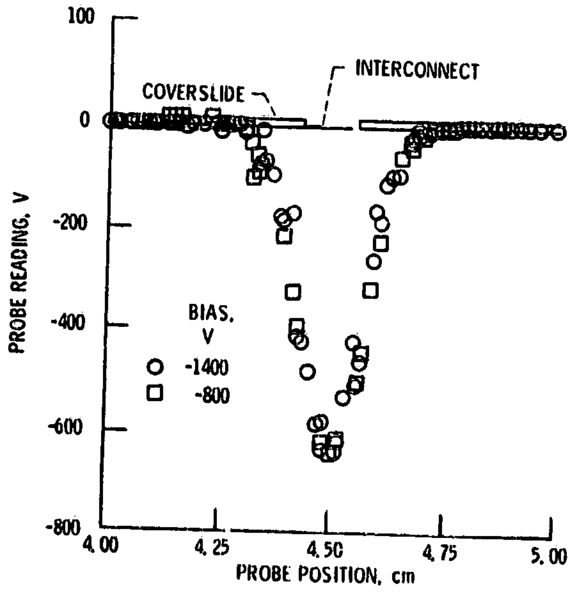
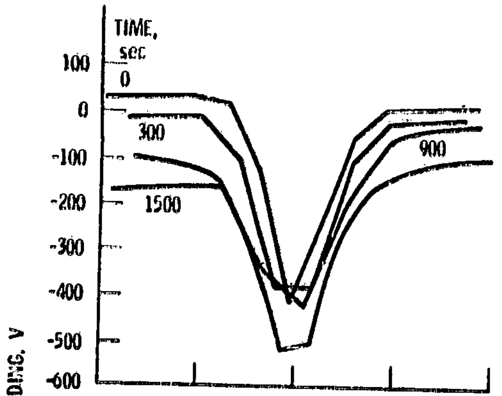
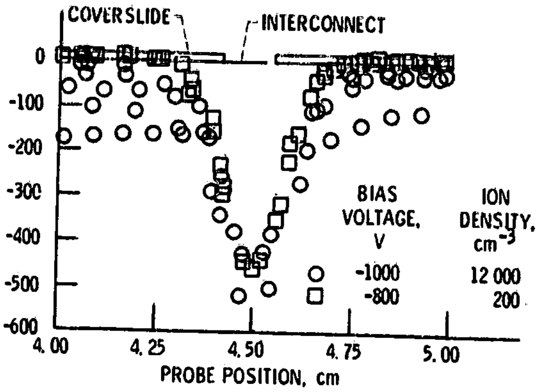


Figure 7. - Profile of potential near an interconnect under conditions where discharges cannot occur. Ion density, 200 cm^{-3}; 800-V reading scaled by 14/8.



(a) Bias, -1000 V; ion density, 12 000 cm^{-3}.



(b) 800-V reading scaled by 10/8.

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

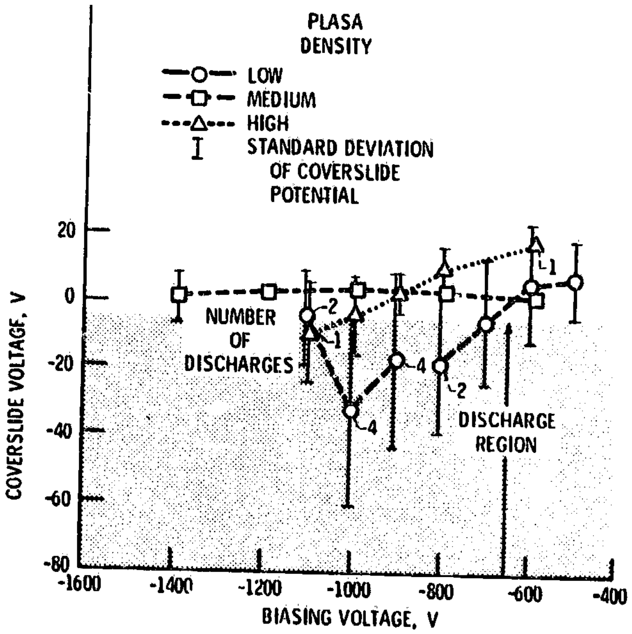


Figure 9. - Summary of average coverslide potentials.