A Threshold Voltage for Arcing on Negatively Biased Solar Arrays

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Abstract

Negatively biased high voltage solar arrays in low earth orbit are known to undergo arcing below a critical voltage with respect to the plasma environment. It is proposed that the arcing is due to the breakdown of gas which is emitted under electron bombardment from the coverglass on the solar cells. A voltage threshold is predicted along with the scaling of the threshold on the key parameters

1 Introduction

As the space program matures there is a growing demand for large power generating systems to be available in low earth orbit(LEO). For example on the planned international space station, there is a current need for 75 kW of power to be made available for housekeeping and scientific experiments. It is desirable to supply this power at high voltage and low current in order to minimize resistive losses and the mass of cabling and harnesses. If this power is supplied by photovoltaic means then the solar arrays will be operating at high voltages. The term high voltage here typically implies voltage drops across the array on the order of one hundred to five hundred volts. Typical solar arrays currently in use have voltage drops ranging from 28 volts to 75 volts.

High voltage solar arrays have been found to undergo two distinct sets of interactions with the space environment above a given threshold[1,2,3,4,5,6]. For reasons of mass savings and also due to insulator degradation on orbit, in some designs the interconnects between the solar cells are exposed directly to the space environment. It is found for the positively biased interconnects with respect to the space potential that the current collection from the space environment can be anomalously large. For the negatively biased interconnects it is observed that below a critical voltage arc discharges occur on the solar array. These arc discharges give rise to electromagnetic noise and may also damage the solar cells[6].

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There have been many observations of the arcing phenomenon on high voltage solar arrays in ground based tests[7,8,9] and in flight tests[10,11]. The only theoretical hypothesis so far has been in Ref. [12]. In this work it was proposed that there is a thin layer of insulating contaminant over each of the interconnects. Such contaminant could arise by exposure to air or be created in the manufacturing process. Ions from the space plasma are attracted by the negative potential on the interconnects. These ions accumulate in the surface layer resulting in a buildup of electric field in the layer. As the layer continues to charge the internal field becomes large enough to cause electron emission into the space plasma. This electron current leads to subsequent heating and ionization in the layer. This is what is seen as the discharge.

In this paper we have concentrated on the behaviour of negatively biased solar arrays in LEO and we propose a new explanation for the arcing observed. It is proposed that the prebreakdown current observed experimentally causes neutral gas molecules to be desorbed from the sides of the coverglass over the solar cells. These molecules build up over the interconnects and arcing occurs inside this surface gas layer. An expression for the voltage threshold is derived and the scalings with the gas and geometric properties are examined. The voltage threshold is independent of the plasma density and depends strongly on the geometric structure of the solar cell-interconnect connection.

In section 2 the experimental work is reviewed and the plasma and neutral environment characterized for LEO. In section 3 the breakdown model is developed and the breakdown threshold obtained. In section 4 we discuss the scaling with gas and geometric parameters and the application of experimental data to this theory. Finally in the last section a number of experimental tests are proposed to elucidate the theoretical model.

2 Review of Experimental Work

Experimental work has been undertaken in ground based plasma chambers[2,7,8,9] as well as in two flight experiments, the plasma interactions experiments I and II (PIX I and II)[10,11]. The plasma and neutral gas environments in the plasma chambers are typically Argon or Nitrogen with a pressure range of 10^{-7} to 10^{-5} torr. The plasma density range is from 10^{3} cm^{-3} to 10^{6} cm^{-3}. The ion energy ranges between 1 and 100 eV while the electron thermal energy is approximately 0.1 to 0.3 eV. By contrast the ambient space environment at the altitude (300-500 km) where high voltage solar arrays will operate is mainly atomic and ionic oxygen. The pressure range is from 10^{-8} to 10^{-7} torr with a plasma density of the order of 10^{4} cm^{-3} to 10^{6} cm^{-3}. The ram energy of the ions is 5 eV while the electron thermal energy (T_e) is in the range 0.05 to 0.1 eV. However the environment around the solar array may differ substantially from the ambient space environment if the solar array is mounted on a large vehicle which is actively emitting effluents. This is very likely since it is precisely such vehicles which will demand large amounts of power and hence will need the high voltage solar arrays. The evidence from the Shuttle[15] suggests that the solar arrays could have an environment which has enhanced neutral and plasma densities relative to the ambient. The enhanced densities will be about an order of magnitude above the ambient. The enhancement arises from passive emissions from the vehicle such as outgassing of water as well as active emissions such as the products of thruster firings or liquid dumps. A neutral build-up may occur on surfaces exposed to the ram direction if the incoming streaming neutral particles substantially accommodate on the surfaces. The enhancement depends strongly on the surface accommodation coefficients which are not well known for the impact of 5 eV atomic and ionic oxygen. If the ambient oxygen neutrals are reflected after thermal accommodation on the surface then for numbers typical of LEO a density enhancement of fifty might be expected as can be obtained from simple flux balance. Hence for orbits in LEO it is not unreasonable to assume that the neutral density around a solar array may be one to two orders of magnitude above the ambient densities.

The experimental work suggests the following observations: firstly, the key elements involved in the discharge process are the solar cell coverglass, the metallic interconnect and the plasma environment. This can be deduced from a set of experiments by Fujii et al[9]. In their experiments a metallic plate biased to highly negative voltages was exposed to the plasma in a plasma tank. No arcing was observed except for very large negative voltages where the arc took place to the substrate. The plate was then partially covered with silica coverglass slides. Arcing was now observed at the interfaces of the metal and the coverglasses. When actual solar cells were used with coverglasses the arcing results were qualitatively similar. Secondly, there is a prebreakdown electron current that flows away from the interconnect prior to a discharge. This electron current was observed in the experiments of Fujii et al [9] as well as the experiments of Snyder[7]. Calculation of the electron trajectories in the electric field of the interconnects indicate that the electrons must be coming from the interconnect and not from the plasma[12]. The source of this current is hard to understand. Fujii et al. speculate that this is due to field enhanced emission from the interconnect. The evidence for this is that as the number of coverglasses is increased, presumably increasing the local electric fields over the neighbouring interconnects, the electron current is observed to increase. On the other hand in the experiments of Snyder at low plasma densities and very negative voltages no electron current flowing away from the interconnect was seen. This does not prove that no current existed since it could have been below the threshold for detection in the experiments. However as the plasma density was increased and all other factors kept constant the ion current to the interconnect increased and the electron current appeared. Therefore the electron current seems to depend on the presence of a certain level of incoming ion current as well as the local electric field.

It is easy to see that the electron current flow is unlikely to be due to field emission from a calculation of the field emission current. The field emission current density[14] is

$$j_{IF} = \frac{1.55 \times 10^{-6}}{\phi} E^2 \exp(-\frac{6.85 \times 10^9}{E} \phi^{3/2})$$

where ϕ is the work function of the surface, E the electric field right over the surface and all quantities are in MKS units. Even if E is said to be enhanced by whiskers on the surface of the conductor so that E is estimated by $E \simeq \beta V/d$ where β is the aspect ratio of the whisker then for reasonable values of $\beta = 100$, $V = 500$ Volts, $d = 150$ μm and taking the work function for silver as $\phi = 4.3$ eV, the current density is of the order of 10^{-68} A/m^2. This is far too low to account for the electron current observed in the experiments.

The sequence of events associated with the arcing is the following: if a conductor with an insulating coverglass attached is put into the plasma and the conductor is initially not biased then both the conductor and coverglass accumulate a negative charge. This occurs since the electrons are more easily collected than the ions. The final negative potential achieved ($V_{surface} \simeq -4T_e$) is such as to make the net electron flux equal to the net ion flux. If the conductor is now biased to a large negative potential then the cover glass initially takes the same potential as the conductor and then slowly returns to a slightly negative potential with respect to the plasma. This is because ions are initially attracted to the system and accumulate on the surface of the coverglass. The conductor below the coverglass acquires a negative (image) charge as shown in Fig. 1. The potential drop between the conductor and the surface of the coverglass is almost equal to the bias voltage ($|V|$). The surface charge density is $\sigma = C|V|$ where C is the capacitance per unit area of the coverglass. Below a certain voltage an electron current is observed to flow from the conductor. Some of the electrons leaving the interconnect strike the coverglass. There are two pieces of evidence which support this observation. First there is observed to be a potential barrier over the interconnect[6] which tends to keep the electrons from escaping to space. Secondly the surface potential of the coverglass is observed to undergo frequent fluctuations towards negative potentials[13]. As the bias on the conductor becomes more negative the magnitude of the voltage fluctuations on the coverglass increases and below a critical voltage a discharge occurs from the interconnect. The discharge time is typically a few microseconds[7] and once the discharge occurs the surface charge on the coverglass is neutralized and the cover glass potential becomes the same as the conductor potential[7]. The sequence now repeats itself with the cover glass slowly reaccumulating positive charge from the plasma.

The flight data from the PIX I and II experiments were taken at 900 km and show similar results to the ground based data. The current collection to the interconnects was measured to scale linearly with the voltage. There was substantial difference in the arc rate as compared to the ground based data. The arc rate $\dot{R}$ was measured[16] to scale as

$$\dot{R} \sim n_i(T_i^{1/2}/m_i^{1/2})V^a \tag{1}$$

where $a \simeq 3$ for flight data and $a \simeq 5$ for ground data. In Eq. 1 all quantities with subscript i refer to ions. The ambient plasma density is n, the ambient temperature is T and the mass of the ambient plasma particles is m. The dependence of the arc rate on these quantities can be explained as due to the recharging of the coverglass surface by the thermal flux of ions. The thermal ion current scales as $n_i(T_i^{1/2}/m_i^{1/2})r_s^2$ with a sheath radius r_s.

The voltage threshold appears to be of the order of -200 to -250 Volts in some ground based tests[13] and -400 to -500 Volts on other tests[6,3]. It has been suggested that the voltage threshold depends on the plasma density[9,12] although the data range is not large and the evidence for a density dependence is ambiguous. If it exists it is very weak.

From these experimental observations two questions arise:
What causes the initial electron current flow from conductor to either space or the insulator?
What causes the electron current flow to avalanche and leads to a discharge?
The two questions can be addressed independently. The answer to the first question probably lies in the details of the interconnect surface and the fine structure of the electric field over the surface. In this paper we shall leave this question alone and assume that an electron current exists and is flowing from the interconnect. With this assumption we shall show that with reasonable bounds on the current it is possible to construct a consistent model of electron induced desorption of neutral

gas from the coverglass which then undergoes breakdown. From this model we can derive a voltage threshold and deduce how it scales with key parameters.

3 Breakdown Model

We shall work with a model for the coverglass/conductor interface as shown in Fig. 2. As assumed from the experimental results we take there to be a precursor electron current flow from the conductor to the coverglass. The coverglass is taken to have material properties typical of fused silica, namely that above a threshold energy and under electron bombardment the material emits secondary electrons. For all insulating materials the secondary electron yield as a function of incident electron energy increases monotonically from zero for small incident energy until a maximum yield is reached and then asymptotically approaches zero as the incident energy becomes very large. If the maximum yield of the material exceeds one then there are two distinct incident energies at which the yield is unity. We shall call these two energies $\mathcal{E}_1$ and $\mathcal{E}_2$ where $\mathcal{E}_1 < \mathcal{E}_2$. Typical values for $\mathcal{E}_1 \simeq 30 - 100$ eV and $\mathcal{E}_2 \geq 1$ keV[17,18,19].

Our basic model is that neutral gas is desorbed from the coverglasses due to bombardment by ions and electrons. Some of this neutral gas accumulates in the gap between coverglasses where it forms a (possibly) high pressure layer which can break down when the experimentally observed electron current from the interconnect flows through it. We shall take the ordering $d \ll l_i \ll l_c$. The smallest dimension of the gas slab over the interconnect is d so that a ***sufficient*** condition can be placed on the electron mean free path for ionization by requiring that it be less than d. If this is the case then there is a high probability that the gas slab will ionize so leading to a discharge. A ***necessary*** condition is that the electron mean free path for ionization be less than the largest dimension of the gas slab i. e. l_i. If this condition is violated then it is highly unlikely that as the electrons flow from the interconnect through the gas slab that they will have enough ionizing collisions to initiate a discharge. Hence we can obtain a *lower* bound on the discharge voltage by taking

$$\lambda_{mfp} \leq l_i \tag{2}$$

where $\lambda_{mfp} = 1/(n_n \sigma_{ion})$ is the electron mean free path for ionization for the electrons flowing through the neutral gas with n_n being the average neutral density and σ_{ion} being the ionization cross section. The distance l_i can be interpreted as the maximum distance an electron can travel between the coverglasses before it escapes.

The sides of the coverglasses are being bombarded by electrons. These electrons arise from two sources. Firstly the current flow from the interconnect and secondly by secondary electrons which are emitted from the cover glass under the primary electron bombardment and which then return to the surface. It is well known that insulators like silica will desorb neutral gas under electron bombardment[22,23]. This phenomena of electron bombardment causing desorption of gas molecules from surfaces is well known, and is called electron stimulated desorption (ESD). ESD has been the subject of several recent reviews[20,21]. The electron bombardment induces desorption by causing an electronic excitation in the adsorbed molecule. This causes the molecule to go from a energetically stable condition to an antibonding condition that leads to desorption. It is this electronic mechanism that occurs as opposed to other possible mechanisms such as energetic impact or thermal heating. Yields have been found to be as high as 10^{-2} atoms per impacting electron[22,23]. Desorption yields mostly neutrals although emission of ions is also possible. The impacting electron must have an energy of greater than 5 eV for desorption to occur.

If we call the desorption efficiency Γ, the primary electron current $I_e(V)$ and N_t the multiplication factor due to the emission and reabsorption of secondary electrons then the neutral density over the surface of the interconnect is given by a flux balance

$$A n_n v_n = \Gamma N_t \frac{I_e(V)}{e} \tag{3}$$

where A is the area of the edge of the cover glass participating in the process, v_n is the average velocity of the neutral gas leaving the surface and e is the charge on an electron. If we combine Eqs. (2) and (3) and define the primary electron current density as $J_e(V) = I_e(V)/A$ then we obtain an equation for the threshold voltage V_t above which a discharge is possible

$$\frac{e v_n}{\Gamma l_t \sigma_{ion}} = N_t J_e(V_t). \tag{4}$$

The multiplication factor N_t can be estimated in the following manner. If an electron is released from a surface with mean energy $\mathcal{E}_0$ under the influence of a normal and tangential electric field as shown in Fig. 3 then the mean distance that the electron will go antiparallel to the direction of the tangential electric field[24] is given by

$$l_{mean} = -\left(\frac{E_t}{E_n}\right)\frac{\mathcal{E}_0/e}{E_n}. \tag{5}$$

A normal field must exist if the coverglass edge has accumulated any charge. If we consider the electric field tangential to the side of the coverglass (see Fig. 2) then from Maxwell's equations the field just outside the coverglass is the same as the tangential field just inside the coverglass which we can estimate as

$$|E_t| = \frac{V}{d} \tag{6}$$

where we have taken the voltage on the upper surface of the coverglass as being approximately at plasma ground. If the secondary electron yield per primary electron is greater than one then the coverglass will charge positively under the electron bombardment. The experimental data suggests that the charge on the coverglass is not increasing[7] so that we can bound the secondary yield at one. This means that electrons are striking the surface with at most energy $\mathcal{E}_1$ so that one electron is emitted for each electron that impacts. We can solve for the ratio E_t/E_n necessary to achieve this impact energy[24]. We find that

$$\left(\frac{E_t}{E_n}\right)^2 = \frac{\mathcal{E}_1 - \mathcal{E}_0}{2\mathcal{E}_0}. \tag{7}$$

We use Eqs. (6) and (7) in (5) to obtain

$$\frac{l_{mean}}{d} = \frac{(\mathcal{E}_1 - \mathcal{E}_0)/e}{2V}. \tag{8}$$

The number of sec[illegible]dary electrons [illegible] per [illegible] primary electron is d/l_{mean}. This assumes that we are [illegible] considering [illegible] as [illegible] as they are striking the side of the coverglass. [illegible] may [illegible] the [illegible] surface of the coverglass but in this case the neutr[illegible] to the dense gas layer over the inter[illegible] per primary electron is

$$[illegible] \quad (9)$$

[illegible] represents an *upper bound* on the [illegible]

[illegible] threshold voltage if we know [illegible] explicit form we can [illegible] current density that can [illegible]

$$[illegible] \quad (10)$$

[illegible] This expression is [illegible] and incoming ions over a distan[illegible] ion current density ratio must [illegible] complete space charge limited express[illegible] differ in the premultiplying numerical fact[illegible] electron current is not space charge limited then [illegible] current will depend on the plasma density.

We take the neutral flow out of the region between the coverglasses to be choked. Hence if γ is the ratio of specific heats for the neutral gas and if the gas is in thermal equilibrium with the coverglass surface then $v_n = \sqrt{\gamma T_s / m_n}$ where T_s is the surface temperature. This assumption is based on the presence of the high density gas slab over the interconnect surface so that as fresh gas is desorbed from the coverglass it quickly equilibrates with the gas there which is taken to be in thermal equilibrium with the surface. This is a strong and important assumption which sets the magnitude of the neutral velocity. It is possible that the neutrals may leave with much larger velocities since the energy with which a gas molecule leaves a surface on which it has been absorbed can vary from 1 eV to 10 eV if it is expanding into a vacuum. With the use of Eq. (10) in Eq. (4) and since N_t and J_e are upper bounds we obtain a lower bound for the threshold voltage for an arc as

$$V_t = \left[0.605 \frac{e}{\epsilon_0} \left(\frac{d}{l_i} \right) \left(\frac{\gamma T_s / e}{2 m_n / m_e} \right)^{1/2} \frac{[(\mathcal{E}_1 - \mathcal{E}_0)/e]d}{\Gamma \sigma_{ion}} \right]^{2/5} . \quad (11)$$

In obtaining Eq. (11) we have taken $N_t \simeq [2V/(\mathcal{E}_1 - \mathcal{E}_0)/e]$.

In Fig. 5 we show the threshold voltage as a function of coverglass thickness over a range of values for $\mathcal{E}_1$. The range for $\mathcal{E}_1$ was chosen to reflect the range of secondary emission properties that might result from different coatings on the coverglasses. The dependence on energy at which the yield is unity arises from the assumption used to obtain the bound on the ratio of the tangential to normal electric field at the coverglass surface. By contrast with the weak dependence associated with the coverglass material, the dependence on the geometric lengths is much stronger. The threshold voltage increases with the thickness of the coverglass since the space charge limited current density available for ionization decreases with thickness. The voltage decreases with length of the interconnect since the electrons can stay within the neutral gas cloud longer as the length increases. These results suggest a set of experiments to systematically vary the lengths associated with the coverglass and conductor so as to determine the scaling of the threshold voltage with these lengths.

The threshold voltage found in Eq. (11) does not contain any dependence on the plasma density. As we have seen the ionization takes place in the gas layer coming from the surface of the coverglass. The electron current flow from the interconnect that we have taken is a space charge limited bound and hence density independent. For smaller electron currents there will be a dependence on the plasma density arising from the proportionality to the ion current. The plasma does play a crucial role in supplying the initial positive charge on the coverglass and in resupplying the positive charge once the arc discharge has occurred. Hence we expect a dependence of the arc rate on plasma density but within the context of our model do not find any dependence of the threshold voltage on the plasma density. The data for LEO conditions indicates very weak, if any, dependence on plasma density in the plasma density range 10^3 cm^{-3} to 10^5 cm^{-3} covered by both laboratory and PIX data[25].

Finally we note that differential charging of the interconnector and the coverglass can be realized in several ways. One way is under the influence of a photon flux due to the photoelectric effect while another way is due to an electron beam striking the insulator when the secondary electron emission yield is larger than one. In both cases the threshold differential voltage for arcing is the same as when the charging is due to the ambient plasma[26]. Based on our model, this arcing will occur for the same reasons as on a solar array, namely that breakdown occurs in a gas surface layer desorbed by the electrons.

Recently, another hypothesis has been advanced, namely that the breakdown is the result of the electrons desorbing ions rather than neutrals[27]. The ion return current from the side of the coverglass in the model of Ref. [27] is given by

$$J_{ir} = (\gamma_{ie} J_i) P_e \gamma_{ee}^{N_i} \Gamma_{ie}. \tag{12}$$

In this expression, J_i is the incoming ion current to the interconnector, γ_{ie} is the yield of secondary electrons emitted from the interconnector under ion bombardment, P_e is the probability of the electron emitted from the interconnector reaching the side of the coverglass, γ_{ee} is the secondary electron yield of the coverglass and Γ_{ie} is the ion yield of the coverglass surface under electron bombardment. Breakdown will occur when $J_{ir} \geq J_i$.

A typical number for $\gamma_{ie} \simeq 0.1$ while a typical number for $\Gamma_{ie} \simeq 0.0001$ since it usually two orders of magnitude less probable than neutral desorption[28]. The probability that an electron strikes the coverglass is a complex function of many parameters but a good estimate is 0.01. Hence $\gamma_{ee}^{N_i} > 10^7$ in order that $J_{ir} \geq J_i$. Clearly if $\gamma_{ee} = 1$ then this condition cannot be met and breakdown cannot occur by this means. The condition $\gamma_{ee} = 1$ comes from the requirement of steady state charge balance on the surface. Under this condition each incoming electron causes the emission of an electron so that the net charge on the surface does not change. If $\gamma_{ee} > 1$ then breakdown is possible, however the surface will not be in an equilibrium state. We might anticipate that if the timescale for the surface to reach equilibrium is much smaller than the discharge time then the condition $\gamma_{ee} = 1$ must be true and no breakdown is possible. On the other hand if the timescale to reach equilibrium is much larger than the discharge time then a discharge can develop. This will depend on the capacitance of the coverglass and the magnitude of the current flowing to it during the discharge. If we assume that the capacitance of the coverglass is very large than we can obtain the lower bound on the voltage by taking the maximum value for γ_{ee}. For SiO_2 the maximum value of $\gamma_{ee} = 2.4$. If we use Eq. (9) then for $\mathcal{E}_1 = 250$ eV; $\mathcal{E}_0 = 2$ eV we obtain the threshold voltage as approximately -1800 Volts. This indicates that this ion desorption mechanism may be possible and may give reasonable breakdown voltages. From an experimental point of view, it would be possible to distinguish between the gas desorption process and the ion desorption process by changing the capacitance of the coverglass. This may be done by changing the area of the coverglass while keeping all other parameters constant.

5 Conclusions

We have developed a simple model to describe arcing on a high voltage solar array. The basic elements of the model are an electron current flow from the interconnect to a neighbouring coverglass which desorbs neutral molecules under the electron bombardment. These neutral molecules form a gas layer over the interconnect which breaks down when the voltage on the interconnect is sufficiently high. The model makes specific scaling predictions with the geometric structure and with the gas properties.

In Ref. [6] the authors speculated that the ionization might take place in the background neutral gas. The work in this paper suggests that this is unlikely since the gas cannot be concentrated enough (at least four orders of magnitude) to give breakdown thresholds in the range observed. In Ref. [12] the authors suggested that ionization took place in the solid phase at the surface of the interconnect. In this work we suggest in contrast to earlier work that the ionization takes place in a gas layer generated from the coverglass surface. We note that while in this paper we have suggested that the ionization takes place in a gas layer which is desorbed from the coverglass surface, a gas layer may be created by some other means. One such means is the outgassing of the adhesives used to bind the solar cell to the substrate[29]. While in this case the source of the gas differs from our hypothesis, the gas pressure required for breakdown will be similar to the numbers in this work since this is determined only by the condition that the mean free path be smaller than the geometric size of the interconnect. These differing ideas suggest that a spectroscopic analysis of the radiation emitted during the arcing may shed light on the molecules participating in the discharge.

In order to elucidate the fundamental physics of the arcing on high voltage solar arrays it is proposed that experiments be undertaken to understand the role of the interconnect and coverglass materials by detailed electron micrographs. It is also proposed that the density dependence, if any, of the threshold voltage be clarified. This can be done by careful and systematic tests over a wide range of plasma densities. It is very important to understand this since operation of planned systems may be affected by the results. Finally the nature of the electron current flow from the interconnect must be clarified.

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Figure Captions

Figure 1 Schematic showing charge and equipotential contours for an insulator on (a) an unbiased and (b) a biased conductor

Figure 2 Geometric Structure of Coverglass/Conductor Interface

Figure 3 Electron Motion under the Normal and Tangential Electric Fields

Figure 4 Bound on Threshold Voltage versus surface temperature showing range of variation with gas desorption efficiency. Other parameters are: $m_n = 44$ amu; $\mathcal{E}_1 = 40$ eV; $\mathcal{E}_0 = 2$ eV;$d = 0.15$ mm; $d/l_i = 0.1$; $\sigma_{ion} = 10^{-20}$ m^2 and $\gamma = 1.2$

Figure 5 Bound on Threshold Voltage versus coverglass thickness showing range of variation with secondary emission properties. Other parameters are: $m_n = 44$ amu; T_s= 300 K, $\Gamma = 0.03$; $\mathcal{E}_0 = 2$ eV; $d/l_i = 0.1$; $\sigma_{ion} = 10^{-20}$ m^2 and $\gamma = 1.2$.

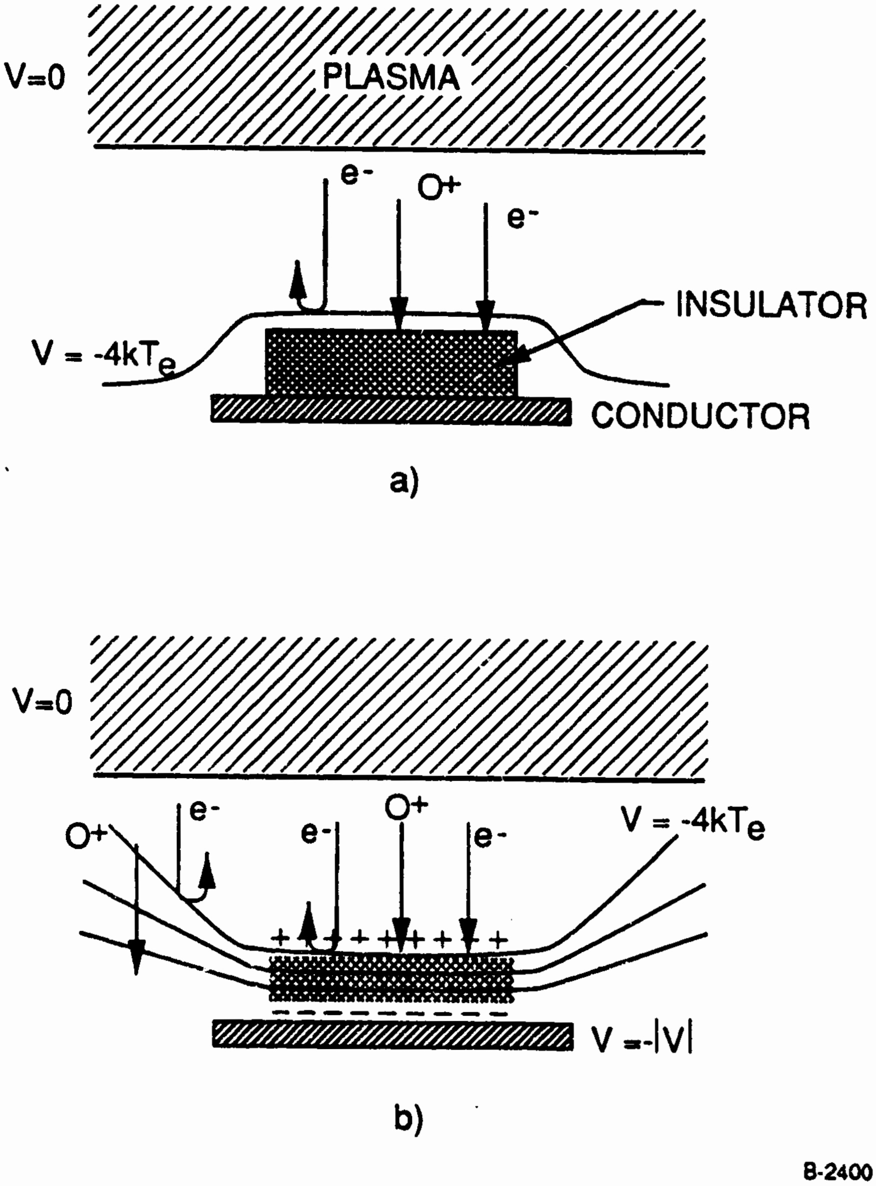

Figure 1: Schematic showing charge and equipotential contours for an insulator on (a) an unbiased and (b) a biased conductor

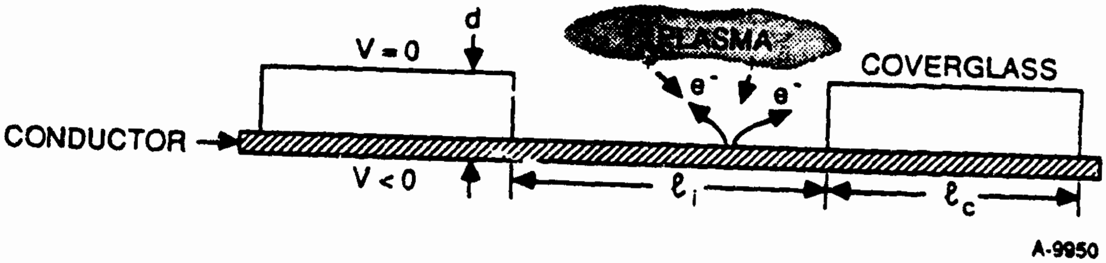

Figure 2: Geometric Structure of Coverglass/Conductor Interface

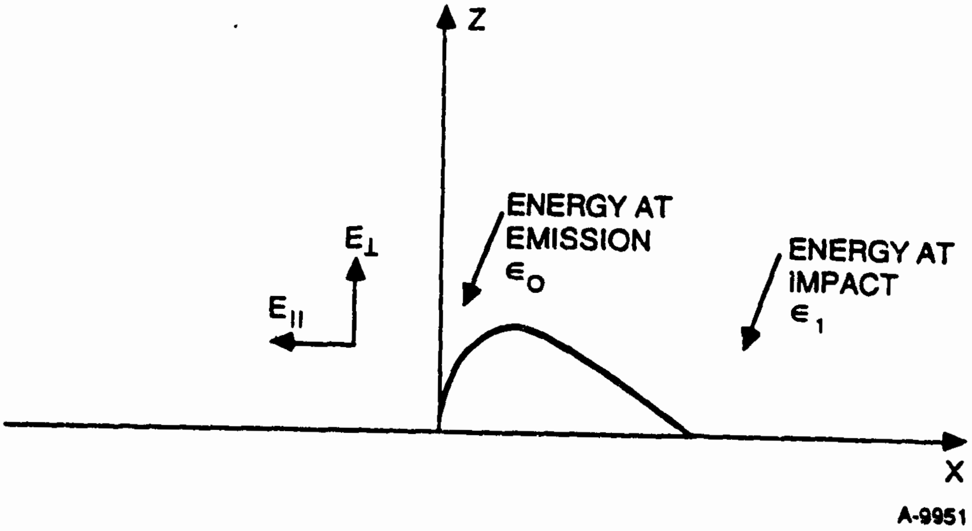

Figure 3: Electron Motion under the Normal and Tangential Electric Fields

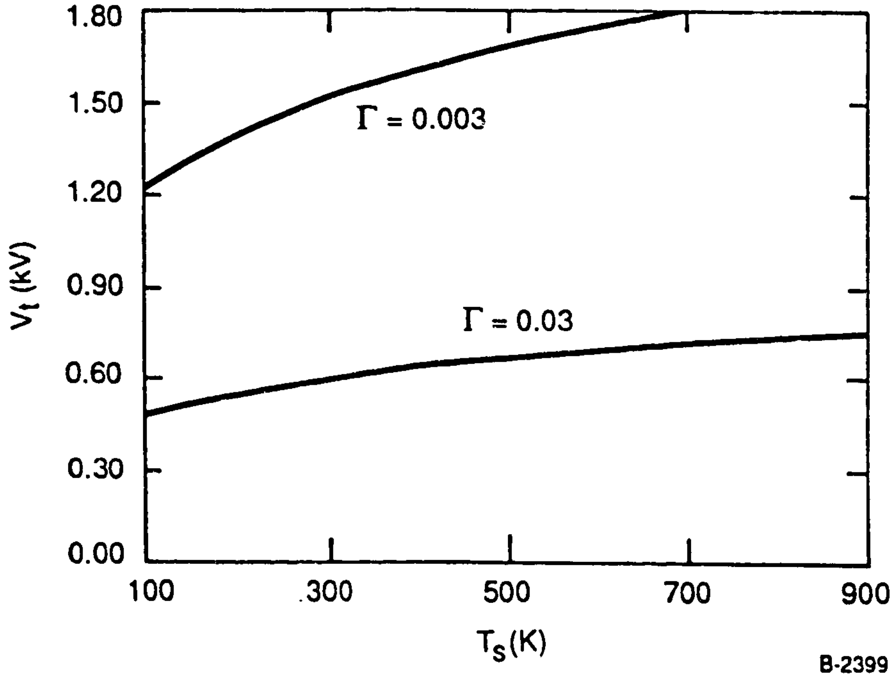

Figure 4: Bound on Threshold Voltage versus surface temperature showing range of variation with gas desorption efficiency. Other parameters are: $m_n = 44$ amu; $\mathcal{E}_1 = 40$ eV; $\mathcal{E}_0 = 2$ eV;$d = 0.15$ mm; $d/l_i = 0.1$; $\sigma_{ion} = 10^{-20}$ m^2 and $\gamma = 1.2$

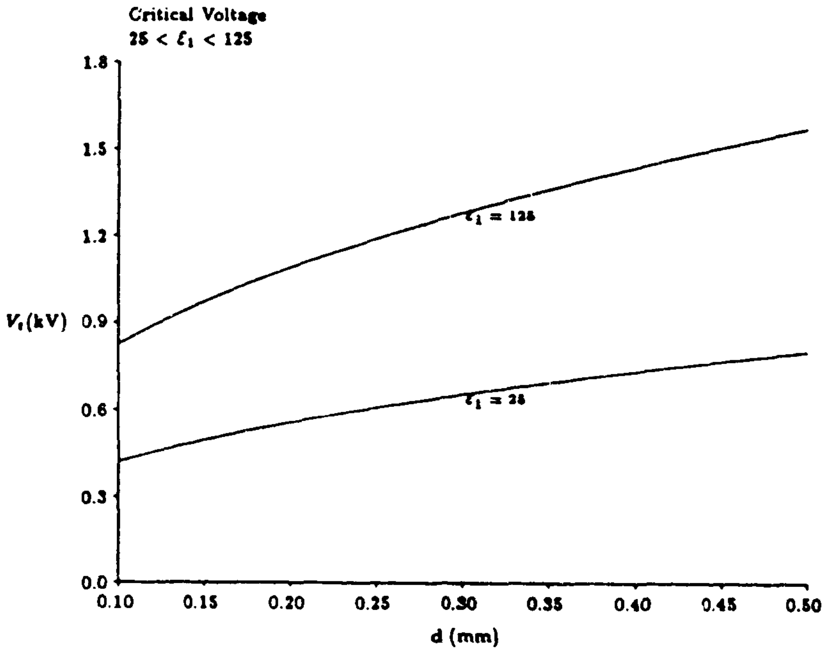

Figure 5: Bound on Threshold Voltage versus coverglass thickness showing range of variation with secondary emission properties. Other parameters are: $m_n = 44$ amu; T_s= 300 K, $\Gamma = 0.03$; $\mathcal{E}_0 = 2$ eV; $d/l_i = 0.1$; $\sigma_{ion} = 10^{-20}$ m^2 and $\gamma = 1.2$.