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DIELECTRICS FOR LONG TERM SPACE EXPOSURE AND SPACECRAFT CHARGING A BRIEFING

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DEEP DIELECTRIC CHARGE EFFECTS

Charging of dielectrics is a bulk, not a surface property. Radiation driven charge stops within the bulk and is not quickly conducted to the surface. Very large electric fields develop in the bulk due to this stopped charge. At space radiation levels, it typically requires hours or days for the internal electric fields to reach steady state.

The resulting electric fields are large enough to produce electrical failure within the insulator. This type failure is thought, by this author, to produce nearly all electric discharge anomalies.

Radiation also induces bond breakage, creates reactive radicals, displaces atoms and, in general, severely changes the chemistry of the solid state material. Electric fields can alter this process by reacting with charged species, driving them through the solid. Irradiated polymers often lose as much as a percent of their mass, or more, at exposures typical in space. Very different ageing or contaminant emission can be induced by the stopped charge electric fields.

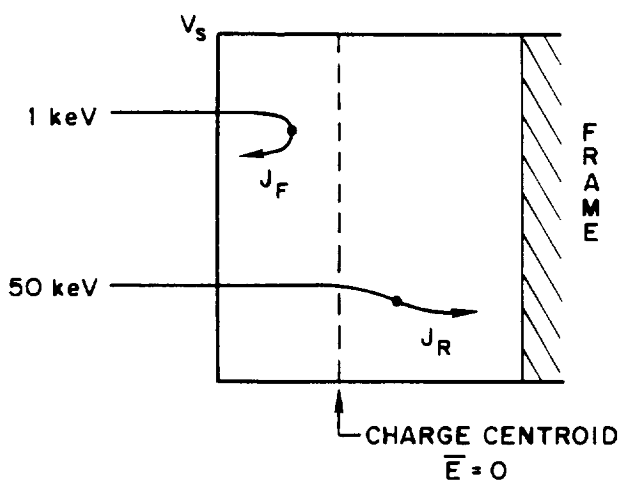
- Modifies or controls surface voltage
- Controls currents within dielectrics
- Increases response time to hours or days
- Causes most electric discharge anomalies
- Modifies properties and ageing of dielectrics
- Modifies emission of contaminants

SURFACE VOLTAGE, V_S

Surface voltage calculations must include the effects of stopped charge. Some of the stopped charge is conducted back to the insulator surface. The rest of the stopped charge is conducted to the satellite frame which, being conductive, is at one potential. The demarcation is marked by the centroid of stopped charge which forms a plane in which the electric field is zero.

The front surface reaches steady state only when these two currents are in steady state and when the position of the zero field plane is constant. For typical insulators, at space radiation levels, it can take hours or days to attain this steady state. However, since space radiations on a given surface of a satellite are not stable in this time interval, steady state is not achieved in most cases.

The major fluctuations in incident radiation are due to sunlight-to-dark transitions, and to passage through differing radiation "belts" during orbit. These fluctuations are sufficient to cause kilovolt excursions relative to frame potential. However, the actual value of surface potential is very dependent on the material properties, thickness, capacitance to frame, etc. but especially to the density of the local space plasma and sunlight intensity. Even when internal fields are large, the surface potential can be clamped to satellite frame potential by sufficient space plasma or sunlight.



- Steady State: J_F == Surface Charge
  J_R == Frame Charge
- BUT, Often, Time Constant > Hours
  STEADY STATE NEVER ACHIEVED

IMPORTANCE OF DEEP CHARGE FOR SURFACE VOLTAGE

Stopped charge within the dielectric does not always alter surface potential calculations. In some situations, only the surface secondary emissions term needs to be considered. For example, small area dielectrics may not strongly affect the average satellite potential as long as they are not the most negative tending surface. For very small dielectrics with high secondary emission yields (which is typical) the surrounding material will control the surface potential, even of the dielectric. In addition, for very thick dielectrics, nearly no current will pass through the insulator, most will return to the surface; thus NASCAP procedures are sufficient when considering only surface emission.

However, there are cases where stopped bulk charge is very important. For typical space spectra, we can expect that thicknesses between 1 micron and 1 mm require detailed calculations to determine the relative flows to the insulator surface and through the bulk to the satellite frame. For such thicknesses, then, determination of the insulator surface potential, relative to the satellite frame, is difficult, and requires calculation of electric fields and currents within the insulator.

- <u>NONE</u>: Average Satellite V. Differential V where: thickness > 10x max range, or thickness < 2nd Xover range.
- <u>LARGE</u>: Differential V where insulator thickness is between 1 mm and 1 micron.

TIME CONSTANT

The time constant for charging within an insulator is similar to the capacitor time constant, RC. However, because each layer of insulator material contacts only other insulator material, the "series resistance" is very high. The effective resistance of space plasma is lower so that the time constants for satellite surface voltages are short compared to the time constants for internal insulator voltages. In the insulator, the time constant, τ, is given by

$$\tau = \epsilon/\sigma = \text{(dielectric constant)/(conductivity)}$$

where σ is a strong function of position depending on dose rate, temperature, UV level, and other factors.

High energy particles stop via atomic collisions, nearly independent of electric field, and produce electric fields. These fields drive conduction carriers thus generating further changes in the fields. The process comes to steady state only when the divergence of current is zero everywhere. Conceptually, the process comes to equilibrium as an exponential but in reality there are many coupled exponentials because of the broad distribution of conductivities throughout the dielectric. It suffices here to warn of some very long time constants in space applications.

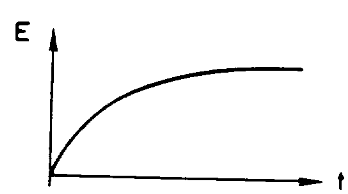
$$\tau = RC \longrightarrow \epsilon/\sigma$$

- High energy particles' range nearly independent of electric field.
- Conduction currents redistribute stopped charge.

$d/dx\ \{J_{fast} + J_{cond}\} \longrightarrow d\backslash dt\ \{\text{deep chg}\}$

$d\backslash dt\ \{\text{deep chg}\} \longrightarrow d\backslash dt\ \{\text{ E field }\}$

$\text{E field} \longrightarrow 1 - \exp\{-\sigma\{x\}t/\epsilon\}$



DISCHARGE ANOMALIES

Dielectric discharge pulses can be characterized in simple ways in order to predict the impact on electronics:

a) The pulse consists of a transient surge of current producing a classical vector potential about the space of the satellite.

b) The currents result from the collapse of energy stored in electric fields into which a dense plasma has been injected. The plasma is created by a failure in a dielectric. The collapsing electric fields cause "image charge flows" in surrounding conductors along with displacement currents.

c) The dense plasma is produced by material responding to the same, or different, electric field. Strong fields separate valence electrons from molecules and thus ionize the material producing a plasma. Field enhancement at a sharp discontinuity continues the process producing a discharge streamer, and the streamer itself becomes a discontinuity and propagates deeply into the material.

d) Rise times can be bracketed by experience, but can not be predicted. They depend on the rate at which material is ionized and injected into regions of high field. This is a very complex, poorly understood, process. See literature for data, especially papers by K. Balmain, et al.

e) Coupling of pulse energy into circuits is complex. Prediction would require full modeling of the induced currents and voltages in all elements of the satellite. Because we are in the near fields ($< 5 \lambda$) all modes of coupling are to be considered, not just TEM.

f) The entire frequency domain is to be considered, from 10^5 to 10^{10} Hertz.

- Electric Pulses Couple to Systems
- Energy Source is Electric Fields:
  Deep Charge or Applied Field
- Fast Rise Time
  Characteristic of Material Collapse
  Not Understood
  Analogy to Lightning
- Coupling is a Large Variable
  All Near-Field Modes
  Energy Limits: I^2R, $1/2\epsilon E^2$, $1/2\mu B^2$
- Pulse widths
  Frequency Domain 10^5 to 10^{10} Hz

PULSES

Sufficient pulses have been created in the laboratory that we can outline their form. Refer to the literature for details, especially the work of K. Balmain, et al. on scaling laws for discharge pulses; amplitudes and slew rates are well reported.

The largest pulses are those which remove the surface voltage of a highly charged insulator. Although not investigated yet, even larger pulses should be expected for high voltage power supplies. A one square meter insulator irradiated with 20 keV electrons has produced pulses which peaked at several hundred amperes and which discharged the insulator surface from initially 18 kV to nearly zero volts. It is presumed that larger pulses would occur for larger samples or for higher surface voltage.

However, small pulses are also seen, and only partial surface discharge occurs. It is presumed that the quantity of plasma produced by the failing dielectric was not sufficient to discharge the surface. Composite materials, such as fiberglass, have been seen to produce small pulses at a rate of a few per second to a few per minute, and continue to do so for days after the radiation ceased. The radio frequency noise of such structures should be considered.

Similar phenomena are intensively studied and reported in the electrical insulation literature under the heading Partial Discharges or Prebreakdown. It appears that all spacecraft events are of this class. In partial discharge only a portion, usually small, of the electric field is collapsed and the electrodes are not bridged by a full arc. After the partial discharge, the dielectric returns to normal and is fully serviceable.

Based on this phenomenology we have two design guidelines! Never allow a large electric field in a large space volume to occur adjacent to a dielectric which may be irradiated; both spacecraft charging and power supply related fields are to be avoided. And, be prepared for rf noise with composites.

- Rise time is controlled by rate of carrier injection into E field.
  - field injection
  - mass transport, pressure
  - avalanching
  - photons {cascade, losses}
  - recombination losses
- HEIGHT, 0 ⟶ 300 Amperes
- WIDTH, 0 ⟶ 10 Microseconds
- ENERGY, Will not exceed stored static energy so we have a DESIGN GUIDELINE.

METAL TO METAL ARCS ?

NOT LIKELY

Currents in space generally do not exceed a nanoampere per square centimeter. If a metal surface becomes highly charged and is associated with a large normal electric field, then one would expect (Fowler-Nordheim) tunneling emission from the surface to equilibrate with the incoming electron currents. The currents and voltages would not be sufficient to cause "vaporization" of the metal surface. Without the emission of large quantities of surface material, an arc in an evacuated space between electrodes will not occur. Tunneling currents will increase to cancel the effects of in-coming space electrons.

Satellites with high voltage power supplies may be another story. If emission from a surface reaches a certain level, then currents in the gap, accelerated by the power supply, may contain enough energy to "vaporize" some electrode surface, and thereby provide the source of ions and electrons to form an arc. A strong power supply is needed to do this. The most likely process, even for the power supply case, is an event triggered by an adjacent dielectric partial discharge pulse. The partial discharge introduces enough plasma so that acceleration by the power supply heats the metal electrode and generates more plasma directly from the electrode. Avalanche can then occur between the electrodes.

We need to definitively answer the question concerning the existence of direct metal to metal arcs. The work should be performed on actual, to be flown, metals because it is impurities characteristic of the metal surface which control the onset of arcing (as discussed in the literature on vacuum circuit breakers used for high voltage transmission line lightning protection.)

A great deal is already known from the high voltage power distribution community and direct arcs are very unlikely at the voltages encountered in space charging. But, perhaps the simultaneous irradiation by the high energy "tail" would activate some surface impurities or oxides to produce partial discharges.

The figure describes an experiment whereby a faraday cup is used to achieve high voltage. The secondary suppressor (see battery) can be used to control the steady state potential by controlling back emission of low energy electrons from the cup. A few high energy particles can penetrate the cup to irradiate the gap along with the bremmstrahlung, if such is desired.

A control experiment should be simultaneously performed. The control should contain an irradiated dielectric adjacent to the metal gap. It is expected that the dielectric will induce many metal to metal current pulses, while the experiment without a dielectric will require inordinant voltage to induce pulses.

METAL TO METAL ARCS
NOT LIKELY

- Space currents do not exceed nanoamp per square cm.

- At high fields, Fowler-Nordheim emission equilibrates with space currents to reach steady state.

- Steady state current insufficient to vaporize metal, so no arc develops.

- BUT, a high voltage power source could vaporize metal to start arc.

- DIELECTRIC IS THE PROBLEM. Discharge in dielectric initiates vapor to start the arc, even in applied field case.

BIBLIOGRAPHY

This briefing focuses on a broad range of materials and effects. The concepts come from exposure to many works and people from several communities. A concise reference list cannot be composed. Instead, the following basic concepts can be found by study of the appropriate literature.

1. Discharge pulses: IEEE Trans. Nuc. Sci. December issues from 1975 to the present. Proceedings of the Spacecraft Charging Conferences which appear as NASA documents CP-2071 (1978), TMX-73537 (1977), CP-2182 (1980), and CP-2359 (1983). The NTIS numbers for the NASA documents respectively are AD/A084626, AD/A045459, AD/A114426, and N85-22470.

2. Dielectric breakdown: IEEE Trans. Elec. Ins. and various proceedings of the international symposium on discharge and electrical insulation in vacuum.

3. Development of leaky materials and review of test procedures: Spacecraft Dielectric Material Properties and Spacecraft Charging by A. R. Frederickson et al., AIAA Progress in Astronautics and Aeronautics Vol. 107 (1986). This is a brief review and a compilation of literature citations, over 200 of them.

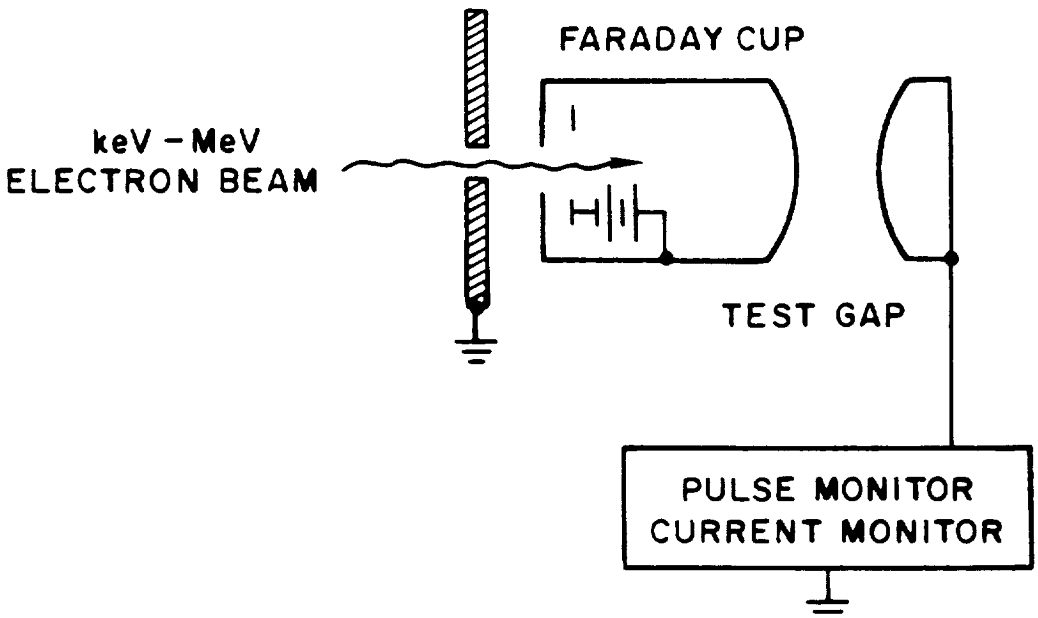
4. Electric fields in irradiated insulators. Same literature listed in 1. above.

METAL TO METAL ARCS
NOT LIKELY

- Space currents do not exceed nanoamp per square cm.
- At high fields, Fowler-Nordheim emission equilibrates with space currents to reach steady state.
- Steady state current insufficient to vaporize metal, so no arc develops.
- BUT, a high voltage power source could vaporize metal to start arc.
- DIELECTRIC IS THE PROBLEM. Discharge in dielectric initiates vapor to start the arc, even in applied field case.

METAL TO METAL ARCS ?

EXPERIMENT



- Faraday cup contains secondary emission suppressor.
- Voltage of faraday cup is monitored using external field probes.
- Beam can partially penetrate if secondary electrons are needed.

INSULATOR FAILURE, STREAMERS

High Electric fields within the insulator interact with imperfections or impurities to initiate a local discharge. The initiated discharge continues to propagate because of amplification of the field strength (x100 in this case) at the sharp tip of the streamer. The amplified field ionizes molecules and the resulting plasma may be liberated to vacuum. The needle-like streamer continues to propagate as long as the field (x100) is sufficient to ionize at its tip, and plasma continues to be produced, escaping from the material where the streamer intersects the surface.

Energy from the electric field within the dielectric heats the plasma and the resulting pressure forces plasma to pass through the streamer to the exit point. The plasma collapses the electric field within itself. There is a radially directed electric field at the wall of the streamer tube which can erode the tube to larger diameter and add to the total plasma production. Recombination within the plasma may be of interest but has not been investigated. The dynamics of streamers is only now being studied, and the knowledge is not sufficient to help us predict what can happen with much certainty.

Externally monitored current pulses are very small when the plasma is collapsing only the fields within the streamer tube in the insulator. However, escaped plasma in the external vacuum is highly mobile and produces large current pulses if an electric field is present in the vacuum. Preventing streamers will prevent pulses.

- High E fields create Streamer type of discharge {not avalanche}.
- Streamers propagate as narrow tubes.
- Tubes of plasma escape the solid. Pressure, Recombination, Erosion
- Escaped plasma collapses the external electric fields -- Large Pulses.
- Internal field collapse, small pulses

SOLUTION = Prevent Streamers !

PREVENT STREAMERS

Pulses are most generally eliminated, at least in dielectrics, by preventing streamers from developing. Experience has shown that prebreakdown pulses usually do not occur for applied fields below 10^4 V/cm. Since prebreakdown pulses are generally associated with small streamers in a local region of a dielectric near a void or imperfection, experiments imply that even with field amplification and field initiated defect growth, fields of 10^4 V/cm will not initiate a streamer.

For space radiation levels, the stopped charge induced fields will be kept to acceptable values if the dark conductivity within the insulator bulk is held to greater than 10^{-12} S/cm. For many insulators, this will occur only by modification of the material. Such modification is not well understood and its reliability in this environment is suspect. Such dark conductivity is the most important solution to the electric discharge anomaly problem.

Another solution is to make thin dielectrics, where they may serve a useful function, in place of thicker dielectrics. Firstly, it is not clear whether streamers will form and propagate for insulators thinner than one micron. Films of < 1000 angstrom thickness discharge or breakdown by other processes. Space radiations are not likely to ever induce sufficient fields in such thin insulators to initiate these other breakdown processes. Useful materials should be tested as a function of thickness using the standard electron beam technique.

In addition, thin films can have a higher conductivity than thick films because the mean free path before deep trapping may exceed the film thickness, and because the environment itself is the source of charge carriers. Thus, because of specific charge transport properties in the material, a thin film may not develop electric fields sufficiently strong to propagate a discharge.

Finally, thin films will have a larger average conductivity due to low energy particle bombardment and penetration, and thus are, again, less likely to support large electric fields.

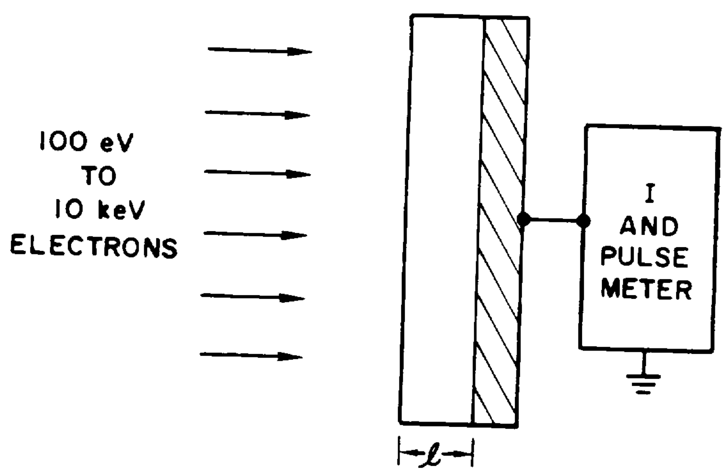
- Limit Fields to 10^4 V/cm
- Add Conductivity > 10^{-12} S/cm
- Decrease Thickness < 1 micron ?
  can streamers form ?
  enhanced conductivity, mfp

THIN FILM EXPERIMENTS

Dielectrics in common use should be made as thin as possible. Even thick dielectrics can be made effectively thin for streamer purposes by burying a ground plane, say a 1000 Å thick metal film, below the dielectric surface at a depth, ℓ, such that discharges will not occur. The thickness dependence on ℓ for the onset of pulsing should be determined.

A number of spectra should be used to investigate a range of thicknesses (1000Å < ℓ < 10 microns) in common dielectrics. For some spectra, a relatively large ℓ will be small enough to eliminate pulses while for other spectra only very thin dielectrics will eliminate pulses. We need a range of data in order to develop design guidelines.

This work should be performed taking into account that long term exposure to vacuum and low level radiation is likely to enhance the probability of pulsing.



- In Vacuum
- Vary Thickness, ℓ, from 1 to 25 microns
- At each ℓ, use 100 eV to 10 keV
- Find ℓ where pulses don't occur

DEVELOP BETTER MATERIALS

Conduction in polymeric dielectrics is becoming a well studied field. Useful concepts and information are steadily developing. Strongly conducting polymers are heavily studied for the obvious terrestrial applications, including superconductivity. The space community does not need to add to the fray in this discipline because progress is already rapid. But enhancing conductivity in good insulators, a need in space applications, sounds like nonsense to most people. The space community needs to help the work in this discipline (leaky insulators) because making normal dielectrics leaky is the best solution to the electric discharge anomaly problem.

The terrestrial applications include photoconductors and antistatic materials. A recent survey of possible new materials (this author with others published by AIAA) indicates that good spacecraft candidates include: polyvinylcarbazole, polyimide, polythiazyl, polypyrrole and polyacrylonitrile. But such materials require special development.

The rigors of the space environment are very different and usually more severe than on earth, at least for polymers. The material properties must be matched against these problems. Testing for space applications, at this time, does not take into consideration the effects of electric fields and radiation gradients on the materials. Electric fields will drive the reactants through the sample, over long time scales, producing different end of life results. Radiation chemistry in polymers must be addressed with respect to electric fields and with respect to effects on conductivity. This is a withered field which needs some fertilizer. As leaky materials are developed for space applications, proper testing is needed to predict the long term stability of the level of leakiness.

- Maintain Enough Conductivity
- Reliable > 10 Years
- Radiation Effects
- Other Damage
- Accelerated Testing

PARAMETERS TO TEST

Candidate materials (leaky insulators, paints, etc.) require realistic testing prior to launch. All the standard tests would be continued, of course. In addition, the following tests would need to be added:

a) Amount and kinds of impurities desorbed while under UV, optical, proton and electron irradiation; all in the presence of both polarity electric fields up to 10^5 V/cm within the dielectric.

b) Reaction rates at interfaces where electric fields accelerate flow of reactants to the interface. Perhaps a bond failure will be accelerated by this process.

c) The relative levels of constituent atomic species emitted into vacuum under irradiation is an indication of the kinds of bond breaking created by radiation. This should be studied in the presence of extreme electric fields, $10^4 < E < 10^5$ V/cm.

d) Radiation enhances conductivity by generating mobile charge carriers. Electric fields can sweep out such carriers or deposit them in sensitive regions. Alternatively, radiation can create traps and lower the number of mobile species. Transient conductivity might increase while dark conductivity decreases; both are important independently. The effects of electric fields on both forms of conductivity, over long radiation exposure times needs to be assessed for critical, actually used dielectrics.

- Typical such as strength, color, etc.
- Desorbed Impurities
- Desorbed Radicals
- Impurities, radicals react at rear attachment
- Atomic Species Emitted
- Long Term Dark Conductivity
- Field-Driven Reactant Currents

QUICK TESTS - DAYS

Some of the tests can be performed quickly, in a few days. Tests of the material to study its initial response, those effects which happen rapidly, can be done using electron or proton beams. Charging by the beams creates the electric fields. Irradiation at higher than space intensity speeds up some of the effects.

We should look at emission of atoms and molecules once the field has developed (10^5 rads) using mass spectrometers. Comparison to zero field and reverse field emissions should be made.

Conductivity, both dark and transient, should be made soon after and during irradiation. The method of measurement must quantitatively account for the fields of stopped charge to truly measure conductivity. Conductivity is likely to be a function of dose rate, accumulated dose, field strength, trap density, loss of ions to vacuum, radiation generated radicals, etc. Therefore, changes in conductivity should be noted over a period of time.

Electron emission should be measured immediately upon irradiation before the surface changes potential. Thereafter it should be measured periodically to see if radiation chemistry effects may have changed the surface. This should be done with differing internal fields so that the field driven radical effects can be discerned. Perhaps positive radicals do not change secondary emission whereas negative radicals do. Positive radicals are driven away from the surface by electron beam charging, so other methods (proton beam, rays, X-rays, applied bias) are required to send positive radicals to the surface.

SOME TESTS CAN BE DONE WITH ELECTRON BEAMS

- Initial Radical or Impurity Release, mass spectrometer
- Initial Test of Conductivity, S/cm
- Initial Electron Emission Level, secondary emission
- Above tests again later, after exposure to vacuum/radiation

LONG RANGE TEST PROBLEMS

There are long term problems, the interpretation of which lead us to further investigation of candidate materials. For many important processes, accelerated testing is very difficult. When we measure conductivity in these materials, what are we seeing? Very often we see short term mobility of radiation generated ions/radicals. Slowly, over time, the effect of these species can change by orders of magnitude. This is but one example of the classical materials ageing problem, addressed specifically to conductivity.

Conductivity caused by radicals and mobile ions can not be relied upon in space. There may not be an electrode on the dielectric surface to trap the mobile species inside. Yet charge exchange can occur, bonds broken, and thus the species can outgas. Only electronic carriers (holes, electrons, protons, ...) can be relied upon since space is a source of them, yet, they are not always sufficiently mobile. The measurement of conductivity must distinguish charged mass currents from electronic currents.

Charged mass (ions, etc.) must be carefully investigated for stability. Do they escape over time, do they bond and thus become inactive as carriers, are they a source of ageing/failure at interfaces, and are they driven to interfaces by electric fields? Temperature may play an important role. High temperatures may not be bad as it can allow annealing of damage created by radiation. All of these things need to be investigated under the influence of electric fields which can drive reactions into or out of specific regions of the material.

- Do conducting ions escape ?
- Do radicals escape ?
- Do radicals accumulate and change the material ?
- Does electric field drive atoms, radicals or impurities ?
- Slow Chemistry, field enhanced
- Conductivity Increases or Decreases ?
- Which is worse, hot or cold ?

ACCELERATED LIFE TESTS

Man-made leaky dielectrics form an essentially new class of material. Requiring them to have specific levels of conductivity over long times in difficult environments is an unusual requirement. Semiconductors are disrupted in the space environment by the creation, over long times, of displaced atom defects. Relative to insulators, semiconductors have very high concentrations of charge carriers, so the space environment does not appreciably alter the carrier concentration. In insulators, however, the environment can severely alter the charge carrier density as well as the material structure and carrier transport properties. There is little good information on carrier transport properties, nor on structural defects relating to carrier transport, in insulators.

We can not accelerate testing on leaky dielectrics, at this time, because we can not describe the physics/chemistry well enough to use short tests to predict long term behavior. Running an electron beam for a year is not practical, but the same effects, including generation of stopped charge fields, can be performed using radioisotopes such as cesium or cobalt. The long term exposure can be interrupted, perhaps monthly, to measure the properties of the material. Generally, electron beams will be the best probe to measure the properties.

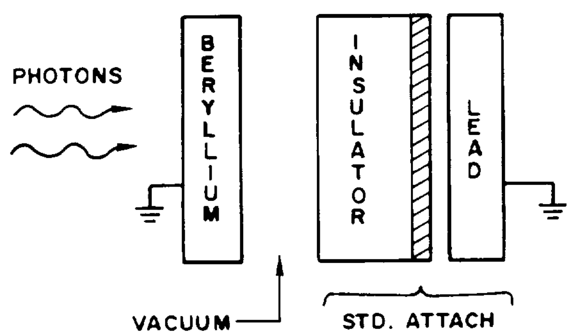
- Impossible, but let's try.
  How about 1 year for 10 year life ?
- Use cobalt 60, cesium 137, or reactor
- Test at: 10^6 rads/hr. $\longrightarrow$ 10^{10} rads
  10^5 rads/hr. $\longrightarrow$ 10^9 rads
- Use high atomic number interface to produce large E field
- Periodically test for parameters using electron beam:
  conductivity/breakdown
  secondary emission
  radical emission

CO 60 OR CS 137 TESTS

This is a method for creating large electric fields in insulators using gamma rays. I have created lichtenberg discharges using this technique. Windows in cobalt 60 cells have broken due to electrical discharges caused by an analog to this structure.

The beryllium, along with air in front, creates a strongly forward directed flux of high energy electrons, mostly compton electrons. Beryllium thicknesses of 3 mm to 10 mm are fine. The lead creates a flux of photo and compton electrons, a reasonable proportion of which are directed backwards into the insulator. Breakdown strength fields can be attained after as little as 10^5 roentgens exposure in this configuration. On the other hand, if carbon were to surround a polymeric insulator (carbon based, not silicon based) then large E fields would never be attained.

One can test the long term response of insulators to the combined action of radiation, vacuum and electric fields. Even a surface bond, such as glue or evaporated metal can be tested, as shown. The change in material properties would be monitored primarily by periodically removing the sample for short periods of testing. Electron beams would be a good probe to measure properties such as conductivity after the above radioisotope exposures are performed.



- Vacuum allows escape of mobile species.
- Be and Pb create divergent electron current, negative charge build-up.
- > 10^5 V/cm in good insulators
- Also tests "glue" or attach

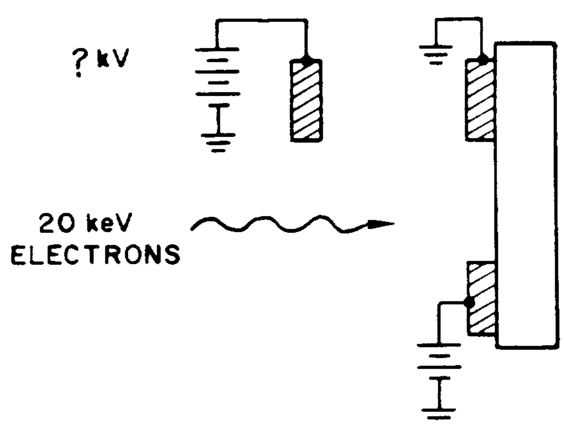
NEW PROBLEM

Some initial experiments have been performed by this author and coworkers which indicate that radiation can initiate electrical breakdown in capacitor structures. The process had been neglected because generalized "irradiate it and see what happens" experiments over the years found no statistically significant change in the probability of breakdown for insulators in or out of radiation.

We find that by choosing the radiation spectrum based on the electrode/-insulator geometry, one can quickly initiate full breakdown for some geometries. Much more work needs to be done. These results are in the process of writing and hopefully will appear in the literature next year. The electric fields in the insulator are caused by the combination of applied (power supply) voltage and deep charge induced fields. When the combined field initiates and propagates a streamer which spans the dielectric, then the electrodes are shorted by the plasma in the streamer, and full breakdown can occur. Space and ground experiments need to be performed.

Dielectric Discharges Next to a Power Line - Will this arc the power supply by initiating a wire to wire plasma arc ?

EXPERIMENT



Much more work needs to be done, but initial answer is YES !

RECOMMENDATIONS

1. Perform ground tests on dielectrics for the combined effects of total dose and electric fields upon the properties critical for surface charging calculations (such as in NASCAP).

2. Perform ground tests for long term effects of dose and electric field on conductivity of insulators used in space. Such measurements would be best if performed with electron beams as the measurement probe.

3. Perform space experiments on the long term conductivity of insulators in space. Satellite surface insulators as well as those inside the structure should be tested by periodically measuring the current between electrodes as a function of voltage applied. Interdigitated electrodes are preferred. Electron gun measurements would be ideal but would make the experiment much more complicated and limit the number of samples which can be tested.

4. With constant applied bias, monitor exposed dielectrics for electrode to electrode arcing caused by streamer propagation completely spanning the space between electrodes. Perform ground experiments first in order to scope the problem, and then design space experiments based on those experiments.

5. Develop new semi-insulating polymers for space applications. Several approaches look promising and some work is in progress. These materials must be tested for long term exposure to see if the conductivity remains stable. Space and ground tests are needed, remembering to be especially careful to test under all internal electric field conditions: positive, zero and negative fields adjacent to the surface.

6. Perform both space and ground experiments when a power supply produces the electric fields in the space adjacent to a dielectric. Irradiate the dielectric to create discharge pulses, and look for large currents to the power supply lines. Is there some power supply voltage which sustains an arc, once initiated ?

7. Without dielectrics present, perform ground experiments to show that metal to metal arcs can, or cannot, occur. For typical spacecraft potentials, I predict that they cannot occur.

8. Perform ground tests of the thin film hypothesis; that very thin films can not produce an internal discharge and thus can be used even though their bulk conductivity is too low for thick film applications. Space tests would follow the ground tests, if successful.

9. Develop accelerated testing procedures using radioisotopes where one year exposure is not too expensive. These ground tests should be performed on existing insulators as well as on those developed for future use.

10. Determine the spectral distribution of radio frequency noise generated by irradiated composites.

BIBLIOGRAPHY

This briefing focuses on a broad range of materials and effects. The concepts come from exposure to many works and people from several communities. A concise reference list cannot be composed. Instead, the following basic concepts can be found by study of the appropriate literature.

1. Discharge pulses: IEEE Trans. Nuc. Sci. December issues from 1975 to the present. Proceedings of the Spacecraft Charging Conferences which appear as NASA documents CP-2071 (1978), TMX-73537 (1977), CP-2182 (1980), and CP-2359 (1983). The NTIS numbers for the NASA documents respectively are AD/A084626, AD/A045459, AD/A114426, and N85-22470.

2. Dielectric breakdown: IEEE Trans. Elec. Ins. and various proceedings of the international symposium on discharge and electrical insulation in vacuum.

3. Development of leaky materials and review of test procedures: Spacecraft Dielectric Material Properties and Spacecraft Charging by A. R. Frederickson et al., AIAA Progress in Astronautics and Aeronautics Vol. 107 (1986). This is a brief review and a compilation of literature citations, over 200 of them.

4. Electric fields in irradiated insulators. Same literature listed in 1. above.