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9. A Rugged Electron/Ion Source for Spacecraft Charging Experiments

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1. BACKGROUND

For the past several years, SRI has been involved in a laboratory investigation of the behavior of materials under simulated spacecraft charging conditions. These tests require that a sample be installed in the vacuum chamber, the chamber pumped down, the test run, and a new sample installed with the minimal delay. To carry out such a program, it has been necessary to have a rugged, reliable electron/ion source available. A simple, novel technique has been developed for generating a large-diameter, uniform electron beam with appropriate current density for spacecraft charging studies.

Our experimental work started using thermoelectric sources. The following difficulties were experienced:

(1) Contamination – the cathode became contaminated by products evolved from the test sample. (Differential pumping was not used in our system.)

(2) Beam uniformity – achieving a large-diameter beam with uniform current density proved difficult.

(3) Beam diameter – expanding the beam from a thermionic cathode to a diameter of 8-10 in. in a distance of a foot was difficult.

(4) Beam characteristics depend on accelerating voltage – it was found that with simple lens arrangements, changing beam energy also changed other beam parameters.

(5) Complex electrostatic lenses required – progressively more complex lenses were needed to achieve desired beam properties.

(6) Light from filament – in photoconductivity experiments, the light from the filament can alter material behavior.

Accordingly, it was decided that an alternate electron source should be devised.

2. MULTIPACTOR BREAKDOWN

Past experience with rf voltage-breakdown mechanisms in low-pressure systems indicated that a process was available with the promise of generating an electron beam without the disadvantages of thermionic cathode systems. As indicated in Figure 1, when an rf signal is applied to a pair of parallel plate electrodes and the ambient pressure is reduced monotonically, one finds that the voltage required to produce breakdown decreases until a minimum is reached (at a pressure of ≈ 50 microns Hg in the Figure) and then increases again (along the dashed line in the Figure).[1] If the electrode spacing is correct, however, one finds that the breakdown voltage becomes independent of pressure and follows the solid curve at low pressures.[2,3] In this case, a new type of breakdown called "multipactor" occurs.

The mechanism of multipactor discharge is illustrated in Figure 2. If rf frequency and spacing are correct, an initial electron occurring near the lower electrode will be accelerated across the gap, strike the upper electrode, and generate one or more secondary electrons just as the field changes polarity. The secondary electrons, in turn, are accelerated across the gap and generate additional secondaries when they strike the lower electrode. In this way, the number of electrons in the breakdown cascades until various loss mechanisms come into play and limit further growth in the number of electrons participating in the breakdown.

Thus, the multipactor breakdown may be thought of as a sheet of electrons oscillating between a pair of electrodes in synchronism with the applied rf field. It should be noted that there is no requirement for the presence of gas molecules to sustain the breakdown. In fact, if there are air molecules present, they will ultimately be struck by an electron and ionized. These ionized gas molecules are responsible for the slight glow visible in the breakdown. The multipactor proceeds very well, however, even in hard vacuums.

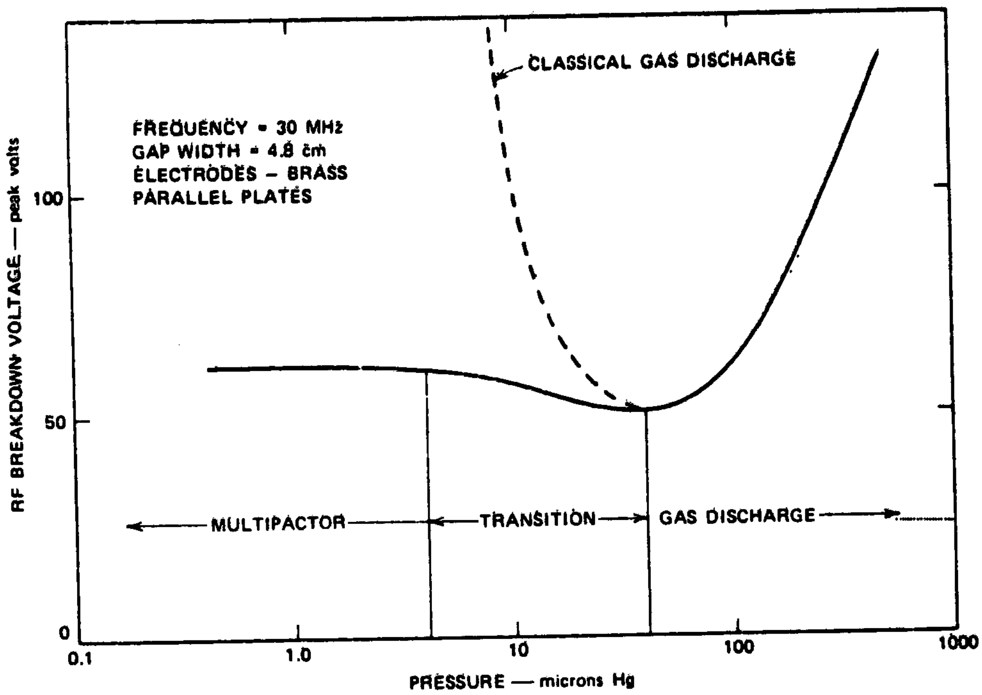

Figure 1. Variation of RF Breakdown Voltage With Pressure

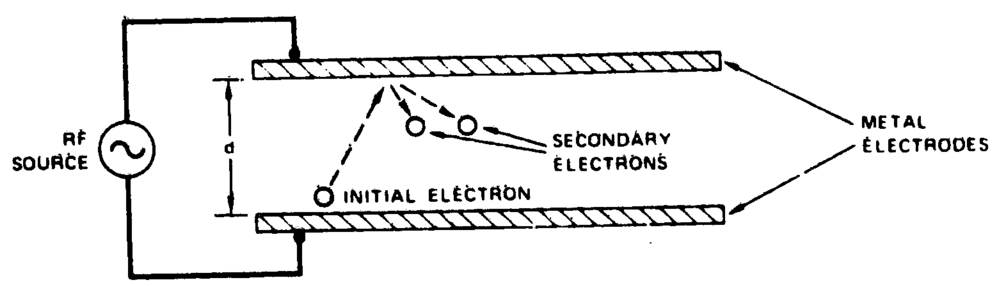

Figure 2. Illustrating Multipactor Discharge

Although the multipactor breakdown is a resonance phenomenon, the resonance is very broad as is evident from Figure 3 which shows the regimes over which multipactor breakdown can occur. For example, frequency can be varied over a 2 to 1 range, and applied voltage can be varied by a factor of 3 without extinguishing the breakdown. The numbers (n) indicate the various modes possible (n corresponds to the number of half cycles required for an electron to cross the gap).

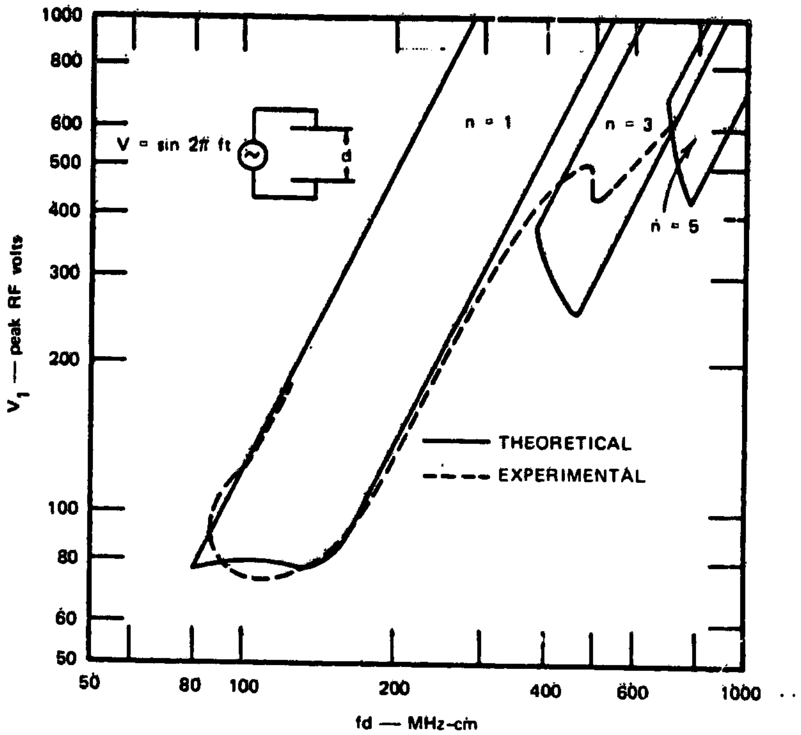

Figure 3. Multipactor Breakdown Voltage as a Function of Frequency and GAP Width for Parallel-Plane Electrodes

3. MULTIPACTOR ELECTRON SOURCE

As was indicated earlier, the number of electrons participating in the breakdown increases until loss mechanisms become important. These include diffusion of electrons from between the gaps as the result of Coulomb forces, deviation from synchronism of some of the electrons, etc. Past experience in trying to avoid multipactor indicated that considerable additional loss can be tolerated without extinguishing the discharge. This in turn indicated that it should be possible to deliberately extract a sizable electron current from the discharge.

The first approach at devising a scheme for electron extraction is shown in Figure 4. Holes were simply drilled in one of the electrodes to permit part of the electron sheet to pass through the electrode once per rf cycle. It was found that this scheme worked remarkably well. It was possible to drill a sufficient number of holes in the plate that at a distance of 12 to 18 in. from the multipactor source, there was no pattern evident in the beam when it illuminated a phosphor target.

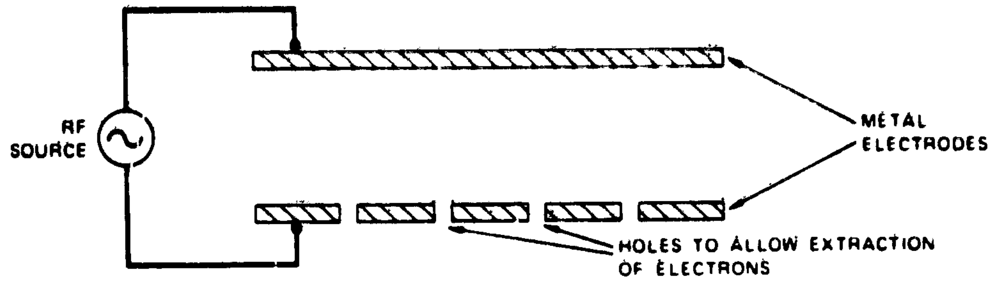

Figure 4. Multipactor Discharge Electrode Modified to Permit Extraction of Electrons

As the result of this initial success, and because an electron source was badly needed for a series of experiments that were getting under way, there was no further experimentation to devise alternate schemes for electron extraction.

The setup presently in use for the study of insulator photoconductivity is shown in Figure 5. A control grid (consisting of a second metal sheet drilled with the same hole pattern as the lower multipactor electrode plate) was added to the source to permit simple control of beam current. For these experiments, the accelerating voltage is applied between the gun and the target. By simply adding a grounded grid above the target, it is possible to obtain the same beam current while maintaining a region of zero field above the target. Radio frequency power requirements to feed the source are modest (under 10 W). Ceramic capacitors are used in series with the coaxial cable from the rf source to provide isolation for the 0-20 kV accelerating voltage used with the system.

The multipactor source currently in use provides a beam 8 in. in diameter at the source, and somewhat larger at the target. In the limited experimentation carried out on the source so far, electron beam current densities of up to 5 $\mu A/cm^2$ have been achieved. It is not clear that this represents the highest current achievable with this source. It is also likely that the present source design does not represent the optimum scheme for generating maximum current, however, the presently attainable beam current density is almost 3 orders of magnitude higher than typical substorm currents.

A larger beam can be achieved by using larger diameter plates in making the source. An advantage of this approach over trying to spread the beam via lenses is that, with the present setup, beam size is virtually entirely independent of accelerating voltage.

The characteristics of the mutlipactor source can be summarized as follows:

(1) Contamination resistant

(2) Physically simple

(3) Produces large diameter beam directly

(4) Beam characteristics independent of accelerating voltage

(5) Stability good

(6) No light output

Its operation, in the year since it was first assembled, has been highly satisfactory, and it is recommended as an electron source for systems that must operate under conditions where normal good vacuum practice regarding long term cleanliness must be ignored.

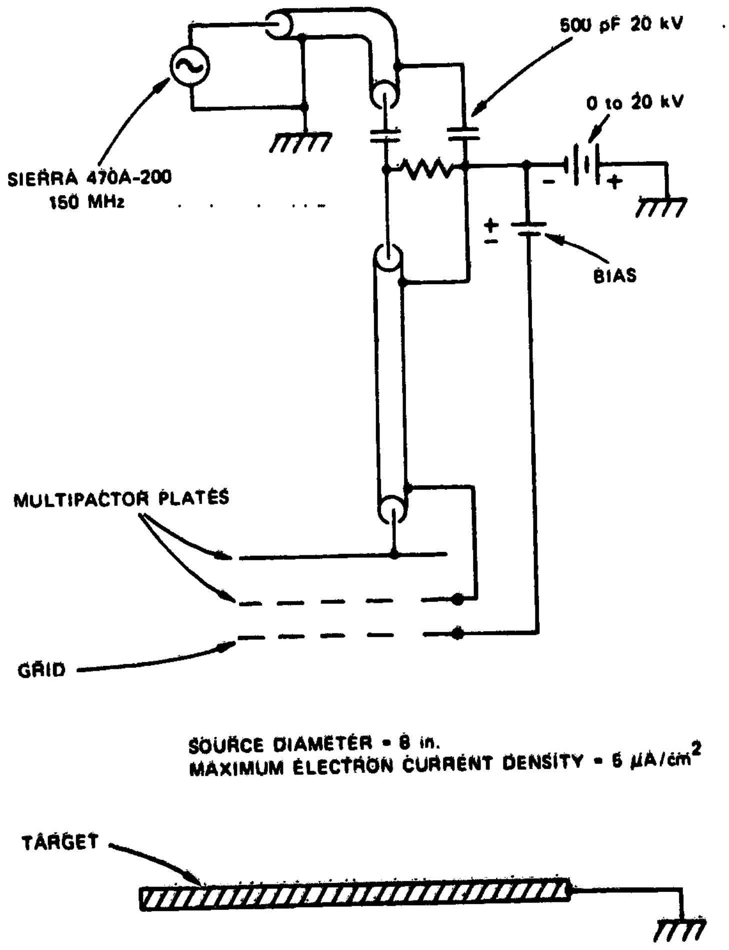

Figure 5. Schematic of Multipactor Electron Source

References

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2. Chown, J.B., Nanevicz, J.E., and Vance, E.F. (1970) VHF Breakdown on a Nike-Cajun Rocket, JPL Technical Memorandum 33-447.
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