EMBEDDED-PROBE FLOATING POTENTIAL CHARGE-DISCHARGE MONITOR

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Abstract

Described is a device that responds to the floating potential of an electrically isolated (or "floating") metal probe embedded in a dielectric slab and exposed to a source of energetic electrons. With the passage of time, the probe potential becomes increasingly negative due to the accumulation of electric charge both on it and nearby it in the surrounding dielectric, until equilibrium is reached between charge influx and charge conduction or emission.

The device ultimately would be mounted on a spacecraft positioned in an energetic-electron environment, typically in geo-synchronous orbit or geo-transfer orbit. The probe-plus-dielectric configuration would be designed to represent a relevant possible site for electrical breakdown, for example with the metal probe representing the inner conductor of a coaxial cable or a metallic trace on a printed-circuit board. A high probe floating potential or an abrupt change in potential would serve as advance warning of a charge accumulation threat or an electrical breakdown threat in the vicinity of the monitor. Multiple units with probes at different depths would respond preferentially to electrons with different penetration depths (i.e. different energies), thus conceivably providing data for correlation with energetic-particle spectra from other instruments on the same satellite or ones nearby.

Two designs are described, one motor-driven and one piezo-vibrator-driven, so that the mechanical movement can generate an electrical signal suitable for processing because it is proportional to the floating potential. Under high-vacuum exposure to Strontium-90 electrons up to 2 MeV, floating potentials to 12 kV have been measured, with breakdown and breakdown recovery detected. Various laboratory measurement examples will be presented.

Introduction

This paper describes two versions of a charge monitor. The main difference between the two versions are the means by which an AC signal that is proportional to the probe floating potential is generated. The first version involves a motor-driven perforated drum as a field interruptor and the other one involves a modulated high-voltage capacitor.

Figure 1. Motor-driven monitor: dielectric samples and embedded probes in the motor-driven monitor.

The first two sections of this paper describe the motor-driven and the piezo-driven versions, respectively. This is followed by one section each on the experimental results from each monitor.

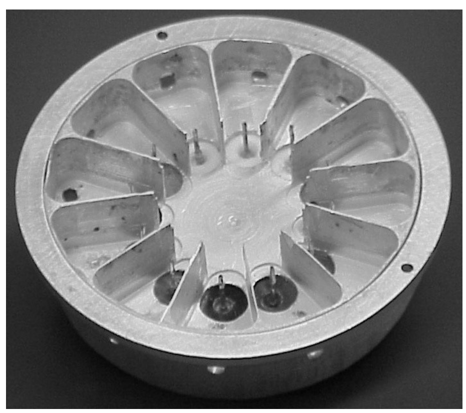

Figure 2. Motor-driven monitor: probes from dielectric samples, adjacent to perforated drum (not shown).

Motor-Driven Charge Monitor

This monitor includes an aluminum housing which is divided into twelve triangular sections, each separated by aluminum partitions which are part of the housing. These triangular sections each hold a dielectric sample such that the sample exactly fits into the space between the partitions. Each sample has a wire embedded in it which can be at three different depths in the dielectric – on its surface, or in the interior at depths of 2 mm or 4 mm. Figure 1 shows the top view of the setup, which is the side which is exposed to highly energetic particles. Some of the embedded wires are clearly visible in Figure 1.

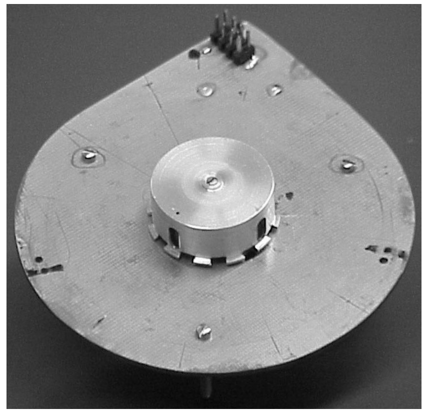

Figure 3. Motor-driven monitor: perforated-drum field interruptor.

The embedded wires are connected to one probe each, protruding from the bottom of the housing. Note that the wires are not in electrical contact with the housing and therefore can be considered as floating. Figure 2 shows the bottom of the setup with the twelve probes arranged in a circle. Partitions exist there as well to suppress crosstalk from the probes.

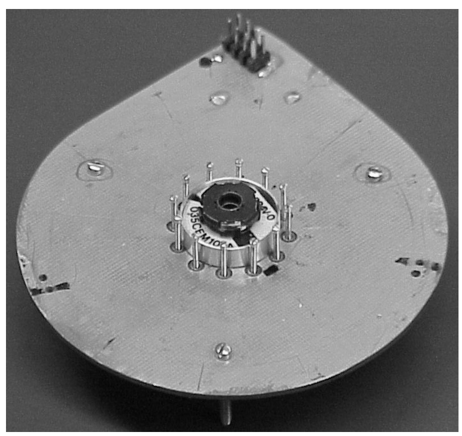

Figure 4. Motor-driven monitor: drive motor and probes to electronics.

Figure 3 shows the base of the setup which has a rotating drum that fits into the circle in which the probes are arranged in Figure 2 and is adjacent to the probes. A motor drives the drum which has a periodically perforated wall which is between the probes and a separate set of probes, which we may call sensing posts. The motor and the sensing posts are shown in Figure 4. Each sensing post is connected to an operational amplifier which provides an amplified signal proportional to the voltage on the probe. The electronics board is shown in Figure 5.

The rotation of the perforated drum opens and closes the windows, thus periodically turning on and off the weak electric field between each probe and its corresponding sensing post. Therefore the DC voltage on the probes is converted to an AC voltage on the sensing post.

The rim of the drum is notched to form tabs which extend outwardly from the drum wall (Figure 3) and a hole is located in the base positioned such that the tabs periodically over it so that a light beam emerging from a light source below the base is reflected back to an optical reader. This is used to synchronize the system.

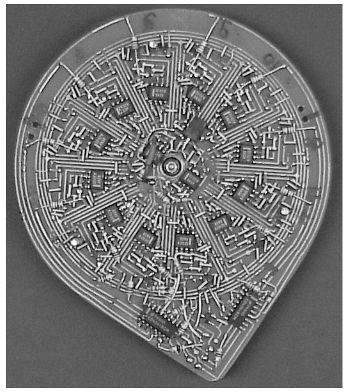

Figure 5. Motor-driven monitor: electronics board.

Piezo-Driven Charge Monitor

A cut-away drawing of another type of charge monitor is shown in Figure 6. This monitor can be operated mounted on a satellite or in a laboratory vacuum chamber. One main difference compared to the monitor described in the previous section is that no moving parts are needed to generate the AC signal. This entire charge monitor is contained within a cylindrical aluminum housing. A cylindrical aluminum screw holds in place a dielectric sample with an embedded metallic probe. The probe is connected to a metal disk which is electrically floating and is parallel to and spaced from a grounded metal disk on which a piezoelectric ceramic driver is mounted to vibrate it at a selected frequency. In order to make electrical contact between the embedded probe and the floating metal disk a pressure contact is maintained via a metal spring that presses directly against the probe. The spring is mounted over a conducting rod threaded into an insulating Teflon web. To avoid residual-gas breakdown, an elastomer O-ring seals a potential breakdown path through the channel that carries the spring and the rod. The floating metal disk is also connected to three identical 80 pF high-voltage capacitors C_3, C_4, and C_5. Since the probe can charge up to a floating potential of 15 kV, everything connected to the probe, including the floating metal disk, has to be contained in a Teflon insulating chamber.

The grounded metal disk and the floating disk which is at the probe potential form a parallel-plate capacitor and, due to the grounded disk driven by the piezoelectric vibrator, its capacitance oscillates. In the equivalent circuit of Figure 7, which also includes the high-voltage capacitors C_3, C_4, and C_5, this oscillating capacitance is labelled as C_1 and the probe voltage is denoted as “test voltage V”. The oscillating capacitance produces an oscillating capacitor plate charge and therefore an oscillating current and AC voltage picked up by the signal processor at point A in Figure 6. This corresponds to voltage V across R in the circuit in Figure 7.

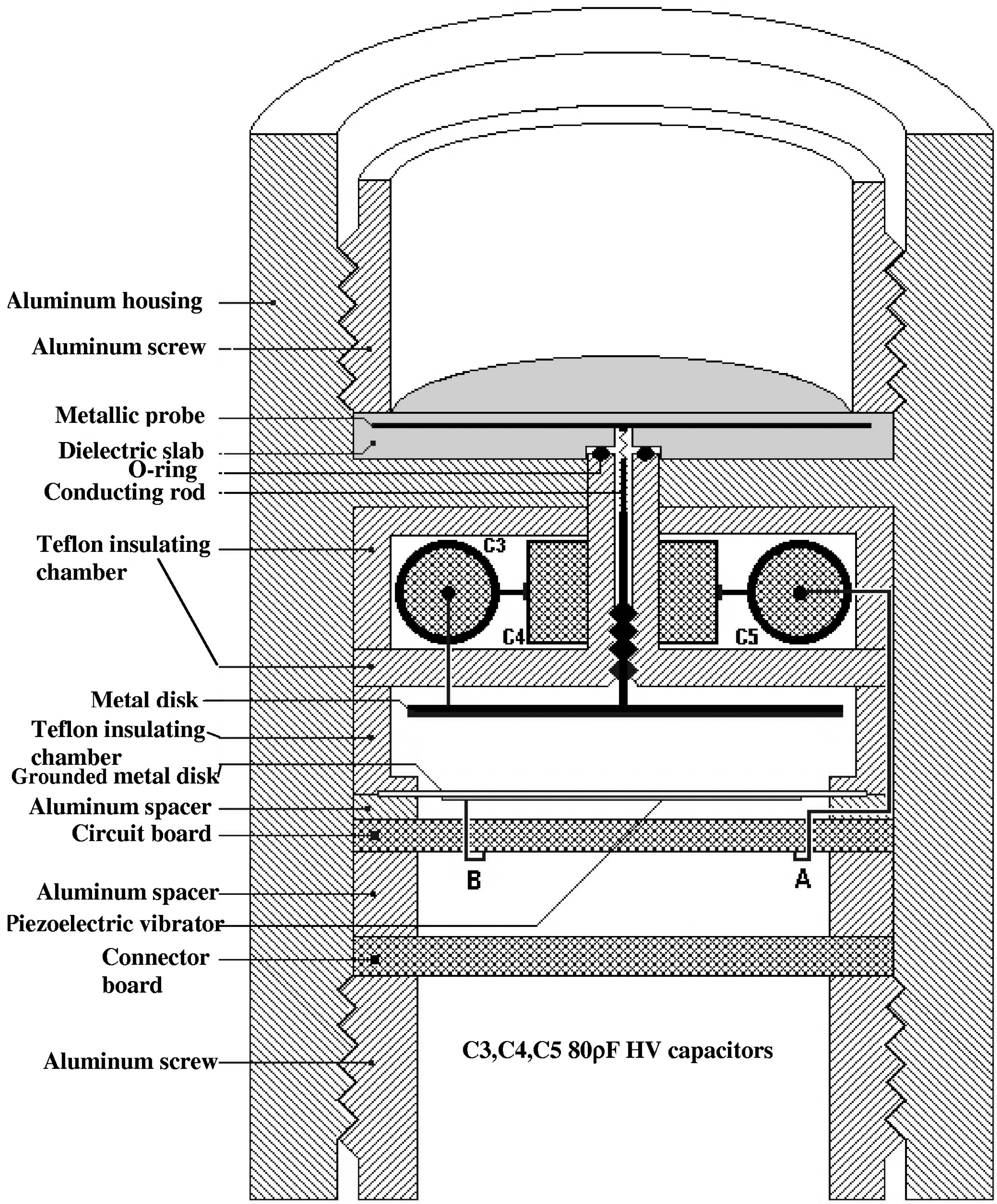

Figure 6. Piezo-driven monitor: cut-away drawing.

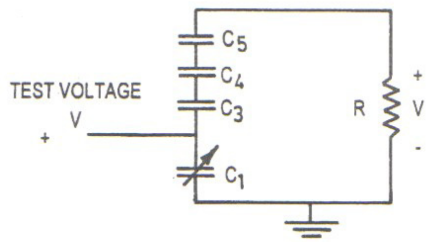

Figure 7. Piezo-driven monitor: circuit showing piezo-driven capacitor C_1 and high-voltage fixed capacitor C_3, C_4, C_5, connected in series for a sufficient high-voltage rating. R is the input impedance of the signal processor.

Figure 8 is the top view of the monitor with dielectric slab removed showing the container well and the probe contact. Figure 9 displays its connector end displaying the view of the connector board. In Figure 10 the connector board has been lifted up to show the electronic circuit board.

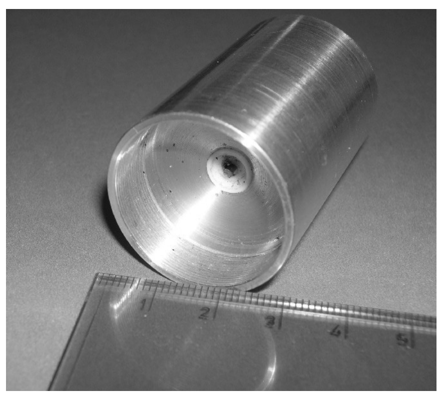

Figure 8. Piezo-driven monitor: container well for dielectric sample showing probe contact.

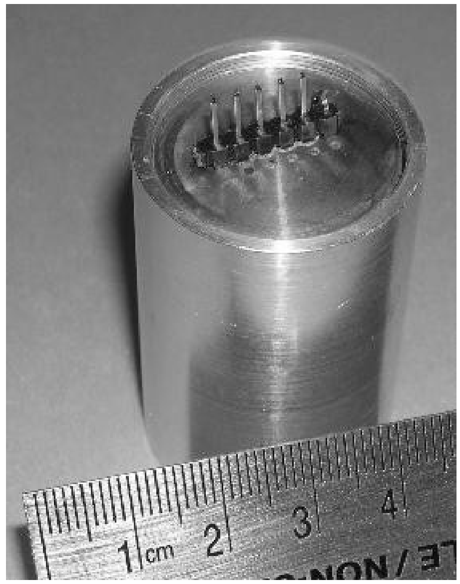

Figure 9. Piezo-driven monitor: connector end.

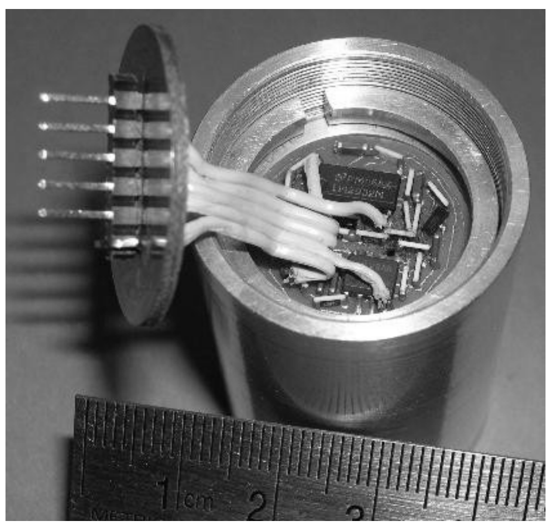

Figure 10. Piezo-driven monitor: connector and electronics.

<u>Experimental Results for the Motor-Driven Monitor</u>

Experiments using a Sr^{90} source emitting electrons with energies up to 2 MeV have been carried out using the motor-driven monitor. Results for samples of Rexolite, Acrylic, and Teflon are shown in Figure 11.

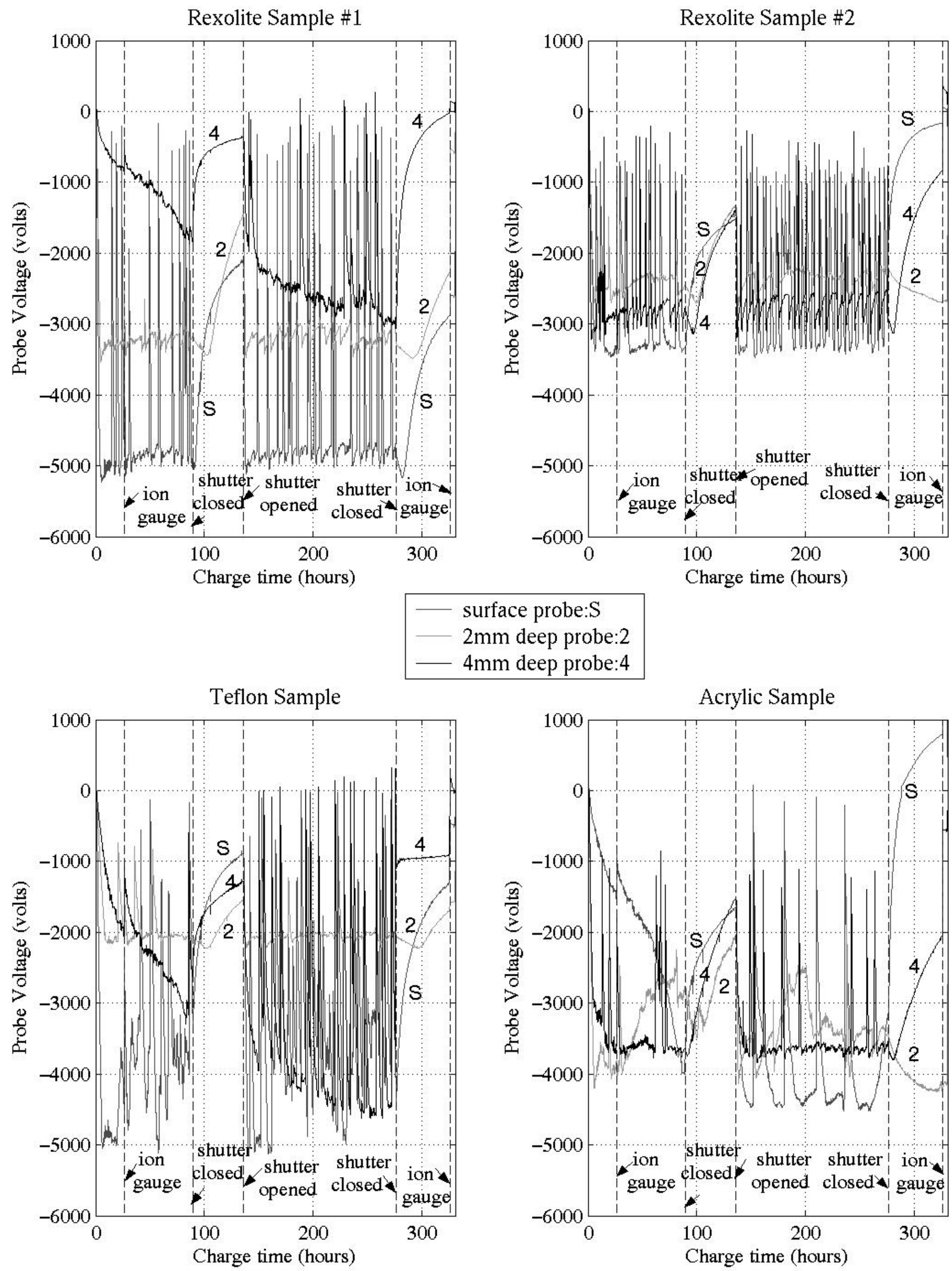

Figure 11. Motor-driven monitor: results for two Rexolite samples (top), a Teflon sample (bottom left) and an Acrylic sample (bottom right).

The various samples exhibit similar phenomena. Turning on the ion gauge produces enough ions to partly neutralize the surface. Closing the shutter starts a decay lasting about two days. The probes exhibit greater charging and more discharges as the probe locations become closer to the surfaces. However the sample to sample variations are significant but as yet unexplained.

Experimental Results for the Piezo-Driven Monitor

Initial measurements using the Sr^{90} source were carried out with the piezo-driven monitor with a Teflon sample. The results are shown in Figure 12. Qualitatively the sample results are similar to the motor-driven case.

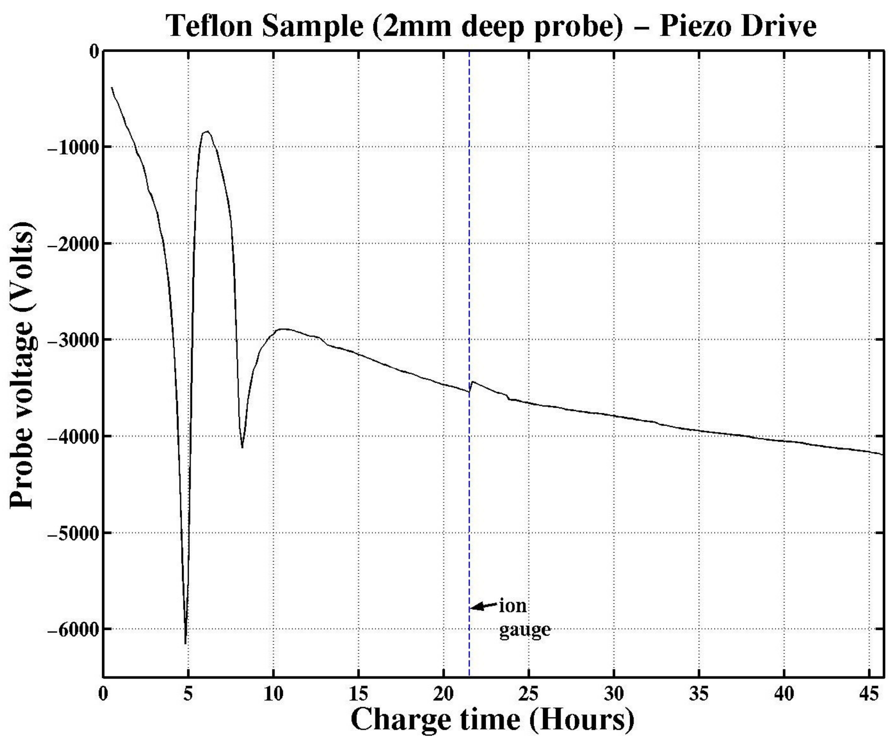

Figure 12. Piezo-driven monitor: initial results for Teflon.