TEMPORAL AND SPATIAL CORRELATIONS IN ELECTRON-INDUCED ARCS OF ADJACENT DIELECTRIC ISLANDS

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ABSTRACT

This study investigates very short duration (<1ms) light flashes caused by rapid discharge arcs from isolated charged insulating epoxy “glue dots” to an underlying grounded conductive sheet under electron irradiation. Temporal coincidence between arcs in separate samples was investigated, as was the dependence of such correlations with “glue dot” separation. While most arcs were found to be random localized events, for 40 keV incident beams some correlation was observed. A power law fit to the coincidence arc data versus “glue dot” separation found a power of -1.06±0.09, consistent with a field falling off inversely with separation distance for charges spreading out across a 2D conducting surface.

1. INTRODUCTION

Dielectric materials exposed to energetic electron fluxes similar to those in space plasma environments can charge and then discharge emitting light in various forms [1], causing spacecraft anomalies [2]. This study examined a common form of electron-induced light emission termed here as “arcs.” Arcs are short duration (<1 ms), bright photon emissions, caused by the rapid discharge of charged insulators [3]. This study investigated arcing which sometimes occurred nearly simultaneously in electrically isolated neighbouring charged samples and the relationship between these coincident arcing events and sample separation.

2. EXPERIMENTAL METHODS

Thirty-six small (~3 mm diameter), hemispherical bisphenol/amine epoxy “glue dots” were placed around the edges of a large conductive sheet of a polymeric/carbon nanocomposite (Black Kapton^{TM}) substrate (Fig. 1) attached to a cooled grounded metal plate [4].

The samples were mounted in a vacuum chamber (<10^{-4} Pa) at Marshall Space Flight Center and cooled to ~120 K using liquid nitrogen. Nearly uniform electron irradiation (±5%) was accomplished with a high energy (12-40 keV) electron flood gun to simulate fluxes (0.3-5 nA/cm^2) and energies seen in a typical space environment. Light emitted from the samples was measured using a NIST calibrated visible to near IR (400-900 nm) CCD video camera [5].

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Absolute radiance from each sample was measured for every video frame. Data were background corrected by subtracting the values from dark (beam off) frames to remove contamination from ambient stray light in the chamber. The samples were exposed to electron fluxes for about 15 min, at 12, 25 and 40 keV incident energies, with a two minute break in between each.

3. DATA ANALYSIS

The algorithm developed to find arcs in the data produced a histogram of the radiance data, determined a light threshold in the intensity distribution which signified an arc, and then found each “glue dot” in every frame which had a radiance above this threshold.

A temporally correlated arc was defined to be an arc that occurred within ±1 frame (±33 ms) of an arc in a separate sample. To test for spatial correlation between arcs in nearby samples the following definition was used. Sample separation was computed for each sample pair with the Pythagorean theorem using the pixel

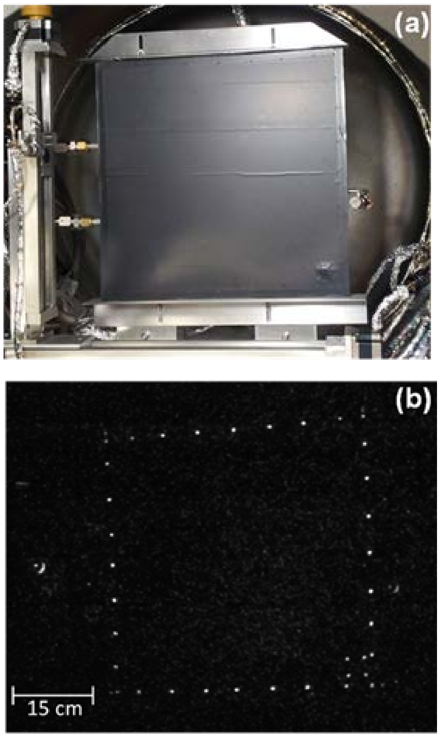

Figure 1. Sample tested. (a) Large conductive sheet mounted on a 41x41 cm conductive plate in the vacuum chamber. (b) Sample under electron beam irradiation showing 36 “glue dots” luminescing around the periphery of the sample substrate.

values of the center of each region. The total number of correlated arcs in sample *j* caused by arcs in sample *i*, $N_{i,j}$, was divided by the total number of arcs in sample *i*, $N_{total}(i)$ to determine a correlation value between samples *i* and *j* for the element $C_{i,j}$:

$$C_{i,j} \equiv N_{i,j} / N_{total}(i) \quad . \qquad (1)$$

This produced a two dimensional correlation matrix with values ranging from 0 (no correlation between the samples) to 1 (perfect correlation).

4. RESULTS

The dependence of arc correlations with “glue dot” separation was studied. The correlation analyses described above were done for incident electron energies between 12 and 40 keV and for fluxes between 0.71 and 5.82 nA-cm^{-2}. Analyses of the 12 and 25 keV data showed very little structure; that is, little to no correlation was observed [Fig. 2(a)]. We conclude that for lower incident electron energies most arcs are found to be random events, which occur as localized phenomena when built up charge produces an electric field large enough for electrostatic breakdown to occur.

By contrast, for large incident energies higher correlation was found for higher incident energy data at 40 keV [Fig. 2(b)]. A power law fit to these data found an inverse relation between the correlation and the separation distance, with a power of -1.06 ± 0.09.

5. CONCLUSION

The results of this study found little to no correlation was observed for lower incident electron energies. However, for higher incident energies (and consequently, higher power and dose rates), correlation of arcing between some regions was observed. The coincidence rates of these correlated regions also exhibited a trend with separation distance; closer samples tended to be more correlated.

One possible explanation for the lack of correlated arcing at lower incident electron energies may be the need for the samples to be charged close to their individual breakdown potentials in order for one discharge to trigger other discharges. It appears that coincident arcs are most likely to happen when the incident electron dose rate is large enough to ensure that most of the samples are charged close to their respective breakdown limits at any given time; this was only seen with incident energies of 40 keV in this study.

A discharge in one “glue dot” may cause a sudden spike in the electric field of neighbouring “glue dots” which could trigger premature arcing. Such stimulated arc rates might reasonably be expected to scale with electric field intensity. If confined to a 2D surface (*i.e.*, discharged current spreading out on the conductive plate), the field—and hence the correlation rate—would fall off inversely with separation distance. The power law fit to the arc data found for higher energy data is consistent with this 1/r power drop off model.

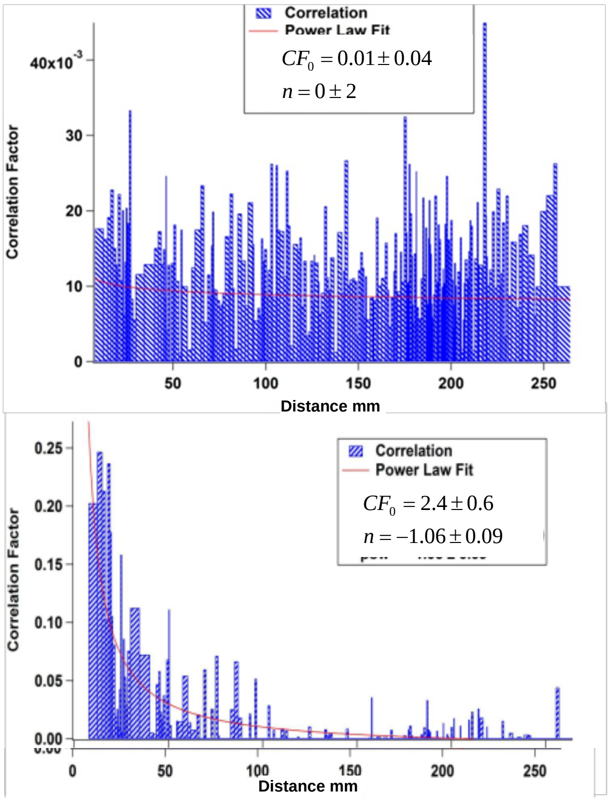

Figure 2. Correlation versus separation distance curves for (a) 25 keV and (b) 40 keV incident energies. The power law fit has the form $CF(r) = CF_0 \bullet r^n$*. Only the 40 keV run showed dependence on distance.*

6. REFERENCES

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