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Temporal and Spatial Correlations in Electron-induced Arcs of Adjacent Dielectric Islands

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I. Introduction

This study investigated coincidence behaviour of a common form of electron-induced light emission [6]. These very short duration (<1 ms) flashes termed "arcs" are caused by rapid discharge arcs from isolated charged insulating epoxy "glue dots" to an underlying grounded substrate, while the dielectric materials are exposed to space-like energetic electron fluxes through electron bombardment [1,7]. It is important to understand charge and discharge phenomena that occur under space like conditions, because spacecraft charging is the leading environmental cause of spacecraft anomalies [2,3].

These arcs are often, but not always, localized to small regions of the charged surface. In previous studies of spacecraft charging, arcing sometimes occurs in neighbouring samples nearly simultaneously, even though they are electrically isolated from one another. In this study we investigated the relationship between coincident arcing events of nearby charged samples and sample separation. The possibility that a given arc might stimulate arcs in adjacent "glue dots" was investigated through coincidence correlation analysis, as was the dependence of such correlations with "glue dot" separation.

II. Experimental Details

- Data acquired at NASA Marshall Space Flight Center [4].
- All samples simultaneously exposed to uniform electron beams with space-like energies and fluxes.
- Numerous small isolated samples were mounted around the periphery of a large conductive substrate (see Fig. 1). The insulators were 36 separate, electrically-isolated, small (~3 mm diameter), approximately hemispherical bisphenol/amine epoxy "glue dots" (see Fig. 4).
- The substrate was mounted inside a high vacuum chamber, attached to a cooled grounded metal plate. Low conductivity at ~120 K minimized charge dissipation.
- Video data and incident current flux densities were collected [4,5].

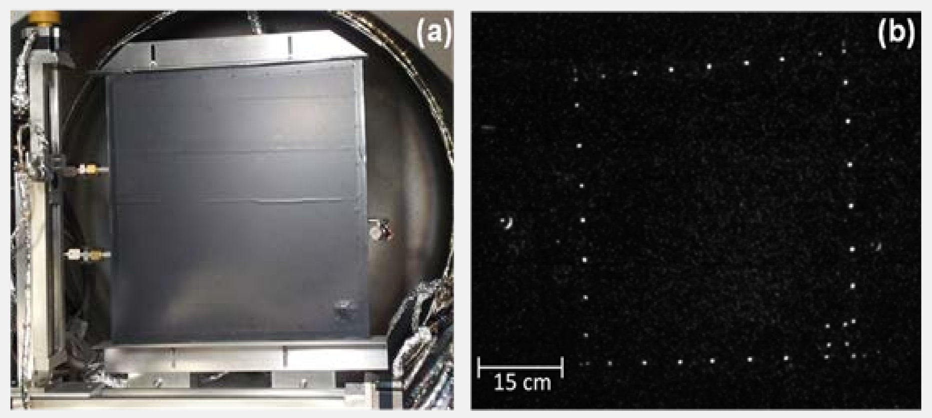

Figure 1. (a) 41x41 cm conductive substrate mounted in vacuum chamber. (b) 36 samples on the periphery of the sample substrate luminescing under electron beam irradiation.

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III. Analysis

Arc Identification To analyse the data, the video files were converted to individual frame images. Radiance values were calculated for each sample in each video frame as the average sample pixel value converted to absolute spectral radiance using NIST traceable video camera calibration. Analysis of regions for each glue dot and several background regions of sequential frames after correction for stray light contamination, created an array of calibrated intensities (absolute spectral radiance) versus time for each region. These data were normalized with the electron flux data. Fig. 2(a) shows a typical curve of absolute spectral radiance versus exposure time for a single "glue dot".

Arcs were deemed as any data point above the threshold intensity. The threshold was set as the upper bound (first zero to the right of peak) of a histogram of the spectral radiance data [see Fig. 2(b)]; however, relative arc rates and coincidence analysis were largely independent of how the threshold was chosen.

Arc Correlation 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. 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 $C_{i,j}$. These values are graphed in Fig. 3.

To improve contrast of non-diagonal correlation matrix elements, their values were normalized to show how each element related to the average, C_{avg}, and standard deviation, σ_C, of the correlation matrix. See Fig. 4.

$$C_{i,j} \equiv N_{i,j} / N_{total}(i)$$

$$C_{i,j}^{norm} = (C_{i,j} - C_{avg}) / \sigma_C$$

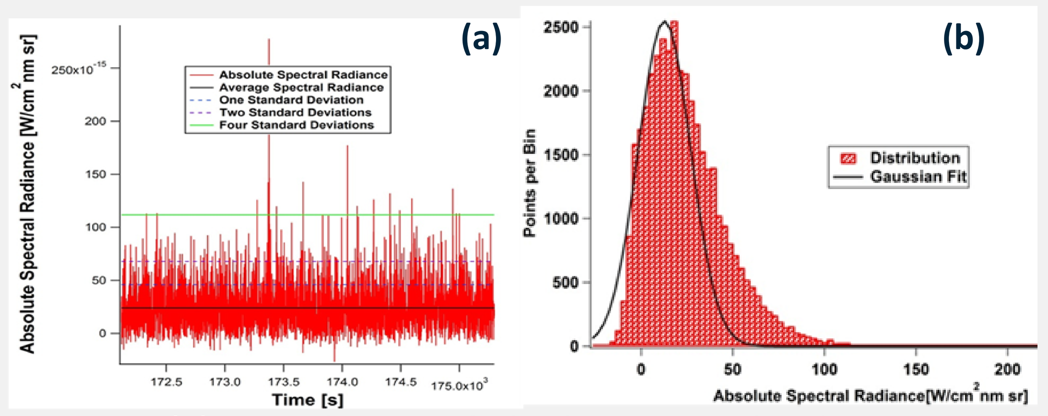


Figure 2. (a) Typical curve of absolute spectral radiance versus exposure time for a single "glue dot". The average spectral radiance and levels on 1, 2 and 4 standard deviations above this are indicated. (b) Histogram of absolute spectral radiance for a single analysis region over prolonged beam exposure. Comparison to a Gaussian fit shows the intensity distribution is decidedly asymmetric.

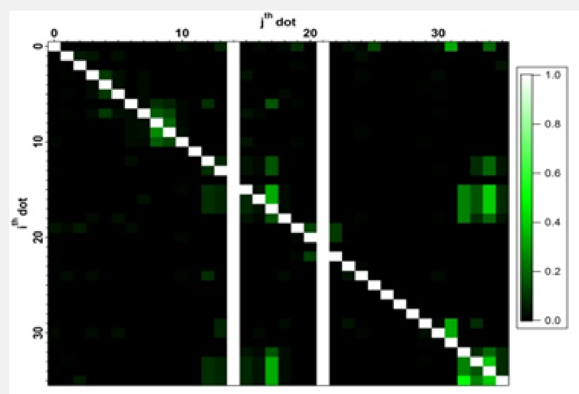


Figure 3. Correlation matrices for "glue dot" arcs for 40 keV incident electron energies. Diagonal is self correlation, and white stripes are samples with no arcs.

References

[1] Dennison, J., Jensen, A.E., Dekany, J., Wilson, G., Bowers, C.W. & Meloy, R. (2013). Diverse Electron-induced Optical Emissions from Space Observatory Materials at Low Temperatures, In *Proc. Soc. Photo-Optical Instrum. Engineers Cryogenic Optical Systems and Instruments Conf.*, Vol. 8863, pp0B1-0B15.

[2] Andersen, A., Moser, K. & Dennison, J. (2016). Perspectives on the Distributions of ESD Breakdowns for Spacecraft Charging Applications, *Proceedings of the* 14th *Spacecraft Charging Tech. Conf.,* Space Research and Technology Centre, European Space Agency (ESA/ESTEC), Noordwijk, The Netherlands.

[3] Leach, R.D. & Alexander, M.B (1995) Failures and anomalies attributed to spacecraft charging, *NASA Reference Publication 1375*, NASA Marshall Space Flight Center.

[4] Dekany, J., Christensen, J., Dennison, J., Jensen., A.E., Wilson, G., Schneider, T., Bowers, C.W. & Meloy, R. (2015). Variations in Cathodoluminescent Intensity of Spacecraft Materials Exposed to Energetic Electron Bombardment, *IEEE Tran. Plasma Science*, **43**(11), pp3948-3954.

[5] Dekany, J., Johnson, R.H., Wilson, G., Evans, A. & Dennison, J. (2014). Ultrahigh Vacuum Cryostat System for Extended Low Temperature Space Environment Testing, *IEEE Trans. on Plasma Sci.*, **42**(1), pp266-271.

[6] Jensen, A.E., Wilson, G., Dekany, J., Sim, A.M. & Dennison, J. (2014). Low Temperature Cathodoluminescence of Space Observatory Materials, *IEEE Trans. on Plasma Sci.*, **42**(1), pp305-310.

[7] Wilson, G., Dennison, J., Jensen, A.E. & Dekany, J. (2013). Electron Energy-Dependent Charging Effects of Multilayered Dielectric Materials, *IEEE Trans. on Plasma Sci.*, **41**(12), pp3536-3544.

IV. Results

Single Arcs Most arcs were observed as localized (see Fig. 4) random events which occurred when the built up charge created a strong enough electric field to break down the insulating material. An average arc rate of 1-3 arcs per min were observed, with the rate exhibiting a small exponential decrease with increasing incident energy [4].

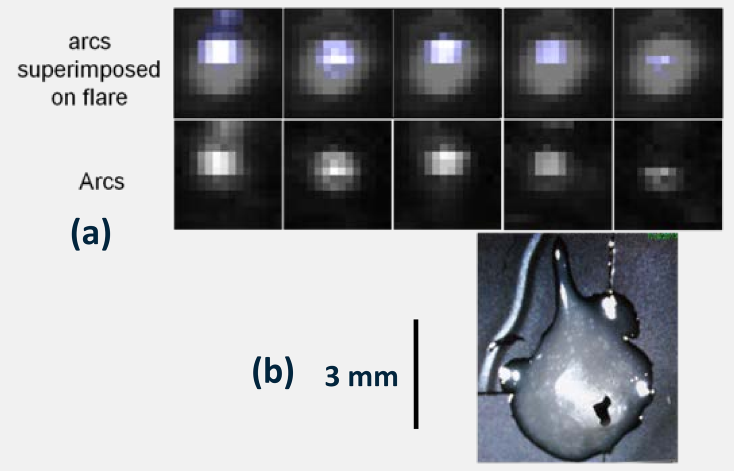


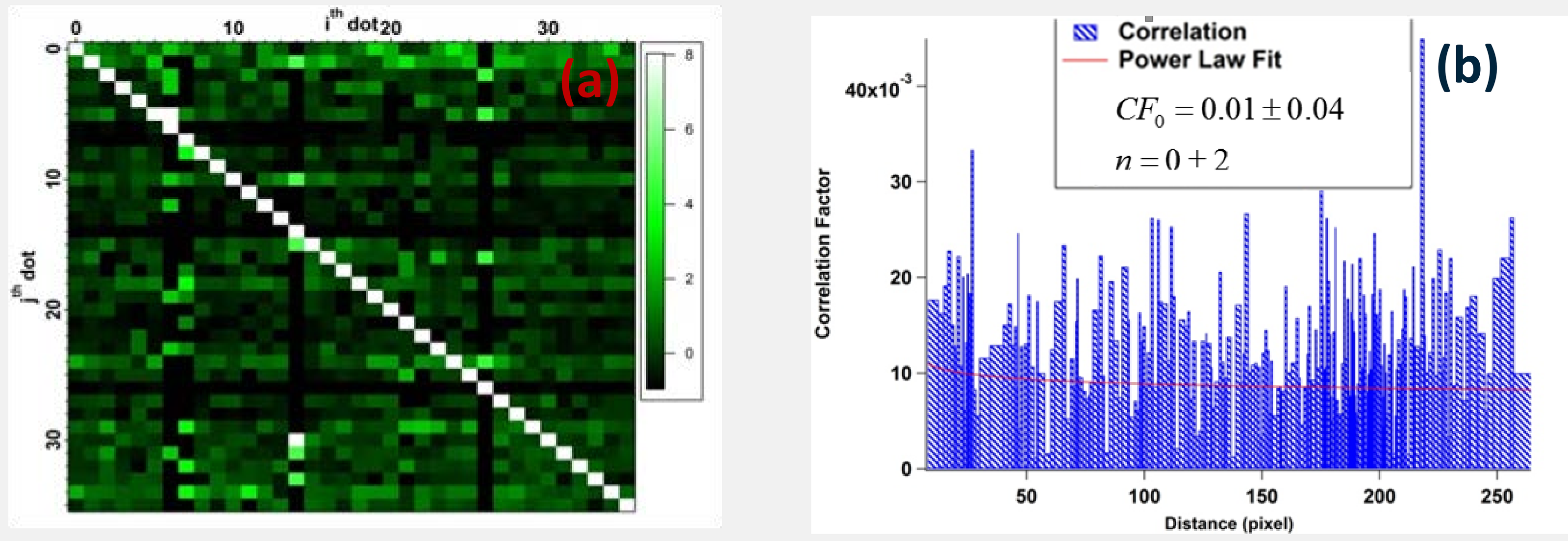
Figure 4. (a) Various arc events appear in different locations around the sample. (b) Higher magnification image of the glue dot shown in part (a).

Correlated Arcs Correlation studies were performed on data for incident energies of 12-40 keV and fluxes of 0.71 and 5.82 nA/cm². Dependence of arc correlation on separation distance was also studied.

These studies showed:

- Little arc correlation for ≤25 keV incident electron energies [see Figs. 5(a) and (b)]. Perhaps for lower energies, insufficient charge could be stored in samples to have a triggered discharge.
- For 40 keV data some temporal and spatial correlation was observed [see Figs. 5(c)].
- 40 keV data showed an inverse power law relation between the correlation and the separation distance, with n=-1.06 ± 0.09, consistent with a 1/r falloff.
- Discharge in one "glue dot" may cause sudden E-field spikes in neighbouring "glue dots", which could trigger premature arcing. Such stimulated arc rates might be expected to scale with E-field. If confined to a 2D surface (*i.e.*, discharged current spreading out on the conductive substrate), the field—and hence correlation rate—would fall off inversely with separation.

No Spatial Dependence of Correlated Arcs at Low Incidence Energies



Positive Spatial Dependence of Correlated Arcs at High Incidence Energies

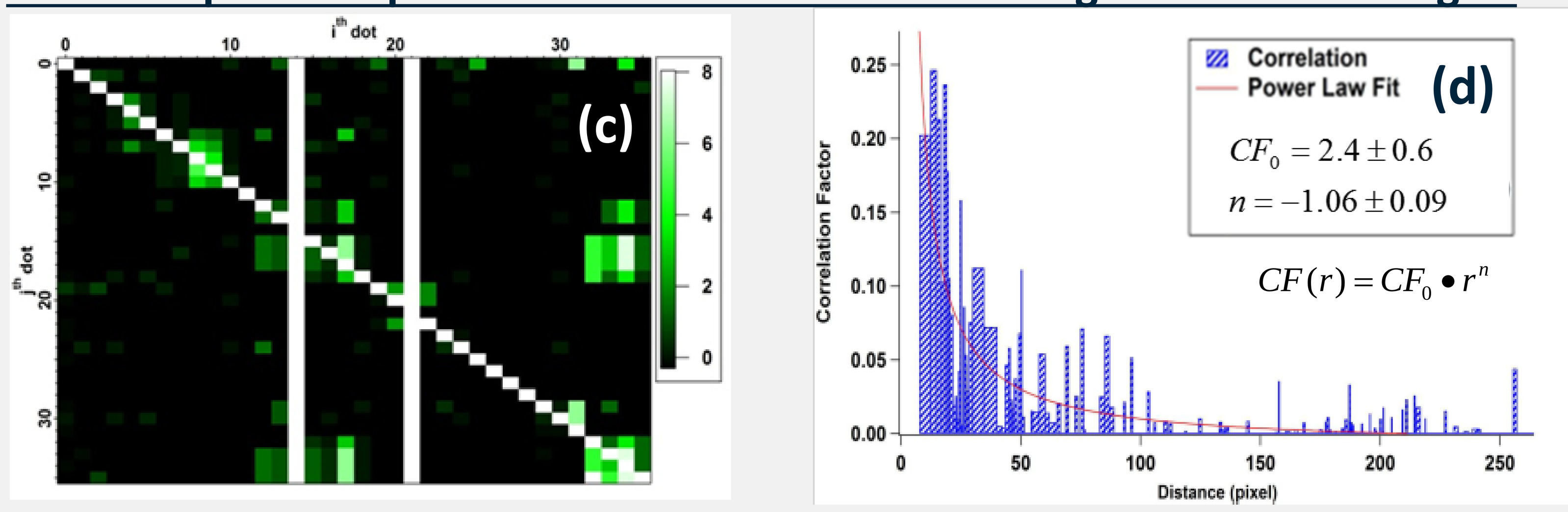


Figure 5. Normalized correlation matrices for "glue dot" arcs. Correlation values for (a) 25 keV and (c) 40 keV incident electron energies. Correlation vs. Distance curves for (b) 25 keV and (d) 40 keV incident energies. Only the 40 keV run showed dependence on distance.