Secondary Electron Yield Analysis of Space-Induced Contamination on Long Duration Exposure Facility Panels

Trace Taylor, Phillip Lundgreen and JR Dennison

Material Physics Group, Physics Department, Utah State University

Overview

This project studies the changes in electron emission of materials flown on the Long Duration Exposure Facility (LDEF) induced by prolonged exposure to the harsh space environment. LDEF flew in the LEO environment from 1984 to 1990.[1] Myriad LDEF surfaces showed pronounced effects, including the heavily modified panels studied here.

Electron emission can generate large enough electrical potential differences in spacecraft to cause electrostatic discharges which may result in enormous damage, anomalies in mission performance, or even total mission failure. Secondary electrons are generated by inelastic scattering events when a material is struck by highly energetic electrons—for example by those from space plasma fluxes—whereby internal electrons are excited enough to be liberated from the material [see Fig. 2 (A).][2] Secondary electrons may be generated from photons, electrons or ions, but the secondary electron yield (SEY) from electrons is usually the most significant for space applications. SEY is affected by factors such as surface roughness, oxidation, and contamination, all of which evolved for LDEF as it was bombarded by radiation and small orbital debris.[3]

LDEF Summary

Adhesives, insulating polymers, and other volatile materials in a vacuum environment outgas. Many room temperature vulcanizing (RTV) adhesives were used on LDEF, which outgassed and contaminated much of the satellite in a thin film of silicone accumulating evenly across the surface.[4] Another observed result from the long term space exposure was browning that likely occurred due to ultraviolet light interacting with the Aeroglaze A276 polyurethane thermal control coating.[4] Due to the interaction with atomic oxygen (AO) this coating may have worn away. Samples were taken from three locations to observe the impact the differences in color may have had. Figure 1 shows three samples taken from locations exhibiting varying degrees of discoloration

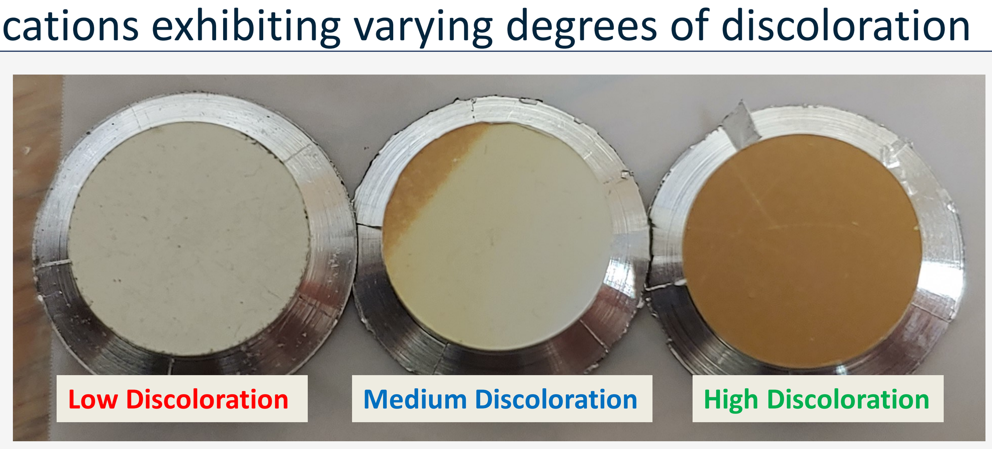

Fig 1. Three 12 mm samples from a large plate flown on LDEF panel H-06 with different levels of discoloration. From left to right they are referred to as low, medium, and high discoloration throughout the study. The aluminum bevel on the outside of the surfaces facilities sample mounting.

SEY Measurements

In order to measure SEY, the backscattered electron yield (BSEY) and total electron yield (TEY) are measured. SEY is calculated as the difference between the two. BSEY is described as the electrons that are emitted from the sample that originates from the incident beam. Typically with emission energies >50 eV.[2] SEY are the emitted electrons that originate from the sample itself and are excited from inelastic collisions they typically have emission energies <50 eV.[2] A good way to model SEY datasets is by using a four-parameter semiempirical model (Equation 1) where E_0 is the incident energy, δ_{max} is the maximum electron yield, E_{max} is the energy associated with δ_{max}, and n and m exponents are related to surface contamination and morphology.[3]

$$\frac{\delta(E_0)}{\delta_{max}} = [1 - e^{-r_0}]^{-1} \cdot \left(\frac{E_0}{E_{max}}\right)^{1-n} \cdot \left[1 - e^{\left(-r_0\left(\frac{E_0}{E_{max}}\right)^{n-m}\right)}\right] \quad (1)$$

Figure 2 (b) shows a hemispherical grid retarding field analyzer (HGRFA) used to measure the TEY. Biased concentric hemispherical grids are used to energetically discriminate the collected electrons for BSEY.[5]

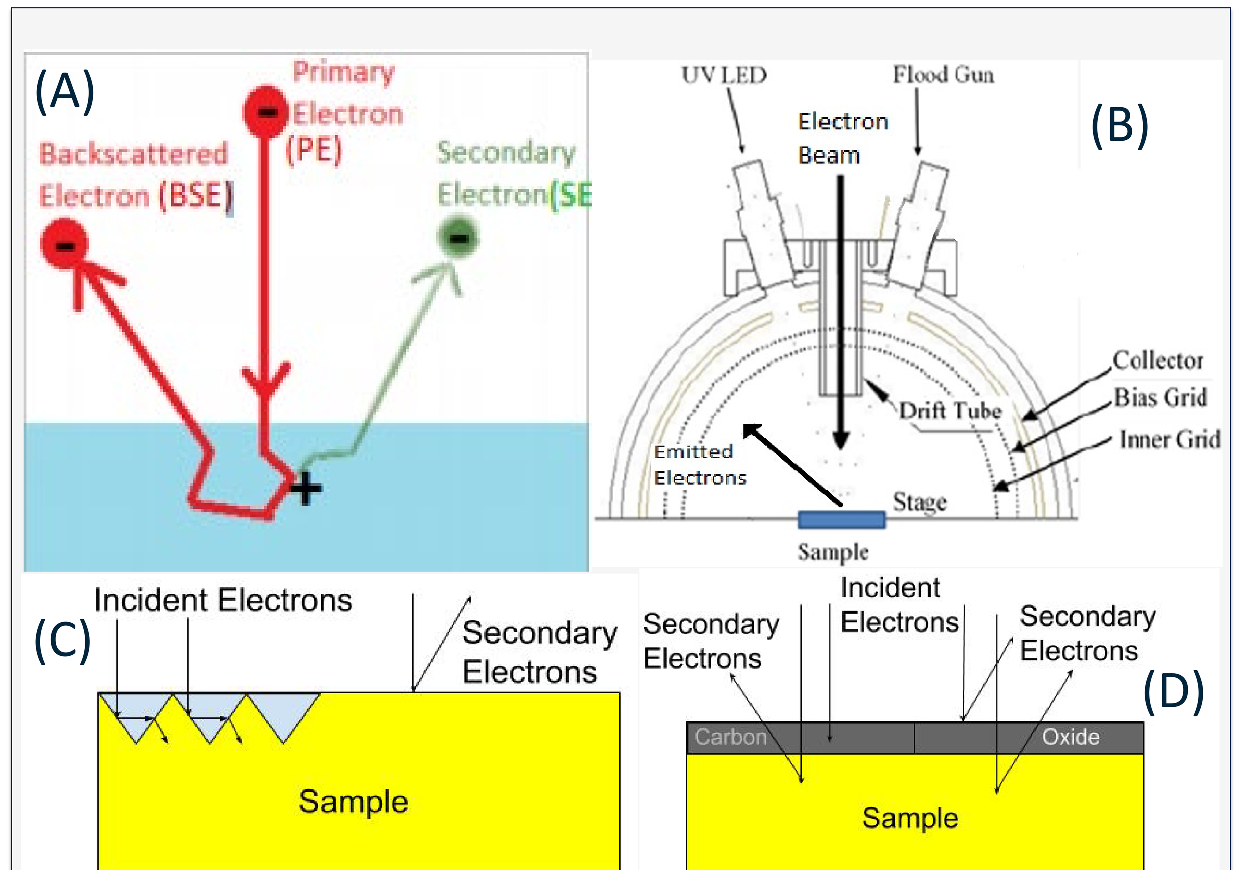

Fig 2. (A) Diagram showing incident primary electrons, emitted backscattered electrons and secondary electrons. (B) Detector schematic with incident and emitted electrons shown. Effects of sample (C) roughness and (D) contamination on electron emission

EDS Measurements

Energy-dispersive X-ray spectroscopy (EDS) measurements were performed (at 10 keV) to check for any contaminating materials that may have been responsible for the browning as well as how the expected elemental surface composition may have changed. The silicone contamination amount was consistent with the publication by Crutcher.[4] The aluminum measured is likely a result of penetrating the coating on the substrate.

Table 1. Measured atomic percent for each element for each sample.

	Titanium	Oxygen	Carbon	Silicon	Aluminum
Low Discoloration	44.0	20.7	34.0	0.80	0.50
Medium Discoloration	48.0	20.1	30.6	0.70	0.40
High Discoloration	40.7	21.3	37.1	0.70	0.30

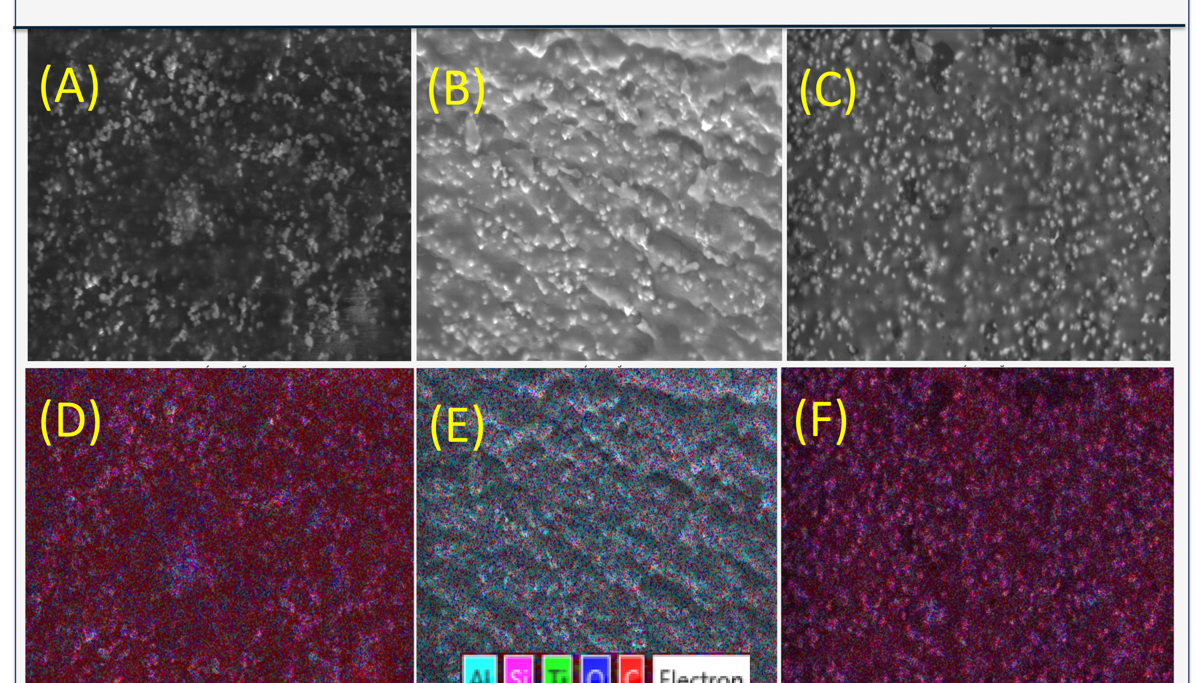

Figure 3. SEM images of (A) low discoloration, (B) medium discoloration, and (C) high discoloration samples. The EDS data is overlaid on the SEM image for (D) low discoloration, (E) medium discoloration, and (F) high discoloration samples. All images are ~20 µm across.

Surface Characteristics

The surface conditions of a sample are known to have an impact on the SEY. The roughness will lower the SEY by increasing the function of incident electrons recaptured by the surface.[6] Contaminants will alter the SEY in a more complicated way depending on the thickness of the contaminant layer and whether it is high-Z or low-Z.[6] A high-Z conducting material may increase SEY while a low-Z may do the opposite.[6] These relationships are illustrated in Figures 2 (C) and (D).

Results and Conclusions

TEY and BSEY measurements were taken from 15 eV to 5 keV. The calculated SEY curves are shown in Figure 4, which show a large variance in the maximum secondary electron yield (δ_{max}). The δ_{max} for the highly discolored sample was nearly the same as previous studies have reported for contaminated aluminum possibly due to the thickness of the coating.[6] The medium discolored curve δ_{max} matches with measured values for titanium oxide and the sample had the most titanium remaining.[7] There were several relative peaks for the lowly discolored sample at 150, ~700, and 1000 eV suggesting it may have a more layered structure than the other samples. Studying the SEY of a freshly coated A276 sample would help to further identify how the space environment affected all of the samples.

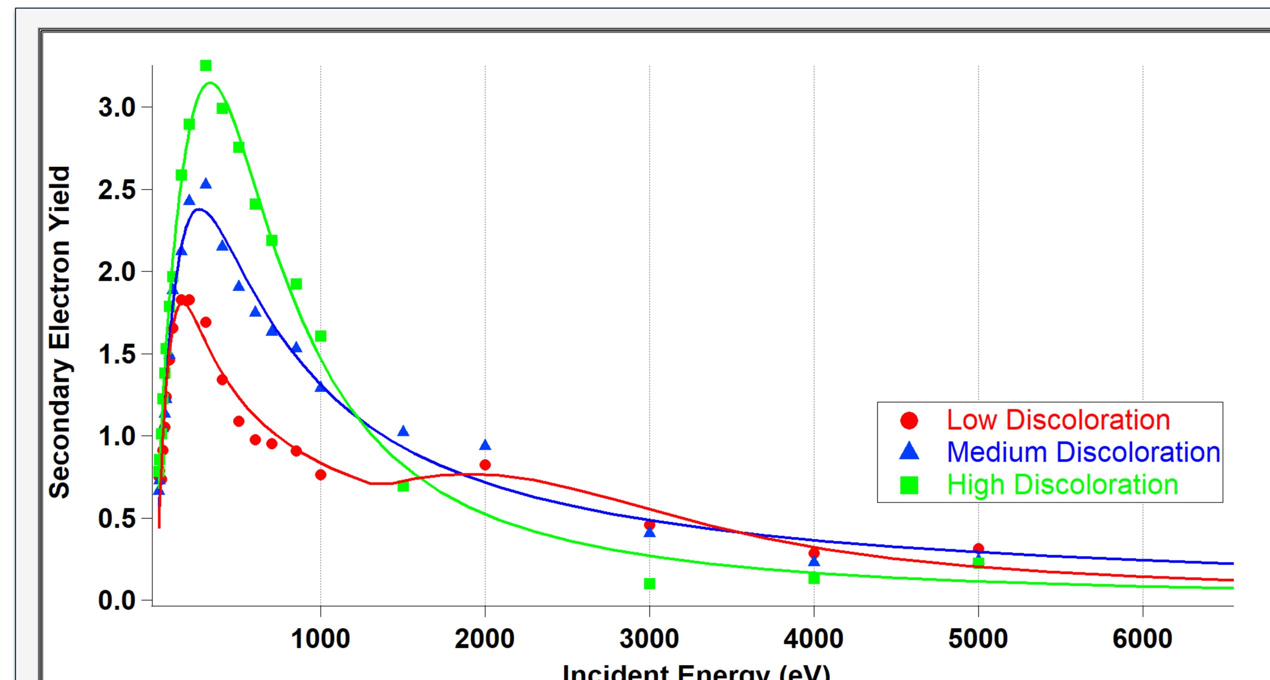

Figure 4. Secondary electron yield vs incident energy for LDEF Samples.

	E_{max}	δ_{max}	n	m
Low Discoloration	150	1.8	0.58	1.35
Medium Discoloration	300	2.5	0.50	1.52
High Discoloration	300	3.3	0.49	2.03

Table 2. Fitting parameters for Equation 1 which include the max secondary electron yields and the corresponding incident energies.

Acknowledgements

We gratefully acknowledge USU Physics Professor Emeritus Don Lind who was a Space Shuttle Mission Specialist and LDEF Principle Investigator. Lind arranged for the LDEF panels to be used for this study. We also acknowledge Joshua Boman who acquired the SEM and EDS images at the USU Core Microscopy Facility.

References:

1. O'Neal, R. L., and E.B. Lightner, "Long Duration Exposure Facility – A General Overview, " Proc. of First LDEF Post-Retrieval Symposium, June 1991, NASA CP 3134, pp. 3- 48, January 1992.
2. Reimer, L., Scanning Electron Microscopy. Physics of Image Formation and Microanalysis, (Springer-Verlag, New York, 1985)
3. Lundgreen, P., and J.R. Dennison. (2020). Strategies for Determining Electron Yield Material Parameters for Spacecraft Charge Modeling. Space Weather, 18, e2019SW002346. https://doi.org/10.1029/2019SW002346
4. Crutcher, E. R., and K. T. Warner, "Molecular Films Associated with LDEF," Proc. of First LDEF Post-Retrieval Symposium, June 1991, NASA CP 3134, pp. 155-177, January 1992.
5. Nickles, N. E., "The Role of Bandgap in the Secondary Electron Emission of Small Bandgap Semiconductors: Studies of Graphitic Carbon" (2002). All Graduate Theses and Dissertations. 1696.
6. Baglin, V., J. Bojko, C. Scheuerlein, O. Gröbner, M. Taborelli, B. Henrist and N. Hilleret (2000). "The secondary electron yield of technical materials and its variation with surface treatments," Proc. EPAC 2000, Vienna, Austria.
7. Dennison, JR, J. Abbott, R. Hoffmann, A. Sim, C.D. Thomson, and J. Corbridge, Final Report Part V: Additional Materials Reports, NASA Space Environments and Effects Program Grant, "Electronic Properties of Materials with Application to Spacecraft Charging," December 2005. Unpublished.

Scan code to access other USU MPG articles.