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Kelby T. Peterson
Utah State University

JR Dennison
Utah State University

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**Atomic Oxygen Modification of the Nanodielectric Surface Composition of Carbon-Loaded Polyimide Composites**

Kelby T. Peterson and J.R. Dennison
Utah State University, Logan, UT 84322-4414
Materials Physics Group
E-mail: kelby.peterson@aggiemail.usu.edu

**Abstract**

Carbon-Loaded Polyimide is a nanodielectric composite of carbon particles (~100-500 nm) embedded in an insulating polyimide polymer matrix (~100-500 nm depth). Analysis of this nanodielectric composite has been done via optical imaging, scanning electron microscopy, and energy-dispersive x-ray analysis in order to gain insight into its nanodielectric properties. The insulating polyimide is known to be inert and impervious to strong bases and acids, but is affected by atomic oxygen exposures. We have observed changes in the surface structure and relative carbon-polymer concentrations in MISSE-6 samples that were exposed to the low earth orbit environment for 18 months outside the International Space Station. The MISSE-6 sample tray arrangement permitted studies of the effects due to varied atomic oxygen exposure. MISSE-6 samples received maximum atomic oxygen exposure on the ram side with decreased exposure on the wake and shielded sides, respectively. Early observations suggest that the atomic oxygen modifications reduce the polymer matrix on the surface, whilst the carbon-loaded regions remain largely unaffected by the exposure. Effects of the surface modifications on spacecraft charging and cathodoluminescence will be discussed.

**Relative Surface Concentrations**

The relative surface concentrations of the stock and MISSE-6 samples give insight into the erosion due to atomic oxygen exposure and UV radiation whilst suspended from the International Space Station. Via optical analysis it is evident that erosion occurred. Low surface sensitive EDAX analysis shows little variation in the elemental concentrations of the sample. Region-SEM high surface sensitivity shows decreased polymer (dark) regions and increased full width at half max (FWHM) with increased magnification.

**Conclusions**

Analysis of the full width at half maximum of the histograms of the SEM data shows that there is a significant increase in the range of intensities of the charged region. SEM analysis of the conducting and charging regions shows a correlation between magnification and percent of light regions, charging regions. This corresponds to an increased variation in the light and dark regions present on the material surface. This implication reaffirms the expected atomic oxygen erosion by eliminating the repetitive pattern of the stock material's surface features.

**Future Work**

Current analysis has been done on a MISSE-6 wake sample; further analysis will be done on ram samples to determine if the effects are more prominent. Beyond that there will be an analysis of the remaining MISSE-6 samples to find a correspondence between exposure and the noted effects. There will also be analysis of the changes in reflectivity and emission of the samples.

**Acknowledgements/References**

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**Figure 1** MISSE-6 Sample Containers suspended from the International Space Station

**Figure 2** Note the Carbonated Polyimide/White Kapton store

**Figure 3** Structure of typical polymer (C<sub>n</sub>H<sub>2n</sub>O),

**Figure 4** Carbonated Polyimide Samples (Wakeeous Kapton Store)

**Figure 5** Carbonated Polyimide/White Kapton store

**Figure 6** (Right): SEM image of stock Doped Carbon Loaded Polyimide XE sample at 5.1k magnification

**Figure 7** (Left): SEM image of MISSE-6 wake Carbonated Loaded Polyimide XE sample at 5.1k magnification

**Figure 8** Scanning Electron Microscopy Analysis

**Figure 9** Energy Dispersive X-Ray Analysis

**Figure 10** Scanning Electron Microscopy (SEM) of stock Doped Carbon Loaded Polyimide XE sample at 5.1k magnification (below) EDAX analysis of percent concentrations and graph of the elemental composition.

**Figure 11** Optical analysis of carbon and oxygen on MISSE-6 samples.

**Figure 12** Carbon Loaded Polyimide Properties

**Macro-Scale Properties:**
- Nanodielectric material consisting of an insulating polyimide (~100-500 nm depth) loaded with conductive carbon particles (~100-500 nm).
- Insulating region builds up charge that ultimately leads to cathodoluminescence and arcing of the material, particularly at low temperature vacuum environments like those used for space-based observations.

**Nano-Scale Properties:**
- High conductivity material ranging from 10<sup>9</sup> to 10<sup>13</sup> (Ω·m) dependent on the carbon concentrations. Designed to withstand high voltages and extreme temperatures. Polyimide is utilized to determine the flux of Atomic Oxygen based on the rate of the degradation of the polymer.

**EDAX analysis provides information about the chemical characterization of a material. EDAX has low surface sensitivity due to the nature of the electron penetration in the material. Surface variations due to atomic oxygen and UV exposure occur in the top few nm but EDAX probes 1-10μm deep. This prevents light elements, such as Hydrogen to be viewed. Due to this high energy, little carbon variation between the stock and MISSE-6 flight Carbonated Polyimide samples.”**

**Figure 13** Optical imaging of Carbonated Polyimide/White Kapton store

**Figure 14** (Right): EDAX image of MISSE-6 wake Carbonated Loaded Polyimide XE sample at 5.1k magnification (below) EDAX analysis of percent concentrations and graph of the elemental composition.

**Figure 15** (Left): EDAX image of stock Doped Carbon Loaded Polyimide XE sample at 5.1k magnification (below) EDAX analysis of percent concentrations and graph of the elemental composition.