Predicting Material Performance in the Space Environment from Laboratory Test Data, Static Design Environments, and Space Weather Models

Joseph I. Minow and David L. Edwards
NASA, Marshall Space Flight Center

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Introduction

• Materials are evaluated for use in space environments by laboratory exposure to VUV/UV, AO, and charge particle environments to determine effects on material properties

• Standard “static” design environments are typically used to establish exposure periods and the corresponding photon, AO, and charged particle fluence to meet mission requirements

• Questions:
  – How well do static models represent the real environment?
  – What is the contribution of “space weather” events to material exposure environments?

• Today’s presentation will
  – Examine VUV/UV environments used in laboratory tests with emphasis on surface exposures
  – Examine importance of “space weather” event contributions to environment
VUV/UV Penetration Depth

- Long wavelengths penetrate deeper into polymers

<table>
<thead>
<tr>
<th>( \lambda ) (nm)</th>
<th>50% depth (µm)</th>
</tr>
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<tbody>
<tr>
<td>300</td>
<td>----</td>
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<tr>
<td>250</td>
<td>128</td>
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<tr>
<td>224</td>
<td>65</td>
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<tr>
<td>200</td>
<td>22</td>
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<td>190</td>
<td>17</td>
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<td>184</td>
<td>14</td>
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- VUV wavelengths where solar variability is strongest primarily impacts material surfaces

[Dever et al., 2002]
Solar Spectrum and Models

- Static models
  - NRLEUV
  - EUVAC
  - EUV81
  - ASTM E490

- Climatology
  - Solar2000 (S2K)
  - Space Environment Technologies
    - Tobiska et al.
      - constant  122.5 – 1x10^6 nm
      - variable  0.5 – 121.5 nm
    - Δt = 1 day

- Space weather
  - Flare Irradiance Spectral Model
  - LASP/CU Boulder
    - Chamberlin et al.
      - 0.1 – 194 nm
    - Δt = 1 minute

[Source: Tobiska and Nusinov, 2004]
Solar XUV/EUV/UV Variability

Solar2000
• Static ASTM E490
• Variable XUV/EUV

Reference Spectrum
• Mean S2K

• Nomenclature
  XUV 0.1 ≤ λ < 10
  EUV 10 ≤ λ < 200
  UV 200 ≤ λ < 400

  VUV 20 ≤ λ < 200

[ISO_DIS_21348_E_revB, 2008]
Solar XUV/EUV/UV Variability

Solar2000
• Static ASTM E490
• Variable XUV/EUV

Reference Spectrum
• Mean S2K

\[ I_{\lambda_a - \lambda_b} = \frac{\sum_{k=1}^{n} I(\lambda_k) d\lambda_k}{\sum_{k=1}^{n} d\lambda_k} \]

Mean S2K

\begin{figure}
\centering
\includegraphics[width=\textwidth]{solar_xuv_euv_uv_variability.png}
\caption{Mean S2K with wavelength ranges: 5 to 100 nm, 100 to 250 nm, 250 to 400 nm.}
\end{figure}
Solar UV/VUV Variability

- Solar intensity in terms of UV Suns based on mean S2K design model

- Solar source yields UV Suns exceeding unity when mean model is used as reference spectrum

\[ \text{UV Suns}_{\lambda_a - \lambda_b} = \frac{I_{\lambda_a - \lambda_b, \text{source}}}{I_{\lambda_a - \lambda_b, \text{reference}}} \]
Solar UV/VUV Variability

Solar2000
- Static ASTM E490
- Variable XUV/EUV

Reference Spectrum
- 90% S2K
Solar XUV/EUV/UV Variability

Solar2000
- Static ASTM E490
- Variable XUV/EUV

Reference Spectrum
- 90% S2K
Solar UV/VUV Variability

- Solar intensity in terms of UV Suns based on 90% S2K design model

- Conservative model yields fewer UV sun values exceeding design models
ASTM E490 and Solar Variability: Spectrum

- S2K model intensity exceeds ASTM-E490 at Lyman-α wavelengths

- S2K as ASTM-E490 for wavelengths longer than Lyman-α

- Materials sensitive to wavelengths shorter than Lyman-α may underperform in space environment if
  - qualified only to ASTM-E490
  - degradation dominated by <200 nm environment
UV Suns based on Solar2000 exceed the ASTM-E490 environments for all solar cycles from 1950 through 2004 for wavelengths shorter than Lyman-α.

ASTM under represents the solar spectrum?
UV source: UARS

Solar2000 XUV/EUV data measured on orbit [Tobiska and Bouwer, 2006]:
- TIMED
- SOHO
- SORCE
- SNOE
Flare Irradiance Spectral Model (FISM)

- Empirical solar irradiance model developed by LASP/CU [Chamberlin et al., 2007]
  - Resolution
    \[ \Delta \lambda = 1 \text{ nm} \quad 0.1 \text{ nm} < \lambda < 194 \text{ nm} \]
    \[ \Delta t = 60 \text{ seconds} \]
  - Data sources
    - Solar Extreme Ultraviolet Experiment (SEE)/TIMED
    - Solar Stellar Irradiance Comparison Experiment (SOLSTICE)/UARS

- FISM developed to provide VUV solar spectral irradiances for input to ionosphere, thermosphere models
  - 100% coverage from 1986 to present

FISM URL:
http://lasp.colorado.edu/LISIRD/fism.htm
Solar VUV 2005

Solar minimum

FISM 2005

Wavelength (nm)

Time (UTC)

Log_{10} W/m²-nm

-2

-3

-4

-5

-6
Solar VUV 2005

Solar minimum

FISM 2005

Time (UTC)
• Static design models typically used to establish laboratory test protocols for determining material response to the UV/VUV space environment
  – Need to be careful with choice of reference model if test results are to be used for qualifying materials for extended use in space

• Space climatology and space weather models provide a useful technique for evaluating projected on-orbit performance to a “static” design specification

• Solar2000 and FISM models are useful tools for
  – Characterizing dynamic changes in on-orbit solar VUV environments
  – Developing appropriate design environments for screening materials to VUV environments