UV LED charge control of an electrically isolated proof mass at 255 nm

Karthik Balakrishnan
Department of Aeronautics and Astronautics
Hansen Experimental Physics Labs
Stanford University
karthikb@stanford.edu
MGRS System Overview

**Differential Optical Shadow Sensor**
- Nanometer sensing for drag free signal
- Lower resolution, high dynamic range

Andreas Zoellner

**Grating Angular Sensor**
- Nanoradian level angular sensing

**Grating Displacement Sensor**
- Picometer sensing for science signal
- High sensitivity, low dynamic range

Graham Allen (alum)

**Proof Mass Caging**
- 700 g clamping of proof mass during launch
- Minimal residual velocity on release
- No damage to proof mass surface

Eric Hultgren, Chin-Yang Lui

**UV LED Charge Management**
- Solid state 255nm light source
- Charge control of proof mass and housing potential

Karthik Balakrishnan

**Full System**
- 2.9 kg 70mm dia 70-30 Au-Pt sphere
- Carbide coated sphere
The spacecraft and housing protect the proof mass from many disturbances: solar, atmospheric, micrometeoroids, etc.

However, direct and secondary charging of the proof mass is still possible leading to a potential imbalance between the proof mass and housing walls.

- **Direct**: High energy particles pass through the shielding and directly accumulate on either proof mass or housing.
- **Secondary**: High energy particles interact with spacecraft materials, knocking off electrons which then accumulate on the proof mass or housing.
- **Approx 50-200 electrons/second** expected charging rate.

Potential imbalance leads to an electrostatic force on the proof mass.
UV LED Properties

- UV LEDs are:
  - AlGaN based wide-bandgap (4.86eV) device with 255 nm line (12 nm FWHM)
  - Small power consumption (< 1W) for a full system, small mass (< 1kg)
  - Wide range of output powers (<1nW to >100 µW)
  - High dynamic range (> 1 kHz modulation is possible)
- Operate CM outside the science band

Voltage-Current
Voltage-Power
Current (L)-Current(P)
Spectrum
UV LED Space Qual Level Testing

- Extensive campaign with to test LEDs to MIL-1540 (E) levels of thermal and vibe
  - 27 cycles of -34 to +71 under vacuum
  - 14 g RMS vibration, 3 minutes per axis, 3 axes

No change seen in I-V and spectrum, minimal change in output power
Charge Management Overview

“Positive Charge Transfer”

“Negative Charge Transfer”
Charge management experimental setup
Charge management results

- System capacitance to ground is 17 pF
- 10 μW incident UV power (255 nm), modulated at 100 hz, 50% duty cycle, 3.0 V_{pp} bias
- Sphere potential was measured using non-contact probe relative to housing

Peak charging rates are 0.53 pA (positive) and 0.40 pA (negative)
(Approx. 3e6 e⁻/sec)
Proof mass coatings – alternative to Au

• The traditional choice for proof mass coatings has been gold (or Au-Pt alloy)
  – High reflectivity
  – Standard coating and cleaning processes
  – Well characterized and understood material

• Problem with gold: soft and prone to sticking, scratching, and deforming
  – During caging, 100 g’s preload on proof mass
  – Want proof mass surface to be robust in the event it contacts housing walls
  – Alternatives: carbide coatings
  – Very tough, wide bandgap (close to AlGaN)

• Desired properties at 255 nm
  – Sufficient QE at 255 nm (> approx. 1E-9)
  – Reflectivity > 5%
  – Workfunction near or lower than 4.86 eV (can be slightly higher due to Fermi Tail)
Coatings – samples

• Test: carbide pellets coated on to aluminum substrates via e-beam deposition
  – Substrate material: Al 6061-T6 machined into 1” squares, with a machine finish of Ra 64
  – Pellets: 2-4 mm diameter
  – Samples cleaned via HF etch prior to coating, then immediately vacuum bagged for cleanliness
  – Samples immediately vacuum bagged after coating for cleanliness

• Sample materials:
  – Carbides: SiC, TiC, MoC, ZrC, TaC
  – Metals: Au (traditional proof mass coating), Nb (GP-B)
  – Ir – reflectivity standard

Top row (from left): Au, Nb, Ir, SiC
Bottom row (from left): TiC, MoC, ZrC, TaC

SiC coated Al sphere
Proof mass coating measurements

- **Measurements:**
  - Quantum efficiency ($\lambda_{\text{cent}} = 255 \text{ nm}$)
    - Measured twice: 2 weeks after coating, and 16 months after coating
    - Used an integrating sphere with 10 V bias between coated sample and sphere
    - Samples isolated from ground via $10^{14} \Omega$ Ultem tubes
    - 50 µW UV incident power
    - Current measured using Keithley 6485 Picoammeter
  - Reflectivity ($\lambda_{\text{cent}} = 255 \text{ nm}, \theta = 45^\circ$)
    - Used Newport 918D head connected to Newport 1931-C power meter

<table>
<thead>
<tr>
<th>Material</th>
<th>QE (2 wk)</th>
<th>QE (16 mos)</th>
<th>R (255 nm)</th>
<th>$\phi$ (eV)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au</td>
<td>3.40E-07</td>
<td>4.4E-07</td>
<td>0.17</td>
<td>4.57</td>
</tr>
<tr>
<td>Nb</td>
<td>5.64E-07</td>
<td>2.4E-07</td>
<td>0.17</td>
<td>4.30</td>
</tr>
<tr>
<td>SiC</td>
<td>4.34E-07</td>
<td>1.4E-07</td>
<td>0.12</td>
<td>4.80</td>
</tr>
<tr>
<td>TiC</td>
<td>4.48E-07</td>
<td>1.3E-07</td>
<td>0.15</td>
<td>3.80</td>
</tr>
<tr>
<td>ZrC</td>
<td>3.85E-07</td>
<td>2.1E-07</td>
<td>0.11</td>
<td>3.70</td>
</tr>
<tr>
<td>MoC</td>
<td>6.82E-07</td>
<td>1.1E-07</td>
<td>0.15</td>
<td>4.74</td>
</tr>
<tr>
<td>TaC</td>
<td>6.35E-07</td>
<td>1.4E-07</td>
<td>0.13</td>
<td>5.0</td>
</tr>
<tr>
<td>Ir</td>
<td>--</td>
<td>--</td>
<td>0.6</td>
<td>--</td>
</tr>
</tbody>
</table>
Small satellite demonstration

- 16 total LEDs
- Four bias plates
- Gold coated sphere (e-beam dep’n)
- Contact probe
- Gold coated Ultem tubes - shielding

Electronics currently in a “flatsat” configuration – easier to debug

Shown are:
- 1 charge amp set
- 1 power board
- 1 main processing board
- UV LED holder + amplifiers

Scheduled for launch in June 2013
UV LED charge control of an electrically isolated proof mass in a Gravitational Reference Sensor configuration at 255 nm

Karthik Balakrishnan, Ke-Xun Sun, Abdul Alfauwaz, Ahmad Aljadaan, Mohammed Almajeed, Muflih Alrufaydah, Salman Althubiti, Homoud Aljabreen, Sasha Buchman, Robert L Byer, John Conklin, Daniel DeBra, John Hanson, Eric Hultgren, Turki Al Saud, Seiya Shimizu, Michael Soulage, Andreas Zoellner

(Submitted on 3 Feb 2012)

Questions?

Construction of satellite engineering model ongoing at NASA Ames