Carbon Nanotube Flat Plate Blackbody Calibrator

Sandra Collins, John Fleming, Beth Kelsic, David Osterman, Bevin Staple

CalCon
August 23, 2016
Outline

- InVEST CIRiS project
- Overview of the CNT flat plate blackbody calibrator
- Results
  - Environmental
  - Ambient breadboard tests
Compact Infrared Radiometer in Space (CIRiS) to Validate CNT Blackbody

- ESTO InVEST-15 (In-space Validation of Earth Science Technologies) program to validate microbolometer detector arrays and CNT blackbodies
- BESST (Ball Experimental Sea Surface Temperature) airborne LWIR three channel radiometer modified for a CubeSat
- Program began in January, 2016
CIRiS Blackbody Based on Laboratory Breadboard

General Requirements for the CIRiS calibrator

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>Flat Plate CNT BB Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Range</td>
<td>9 – 14 µm</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>270 – 330 K</td>
</tr>
<tr>
<td>Emissivity</td>
<td>&gt;0.995</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Time to change temperature</td>
<td>2 K/min (heating)</td>
</tr>
<tr>
<td>Time to stabilize</td>
<td>Seconds</td>
</tr>
<tr>
<td>Uniformity at 350K</td>
<td>230 mK</td>
</tr>
<tr>
<td>Temperature accuracy</td>
<td>200 mK</td>
</tr>
</tbody>
</table>

Breadboard calibrator

- Carbon Nanotube surface
- heater cables
- PRT cables
Carbon Nanotubes are Unique from all other Forms of Carbon

- Vertically Aligned Carbon Nanotubes (VACNTs) are hollow cylinders of sp\(^2\) bonded carbon
- 10s of nm diameter, 100s of \(\mu\)m length, >10\(^{10}\) CNTs/cm\(^2\) density

Optimal Substrate and Growth Parameters Determined
Emissivity of CNT Samples Verified by NIST

- Highly emissive and Lambertian surface in the IR
- NIST measurement uncertainty ±10^{-4}

Emissivity and BRDF comparable to cavity blackbodies
No Visual Change or Measurable BRDF change after Thermal Cycling Demonstrates Survivability

BRDF (Bidirectional Reflectance Distribution Function) remained unchanged after thermal cycling (-30 °C to 50 °C)
Vibration Testing Shows Almost No Particulates

- Results from all CNT vibration tests < Level 300
  - Tested CNTs from multiple vendors
- All particulates found are counted even though they are not all CNTs
- Vibration in 2 axes at 14.1 Grms (GEVS) and 43.8 Grms
- Typical particle counts for Martin Black > Level 300
- Typical particle counts for Ball IR Black (JWST) = Level 300
No Change in Visible Reflectance Due to Radiation Exposure

- Exposure equivalent to 5 years in a 700 km sun-synchronous orbit with 5 mils aluminum equivalent shielding
Breadboard CNT Blackbody Tested From 297 K to 350 K in Ambient Laboratory Environment

- Temperature Rate of Change for Heating is > 2 K/min
- 4 minutes to reach stability of 5 mK
- Temperature Uniformity between 3 PRTs is < 200 mK
CNTs Are an Enabling Technology

- CNT blackbodies are highly emissive and Lambertian
- Survive relevant environments (thermal, vibration and radiation)
- Breadboard calibrator performance demonstrated
- Thermal vacuum tests are ongoing
- CNT blackbodies are an integral part of the INVEST CIRiS project
Thanks to a LARGE Cast of Characters

Bevan Staple          John Fleming
Tim Valle             Laura Coyle
Matt Gross            Zongying Wei
Beth Kelsic           Ray Rehberg
Lindon Lewis          Glenn Taudien
Carol Dunn            Jerry Valentine
Keith Spargo          Robert Johansson
Kevin Weed            Jordan Marks
David Osterman        Holden Chase
Kim Kish              Allan Sword
Valaree VanDyken      Paul Hauser
Diane Fear            Richard Gonzales
Richard Jetley        Nathan Meister
Neil Doughty          Aaron Seltzer

Joe Sprengard and Jae Hak Kim at General Nano
The Contributors Include

- Ball Internal Research and Development
- General Nano
- JPL SBIR sponsorship
- Nanolab
- NASA Earth Science Technology Office (ESTO) InVEST-15
- NIST Physical Measurement Laboratory
- NASA GSFC
  - JWST BIRB particle data