New Generation Bolometric Detector for Measurement of Solar Spectral Irradiance

Dave Harber[1], Zach Castleman[1], Ginger Drake[1], Karl Heuerman[1], Greg Kopp[1], Joel Rutkowski[1], Heather Passe[1], Matt Smith[1], Paul Smith[1], Jacob Sprunck[1], Erik Richard[1]
Nathan Tomlin[2], Michelle Stephens[2], Malcolm White[2], Chris Yung[2], and John Lehman[2]

[1]Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, Colorado 80303

[2]Quantum Electronics and Photonics Division, Sources and Detectors Group, National Institute of Standards and Technology (NIST), Boulder, Colorado 80303

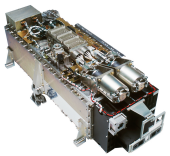
Introduction

Bolometeric detectors are critical for long-term on-orbit monitoring of the solar spectral irradiance (SSI) because they have flat spectral response, are very stable, and are robust to on-orbit degradation. We have developed a next-generation bolometric detector for monitoring of the solar spectral irradiance based on silicon and using multiwall vertically aligned carbon nanotubes (VACNTs) as the black absorber. These technologies both ease fabrication and provide higher performance. This new detector is implemented in a new 6U cubesat SSI monitor instrument under development; the Compact Solar Irradiance Monitor (CSIM).

Background

Monitoring of the variability of the solar spectral irradiance (SSI) is critical for climate modeling. LASP has built two generations of SSI instruments and is currently developing a prototype third-generation instrument that can be flown as a 6U cubesat. The SSI instruments all cover 200-2400 nm and use redundant channels for degradation tracking.

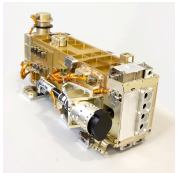
SORCE SIM



2003-Present
Free flyer satellite
First-generation
Two redundant channels

Bolometer:
- Diamond substrate
- NiP black absorber
- Kapton thermal link

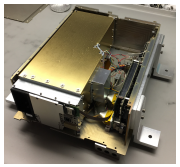
TSIS SIM



Planned late 2017 launch
Pointing platform on ISS
Second-generation
Three redundant channels

Bolometer:
- Diamond substrate
- NiP black absorber
- Kapton thermal link

CSIM

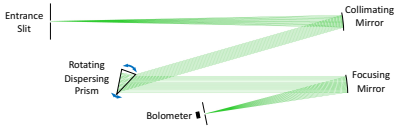


In development
6U Cubesat
Prototype third-generation
Two redundant channels

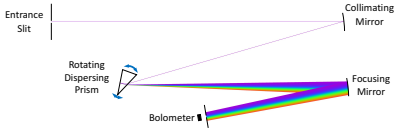
Bolometer:
- Silicon substrate
- VACNT black absorber
- SiN thermal link

CSIM Optical Layout

Single Wavelength, Vary Field Angle

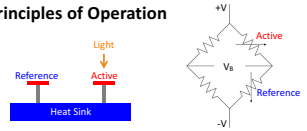


Vary Wavelength, Single Field Angle



Bolometer

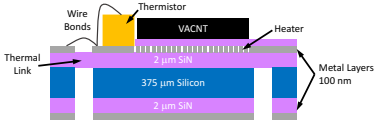
Principles of Operation

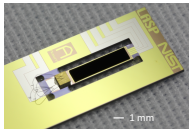


The bolometer is implemented as a paired electrical substitution radiometer. Thermistors on the two bolometers form one arm of a resistance bridge. A fixed heater power level is applied to the reference bolometer. The heater power applied to the active bolometer is adjusted to keep the bridge in balance (V_B=0). To measure optical power, the active bolometer is illuminated; the measured optical power is the change in heater power applied to the active bolometer.

Bolometer Fabrication

The bolometer is fabricated by NIST using silicon processing techniques. This allows the replacement heater, thermal link, heat sink, and VACNT all to be integrated. The thermistor is then bonded on, and wire-bond connections are made to the thermistor and from the bolometer to the drive electronics.



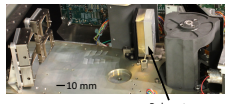


Next generation silicon bolometer with thermistor and wire bond connections. The VACNT absorber is the black rectangle at the center.

Integrated Bolometer

Both bolometers are fabricated from one piece of silicon. This silicon is mounted into a housing and wire bonded to the drive electronics board:

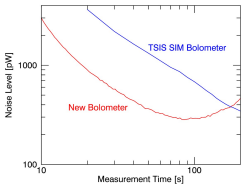
The bolometer housing mounted onto the optical bench:



Results

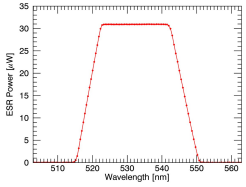
Noise Level

With a measurement time of 80 seconds the noise level of this bolometer is 284 pW, this is 3x lower than the previous generation.



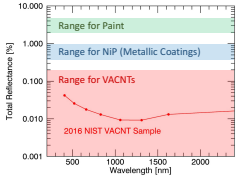
Measurements in the Instrument

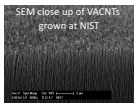
Spectrum of a 532 nm laser taken with CSIM using the bolometer as the detector. The spectral width is due to instrument design; the laser is <1nm wide.



VACNT Reflectance

The reflectance of VACNT is much lower across a broad range of wavelengths than previous absorbers used in bolometers.





Benefits of the New Design

Integrated Silicon Fabrication
- Simplified fabrication
- Precise control of thermal link conductance
- Controls and minimizes thermal mass
- Facilitates miniaturization

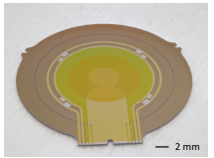
Lower Noise
- Increased S/N of spectra
- Full solar spectra can be taken 4x faster:
  - Less instrument degradation per each spectra
  - Better instrument stability
  - Increased precision in monitoring of long-term solar trends

VACNT Absorber
- Recent NIST samples have total hemispherical reflectivity <100ppm
  - On the order of the *cavity* reflectance for primary standard radiometry
  - Allows for higher accuracy bolometers
- High optical damage threshold
  - Expected to show low degradation with solar-exposure
- Large thermal conductivity
- Grown on silicon at 700º C
  - Limits materials used in the bolometer

Ongoing Work

We are currently doing performance and qualification testing of the CSIM instrument. This will include flight qualification testing of CSIM (thermal vacuum, vibe), including the new bolometer design. On a related project we are developing a next-generation bolometer based on the same techniques for total solar irradiance monitoring.

Prototype silicon bolometer for total solar irradiance. The VACNT will be grown on the orange circle visible in the center.



Contact: harber@lasp.colorado.edu