
Sonic Thermometer for High-Altitude Balloons

A stand-alone version of the sensor would have utility as a gas composition sensor in industrial process situations.

Goddard Space Flight Center, Greenbelt, Maryland

The sonic thermometer is a specialized application of well-known sonic anemometer technology. Adaptations have been made to the circuit, including the addition of supporting sensors, which enable its use in the high-altitude environment and in non-air gas mixtures.

There is a need to measure gas temperatures inside and outside of super-pressure balloons that are flown at high altitudes. These measurements will allow the performance of the balloon to be modeled more accurately, leading to better flight performance. Small thermistors (solid-state temperature sensors) have been used for this general purpose, and for temperature measurements on radiosondes. A disadvantage to thermistors and other physical (as distinct from sonic) temperature sensors is that they are subject to solar heating errors when they are exposed to the Sun, and this leads to issues with their use in a very high-altitude environment.

While sonic anemometers and thermometers are commonly encountered

in surface-based applications, they are not found in a high-altitude [e.g., 100,000 ft (≈ 30.5 km) and above] environment. One reason for this is the very thin air and correspondingly poor sound propagation encountered at these altitudes. A second issue is that the gas temperature inside the balloon is required. Aside from mounting considerations, this also leads to a need to operate correctly in a helium or helium/air gas mixture. The gas composition must be known via some means in order to compute accurate temperatures.

To make accurate sonic temperature measurements, the mean molecular weight of the gas the sensor is working in must be known, as must the value for gamma (the ratio of gas heat capacity at constant pressure divided by gas heat capacity at constant volume) for that gas. Therefore, a supporting measurement is required that directly or indirectly allows gas composition and gamma to be determined. With this data, the speed of sound as measured by the sonic thermometer can then be used to compute an accurate temperature.

The key addition to the basic sonic thermometer design was a sensor that, in this case, measured gas heat capacity at constant pressure. This data could then be used to identify the gas mixture composition (ranging from pure helium to pure air), and with that data both mean gas molecular weight and gamma could be computed. In turn, this data is required for the temperature calculation.

The supporting sensor used for gas composition/molecular weight/gamma measurement is built as an integral part of the sonic thermometer circuitry, and consists of a pair of simple semiconductor sensors. During measurements, a gas composition measurement is made at the same time as a speed of sound measurement is made by the sonic thermometer. Thus, each measurement has its own gas composition data associated with it, enabling a precise temperature computation to be completed.

This work was done by John Bognar of Anasphere for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16104-1

Near-Infrared Photon-Counting Camera for High-Sensitivity Observations

Extremely faint phenomena and NIR signals emitted from distant celestial objects can be observed and imaged.

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The dark current of a transferred-electron photocathode with an InGaAs absorber, responsive over the 0.9- to 1.7- μm range, must be reduced to an ultralow level suitable for low signal spectral astrophysical measurements by lowering the temperature of the sensor incorporating the cathode. However, photocathode quantum efficiency (QE) is known to reduce to zero at such low temperatures. Moreover, it has not been demonstrated that the target dark current can be reached at any temperature using existing photocathodes.

Changes in the transferred-electron photocathode epistructure (with an InGaAs absorber lattice-matched to InP

and exhibiting responsivity over the 0.9- to 1.7- μm range) and fabrication processes were developed and implemented that resulted in a demonstrated $>13\times$ reduction in dark current at -40°C while retaining $>95\%$ of the $\approx 25\%$ saturated room-temperature QE. Further testing at lower temperature is needed to confirm a $>25^\circ\text{C}$ predicted reduction in cooling required to achieve an ultralow dark-current target suitable for faint spectral astronomical observations that are not otherwise possible. This reduction in dark current makes it possible to increase the integration time of the imaging sensor, thus enabling a much higher near-infrared (NIR) sensitivity

than is possible with current technology. As a result, extremely faint phenomena and NIR signals emitted from distant celestial objects can be now observed and imaged (such as the dynamics of red-shifting galaxies, and spectral measurements on extra-solar planets in search of water and bio-markers) that were not previously possible. In addition, the enhanced NIR sensitivity also directly benefits other NIR imaging applications, including drug and bomb detection, stand-off detection of improvised explosive devices (IED's), Raman spectroscopy and microscopy for life/physical science applications, and semiconductor product defect detection.

A set of methods was developed for implementing an InGaAs photocathode whereby the dark current can be reduced by lowering the temperature to the ultralow target level, while at the same time, exhibiting QE that is high enough to perform the astrophysical measurements.

This innovation features a thin, n-type InP cap layer that is etched during final cleaning between the grid lines. Along with an n-type InP layer at the heterointerface and a p-type InP emitting surface layer, the extra degree-of-freedom provided by the n-type InP cap layer enables independent tailoring of the electric field at 3 key locations in the device: beneath the grid lines, at the emitting InP

surface between grid lines, and at the p-type InGaAs absorber/n-type InP heterointerface. This enables minimization of the field beneath the grid lines while the emitting surface and heterointerface fields are balanced such that the onset of high escape probability and turn-on completion of the heterointerface occur at the same reduced device bias. The resulting effect is that dark current components are minimized, including those due to undue extension of the depletion region into the low bandgap absorber and premature emitting surface field development with bias, while maintaining high QE and minimal grid line leakage.

The innovation features an InP:Zn emitting surface layer doped below the

onset of Zn diffusion (thus minimizing epitaxy and process variability), absence of an undoped InP drift layer (along with the avalanche-current-inducing voltage drop across it), and an InGaAs step grade layer introduced at the InGaAs absorber/InP:Si layer heterointerface (further reducing dark current components associated with the depleted low bandgap absorber). Employment of a SiON dielectric beneath the grid line promotes device stability and the absence of fixed mobile charge in the metal/dielectric/InP stack.

This work was done by Michael Jurkovic of Intevac Photonics for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16044-1

Integrated Optics Achromatic Nuller for Stellar Interferometry

Nuller allows faint off-axis light to be much more easily seen.

NASA's Jet Propulsion Laboratory, Pasadena, California

This innovation will replace a beam combiner, a phase shifter, and a mode conditioner, thus simplifying the system design and alignment, and saving weight and space in future missions. This nuller is a dielectric-waveguide-based, four-port asymmetric coupler. Its nulling performance is based on the mode-sorting property of adiabatic asymmetric couplers that are intrinsically achromatic. This nuller has been designed, and its performance modeled, in the 6.5-micrometer to 9.25-micrometer spectral interval (36% bandwidth). The calculated suppression of starlight for this 15-cm-long device is 10^{-5} or better through the whole bandwidth. This is enough to satisfy require-

ments of a flagship exoplanet-characterization mission.

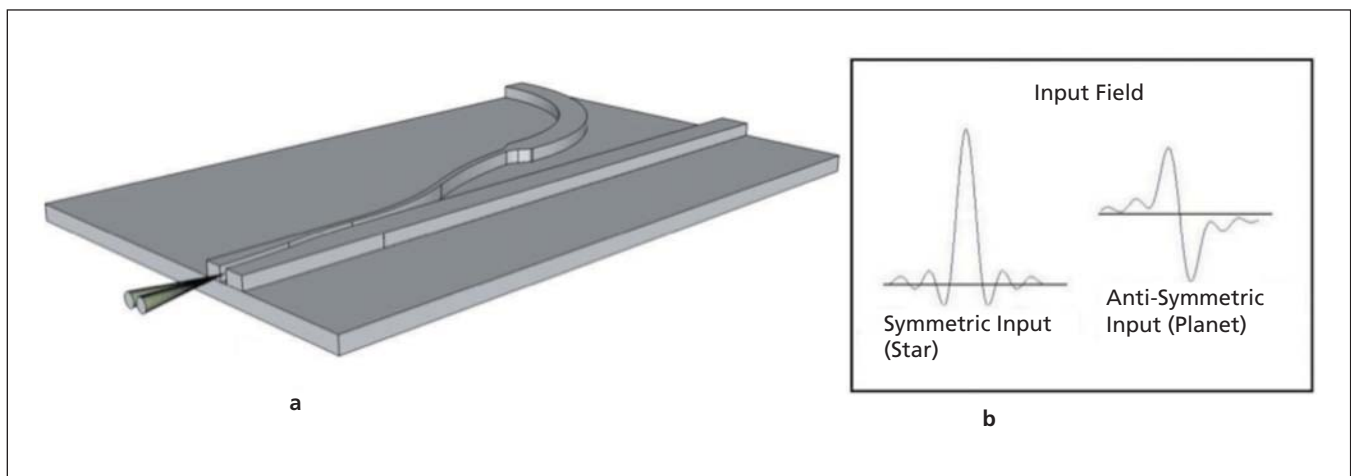
Nulling interferometry is an approach to starlight suppression that will allow the detection and spectral characterization of Earth-like exoplanets. Nulling interferometers separate the light originating from a dim planet from the bright starlight by placing the star at the bottom of a deep, destructive interference fringe, where the starlight is effectively cancelled, or nulled, thus allowing the faint off-axis light to be much more easily seen. This process is referred to as nulling of the starlight.

Achromatic nulling technology is a critical component that provides the

starlight suppression in interferometer-based observatories. Previously considered space-based interferometers are aimed at approximately 6-to-20-micrometer spectral range. While containing the spectral features of many gases that are considered to be signatures of life, it also offers better planet-to-star brightness ratio than shorter wavelengths.

In the Integrated Optics Achromatic Nuller (IOAN) device, the two beams from the interferometer's collecting telescopes pass through the same focusing optic and are incident on the input of the nuller.

The dual-input waveguide structure accommodates two modes, while each of



A 3-dimensional view of the **Integrated Optics Achromatic Nuller** device. (a) The scales are distorted for visual clarity. The input from the two telescopes is incident on the device from the left. (b) The input field for the case of the two telescope beams arriving in-phase (starlight) and exactly out-of-phase (planet light).