Project Summary

PSI-2882

Firm: Physical Sciences Inc.
Contract Number: NNA05BE72C
Project Title: THz Quantum Cascade Laser Based Sensor for Hypersonic Flows

Identification and Significance of Innovation: (Limit 200 words or 2,000 characters whichever is less)
Ground test facilities are used by NASA to simulate the conditions present during flight at hypersonic velocities. These facilities are used to develop thermal protection systems for the Space Shuttle and other space vehicles which must undergo atmospheric re-entry. In the future these facilities will be used to design new hypersonic aircraft. To ensure the accuracy and usefulness of ground test results, the state of the gas being used in the ground test facility must be known. Key components of the test gas, such as atomic oxygen and atomic nitrogen, can be monitored today using pulsed laser sources operating in the ultraviolet region of the spectrum. However, this measurement scheme is complex, indirect, and too slow to detect rapid fluctuations present during a ground test. Our innovation is a compact, portable source of tunable laser radiation in the far-infrared (Terahertz) region of the spectrum which can be used to directly measure the number density and velocity of atomic oxygen continuously during a ground test. This laser source is innovative not only because of the novel laser technology it incorporates but also because it introduces a previously unavailable capability, namely continuous monitoring of the oxygen atom concentration in hypersonic flows.

Technical Objectives and Work Plan: (Limit 200 words or 2,000 characters whichever is less)
The objective of this Phase II effort was to design, built, test, and deliver to NASA a prototype sensor to continuously monitor the amount of atomic oxygen in a hypersonic flow. The sensor is designed to operate at the NASA Ames Aerodynamic Heating Facility (AHF). It makes direct absorption measurements of the atomic oxygen concentration using an innovative external cavity terahertz quantum cascade laser (EC THz QCL). Successful completion of this effort would introduce a previously unavailable capability to better characterize the state of hypersonic flow fields.

Technical Accomplishments: (Limit 200 words or 2,000 characters whichever is less)
As a result of this program, PSI demonstrated and built the first of its kind external cavity terahertz (THz) quantum cascade laser (QCL) capable of tuning continuously without mode hops over 12 gigahertz (GHz) and broadly with mode hops over 120 GHz. These significant results were published in a peer reviewed journal. Although this laser was not able to address the atomic oxygen fine structure transition at 4745 GHz, the capability for extended tuning of a THz QCL developed under this program brings to NASA the potential for significant further advancement in this area.

NASA Application(s): (Limit 100 words or 1,000 characters whichever is less)
The laser-based diagnostic developed during this project will increase the accuracy of test results at hypersonic wind tunnel facilities used to simulate atmospheric re-entry. Using these test results, NASA will be able to optimize the amount of thermal protection material used in the Space Shuttle and other vehicles, so that safety can be ensured without unnecessarily reducing the payload. The diagnostic will also facilitate the design of engines for future hypersonic aircraft. The novel laser source developed under this project will also enable high resolution spectroscopy in the far-infrared for the astrophysics community.

Non-NASA Commercial Application(s): (Limit 200 words or 2,000 characters whichever is less)
Compact, tunable terahertz lasers will be useful for container-penetrating detection of dangerous substances for homeland defense applications, detecting contraband substances for law enforcement applications, and detecting trace amounts of moisture for industrial process control.

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NASA SBIR/STTR Technologies

Phase II – THz Quantum Cascade Laser Based Sensor for Hypersonic Flows

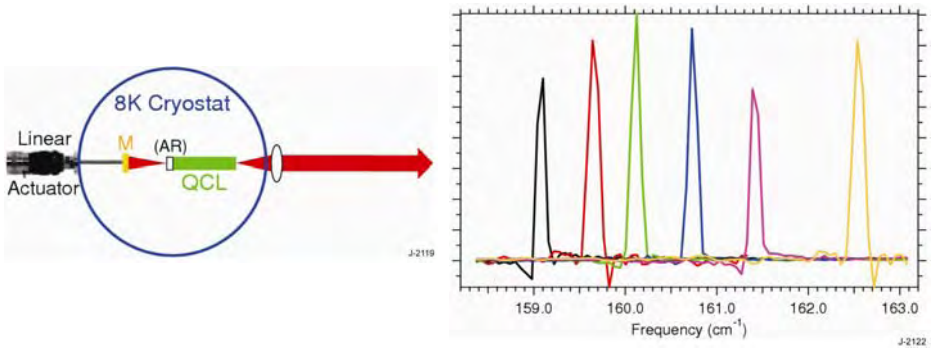
PI: Joel Hensley / Physical Sciences Inc. – Andover, MA

Proposal No.: 03-II A2.06-9450 (PSI-7275-020)

Identification and Significance of Innovation

- Quantum cascade laser-based sensor for direct absorption spectroscopy measurements of atomic oxygen
  - Hypersonic flow facilities require accurate knowledge of the state and dynamical behavior of the flow field.
- New capability: Continuous monitoring of oxygen atom concentration in hypersonic flows.
- Novel broadly tunable far-infrared laser source
  - 4.7 terahertz (THz) quantum cascade laser (QCL)
  - Coupled to an external cavity (EC).

Achieved TRL = 3



Broad tuning of a 4.7 THz QCL over 4 cm^{-1}

Technical Objectives and Work Plan

- Technical objective:

  Design, build, test, and deliver to NASA a prototype sensor to continuously monitor the amount of atomic oxygen in a hypersonic flow.
- Work plan:

  Task 1: Determine optimal feedback for external cavity

  Task 2: Improve operating characteristics of QCL devices

  Task 3: Build oxygen-atom sensor

  Task 4: Test sensor at PSI

  Task 5: Deliver prototype sensor to NASA Ames and support training, installation and testing.
- Achievements:
  - Mode-hop free continuous tuning over 0.4 cm^{-1}
  - Broadband tuning over 4 cm^{-1}.

NASA Applications

- Diagnostic tool for hypersonic flow facilities.
- With the laser source developed under this project, NASA scientists will be able to measure terahertz emission from at least one new target species of importance to astronomy or atmospheric science. Future versions of this laser source can be tailored to match other target species, until the entire terahertz region of the spectrum has been covered. As a result, the NASA research team will be able to develop a better understanding of the evolution of the universe and learn more about problems with Earth's atmosphere, including global warming, ozone destruction, and pollution.

Non-NASA Applications

- Compact, tunable terahertz lasers will be useful for container-penetrating detection of dangerous substances for homeland defense applications, detecting contraband substances for law enforcement applications, and detecting trace amounts of moisture for industrial process control.

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NON-PROPRIETARY DATA