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Rapid-Tuning Infrared Laser System

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Final Report

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We have acquired a rapid-wavelength-tunable, continuous-wave, narrow-linewidth external-cavity quantum cascade laser system to enable the measurement of the full fundamental rovibrational absorption band of nitric oxide (NO) and other mid-infrared active molecular species in high-temperature and high-pressure conditions. We previously were able to measure the fundamental rovibrational bands of NO and other species over only a limited set of wavelengths at moderate wavelength-tuning rates; the acquisition of this laser system will now enable the creation of a comprehensive high-temperature and high-pressure spectral database that will increase the range of applicability of NO absorption sensing to infer the temperature of high-enthalpy flows in ground-test facilities used to evaluate new propulsion concepts.
This equipment will also be used in the training and education of the next generation of graduate students in mechanical engineering in the areas of interest to the Air Force: hypersonics, laser diagnostics, and shock tube methods.

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FINAL REPORT

RAPID-TUNING INFRARED LASER SYSTEM

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1 ABSTRACT

We have acquired a rapid-wavelength-tunable, continuous-wave, narrow-linewidth external-cavity quantum cascade laser system to enable the measurement of the full fundamental rovibrational absorption band of nitric oxide (NO) and other mid-infrared active molecular species in high-temperature and high-pressure conditions. We previously were able to measure the fundamental rovibrational bands of NO and other species over only a limited set of wavelengths at moderate wavelength-tuning rates; the acquisition of this laser system will now enable the creation of a comprehensive high-temperature and high-pressure spectral database that will increase the range of applicability of NO absorption sensing to infer the temperature of high-enthalpy flows in ground-test facilities used to evaluate new propulsion concepts.

This equipment will also be used in the training and education of the next generation of graduate students in mechanical engineering in the areas of interest to the Air Force: hypersonics, laser diagnostics, and shock tube methods.

2 RAPID-TUNING INFRARED LASER SYSTEM

Through this DURIP we have acquired a new Daylight Solutions MIRcat mid-infrared laser system. Figure 1 shows the MIRcat system recently installed for use on the Stanford Kinetic Shock Tube facility. This system provides rapid-scan, ultra-broadly tunable access to wavelengths from 5 - 8.6 μm for the measurement of the absorption spectra of important aerothermodynamic molecular species such as NO at high-temperatures and high-pressures. In combination with our shock tube facilities for generating well-known high-temperature/pressure conditions, the rapid-scan capability of this laser system enables a game-changing transition from line-by-line to branch-by-branch measurements. This orders-of-magnitude increase in efficiency has, for the first time, made the construction of a high-temperature/pressure spectral database possible.

The construction of such a database will enable the development of high-accuracy laser-based diagnostic tools for harsh flow environments. For example, the work presently being performed to develop a high-T/P database for NO is currently being leveraged to develop a thermometry diagnostic for the Hypersonic Aero Propulsion Clean Air Testbed (HAPCAT). Additionally, the database will be used for measurements in the Caltech T5 reflected shock tunnel to characterize non-equilibrium conditions in the nozzle flow and flows over bodies. The public availability of such databases will have a sizable impact on the development of laser-based sensors for the characterization of high-enthalpy air flows.

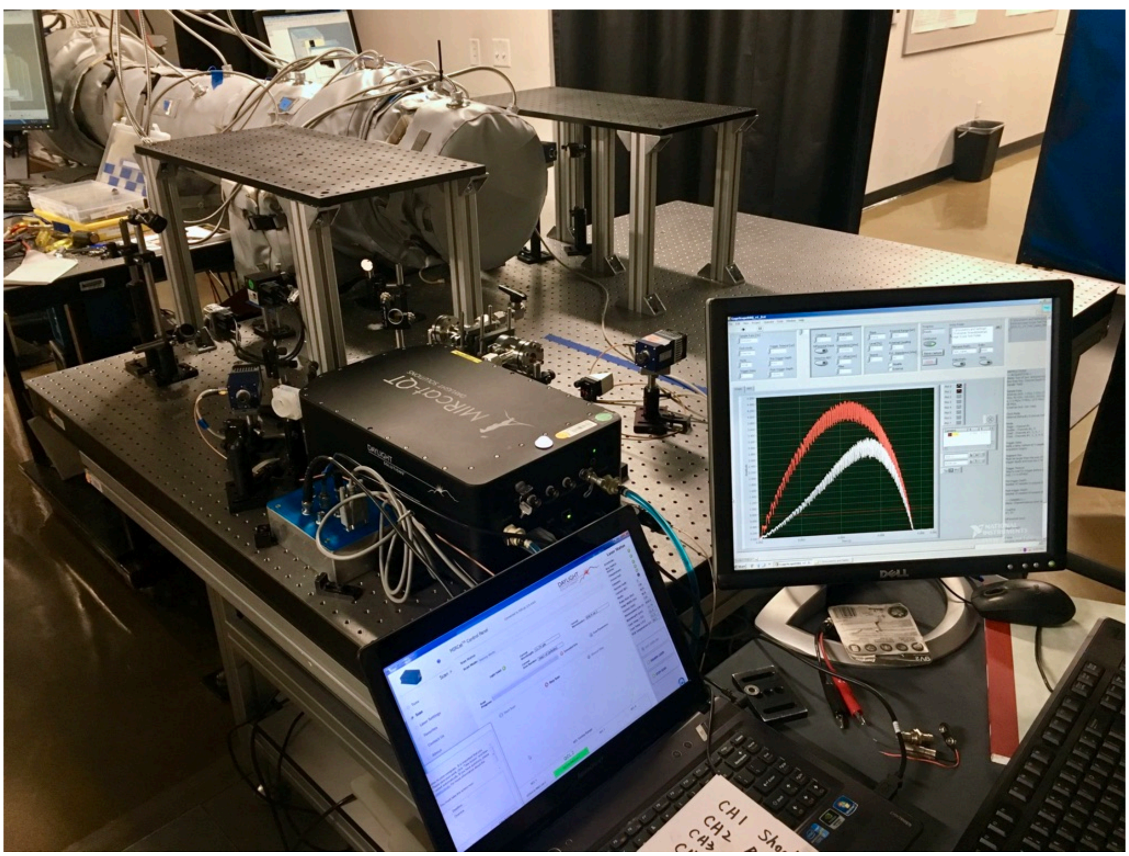

Figure 1: Daylight Solutions MIRcat system in use on the Stanford Kinetic Shock Tube Facility.

3 ADDITIONAL INFORMATION

3.1 RESEARCH FACILITATED

The overall goal of acquiring these laser systems is to facilitate advanced fundamental research sponsored by DoD and other federal agencies. Funded programs benefitting from this equipment include:

- AFOSR: "Fundamental Aspects of NO IR Spectroscopy in High T and P Air"
- Air Force: "Research to Support the Development and Testing of Novel Sensor for Temperature in High-Pressure Air"
- AFOSR: "Spectroscopic Measurements and Nonequilibrium Modeling for High-Enthalpy Air"
- AFOSR: "Development of HyChem – A Jet and Rocket Propellant Fuel Model"
- ARO: "Kinetics Studies of ARO-Relevant Fuels using Shock Tube/Laser Absorption Methods"
- FAA: "ASCENT Project 25: Continuation of Shock Tube and Flow Reactor Studies of the Kinetics of Jet Fuels"

Additionally, a wide range of publishable research supported by AFOSR and other government agencies has already been, and will continue to be enabled by the acquisition of equipment under this DURIP grant. Early examples of research supported by this DURIP equipment is given by the following papers presently in preparation:

- Almodovar, C. A., Su, W-W, Strand, C. L., Hanson, R. K., "High-Pressure Absorption Cross-Sections and Line-Mixing of Nitric Oxide Near 5.3 μm," Journal of Quantitative Spectroscopy and Radiative Transfer (In Preparation).
- Ding, Y., Strand, C. L., Hanson, R. K., "High-temperature mid-infrared absorption spectra of acetone and acetaldehyde near 5.7 μm," Journal of Quantitative Spectroscopy and Radiative Transfer (In Preparation).

3.2 USEFUL LIFE OF EQUIPMENT

The useful life of this equipment is estimated at 5 years, although previous major laser purchases in the Hanson laboratory have attained significantly longer useful lives.

3.3 EFFECT ON GRADUATE EDUCATION

The acquisition of this equipment benefits the training and education of the next generation of graduate students in mechanical engineering in the areas of combustion, propulsion, laser diagnostics and shock tube methods. The greater portion of the graduate students who have pursued higher degrees, M.Sc. and Ph.D., under the supervision of Professor R. K. Hanson at Stanford University have done so with the support of DoD funding. Over 100 students have received Ph.D. degrees from the Hanson group. Several of these students have learned to develop and use state-of-the-art laser diagnostic and spectroscopic techniques, to design and use shock tube facilities, and to apply these tools to studying current combustion problems of interest to the DoD. More than 30 of the graduating students have gone on to become professors in their own right. Students who work on this equipment will be well trained in new scientific methods and able to pursue careers as leaders in science and engineering in the United States.