Title of Investigation:

High-Resolution Spectroscopy at Mid-infrared Wavelength

Principal Investigator:

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Other Investigators:

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Initiation Year:

FY 2004

FY 2004 Authorized Funding:

$68,000

Actual or Expected Expenditure of FY 2004 Funding:

$68,000

Status of Investigation At End of FY 2004:

To be continued in 2005 with funds remaining from FY 2004 and FY 2005 extension.

Expected Completion Date:

FY 2005

Purpose Of Investigation:

The goal of this investigation is improving and expanding the capabilities of Infrared Heterodyne Spectrometers (IRHSs) operating in the mid-infrared spectral region. The heterodyne technique is a clever way of detecting and analyzing radiation. With this technique, the detected radiation is combined with a known frequency from a signal generator in the receiver and the beat or difference frequency between the two is measured and analyzed. The beat frequency preserves spectral and intensity information on the incoming radiation and the technology to analyze if it is generally more highly developed. IRHSs can be compared to the common radio receiver, which detects a radio frequency transmitted by a radio station and converts it to audio frequencies (e.g., music). The IRHS detects infrared light emitted by molecules and atoms and transforms it into radio frequencies, which can be analyzed to extract information on the emitting gas and its environment. This technique permits very precise measurements of a region's temperature, molecular abundance, and wind speeds. Infrared heterodyne instruments that offer high-spectral resolution and high sensitivity provide more detailed information on the physics and chemistry of gaseous sources.

In the past, Goddard-built instruments, including the IRHS and the Heterodyne Instrument for Planetary Wind And Composition (HIPWAC), have identified and characterized natural carbon-dioxide lasers on Mars and Venus, studied the thermal infrared aurora on Jupiter, directly measured the winds on Venus and Titan, one of Saturn's moons, measured ozone on Mars and the Earth's atmosphere, and detected minor constituents in planetary atmospheres.

In recent years new devices have been introduced into the field of infrared technology. These devices offer high potential for being adapted to mid-infrared spectroscopy—particularly in the area of heterodyne techniques and remote and astronomical studies. New semiconductor devices, quantum-cascade-lasers (QCL), and quantum-well-infrared-photodetectors (QWIPs), are of interest with regard to their use as laser local oscillators (Los) and photomixers in high spectral resolution heterodyne receivers. The QCLs are much smaller and require less electrical power to run than currently used gas laser LOs and can be made to operate over greater spectral regions than the gas lasers. The QWIP devices may permit greater instantaneous spectral coverage in a single measurement, greater bandwidth.

The use of a QCL could extend the LO wavelength coverage to about 8-25 microns if the lasers have enough power, emit at precise frequencies (narrow line width), and have high stability. QWIPs also provide the potential to offer a wider wavelength range of operation, in addition to a mixer bandwidth that is at least a factor of three greater than current technology. These potential improvements would enable more atoms and molecules to be measured and a greater number of astronomical and Earth-based sources to be studied remotely. The goal of the presented study is to acquire and test these devices in a laboratory environment and to project their use in a field and a possible flight instrument.

Accomplishments to Date:

Preliminary test were done for "off-the-shelf" QWIP detectors. To do so, the laboratory setup was modified to have the necessary capability to test the available devices. Required electronic components and existing bias supplies were modified to supply the required stable bias voltages, which are higher than those usually used with our current MCT detector/photomixers.

Figure 1. Jet Propulsion Laboratory QWIP device in mount. The chip contains many detectors and was originally designed for IR cameras. For heterodyne purposes, only one element is connected. The size of a single element is roughly 100x100µm2.

The optical test bed was also modified to provide the higher amount of laser power needed to pump the QWIP devices for heterodyne detection. The spectrometer radio frequency, RF, electronics were upgraded to allow measurements up to 4 GHz compared with the current 1.6-GHz capability.

We tested three devices, two were provided by Murzy Jhabvala, who is with Code 550, and the third by Sarath Gunapala, who is with the NASA Jet Propulsion Laboratory (JPL). (JPL's device is shown in Figure 1.) All three devices were off-the-shelf QWIPs, not optimized for the required wavelengths or for heterodyne operation. In our measurements, the JPL device unfortunately showed sensitivity at least 10 times lower than predicted. The reason for the apparent loss of sensitivity is currently under investigation. The developers see a high potential for improvement so that a retest with an optimized device will be performed in the future.

The two Goddard Space Flight Center devices are optimized for wavelengths lower than the tuning range of currently used CO_2 laser local oscillators; however, a device operating at a much longer wavelength (~12 microns) is already under development. When available, it will be tested and the potential for a substantial improvement in heterodyne performance will be evaluated. Work will be done in the second year if support for the effort is renewed.

We designed and modified a liquid nitrogen dewar for use in testing the capabilities of the quantum-cascade (QC) laser as a local oscillator in a heterodyne system. An available diode laser power supply was modified to provide the higher voltage and current combination needed to operate the lasers.

Unfortunately, a laser could not be acquired in FY 2004 due to lengthy negotiations with the only commercial manufacturer of QCLs, AlpesLaser/Switzerland. An acceptable device has been identified (see characteristics in Figure 2) and the purchase has been initiated.

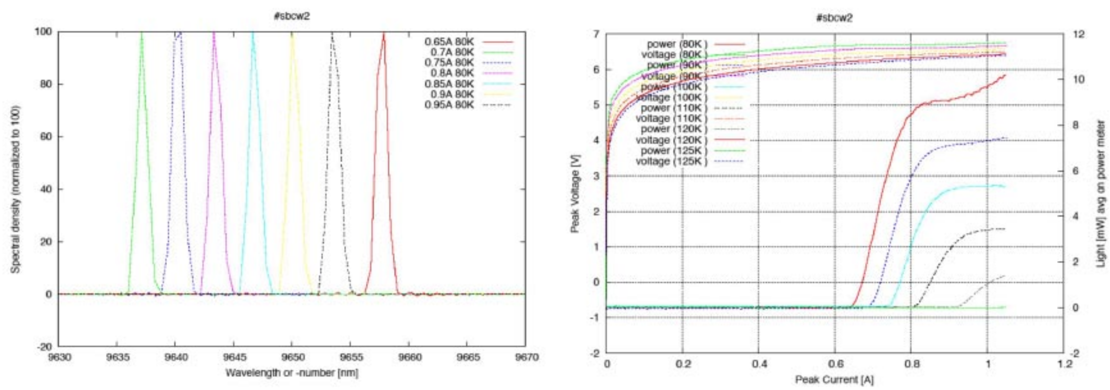

Figure 2. Frequency at various currents and temperatures (left) and output power at various currents and temperatures (right) for the desired AlpesLaser QCL device. The available optical power is likely to be sufficient for heterodyne operations of MCT detectors.

An ongoing collaboration with the University of Cologne/Germany (UoC) was expanded to include the evaluation of the new lasers. Tests on a similar device there are very promising (see Figure 3).

Planned Future Work:

We will pursue the development of the 12-micron QWIP elements and their optimization for the heterodyne operation. We also will continue collaborating with JPL and will acquire another device that will better meet the wavelength and direct detection sensitivity specifications. The new devices can be easily tested in the laboratory setup we created during the first year.

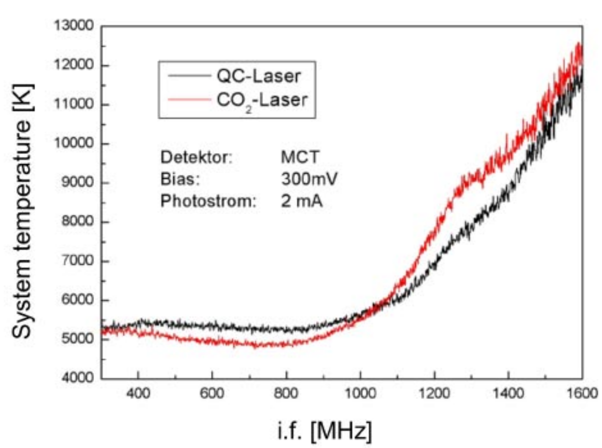

Figure 3. Preliminary results from collaboration with the University of Cologne. Shown is a comparison of heterodyne sensitivity over frequency achieved using a CO2 laser and a QCL in the Cologne spectrometer. Both lasers reach the same sensitivity level. Other parameters like stability and laser linewidth are yet to be determined.

In collaboration wit UoC we will combine our efforts to characterize the QC laser that is already available at their lab. For this purpose either a PhD student from UoC will come to GSFC with the device to perform the desired tests or a collaborator from here will travel to Germany. In addition the negotiations with AlpesLaser are completed and a QC laser ordered. We expect to receive a laser with specifications adequate for testing as an LO in a heterodyne spectrometer operating near 9.5 micron. Work to extend operation to longer wavelengths will then be proposed.

Summary:

This effort will extend the operating wavelength of infrared spectrometers to longer wavelengths, with full spectral coverage over nearly the entire mid-infrared region. As a result, instruments will be able to take spectral measurements that are several orders-of-magnitude more detailed than those with current spectrometers. With this capability, we will be able to retrieve data on winds, temperature, and chemical abundances in gaseous sources. For NASA and Goddard, the benefits are significant. We will be able to build more compact and versatile spectrometers to study astronomical sources and the Earth's atmosphere, both from ground-based and space platforms. More importantly, this instrument will take measurements not currently possible with other techniques. If the devices perform as predicted, the only limitation in space-flight applications will be the need for moderate cryogenic cooling to 80-100 K of both the QCL and the QWIP. In addition, we will need more complex techniques for stabilization and identification of the output frequencies of the QCL. These should not be limitations on ground-based and airplane platforms.