Status of the Laser Risk Reduction Program at NASA Langley Research Center

Frank Peri, Jr.
Laser & Electro-Optics Branch
NASA Langley Research Center
Hampton, VA 23681

Michael J. Kavaya
Laser & Electro-Optics Branch
NASA Langley Research Center
Hampton, VA 23681

Upendra N. Singh
Systems Engineering Competency
NASA Langley Research Center
Hampton, VA 23681

Abstract- **In 2002 the Earth Science Technology Office (ESTO) created a new program to address the risks of developing laser and lidar technologies for space-based remote sensing applications. This program grew out of concern that there are no lasers as active sources for space-based remote sensing that have been space qualified for long-term science measurements. Presently, the risks inherent in developing these technologies have been born by programs funded to produce scientific results. The intention of this program is to mitigate risks in certain technical areas so that other technology programs can further the maturation of the instruments prior to infusion into a science program. The program has invested in several critical areas, including: advanced laser transmitter technologies to enable science measurements (tropospheric ozone, water vapor, winds, altimetry), development and qualification of space-based laser diode arrays, and advanced nonlinear wavelength conversion technology for space-based lidars**

In this paper we will describe the accomplishments of the work performed at NASA Langley Research Center during the second year of this program.

I. INTRODUCTION

An area of Earth science instrument technology that will see increased technology advancement is lasers, specifically, lasers for light detection and ranging (lidar) and differential absorption lidar (DIAL). These measurement techniques are finding uses in several Earth science areas, including: atmospheric chemistry, water vapor, aerosols and clouds, wind speed and direction, pollution, oceanic mixed layer depth, land-locked ice, sea ice, vegetation canopy and crop status, biomass, vegetative stress indicator, surface topography, and others. While much of this science has been ongoing over the past decade using lasers, the measurements have been made almost exclusively from the ground or from aircraft. Advancements in these science areas could benefit from improved spatial and temporal coverage by using space-based lasers for remote sensing.

Lasers for remote sensing instruments require significant platform resources (primarily power and volume) while also suffering from low reliability and consequently short operational lifetimes. Technology advancements will be necessary to enable long-term, space-based operation of lasers. Strategies for developing laser technologies will focus on the development of reliable, efficient laser pump sources at 1- and 2-microns, efficient frequency conversion devices such as second and third harmonic generators and optical parametric oscillators and a variety of elements common to all measurement techniques including: improved heat rejection using high thermal conductivity materials, improved laser diode lifetime and reliability, improved frequency control and strict contamination control. Future enhancements may also include the capability to scan the laser output and the development of a high spectral resolution lidar. Advancements in receiver technologies will also be necessary to help mitigate laser transmitter power requirements. These improvements will include large (3-meter class), lightweight (1-10 kg/m2), deployable telescopes and high efficiency detectors. Finally, improvements in filter technologies, including narrowband linear variable etalon filters will be necessary for many multispectral measurements.

II. LASER RISK REDUCTION PROGRAM

The ESE and ESTO began the Laser Risk Reduction Program (LRRP) in FY02 in response to 1) concerns about the risk of space-based lidar missions, 2) the November 2000 report of an Independent Laser Review Panel, and 3) the June 2001 recommendations of the Integrated NASA Lidar Systems Strategy Team (INLSST) (Singh and Heaps). The goal of this program is to develop enabling technologies for space-based measurements of a variety of ESE science measurements including those mentioned previously. The technologies under development also have numerous applications for other NASA Enterprises, such as aeronautics, space science (planetary atmospheric measurements, surface mapping and spacecraft landing and rendezvous), and homeland defense. The technology program is focused into four areas: laser transmitter design, laser diode research, frequency conversion and lidar receivers/detectors whose recent accomplishments will be discussed further.

III. TWO-MICRON LASER TRANSMITTER

The objective of the 2-micron laser transmitter development is to demonstrate related technologies leading to a conductively cooled, diode-pumped 2-micron laser that is suitable for space-borne lidar application. A new laser crystal material was developed, using Ho and Tm ions doped in Lutetium Lithium Fluoride (LuLF) instead of Yttrium Lithium Fluoride (YLF). Quantum mechanical modeling predicted that this material could be more efficient than the predecessor material HoTm:YLF. Researchers have successfully demonstrated a Ho:Tm:LuLF laser system with 1050 mJ Q-switched output energy. This was accomplished using one power oscillator and two amplifiers. The first amplifier is operated in a double-pass configuration, and the second amplifier is operated in a single-pass amplification

due to high energy damage considerations. This is the first time that a Q-switched 2-micron laser has exceeded 1 Joule, and is one order of magnitude higher energy than demonstrated by any other group. In the last 10 years, LaRC has advanced the energy of 2-micron lasers from 20 mJ to 1 Joule. This accomplishment is significant because notional space-based wind profiling measurement scenarios require pulse energies from 1 to 5 Joule. This accomplishment greatly lowers the credibility gap and risk for space missions using this laser technology.

This laser system is based on a partially-conductively cooled laser head, which is not adaptable to a space-based application. Consequently, this task will also develop a fully conductively cooled laser head utilizing advanced heat pipe technology. Advanced thermal management technologies are being investigated that will address the challenges of removing excess heat from the laser diodes. LaRC researchers are collaborating with engineers at NASA's Goddard Space Flight Center (GSFC) to develop concepts to reject heat from the laser head through the spacecraft. Potential solutions include using heat pipes in conjunction with electro-hydrodynamic pumping, spray cooling and mechanical pumping. Extensive thermal and stress modeling of the fully conductively cooled laser head has been conducted. This task will result in the completion of the mechanical design of the fully conductively cooled laser head, including oscillator and amplifier, and the completion of performance measurements of the laser head. This technology development can serve two important scientific missions of the Earth Science Enterprise, namely, DIAL measurement of carbon dioxide and global profiling of wind fields.

IV. CHARACTERIZATION OF HIGH POWER LASER DIODES

Laser Diodes (LDs), used to pump lidar transmitters, are a major risk area in deployment of lidar instruments in space. Reliability and performance data is in very short supply for these components, particularly when operated in a space environment. As part of the LRRP, GSFC has been given the responsibility of LDs operating in 808 nm wavelength used for pumping 1-micron Nd:YAG solid state lasers and LaRC is focusing on 792 nm LDs used in 2-micron lasers.

To date, the activities under this task have been focused on the development of the Laser Diode Characterization/ Lifetime Test Facility (LDCF) and on the investigation of advanced technologies leading to improvement of laser diode arrays operating at 792-nm wavelength. All the laboratory fixtures, environmental control, and safety equipments were installed in the permanent LDCF location, and the assembly of the Characterization Station has been completed except for the thermal and far-field measurement setups. Using the Characterization Station, over 25 laser diode arrays have already been characterized for operation in 2-micron solid-state lasers (refer to figure 1). In addition to basic characteristics parameters measurements (e.g., power, wavelength, and efficiency), the LDCF is capable of some unique measurements such as thermal profiling of laser diode facets, near and far field beam profiling, and high-resolution spectral measurements. Work on the Lifetime Test Station of the LDCF continued over this reporting period. The detail design of the Lifetime Test Station was completed and almost all the equipment were procured and delivered. The Lifetime Test Station will utilize optical and electronic mutiplexers to simultaneously test 8 laser diodes using a single set of instruments. This will allow for true comparative measurements of different laser diodes. A computer program is being developed for automating the operation of the Lifetime Test Station and controlling all aspects of the measurements.

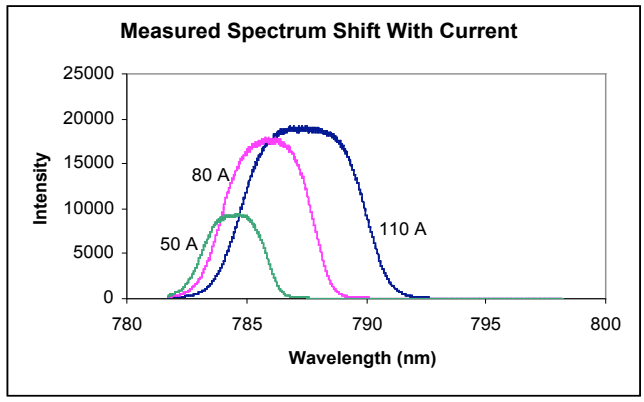

Figure 0 Example of Laser Diode Array Measurements. Spectrum of conductively-cooled 6-bar array generating 600 W of peak power.

Using a novel packaging concept, 7 laser diode arrays were fabricated and delivered. These laser diode arrays use diamond materials as their substrate and heat sink for better thermal characteristics and higher reliability. In order to accurately measure the improved performance of the diamond-substrate lasers, 5 additional laser diode arrays, with bars from the same wafer, were fabricated using conventional substrate and heat sink materials.

A number of LDs with different architectures and package types will be evaluated. Some of these LDs will be selected for lifetime testing that will run over a year. The characterization of different types of LDs will allow researchers to identify the areas of improvements that impact the reliability and efficiency of the laser diodes when operating in space environment. The development of more advanced diode lasers that better suite NASA's intended applications and provide improved performance will begin once the characterization laboratories are complete. Following that, the performance of advanced LDs will be demonstrated, and a lifetime database for standard LD packages will be established. This database will allow for

formulating future lidar missions and performing meaningful cost and risk assessment analyses. The LD characterization and lifetime tests activities will also produce well-defined reliability and space-qualification test procedures allowing for better specification of laser diodes for future Lidar missions envisioned by the ESE, particularly Doppler Wind Lidar and CO2 DIfferential Absorption Lidar (DIAL).

This research will quantify the performance of these laser diode arrays and attempt to answer the following questions:

- What is the reliability of laser diode arrays?
- What is the lifetime of diode arrays?
- What is the effect of derating power?
- What is the effect of running diodes at higher/lower temperatures?
- What is the effect of thermal cycling?
- What is the effect of running constant current vs. constant power?
- What is the effect of radiation on diode performance?
- What is the effect of a vacuum environment on diode performance?
- What is the effect of air quality (humidity, contamination, etc.) on diode performance?
- What are the degradation/failure mechanisms of diode lasers?
- What (if any) measurements can be made to select the best diodes?
- Is there a model which will predict future diode performance?

In order to assess the quality of the laser diode arrays, we will make quantitative performance measurements and diagnostic measurements to indicate possible degradation mechanisms. Parameters that will be monitored include:

- Optical output power
- Electrical input power
- Wavelength
- Efficiency
- Diode temperature
- Ambient environment (i.e. temperature, humidity, cleanliness, pressure)
- Power distribution (i.e. emitter/facet pattern)
- Spectrally resolved image of facet emission
- Package integrity (i.e. changes in solder or flux)
- Device specifications

The progress in this task has already benefited from close collaboration amongst researchers at both LaRC and GSFC and also with major LD manufactures and we expect an even broader scope of collaboration as we complete the LD characterization facility and begin development of advanced LDs. Over the past year, we have held a number of meetings with LD manufacturers toward establishing efficient working relationships and partnerships.

V. UV LASER WAVELENGTH CONVERSION

The objective of this task is to develop wavelength conversion technology to convert a Nd:YAG laser into an efficient, high-energy, pulse UV laser in the 305-308 nm and 315-320 nm wavelength range capable of space-based operation in future ESE missions including DIAL measurement of ozone. The two major technical requirements, which are also the most challenging for this laser, are: 500 mJ per pulse of total output energy and a wall-plug efficiency of 2%. While obtaining the total 500 mJ in a single beam has many risks associated with it, having three laser transmitters at 200 mJ will mitigate many of them. The approach of this task is to develop a 200 mJ UV unit laser, with the understanding that multiple laser transmitters will be required for a mission. The required efficiency (2% or better wall-plug efficiency) is divided among the Nd:YAG laser and the non-linear conversion technology. This task is responsible for converting 1-micron to UV with the objective of obtaining conversion efficiency of 10 to 20% from 1 micron to 320 nm and 305 nm. To obtain the desired 1 micron to UV conversion efficiency, the Nd:YAG laser must have a wall plug efficiency 10% to 20%. This is outside the scope of this task.

The UV conversion efficiency from one micron to UV obtained from FY02 activities was ~10% with a maximum output energy of 150 mJ at 320 nm. Improving the UV conversion efficiency was the major thrust of work over these two months. Two major designs have been identified that have the potential of increasing the system efficiency. The first design uses a double pumped optical parametric oscillator (OPO) as a basis for improving UV conversion efficiency. In this design two 532 nm beams will pump the 803 nm OPO, one with a long temporal pulse width (10's of microseconds) and the other with a pulse width of about 10 nanoseconds. The goal is to generate an 803 nm beam that has a temporal width that closely approaches the temporal width of the nanosecond 532 nm pump beam. The final step in generating UV involves mixing the 803 nm beam with the 532 nm pump beam through SFG. The output temporal width of an OPO is nominally about 75 to 80% of the pump beam from which it was generated. This makes a temporal mismatch in the SFG process that results in low conversion efficiency. By pumping with a long pulse width pump beam the OPO will be above threshold at the arrival of the nanosecond pump beam. The generated 803 nm temporal will then closely match that of the pump beam. The initial

approach to produce the long pulse pump beam was to create a normal mode Nd:YAG laser cavity with an intra-cavity SHG. The major challenge was to eliminate spiking that is common in normal mode lasers. Efforts so far to generate long pulse 532 nm beams without any spiking have been unsuccessful using the approach described above. An alternative scheme has been tried and is showing promise. A cw 300 mW Nd:YAG is multi-passed through a pulse amplified chain. The output generated was a 130 mJ beam with a pulse width of about 80 microseconds at 1064 nm with no spiking. An electro-optical switch is being designed to reduce the temporal width down to 10 microseconds. To convert the beam to 532 nm, an external SHG cavity is also being designed that is capable of producing 65 mJ at 532 nm. This will be enough to pump the OPO.

The second design to improve the UV conversion efficiency is being carried out by DOE's Sandia National Laboratories. This design uses their patented RISTRA (Rotated Image Singly-resonant Twisted RectAngle) OPO design. The major feature of this design is two-fold, improve beam quality of the 803 nm beam and increase pump depletion using self-seeding. To date they have demonstrated above 60% pump depletion; with a goal to reach above 70%. The ideal here is that as more pump beam used in OPO operation, the temporal width of the generated 803 nm beam will approach that of the 532 nm pump beam. A major portion of their efforts has been geared toward improving their commercial Nd:YAG pump beam. They ran a number of simulations that shows higher conversion efficiency is possible. During a brain storming session between Sandia Labs and Langley researchers, an idea was developed to combine the RISTRA OPO design with an intra-cavity SFG. The intra-cavity SFG OPO work was done at Langley in FY02. Sandia ran a number of simulations of this design and the results are very promising.

VI. ADVANCED 2-MICRON DETECTOR TECHNOLOGY

The goal of this effort is to advance detector technology for noncoherent (direct) detection DIAL lidar remote sensing near 2 microns wavelength. Preparations are being made to accommodate various detectors in a cryogenic chamber so that single detector element can be characterized at liquid nitrogen temperatures.

Two InGaAsSb detectors were recently obtained from AstroPower. Researchers performed characterization tests on these detectors including current vs. voltage (I-V), spectral response, and noise measurements. None of the detectors indicated an APD behavior as concluded from the I-V measurements. In addition to this, a wafer from Rochester Polytechnic Institute (RPI) was acquired and prepared for characterization. The wafer consists of several InGaSb photo detectors, with different areas. Also on the wafer are several pn diodes. Finally, researchers investigated the surface quality of the InGaSb substrate sample using an atomic force microscope (AFM).

VII. ADVANCED 2-MICRON LIDAR RECEIVER TECHNOLOGIES

There are two major activities under this task: Integrated Optical Heterodyne Receiver (IOHR), and Lightweight Scanning Lidar Telescope. The IOHR concept combines the optical and electronic components of a heterodyne lidar instrument in an integrated package less than a few cubic centimeters. The integrated components include optical beam combination elements, photodetectors, radio frequency amplifiers and electronics, and a 2-micron semiconductor diode laser that serves as the local oscillator (LO). Compared with a conventional lidar receiver, integration of these components will result in higher sensitivity, reduced size, and increased robustness when exposed to severe thermal and vibrational environments. The Lightweight Scanning Lidar Telescope (LSLT) concept is based on an athermal design using nickel shells optics and structure that is lightweight enough to be rotated about its axis for providing a step-stare conical scan pattern.

A design for a Multi-Chip Module (MCM) Integrated Receiver has been revised to allow for more flexibility during laboratory experiments. The MCM receiver is based on dual balanced-detector architecture using a commercial SiGe Trans-impedance Die Amplifier. The new layout can be re-configured to allow characterization of individual components as well as implementing at least two different receiver designs. The design of the custom-designed GaAs trans-impedance amplifier, matching the detector parameters for optimum sensitivity, has been delayed because of unsuccessful attempt to obtain export control agreement for fabrication of the amplifier by OMMIC in France. Two viable domestic foundries have been identified and their design models were evaluated. Contract award to one of these domestic foundries is expected by mid summer 2003.

As part of the Lightweight Scanning Lidar Telescope activities, 3 aluminum mandrels were coated by nickel using an electroless plating process. The electroless coated mandrels will be then plasma sprayed to produce a thick nickel shell mirror. It is hoped that the nickel-coated mandrels will allow for a better separation than previously sprayed mandrels. Earlier plasma spray runs experienced bowing of the spray near the edges due to the tensile stresses. The nickel-coated mandrels are expected to allow for an easier release and better surface figure.

VIII. CONCLUSIONS

The results from the LRRP are contributing enabling technologies for future measurement needs of the Earth Science Enterprise. Achievements from the LRRP, both at GSFC and LaRC and their collaborators, will reduce the risk of future space-based laser/lidar instruments and will establish a capability that will yield tremendous science knowledge and benefit to humanity.