TWO MICRON LASER TECHNOLOGY ADVANCEMENTS AT NASA LANGLEY RESEARCH CENTER

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1. ABSTRACT

An Independent Laser Review Panel set up to examine NASA's space-based lidar missions and the technology readiness of lasers appropriate for space-based lidars indicated a critical need for an integrated research and development strategy to move laser transmitter technology from low technical readiness levels to the higher levels required for space missions. Based on the review, a multiyear Laser Risk Reduction Program (LRRP) was initiated by NASA in 2002 to develop technologies that ensure the successful development of the broad range of lidar missions envisioned by NASA. This presentation will provide an overview of the development of pulsed 2-micron solid-state laser technologies at NASA Langley Research Center for enabling space-based measurement of wind and carbon dioxide.

2. INTRODUCTION

Lidar remote sensing enjoys the advantages of excellent vertical and horizontal resolution; easy aiming; independence from natural light for the signal and from background noise; and control and knowledge of transmitted wavelength, pulse shape, and polarization and received polarization. Lidar in space is an emerging technology now being developing to fit applications where passive sensors cannot meet current measurement requirements. Technical requirements for space lidar are more demanding than for ground-based or airborne systems. Perhaps the most distinguishing characteristics of space lidars are the environmental requirements. Space lidar systems must be specially designed to survive the mechanical vibration loads of launch and operate in the vacuum of space where exposure to ionizing radiation limits the electronic components available. Finally, space lidars must be designed to be highly reliable because they must operate without the need for repair or adjustment. Lifetime requirements tend to be important drivers of the overall system design. The maturity of the required technologies is a key to the development of any space lidar system.

NASA entered a new era in the 1990's with the approval of several space-based remote sensing missions employing laser radar (lidar) techniques. Following the steps of passive remote sensing and then active radar remote sensing, lidar (light detection and ranging) sensors were a logical next step, providing independence from natural light sources, and better spatial resolution and smaller sensor size than radar sensors. The shorter electromagnetic wavelengths of laser light also allowed signal reflectance from air molecules and aerosol particles. The smaller receiver apertures allowed the concept of scanning the sensor field of view. However, technical problems with MOLA I, LITE, MOLA II, VCL, and SPARCLE during that decade led to concern at NASA about the risk of lidar missions. An external panel was convened to make recommendations to NASA. Their report in 2000 strongly advocated that NASA maintain in-house laser and lidar capability, and that NASA should work to lower the technology risk for all future lidar missions. NASA then formed an Integrated NASA Lidar Systems Strategy Team (INLSST), chaired by U. N. Singh at Langley Research Center (LaRC) and W. S. Heaps at Goddard Space Flight Center (GSFC), to make specific recommendations for implementing the external panel's advice. Their plan for a NASA Laser Risk Reduction Program (LRRP), to be lead by LaRC and GSFC with participation and collaboration from industry and academia, was approved by NASA's Administrator in June 2001. Funding of the LRRP began in 2002.

3. THE LRRP CONCEPT

The LRRP implemented the recommendations to work on lidar technologies before mission approval and to maintain in-house capability by using the strengths in 1-micron solid-state lasers at GSFC and the strengths in 2-micron solid-state lasers at LaRC to work on fundamental issues concerning these two laser technologies, as listed on the left side of Figure 1. With additional work on wavelength conversion technologies, the four lidar techniques of altimetry, Doppler, Differential Absorption Lidar (DIAL), and basic lidar backscattered signal strength profiling would be able to make 6 high priority earth science measurements: surface and ice mapping, horizontal vector wind profiles, river currents, CO_2 profiles, O_3 profiles, and aerosols/clouds. Through collaboration and communication between LaRC and GSFC of questions, capabilities, and results, the advancement of the commonly needed areas of laser and wavelength conversion development would proceed faster and without duplicated effort. The goal of the LRRP is to advance the technologies to the point that science mission proposals could be confident of acceptable risk upon selection.

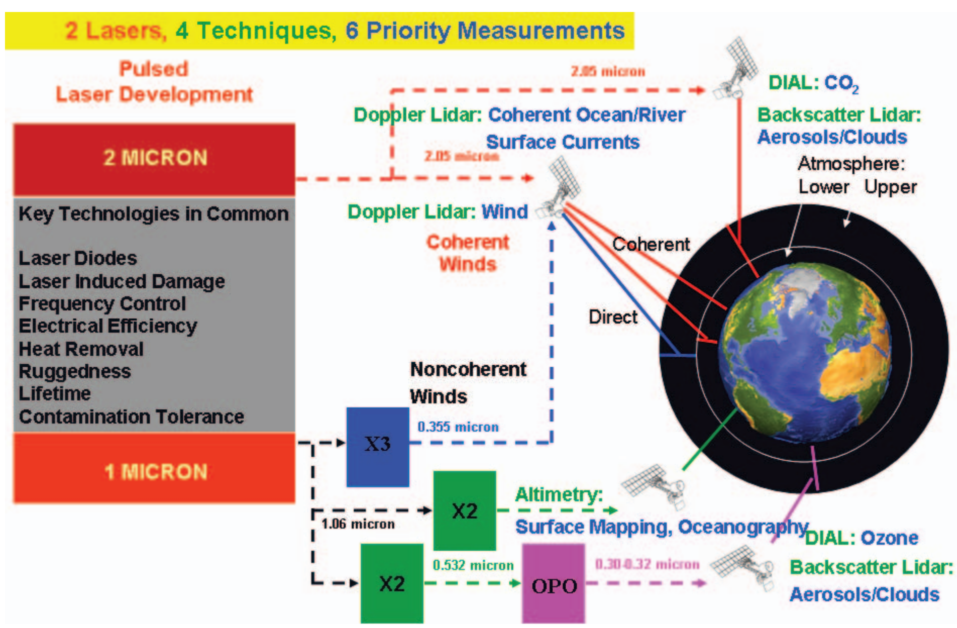


Figure 1. Connection between technology development and 6 priority measurements

4. SUMMARY AND RESULTS

In the 1980s the largest demonstrated 2-micron pulse energy was 20 mJ, while simulations showed a requirement of 20 J with a 1.5 m diameter telescope for coherent-detection space-based global winds. The pulse energy deficit of a factor of 1000 was very daunting and the mission was deemed high risk. The 2-micron laser group at NASA

LaRC worked to increase the pulse energy while also working on the important space mission considerations of high efficiency, excellent beam quality, narrow pulse spectrum, long lifetime, compact packaging, and space qualification. The technique of measuring wind was to be coherent-detection Doppler lidar. This high velocity accuracy, high sensitivity technique required excellent beam quality for sufficient signal, and narrow pulse spectrum for high accuracy.

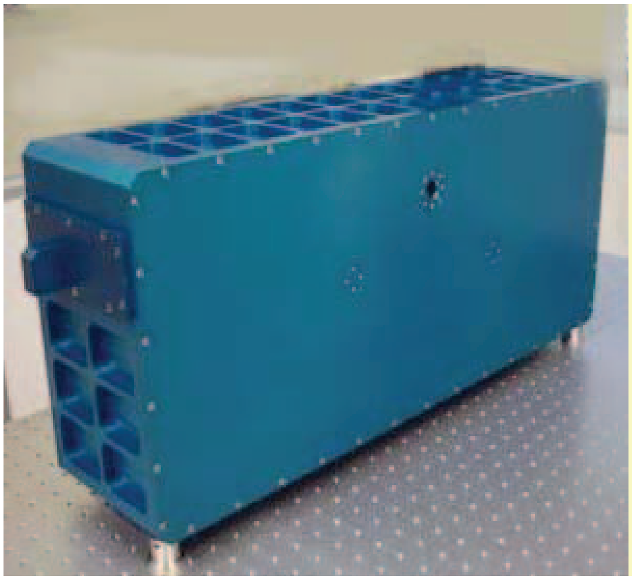
The LaRC team worked on several fronts and made continuous progress. The team demonstrated 700 mJ at 1 Hz pulse repetition frequency (PRF) with 5 laser amplifiers in 1996; and 600 mJ at 10 Hz with 4 amplifiers in 1997. These laser designs all used liquid cooling for both the laser diode arrays (LDAs) and the laser rod. The team also demonstrated 355 mJ at 2 Hz with 1 amplifier and the novel Ho:Tm:LuLF laser material with the new conductively cooled LDA laser head design in 2002; 95 mJ at 10 Hz with no amplifiers (pulsed oscillator only) in 2003; 1200 mJ at 2 Hz with 2 amplifiers in 2005; and 355 mJ at 10 Hz with one amplifier and the new AA package LDAs in a compact package in 2007. Prior to 2007, the A package LDA had been used.

A parallel effort to design a fully conductively cooled laser head design produced 400 mJ at 5 Hz with one amplifier in 2007. This was very important since a laser for space needs to be all conductively cooled. The fully conductively cooled lasers permitted operation at much cooler temperatures. This led to the demonstration of much higher laser gain at lower temperatures. Another benefit to lower temperature operation is the ability to run both the LDA's and the laser rod at the same temperature rather than trying to keep them at different temperatures. In a teaming arrangement with one of the primary USA-based space-based laser developer, NASA LaRC researchers are transferring these breakthrough technologies for the development of two space-qualifiable laser transmitters to conduct the risk reduction efforts leading to qualify them for space operation. This partnership between government and industry will permit NASA developed technologies available to other federal agencies for future development of operational global wind profiling systems.

During these years the global wind mission design continued. Instead of coherent detection only, a "hybrid" Doppler lidar approach, consisting of coherent- and direct-detection Doppler lidars systems sharing the job of vertical coverage of the troposphere, was adopted. The coherent-detection pulse energy requirement dropped by approximately a factor of 100 with this change (from 20 J to 200 mJ). The scanning was changed from continuous conical to step-stare conical with dwell time at each direction sufficient to use 60 coherent lidar shots for the measurement instead of 1. This changed dropped the pulse energy requirement about a factor of 8 (from 200 to 25 mJ). Later the step-stare conical scanner was changed to four fixed position 50-cm telescopes instead of one 150-cm diameter telescopes in order to eliminate the scanner's heavy moving parts. The smaller optical diameter raised the required pulse energy by approximately a factor of 10 (from 25 to 250 mJ). The situation has changed to a requirement of 250 mJ, with 1200 mJ already demonstrated, for a margin factor of 4.8. For pulse energy alone, moving from an x1000 deficit to an x4.8 margin represents a tremendous reduction in mission risk.

For ground and airborne borne measurement an engineering packaged 2-micron laser transmitter for the wind lidar was designed and developed. This compact laser is configured as a master oscillator and power amplifier system. It is injection seeded with a highly stabilized seed laser operating at 2.053 µm which is very close to the oscillator operating wavelength. The line width measurement of the seed laser is done by beating two similar lasers, the result showed a line width better than 13 KHz. The oscillator output is amplified with a double pass amplifier. The target output energy is 250mJ at 10Hz pulse repetition rate.

The overall dimension of the laser is 67 cm X 16.5 cm X 26 cm (Figure 2). The optical bench is populated on both sides. The seed laser and the associated fiber optics couplers and the Faraday isolators are on the back side of the bench while the oscillator and the amplifier are mounted on the front. All the optical mounts are designed to be adjustable and lockable and hardened to withstand vibrations that can occur in ground or airborne operation.



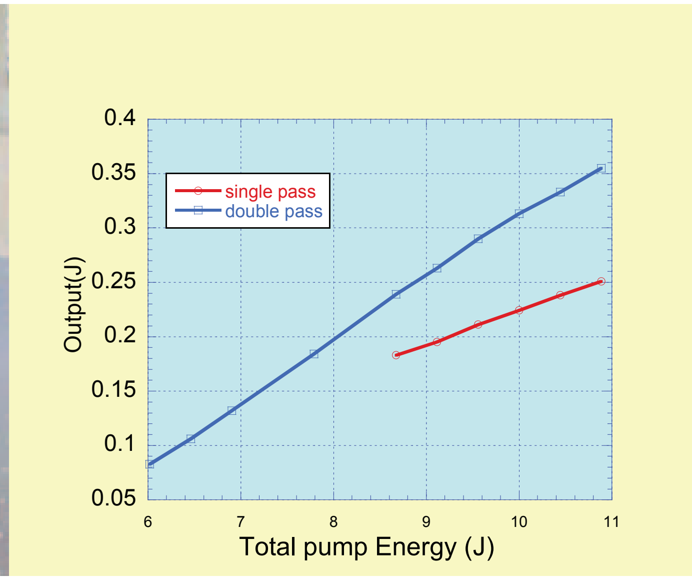


Fig.2 Compact 2-micron laser transceiver

Fig 3. Amplifier performance with 100mJ input from the oscillator

The performance of the oscillator has been evaluated at different repetition rates and at different rod coolant temperatures. The maximum Q-switched output obtained ranges from 118 mJ at 10 Hz to 150 mJ at 2 Hz. Since the laser material is not a 4-level laser, it is sensitive to heat load; and hence the output drop at higher repetition rate is not totally unexpected. Using 100mJ as a probe beam from the oscillator, the double pass amplifier produced over 300mJ (Fig 3). At of 5°C with a double pass gain is slightly over 3. At a higher rod temperature of 8°C, the output energy was 275 mJ. This was partially due to the reduction of the probe beam energy to 95mJ, but the main reason is the thermal populating of the lower laser level. This shows the importance of depopulating the lower laser level for efficient operation.

Through this extended effort a hardened 2μm laser, capable of producing over 300 mJ has been designed, and the performance has been verified. This diode pumped injection seeded MOPA has a transform limited line width and diffraction limited beam quality. Although it is primarily designed as a wind Doppler lidar [1], with minimal modification it can be used as a Differential Absorption Lidar (DIAL) instrument for CO_2 sensing. In addition to being used as a field instrument, the laser will also be used as an engineering design tool for evaluating essential wind lidar parameters for a long term flight instrument.

In summary, Laser development progress at NASA Langley Research Center (LaRC) under the NASA's Earth Science Technology Office (ESTO) funded Laser Risk Reduction Program (LRRP) has eliminated a large amount of risk for NASA's goal of global wind measurement.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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