Solid-State, High Energy, 2-micron Laser development for Space-based Remote Sensing

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Summary

Lidar (light detection and ranging) remote sensing enjoys the advantages of excellent vertical and horizontal resolution; pointing capability; a signal source independent from natural light; 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 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 several space-based lidar missions 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. A multi-Center NASA team formulated an integrated NASA strategy to provide the technology and maturity of systems necessary to make Lidar/Laser systems viable for space-based study and monitoring of the Earth's atmosphere. In 2002 the NASA Earth Science Enterprise (ESE) and Office of Aerospace Technology (OAT) created the Laser Risk Reduction Program (LRRP) and directed NASA Langley Research Center (LaRC) and Goddard Space Flight Center to carry out synergistic and complementary research towards solid-state lasers/lidars developments for space-based remote sensing applications.

An area of Earth science instrument technology that will see increased technology advancement is in solid-state 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.

The LRRP has invested in several critical areas, including: advanced laser transmitters to enable science measurements (tropospheric ozone, carbon dioxide, water vapor, winds, and altimetry). The LRRP is focused into four areas: laser transmitter, laser diode, laser frequency conversion and lidar receivers/detectors. 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 wind measurements. 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 chosen wind measuring technique was coherent-detection Doppler lidar. This high sensitivity technique required excellent beam quality for sufficient signal and narrow pulse spectrum for high velocity 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. 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 space-based laser needs to be all conductively cooled for operational purposes. 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.

Recently, a hardened 2µm laser, capable of producing over 300 mJ has been designed, and the performance has been verified. This diode pumped injection seeded master oscillator and power amplifier (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 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. This presentation will provide an overview of the lidar techniques; the NASA's Laser Risk Reduction Program and the progress made at NASA LaRC towards laser risk reduction efforts for space-based remote sensing of the Earth's atmosphere.

Reference

[1] G.J. Koch, J.Y. Beyon, B.W. Barnes, M. Petros, J. Yu, F. Amzajerdian, M.J. Kavaya, and U.N. Singh, "High Energy Doppler 2µm Doppler Lidar for Wind Measurements," Optical Engineering, 46 (11), pp. 116201-116214, 2007