

Progress on High-Energy 2-micron Solid State Laser for NASA Space-based Wind and Carbon Dioxide Measurements

Upendra N. Singh

Engineering Directorate, MS 433

NASA Langley Research Center, Hampton, VA 23681 USA

ABSTRACT

Sustained research efforts at NASA Langley Research Center during last fifteen years have resulted in significant advancement of a 2-micron diode-pumped, solid-state laser transmitter for wind and carbon dioxide measurements from ground, air and space-borne platforms. Solid-state 2-micron laser is a key subsystem for a coherent Doppler lidar that measures the horizontal and vertical wind velocities with high precision and resolution. The same laser, after a few modifications, can also be used in a Differential Absorption Lidar system for measuring atmospheric CO₂ concentration profiles. Researchers at NASA Langley Research Center have developed a compact, flight capable, high energy, injection seeded, 2-micron laser transmitter for ground and airborne wind and carbon dioxide measurements. It is capable of producing 250 mJ at 10 Hz by an oscillator and one amplifier. This compact laser transmitter was integrated into a mobile trailer based coherent Doppler wind and CO₂ DIAL system and was deployed during field measurement campaigns. This paper will give an overview of 2-micron solid-state laser technology development and discuss results from recent ground-based field measurements.

Keywords: Diode-pumped lasers, Solid state laser, Doppler wind lidar, Space lidar, CO₂, Airborne lidar, Differential Absorption Lidar

1. SUMMARY

The 2-micron lidar technology developed by NASA LaRC is critical to achieve one of the National Research Council (NRC) 2007 Earth Science Decadal Survey missions recommended to NASA, and is a potential candidate for a second recommended mission. It is the leading candidate for the “3D-Winds” mission, and is a potential candidate for space-based CO₂ measuring mission called ASCENDS using the same laser technology with the Differential Absorption Lidar (DIAL) technique. The future could possibly also include wind and CO₂ measurements simultaneously from one lidar.

Solid-state 2-micron laser is a key subsystem for a coherent Doppler lidar that measures the horizontal and vertical wind velocities with high precision and resolution [1]. The same laser, after a few modifications, can also be used in a DIAL system for measuring atmospheric CO₂ concentration profiles [2]. Development of a high energy, high efficiency, high beam quality, single frequency, compact and reliable solid state 2-micron laser is critically needed for such lidar systems. Although the capability of producing multi-joule energy by 2-micron solid state lasers was predicted a decade ago, the significant advancements in the high energy 2-micron laser demonstration have not been achieved until recently. A 600 mJ Q-switched diode-pumped Tm:Ho:LuLF using a Master Oscillator Power Amplifier (MOPA) system at double pulse format was published in 2003 [3]. A Joule level 2-micron laser MOPA system was reported in 2004, but it was operated in double-pulse format [4]. Conductively cooled 2-micron lasers recently have been demonstrated [5-6].

With support from NASA Laser Risk Reduction Program (LRRP) and Instrument Incubator Program (IIP), NASA LaRC has developed a state-of-the-art lidar transceiver in a compact rugged package. With an unprecedented laser pulse energy of 250-mJ, this transceiver is ideal for a pulsed coherent Doppler lidar wind measurement system. The novel high-energy, 2-micron, Ho:Tm:LuLiF laser technology developed at NASA LaRC was employed to study laser technology currently envisioned by NASA for future global coherent Doppler lidar winds measurement. The 250mJ, 10 Hz laser was designed, under NASA Earth Science Technology Office (ESTO) funded IIP proposal “Doppler Aerosol Wind Lidar (DAWN),” as part of an integral part of a compact lidar transceiver developed for future aircraft flight. This high pulse energy is produced by a Ho:Tm:LuLiF laser with an optical amplifier. While the lidar is meant for use as an airborne instrument, ground-based tests were carried out to characterize performance of the lidar. Atmospheric measurements will be presented, showing the lidar’s capability for wind measurement in

the atmospheric boundary layer and free troposphere. Lidar wind measurements are compared to a balloon sonde, showing good agreement between the two sensors. Ground-based wind profiles made with this transceiver will be described. NASA LaRC is currently funded to build complete Doppler lidar systems using this transceiver for the DC-8 aircraft in autonomous operation (DAWN Air-I and DAWN Air-II). Recently, LaRC 2-micron coherent Doppler wind lidar was selected to contribute to the NASA Science Mission Directorate (SMD) Earth Science Division (ESD) hurricane field experiment in 2010 titled Genesis and Rapid Intensification Processes (GRIP). The GRIP campaign results will be presented.

Additionally, there is a great urgency to understand the process of CO₂ exchange in the context of global climate change. Knowledge of the spatial and temporal distribution in addition to the Natural and manmade sources/sinks in a global scale is crucial to predict and possibly manage the process. Most of the CO₂ measuring instruments, which contributed to the present knowledge base, are passive instruments that measure flux near the ground. Since aerosols are abundant in the atmospheric boundary layer, the pulse approach can determine CO₂ concentrations as a function of distance with high spatial and temporal resolution, a valuable data product that is not currently available. In response to the challenges, laser based active instruments are being developed. These instruments rely on the measurements of the differential absorption between different wavelengths.

Researchers at NASA LaRC have been looking at this problem and have used an instrument initially designed as a wind coherent Doppler Lidar, to modify and develop a lidar to measure CO₂. Similar architecture has been used to develop a high energy, Ho:Tm:YLF pulsed 2- μ m DIAL instrument based on coherent heterodyne technique that provides atmospheric CO₂ measurements [7]. The operating wavelength around 2 μ m has a favorable weighting function near ground surface. The R (30) CO₂ line at 2050.967 nm (4875.75 cm⁻¹) is selected for its temperature insensitivity, absorption strength and absence of absorption from other species. Similar efforts, as described in the earlier sections for developing a wind lidar transmitter, were undertaken for designing a double pulsed, injection seeded, and 2 μ m compact coherent DIAL transmitter for CO₂ sensing. This system was hardened for ground and airborne applications. The design architecture includes three seed lasers which provide controlled 'on and 'off' line seeding, injection seeded power oscillator and a single amplifier operating in double pass configuration. The attractive feature of this instrument is that laser material with a long upper laser lifetime and as a result can produce two or more consecutive pulses within a few hundred microsecond spacing with a single pump pulse. This instrument will measure atmospheric CO₂ profiles (by DIAL) initially from a ground platform, and then be prepared for aircraft installation to measure the atmospheric CO₂ column densities in the atmospheric boundary layer (ABL) and lower troposphere. The airborne prototype CO₂ lidar is simulated to measure atmospheric CO₂ column density in a range bin of 1km with better than 1.5% precision at horizontal resolution of less than 50km.

2. REFERENCES

- [1] W. E. Baker et al., "Lidar-Measured Winds from Space: A Key Component for Weather and Climate Prediction" Bull. Amer. Meteorol. Soc., Vol 76, No. 6, 869-888 (1995)
- [2] Grady J. Koch, B. W. Barnes, M. Petros, J. Y. Beyon, F. Amzajerjian, J. Yu, R. E. Davis, S. Ismail, S. Vay, M. J. Kavaya and U. N. Singh, "Coherent differential absorption lidar measurements of CO₂", Appl. Opt., Vol. 43, No. 26, 5092-5099 (2004)
- [3] Jirong Yu, Alain Braud and Mulugeta Petros, "600 mJ, Double-pulsed 2-micron laser" Opt. Lett., 28, 540 (2003)
- [4] S. Chen, J. Yu, M. Petros, Y. Bai, B. C. Trieu, U. N. Singh and M. J. Kavaya, "Joule level Double-pulsed Ho:Tm:LuLF Master-Oscillator-Power-Amplifier (MOPA) for potential spaceborne lidar applications", Proc. SPIE, 5653, 175 (2004)
- [5] M. Petros, J. Yu, Tony Melak, B. C. Trieu, S. Chen, U. N. Singh and Y. Bai, "High energy totally conductive cooled, diode pumped, 2 μ m laser", in OSA Trends in Optics and Photonics Series (TOPS) vol. 98, Advanced Solid state Photonics, Craig Denman and Irina Sorokina, ed. DC 2005, pp 623-627
- [6] B. C. Trieu, Jirong Yu, M. Petros, Luis Ramos-Izquierdo, Glenn Byron, Perk Sohn, Yingxin Bai, S. Chen, U. N. Singh, M. J. Kavaya, "Design of a totally conductive cooled, diode pumped 2-micron amplifier", Proc. SPIE 5887, p. 5887OM-1-5887OM-11, 2005
- [7] Grady J. Koch, Jeffrey Y. Beyon, Fabien Gibert, Bruce W. Barnes, Syed Ismail, Mulugeta Petros, Paul J. Petzar, Jirong Yu, Edward A. Modlin, Kenneth J. Davis, Upendra N. Singh" Side-Line Tunable Laser Transmitter for Differential Absorption Lidar Measurements of CO₂: Design and Application to Atmospheric Measurements" Applied Optics, Vol. 47 issue 7 pp.944-956, 2008