Tm:Fiber Pumped Solid-State Ho:YLF 2-µm Coherent Laser Transmitter for Air and Space-based CO_2 Measurements

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Abstract:

Researchers at NASA Langley Research Center have developed an efficient, high repetition rate, pulsed, 2-µm coherent DIAL/IPDA transmitter for CO_2 measurements. This transmitter will be employed to measure atmospheric CO_2 profiles (by DIAL) initially from a ground platform, and then measure both the atmospheric CO_2 profiles (by DIAL) and column densities (by IPDA) from an airborne platform with the potential for measuring CO_2 column density from a space-borne platform. The transmitter consists of a pulsed Q-switched ring-cavity Ho:YLF laser operating at 2.05 micron, being pumped by a Tm:fiber laser. The repetition rate can be adjusted from a few hundred Hz to 10 kHz with corresponding energy of 25 to 1 mJ, respectively. This transmitter can be used for direct or coherent detection of CO_2 from ground, air or space-borne platform, as it is capable of providing required energy/repetition rate even from space platform. This presentation will describe the details of the injection-seeded high-repetition rate 2-micron transmitter and demonstrate its flexibility for direct or coherent detection of CO_2.

Introduction

Carbon dioxide (CO_2) has been recognized as one of the most important greenhouse gases. It is essential for the study of global warming to accurately measure the CO_2 concentration in the atmosphere and continuously record its variation. Studies of the carbon cycle are limited by the tools available to precisely measure CO_2 concentrations by remote sensing. Passive remote sensors under development to measure CO_2 column content cannot make measurements at night or through intervening clouds. Most active sensors under development use a continuous-wave (CW) laser with the goal of making column integrated measurements. This approach is limited in that the topographical scattering target must be at a known distance (requiring an ancillary laser altimeter) and cannot distinguish the desired signals reflected from topography from those reflected from clouds or dense aerosol layers. There exists a critical need to develop energetic pulsed transmitter, at a suitable wavelength with a weighting function optimized near the earth's surface, to make accurate measurements of CO_2 either by direct or coherent detection in the boundary layer.

NASA LaRC's 2-micron pulsed laser transmitter possesses advantages over current passive and CW active sensors. First, the pulsed format provides a built-in means for determining range to the scattering target. Second, by concentrating the laser energy into a pulse, sufficient backscatter signal strength can be obtained from aerosol scattering rather than relying on a hard target at a known distance. Third, the absorption line at the 2.05 µm band is ideally suited for

the CO_2 concentration measurement. In particular, the weighting function of 2 μm is optimum for measurement in the lower troposphere where the sources and sinks of CO2 are located.

Summary and Results

A high repetition rate, highly efficient, Q-switched 2-micron laser system as the transmitter of a coherent/direct differential absorption lidar for CO_2 measurement has been developed at NASA Langley Research Center. This laser system is capable of making a vertical profiling of CO_2 from ground and column measurement of CO_2 from air and space-borne platform. The transmitter is a master-slave laser system. The master laser operates in a single frequency, either on-line or off-line of a selected CO_2 absorption line. The slave laser is a Q-switched ring-cavity Ho:YLF laser which is pumped by a Tm:fiber laser. The repetition rate can be adjusted from a few hundred Hz to 10 kHz.

A Ho:YLF laser operating in the 2.05 μm range can be tuned over several characteristic lines of CO_2 absorption. Experimentally, a diode pumped Ho:Tm:YLF laser has been successfully used as the transmitter of coherent differential absorption lidar for the measurement of CO_2 with a repetition rate of 5 Hz and pulse energy of 75 mJ. For coherent detection, high repetition rate is required for speckle averaging to obtain highly precise measurements. However, a diode pumped Ho:Tm:YLF laser can't operate in high repetition rate due to the large heat loading and up-conversion. A Tm:fiber laser pumped Ho:YLF laser with low heat loading can operate in high repetition rate.

A theoretical model has been established to simulate the performance of Tm:fiber laser pumped Ho:YLF lasers. For continuous wave (CW) operation, high pump intensity with small beam size is suitable for high efficiency. For Q-switched operation, the optimal energy extraction relies on the pump intensity, pump volume, and pump duration which is inversely proportion to the repetition rate. CW and Q-switched Ho:YLF lasers with different linear cavity configurations have been designed and demonstrated for a 30 W Tm:fiber pump laser. The CW Ho laser slope efficiency and optical-to-optical efficiencies reach 65% and 55%, respectively. The pulsed laser efficiency depends on the repetition rate. For 1 kHz operation, the optical-to-optical efficiency is 39% when the pump power is 14.5W. Currently, the injection seeding success rate is between 99.4% and 99.95%. After a ten thousand pulses, the standard deviation of the laser frequency jitter is about 3 MHz. It meets the requirements of highly precise CO_2 concentration measurement.

In conclusion, an injection seeded, high repetition rate, Q-switched Ho:YLF laser has been developed for a coherent/direct CO_2 differential absorption lidar. This master-slave laser system has high optical-to-optical efficiency and seeding success rate. It can potentially meet the requirements of the coherent/direct detection of CO_2 concentration by a differential absorption lidar technique.