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High Pulse-Energy Atmospheric Aerosol Lidar at 1.5-microns Wavelength: Opportunities for Innovation from a Meteorologist's Perspective

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Abstract: Laser and optical engineering challenges and recent progress in the area of high pulse-energy direct-detection atmospheric lidar near 1.5 microns wavelength are described.

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1. Introduction

This paper is based upon the author's experience in co-developing and operating the Raman-shifted Eye-safe Aerosol Lidar (REAL, http://www.phys.csuchico.edu/lidar). The instrument was developed at the National Center for Atmospheric Research (NCAR), in Boulder, Colorado, between 2001 and 2007 and currently resides at the California State University Chico. Through a federal licensing agreement, ITT Corp. has produced several duplicates of the REAL for the Department of Defense (DOD). The NCAR REAL at Chico State has been deployed in several atmospheric field experiments and remains available for use in atmospheric research. Despite these successes, several hardware encumbrances prevent this technology from reaching higher popularity. This paper, and the corresponding talk, will describe the key optical and laser engineering requirements and the design choices made to create the present REAL. It will also suggest the areas where laser and optical innovations are needed to make high-performance, ground-based scanning eye-safe aerosol lidars easier to use, more reliable, and more attractive to potential customers and markets.

2. Laser Transmitter

Atmospheric lidar operation at 1.5 microns wavelength offers several advantages when compared to other laser wavelengths including: (1) maximum eye-safety, (2) invisible beam, (3) superior performance photodetectors compared with those used at longer wavelengths, (4) low atmospheric molecular scattering when compared with operation at shorter wavelengths, (5) good aerosol backscattering, (6) atmospheric transparency, and (7) availability of optical and photonic components used in the modern telecommunations industry. A key issue for creating a high-performance direct-detection lidar at 1.5 microns is the use of InGaAs avalanche photodetectors that have active areas of at most 200 microns in diameter. The small active area imposes a maximum limitation on the lidar receiver's field-of-view (about 0.54 milliradians for REAL). As a result, a key requirement is creating a transmitter subsystem that can produce a pulsed (≥10 Hz) beam with low divergence (≤ 0.25 milliradians full-angle), high pulse-energy (≥ 150 mJ), and short pulse-duration (≤ 10 ns). At NCAR, we found the only affordable solution was to use a commercially-available flashlamp-pumped Nd:YAG laser and a Raman wavelength shifter. Details on the REAL transmitter can be found in several journal articles [1-4] and will be presented in the talk.

Currently, replacement of laser flashlamps at intervals of approximately 20M pulses (every 23 days at 10 Hz) results in the largest operating inconvenience and potential for introducing problems. Therefore, long-life flashlamps or diode pumping of the Nd:YAG laser would be highly advantageous. Pump energy must be on the order of 600 mJ or greater with a high degree of linear polarization for use with the REAL Raman cell. When pumped consistently, the Raman cell we developed does not suffer from the problems of traditional Raman cells such as internal sooting, thermal blooming, and etching of the coatings on windows and mirrors. By injection seeding the Nd:YAG and the Raman cell (at the Stokes wavelength) we have produced more than 40% conversion efficiency in the lab [2] and typically operate at 25% conversion efficiency in the field. Certainly, a solid-state wavelength converter is desirable to avoid the use of compressed methane in a Raman cell, but any solid-state solution must not be vulnerable to laser damage and must produce a low-divergence beam (≤ 0.25 milliradians full-angle) of at least 150 mJ at 10 Hz. Moving towards a lower maintenance, more compact and lower weight transmitter at a cost comparable with the current REAL transmitter remains a top challenge. Currently, components comprising the REAL transmitter (not including the optics table, cost of labor to assemble, or institutional overhead) do not exceed approximately $150K.

Improved transmitter diagnostics, such as pulse energy and beam-divergence, that run continuously are needed. These may seem like needs that should be met by current commercially available solutions, but we have not yet found ones that are adequate. Precise measurements of pulse energies are needed to normalize the corresponding changes in aerosol backscatter intensity. This requires an accurate sample of the entire transmit beam cross-section to account for the constantly changing beam profile (as a result of a gas wavelength converter) and fast responsiveness to capture the energy in a 6 ns pulse. The pulse energy must be communicated to the lidar data acquisition system within the inter-pulse period of the transmitter so that the energy can be recorded with the corresponding backscatter intensity waveform. In addition to these fundamental diagnostics, any others technologies that enable sensing of the health of the transmitter, appropriate automatic adjustments (like increasing flashlamp voltage) or a graceful shutdown to prevent damage to other transmitter components would be very useful.

3. Beam-steering unit mirrors

Achieving high signal-to-noise ratio aerosol backscatter data requires strong transmit-energy and receiver-aperture product. We find with pulse energies of at least approximately 150 mJ, a 40 cm diameter telescope is needed to detect background aerosol to ranges of at least several kilometers during relatively high visibility conditions. Therefore, to scan the laser beam from the roof of a shelter, a laser beam steering unit (BSU) is needed with two flat mirrors that are at least 40 cm by 60 cm. Through ray tracing we determined that our flat BSU mirrors could have irregularities up to 10 waves over the full aperture [3]. To achieve this, a traditional mirror solution would weigh 56 kg (123 lbs!) per mirror and result in awkwardly large electrical and mechanical requirements. Therefore, we overcame this problem by gluing 25 mm thick Zerodur mirrors to 38 mm thick Hexcell aluminum panels with silicon adhesive resulting in “composite” mirrors weighing 14 kg each. The surfaces of our composite mirrors were measured with a coordinate-measuring machine and the top surface data entered into the receiver ray-trace model to verify sufficient flatness. Still, at 30 lbs per mirror, the BSU is a relatively heavy device requiring substantial electrical power and mechanical support to operate and a forklift to install or remove. The entire BSU weighs < 100 kg and costs on the order of $100K-$200K to fabricate. Lower-cost and lighter-weight mirrors are needed to reduce the mass and procurement cost even further.

4. Conclusions

Important environmental applications exist for ground-based, scanning, eye-safe, direct-detection, aerosol lidars such as REAL. These include two-component, two-dimensional remote wind sensing [5] and the detection of potentially hazardous aerosol plumes [6]. However, a primary requirement is nearly continuous and unattended operation. Furthermore, the first commercially produced versions have cost on the order of $1M to deliver and more than 10% of the purchase cost for annual operating expenses. This has limited the market to the DOD. The key subsystems that must be innovated to lower the purchase cost and maintenance expenses of these devices are the laser transmitter and beam steering unit. I have suggested that the integration of long-life flashlamps or diode pumping, solid-state wavelength converters, laser diagnostics and feedback, and ultra-light mirrors will be the critical areas that lower the cost and increase the reliability of this instrument.

5. References

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