

Infrared differential absorption lidar for stand-off detection of chemical agents

A K RAZDAN*, S VEERABUTHIRAN, M K JINDAL and R K SHARMA

Lidar and Beam Diagnostics Division, Laser Science & Technology Centre, Delhi 110 054, India

*Corresponding author. E-mail: akraz61@rediffmail.com

DOI: 10.1007/s12043-014-0696-7; **ePublication:** 14 February 2014

Abstract. A compact trolley-mounted pulsed transverse electric atmospheric pressure (TEA) carbon dioxide laser-based differential absorption lidar (DIAL) system capable of stand-off detection of chemical clouds in aerosol and vapour form upto about 200 m range in the atmosphere has been developed and assembled at Laser Science and Technology Centre (LASTEC), Delhi. The system was tested successfully with diethyl ether (DEE) (a toxic industrial chemical (TIC)) and differential absorption signals at λ_{on} (strong absorption, 9R16) and λ_{off} (weak absorption, 10R26) wavelengths were recorded for stand-off distances upto ~ 100 m (open air ground path). This paper discusses the technical details of trolley-mounted CO₂ DIAL system and the data generated during the test and evaluation of this sensor using DEE aerosols.

Keywords. LIDAR; DIAL; TEA CO₂ laser; aerosol; stand-off sensing.

PACS Nos 42.68.wt; 42.68.ca; 42.62.Fi; 92.60.mt; 82.33.Tb

1. Introduction

The technique of light detection and ranging (LIDAR) has been used since 1930s. With the development of lasers in 1961, this technique gained a lot of importance, as laser-based systems employing pulsed lasers are highly sensitive and can detect extremely low concentrations of different chemical species present in the atmosphere at distances of several kilometres with very high degree of discrimination among molecules of different species. The unique characteristics of lasers offer significant improvements in length of range, detection limits and species selectivity as compared to weaker broadband optical sources. Very high degree of monochromaticity in laser beams is responsible for discriminating between molecules of chemical agents having closely spaced transition lines in the absorption and emission spectra. High degree of wavelength tunability over a wide spectral range coupled with fast frequency agility in lasers can identify and detect a large number of agents in near real time. Very low beam divergence of laser beams can pinpoint small region of clouds of interest at very long distances. High-energy pulses of laser

beams are responsible for detecting species at very long distances of several kilometres in the atmosphere. Q-switched pulse widths of the order of few nanoseconds can provide high degree of accuracy in the range-resolved measurements.

In India, there are several groups working on lidar technology but most of the work is based on fixed frequency lasers (or lasers with very limited tunability) for applications like atmospheric profiling, measurement of aerosol distribution, wind velocity measurement, etc. To the best of our knowledge, there is no group within India which is actively involved in the work on tunable laser-based differential absorption lidar for stand-off detection of chemical agents present in the atmosphere. However, many groups around the world have proved DIAL as a potent stand-off technique to detect toxic chemicals present in the atmosphere [1,2]. Pulsed TEA CO₂ lasers (emitting in the wavelength band 9–11 μm) have commonly been used for the detection of chemical agents and cover a part of the desired wavelength region [3]. Optical parametric oscillator (OPO) technique is used to generate tunable mid-IR laser in the spectral band 2–5 μm, which is also used as a transmitter in the DIAL system [4]. Our group at Laser Science & Technology Centre has been working on the design and development of differential absorption lidar based on tunable IR laser technology (in 3–5 μm, using solid-state laser technology and 9–11 μm, using gas laser technology) for detecting a variety of chemical species both in aerosol and vapour forms at sufficient stand-off ranges [5]. We have designed and assembled two differential absorption lidar sensors. First one is based on an optical parametric oscillator (OPO) based laser operational in 3–3.5 μm and the second one is a tunable TEA CO₂ laser-based system operational in 9–11 μm IR band. Several chemical species (both toxic and non-toxic) which may be present in the atmosphere (naturally or disseminated artificially) have absorption lines falling within these two potential wavelength bands [6]. Moreover, there is less atmospheric attenuation in these spectral regions which enables longer detection range capability [7]. In this paper, we shall discuss the DIAL set-up based on TEA CO₂ laser (9–11 μm) only.

2. Differential absorption lidar technique

Differential absorption lidar (DIAL) is the most frequently used technique employed for the detection of pollutants, toxic gases and other chemical agents in the atmosphere. Two laser pulses with different wavelengths are emitted into the atmosphere for the detection of the chemical species. One wavelength (λ_{on}) is tuned exactly to the centre of specific absorption line of the molecule of interest. The second wavelength (λ_{off}) is detuned to the wing of this absorption line with no specific absorption. The absorption cross-section of the molecule of interest at λ_{on} is very large as compared to that at λ_{off} . Strong return signals at both wavelengths can be detected due to large Mie scattering cross-section but the return signal at λ_{on} is weaker than at λ_{off} . Knowledge of which wavelength has been absorbed (indicated by a highly depleted return signal as compared to that at other wavelengths) gives information about the specific constituent of the atmosphere. Ratio of the return signals at these wavelengths determines the concentration of the molecules of interest due to differential absorption. Finally, the time elapsed between the transmitted laser pulse and the return pulse gives information about the distance (range) at which the cloud of the chemical species is located in the atmosphere.

3. Experimental details and results

DIAL set-up designed and assembled at Laser Science & Technology Centre, Delhi, comprises of a compact pulsed tunable TEA CO₂ Laser (M/s OptoSystems Ltd., Russia) emitting ~50 mJ energy (max. energy at peak wavelength) and tunable in the wavelength range of 9.2–10.8 μm (with pulse width of 2 μs) as a transmitter. This fully computer-controlled laser with controllable PRF (from 10 to 100 Hz) can fire laser pulses as per a predefined program allowing selection of λ_{on} and λ_{off} wavelengths corresponding to the absorption spectrum of suspected target molecule. The receiver system comprises of a 200 mm beam reducing telescope (0.1X) together with focussing optics ($\Phi = 25.4$ mm, focal length = 15 mm, ZnSe lens) placed at its exit port which focusses the received backscattered radiation on a liquid nitrogen-cooled MCT detector (active area 0.1 mm \times 0.1 mm, from M/s Laser Monitoring Systems, USA). An optical filter in the 9–11 μm band is employed in the receiver optics chain to cut down incoming optical radiation outside the desired band. A National Instruments, 12 bit, 10 MS/s DAQ card is used for acquiring the lidar return signals. The CO₂ laser beam was folded at 90° to be sent into the desired direction by the firing mirror@45 degree positioned at the centre of entrance aperture of the receiver telescope. This allowed a coaxial configuration for the transmitter and receiver. The experimental scheme of the CO₂ DIAL set-up is shown in figure 1. The whole system was mounted on a trolley as shown in figure 2 to make the system transportable. The lidar system was used in a topographic target configuration for measuring the absorption at λ_{on} and λ_{off} wavelengths for diethyl ether (DEE). Aerosols of the diethyl ether were enclosed in a perspex chamber of dimensions (40 cm \times 40 cm \times 40 cm) shown in figure 1, with openable windows of 8 cm \times 8 cm size (cut at a height of 15 cm from the bottom of chamber) for laser beam to pass through. The perspex chamber mounted on a metallic frame was placed at various distances from the laser transmitter. An atomizer (M/s TSI Inc., USA) was used to create aerosols of the chemical species (DEE, liquid at room temperature). Dry nitrogen in standard gas cylinder was used as the carrier gas for generating the aerosols. The windows were kept closed initially for aerosols to be trapped inside the enclosure. During laser firing (and DIAL sensor testing) the windows were opened to allow laser beam to pass through. DEE aerosols started dispersing out of the chamber, when windows were opened at both the sides. During the experiments, it was also observed that DEE aerosols were present inside the chamber for more than a minute.

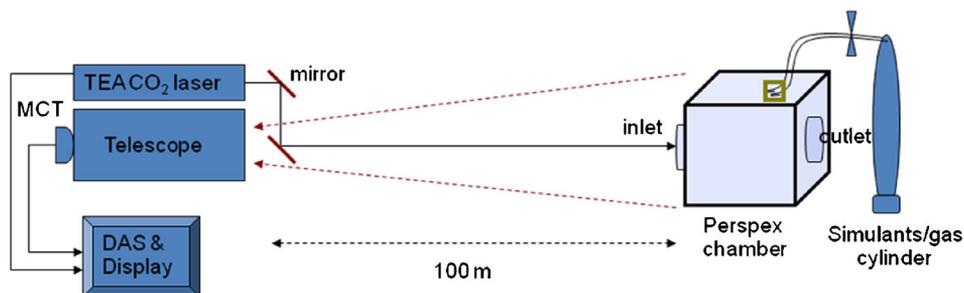


Figure 1. Experimental scheme of CO₂ DIAL set-up.

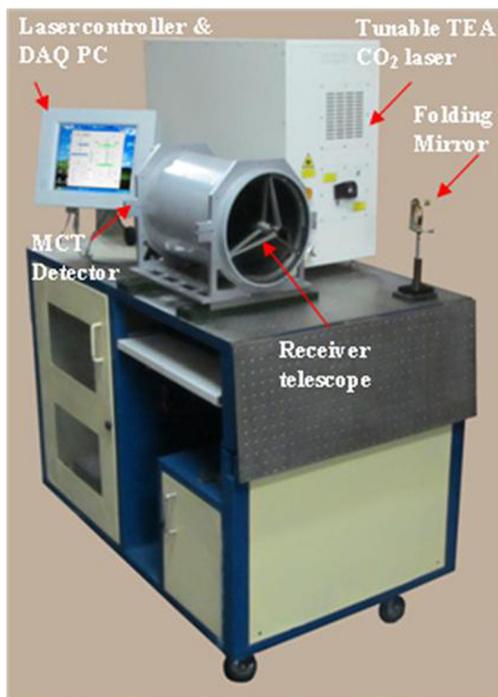


Figure 2. Photograph of the trolley-mounted CO₂ DIAL system.

In order to test the DIAL sensor, we have carried out some laboratory experiments with this assembly using the chemical, DEE. Aerosols of DEE were released in the perspex chamber. The chamber was positioned on a metallic frame at a distance of 60 m in the laser beam path so that the beam interacts with DEE molecules and gets reflected from the hard target at a distance of 100 m. We have used $\lambda_{\text{on}} = 9.2824 \mu\text{m}$ (9R18) and $\lambda_{\text{off}} = 10.2071 \mu\text{m}$ (10R26) for detection of DEE chemicals. We have averaged 50 pulses for each wavelength, when the system operated at the pulse repetition rate of 50 Hz. The firing sequence of the laser was programmed so as to introduce a time gap of 1 s between two pulses of different wavelengths. Energy stability of the laser source is $\pm 2\%$. Firstly, the laser beam at both wavelengths with equal energy of 7 mJ was transmitted through the chamber without DEE aerosol inside and the return signals at both wavelengths were recorded as shown in figure 3a. It was observed that return signals at both wavelengths were approximately equal, which means no absorption was taking place inside the chamber. Subsequently, the chamber was filled with aerosolized diethyl ether and return signals were once again measured at both wavelengths (figure 3b). The return signal strength at λ_{on} ($9.2824 \mu\text{m}$) showed significant reduction of about 280 mV from its original value due to absorption by DEE molecules whereas no significant change was observed at λ_{off} ($10.2071 \mu\text{m}$). A minimum concentration of 40 ml of diethyl ether was measured using this set-up in the present experiment.

Infrared differential absorption lidar

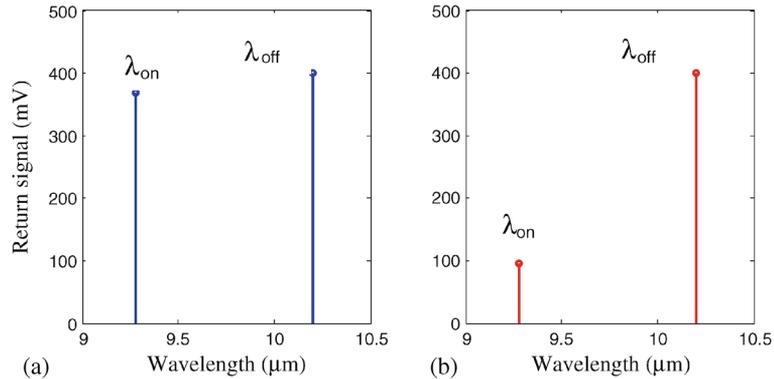


Figure 3. Return signals recorded at λ_{on} ($9.2824 \mu\text{m}$) and λ_{off} ($10.2071 \mu\text{m}$) wavelengths. **(a)** Signals measured in the absence of DEE aerosol in the chamber and **(b)** signals measured in the presence of DEE aerosols in the chamber.

References

- [1] C R Prasad, P Kabro and S Mathur, *Proc. SPIE* **3757**, 87 (1999)
- [2] F M D'Amico, R G Vanderbeck and R G Warren, *Proc. SPIE* **3855**, 128 (1999)
- [3] C B Carlisle, J E Van der Laan, L W Carr, P Adam and J P Chiaroni, *Appl. Opt.* **34**, 6187 (1995)
- [4] S Chandra *et al.*, *Proc. SPIE* **4036**, 200 (2000)
- [5] S Veerabuthiran and A K Razdan, *J. Battle. Technol.* **13**(3), 11 (2010)
- [6] L D Hoffland, R J Piffath and J B Bouck, *Opt. Eng.* **24**, 982 (1985)
- [7] H Kariminezhad, P Parvin, F Borna and A Bavali, *Opt. Laser Eng.* **48**(4), 491 (2010)