Tunable semiconductor lasers can monitor air pollution

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Continuous monitoring of industrial pollution sources can be accomplished with relatively-simple eye-safe laser systems using retroreflectors.

Global atmospheric pollution can pose serious health threats and endangers our quality of life. It is imperative to reverse anthropogenic damage to the atmosphere by tightly controlling and reducing the release of pollutants. However, the lack of rugged automatic instruments for profiling gas concentration currently makes monitoring and enforcing compliance virtually impossible. Optical remote sensing, a technology capable of mapping gas concentration profiles in real time, promises to fill this void. Range resolved monitoring of pollutant concentrations in ambient air enables the identification and characterization of sources and facilitates air pollution control.

Light detection and ranging (LIDAR) with searchlights was adopted for atmospheric profiling long before the laser era. Two powerful methods became available with the advent of the laser: differential absorption LIDAR (DIAL) and tunable diode laser spectroscopy.1 DIAL systems are suitable for profiling gas concentration over distances up to a few tens of kilometers but they are highly complex, fragile, bulky, and can harm vision. A compact and rugged tunable laser sensor, on the other hand, cannot perform range-resolved measurements. To incorporate the advantages of both approaches, we have implemented the DIAL method with tunable semiconductor lasers using a group of retroreflectors (RRs).2

In our approach, retroreflectors divide the absorption path into range intervals similar to those of the DIAL method. Since the path length dependence of the DIAL signal is a function of the absorbing gas concentration, a series of path-integrated measurements allow for the calculation of the gas concentration in each range interval. The spacing between the RRs determines the spatial resolution. To extract fast-changing gas concentration profiles, the measurements need to be completed on a time scale in which major changes in the gas concentrations will not develop. Short laser pulses can be used to retrieve gas concentration profiles undisturbed by atmospheric turbulence.

We validated the method using pulsed quantum-cascade lasers which can cover the fundamental absorption bands of many air pollutants.3 The linear frequency shift within a short laser pulse was used to scan an absorption feature, thus enabling temporal separation of laser pulses returned by the different retroreflectors. We recorded the absorption lines of ammonia and ethylene with 200ns pulses of lasers operating near 10.3 and 10.9µm. A quantum cascade laser with an average output power of about 1mW was shown to be suitable for range-resolved NH₃ detection over distances of up to ~1km with a detection limit of ~20ppbv per 30m segment.2

The greater the line strength of a target absorption feature and the more sensitive the instrument for absorption measurements, the higher the spatial resolution that can be achieved with the proposed method. To overcome the spatial resolution limit imposed by the laser pulse width, we implemented a continuous-wave tunable laser diode into the system and scanned its beam

Figure 1. The scalable model of a laser system for fenceline monitoring of industrial air pollution sources.

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over the retroreflectors. Seven retroreflectors were scanned in ∼9ms using a rotating mirror to extract ambient H₂O concentration profiles in real time. A 10cm spatial resolution was demonstrated using a laser diode tuned to a strong H₂O absorption line at 7199.34cm⁻¹ (∼1389nm).4,5

Continuous high-spatial-resolution mapping of air pollutants downwind from an emission source allows the application of atmospheric dispersion models to assess the time-varying source strength and to predict the dispersion of air pollutants. To study the applicability of the proposed method to fenceline monitoring, we have developed a fully scalable model of the instrument (see Figure 1). Nine retroreflectors are arranged along an absorption path and scanned with a rotating mirror. The pollution plume is simulated with boiling liquid nitrogen. Time-variable H₂O concentrations in the segments purged with nitrogen can be recorded under controllable conditions to optimize measurement strategies.

Simple and reliable instruments for air pollution profiling can be developed using the proposed approach. The retroreflectors required for the method are simple optical elements capable of withstanding harsh environmental conditions without any maintenance. Once installed on a perimeter or inside a zone of interest, a group of retro-reflectors can be used to locate and characterize sources and fluxes of air pollutants. Eye-safe emission of semiconductor lasers allows for deploying the system in busy areas, such as city streets, manufacturing plants, and transportation terminals. We are currently exploring these and other opportunities arising from the new approach.

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References

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