METAL–VAPOR LASERS FOR APPLICATIONS TO SENSING OF ATMOSPHERIC AEROSOL

V.D. Burlakov, V.V. Zuev, G.S. Evtushenko, A.V. El'nikov, V.N. Marichev, and V.L. Pravdin

Institute of Atmospheric Optics
Siberian Branch of the Russian Academy of Sciences, Tomsk

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This paper presents a discussion of applications of metal–vapor lasers in lidar sounding of atmospheric aerosol. In particular, it is shown that data on the aerosol size spectra which are obtained with a metal–vapor–lasers–based lidar allow one to correct simultaneously acquired data on the ozone density profiles for the atmospheric aerosol. A stationary Cu–vapor–based lidar for detecting spatial distribution of industrial aerosols in the atmosphere over an industrial center is described.

1. INTRODUCTION

The change in natural aerosol concentration both in the troposphere and stratosphere strongly influences the optical radiation propagation, radiative budget, the content of the molecular components of the atmosphere including ozone, and other processes of the earth–atmosphere system which govern the weather and climate formation.

Therefore, the aerosol dynamics, its diurnal and seasonal variations, altitude and regional distribution are of great interest for meteorologists, climatologists, and atmospheric optics scientists. Complex investigations of the atmospheric aerosol pollution of industrial origin are urgently needed within the frameworks of environmental studies in big industrial centers.

Lidar methods of aerosol sensing[1] provide both for local and large–scale operative systematic control of the aerosol state in the atmosphere. A single–frequency laser sensing, under certain assumptions on the atmospheric models and using some *a priori* information, makes it possible to reconstruct the extinction coefficient profile and to estimate the aerosol concentration from a lidar return signal. An extension of the bulk of measurement information due to sensing at several wavelengths[2] allows one to solve the complex problem of investigating the atmospheric aerosol, i.e., determination of the particle size spectra and reflective index of the particulate matter, i.e., the aerosol chemical composition.

Usually, solid–state lasers delivering pulses of from tens to hundreds of mJ energy at a repetition rate of units or tens of Hz are used for sensing the atmospheric aerosol. Signals returned from the upper troposphere and stratosphere are normally recorded with the highly sensitive photoelectron multiplier (PMT) in the photon counting regime. Then the PMT afterpulsing, which results in the error in counting the photons in a large dynamic range of the signal, appears due to overloading of the PMT by the powerful signal reflected from the near zone of sensing. Therefore, it is possible to use the laser sources with a less energy per pulse but greater (~ kHz) pulse repetition rate for the vertical sensing. This provides a short time (several minutes) of the signal accumulation in the photon counting regime. Some metal–vapor lasers (MVL) meet these requirements.

The Cu– and Au–vapor–lasers–based lidar systems were used for measurements of the vertical profiles of aerosol distribution in the troposphere and stratosphere.[3,4] The Cu–vapor laser is used in Raman lidars for measuring temperature and humidity profiles in the lower troposphere.[5,6] A Cu–vapor–laser–based lidar for investigating aerosol and molecular scattering based on Doppler broadening of lines is described in Ref. 7.

The metal–vapor generation is realized in a broad spectral range, consequently one can select a number of laser sources for the multifrequency sensing of the microphysical aerosol parameters. Taking into account typical size of aerosol particles, it is necessary to carry out the multifrequency sensing in the 0.3–1.5 μm spectral range. Because of poor performance parameters of the PMT in the spectral region above 0.8 μm, we have selected the following metal–vapor lasers for multifrequency sensing of aerosol: Sr^+ – 430.5 nm, Cu – 510.6 nm, Au – 627.8 nm, and Pb – 722.9 nm.

These lasers have a mean output power of 1–2 W and a pulse repetition rate of 2.5 kHz that corresponds to a maximum sensing distance of 60 km, and beam divergence 0.2–0.3 mrad, if an unstable resonator is used. Use of these lasers in multifrequency lidars significantly expands their capabilities, in particular, it makes it possible to correct simultaneously acquired data on the ozone concentration profiles for the atmospheric aerosol.

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2. USE OF A MVL IN A MULTIFREQUENCY LIDAR FACILITY BASED ON A 2.2–M–DIAMETER RECEIVING TELESCOPE FOR SIMULTANEOUS SENSING OF VERTICAL DISTRIBUTION OF OZONE AND AEROSOL IN THE STRATOSPHERE

As a rule, laser sounding of ozone is carried out in the UV spectral range in the Hartley and Higgins absorption bands using a DIAL technique. Since the UV absorption bands of ozone have no fine structure or absorption selectivity one should choose essentially different sounding wavelengths. In this case to reconstruct the ozone profile from lidar sounding data it is necessary to take into account spectral behavior of the aerosol scattering and extinction coefficients in such a wide spectral range. This situation is usual in the troposphere, especially in its lower part due to high density of aerosols of different origin and composition. In the stratosphere this can occur, as a rule, only after huge volcanic eruptions which emit a lot of aerosols and different gases, which, in turn, initiate formation of additional stratospheric aerosol. As known, at present the strong aerosol disturbance by the products of Mt. Pinatubo eruption happened in June 1991 is observed.[8] Therefore, the correction of the ozone data for the atmospheric aerosol is an urgent problem now not only for the troposphere, but also for the stratosphere.

To carry out the "aerosol correction" one needs knowledge about the atmospheric aerosol microstructure which can be obtained from the data of the multifrequency laser sounding of the aerosol simultaneously with the ozone sounding data.

To do this we have developed a multifrequency lidar on the basis of the receiving telescope with the primary mirror 2.2 m in diameter and a multiwave laser transmitting system. Block diagram and specifications of the system can be found in Ref. 9. An excimer XeCl laser and a frequency–doubled Nd: YAG laser radiation were used in the lidar. Sounding can be carried out simultaneously at the wavelengths 308, 353, 532, and 683 nm because we used stimulated Raman cells to transform pumping radiation in hydrogen. It is possible to expand the region of sounding wavelengths by using Cu–, Au–, Pb–, and Sr^+–vapor lasers. A multifrequency and multichannel laser operation regime makes it possible to simultaneously record the vertical profiles of the distribution of ozone, aerosol, and aerosol particles size spectrum.

An example of sounding by means of the described lidar during nighttime on April 27, 1992 is shown in Fig. 1. Four sounding wavelengths: 308, 353, 532, and 628 nm of a XeCl laser with a Raman cell, an Nd: YAG laser, and a gold–vapor laser have been used in the experiment. Figure 1 shows scattering ratio profiles measured at the corresponding wavelengths. The situation presented in this figure is typical of that time when the stratosphere was polluted with the products of Mt. Pinatubo eruption.

$$R(H) = \frac{\beta_a(H) + \beta_m(H)}{\beta_m(H)},$$

where H is the height, $\beta_a(H)$ is the aerosol backscattering coefficient, and $\beta_m(H)$ is the molecular backscattering coefficient.

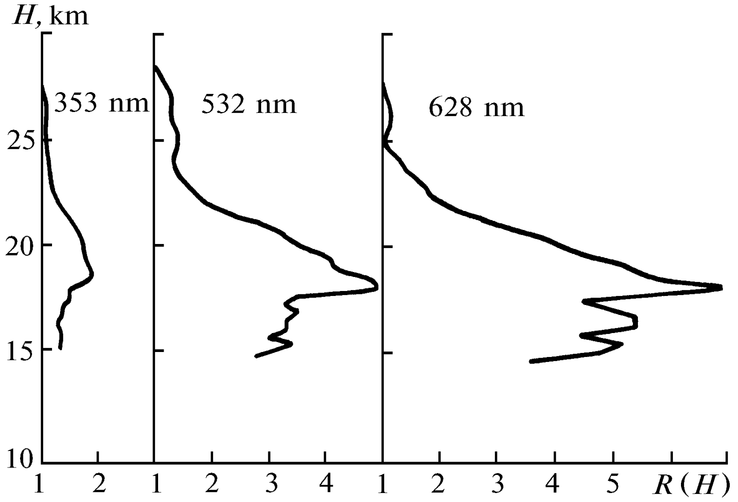

FIG. 1. Vertical Profiles of the scattering ratio.

The ozone profile reconstructed according to usual scheme of differential absorption for sounding only at two wavelengths 308 and 350 nm is shown in Fig. 2 by dashed line. The ozone–sonde data obtained simultaneously with the lidar sounding data are given in Fig. 2 by dots. A strong disagreement between the ozone–sonde and lidar data on the ozone profiles is obvious from this figure. The ozone profile reconstructed using a correction for the atmospheric aerosol extinction spectral behavior is given in Fig. 2 by solid line. It can be seen that these data are in a much better agreement with the ozone–sonde data.

Of course, creation of this multichannel lidar was associated not only with the necessity of correcting the ozone lidar sounding data for the aerosol extinction, but also because of the need for obtaining detailed information about the stratospheric aerosol microstructure and revealing the stratospheric ozone and aerosol interaction, and solving a number of other problems. The use of the whole complex of selected MVL will promote that.

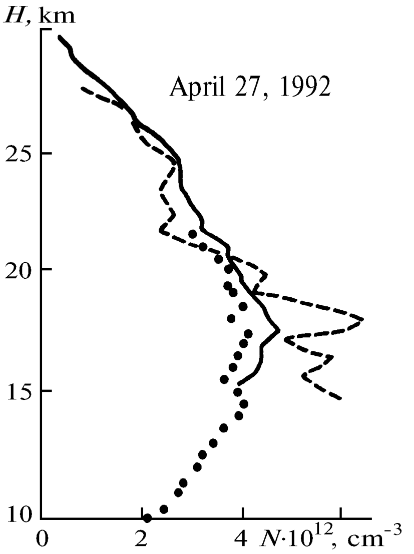

FIG. 2. Profiles of the ozone concentration.

3. CU–VAPOR –LASER –BASED LIDAR FOR SOUNDING INDUSTRIAL AEROSOL

To monitor general ecological situation over an industrial area, to sound accidental and every day emissions of aerosol into the atmosphere, and to select new building up areas for industrial plants and inhabitation in a city and in its outskirts where admissible levels of environmental pollutions can be safety maintained, operative methods and means for monitoring atmospheric emissions from plants are needed. A lidar based on a laser operating with high pulse repetition frequency (~ kHz) enables one to solve such a problem and can provide a sounding range along a horizontal path up to 10 km. In this case, if a lidar is placed at an elevated site or in a mobile platform an operative control of the general aerosol situation over a city is possible.

A simplified block diagram of a lidar is shown in Fig. 3. Such a lidar was constructed as a stationary complex. The optical–mechanical receiving–transmitting unit *1* of the lidar was, as a whole unit, mounted on a scanning platform which provided scanning over azimuthal angles from 0 to 360° and over the elevation angles from 0 to 90°. The scanning or rotatable platform was placed at the top of a 4–storied building which was at a significant elevation compared to the down town. Therefore, it was possible to carry out sounding over the whole down–town area over horizontal and slant paths. The block of laser sources (II) and the block of the recording electronic and processing instrumentation (III) were in a separate room of the building, what significantly simplified the operators' work. The optical radiation is transferred from block II to block I with a monofiber optical waveguide of fused silica. The diameter of the quartz fiber was 1 mm. To transport an optical signal from the receiving mirror to a PMT we used a focon, which was optically spliced or welded with the optical waveguide. The optical efficiency of the focon–waveguide block was about 50 %.

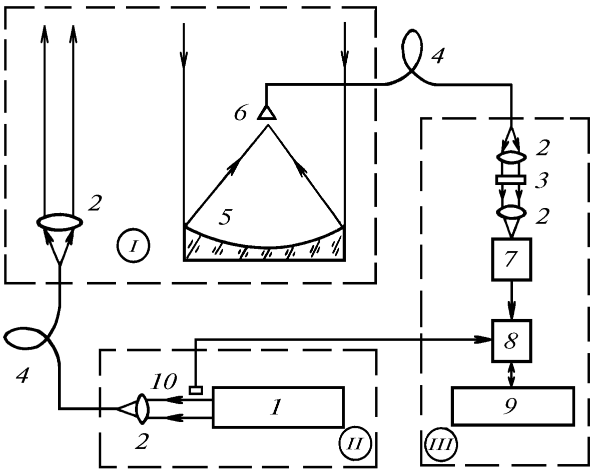

FIG. 3. Block–diagram of the lidar:
1) MVL, 2) lenses, 3) interference filters, 4) light conductors, 5) receiving mirror (∅ = 500 *and* F = 1500 mm*), 6) focon, 7) PMT–130, 8) photon counter, 9) computer and 10) starting phototransistor.*

Use of optical waveguides to transport laser beams makes it possible to change laser sources quickly depending on the problem to be solved keeping the alignment of the receiving–transmitting optics. In particular, it makes it possible to use several laser sources with different wavelengths which provide, by means of multifrequency sounding, identification of the pollution source by chemical composition of aerosol in the emission.

To illustrate the capability of the lidar, the scattering ratio $R(H)$ obtained when sounding at the wavelength 510.6 nm of a Cu–vapor laser along a horizontal paths over Tomsk is shown in Fig. 4. This ratio characterizes the content of the aerosol and molecular components in the atmosphere. The peaks of an aerosol signal which well correlate with the industrial objects and smoke plumes along the path are recorded at the distance of 2.5, 3.5, and 6.5 km.

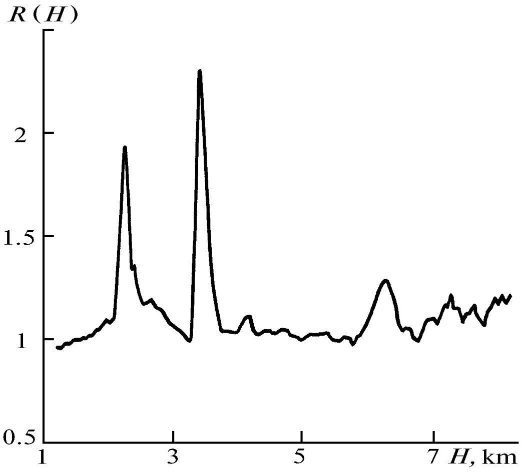

FIG. 4. Horizontal profile of the scattering ratio.

Return signals are reliably recorded at distances up to 10 km. Let us note that the parameters of this lidar system were not optimized. To decrease the PMT overloading by a signal from the near zone the energy of laser pulses was by almost an order of magnitude lower than the possible one. The mean power of a Cu–vapor laser beam at the green line was about 1 W at the pulse repetition frequency of 5 kHz. The beam divergence, which is determined by the operational diameter of the optical waveguide and focal length of the collimating lens, was 3 mrad. The field of view of the receiving system was comparable with this value. One can decrease the radiation divergence by using optical waveguides with a smaller diameter or by using collimating optics with longer focus for the transmission of radiation. Thus, it is possible to significantly increase the sounding distance by changing the power and geometric parameters of the lidar.

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