MULTIFREQUENCY LIDAR ON THE BASIS OF THE TELESCOPE WITH THE RECEIVING MIRROR 2.2 m IN DIAMETER FOR SIMULTANEOUS SOUNDING OF VERTICAL DISTRIBUTIONS OF OZONE AND AEROSOL IN THE STRATOSPHERE

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Block diagram and specifications of a lidar are presented. The multifrequency and multichannel modes of lidar operations permit to record simultaneously the vertical profiles of ozone and aerosol distributions and of the aerosol particle size spectrum. As base lasers, a frequency doubled Nd : YAG laser and an excimer XeCl laser were used. In combination with the stimulated Raman–scattering (SRS) conversion of radiation of pumping lasers in hydrogen, sounding can be simultaneously performed at wavelengths of 308, 353, 413, 532, *and* 683 nm. *The possibility exists of extending the range of sounding wavelengths due to the use of a gold–vapor* (628 nm) *and lead–vapor* (723 nm) *lasers. The data on the size spectrum of aerosol particles obtained simultaneously with data of ozone sounding, allow one to correct the profiles of ozone concentration for the aerosol contribution.*

Laser sounding of ozone is carried out, as a rule, in the UV spectral range in Hartley and Huggins absorption bands by a lidar technique of differential absorption. Because the UV–absorption bands of ozone have no pronounced selective structure, the sounding wavelengths must be spaced widely enough across the spectrum. When reconstructing the ozone profile from the data of lidar sounding, it is necessary to take into account the fact that the spectral variations of the aerosol extinction and scattering coefficients may be pronounced in this spectral region. It is the case for the troposphere, especially for its lower part characterized by the enhanced content of aerosols of different origin and composition. In the stratosphere this phenomenon, as a rule, occurs after powerful volcanic eruptions emitting into the stratosphere a huge amount of aerosols and various gases resulting in additional formation of stratospheric aerosol. At present, as is well known, the strong aerosol disturbance of the atmosphere by the products of eruption of the Pinatubo volcano, which took place in Philippines in June, 1991, is observed, and for this reason the problem of correction of data of laser sounding of ozone for aerosol contribution is the urgent problem not only for the troposphere but also for the stratosphere.

In order to perform the "aerosol correction", the information is needed about the microstructure of atmospheric aerosol that may be derived from data of multifrequency laser sounding of aerosols obtained simultaneously with data of ozone sounding.

To this end we have developed the multichannel lidar on the basis of large telescope with the receiving mirror 2.2 m in diameter and multiwave laser transmitting system. Block diagram of the lidar is shown in Fig. 1, while its basic specifications are listed in Table I. A lidar transmitter consists of a solid Nd : YAG laser, excimer XeCl laser, and cells filled with hydrogen at high pressure and equipped with focusing and collimating optics. The cells provide the shift of the laser radiation frequency due to SRS. The efficiency of the SRS conversion of laser frequencies, as is well known, depends on many factors (such as spatio–energetic parameters of lasers, focal lengths, quality of focusing optics, and pressure and composition of gaseous medium in the high–pressure cell). Essentially, each laser is characterized by its individual energy redistribution between the main and Raman frequencies in the process of the SRS conversion.

In order to determine the optimal modes of operation of the SRS conversion of laser frequencies of our lidar transmitter, the behaviour of the intensities of radiation lines was investigated as a function of the pressure of pure hydrogen or hydrogen–nitrogen mixture. Strainless steel cells with an internal diameter of 36 mm and a length of 1 m were used as the SRS cells. Input and output windows were made of quartz plates 10 mm thick. In order to obtain the necessary energy density of pumping, the radiation from the laser generating the fundamental frequency was focused into the cell center with a quartz lens of focal length 1 m. The gas pressure in the cell was varied from 0 to 24 atm. At the exit from the cell the collimated lens was positioned confocally with the focusing lens. The spectral selection of the SRS components was carried out with the help of a prism or diffraction grating.

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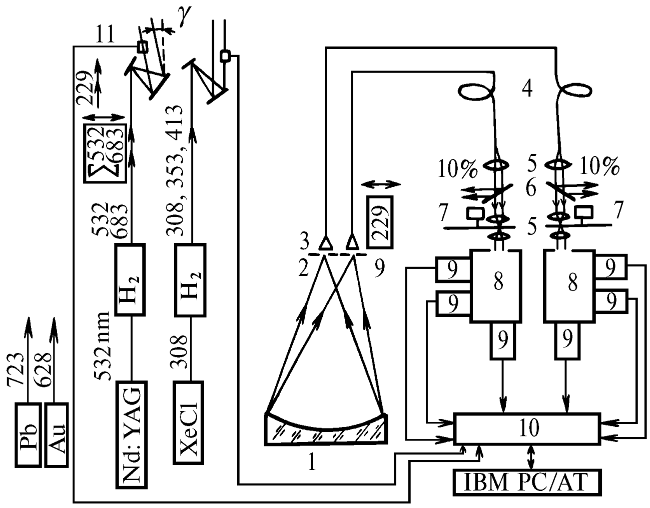

FIG. 1. Block diagram of the lidar. Receiving mirror (1), field diaphragms (2), focons (3), light guides (4), lenses (5), light–splitting mirrors (6), mechanical shutter (7), cells of spectral selection (8), PMT (9), photon counter (10), and phototransistors (11).

TABLE I. Lidar specifications.

Transmitter					
Laser source	λ, nm	E_u, mJ	P_{av}, W	*f, Hz*	γ, mrad
XeCl	308	50		50–100	0.1–0.2
XeCl→SRS(H_2)	353	30		50–100	0.1–0.2
	413	20		50–100	0.1–0.2
N_d : YAG	1064	150		15	0.1–0.2
	532	50		15	0.1–0.2
N_d:YAG(532)→SRS(H_2)	683	30		15	0.1–0.2
Σ532, 683	299	5		15	0.1–0.2
Au	628		1	(2–3)·103	0.1–0.2
Pb	723		1	(2–3)·103	0.1–0.2

Receiver	
Diameter of the receiving mirror, m	2.2
Focal distance of the receiving mirror, m	10
Field of view angle, mrad	0.5
Spatial resolution, m	100–500
Temporal resolution, min	15–30

Recording system	
Photodetector	FÉU–130, FÉU–142, FÉU–157
Number of time periods	512
Computer	IBM PC/AT

Figure 2 shows the dependence of the intensities of the fundamental frequency radiation of the XeCl laser and of the Stokes SRS components up to the fourth order on the pressure of gases under investigation. It can be seen from the figure that in pure hydrogen at a pressure of 18 atm, the intensities of the fundamental, first, and second Stokes spectral lines become practically identical. However, as the pressure rises, the divergence of the Stokes components, especially of high orders, deteriorates. Since our lidar has long–focus receiving telescope (F = 10 m), while the input diameter of focons, concentrating the received radiation onto a light guide, is 6 mm, the critical beam divergence of lidar transmitter is 0.5 mrad.

For this reason for sounding with the use of the second Stokes component the operating pressure in the SRS cell must be equal to 13 atm, and when only the first component is used, reduced pressures (9 atm) are more preferable. Such a sounding scheme is more useful in investigations of ozone at the altitudes above the stratospheric maximum where the sounding radiation at a wavelength of 308 nm is primarily absorbed.

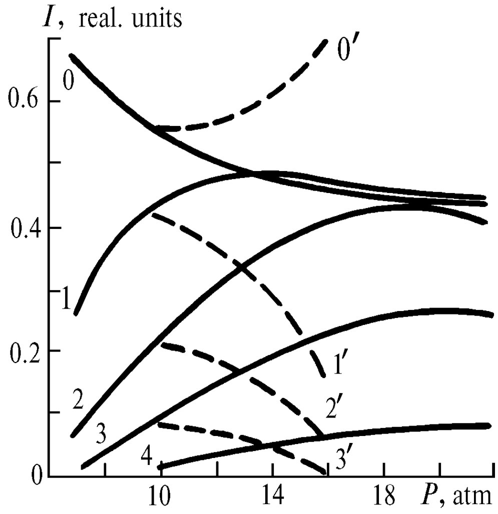

FIG. 2. Dependence of the intensity of components of the SRS conversion on the pressure: in pure hydrogen (0, 1, 2, 3, and 4); in hydrogen under initial pressure of 10 atm *(0′, 1′ , 2′, and 3′) with subsequent addition of argon.* λ = 308 *(0)*, 353 *(1)*, 413 *(2)*, 499 *(3)*, *and* 628 nm *(4)*.

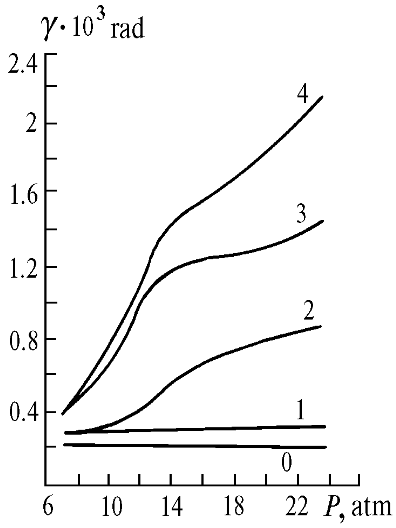

FIG. 3. Dependence of the divergence of the SRS conversion components of the XeCl *laser on the pressure of hydrogen:* λ = 308 *(0)*, 353 *(1)*, 413 *(2)*, 499 *(3)*, *and* 628 nm *(4)*.

Figure 4 shows the curves of the intensities of the fundamental, first, and second Stokes and anti–Stokes lines in the case of the SRS conversion of the second harmonic of the Nd : YAG laser operating at a wavelength of 538 nm. It is evident from the figure that the most optimal pressure for our lidar is 4 atm by virtue of the fact that lower sensitivity of the PMT and lower backsattering efficiency in the long–wave region favour in converting the energy into the first Stokes component with a wavelength of 638 nm.

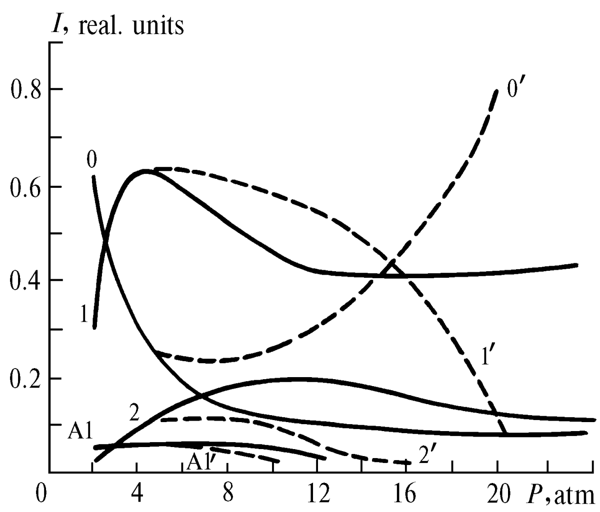

FIG. 4. Dependence of the intensity of components of the SRS conversion on the pressure: in pure hydrogen (A1, 0, 1, and 2), in hydrogen under initial pressure of 4 atm *with subsequent addition of argon (A1′, 0′, 1′, and 2′).* λ = 532 *(0)*, 683 *(1)*, 954 *(2)*, *and* 436 *(A1)* nm.

We have also investigated the SRS conversion of laser frequencies in the case of addition of argon into the SRS cell (dashed lines in Figs. 2 and 4). It turned out that addition of argon changes the ratio of the intensities in favour of the fundamental component. In so doing the behaviour of the intensity components is different for the XeCl and Nd : YAG lasers. In the case of the XeCl laser the addition of argon results in decrease of the intensities of all the components of the SRS conversion and in the corresponding intensification of the fundamental line. In the case of the Nd : YAG laser the addition of argon results in changing the ratio of the intensities in favour of both the fundamental line and the first Stokes component. However, the addition of argon have no positive effect in the case of our concrete sounding scheme.

In addition to the laser transmitters described above, our lidar has standby channels on the basis of the Au and Pb vapor lasers. Specifications of these lasers are also given in Table I.

The multichannel mode of operation of our lidar is accomplished by the tilt of one of the laser beams at a small angle of ~ 35′, in so doing the focus of the tilted beam is shifted at a distance of ~ 10 cm from the central focus. The optical signal is transmitted from the focus of the receiving mirror to the cells of spectral selection with the help of focons and gradan lenses which are optically glued or welded to the light guide 200 μm in diameter. The total efficiency of the systems "focon – light guide" or "gradan – light guide" is equal to 40–70 % depending on the spectral region at hand (lower efficiency is for the UV–range). The cell of spectral selection permits to receive the sounding radiation at three wavelengths simultaneously by adjusting the appropriate light–splitting mirrors and interference filters.

For gating out the near zone the mechanical shutters are employed which operate synchronously with lasers. The signal from the near zone (troposphere) can be recorded simultaneously when inserting the light–splitting mirrors reflecting 10 % of light flux in the direction toward the additional cells of spectral selection. The lidar returns from the stratosphere were recorded by the multichannel counter of events in the regime of counting of photocurrent pulses integrated over 512 gates 100 m long to avoid errors in counting the single–electron pulses in a wide dynamic range of lidar returns. The photomultiplier tubes FÉU–142, FÉU–130, and FÉU–157 were used as the photodetectors operating in 308–413, 532–628, and 683–723 nm bands, respectively.

For simultaneous sounding of ozone and aerosol with the help of the lidar described above, four sounding wavelengths were employed (308, 353, 532, and 628 nm) generated by the XeCl laser with the SRS cell, Nd : YAG laser, and Au vapor laser. Figure 5 shows the obtained profiles of the scattering ratio R at three wavelengths that illustrate the typical aerosol situation in the stratosphere disturbed by the products of eruption of the Pinatubo volcano.

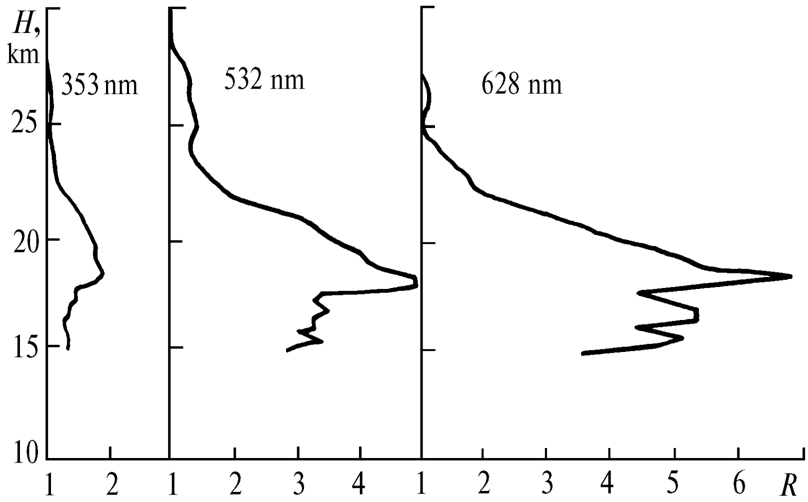

FIG. 5. Profiles of the scattering ratio obtained on April 27, 1992.

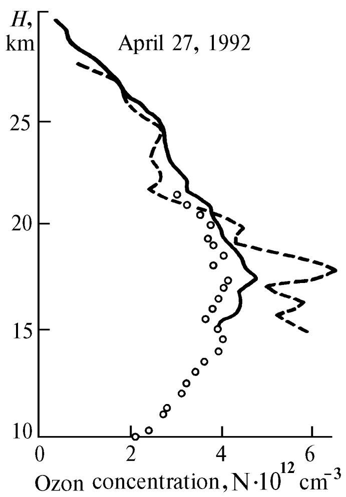

FIG. 6. Profiles of the ozone concentration.

In Fig. 6 dashed line denotes the ozone profile which was reconstructed according to the conventional technique of differential absorption when sounding only at two wavelengths (308 and 353 nm). In this figure the data of ozonesonde, which were obtained simultaneously with the data of lidar sounding, are denoted by circles. The complete disagreement between the ozonesonde and lidar profiles of ozone concentration is evident. Solid line denotes the ozone profile reconstructed with correction for aerosol contribution. It can be seen that these data agree fairly well with the ozonesonde data.

Of course, the development of the multichannel lidar is caused to a lesser degree by the necessity for correction for aerosol contribution than by obtaining the detailed information about the microstructure of stratospheric aerosol, revealing the interaction of stratospheric ozone and aerosol, and solving the other problems.