LIDAR FOR SOUNDING OF TROPOSPHERIC OZONE USING NONLINEAR CONVERSION OF COPPER VAPOR LASER EMISSION

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Received July 15, 1994

We propose a lidar for the tropospheric ozone sounding by the differential absorption method using nontraditional pairs of laser spectral lines, namely, 271–289 nm *(the net frequency of yellow and green radiation lines of copper vapor laser and the second harmonic of yellow line of copper vapor laser, respectively) and* 289–308 nm *(*308 nm *is the wavelength of the excimer* XeCl*–laser radiation). The paper presents the results of investigation into the efficiency of CVL harmonics generation in nonlinear crystals of* β–BaB_2O_4 *as well as the results of numerical simulation of potentialities of the lidar under study for the tropospheric ozone sounding.*

1. INTRODUCTION

Ozone is of much significance to ecology and global planet's climate and thus plays an important role in atmospheric monitoring. Urgency of investigations of ozone and ozone–cycle components essentially increased during last decade in connection with the ozonehole detection and observation of steady elevated content of tropospheric ozone in some European regions.

Lidar methods of sounding provide the routine information about ozone content throughout atmospheric column with required spatial and temporal resolution. Lidar sounding of stratospheric ozone in Institute of Atmospheric Optics (city of Tomsk, 56°N, 85°E) has been carrying out since 1989. First measurements were performed by lidar with receiving mirror 1 m in diameter (Ref. 1). Nowadays stratospheric ozone measurements with simultaneous sounding of vertical aerosol distribution are conducted at the Station for High–altitude Sounding of the Atmosphere (SHSA) with receiving telescope 2.2 m in diameter (Ref. 2). To investigate the general dynamics of atmospheric ozone and tropospheric–stratospheric interchange processes, the measurements of tropospheric and stratospheric ozone must be performed at one time. To this end, we elaborated the tropospheric ozone sounding channel based on receiving mirror with diameter of 0.5 m, which complements the stratospheric one at SHSA.

At present time, laser sounding both tropospheric and stratospheric ozone in UV spectral range (Hartley band) is mostly performed with excimer XeCl, XeF, KrF lasers and generators of the 4th harmonic of ND : YAG laser in combination with stimulated Raman scattering (SRS) technique.[2,3] Energy per pulse for these lasers reaches 100 mJ at pulse repetition frequency of 10...100 Hz. Herewith, in recording the lidar echo signals with fast photomultipliers (PM) in photons counting regime, powerful clutter illumination from the nearest sounding zone causes PM aftereffect, which leads to photons discounting in a wide dynamic range of lidar echo signals and distorts the whole of signal shape. Therefore, for tropospheric ozone sounding it is possible to use laser sources with lesser energy per pulse, but greater pulse repetition frequency (~1 kHz), that ensures fast (a few minutes) signal storage in photons counting regime.

Basing on the results of investigation of copper vapor laser (CVL) harmonics generation in nonlinear crystals obtained in the Institute of Atmospheric Optics,[4] we propose a lidar for tropospheric ozone sounding with use of nontraditional laser spectral lines. For differential absorption method of sounding, we take these lines: 289 nm being the second harmonic of CVL yellow (578) line and 271 nm being the net frequency of yellow and green (511) CVL line. High repetition frequency of CVL (6–10 kHz) in combination with low energy per pulse makes this laser most suitable for sounding in photons counting regime under low–background conditions typical for tropospheric ozone sounding at $\lambda < 300$ nm.

2. EXPERIMENTAL RESULTS OF INVESTIGATION INTO CVL HARMONICS GENERATION

Basic features determining the efficiency of the harmonics generation are the pulse power at fundamental pumping frequency, the divergence of pumping laser, and the nonlinear properties of a crystal itself. If powerful solid lasers (the pulse power varies from units to tens of megawatts) are used, the efficiency of conversion amounts up to 60% and more. As for typical CVLs with pulse power of tens of kilowatts, very little progress has been made towards increase of the conversion efficiency.[5,6] Thus, for the generation of second harmonic (SHG) of green CVL line in nonlinear crystals of β–BaB_2O_4 (BBO) only efficiency of 9% has been reached.[6]

The diagram of our experiments on CVL emission conversion to SHG and net frequency is presented in Fig. 1.

Pumping laser converting each emission line is realized as a chain "driving generator–amplifier". Driving generator (DG) includes a gas–discharge tube *5* and unstable telescopic resonator. This latter is formed by fully reflecting spherical mirrors *2* and *4* with focal distances of 6 and 100 cm, respectively, and flat output mirror *3* with a window. Necessary polarization of radiation is ensured by the Glan prism *1*. Hereafter the DG radiation passes through a specular spatial filter–collimator (SSFC), which isolates the radiation component with requisite divergence

0235-6880/94/11–12 876-03 $02.00

and consists of confocal mirrors *6* and *7* with focal distances of 60 and 150 cm, respectively, and diaphragm *8* placed in mirrors focus. The diaphragm diameter of 50 μm gives, empirically, the best efficiency of conversion. At last, a rotating mirror *9* guides radiation to an amplifier *10*.

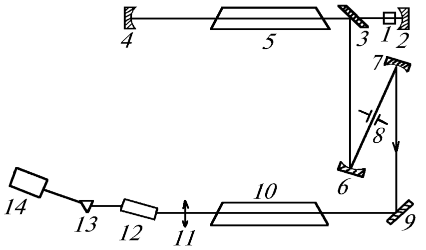

FIG. 1. Diagram of the setup for conversion of CVL emission in nonlinear crystal.

For DG and amplifier we used a KULON discharge tubes (active zone length of 30 cm, diameter of 1.2 cm) and a GL–201 one (length of 75 cm,diameter of 2 cm). Activation of DG was performed with a cable delayer.

Lens *11* with focal distance of 150 cm focused radiation in the center of nonlinear BBO crystal *12* 4×4×6 mm in size, being cut at angles of θ = 48° and φ = 90°. Synchronous *ooe* interaction was ensured by the θ–angle adjustment of a crystal. To isolate generation lines we used quartz prism *13* and a set of light filters. The radiation power was recorded with an IMO–2N device *14*.

During the experiments, we varied mirrors magnification factor and radius of diaphragm of SSFC and focal distance of lens *11*. Optimum values of these parameters were presented above. The obtained conversion efficiency reached 25% for SHG and 14% for net frequency.

3. RESULTS OF NUMERICAL SIMULATION OF TROPOSPHERIC OZONE SOUNDING

Achieved conversion efficiency ensured generation parameters suitable for tropospheric ozone sounding: average radiation power of 0.3 W for each line with pulse repetition frequency of 7 kHz and radiation divergence being approximately equal to 0.2 mrad.

The tropospheric ozone sounding channel is elaborated on the base of receiving mirror with diameter of 0.5 m. It complements the stratospheric ozone sounding channel at SHSA with use of excimer XeCl laser radiation. Therefore, we studied the possibility of ozone sounding by the differential absorption method on pairs of lines 271–289 and 289–308 nm. Parameters of designed lidar are presented in Table I.

Receiving telescope is made according to Newton's diagram. Cuvette of signal spectral isolation, which consists of collimating and focusing lenses, spectrum splitting mirrors, interference filters and photomultiplier is placed in focal plane of telescope. Signals recording proceeds in the photons counting regime.

Numerical simulation of ozone sounding for lidar parameters given in Table I was performed considering transmission of optical elements and PM sentitivity. Results in the form of mutual dependence between error and altitude sounding range are presented in Fig. 2.

TABLE I. Lidar specifications.

Transmitter				
Laser	λ, nm	*E*, mJ	P_{av}, W	*f*, Hz
Cu	289		0.3	$7\cdot10^3$
Cu	271		0.3	$7\cdot10^3$
XeCl	308	50		50
Divergence 0.2 mrad				
Receiver				
Mirror diameter, m			0.5	
Focal distance, m			1.5	
Field of view, mrad			0.5	
Photodetectors			FÉU–130, FÉU–142	
Photons counting regime				
Spatial resolution, m			100	

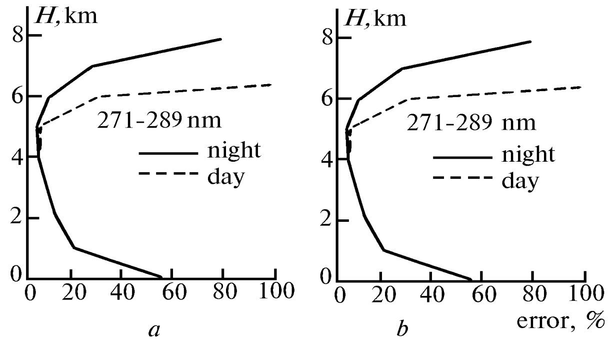

FIG. 2. Results of numerical simulation of ozone sounding error at wavelengths of 271–289 *(a) and* 289–308 nm *(b).*

It is seen that integrated use of all three emission lines makes it possible to perform measurements in altitude range of 3...7 km by day and of 3...12 km at night.

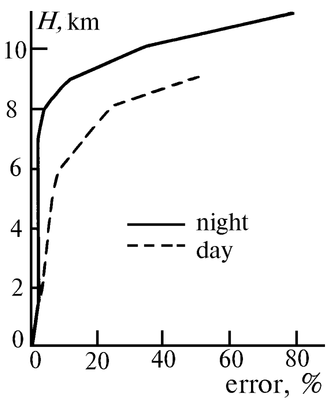

FIG. 3. Results of numerical simulation of the error of water vapor sounding from RS signals.

In addition, we consider the possibility of simultaneous RS signals measurements at wavelengths of 323 (the RS signal from the H_2O molecules on line of 289 nm) and 310 nm (the RS signal from the N_2 molecules on line of 289 nm), which enables the humidity profile to be reconstructed. Results of numerical simulation of humidity sounding from RS signals measurement are presented in Fig. 3. It shows the possibility of measuring up to 3 km by day and 8 km at night.

Note that all simulations were performed for signals storage time of 10 min. This value can be essentially increased at least for the night sounding. At a present time, the lidar installation in measurements regime is proceeding.

ACKNOWLEDGMENTS

The work is supported by Russian Fund for Fundamental Researches (Project Code 93–05–9383).

REFERENCES

1. A.V. El'nikov, V.N. Marichev, K.D. Shchelevoi, et al., Opt. Atm. **1**, No. 4, 117–123 (1988).
2. V.D. Burlakov, A.V. El'nikov, V.V. Zuev, et al., Atmos. Oceanic Opt. **5**, No. 10, 664–667 (1992).
3. H. Nakane, S. Hayashida, et al., in: *Abstract of papers 16 ILRC* (1992), pp. 23–26.
4. V.O.Troitskii, Atmos. Oceanic Opt. **6**, No. 6, 392-395 (1993).
5. D.W. Coutts, M.D. Ainsworth, and J.A. Piper, IEEE J. Quantum Electron. **25**, No. 9, 1985–1987 (1989).
6. K. Kuroda, T. Shimura, T. Omatsu, et al., in: *Tech. Dig. Conf. Lasers Electro. Opt. Soc. Amer.,* Washington DC (1988), Paper WV 4.