MULTICOLOR LASER FOR A LIDAR FOR SOUNDING THE PARAMETERS OF THE ATMOSPHERE

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The results of the development and investigation of a multicolor laser based on lasers operating and dyes and a nonlinear crystal, which are pumped by copper-vapor laser, are presented. The laser described is intended to be used in a lidar whose receiving mirror has a diameter of 2 m and which is used for multifrequency sounding of the microphysical parameters of atmospheric aerosol for altitudes not less than 15 km as well as for RS sounding of the moisture control and temperature of the atmosphere up to an altitude of 5 km. The lidar transmitter operates at wavelengths of 510.6, 578.2, 654.0, and 271.2 nm. The average power of simultaneous lasing in the first three lines is not less than 1 W. The maximum total average power at the green and yellow wavelengths exceeds 30 W, the average power at the red wavelengths reaches 9 W, and the average UV power is 0.9 W.

The study of weather- and climate-formation processes requires the development of integrated methods and instrumentation for sounding the atmosphere. An integrated lidar station (KOLIS) is under development at the Institute of Atmospheric Optics of the Siberian Branch of the Academy of Sciences of the USSR.[1] This station is based on a receiving system whose main mirror has a diameter of 2.2 m diameter and a collection of lasers which is to be employed for simultaneous sounding of the vertical profiles of moisture content, the temperature, and the microphysical parameters of the aerosol, including the altitude profiles of the lidar ratio.

In this paper we present the results of the development and study of one of the laser transmitters used in the KOLIS station, namely, a multicolor laser based on dye lasers pumped with copper-vapor lasers. This laser is to be used for multifrequency sounding of the microphysical parameters of atmospheric aerosol[2] as well as for RS sounding of the moisture content and temperature.[3]

The method of multifrequency sounding of aerosols requires three or four sounding radiation lines separated approximately by 80–100 nm in the atmospheric transmission windows.[2] Therefore the lines can have a width of ~ (10÷40) Å and a wavelength reproducibility of ~ 1 Å.

Visible laser radiation can also be used to determine by the RS method the same microphysical parameters of aerosols as well as the moisture content and temperature of the atmosphere, but UV radiation is preferred.[4]

One of the most efficient visible-range lasers is the copper-vapor laser. This laser was selected as the source of yellow-green radiation for aerosol and RS sounding as well as the source for pumping tunable dye visible-wavelength lasers operating on nonlinear crystals, which are used to obtain UV radiation.

The foregoing considerations, our model calculations, and the accuracy, with which the atmospheric parameters were determined, made it necessary to develop technical requirements which the main parameters of the lidar transmitter must meet; these are given in Table I.

To obtain the lidar transmitter characteristics given in Table I copper-vapor "generator-amplifier" systems were studied in order to obtain pump radiation with high energy parameters. There are a number of works[6–8] devoted to the study of such systems. It is shown there, in particular, that combining amplifier cascades and a spatial selector after the generator makes it possible to increase substantially the lasing power in the diffraction beam. We studied sealed active elements with different geometry and volume and with different types of resonators. The experiments were performed with gas-discharge tubes, whose discharge channel ranged from 10 to 35 mm in diameter and 500 to 1000 mm in length. The switches consisted of TGI 1-1000/25, TGI 1-2000/35, and TGI 1-2500/50 thyratrons. The working frequencies ranged from 4 to 10 kHz, the delay time of the radiation pulse from the generator relative to the amplifier varied from –30 to +80 nsec, and the pressure of the buffer gas ranged from 10 to 5000 mm Wg.

TABLE I.

Technical requirements for a lidar transmitter

No.	Lidar transmitter radiation parameters;	Problems and methods of sounding	
		Multifrequency sounding of the microphysical parameters of aerosols up to altitudes of 15 km	RS sounding of the microphysical parameters of aerosols, the moisture content, and the temperature up to altitudes of 5 km
1	The average lasing	10 (λ_1, λ_2, λ_3)	10.0 (λ_1+λ_2) 0.5(λ^4)
	power in one line, W	<10	<30
2	The repetition frequency, kHz	10÷30	10÷30
3	Pulse duration, nces	≤0.5	≤0.5
4	Beam divergence, mrad	λ_1=510.6	λ_1=510.6
5	Wavelength, nm	λ_2=578.2	λ_2=578.2
6	Spectrum width, nm	λ_3=654.0	λ_3=271.2
7	Wavelength reproducibility, arbitrary units	≤1.0 5·10^{-4}	— —

TABLE II.

The characteristics of some laboratory models of copper-vapor lasers.

No.	Diameter of discharge channel, nm	Discharge length, mm	U_b, kV	J_{av}, A	P_{Ne}, mm Hg	f, kHz	P_{av}, W	$P\Sigma_{av}$, W	Remarks
1	15	560	5.5	0.34	400	5.80	3.8	—	Two
2	25	720	5.0	0.80	20	6.25	12.5	—	
3	27	1000	5.5	0.63	37	7.70	15.5	—	Water-cooled TGI1 -1000/25 plane-parallel resonator;
4	35	1000	5.5	0.77	70	6.67	17.0	—	
5	35	1000	5.4	0.95	—	5.88	11.5	22.0	Generator
6	35	1000	5.2	0.57	—	5.88	14.5		Amplifier
	15	560	4.0	0.35	300	6.25	1.5		Generator
	35	1000	6.0	1.00	200	6.25	12.0	31.5	Amplifier
	35	1000	6.0	0.70	200	6.25	14.0		Amplifier

Table II gives some of the results of our studies. The results given in the first, fifth, and sixth rows of Table II were obtained using a circuit for supplying power to the lasers with a pulsed transformer and magnetic compression of the pulse after switching with two TGI 1-1000/25 thyratrons connected in parallel; the results in the second, third, and fourth rows were obtained using a circuit with resonance recharging capacitance directly on the gas-discharge gap. For lasers with channel diameters of 15 and 25 mm the radiation power was measured with a telescopic resonator (M = 14). The average radiation power with a divergence of 0.2 mrad was equal to 2.4 W with a channel diameter of 15 mm and 8.8 W with a diameter of 27 mm. The fifth and sixth rows of Table II give the test results for two- and three-cascade laser systems. In the two-cascade system a six-meter optical delay was inserted between the generator and the amplifier. In the three-cascade system a collimator was inserted between the generator and the first amplifier in order to expand the beam up to 34 mm with a spatial selector in the form of a diaphragms and a 5 m optical delay. The generator in the three-cascade system operated with a telescopic resonator, and the total average power generated, given in Table II, is the power in a beam whose divergence is close to the diffraction limit.

The shape of the pulse generated in the "generator-amplifier" system is, as a rule, identical to that of the pulse generated by the master oscillator, and its duration is somewhat longer than that of the latter pulse. The maximum power of the system is achieved when the generator excitation pulse is delayed by 20 nsec relative to the amplifier excitation pulse. The beam divergence is 0.1—0.3 mrad when a telescopic resonator with $M = 14$ is employed. The duration of lasing at half height ranges from 20 to 50 nsec.

It follows from the results presented in Table II that the parameters of the lidar transmitter at the wavelengths λ_1 and λ_2 (Table I) are already obtained by a two-cascade "generator-amplifier" system with active elements which have a discharge channel 27 mm in diameter and a 1000 mm long discharge.

To develop a laser operating at the wavelength $\lambda_3 = 654.0$ nm, corresponding to one of the atmospheric transmission windows, the spectral and energy characteristics of organic-dye lasers, pumped by a copper-vapor laser in order to obtain the maximum efficiency of conversion of pump radiation into radiation at the wavelength λ_3, were studied. In the yellow-red region we investigated compounds synthesized at the Scientific Research Institute of Organic and Intermediate Products and Dyes as well as rhodamine B produced by the Lambda Physik Company and rhodamine B produced in Poland.

The experimental setup (Fig. 1) included a copper—vapor pump laser, arranged as follows: master oscillator (MO) with a channel diameter of 15 mm-amplifier (AMP) with a channel diameter of 30 mm. An unstable resonator 1, 2, 3 with $M = 10$ was employed in the MO. A spatial filter 4, 5, 6 was placed between the MO and AMP cascades. The pump radiation was directed with the help of a spherical mirror 7 and a cylindrical lens 8 into the cell 9 of the dye laser. The cavity of the dye laser consisted of a flat mirror 10 with 99% reflection in the region of lasing and a plane-parallel plate 11 as the output mirror. Three film interferometers 12, 13, and 14 placed inside the cavity were used to select the dye-laser spectrum. The active media were studied using a quasi longitudinal arrangement of the dye laser, described in Ref. 9. In this scheme a rotating cell with a volume of 5 ml was employed; this made it possible to study small batches of dye and to evaluate the photostability of the active solution. In all cases doubly distilled ethyl alcohol was used as the solvent. The average lasing and pump powers were measured with the help of IMO-2 power meters, and the spectral characteristics were recorded using an MDR-23 FEU-FER2 system with output on an automatic plotter. The experimental procedure is described in greater detail in Ref. 10.

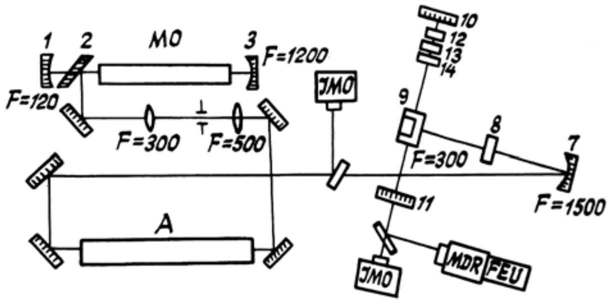

FIG. 1. Diagram of the experimental arrangement employed studying the lasing characteristics of dyes.

TABLE III.

The lasing parameters of dyes in the red region of the spectrum.

Dye	Luminescence			
	λ_{nak}, nm	λ_{max}, nm	$\Delta\lambda(0.5)$, nm	I, %
OK-17	510.6 578.2	636	613-664	15
F-430	the same	630	616-649	16
KVN-124	the same	627	616-646	16

Dye	Lasing in the resonator					
	nonselective			selective		
	λ_{max}, nm	$\Delta\lambda(0.5)$, nm	η/η_{ok-17}	λ_{max}, nm	$\Delta\lambda(0.5)$, nm	$\frac{\eta(654)}{\eta_{ok-17}(654)}$
OK-17	638	635-643	1.0	639	615-683	1.0
F-430	629	626-635	1.1	629	612-658	0.8
KVN-124	628	625-637	1.3	634	616-655	0.9

Table III gives the lasing characteristics of compounds emitting in the region $\lambda_3 = 654$ nm. The rightmost column of Table III gives the efficiency of the compounds tested in the region 654 nm to the efficiency of OK-17. Analysis shows that OK-17 had the best energy parameters in this region.

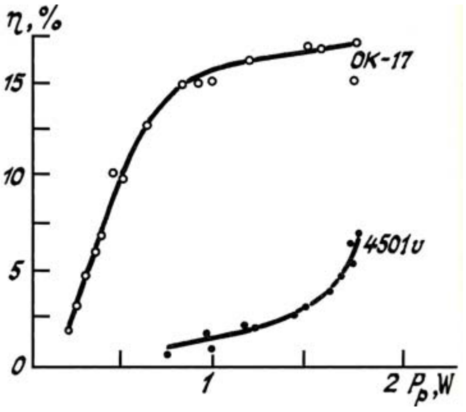

FIG. 2. The average lasing power of the dyes OK-17 and No. 4501u versus the pump power.

Photostability tests of the same dyes in the quasilongitudinal pump arrangement gave the following result. OK-17 turned out to be most subject to photodecomposition. The time over which the lasing power dropped by 50% for this laser would be an order of magnitude shorter than for the other dyes. According to the results obtained one liter of the OK-17 solution operated continuously for 100 h. Figure 2 shows the lasing power of OK-17 as a function of the pump power. The curve has a tendency to saturate, and the radiation conversion efficiency is close to 15%. Figure 3a shows a spectrogram of the radiation from a laser operating on the OK-17 solution. The atmospheric transmission window in this spectral range is shown on the wavelength scale.

We also studied the possibility of lasing on No. 4501u polymethine dye in the atmospheric transmission window centered at the wavelength 789 ns. The presence of this wavelength makes it. possible, when necessary, to expand the set of wavelengths for measuring the microphysical parameters of aerosol by the method of multifrequency sounding.

Figure 2 shows the lasing power versus the pump power for this dye. The radiation conversion efficiency reached 6%. A spectrogram of the radiation of the dye in the case when two film interferometers were used for selection is shown in Fig. 3b. One liter of solution had a lifetime of not less than 100 h. The dye circulation system employs a specially developed labryrinthine pump; the pump provided a head equivalent to a 30 m column of water and a flow rate of 10 liters/min through the "filter-cell" system. The pump contains a meter for measuring the dye level in the tank and a sensor for monitoring the operation of the seal.

The dye laser employed in the multicolor lidar transmitter described above was constructed using a scheme with transverse pumping; this makes it possible to obtain high coefficients of conversion of pump radiation into lasing by the dyes. With an average pump power of 30 W the lasing power of the dye laser without spectral selection will reach 9 W. By using a plane-parallel resonator and correcting lens it is possible to obtain the requires divergence, and by introducing film interferometers with baselines of 5, 15, and 40 μm the spectrum of the output radiation can be narrowed down to 0.07 nm without an appreciable loss of dye lasing power.

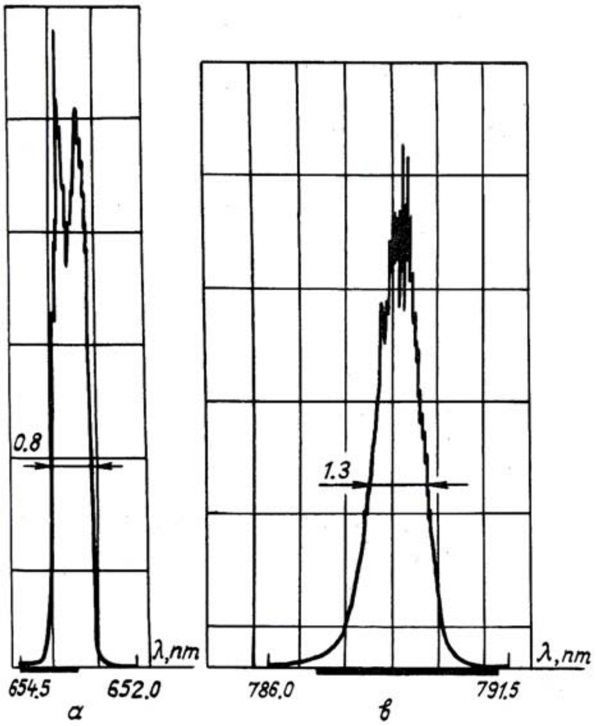

FIG. 3. Spectrograms of the radiation from lasers operating on OK-17 (a) and No. 4501u (b) dyes. The heavy lines on the abscissa axes indicate the atmospheric transmission windows.

Since in this scheme the pump radiation and the lasing radiation of the dye are vertically polarized in order to obtain high energy characteristics, all optical elements are positioned at an angle close to the Brewster angle in order to reduce losses to a minimum. The interferometers have angular adjustment in the vertical plane for frequency matching of the transmission functions.

A 2×2×4 cm KDP crystal without forced cooling (matching of the type "ooe") was employed to convert the coppei—vapor laser radiation into UV radiation (λ_4). The efficiency of conversion of the pump radiation (λ_1 and λ_2) into the sum frequency (λ_4) reached 5% with an average UV-radiation power of 0.9 W.[11]

The lidar transmitter consists of three large units: a special vibration-proof optical table, a laser, and power supply units for the pump lasers.

The laser includes two copper-vapor "generator-amplifier" laser systems (the optical arrangement is shown in Fig. 1; the diameter of the generator channel is equal to 15 mm and the diameter of the amplifier channel is equal to 27 mm), a dye laser, a KDP crystal converter, and an optical-mechanical channel joining them that permits directing the output radiation of the lasers to the input mirror of the transmitting lidar. All this is placed on an optical table consisting of a massive marble slab resting on supports consisting of alternating layers of vibration-absorbing materials with different amplitude-frequency characteristics and functioning as a passive vibration-insulation system.

In conclusion we present the main technical characteristics of the lidar transmitter:

radiation wavelength .. $\lambda_1 = 510.6$ nm; $\lambda_2 = 578.2$ nm;
.... $\lambda_3 = 654.0$ nm; $\lambda_4 = 271.2$ nm;

maximum total average power at λ_1 and λ_2 in each of two pump channels .... 15 W;

maximum average power at λ_3..........less than 1 W;

maximum average power at λ_4 ....0.9 W;

width of the laser radiation spectrum
.... not more than 1.0 nm;

pulse repetition frequency ....5 kHz;

laser pulse duration at half-height .... (25÷30) ns;
beam divergence at half-maximum ....$5 \cdot 10^{-4}$ rad;
power consumption (220/380 V, 50 Hz).....20 kW.

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