DEVELOPMENT AND DESIGN OF POWERFUL EXCIMER LASER-PUMPED DYE LASERS

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This paper comments on the problems encountered in frequency conversion of radiation from powerful excimer lasers by means of dye lasers. New losing media capable of producing laser generation in the 330 to 800 nm spectral range and original designs of dye cells and optical schemes for their excitation are developed. Some models of powerful liquid lasers have been already tested together with a system for regeneration of the active laser medium.

The appearance of powerful excimer UV lasers[1,2] greatly stimulated the development of high-power tuned dye lasers, the unique parameters of excimer-laser excitation pulses such as high power of radiation, high energy per quantum, sharpness of the leading edge, and others explaining much in that progress. High pulse repetition rates achievable in excimer lasers make them promising tools for monitoring of the atmosphere and sea.

Excimer laser pumped systems capable of generating in the 430–550 nm range yield 3 times higher peak power and 5 times higher mean power, as compared to the YAG–pumped systems. That is why they enjoy wide use in DIALs today.[3] However, these systems have a significant disadvantage: laser dye has to be frequently replaced, since it is subjected to photochemical transformations caused by powerful UV irradiation. However, this disadvantage may be overcome. Certain progress achieved in that direction is outlined below.

Besides developing photostable, highly efficient lasing media, the task of converting high–power excimer laser radiation calls for constructing unique optical schemes for dye lasers as well as dye cells: the cylindrical lenses focusing the pumping radiation into rectangular cells, used in conventional optical schemes cannot stand the forcing they suffer. Assuming an input power ~ 40 MW and an area of the incident beam 10×2 mm^2 we find an intracavity power density ~ 250 MW/cm^2 which is the destruction threshold for elements made of optical quarts.

During the last several years we have accumulated certain experience in converting powerful excimer laser radiation at pulse energies up to 10 J and pulse repetition rates up to 1 Hz (Ref. 4).

Two principal problems were solved. Original dye laser cells were designed, constructed, and tested. Photostable lasing media were produced generating in the blue-green spectral range at 5–10 MJ/liter lifetimes (lifetime of such a medium is expressed as energy pumped into 1 liter of solution while its lasing efficiency decreases by a factor of 2) .

1. ACTIVE LASING MEDIA

Comprehensive theoretical and experimental studies of spectre—luminescence and generation characteristics of different organic molecules of different classes and the regular changes in these characteristics depending on their structure, made it possible to design and produce new organic compounds which can be successfully used as active lasing media in powerful excimer pumped dye lasers. As a result, one can obtain stimulated radiation at high efficiencies both in the near UV and IR (these ranges still await detailed studies) and in the blue-green spectral ranges, that provides dye generations from 322 to 800 nm. The new active media are listed in Table I.

As for the near UV we obtained the shortest wavelengths from solutions of organic compounds (column *I*, Table I, λ_{gen} = 322 nm) pumped by a KrF* laser radiation at pulse energy ~ 40mJ. A new class of compounds was discovered. They are ethanol soluble and may fill the 322–400 nm gap. This is important since substances generating in the above range (paraterphenyl, some oxazole derivatives) are limited in number and have poor ethanol solubility. Meanwhile, such a solubility is decisive for generation in the UV, since ethanol is transparent in that spectral range.

A compound showing significant promise is water soluble OOI, thus it is a cheap and fire–safe solvent. Water soluble compounds emitting in the UV are quite rare. Generation has been attained in a new class of triazole—substituents. In spite of low efficiency of dye conversion in the near UV it is preferable to achieve generation without any nonlinear effects due to simplicity and economic feasibility of such laser systems. Substances generating in the blue–green range are coumarine derivatives with low photostability. Optimizing their structure makes it possible to obtain compounds with photostability much higher than that of the known ones. Starting from oxazole we synthesized compounds soluble in the acetonitrile water mixture which also yield stable generation in the blue–green range.

Excimer lasers are universal pumping sources capable of exciting compounds which can emit in the UV to IR. However many of the known dyes generating in the UV suffer deep photochemical transformations when stimulated with powerful UV radiation. Thus the lifetime of the well-known rhodamine 6G dissolved in ethanol and pumped by a xenon chloride laser b about 165 J/cm^3; one of semimethyl dyes (450 IV) hardly reaches 40 J/cm^3, and it is oxazine 17 only which features a sufficiently long lifetime of 1000 J/cm^3. Table I lists the new highly photostable active media radiating in this spectral range-Possibilities of inhibiting the processes of photodecay of active losing media and of constructing multicomponent compositions which would be based on the knowledge of mechanisms of these processes are covered by Table II.

By now set of new active media has already been developed, yielding stimulated radiation when pumped by excimer laser radiation in the 322–823 nm range.

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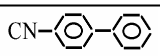
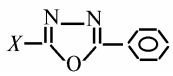
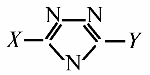
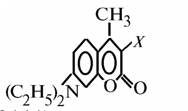
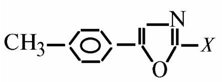
TABLE I. New active lasing media for admer pumped powerful dye lasers.

Compound	Solvent, c, mol/liter	λ_{gen}, nm	Efficiency, %	Lifetime, J/m^3	Pumping laser
	ethanol, 5×10^{-3}	332	1		KrF*–laser
	ethanol, 2×10^{-3}	322	2		–
		323	3		–
		351	6		–
		340	6		–
		401	2.5	1000	–
0.01	water, 2×10^{-3}	346–360	9.5		XeCl*–laser
	pentane, 3.5×10^{-3}	327	3.6		–
	24 compounds ethanol + toluol	347–443	3.5 18	100–1000	–
T698	ethanol, 8×10^{-3}	497	32	850	
MK 6012					–
MK 6013	ethanol, 8×10^{-3}	485	24	900	–
MK 4871	–	501	17	1500	–
MK 4870	–	480	30	860	–
	–		25	950	–
		496			
0111	water, 8×10^{-3}	513	3	680	–
0122	acetonitrile+	505	10	620	–
0326	water, 8×10^{-3}	525	9	800	–
0322		522	14	800	–
					
0010	acetonitrile, 4×10^{-3}	679	19	860	–
		675	23	810	–
0020	ethanol, 2×10^{-3}	712	14	1000	–
0018	acetonitrile, 4×10^{-3}	709	10	1000	–
0016	–	706	14	1000	–
12B	acetonitrile, 7×10^{-3} +H_2O	704	16	1000	–
20B	acetonitrile, 5×10^{-3}	730	12	1000	–
LK 790	acetonitrile, 2×10^{-3}	785	26	516	–
LK 800	–	783	19	1300	–
LK 840	–	823	18	1000	–
Phenalemine 512	ethanol, 8×10^{-3}	625	16.5	1000	–
M 316	–	718	14	560	–
DCM–1	ethanol, 5×10^{-3}	630	12	850	–
DCM–2	–	630	20	555	–
Rhodamine 6Zh	ethanol, 2×10^{-3}	583	25	165	–
Polymetine dye 450IV	–	783		40	–
			13.6		
Oxazine–1	–	782.6	22	84	–
Oxazine–17	–	665	15	1100	–

Note: Active media presented in the table are covered by authorship certificates and patented.

TABLE II. Active lasing media with increased photostability for the blue–green spectral range.

Laser active medium	λ_{gen}, nm	Efficiency, %	Lifetime, J/m^3
Coumarine 102 in ethanol + DABCO	476	33 (32)	1700 (300)
AC3F in ethanol + DABCO	497	31 (31)	3000 (1700)
T698 in ethanol + DABCO	497	31 (32)	3200 850
MK4871 in ethanol+DABCO	480	30 (30)	8600 (860)

Note: Data on pure ethanol without inhibitors of photodecomposition are given in parentheses.

2. DYE LASERS

New active media are used in the excimer pumped powerful dye lasers. Three laboratory units, "MZhL–01", "MZhL–02", and "MZhL–03" were developed and tested. As pointed above, special cells capable of heavy pumping without disintegration are necessary to convert powerful excimer laser pulses of 1 J energy. Such cells were designed, constructed and used in all the models. A rectangular dismountable cell being composed of quartz blocks 20 mm thick padded with silicone rubber and fixed in metal frame is capable of converting radiation with pulse energy in excess of 1.5 J, provided pumping in radiation is focused "softly". It is a flow-through cell, therefore it may operate at pulse repetition rates up to 50 Hz.

Prism cell does not require focusing of pumping radiation. It is built as a rectangular quartz prism with a cavity drilled for dye solution. Total internal reflection is provided, so that pumping radiation enters the dye–filled cavity as four beams thus providing uniform pumping and homogeneous output radiation at an optimal concentration of the medium. The conversion efficiency of such a cell is close to that of a rectangular one (~ 25–30%), provided however that the pump power density exceeds 2 MW/cm^2.

A cone cell is a truncated quartz cone with a cavity for dye solution along its axis, or a truncated metal cone of high surface reflectivity, where the cell with dye is oriented along its axis. The well–known property of an axicone reflector, is employed here, that of focusing pumped-in radiation along its axis, so that the flowing–through dye solution is circularly pumped. Sharpness of focusing may be controlled altering the size of the cavity (its diameter). The conversion efficiency reaches 30% in this case it output radiation being highly uniform too.

Figures 1 and 2 show the optical schemes of powerful "MZhL–01" and "MZhL–03" dye lasers. As for "MZhL–02", it is similar to "MZhL–03". The "MZhL–01" laser is designed to convert excimer laser radiation of rectangular beam cross-section (at energies up to 1.5 J) and wide–aperture beams (at diameters up to 150 mm), so it operates in two modes. In the first, the pumped radiation with energy up to 1.5 J is "softly" focused into a rectangular dismountable cell, its cavity is formed by the dead and the exit mirrors or by a diffraction grating operating in the grazing regime and the exit mirror. The radiation line is ~ 0.1 nm wide there. Double-entry pumping is envisaged for higher uniformity of exit radiation. In the second mode the incident pumped radiation hits the cell–cone. The cavity is formed by a dead mirror and a quartz plate which are the windows of the cell-cone. The pumping mono–pulse energy being 10 J radiation from the dye (coumarine 102 dissolved in ethanoi) at λ_{gen} = 475 nm reached ~ 2.5 J.

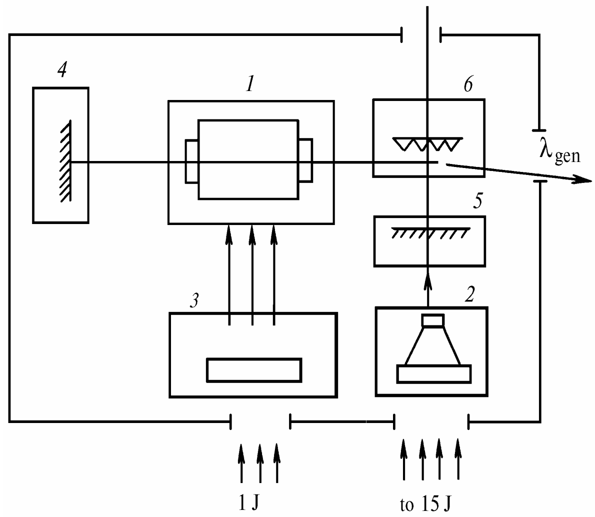


FIG. 1. Block-diagram of the "MZhL–01" powerful dye laser: 1) cel with dye solution, 2) cell–cone, 3) cylindrical lens, 4 and 5) mirrors, and 6) diffraction grating.

The scheme for "MZhL–02" and "MZhL–03" was chosen so as to obtain powerful narrow–band radiation from dyes. That is a scheme of "master oscillator" – "preamplifier" – "amplifier". Radiation from the dye, of about 0.01 nm spectral width is formed in the master oscillator, its cavity is composed of by two diffraction gratings and an exit mirror. One of the gratings prescribes the spectral width of exit radiation. It operates in the mode of grazing beam incidence. The second grating functions in the regime of autocollimation to provide the long-term stability of output radiation. The cascade of amplifiers contains prism cells with total internal reflection.

The emitter is constructed on a monolithic plate to which all the optical elements are fastened. The front panel of the emitter has an opening for exiting radiation while the knob for continuous tuning of wavelength and the window of the wavelength counter are placed on the rear panel. Radiation from the master oscillator in its zeroth order of diffraction from the grating operating at grazing incidence is fed by a mirror to input waveguide of the wavelength meter.

Solutions are independently pumped through the master oscillator, the preamplifier, and the amplifier. The pumping block consists of three 1.5 liter stainless steel tanks with quartz coating. The pumping system pumps solutions through the cells at a 12 mliter/s flow rate. Parallel to the basic pumping channel a system may be cut in for regeneration of the active medium.

The powerful MZhL–03 tunable laser may be used as emitter in ecological DIAL long–range lidars.

The principal parameters of the lasers are given below:

MZhL–01

spectral range, nm	330-800
laser radiation line width, nm	
a) nonselective cavity	15
b) selective cavity	0.1
laser radiation divergence, mrad	3
pulse repetition rate, Hz	10
pulse duration, ns	40-200
energy of output radiation, J	2-2.5
average power of output radiation	2
overall dimensions, mm^3:	
emitter	400×400×350
pumping unit	410×410×140
mass, kg:	
emitter, within	20
pumping system, within	8

MZhL–03

generation range,nm	330–830
laser radiation line width, nm	0.01
radiation divergence, mrad	2.0
pulse repetition rate, Hz	to 20
pulse duration, ns	50
radiation pulse energy, mJ	to 200
maximum peak density of	
output radiation power, MW/cm^2	30
overall dimensions:	
emitter, mm^3	130×600×220
pumping system	∅270×300
power supply	320×350×120
mass, kg	
emitter	50
pumping system	15
power supply	6

REFERENCES

1. V.Yu. Baranov, V.M. Borisov, et al., Kvant. Elektron. **14**, No. 12, 1452–1459 (1987).
2. V.F. Tarasenko, A.N. Panchenko, et al., Kvant. Elektron. **14**, No. 12, 2450–2451 (1987)
3. N.D. Hung and P. Brechignas, Appl. Opt. **27**, 1906 (1988).
4. M.V. Kabanov, B.F. Trinchuk, et al., in: *Proc. of the Fifth International Conference,* Novosibirsk, Part 1, 272–276 (1990).