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Tunable narrow-band UV laser system pumped by a copper vapour laser

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***Abstract*. A narrow-band laser system is designed, which produces 10-ns pulses of tunable UV radiation with an average power of 3 W, pulse repetition rate of 12 kHz, and linewidth smaller than 45 MHz. The system uses a cw dye laser as a master oscillator. Its radiation is amplified by a three-stage dye system whose output signal is frequency doubled in a BBO crystal. The system is pumped by a copper vapour laser.**

Keywords: *dye laser, copper vapour laser, frequency doubling.*

Tunable lasers with a narrow emission spectrum are extensively used for realising selective processes in atoms, detecting various impurities, etc. The technological applications associated with isotope separation [1] require the development of high-power laser systems and second-harmonic generation on their basis. Such systems are usually pumped by pulsed copper vapour lasers. The advantages of these lasers are high average and pulsed radiation powers and a high pulse repetition rate. Such systems have been built in [2 – 4]. However, frequency doubling has been performed only in [5] and only for a laser with an average radiation power of up to 1 W.

It is known that in the case of dye lasers, one of the main reasons responsible for a decrease in the efficiency of SHG is the distortion of the spatial intensity distribution in the beam of fundamental radiation. The aim of this work was to develop a laser system in which a narrow-band cw dye laser pumped by an Ar^+ laser is used as a master oscillator. Its radiation was amplified in a three-stage transversely pumped pulsed amplifying system.

Fig. 1 presents the schematic of the experimental setup consisting of two parallel identical cascades. The master oscillator represented a cw single-frequency jet dye laser [6] with a conventional three-mirror laser cavity. A Lyot filter, an absorption cell, and a Fabry – Perot etalon were used as selectors. The master oscillator was pumped by a cw single-mode Ar^+ laser. A dye laser, in which a solution of Rhodamine 6G in ethylene glycol was used, had a typical output power of 50 mW. The laser wavelength was controlled and measured by a wavemeter with an absolute accuracy of 300 MHz. The radiation linewidth, determined from the spectrum of beats of two identical lasers, was smaller than 5 MHz per 1 s. The long-term frequency drift, measured after heating the system, did not exceed 50 MHz per hour.

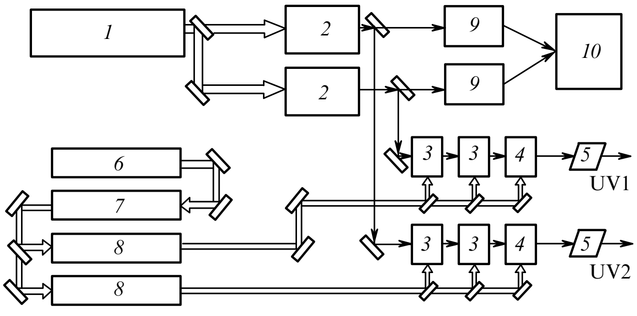

Figure 1. Schematic of the experimental setup: (*1*) Ar^+ laser; (*2*) cw dye master oscillators; (*3*) preamplifiers; (*4*, *8*) final amplifiers; (*5*) frequency doublers; (*6*) copper-vapour master oscillator; (*7*) preamplifier; (*9*) wavemeters; (*10*) computer.

The cw dye laser radiation was amplified by a three-stage amplifying system, which consisted of dye cells that were transversely pumped by a copper vapour laser. The laser system operating on copper vapour was formed by a master oscillator, a preamplifier, and two final amplification stages. Laser radiation with a nearly diffraction divergence was formed in a master oscillator with an unstable cavity. The central region of the radiation distribution was separated by a mirror telescope and an aperture that was placed in the beam waist in the telescope.

The radiation outgoing from the preamplifier was directed into two amplifying stages. Water-cooled active laser elements ('KRISTALL' gas-discharge copper vapour tubes, an LT-30Cu master oscillator, and LT-40Cu amplifiers) were mounted in a single unit. The average output power of the master oscillator reached 6 W, which provided an output power in the preamplifier as high as 55 W. The total output power of the copper vapour laser system reached 140 W (70 W in each channel), with pulse repetition rate of 12 kHz, FWHM pulse duration of 15 ns (Fig. 2), and beam diameter of 2 cm.

The cw dye laser radiation was focused by a lens with the focal distance of 40 cm into a preliminary-amplifier cell, whose design is described in Ref. [4]. The rate of the vertical flow of a dye solution through the cell was 12 litre min^{-1}. The spacing between the side windows of the cell was 0.5 mm, and the cell was 2 cm long. The same cell was used

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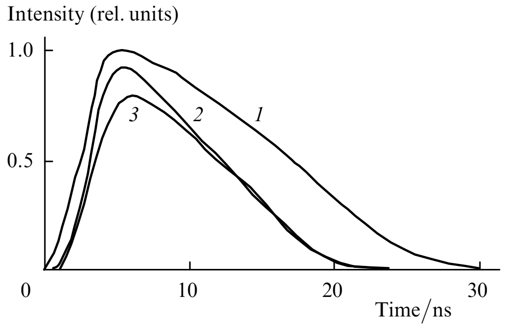

Figure 2. Oscillograms of pump laser (*1*), dye laser (*2*), and second-harmonic (*3*) pulses.

in the second amplifying stage. In the third (final) amplifying stage, we used a cell with 1-mm spacing between the side windows. The amplifying stages used ethanol solutions of phenalemine 512 as an active medium. This dye is suitable for pumping solutions by both emission lines of a copper vapour laser and provides efficient amplification of radiation in a range of 600 – 615 nm.

All amplifying stages were transversely pumped from one side. The dye concentration in all the cells was chosen so that the cells transmitted 30 % of pump power. The transmitted radiation was returned into the cells by a cylindrical mirror. In this scheme, 90 % of the pump power was absorbed in a dye solution and a more uniform distribution of gain in the active region was obtained.

The optical path from the master oscillator to the preamplifier was ~ 10 m, which provided a good optical isolation that excluded feedback. The average pump power of the preamplifier was 10 W. By changing the position of a cylindrical lens ($f = 7.5$ cm), we were able to vary the gain for cw radiation. The limiting gain k was chosen equal to 10^4. For higher k, the superluminescence power exceeded the power of the amplified emission, which sharply decreased the efficiency of conversion of the output-stage radiation to the second harmonic.

The average output power of the preamplifier was 50 mW and saturated at a cw radiation power of about ~ 30 mW. Because of a noncircular cross section of the active medium, the output laser beam had different angular divergences along two coordinates. This beam, when focused into the cell of the next stage, produced an output beam of elliptical shape and, therefore, the input radiation was focused into the second cell by a telescope consisting of two lenses. An aperture of small diameter, which was placed in the common focus of these lenses, worked as a spatial filter. The position of the focus was chosen so that radiation did not touch the cell walls. Otherwise, the output beam had a strongly nonuniform spatial distribution, which decreased the second-harmonic power. In this case, the laser spot in the vertical direction was wider than the pump spot, which caused a loss in the output radiation power. A uniform spatial distribution of radiation could be obtained only by decreasing the input power (by a factor of about two).

For a 12-W pump power, the average output power of the second stage was 450 mW. The average pump power in the third stage was 48 W. In this case, the output power of the laser system was 12 W. In the final stage, the pump radiation was focused into the cell by a cylindrical lens ($f =$ 15 cm) so that the transverse beam size was equal to the cell width. In this case, the spatial distribution of output laser radiation in the final stage was nearly Gaussian (Fig. 3), and we obtained the maximum power in the second harmonic with a good spatial distribution. Due to a high radiation stability of phenalemine 512, the output parameters of the laser system, with 4 litres of dye solution, remained unchanged during continuous operation (longer than 300 h).

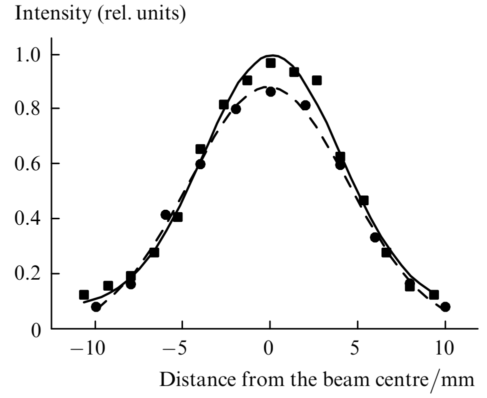

Figure 3. Spatial distributions of dye laser radiation at the output of the final amplifying stage (■) and the second harmonic (●) and the corresponding Gaussian distributions (curves).

The UV radiation was obtained by doubling the dye laser radiation in a BBO crystal 7 mm long. The crystal was placed at a distance of 40 cm from the centre of the cell of the output stage. We made preliminary experiments with different focusing lenses and found that the optimum focal distance was $f_{\rm opt} = 8.5$ cm. For a pump power of 12 W, the second-harmonic power reached 3 W. Of substantial importance was a Glan prism that was placed at the input of the final amplifying stage. By using this prism, we managed to obtain laser radiation with a higher degree of polarisation, which considerably increased the efficiency of radiation conversion to the second harmonic.

Fig. 2 presents oscillograms of pump pulses, dye laser pulses, and second-harmonic pulses. One can see that the dye laser and the second harmonic had approximately the same pulse durations. This is explained by the fact that we worked in the linear region of the dependence of the second-harmonic power on the pump power. Fig. 4 demonstrates the second-harmonic power as a function of the dye laser power.

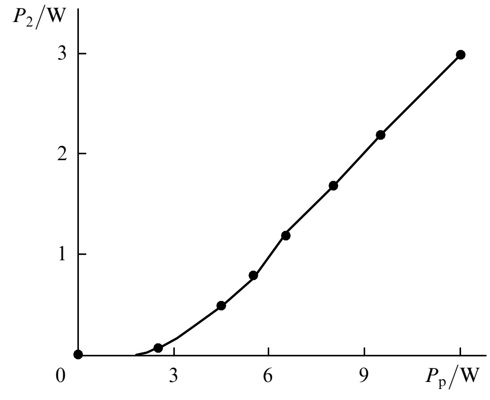

Figure 4. Second-harmonic power P_2 as a function of the pump radiation power $P_{\rm p}$.

We have built two identical laser systems, which were used for isotopically selective excitation of zinc atoms in a heated cell. The atoms were excited into the $6s\,^3S_1$ state by absorbing two counterpropagating photons at $\lambda_1 = 307.6$ nm and $\lambda_2 = 303.6$ nm. The closeness of photon energies in the two-photon process decreases the Doppler broadening below 20 MHz. Fig. 5 presents an example of the luminescence spectrum at 1.3 μm, related to the radiative decay of the upper state. The peaks in the spectrum are asymmetric because of the inequality of energies of two counterpropagating photons. One can see from Fig. 5 that the half-width of the peaks is ~ 90 MHz, which corresponds to the half-width of ~ 45 MHz for each of the UV beams. The emission line of the dye laser was narrower than 25 MHz, which is close to the 20-MHz width of bandwidth-limited pulses.

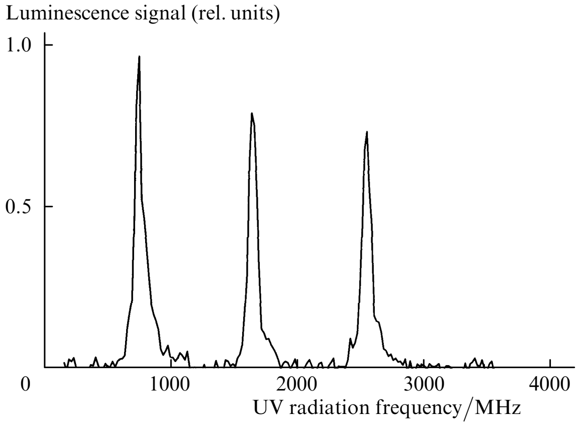

Figure 5. Spectrum of two-photon absorption of zinc atoms in the counterpropagating beams.

Thus, we have built the laser system that generates narrow-band 10-ns pulses tunable in the UV region with an average power of 3 W and pulse repetition rate of 12 kHz. The efficiency of conversion of pump radiation to tunable laser radiation reached 17 %, and the latter was converted to the second harmonic with the efficiency as high as 25 %. The spectral width of radiation corresponds to the bandwidth-limited value caused by a finite pulse duration.

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