Efficient autoscanned single-frequency CW dye laser

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ABSTRACT *(X Int. Conf. "Laser Optics-2000", St. Petersburg, Russia, June 26-30, 2000. Tech. Program, p. 51)*

We report on a CW single-frequency dye laser with a 1-W threshold power. Output power of the laser working on the Rhodamine19 dye was 100 mW out of 2.4 W of the argon ion pump. Smooth frequency scanning in a 20-GHz region with up to 20-GHz/s rate was implemented in a linear dye laser cavity. A special resonator auto-adjustment system with internal reference features the short-term radiation linewidth down to 3 MHz/s and long-term stability level of 150 MHz/hour without any external frequency stabilization systems. Explained are arrangements of original execution units included into the laser control system. The control system's features are discussed.

Keywords: CW dye laser, single-frequency, linewidth, smooth frequency scan

A single-frequency CW dye laser (SF-CW-DL) is a traditional source of a narrow-band smoothly wavelength-tuned radiation in the visible spectrum. An SF-CW-DL is widely used both directly as a radiation source in the spectroscopy of high and superhigh resolution of the visible and UV (on a doubling of radiation frequency) spectrum range, and as master oscillator whose narrow-band radiation of an assigned wavelength may intensify, e.g., in technological (laser isotope separation), astrophysical (creation of artificial guide stars [1]) and other powerful laser systems.

By now the greatest acceptance has been gained by ring SF-CW-DL which provide a higher level of output radiation power and a better stability of a single-frequency oscillation regime as compared to linear SF-CW-DL. The ring SF-CW-DL, however, are distinguished for a more complicated adjustment/maintenance, and with a low level of output radiation power (e.g., 50 – 150 mW) they require a more powerful pumping because of a relatively high oscillation threshold. A typical ring SF-CW-DL contains 22 optical surfaces (8 of which have reflective coatings), and its generation threshold on effective Rhodamine 6G or DCM dyes amounts to about 3 W in pumping with polarized radiation of all the blue-green lines of an Ar-laser.

The present paper reports the results of developing a linear SF-CW-DL rated at a relatively low radiation pumping power (3 W all B-G lines Ar-laser or 2 W CW DPSS-laser, 532 nm) and providing, at this pumping, under a stable single-frequency regime, an output radiation power of up to 150 mW, a smooth radiation frequency tuning in the range of 20 GHz, a short-term radiation linewidth of 3 MHz/s with a long-term frequency drift of no more than 150 MHz/hr without any external frequency stabilization systems.

The scheme of the designed linear SF-CW-DL is presented in fig. 1. The laser's radiation wavelength selectors are: a three-component birefringent filter (the thickness of the first plate is 0.45 μm, the ratio of the plate thicknesses is 1:4:13), a thin (0.5 mm) Fabry-Perot etalon (the surface reflection coefficient $R_{1,2} = 0.3$) optimized in accordance with the recommendations of [2], and a selective reflector which contains a thin metal film and the resonator's output mirror which are aligned parallel to each other.

The possibility of selection one longitudinal mode of the laser's linear resonator by means of a thin absorbing film (TAF), the thickness of which is far less than the length of the radiation wavelength (this possibility was first demonstrated in [3]), makes it equally possible to obtain an effective single-frequency oscillation regime both in continuously operated dye lasers [4, 5] and in lasers of other types [6]. Essentially, the method of selecting longitudinal modes of the laser's linear resonator with the help of a TAF fixed perpendicular to the resonator's axis is as follows. The nodal surfaces of different longitudinal modes in a linear resonator are shifted relative to one another along the resonator axis, so of maximum Q-factor are only the modes in which the electric field nodes coincide with the TAF surface. The correct selection of the ratio of the power absorbed by the film to the laser gain as well as of the distance from the film to the resonator's nearest mirror, of the film thickness and the set of preliminary selectors provides the formation of only one mode in the laser. The TAF is a much simpler selector than the thick Fabri-Perot interferometers consisting of two Littrow prisms and traditionally used at the last stage of single-frequency dye laser mode selection. In addition, the selective reflector from a TAF possesses a higher selectivity [5] as compared with the thick Fabri-Perot interferometer.
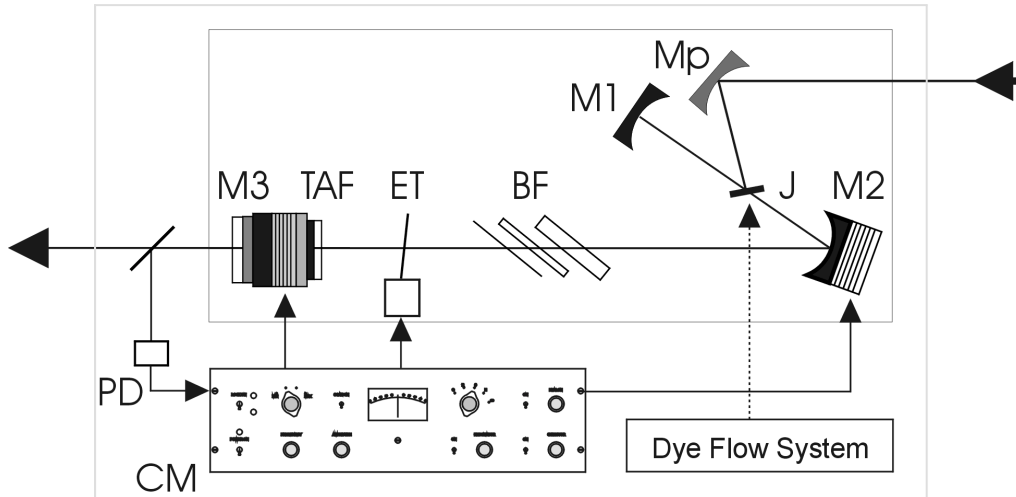
Figure 1. The optical scheme of the dye laser is a three-mirror resonator with astigmatism compensation and non-parallel pumping beam. **M3** is the coupling mirror, transmittance - 3-5%, flat; **M2** is the collimating mirror, curvature radius 50 mm; **M1** is the end mirror, curvature radius 50 mm, **Mp** is the pump mirror, curvature radius 50 mm, **J** - is the dye jet, **BF** - birefringent filter, **ET** - thin etalon, **TAF** – thin absorbing film, **PD** - photodiode with pre-amplifier, **CM** – control module.

The dispersion range of the selective reflector from a TAF is defined by the distance L between the TAF and the output mirror of the laser resonator. In order to effectively separate one longitudinal resonator mode the value of L must lie within the range of

$$4lh/\lambda < L < 2l(1 - 2h/\lambda),$$

where l is the distance from the dye solution jet to the resonator's end mirror defining the frequency interval between the modes that do not compete due to the spatial hole burning effect, λ is the radiation wavelength, h is the thickness of the absorbing film. The lower limit (0.3 cm in this instance) is defined by the condition according to which the distance between the nodes of the electric fields of the selected mode and those of the nearest noncompetitive mode must at least be greater than the thickness of the film at the point of its location. For $L = 2l$ the nodes of the electric fields of the two nearest noncompetitive modes coincide with the TAF surface, so the selection of one of the modes is impossible. At L = l the suppression of the modes not competing with the selected one because of the spatial hole effect becomes the strongest.

The design of the selective reflector from the TAF developed by the present authors (Fig. 2) provides the parallel arrangement of the laser's output mirror and of the TAF at the opposite end faces of a cylindrical monolithic block made of two quartz cylinders glued to the piezoelectric transducer on either side. The inner cavity of the block (between the surfaces of the output mirror and of the TAF) is isolated from dust and air flows, which, combined with the rigidity of the monolithic structure, provides an increased stability of the selective reflector's base. The distance between the output mirror and the TAF was chosen in the above range to meet the condition of sufficiently sharp reflection peaks of this selector and that of the design compactness and amounted to 2.7 cm (FSR = 5.5 GHz).

In order to maintain the single-frequency regime of the laser oscillation for a long time it is necessary to use a system of automatic adjustment of the TAF to the node of the selected mode's electric field or vice versa: of the latter to the former. We have used the latter method which at the same time, thanks to the rigid structure of the selective reflector, has permitted us to stabilize the laser's oscillation frequency as well. The base of the selective reflector is less subject to external perturbations than that of the laser resonator, so the selective reflector of the monolithic-block structure can also play the part of an internal reference device. The automatic adjustment system applied operates as follows: the base of the selective reflector is modulated with the aid of the PZT on a frequency of 1.3 kHz, the periodic deflection of the TAF from the electric field node of the selected mode leads to the modulation of the laser's output power (for the operation of the self-tuning to be stable the amplitude of this modulation may amount to 2 - 3%), but does not cause any change in the laser's oscillation frequency. The

Proc. SPIE, v. 4353 (2001), pp. 189-193, "Laser Optics 2000:
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photoreceiver registers the output power of the laser and gives an electrical signal which is proportional of laser output power to the synchronous detector with frequency of detecting 1.3 kHz. The signal from the synchronous detector amplifies and moves to the piezoelectric package of the collimating mirror so that to reduce amplitude of modulation of the laser output power at the 1.3 kHz frequency. Thus, the automatic adjustment of the single-frequency oscillation regime proceeds concurrently with the stabilization of the laser's oscillation frequency by means of the internal reference discriminator – monolithic-block selective reflector.
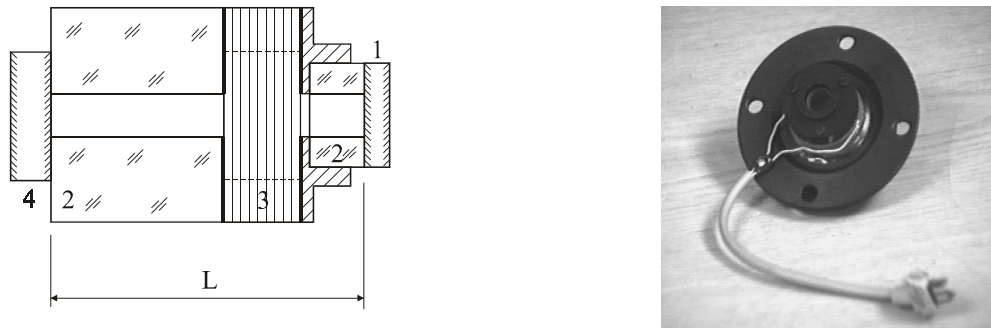

Figure 2. The structure of the designed selective reflector with a TAF. 1 – a TAF (deposed on the left-hand side of the quartz substrate is an aluminum coating with the transmission T = 65%, on the right-hand side – an anti-reflection coating), 2 – quartz cylinders, 3 – a PZT, 4 – an output mirror (deposited on the right-hand side of the quartz substrate is a dielectric coating with the transmission T = 5%, on the left-hand side – an anti-reflection coating), L – the reflector's selective base. The mounts of the output mirror and of the TAF to the monolithic block are not shown.

To measure the short-term instability of the oscillation frequency use was made of the optical heterodyning method involving two identical dye jet lasers. The radiation beams of the lasers were brought into spatial coincidence, the beatings of the lasers' frequencies were recorded by a fast-responding photodiode and by a spectrum frequency analyser CK4-56 with a view band of 0-100 MHz (Fig. 3). A typical width of the frequency beating spectrum of either laser was 8 – 10 MHz/sec FWHM which corresponds to either laser's short-term oscillation frequency instability of no more than 7 MHz/sec. In the perions of the minimum external perturbations the laser's oscillation frequency jitter amplitude per second was 3 – 5 MHz FWHM. The laser's long-term oscillation frequency drift was analyzed with the aid of a high-precision wavelength meter "Angström" to a measurement accuracy of 5×10^{-8} and with automatic temperature correction of the readings. The dye laser's oscillation frequency drift rate recorded by the oscillation wavelength meter did not exceed 150 MHz/hour, although the laser's actual frequency drift rate appears to be lower, because the radiation wavelength meter possesses its own drift of readings at a level of 50 – 100 MHz/hour.
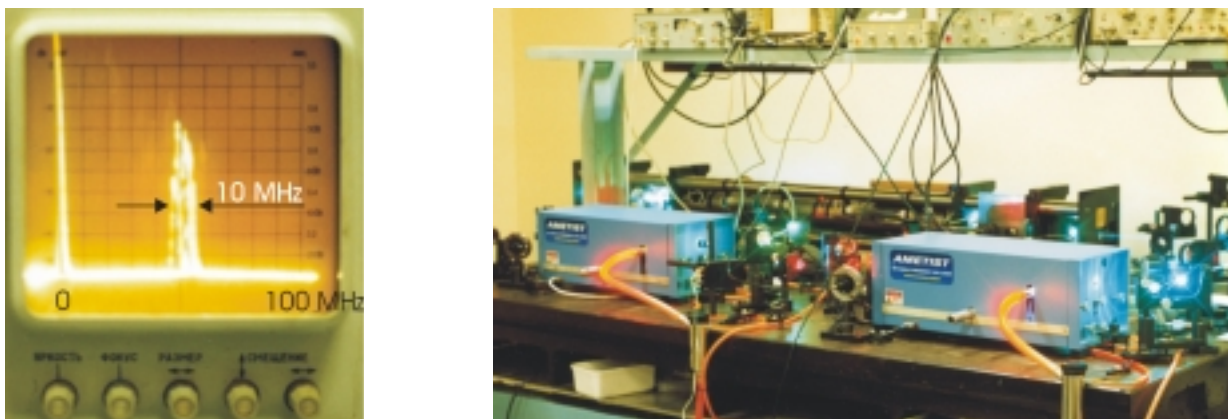

Figure 3. The outward appearance of the system which was used to measure the short-term oscillation frequency instability of the designed lasers by the method of optical frequency heterodyning. Shown from the left is the recorded spectrum of the lasers' frequency beatings (the scale of the X-axis of the frequency spectrum analyser's screen is 0 – 100 MHz)

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The smooth scanning of the analyser's oscillation frequency is performed by changing the selective reflector's base followed by tuning the laser's resonator with the aid of the PZT-controlled collimmating mirror. For a fixed position of the thin etalon the range of the smooth tuning of the laser's oscillation frequency does not exceed 5 GHz. When the range of the smooth frequency tuning broadened to 20 GHz, we performed the synchronous scanning of the thin etalon using a special electro-mechanical drive and the multipiezodrive (four nine-layer PZTs) of the collimating mirror. To linearize the dependence of tuning the peak of the thin etalon transmission according to frequency on the voltage that controls the electrome-chanical drive, use was made of an analog electronic scheme extracting the square root of the input voltage and operating the drive with the thus obtained signal. This linearization allowed the thin etalon to be scanned concurrently with the selective reflector without using an additional feedback loop of automatic adjustment; the rates of tuning these selectors were synchronized by calculating and selecting the appropriate ratio of controlling voltages (a total amplitude of the voltage across the PZT package equal to 570 V). The maximum range of the smooth oscillation frequency tuning ran up to 21.01GHz (cf. Fig. 4), the maximum smooth tuning rate, to 20 GHz/sec.
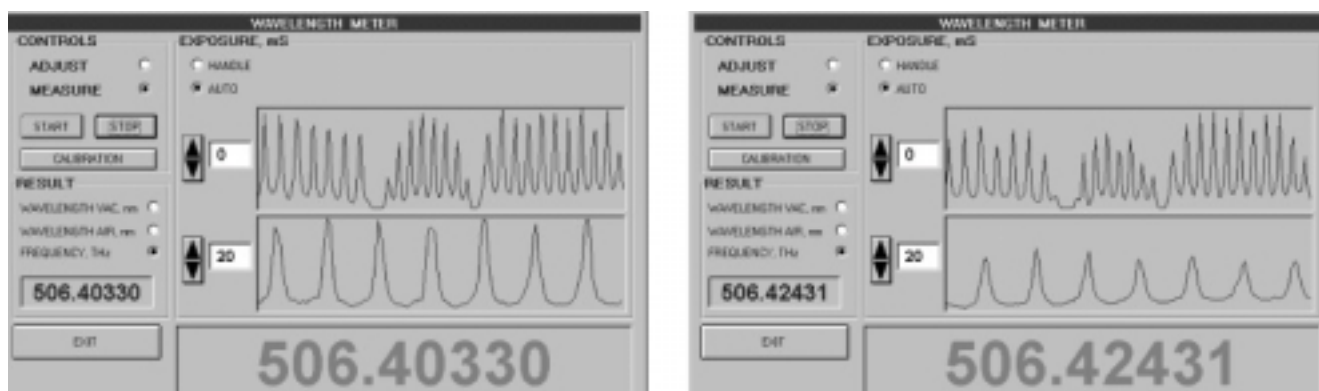

Figure 4. The frequency of the SF-CW-DL radiation in the beginning and in the end of the smooth scanning range - the difference of frequencies in the beginning and in the end of range is 21.01 GHz.

Note that the application of the multipiezoactuator of the collimating mirror for the smooth tuning of the SF-CW-DL's oscillation frequency within a wide range makes it possible to get rid of a number of problems [7] typical of the scanning Brewster plate commonly used for tuning the length of the laser resonator.

The oscillation threshold of the designed SF-CW-DL was no higher than 1 W on the dyes Rhodamine 19 and Rhodamine 6G on pumping by the polarized radiation of all the lines of an Ar-laser. The low oscillation threshold is due to the application of high-quality mirrors (the total radiation losses on a resonator's mirror do not exceed 0.15%) and to small nonselec-tive losses introduced by the birefringent filter, the thin Fabry-Perot etalon and the selective reflector. The birefringent filter and the selective reflector are adjusted by a special technique precluding an incomplete adjustment of these selective elements, i.e. an incomplete speectral coincidence of the peaks of transmitting various plates of the 3-plate birefringent filter or the nonparallelism of the output mirror's working surfaces and of the selective reflector's TAF.

The output power of the designed SF-CW-DL is restricted by the level of 150 – 200 mW above which the absorbing film may be damaged (burnt-out) in the procedures of the laser's adjustments brining about a nonsingle-frequency oscillation regime and, accordingly, a considerable absorption of radiation not selected by the film. At a 100-mW output radiation power of a SF-CW-DL the aluminum films we use can operate for an unlimited time in any procedures of the laser adjust-ment. The pump radiation power required for a Rhodamine 19 dye laser and a Rhodamine 6G dye one at this output radia-tion power amounts to 2.4 and 2.6 W, respectively (all the Ar-laser lines)

ACKNOWLEDGEMENTS

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