Multiple-prism grating solid-state dye laser oscillator: optimized architecture

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A multiple-prism grating solid-state dye laser oscillator was demonstrated with its grating, deployed in a Littrow configuration, under total illumination at reduced intracavity beam expansion. This compact cavity yields laser linewidths in the 350-MHz range and smooth temporal pulses with a near-Gaussian profile. © 1999 Optical Society of America

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Dispersive solid-state dye laser oscillators have been shown to lase in the single-longitudinal-mode regime at linewidths in the $375 \leq \Delta\nu \leq 700$ MHz range[1,2] at half-width. Characteristic of this emission are temporal pulses with a near-Gaussian profile and duration in the 3–6-ns regime at full-width at half maximum (FWHM). One of the emphases of oscillator cavity design has been simplicity and compactness. In this regard multiple-prism beam expanders have been limited to double-prism architectures, and cavity lengths have been confined to the 55–80-mm range.

One important goal in this research is to achieve maximum dispersion from the diffraction grating while minimizing the number of optical elements deployed in the cavity. Traditional use of gratings in a Littrow configuration, in narrow-linewidth oscillators, demands large intracavity beam expansions,[3] which, in turn, imply the use of two or more prisms with a sufficiently large exit prism to enable total grating illumination. An advance in this regard was the demonstration of a compact oscillator[1] employing a double-prism expander that illuminated ~50% of the available diffraction grating grooves. The compactness of this multiple-prism Littrow (MPL) grating oscillator made it possible to attain single-longitudinal-mode lasing at $\Delta\nu \leq 700$ MHz.

Certainly an alternative approach to achieving total illumination of the grating is to deploy it at grazing-incidence or near-grazing-incidence angles. Deployment at grazing-incidence angles eliminates the use of beam expansion. However, it implies larger intracavity losses, and hence lower conversion efficiencies, if a closed cavity configuration is desired.[2,3] In a closed cavity configuration the laser beam exits the cavity via the output coupler. This reduces the amount of amplified spontaneous emission (ASE) and minimizes optical coupling effects with elements external to the cavity.[3] Higher conversion efficiencies can be achieved in closed cavities by use of diffraction gratings at near-grazing-incidence and intracavity beam expansion. With a hybrid multiple-prism near-grazing-incidence (HMPGI) grating solid-state dye laser oscillator,[2] 3–4% conversion efficiencies were achieved at $\Delta\nu \approx 375$ MHz.

Our aim in these experiments was to explore the possibility of achieving total grating illumination and a linewidth performance similar to that of the HMPGI grating cavity in a simpler oscillator architecture. An alternative to achieving this goal is to employ a small double-prism expander and a single grating, deployed for total illumination, in a Littrow configuration. Thus full grating illumination can be achieved in a compact configuration without need of a tuning mirror as required in the HMPGI grating cavity. The MPL grating oscillator architecture selected to fulfill these requirements is shown in Fig. 1.

In this experiment the excitation laser and the longitudinal excitation geometry are identical to those used in previous experiments.[1,2,4] Briefly, the pump laser delivered nearly 2 mJ at 525 nm in a highly polarized beam parallel to the plane of propagation. The gain medium was a rhodamine 6G dye-doped modified poly(methyl methacrylate) matrix[4–7] config-

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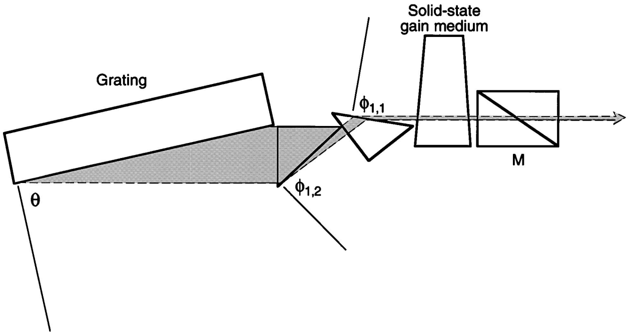

Fig. 1. Schematic of the solid-state MPL grating dye-laser oscillator. This figure presents a fairly accurate description of the optimized architecture with each optical component drawn to scale. The angle of incidence at the 3300-l/mm Littrow grating is $\theta \approx 77°$.

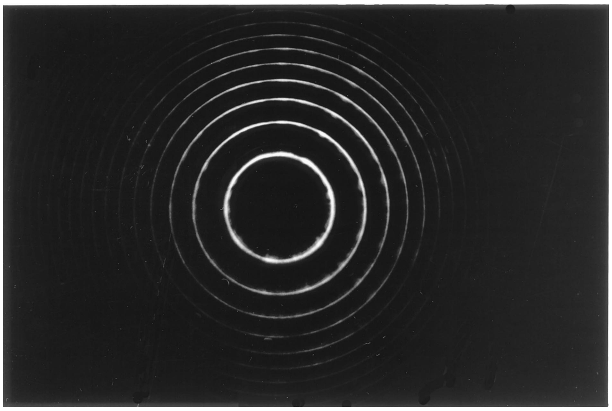

Fig. 2. Fabry–Perot interferogram of the single-longitudinal-mode emission. Here the FSR of the interferometer is 7.49 GHz.

ured in a trapezoidal geometry to eliminate parasitic internal reflections.[8] The windows sustain a 4.3° angle relative to the optical axis and are polished to better than $\lambda/4$. The incident energy density was limited to $\sim$0.7 J/cm^2 to avoid dye bleaching of the dye-doped modified poly(methyl methacrylate) matrix. The concentration of the dye is 0.5 mM. Optical homogeneity, lifetime issues, and other material properties of this gain medium are discussed in detail elsewhere.[4–7] Experiments were performed at a pulse repetition frequency of $\sim$1 Hz.

The solid-state MPL grating dye-laser oscillator is illustrated in Fig. 1. The output coupler mirror is a Glan–Thompson polarizer with an extinction ratio of 5×10^{-5} with its surface toward the gain medium antireflection coated and its output surface coated with a 20% reflectivity. The two prisms that make up the intracavity beam expander are made of fused silica with an apex angle of 42.7° and a hypotenuse of 15 mm. These prisms are deployed in a compensating configuration to reduce significantly their contribution to the overall intracavity dispersion and hence to allow for the frequency characteristics of the oscillator to be determined solely by the diffraction grating. The multiple-prism expander was configured to yield a total intracavity beam expansion of $M \approx 44$. For beam-waist dimensions, at the gain region, of $2w \approx 250$ μm this beam-expansion factor ensures that the second prism provides nearly maximum intracavity expansion. The expanded beam illuminating the diffraction grating has dimensions of $M2w \approx$ 11 mm.

The holographic diffraction grating used in these experiments has 3300 l/mm and is 50 mm wide. At $\lambda \approx 590$ nm the angle of incidence on the grating is $\sim$77°, and its diffractive surface is completely illuminated by the 11-mm-wide intracavity beam. The overall physical cavity length was $\sim$75 mm.

The detection system has been described in detail previously,[1,2,4] and it is composed of a Hamamatsu biplanar phototube (Model R1193U), a Gentec Model ED-200 Joule detector, a Tektronix Model 7834 storage oscilloscope, and a Tektronix Model SCD-1000 transient digitizer with a rise time of $\leq$350 ps. Laser linewidths were monitored with a Burleigh Model RC110 Fabry–Perot interferometer with a free spectral range (FSR) of 7.49 GHz and a finesse of $\geq$30. Interferograms and laser beam profiles were recorded photographically. Tuning ranges and ASE measurements were performed with a Spex Model 1681 spectrometer.

Results are given in Table 1. The laser beam was observed to have an elongated smooth TEM$_{00}$ profile that closely resembles those observed previously.[1,2] The beam divergence was estimated to be 2.2 mrad. A detailed study of beam propagation and beam divergence in this class of dispersive oscillators, by use of ray matrices, has been given elsewhere.[4] A typical interferogram showing a series of single rings, characteristic of single-longitudinal-mode emission, is shown in Fig. 2. The laser linewidth calculated from numerous interferograms was determined to be $\Delta\nu = 350 \pm 60$ MHz. The temporal emission is characterized by smooth near-Gaussian temporal pulses with a duration of 3 ns (FWHM) as shown in Fig. 3. This further corroborates the nature of the emission as being single longitudinal mode, since double-mode emission gives rise to interference between the two intracavity modes and hence to temporal mode beating.[8] The tuning range was determined to be 550–603 nm and the ASE level to be $\sim 10.^{-6}$

At first glance several of the performance parameters of this laser oscillator are rather similar to those

Table 1. Performance of Optimized Multiple-Prism Grating Solid-State Dye Laser Oscillator

Cavity	$\Delta\nu$ (MHz)	$\Delta\theta$ (mrad)	Δt (ns)	Tuning Range (nm)	Efficiency (%)	ASE Level
MPL	350	2.2	3	550–603	$\sim$5	$\sim 10^{-6}$

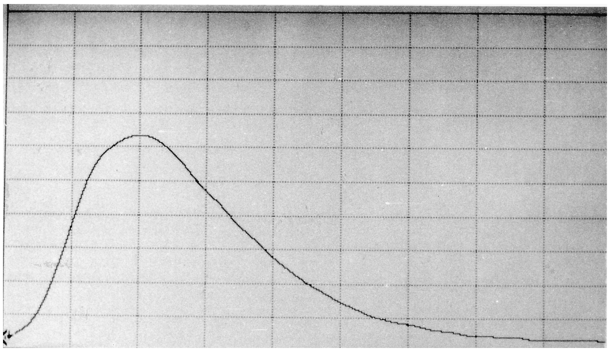

Fig. 3. Smooth near-Gaussian temporal profile typical of the emission of this MPL grating solid-state dye laser oscillator. The temporal scale is 1 ns/div.

reported for a MPL grating oscillator with a 3000-l/mm grating.[1] This similarity concerns conversion efficiency, beam divergence, pulse duration, and ASE level. This is to be expected, since the cavity architecture is basically the same except for the complete illumination of the higher-density groove grating. In addition, the excitation beam characteristics were reproduced as closely as possible relative to those in the first experiment. The main difference in performance between this dispersive laser oscillator and its predecessor[1] is found in a blue-shifted tuning range and narrower laser linewidths. Both of these characteristics are due to the higher-density diffraction grating. In the case of the tuning range it should be indicated that at $\lambda \approx 606$ nm, where the previous grating performs rather well, the present grating ceases to diffract. With regard to laser linewidth it is evident that the overall double-pass intracavity dispersion $M(\partial\theta/\partial\lambda)_G$ with the 3300-l/mm grating increases by a factor of 2.23 relative to the dispersion achieved with the lower-density grating. The dispersive linewidth equation is given by[3]

$$\Delta\lambda_D = \Delta\theta[RM(\partial\theta/\partial\lambda)_G + R(\partial\phi/\partial\lambda)_P]^{-1}, \qquad (1)$$

where R is the number of intracavity passes and $(\partial\phi/\partial\lambda)_P$ is the contribution to dispersion from the multiple-prism expander that in this case is negligible, since a compensating configuration is employed. From Eq. (1) it can be determined that for a single double pass ($R = 1$) the dispersive linewidth is $\Delta\nu_D \approx$ 2.99 GHz. It was previously estimated[1] in this class of oscillators that $R \approx 7$. For an optical cavity length of 92.5 mm the FSR of the cavity is FSR $\approx$ 1.62 GHz, and it is easy to see that multiple intracavity passes can readily reduce the oscillation to a single longitudinal mode.

Therefore it can be concluded that, relative to the previous MPL grating oscillator, the present architecture yields comparable efficiencies for similar beam and temporal characteristics at a significant improvement in laser linewidth. Relative to the HMPGI grating oscillator, single-longitudinal-mode laser linewidths are rather similar, but there is a marginal increase in efficiency while the complexity of the cavity is reduced by elimination of the tuning mirror. Hence, as far as narrow-linewidth solid-state dye laser oscillators are concerned, the present design offers the best reported performance to date with a simple and compact dispersive cavity architecture.

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