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Single mode operation of a narrow bandwidth dye laser using a single prism, grazing incidence grating long cavity

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Abstract

The single mode pulsed dye laser is an attractive tool for many spectroscopic applications. Long cavity tunable dye lasers generally operate in multi-longitudinal modes within the bandwidth of gain profile. Single longitudinal mode oscillation can be obtained by either making the cavity short enough or introducing an additional loss mechanism, in which all modes but one have a gain less than their loss. A new technique to achieve single mode operation in a long cavity dye laser, based on Rhodamine 6G dye in ethanol and ethylene glycol solution, pumped by a high repetition rate copper vapor laser, is reported. This laser, which operates in three modes in grazing incidence grating configuration (cavity length of 16 cm), has been made to lase in single mode by increasing the loss in the resonator through beam walk-off.

Keywords: Single longitudinal mode; Dye laser; Beam walk-off

1. Introduction

Single mode narrow bandwidth pulsed dye lasers are widely used in high-resolution optical spectroscopy [1] as well as in the efficient optical pumping of the excited species, where the spectral lines are very close to each other. Narrow bandwidth dye lasers have been realized in Littrow, multiple prism Littrow (MPL), grazing incidence grating (GIG), multiple prism grazing incidence grating (MPGIG), or hybrid multiple prism grazing incidence grating (HMPGIG) dispersive cavities [2], which usually operate with a number of axial modes. A number of approaches to demonstrate a tunable narrow band pulsed single mode dye laser have been reported, such as pulse amplification of cw single mode [3], external filtering of a multimode laser oscillator [4], a very short cavity oscillator incorporating frequency selective elements [5], etc. Various authors [5–10] have reported the single mode operation of pulsed dye lasers using different techniques such as the usage of intra-cavity etalons [11,12], modified interferometers [13], and short cavities [5], etc. Single mode operation by using an intra-cavity etalon can be achieved by varying the optical path length of the etalon (by adjusting its tilt or temperature) such that one of its transmission maxima coincides with the desired mode and no other transmission maximum falls in the gain bandwidth. The later condition requires that the free spectral range (FSR) of the etalon should be greater than half the gain bandwidth if the desired mode coincides with the center frequency, or in general, greater than the gain bandwidth. This requires precise selection of the FSR and finesse of the etalon to force the lasing in single mode. One way to ensure single mode operation is to use a short resonator length such that the axial spacing ($c/2l$) be greater than the gain bandwidth of the transition. But in practice it is very difficult to minimize the resonator length below a certain limit determined by the component sizes. It is a common practice to use a long cavity and to introduce additional optics (to suppress all modes except one below the loss line) to get single mode. Another approach to ensure single longitudinal mode operation is to increase the effective gain of the desired mode by injecting radiation seed at that mode so that it builds up faster and dominates. However, the power needed to lase a particular mode will increase rapidly as the desired mode moves farther from the line

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center. Further, the injected radiation must be an allowed mode of the resonator, which requires a careful control of the resonator length. An important factor responsible for multimode or single mode is gain/loss line within the gain profile. Laser oscillation on a single mode can be achieved if the losses for all but the desired mode are increased to such an extent that they do not reach oscillation threshold. All these approaches have their own technological challenges.

In this paper, a very simple and novel approach to obtain the single mode operation of a narrow bandwidth dye laser without using any additional optics or modifications in single prism GIG long cavity by introducing losses in the resonator through beam walk-off, is reported.

2. Experimental details

Fig. 1 shows the schematic diagram of the dye laser oscillator. The dye laser is based on the Littman and Metcalf [14] and Duarte and Piper [15] scheme, which makes use of a single diffraction grating used in grazing incidence to provide wavelength selectivity. The construction and design of the dye laser was such that external factors like mechanical vibration do not significantly affect the output characteristics [16]. The cavity consists of an output coupler mirror (20% reflectivity), a dye cell, a single prism beam expander (magnification ~8), and a grating (2400 lines/mm) in grazing incidence with a tuning mirror. The tuning mirror is rotated about an axis perpendicular to the plane of incidence to tune the dye laser. The overall cavity length was 16 cm. Rhodamine 6G (1.0 mM) dye in 30% ethanol and 70% ethylene glycol was flown through the dye cell. The flow was so rapid that the dye molecules irradiated by a pump laser pulse are replaced 2–3 times before arrival of the next pumping pulse. This was done using a dye circulation system. The Reynolds number of the flow of the dye solution was 736. A copper vapor laser ($\lambda = 510.6$ nm, 5 W, 5.6 kHz, plane parallel resonator) was used as pump source. The pump beam was transversely line focused onto the dye cell through a cylindrical lens of 6 cm focal length. The longitudinal modes of the output of the dye laser were analyzed using a Fabry–Perot etalon-based set-up as shown in Fig. 2. This figure shows the optical arrangement for producing the Fabry–Perot interference (FPI) fringes of the dye laser. A beam expander and a scatterer make the beam diverging and uniformly illuminate the etalon having 5 GHz FSR and a finesse ~25. A plano-convex lens of 20 cm focal length was used to image the fringe pattern onto a CCD camera connected to a frame grabber card inside a computer.

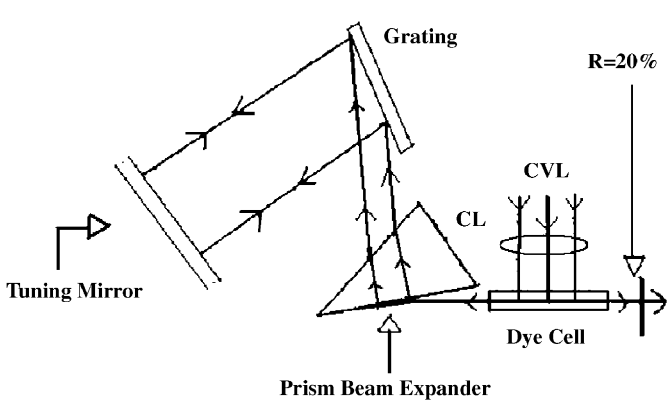

Fig. 1. The schematic diagram of the dye laser cavity.

3. Results and discussion

The GIG configuration with prism beam expander gives a narrow bandwidth output. However, single axial mode operation requires a very short cavity length of only a few centimeters. In practice it is difficult to minimize the resonator length below a certain limit due to the size of the individual components. In a GIG and beam expander cavity, all axial modes of spacing ($c/2l$) with gain exceeding the loss will oscillate. By increasing the resonator losses, the number of axial modes for which gain exceeds losses can be reduced. This principle has been used from a long time in single mode operation of dye lasers.

Shoshan et al. [17] have used a 100% reflecting mirror at one end of the cavity, grating in grazing incidence, and tuning mirror at the other end. The laser output was taken directly from the grating in the form of the zero-order beam and they have achieved narrow linewidth of 2.4 GHz. In this case, as the output was taken from the grating zero-order, it contains a large fraction of amplified spontaneous emission (ASE). ASE has several undesirable effects on the performance of a narrow band pulsed dye laser [18] like reduction of the laser efficiency, restriction of the tuning range, and formation of a broad band spectral background superimposed on the narrow band laser output. Littman and Metcalf [14] have used partially reflecting output mirror, grating in grazing incidence with tuning mirror and have achieved linewidth of 1.25 GHz. Littman [19] has used another grating in Littrow configuration in place of tuning mirror and achieved a single mode linewidth of 750 MHz.

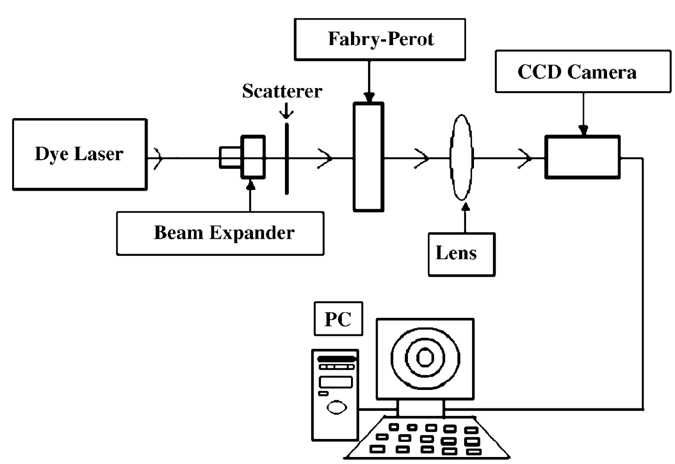

Fig. 2. Optical arrangement for producing and analyzing the FPI fringe pattern of the dye laser.