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Effect of pump beam resonator on the performance of narrow line-width Rhodamine 110 dye laser

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ABSTRACT

This paper presents a study on the effect of pump beam resonator on the performance of Rhodamine 110 dye laser. The pump beams were from copper vapor laser (CVL) with different resonators such as plane–plane and an unstable resonator of same average power of 5.0 W. For a particular pump beam, the dye laser beam power, line-width, divergence, pulse shape and dye gain medium size were measured. The dye laser wavelength stability and pointing stability were also studied for both the pump beams. It is shown that the dye laser beam properties significantly depend on the pump laser resonator configuration. The unstable resonator CVL pumped dye laser produced better line-width (3.6 GHz vs 6 GHz), divergence (9 mrad vs 16 mrad) and power (510 mW vs 410 mW) as compared to that pumped with plane–plane resonator CVL. These differences are attributed to larger pump beam flux and consequently larger dye gain medium size characteristics for unstable resonator CVL pump beam due to its better divergence characteristics as compared to plane–plane resonator CVL. Better wavelength stability of dye laser obtained from unstable resonator CVL pump beam was explained due to its better pointing stability as compared to plane–plane resonator pump beam.

1. Introduction

It is widely understood that in a dye laser, the role of pump beam is to define the dye active gain medium, decide dye laser gain and hence the dye laser power. The relevant pump beam parameters are the laser power, divergence and the focused intensity. These are the attributes of the pump beam optical resonator. On the other hand, the other relevant characteristics of dye laser such as line-width, divergence, pointing and wavelength stability are considered to be solely the attributes of dye laser resonator. However, in a recent study [1], on CVL pumped dye laser, it was demonstrated that for a fixed CVL and dye laser resonators, the pump CVL power not only influenced the dye laser power but also the divergence, pointing, line-width and wavelength stability of the dye laser oscillator. In this study, the CVL pump power was varied externally to the resonator, hence the different average power CVL beams pumping the dye laser, were exactly identical in beam profile, divergence and pointing stability. It would also be very interesting to investigate the dye laser performance with two CVL pump beams of same average power but with different beam divergence, pointing stability and focused intensity characteristics. These differing CVL pump beams can be generated with two different class of resonators namely plane–plane and unstable resonators [2]. It is worth mentioning here that though numerous literatures are available in CVL pumped dye laser [3,4] but at a time using either a plane–plane or an unstable pump beam optical resonator. However in the past, it has been hinted in a few scattered studies [5–8] that in a dye laser the role of pump beam is not confined to decide the dye laser power. In particular, in a streak camera time resolved study within a dye laser pulse, it was demonstrated [5] that intra-pulse variation of dye laser line-width and divergence depend on the pump beam divergence characteristics. Also in an axially pumped dye laser by frequency doubled Nd:YAG laser [6], a close linking between the spatial quality of dye and pump laser was observed. In an another study on N_2 laser pumped superradiant dye laser (with no optical resonator) [7], the measured spatial coherence of dye laser ASE beam was found to depend on the relative position of the pump beam focusing cylindrical lens with respect to dye cell. It is also expected that any pulse to pulse pump beam fluctuation either in intensity, divergence or angular direction (jitter) will lead to path length fluctuation in the dye laser cavity and thereby adversely affects the dye laser wavelength stability [1,8]. These studies are very important for the wide applicability of dye lasers in high resolution spectroscopy, isotope separation industry and medical fields such as skin treatments, port-wine stain/tattoo removal, lithotripsy, angioplasty and photodynamic therapy [9,10].

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This paper presents a study on the effect of pump beam resonator on the performance of Rhodamine 110 dye laser. The CVL pump beams from a plane–plane and an unstable resonator of magnification 100, with same average power of 5.0 W, but with different beam divergence, pointing stability and focused intensity characteristics, were used to pump a narrow line-width dye laser oscillator. The dye laser employed a hybrid multiple prism grazing incidence grating (HMPGIG) resonator. It is shown that the dye laser beam properties significantly depend on the pump laser resonator configuration. The unstable resonator CVL pumped dye laser produced better line-width, divergence, power and wavelength stability characteristics as compared to that pumped with plane–plane resonator CVL. These differences are attributed to better divergence and flux of unstable resonator CVL. The differing trends are explained in terms of change in dye gain medium size and hence dye laser divergence. Better wavelength stability of dye laser was obtained from unstable resonator CVL pump beam due to its better pointing stability as compared to plane–plane resonator pump beam.

2. Experimental details

Fig. 1 shows the scheme of the experimental setup of a CVL pumped dye laser to measure the dye laser beam characteristics with two different pump beam quality. The CVL oscillator (repetition rate ~5.5 KHz) consists of a 28 mm diameter copper vapor laser CVL with mirrors M_1 and M_2 forming the resonator. For confocal positive branch unstable resonator (PBUR, $M=100$) the output was taken from scrapper mirror SC, while in plane–plane resonator (PP) it was taken through the mirror M_2. Both CVL and CVL pumped dye laser are home made. The detailed procedure for measurement of CVL divergence and pointing stability is mentioned in Ref. [11]. The CVL operated in two resonator configurations namely plane–plane resonator and positive branch unstable resonator (magnification 100) are designated as PPR-CVL and PBUR-CVL, respectively. The beam divergence and pointing stability (PS) of PPR-CVL are 3 mrad and 110 μrad and that of PBUR-CVL are 0.12 mrad and 22 μrad, respectively [11]. The pump power of both the beams was 5.0 W. The dye laser mode properties were studied for PPR-CVL and PBUR-CVL pump beams separately. A cylindrical lens of focal length 75 mm focused pump beam on the dye cell. The dye cell used here was a glass dye cell of constricted region gap 0.7 mm. The dye laser resonator consisted of double prism beam expander (magnification ≈20), a grating (2400 lines/mm) in grazing incidence, a broadband tuning mirror, a dye cell and an output coupler of 4% reflectivity. The overall cavity length was 18 cm. 1 mM solution of Rhodamine 110 dye in ethanol was flown through the dye cell. The dye cell was set at 5° with regard to the optical axis to avoid multiple-reflection of the laser beam between the inner surfaces of the cell. The flow rate of the dye solution was controlled by variable frequency drive (VFD) controlling the dye circulation pump. The flow rate was measured by a flow meter (turbine type, Electronet Equipment, FL-100). Temperature of dye medium solution was controlled within (±0.1 °C) using a thermoelectric cooling system [12]. The dye flow rate was fixed at 1.8 l/min. This corresponded to the dye solution flow velocity of about 3 m/s. For this flow velocity, the clearing ratio was in the range 2–3, which is sufficient for heat removal from dye gain medium. The first order diffracted beam was fed back into dye gain medium by a broad band reflecting mirror. The dye laser beam was taken out through the transmission of output coupler.

The dye laser power, beam divergence, pulse shape, pointing stability and wavelength stability were measured when the oscillator was pumped by CVL beams of two different CVL resonators, i.e. plane–plane (PPR) and positive branch unstable resonator (PBUR). While changing the pump beam, the dye laser components were kept intact. The line-width of the dye laser was measured by using a solid F P. etalon of FSR 20 GHz and finesse 25. The fringe pattern obtained by the etalon was imaged on the entrance slit of a CCD camera connected to a frame grabber card inside a computer. The dye oscillator wavelength stability was studied by the wave meter (WS-7, Angstrom, High finesse) at the rate of 30 Hz in pulsed mode [13,14]. Laser radiation was guided into wave-meter through the optical fiber. The dye laser power was measured with a power meter (Gentec, PS- 310 WB). The pulse shapes were recorded by bi-planner photodiode. For dye laser far field measurement and pointing stability, a part of dye laser beam was focused by a lens of focal length 75 cm placed at a distance of 92 cm from the dye laser output coupler. The lens focused the dye laser output beam at a distance of ~290 cm. An aperture was placed at the focal plane of this lens, which removes the ASE component. Another lens of focal length 25 cm re-imaged this ASE, removed focal spot, and suitably magnified at the CCD head, as a scheme reported earlier [1]. The spatial profile at the far field spot of lens was recorded with the help of a visible CCD camera (Pixel fly qe, pixel size 6.45 μm) and analyzed by in-house developed software [15]. Suitable combination of neutral density (ND) filters was used to attenuate the beam intensity below the saturation of CCD. In each case, the dye laser beam was geometrically diverging. The spot sizes were measured using knife-edge method.

In order to measure the dye gain medium width, all optical components except cylindrical lens was removed from the dye laser. This gain width was magnified around 8 times with a lens of

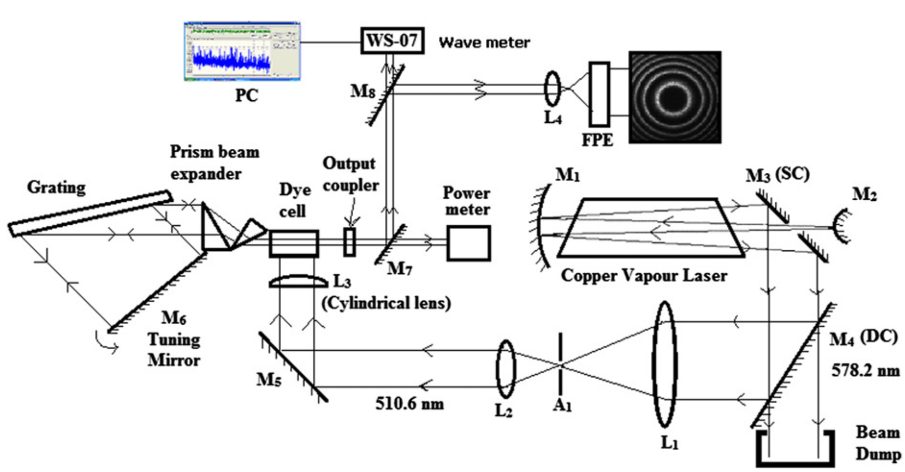

Fig. 1. Experimental setup of CVL pumped dye laser.