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Studies on 20 kHz pulse repetition rate class narrow line-width dye laser

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ABSTRACT

This paper presents a first comprehensive study on 20 kHz pulse repetition rate (PRR) class dye laser with an emphasis to bring out the role of dye solution flow rate on the laser power, line-width, wavelength stability and pulse characteristics of a narrow line-width dye laser. The study was performed for Rh6G–ethanol dye solution for flow rates from 2 to 12 lpm. The dye laser based on glass dye cell and the pump source was copper hydrogen bromide (Cu–HBr) laser at a fixed average power of 8 W and repetition rate of 18 kHz. The dye laser resonator was grazing incidence grating (GIG) cavity with double prism beam expander. A high precision wavelength-meter was used to record the online variation in dye laser line-width and wavelength. It is established that the dye solution flow rate significantly affected the dye laser performance. The best dye laser spectral purity was obtained at 3–4 lpm flow rate regime. The line-width and wavelength stability worsened both below and above the flow rates of 3–4 lpm. The best dye laser output power was obtained at 9 lpm flow rate and it decreased only slightly as flow rate is increased to 12 lpm. The dye solution flow rate also affected the dye laser pulse shape and width.

1. Introduction

The narrow line-width dye laser with pulse repetition rate (PRR) of tenths of kHz is recognized to be optimum [1,2] for atomic vapor laser based isotope separation (AVLIS). This is guided by maximum interaction of evaporated atomic vapor, moving with a finite velocity in interaction zone, with two/three wavelength dye laser radiations for selective excitation/photo-ionization. In general, for other applications of dye laser also, e.g. holography [3], medical [4], high repetition rate leads to faster process speed and data collection. The dye laser of PRRs from 4 to 8 kHz, pumped by standard copper vapor laser (CVL), had been very extensively studied [5–14]. This limitation on dye laser repetition rate was due to narrow PRR range of 5–6 kHz for efficient CVL operation [1]. In order to achieve the required repetition rate of 10 s kHz, electronic and optical multiplexing of several CVL output beams were carried out [15]. This required a complicated scheme of optical and electronic arrangements. For dye laser pumping, a maximum of 26 kHz PRR CVL [15] beams was generated by multiplexing; however, no dye laser performance at such high PRR is reported. With the advent of advanced CVLs (ACVLs) based on additives in copper gain medium, namely Cu–HBr laser [16,17], Cu–HCl laser [18] and $CuBr–H_2$ laser [19] as well as high repetition rate solid state lasers, it became possible to obtain the PRR in the range of 15–25 kHz with optimized performance from a single laser system. However, the studies of dye laser oscillator with these higher PRR ACVLs are only a few [4,20,21] that too in complicated dye jet geometry with laser dye dissolved in ethylene glycol as flowing gain medium. In particular, 20 kHz PRR CuBr laser pumped Kiton red dye laser was investigated in broad band geometry (no dispersive element in the cavity) with emphasis on study dye laser efficiency vs pump power, dye concentration and output coupling [4]. In another experiment, 16.6 kHz CuBr laser pumped Rh6G (R590) was studied for efficient broad band operation as well as for wavelength tunability by replacing one of the cavity mirrors by a grating operating in Littrow mode [21]. Similarly, high efficiency dye laser at 628 nm was investigated for different laser dyes, Rh640, KR620, Rh 610 and CV 670 at 22 kHz PRR [4]. All these jet dye laser studies [4,20–22] were performed at a fixed dye solution flow rate. In general, the free flowing dye jet setup is very complex in view of stringent demand on optical quality of jet and requirement of higher capacity flow pumps to push the highly viscous ethylene glycol solvent with high speed through narrow dye jet slit. It is understandable that 10 s of kHz PRR dye laser based on conventional closed loop glass dye cell as well as with most commonly used ethanol dye solvent will be very user friendly, economical and reliable. However, in such geometry two issues have to be paid attention and tackled. First is the heating of dye solution due to high PRR pumping. It is well known that the dye medium heating produces a temperature/refractive index gradient in direction of pump beam. This in turn leads to non-uniformity and optical distortion in the dye gain medium [23], thereby adversely affecting dye laser performance. Secondly, this detrimental thermal effect can be minimized by fast transverse flow of the dye solution. However high repetition rate dye lasers require very high velocity

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solution flow which leads to turbulence in the gain medium. This in turn leads to generation of vortices/eddies [23] and hence random refractive index variation affecting both dye laser power and spectral purity. The present study focuses on elucidating the role of dye solution flow on high repetition rate dye laser performance with a conventional dye cell and ethanol solvent.

This paper presents a first comprehensive study on 18 kHz pulse repetition rate, dye laser oscillator characteristics, namely real time study of dye laser line-width and wavelength variation, output power and pulse shapes in different regimes of dye solvent flow rates from 2 to 12 lpm. The study was performed for Rh6G dye solution in ethanol, flowing in a closed dye cell with a constricted region, pumped by 18 kHz advanced Cu–HBr laser [17] of fixed average power of 8 W. The narrow line-width dye oscillator was an intra-cavity double prism beam expander based grazing incidence grating (GIG) optical resonator. A precision wavelength meter (Angstrom WS-7) was used for such study. The stability of dye laser line-width and wavelength was relatively much poorer at 2 lpm flow rate. The stability improved till the flow rate of 4 lpm. Beyond the flow rate of 4 lpm and up to 12 lpm, the bandwidth and its variation as well as the wavelength stability again worsened in an increasing fashion. In contrast, the dye laser power followed different trends. The dye laser output power continuously rose with flow rate up to 9 lpm to 630 mW and then slightly decreased to 590 mW at maximum achieved flow rate of 12 lpm. The dye laser pulse shape and width also changed significantly with change in dye solution flow rate.

2. Experimental set-up

Fig. 1(a) shows the experimental set-up of 18 kHz PRR Cu–HBr laser pumped dye laser oscillator system. All the sub-systems used in experiment, namely the pump laser, dye cell and dye flow system, were developed indigenously. The cemented dye cell was made of high quality BK-7 optical glass with optical flatness better than λ/10. The cross-sectional area at the pumped region in the dye-cell was reduced to obtain higher flow speed. The flat dye cell flow region was of dimension 15 mm (width) × 10 mm (height) × 0.7 mm (gap). A 1 mM concentration dye solution made of laser grade Rhodamine 6G dyes in ethanol was circulated by a high flow rate dye circulation system. Fig. 1b shows the schematic of closed loop dye solution circulation system. The dye circulating system consisted of a dye reservoir, a centrifugal pump (Grundfos, Type: CHI2-60A-W-G-BQQV, 40 lpm) to flow the dye solution, a heat exchanger, a water circulating pump, a flow meter and a pressure gauge. The dye solution reservoir was connected to the inlet of the centrifugal pump through one inch SS bellow tube to achieve the required flow rate. The outlet of the pump was connected to the inlet of dye cell through a mechanical valve and a flow meter. The mechanical valve was used to vary the dye flow rate through the dye cell. The flow-meter (Eureka, Type: M2868, range: 1.5–15 lpm) was used to measure the flow-rate. The outlet of the dye cell was connected back to the dye solution reservoir through 0.5 in. SS bellow tube. The flow rate could be varied from 2 to 12 lpm. Due to heat generated by the absorption of pump beam and due to friction of dye solution flow, the temperature of dye solution increases. The temperature of dye solution was measured by a thermocouple, which was dipped in the reservoir of the solution. Temperature of dye solution was controlled by a heat exchanger, which was used to cool the dye solution. It consisted of a compressor and copper tube wrapped on dye reservoir in spiral shape to increase its surface area dipped in to the water contained in water tank (Fig. 1b). Water was circulated through water circulating pump to homogenize the water temperature. During the experiments, the dye solution temperature in dye reservoir was kept constant to 22 ± 1 °C.

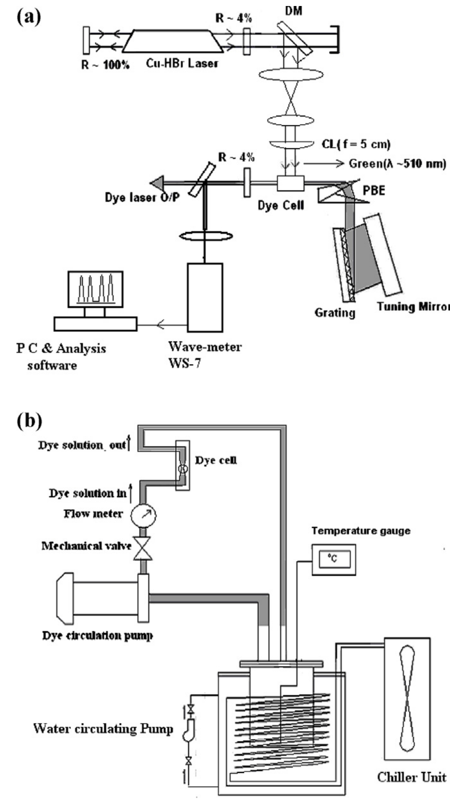

Fig. 1. (a) Experimental set-up of 18 kHz PRR dye laser pumped by Cu–HBr laser and (b) schematic of closed loop dye solution circulation system.

A green beam (λ = 510 nm) of the average power of ∼8 W from a Cu–HBr laser operating at ∼18 kHz PRR transversely pumped the dye laser using a cylindrical lens of focal length 50 mm. The dye laser optical resonator was a standard grazing incidence-grating (GIG) resonator of the cavity length ∼16 cm. It consisted of a grating (groove spacing ∼2400 l/mm), a 4% output coupling wedge, a fully reflecting tuning mirror and two AR coated right angle prism beam expander ($M \sim 22$ at an angle of incidence 80°). The prism beam expander (PBE) also folded the incident dye laser beam about 90° with respect to the dye cell. The folded beam fell on the grating at grazing incidence. The first order dye laser output was taken from the transmission of output coupler. A wave meter (WS-7, Angstrom, High Finesse) was used to online monitor the pulse to pulse dye laser line-width and frequency/wavelength variation over minutes. Use of wave meter to study the laser frequency variation is well known. However, it was also possible to study the laser line-width of both single and multimode lasers up to 10 GHz with an accuracy of 200 MHz [24]. The dye laser line-width was also measured by capturing the rings from the Fabry–Perot (F–P) etalon (FSR ∼10 GHz, Finesse >20) on to the time gated CCD (PCO AG, Pixelfly qe) camera, frame grabber card and beam analyzing software. The dye laser output power was measured by the Gentec (TPM-300) power meter. The dye laser pulse shapes were recorded by a bi-planar photo diode (Hamamatsu, R1193U-51) and 500 MHz digital storage oscilloscope (LeCroy, 6050A).

3. Results and discussion

Fig. 2 shows the simultaneous real time variation of dye laser line-width (upper trace) and wavelength (lower trace). These data, for each of the selected dye solution flow rate (F) from 2 lpm to 12 lpm, were taken for about 1–2 min. The data recording was in sequential manner. For example the line-width/wavelength data