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Characteristics of a cascaded grating multi wavelength dye laser

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ABSTRACT

Characteristics of a multi wavelength dye laser in two cascaded grating resonator configurations are presented. DCM dye dissolved in ethanol, was transversely pumped by second harmonic of Nd:YAG laser and four wavelength, independently tunable, collinear dye laser operation was obtained in Cascaded Grazing Incidence Grating cavity (CGIG) and Hybrid CGIG with fourth grating in Littrow angle (HCGIG) configuration. Gain competition effect of all the sub-cavities was fully characterized and wavelength zones of operation were identified for each cavity for sustaining four wavelength operation. Overall efficiency of the oscillator was measured to be around 2% in CGIG and 7% in HCGIG.

1. Introduction

Resonant ionization mass spectrometry (RIMS) [1], atomic vapor laser isotope separation (AVLIS) [2–4], multi wavelength light detection and ranging (LIDAR) [5,6], gas sensing [7], trace analysis [1] and other similar laser spectroscopic techniques require a spatially overlapped, independently tunable, narrow line width laser beams at 3 or 4 wavelengths. Conventionally these lasers are generated in separate dye oscillators and successively amplified to the required power levels. Further beam combination techniques are utilized to combine different laser beams both spatially and temporally. This makes the laser facility complex and the Master Oscillator Power Amplifier (MOPA) configuration for each wavelength become large and spread out. The composite laser beam may be required to propagate over long distance before their interaction with atoms and molecules. Maintaining the spatial overlap of the constituent beams in the interaction zone over long propagation distance becomes difficult due to extreme alignment sensitivity of the combination and beam shaping optics. Further difficulty in achieving optimum spatial overlap is caused by the unequal aspect ratio of the different beams from different laser chains. As an alternative to this approach, we propose a compact system where a single oscillator will generate the required multiple wavelengths simultaneously with a single spatially and temporally overlapped collinear output beam with identical polarization and aspect ratio. Subsequently, composite laser beam may be amplified through common amplifier stages to boost the power level to the required value. In multi photon laser spectroscopy [8,9], three tunable, narrowband, temporally and spatially overlapped laser beams are used for three step selective excitation and ionization of target isotope. Incorporating fourth wavelength becomes necessary to target atoms in meta-stable states, in the cases, where these states are significantly populated. Cascaded grating multi wavelength dye laser set up reported in this paper will be directly having applications in such multi-step multi-photon resonant photo ionization based spectroscopy methods.

A number of techniques using multiple dispersive elements in telescopic beam expander based cavity, prismatic and grating based cavity designs and grazing incidence grating cavities with and without intra cavity beam expander are studied in depth for efficient narrow band dye laser generation and well reported in literature. Narrow band operation of dye laser using grazing incidence grating without beam expander had been achieved by Shoshan et al. [10] and Littman and Metcalf [11] with line width of the order of 1 GHz. In latter versions, single mode operation had been obtained with line width of 300 MHz [12,13] using similar resonator geometries. Many authors had demonstrated the dual wavelength operation of dye laser by employing various intracavity optical elements and techniques. Nair et al. [14] had reported the double wavelength generation from a grazing incidence

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tunable dye laser without intracavity beam expander. Prior [15] had used different orders of grazing incidence diffraction grating for narrow band double wavelength generation from a nitrogen laser pumped Rh 6 G dye laser.

Most of the well studied dual wavelength designs pose extendability to more than two wavelength operation. However, studies on triple and four wavelength generation from dye laser are scarce. Recently, Khare et al. [16] had reported three wavelength operation from copper vapor laser pumped Rh 6 G dye laser. Two gratings coupled by different diffraction orders in a four prism beam expander cavity were utilized. Two out of three wavelengths were independently tunable and line widths were of the order of 0.3 cm^{-1} (9 GHz). Saito et al. [17] had demonstrated the simultaneous three wavelength generation using dielectric interference filter based cavity with broad linewidth and limited tuning range. Multicolor operation from dye mixtures was achieved by Burlamacchi et.al. in a single grazing incidence grating with two separate tiltable mirror cavities [18]. Recently, in fiber laser technology, cascaded bragg grating based Ultrabroad-bandwidth electro-optic modulator was demonstrated by Khurgin et al. [19]. Campanella et al. had used π-shifted Fiber Bragg Grating Ring Resonator (π-FBGRR) for refractive index sensing application [20].

Simultaneously operable, independently tunable, collinear, four wavelength dye laser is not yet reported to the best of our knowledge. This cavity was finalized after initial experiments using various potential cavities which could generate multiple wavelengths. Configurations with inherent narrow linewidth generation capabilities were selected. Among various cavities, we have tried grazing incidence grating (GIG) cavities with and without dual and four prism beam expander. Four wavelength operation in GIG cavity with prism beam expanders was found to be difficult to achieve due to very high prism losses in comparison to GIG cavity without prism beam expander. We have established four wavelength operation of dye laser in two resonator configurations. In first configuration, four cascaded Grazing Incidence Grating sub-cavities (CGIG) without intracavity beam expander similar to dual wavelength cavity by Nair et al. [12] was studied. In another resonator i.e. hybrid CGIG configuration (HCGIG), fourth grating was aligned in a Littrow configuration instead of near grazing angle in CGIG configuration.

Gain competition plays a significant role in dictating the intensity ratio, tuning range and sustained multiple wavelength operation for collinear out put generation in a homogeneously broadened gain medium. Several authors [21,22] have reported the gain competition behavior in various geometries and configurations but detailed characterization is not reported to identify operable wavelength zones of individual sub-cavities for sustained multiwavelength operation. Detailed characteristics of four wavelength oscillator and role of gain competition effect in the two multi wavelength dye laser resonator configurations are reported in this paper.

2. Experimental setup

We have studied two resonator configurations for simultaneous four wavelength generation using a common dye gain medium. First configuration i.e. cascaded grazing incidence grating (CGIG) resonator (Fig. 1), utilized four diffraction gratings in cascade, aligned at near grazing incidence angle (∼87–89°) with their respective tuning mirrors. These sub-cavities were mutually coupled through zeroth order output from the preceding sub-cavities. Second configuration was hybrid CGIG (HCGIG) in which three diffraction gratings were set at near grazing angle with their respective tuning mirrors whereas fourth grating was aligned in Littrow angle configuration as shown in Fig. 2. In HCGIG, individual sub-cavities were mutually coupled through zeroth order output from the preceding sub-cavity. Output coupler with 4% feedback was aligned for obtaining the collinear tunable dye laser output from the resonator. DCM dye of concentration 3.55 mM dissolved in spectroscopy grade ethanol was circulated through a glass dye cell of 20 mm width and 0.5 mm depth. Second harmonic (532 nm) of Nd:YAG operating at 20 Hz pulse repetition frequency was used as pump laser for DCM dye laser. A cylindrical lens (f = 100 mm) was used to focus the pump laser into the dye cell. The dimensions of pump beam line focus at the dye cell was approximately 20 mm × 0.5 mm. Diffraction gratings of 2400 lines per mm and length of 62.5 mm at near grazing angle of incidences were used for these experiments. High reflectivity (R ∼99%) rectangular mirrors were used as tuning mirrors. Salient feature of the configuration is its compactness, which is advantageous for utilizing pump pulse with short pulse duration. Typically, cavity length of first to fourth sub-cavities were 210 mm, 345 mm, 490 mm and 625 mm respectively for the CGIG resonator and fourth sub-cavity length reduces to less than 600 mm in case of HCGIG resonator configuration due to absence of tuning mirror arm.

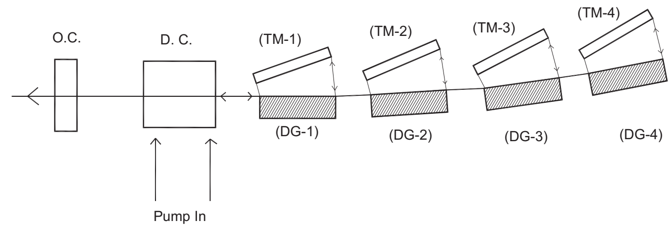

Fig. 1. Schematic of Cascaded Grazing Incidence Grating (CGIG) resonator configuration.

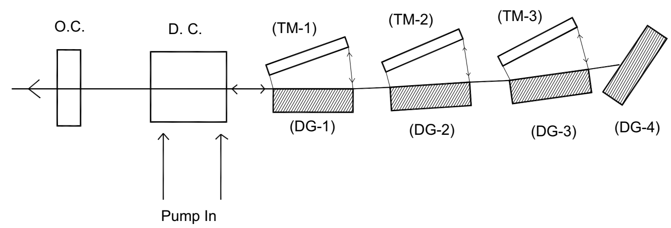

Fig. 2. Schematic of hybrid CGIG (HCGIG) with Littrow resonator configuration.

Figs. 1 and 2 shows the cavity configuration of CGIG and HCGIG. In CGIG configuration, basic resonator consists of output coupler (O.C.), dye cell (D.C.), tuning mirror (T.M.) and grating (D.G.) arranged in GIG configuration. The dye laser was transversely pumped. For this study we have maintained around 52 mm illumination length of all the gratings to ensure constant single pass spectral width. Cascaded GIG configuration has the advantage of variable line width and adjustable cavity losses by varying the angle of incidence of the grating and hence the illumination length. In CGIG, as shown in Fig. 1, sub-cavities C-1 (O.C. → D.C. → D.G.-1 → T.M.-1), C-2 (O.C. → D.C. → D.G.-1 → D.G.-2 → T.M.-2), C-3 (O.C. → D.C. → D.G.-1 → D.G.-2 → D.G.-3 → T.M.-3) and C-4 (O.C. → D.C. → D.G.-1 → D.G.-2 → D.G.-3 → D.G.-4 → T.M.-4) correspond to the first, second, third and fourth sub-cavity with nearest to longest distance from out put coupler. In HCGIG configuration (Fig. 2), sub-cavity C-4 (O.C. → D.C. → D.G.-1 → D.G.-2 → D.G.-3 → D.G.-4) was aligned at Littrow angle instead of grazing incidence.

Avantes make spectrophotometer (Model no: AvaSpec-2048 XL) [23] was used with optical fiber probe to couple the dye laser beam for wavelength measurement and their relative intensity assessment. Ophir make power meter was used for measurement of input pump laser power and output dye laser power.

Line width was measured using Fabry Perot interferometer