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N. KHAN

Demonstration of a nine lines distributed feedback dye laser using three pairs of pump beams

Department of Electrical and Electronic Engineering, Faculty of Engineering, University Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia

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ABSTRACT Controllable, maximum nine-wavelength operation of a wavefront divided, multiple beam pumped, distributed feedback dye laser (DFB), is reported for the first time. Equally spaced three to nine lines have been obtained by pumping a dye solution with three pairs of excitation beams derived from the same source. Experimental results lead to a nine line model of a distributed feedback dye laser (DFDL). The dye cell was excited by the 2nd harmonic of a laboratory built, cavity dumped, passively *q* switched and mode-locked Nd : YAG laser, to induce a temperature phase grating in the dye solution. Different features studied included threshold conditions, simultaneous induction of multiple gratings, impact of pump polarizations, and temporal and spectral characteristics of the emitted lines. This work on the DFDL is in agreement with most of the published results on semiconductor DFB lasers [1–3] and opens a new era of research. This multi-wavelength operation of a DFDL is based on the nonlinear effects of an overwritten multiple dynamic grating on a R6G dye solution in ethanol.

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1 Introduction

Multiwavelength lasers may be designed in solid state, gas, and liquid phases. Most of the reported multiwavelength (MW) lasers come either in DFB semiconductor [1] or erbium doped fiber forms [2]. Different types of MW lasers employing erbium doped fibers, cascaded fiber gratings, phased arrays, Bragg gratings, distributed Bragg reflectors, shadow mask InGaAs/InGaAsP, and binary supergrating techniques have already been reported [2, 3]. Recent interest on the MW operation of distributed feedback is under extensive research at many institutions around the globe. MW operation of lasers has also been achieved in solid [1] and gas lasers [4, 5]. Two wavelength lasers (visible and infrared) at extreme locations in the electromagnetic spectrum with independent tunability capability in wavelength, energy, and pulse duration, have recently been reported [6]. The principle of operation of these lasers is not based on DFB technology, but rather on thin film multilayer dielectric coatings.

Distributed feedback (DFB) gas lasers have successfully been demonstrated and their MW operation with up to four lines has been reported [5]. There is lot of scope for MW operation research in gas phase DFB lasers. Most of the interest remains centered around various types of semiconductor distributed feedback lasers. These lasers cannot produce femtosecond and attosecond pulses due to material limitations. It is however, possible in dye lasers using distributed feedback technique. This work on MW operation of a DFDL is unique, and this is the first time reporting of its present form. Most of the work on single wavelength DFDLs is based on beam amplitude-division instead of wavefront division. No amplitude division based DFDL has been reported with 9-channel capability. Several papers employing different excitation techniques have been published on the principle of operation of a DFDL. Two and five wavelength DFDL operation was reported a few years ago using different principles of use of external gratings [7, 8]. Present work based on multiple wavefront divided pump beams employing a Shank type pumping configuration is reported for three to nine lines for the first time. The number of lines may be extended to several tens of lines subject to broadening effects and medium gain emission profile limitations.

The principle of operation of a DFDL may be explained in terms of coupled wave theory [9]. The positive feedback in distributed feedback dye lasers (DFDL) is provided by the distributed gain grating in the dye solution. This grating may be caused by the interference of two light beams, derived from the same source, at an angle $2\theta_{\mathrm{H}}$. Distributed feedback lasers operate if the periodicity (Λ) of the dynamically induced grating satisfies the Bragg scattering condition given by

$$\Lambda = m\frac{\lambda_{\mathrm{o}}}{2n} \tag{1}$$

Alternatively the periodicity Λ may also be given by

$$\Lambda = \frac{\lambda_{\mathrm{p}}}{2\sin(\theta_{\mathrm{H}})} \tag{2}$$

If λ_{p} is the excitation laser wavelength, n refractive index of dye solution then at m^{th} Bragg index a comparison of (1) and (2) leads to

$$\lambda_0 = \frac{n\lambda_{\mathrm{p}}}{m\sin(\theta_{\mathrm{H}})} \tag{3}$$

✉ Fax: +603-89466327, E-mail: khan@eng.upm.edu.my

However, it is important to note that the operation of a distributed feedback dye laser at higher Bragg indices such as $m \geq 3$, needs more pumping power. The threshold energy at $m = 3$ increases 2.4 times more than at $m = 1$. The authors recommend operation of the DFDL at $m = 1$ for subsequent work described in this paper. If the dye medium is pumped by two or three pairs of beams then the primary phase difference and periodicities of the main gratings may cause oscillation of multiple lines [10]. Findings described in this paper consist of the spectra of a triple overwritten dynamic grating in a dye cell.

2 Experimental setup

The second harmonic of a passively Q-switched and mode locked Nd : YAG laser was used to pump the DFDLs. The beam had a total energy of 700 ± 10 µJ. The main excitation beam was divided using wavefront amplitude division to operate three DFDLs simultaneously at the same location in a dye cell filled with a solution of R6G in ethanol at 1 mM molarity. The pump energies of DFDL_1, DFDL_2, and DFDL_3 were measured to be 282.86 µJ, 142.80 µJ, and 90 µJ respectively. 10% of the main beam was used to trigger the streak camera and 16% was lost in the conveying optics. The experiment arrangement is shown in Fig. 1.

The pump energies of the intended three distributed feedback dye lasers namely DFDL_1, DFDL_2, and DFDL_3 were measured using a pyroelectric detector on the dye cell. The energies of individual pairs were measured separately by blocking the other two pairs together at a time. The pump energy of DFDLs was high enough to cause laser oscillation well above the threshold. The folding mirrors were mounted on moveable mounts to vary the optical path difference (OPD) among the three pairs of pumping beams. Simultaneous operation of the

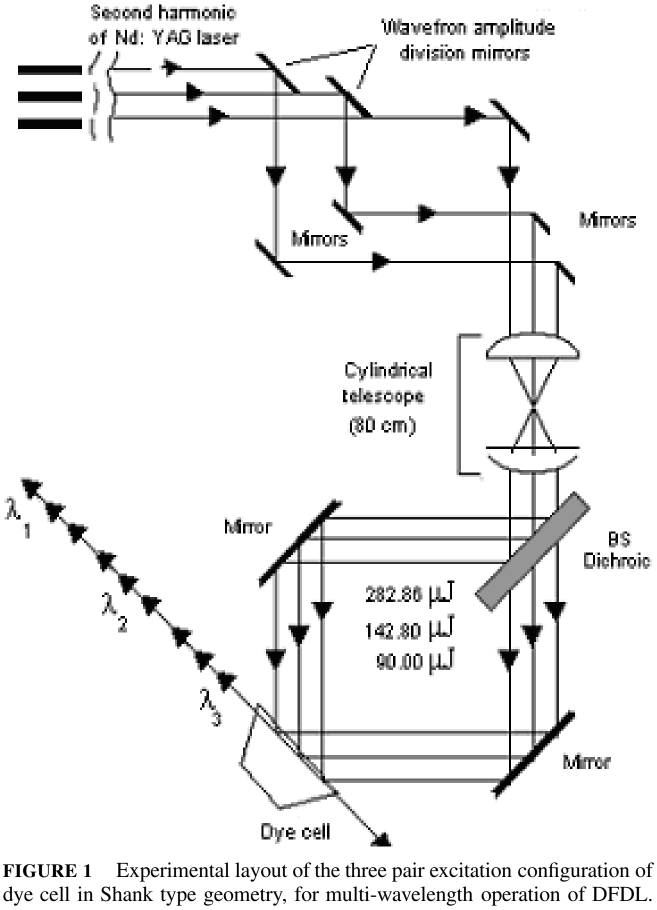

FIGURE 1 Experimental layout of the three pair excitation configuration of dye cell in Shank type geometry, for multi-wavelength operation of DFDL. A cylindrical telescope is used to focus the beams on dye cell

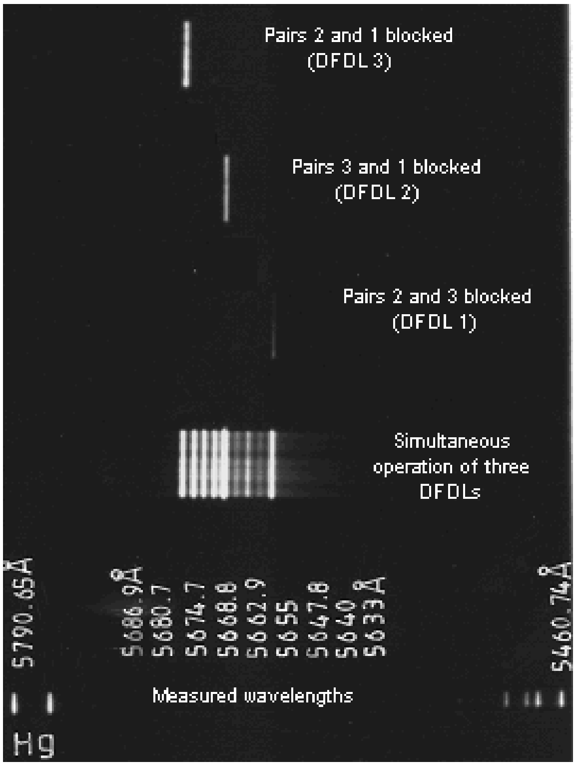

FIGURE 2 Maximum number of lines in MW operation of DFDL. Individual lines were calibrated using a Mercury lamp to measure the wavelengths. Blocking of two pairs of beams resulted in the operation of an individual DFDL shown as D_1, D_2 and D_3

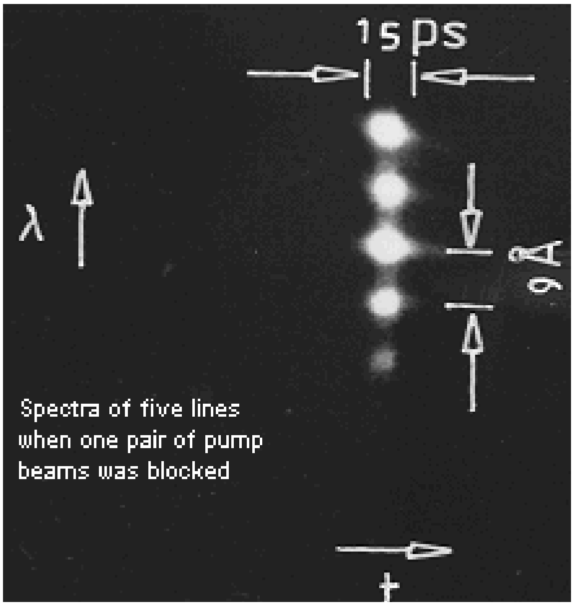

FIGURE 3 Time resolved spectrograph of multiple lines using a 1-m spectrogram and streak camera

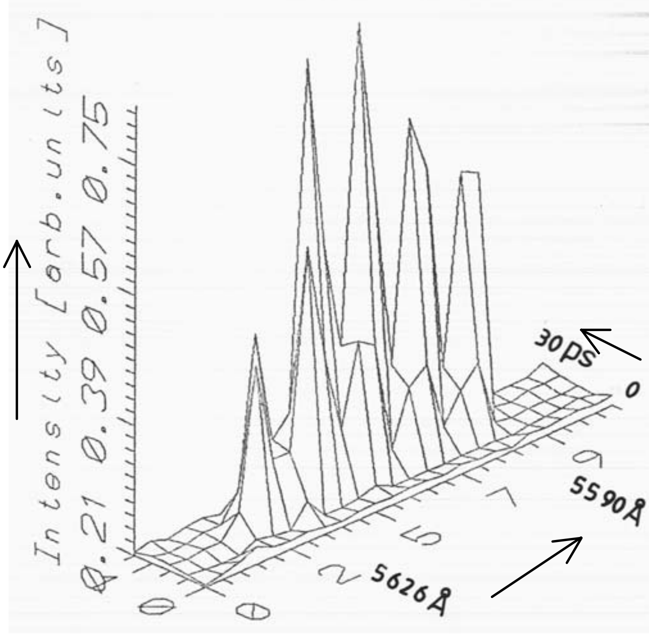

FIGURE 4 Wavelength, pulse duration and intensity 3-D plot of multiple laser lines of DFDL

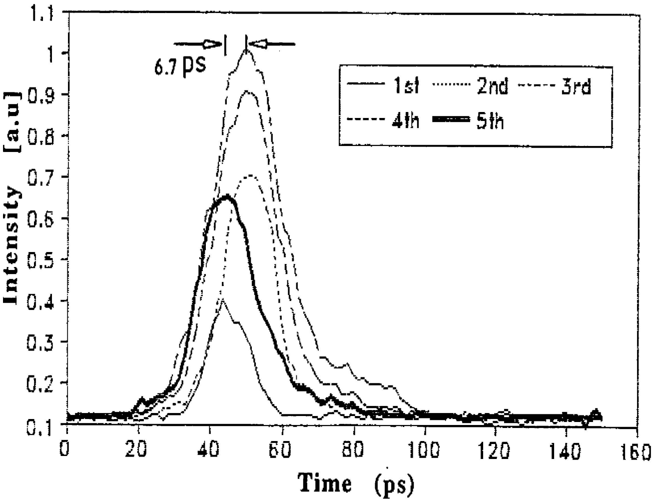

FIGURE 5 Pulse length and intensity plot of five lines. These six lines were obtained for 2 mm OPD between the first two pump pairs and 12 mm between other two pairs of pump beams

DFDLs gave multiple lasing lines depending upon the OPD among them. The number of DFDL lasing lines varied from three to nine at different OPDs. Emission of individual DFDL lines and maximum nine lines in simultaneous operation of three DFDLs is illustrated in Fig. 2. The maximum lines were observed when the OPDs among the three DFDLs were less than 2 mm, and minimum lines were observed when OPDs between the DFDLs were more than 4 mm, which is equal to the coherence length of the pump laser. Simultaneous operations of DFDL_1 and DFDL_2, DFDL_2 and DFDL_3, and DFDL_1 and DFDL_3, were conducted separately by blocking excitation beams for one DFDL at a time. The maximum number of lines was five in each case. In simultaneous operation of three DFDLs the fundamental lines do not change their locations in the output spectrum unless the half-angle is varied. In a few measurements 10 lines were observed. It is believed that the tenth pulse had arisen from spatial coherence effects or a higher order nonlinear grating of the highest intensity. The tenth line was very weak and seldom appeared. It was not repetitive, but the other nine lines appeared whenever OPDs < 2 mm. The wavelength of the tenth line was about 568.3 nm.

3 Results and discussions

The output energy of a DFDL increases linearly when increasing the input excitation energy. However, when the input energy is increased beyond 2.5 mJ (IR) then the output from the DFDL starts to flatten. The efficiency of the DFB laser varied from 8% at lower pump powers, to 7% at higher pump powers, due to saturation. A time resolved spectral/temporal study was conducted using a 1-meter spectrograph and a streak camera. The pulse lengths were found to vary in this case from 10 to 30 picoseconds. The time resolved spectra of five lines along with their 3-D plot are shown in Figs. 3 and 4 respectively.

The negative films were scanned by a computer-controlled microdensitometer to obtain the intensity data for the pulse durations and spectral purities of the DFDL lines. The pulse length of different lines were found to be different from one another in the same spectrum. A 2-D plot of five lines has been shown in Fig. 5. This may be attributed to different intensities of pump beams.

The measured variation in lasing wavelength as a function of refractive index was found to be 10 nm/0.21. It can be tuned further by operating the laser at different Bragg indices (1, 2, 3 ... n). The DFDL was operated using $m = 3$ and 4 for $\theta_\text{H} = 25.1°$ and 18.5° at 560 nm. The threshold energy for $m = 4$ was 15 times higher than the corresponding operation at $m = 1$. The impact of pump polarization on the DFDL output spectrum was studied by rotating a half wave-plate in the main excitation beam. The maximum lines corresponded to linear s-polarization. The DFDL threshold and number of output lines depends upon the nonlinearity of gratings and that in turn depends upon the number of pulses, and polarization of the excitation laser.

4 Conclusion

In conclusion, a successful operation of a MW DFDL has been demonstrated within the spectral range of 5.3 nm. Although, only nine output lines have been obtained using three pairs of pump beams, the principle however, is extensible to several tens of lines. The number of lines is obviously limited by the spectral emission of the gain medium, but is still extendible by using multiple color pump beams and the dye solutions in the same dye cell. The number of upper lines, although not verified, appears to be limited by broadening effects and useful resolution. The DFDL may safely be considered as a MW laser source. The number of output lines can be chosen during operation, which is not possible with the counterpart erbium-doped fiber [2], HeNe [4], CO_2 [5] and semiconductor distributed feedback lasers [1]. The MW operation is caused by induction of additional gratings due to interference between the main overwritten gratings. This explanation is consistent with MW reflection spectra observed in dual overwritten fiber Bragg gratings [10].

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REFERENCES

1 J. Sun, Y. Zhang, X. Zhang: IEEE PTL **14**, 750 (2002)
2 X.P. Dong, S. Li, K.S. Chiang, M.N. Ng, B.C. Chu: Electron. Lett. **36**(19), 1609 (2000)
3 Q. Mao, J.W.Y. Lit: IEEE PTL **14**, 612 (2002)
4 Multiwavelength He-Ne laser, JSC Plasma Website http://www.plasma.com.ru/products/lasers/hene/hene3.html, accessed on July 17 (2002)
5 V.A. Gorobets, V.O. Petokhov, Churakow: Appl. Phys. B **64**, 423 (1997)
6 J. Biegert: Appl. Phys. B, published online July 12 (2002)
7 A. Muller: Appl. Phys. B **63**, 443 (1996)
8 W.J. Wadsworth, I.T. McKinnie, D. Woolhouse, T.G. Haskell: Appl. Phys. B **69**, 163 (1999)
9 H. Kogelnik, C.V. Shank: Appl. Phys. Lett. **18**, 152 (1971)
10 J. Bao, X. Zhang, K. Chen, W. Zhou: Opt. Commun. 34 (2001)