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PICOSECOND LASER PULSE GENERATION BY SECOND-ORDER DISTRIBUTED FEEDBACK DYE LASER

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Abstract. *A second-order distributed feedback dye laser pumped by a nanosecond Nd:YAG laser is setup. Its tuning range of laser wavelength is narrower than that first-order distributed feedback dye laser, but lower noise and more stable laser operation is obtained. Single picosecond laser pulses tunable in the range of 543 nm to 596 nm can be produced by using different laser dye solutions. The tuning range of the second-order distributed feedback dye laser is extended to the shorter wavelengths which are close to pumping wavelength.*

Keywords: dye laser, short pulse laser, tunable laser.

Classification numbers: 42.55.Mv, 42.65.Re, 42.60.Fc.

I. INTRODUCTION

Picosecond laser pulse generation by dynamic distributed feedback dye laser (DFDL) based on the first order $(m = 1)$ of Bragg diffraction was the subject of detailed studies for a long time. This type of DFDL provides the lowest lasing threshold and the widest tuning range for the emitted pulses. However, if a conventional optical cell is employed as the DFB oscillator, lasing wavelength λ_L is limited by the period of the interference pattern Λ formed by pumping radiation of wavelength $\lambda_p(\lambda_L = 2n\Lambda/m$ where $\Lambda = \lambda_p/2\sin\theta$, n is the refractive index of active medium, θ is the incident angle of the pump beam on the active medium) [1]. Therefore, it is impossible to get lasing wavelength close to pumping wavelength without using the special triangular prism as the input window for the pump radiation. At the same time, if the second-order Bragg diffraction regime is employed, no input coupling prism is required for the DFBL oscillator to operate at any wavelength including a short wavelength as the pump wavelength. Unfortunately, the transit from the first to the second order inevitably leads to the higher lasing threshold and narrower tuning range [2, 3]. However, as applied to ultrashort pulse generation under nanosecond laser pumping, the second-order DFDL has the advantage in terms of peak power and energy of the generated picosecond laser pulses [4].

In this work, we report on the efficient picosecond laser pulse generation of a second-order DFDL pumped by a nanosecond Nd:YAG laser (Quantel, 532 nm, 5.6 ns, 10 Hz) or a micro solid-state diode-pumped Nd:LSB (0.5 ns, 532 nm, $f < 500$ Hz). It shows that the properties of laser output are not affected due to high repetition rate of the pumping source. A rather large tuning range can also be obtained in this case using various liquid dye active media.

II. EXPERIMENT

Performance of second-order DFDL

The condition of second-order Bragg resonance, which depends on the phase modulation of the medium's refractive index can be calculated by using the dispersion equation [5]. In the case of first order Bragg resonance, incident angle θ_B and wavelength of laser out λ_{out} are couple by the Bragg relation $2\Lambda\cos\theta_B = \lambda_{out}$ (Λ: Bragg constant). In the case for second order of Bragg diffraction, the angle $\theta = \theta_{2B}$ has to be satisfied the relation of $\Lambda\cos\theta_{2B} = \lambda_{out}$. Additionally, the matching-phase condition of second-order performance is rather significant [3]. The oscillation at the second-order Bragg resonance is depends on the combination of phase and gain modulation in the DFDL operation. The calculation of high-order resonance modeling shows that the oscillation mode rather shifts from lowest mode position to both side of the cavity. It means that laser beam should be priority in only one direction of the cavity. The threshold gain is a factor of c.a.1.5 times higher than first-order Bragg oscillation.

Setting up DFDL's system

The schematic diagram of the DFB oscillator is presented in Fig. 1. Aquartz cell of 1×1 cm (Helma Co.) filled with a dye solution (for example, PM560, rhodamine 6G and rhodamine 610 in ethanol) is used as an active medium. After passing through a cylindrical lens with a focal length of 30 cm, the two identical parts of pump beam, which are splitted from the main beam by two quart plates, are reflected on the two aluminum mirrors (we note that by using these quart plates a wide range of the pump laser wavelengths and whole beam profile can be

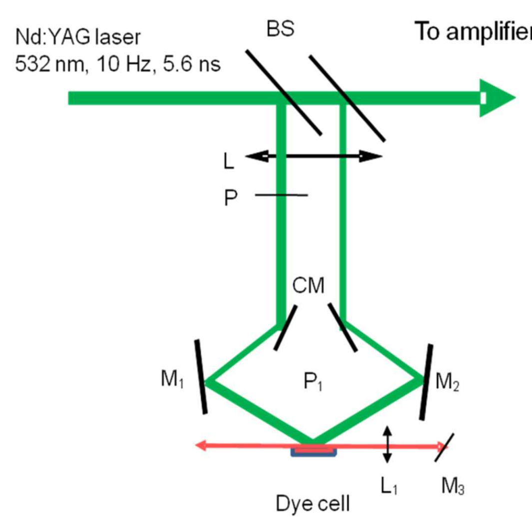


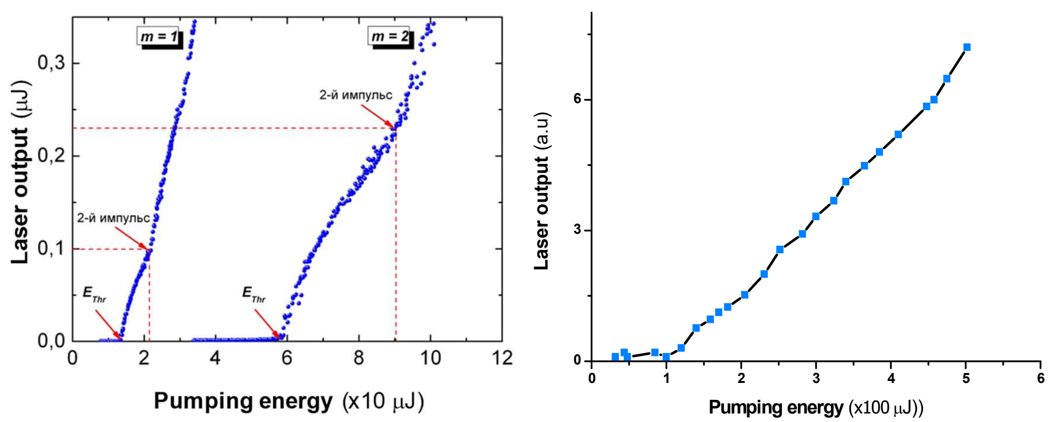
Fig. 1. Configuration of a DFDL pumped by SHG of a Nd:YAG laser: BS: beam splliter; L: cylindrical lens; P: polarizer; CM: two mirrors; M_1M_2: rotable mirrors; L_1: convex lens, M_3: driving mirror.

used without changing the beam splitter) The influence of the excitation area on the threshold of organic second-order distributed feedback lasers was investigated [7]. After reflection from the rotable mirrors M, a coupleof beams is then focused onto the dye cell that contains the dye solution, and forms an interference pattern. The dye laser wavelength λ_L is governed by the spacing Λ of bright grooves.

III. RESULTS AND DISCUSSION

Threshold condition

It is well-known that the laser threshold is defined as the pumping energy where the optical gain surpasses the losses over cavity roundtrip. In this work, the threshold energy level is higher than that of Bragg's first-order laser emission of 1.4 fold by using a low repetition rate pumping laser (for example, lasing threshold at 568 nm of Rh590 dye as 60 μJ and 120 μJ for first- and second order, respectively). It can be explained by the lasing threshold condition corresponding to the case of self-starting excitation. The oscillation at the second order Bragg resonance could be occurred due to combination of phase and amplitude modulations. Additionally, the quality of resonant condition is significantly lower than the first-order Bragg's oscillation (c.a. $1/2$) leading to higher lasing threshold. The curves of laser output variation with difference of pumping energy are shown in Fig. 2.

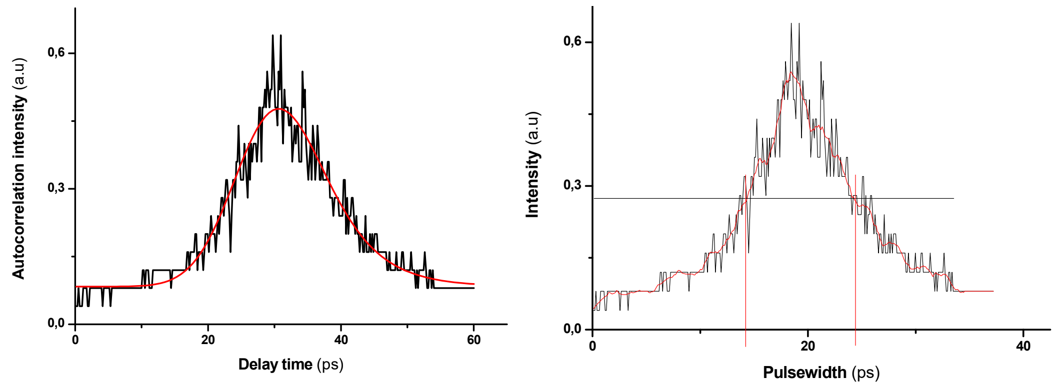


(a) (b)

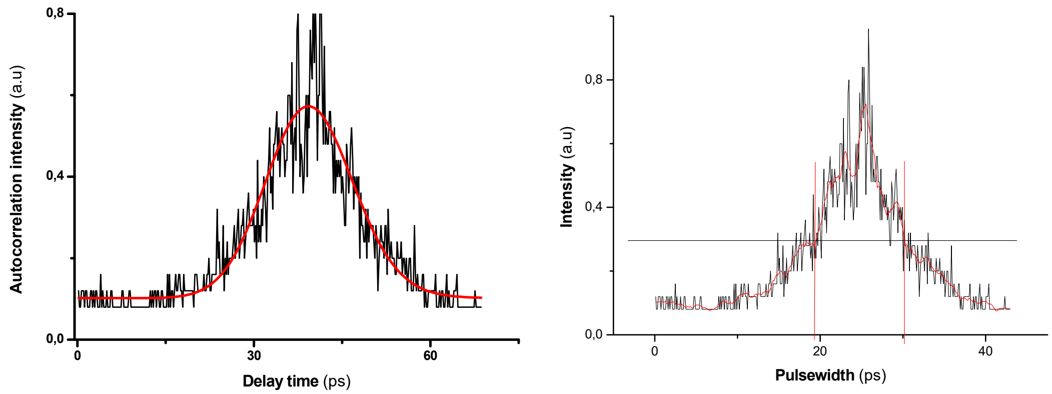
Fig. 2. Laser emission thresholds of the distributed feedback dye laser for 1^{st} and 2^{nd} by using two kinds of pumping source: a) using high frequency Nd:LSB pumped - diode laser; b) by Nd:YAG laser with repetition of 10 Hz.

In the case of pumping by Nd:LSB laser with a repetition rate of 500 Hz, the second-order threshold energy is higher than first-order of 5-folds (Fig. 2a). On the other hand, by using a Nd:YAG laser (pulse-width of 5.6 ns, repetition rate of 10 Hz) the threshold is only about 1.4 times higher than that in the first-order (Fig. 2b) [8]. The difference between the two kinds of pumping sources can be explained by laser pulse power of each laser leading to be different in population inversion of active medium. In other words, the operation of dye laser at high pumping rate is often required a high threshold due to the lost population at upper-laser decayed to triplet level.

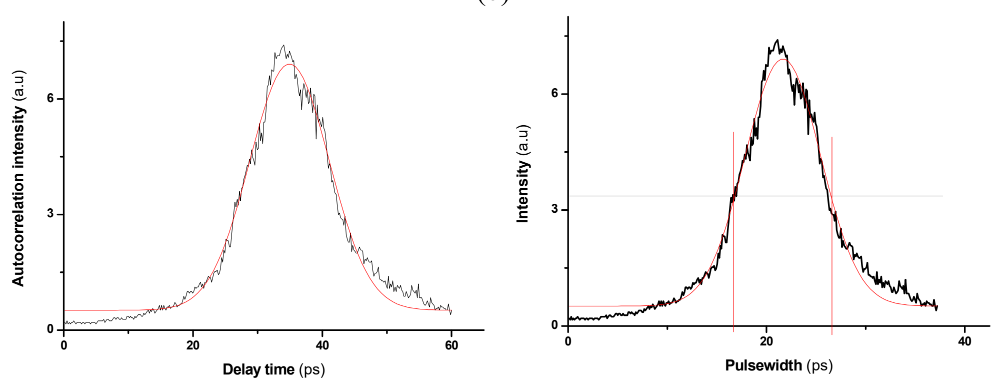
Temporal properties



(a)



(b)



(c)

Fig. 3. Autocorrelation traces (left) and pulse-width of laser pulse from the second order distributed feedback dye laser at various wavelengths: a) at 553 nm; b) 579 nm; c) 589 nm.

The temporal profile of the DFDL output strongly depends on pump energy, pump pulse duration and other cavity parameters. In this study, we investigated the influence of the pumping energy on the laser pulse width by changing the ratio $\gamma = E_p/E_{thr}$ (here E_p – pumping energy and E_{thr} – threshold energy). Normally, the output laser from DFDL at the high γ is a train of pulses with different pulse-width [6]. In the second-order regime, the multiple output direction is observed during laser operation. Additionally, due to the small grating period, the diffraction efficiency at second Bragg angle was truly unsuccessful. It leads to the laser operation is often required the high threshold. The population relaxation on the upper level is insufficient to generate the second-pulses. A typical autocorrelation trace of the amplified DFDL laser pulses measured by the second harmonic generation in a non-linear optical crystal (BBO, 5 mm thick) is shown in Fig. 3. A pulse width of $\sim$ 12 ps is recorded with the active medium length of 3 mm, which is fitted to Gaussian shape (red line). It suggests that in applied experimental condition only a single laser pulse is emitted.

Tuning range

The tuning range and the energy distribution of the DFDL were measured using three different dye solutions as shown in Fig. 4. A rather wide tuning range (543–592 nm) is accomplished by simultaneously tuning the incident angle of the pump beam on the dye cell and by changing the position of the rotating mirrors M to keep the interference pattern on the dye cell. A tuning range of about 10 nm for each of investigated dyes is observed. Although this range is narrower than that in the case of the first-order DFDL, the laser output beam with a low noise and stable intensity is readily obtained. Additionally, the tuning range is extended to the shorter laser wavelengths (543 nm) close to the pump wavelength of 532 nm. Thus, a single picosecond laser pulse tunable from 543 to 596 nm can be obtained in the DFDL by using the second-order Bragg diffraction configuration. It means that the limitation of lasing wavelength by the period of the interference pattern, as discussed above, can be easily overcome.

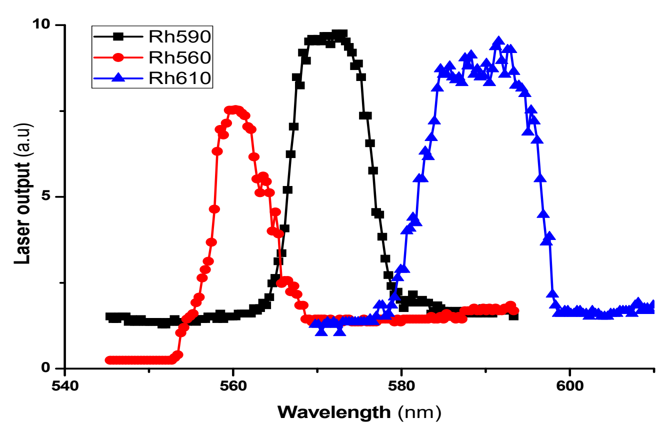


Fig. 4. Tunning range of the second order distributed feedback dye laser using three laser dye solutions of Rh560, Rh590, and Rh610 in ethanol.

IV. CONCLUSION

Single picosecond laser pulses of 12 ± 2 ps pulse width were obtained by using the second-order distributed feedback dye laser. Its wide tunable range of laser wavelength (c.a. 50 nm) with different dye solutions is obtained. Especially, the dye laser wavelength close to the pumping wavelength could be observed in second-order Bragg effect, which suggests that desirable laser wavelength could be recorded from the distributed feedback dye laser (one for pump source and one for construction of period shape).

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