DESIGN OF N_2 LASER PUMPED TUNABLE DISTRIBUTED FEEDBACK DYE LASERS WITH EXTENDED TUNING RANGE

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The range in which N_2 laser pumped distributed feedback dye lasers can be tuned by turning mirrors is limited by the shift of the pump beams along the surface of the dye cell. In this article the pivot axis of the mirrors is determined for which the shift of the pump beams is minimized.

N_2 laser pumped distributed feedback dye lasers (DFDL-s) [1] are inexpensive and simple instruments capable of generating 6—40 ps long [2, 3], transform limited light pulses. Fig. 1 shows the scheme of a DFDL. The pump beam is diffracted by the grating and the DFDL structure is produced by the interference of the two diffracted beams. The period of the interference pattern is

$$\Lambda = \frac{d}{2} \tag{1}$$

where d is the period of the holographic grating. The wavelength of the DFDL is

$$\lambda_\ell = 2 \cdot n_s \cdot \Lambda \tag{2}$$

where n_s is the refractive index of the dye solution. According to equations (1) and (2) the wavelength of the DFDL does not depend on the wavelength of the pump beam, *i.e.* the pumping arrangement is achromatic. If the arrangement satisfies the

$$\frac{x}{y} = \left(\left(\frac{d}{\lambda_p}\right)^2 - 1\right)^{1/2} \tag{3}$$

geometrical condition — where λ_p is the wavelength of the pump beam —, then to each point of the dye cell the interfering beams are diffracted from the same point of the grating. This means that one can use pumping beams with poor spatial coherence. The DFDL can be tuned comfortably by turning the mirrors. The wavelength of the DFDL can be calculated from the equation

$$\lambda_\ell = \frac{n_s \lambda_p}{\sin(\alpha - 2\delta)} \tag{4}$$

where $\alpha = \arcsin(\lambda_p/d)$ is the angle of diffraction. The meaning of the angle δ is shown in Fig. 1. However, the DFDL wavelength now becomes dependent not only on δ, but also on λ_p, *i.e.* this arrangement is chromatic. This problem was investigated in [4], and it was shown that the chromatism is negligible in a tuning range of about 20 nm.

There is another problem, namely, with the turning of the mirrors the incidence points of the two diffracted beams with the surface of the dye solution shift in opposite directions. This can lead to significantly decreasing visibility of the interference pattern since the spatial coherence length of an N_2 laser beam is generally smaller than about 0.5 mm. The decreasing visibility may prevent lasing. This can be compensated by moving the grating or the dye cell during tuning, but then the whole set-up becomes too complicated. There is an alternative compensation utilizing the fact that the relative shift of the incidence point depends on the pivot axes of the mirrors.

Let us determine this dependence with reference to Fig. 2 (which shows only the right side of the DFDL). In the first case the pivot axis is located in the intersecting point (A) of the pump beam and the mirror. Turning the mirror between positions 1 and 2 causes a shift b of the incidence point. According to sine law

$$b = a\frac{\sin(2\delta)}{\cos(\alpha - 2\delta)} \tag{5}$$

where $a = \overline{AB}$. If the pivot axis is located in point 0 (the sign of mirror position and ray path are denoted by 3) then the distance b' can be calculated from the equation

$$b' = 2f\frac{\sin\alpha\cos(\alpha-\delta)}{\cos(\alpha - 2\delta)} \tag{6}$$

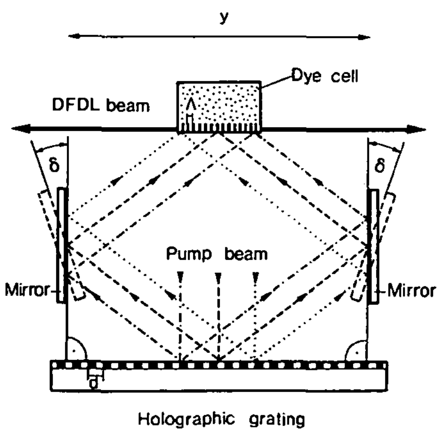

Fig. 1. Pumping arrangement of the DFDL

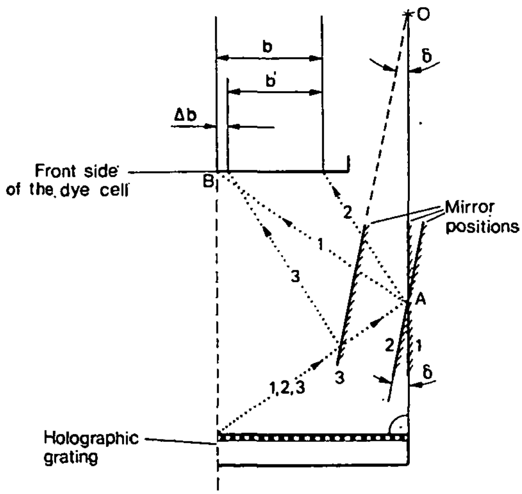

Fig. 2. Change of the ray path during mirror turning

where $f=\overline{AO}$ the arm length of the mirror. Finally the shift of the incidence point is

$$\Delta b = b' - b \tag{7}$$

when the mirror is turned about point 0 with an angle δ. Fig. 3 shows Δb as a function of δ with different arm lengths. The values of f are given in mm. As seen from Fig. 3 the mirror can be turned over a 50 mrad range while $|\Delta b|$ is smaller than 0.05 mm, which is one tenth of the spatial coherence length of the pump beam. Hence with such turning range the shift of the incidence points does not influence significantly the working condition of the DFDL. The curves shown in Fig. 3 were calculated using $a=40$ mm. In the case of $f=68.02$ mm the OB line is perpendicular to the AB line (see Fig. 2). The $\Delta b-\delta$ curves can be compressed vertically using smaller a and proportionally smaller f.

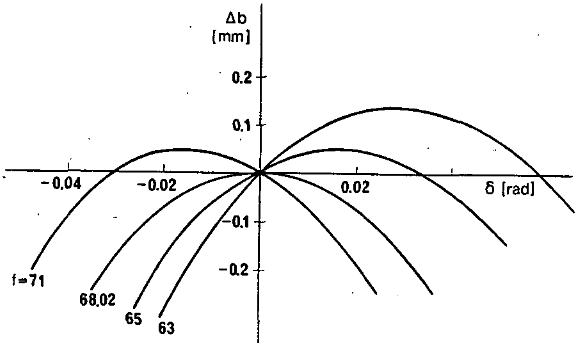

Fig. 3. The dependence of the incidence point shifting on the mirror rotating angle δ with four different arm lengths

According to the calculations for the chromatism [4] and the shift of the incidence point the DFDL is tunable simply by turning the mirrors in a range of few ten nm. This possibility was investigated experimentally. In the experiments a slightly different arrangement [5] as compared to the one shown in Fig. 1 was used (see inset of Fig. 4). The characteristic values of the DFDL were $a_1=50$ mm, $a_2=20$ mm, $f_1=83.8$ mm and $f_2=33.5$ mm. The active medium was a $6 \cdot 10^{-3}$ mol/ℓ solution of Rhodamine 6 G, dissolved in a 1:1 mixture of ethanol and DMSO. A 24C0 ℓ/mm holographic grating was used. The pump source was a N_2 laser oscillator-amplifier system [6]. The pump beam was focussed onto the dye cell by a cylindrical lens having a focal length of 320 mm. In Fig. 4 the full line shows the calculated (from Eqs. (3)) and (4)) and the crosses (x) the measured value of the lasing wavelength as a function of rotation angle δ. The tuning range was 35 nm. In this range the difference between the measured and calculated wavelength was smaller than the accuracy of measurement. The threshold pump power was also measured during tuning. It was found that the change of the threshold was smaler than $\pm 5\%$ in a 9 nm tuning range. This range was probably limited by the chromatism of the pumping since in the case of chromatically compensated pumping arrangement this tuning range was 25 nm [4].

In [4] a quartz prism was attached to the dye cell for chromatic compensation as shown in Fig. 5. (This figure displays only the right side of the symmetrical DFDL.)

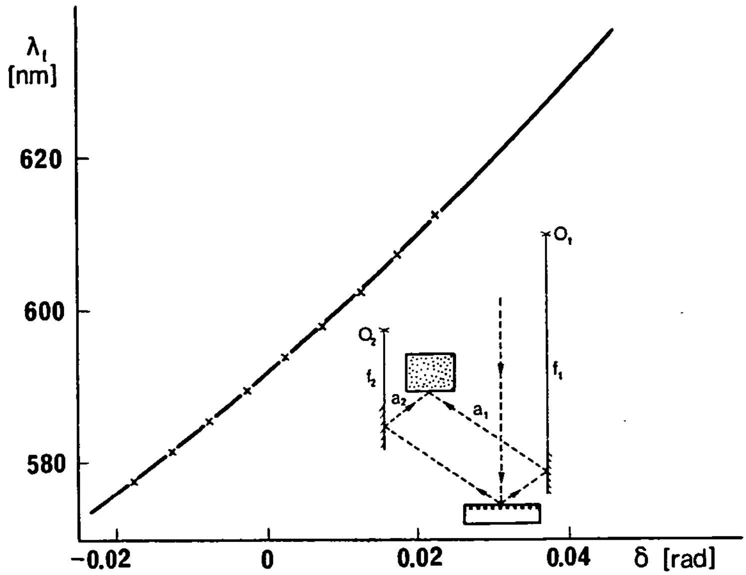

Fig. 4. Calculated (full line) and measured (x) lasing wavelength as a function of angle δ

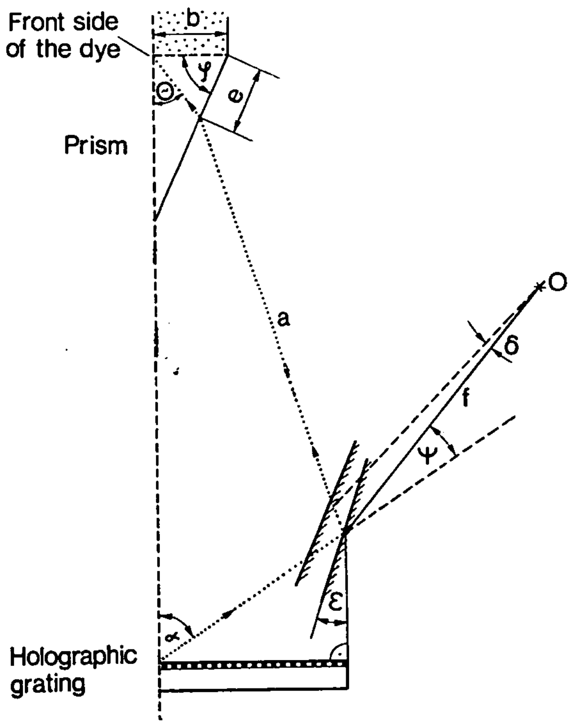

Fig. 5. Figure to define symbols used in equations (8)—(14)

In this case the shift of the pump beam on the surface of the dye during tuning is determined by the equation

$$\Delta b = \frac{\cos\gamma'}{\cos\Theta'}\cdot\left[e+i\frac{\sin(2\varepsilon-2\alpha)}{\cos(\alpha-2\varepsilon-\varphi)}-\frac{\sin 2\delta}{\cos(\alpha-\varphi-2\varepsilon-2\delta)}\left(a+i\frac{\cos(\varphi+\alpha)}{\cos(\alpha-2\varepsilon-\varphi)}\right)\right]-b \qquad (8)$$

where

$$i = 2f\sin\left(\frac{\delta}{2}\right)\frac{\cos\left(\psi-\alpha+\varepsilon+\frac{\delta}{2}\right)}{\sin(\alpha-\varepsilon-\delta)}, \qquad (9)$$

$$e = b\frac{\cos\Theta}{\cos\gamma}, \qquad (10)$$

$$\gamma' = \arcsin\left(\frac{\sin(\varphi-\alpha+2\varepsilon+2\delta)}{n_p}\right) \qquad (11)$$

$$\gamma = \arcsin\left(\frac{\sin(\varphi-\alpha+2\varepsilon)}{n_p}\right) \qquad (12)$$

$$\Theta' = \varphi-\gamma' \quad \text{and} \quad \Theta = \varphi-\gamma. \qquad (13)\text{—}(16)$$

The meanings of the symbols are defined in Fig. 5. n_p is the refractive index of the quartz prism. ε is the initial angle to which $\Delta b=0$. Fig. 6 shows the $\Delta b-\delta$ functions

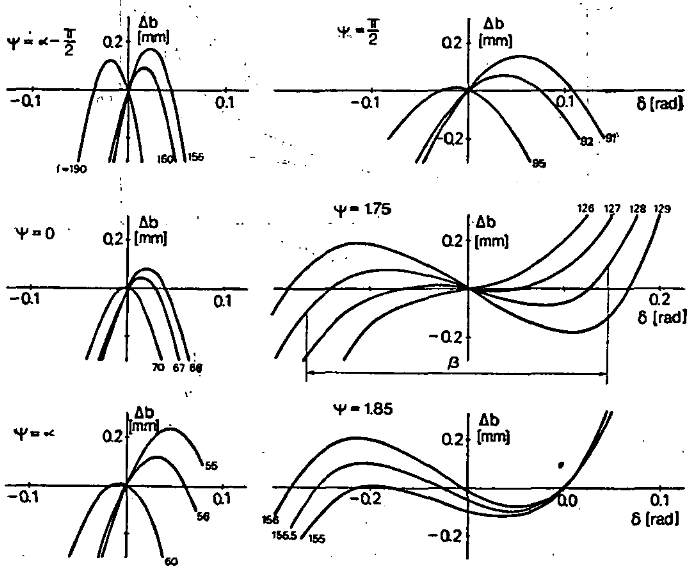

Fig. 6. Series of Δb *vs* δ curves (for six different ψ's) from which the optimal arm lengths can be selected and the values of β (shown only for $\psi=1.75$ rad) are obtained

calculated with $\varepsilon=0.3299$ rad, $b=11.8$ mm, $a=40$ mm, $\varphi=1.1406$ rad, $n_p=1.4795$, $d^{-1}=2442$ mm^{-1}, $\lambda_p=337.1$ nm and different ψ and f values. $\varepsilon\neq0$ was choosen because this arrangement is achromatic when $\varepsilon\neq0$ opposite to the case which is shown in Fig. 2. In Fig. 5 the values of ψ and f are given in rad and nm, respectively. For each ψ we can select an optimal arm length, for which β is maximum. β is the mirror rotation angle range where $|\Delta b|$ is smaller than 0.1 mm (see Fig. 6). Fig. 7 shows the optimal arm lengths and the corresponding β as a function of ψ. Fig. 7 also shows the results of calculations, which were made using $b=5.9$ mm instead of $b=11.8$ mm. According to Figs. 6 and 7 with increasing ψ the value of β also increases, but the shape of the $\Delta b-\delta$ function becomes sensitive to the arm length. The optimal arm length have a minimum at $\psi\sim0.6$ rad. If ψ is large f is significantly larger than its minimal value. This is disadvantageous because of increased demands on the mechanical stability of the mirror holding. In addition if $\psi>1.75$ rad during the turning the mirrors may touch the grating. Therefore, if large mirror tuning range is needed we must choose the pivot axis such that $\psi\lesssim1.75$ rad is valid. It is advantageous to use a smaller quartz prism because in this case β is larger and f is smaller.

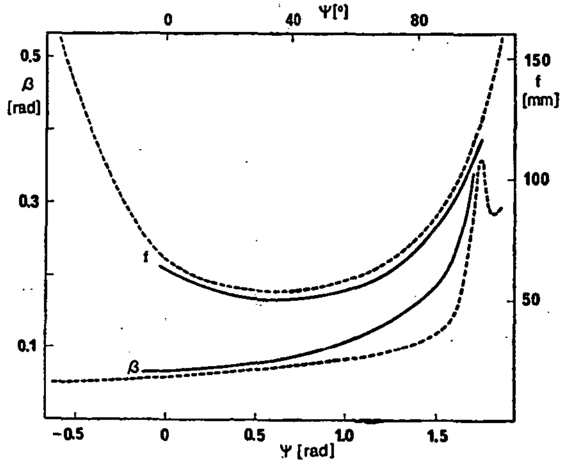

Fig. 7. Optimal arm length and β *vs* ψ with $b=11.8$ mm (broken lines) and $b=5.9$ mm (full lines)

In [4] a DFDL with the arrangement shown in Fig. 5 was investigated. The data were the same as in this article. Since the aim of that experiment was to cover the tuning range of a dye choosing $\psi=0$ rad proved to be satisfactory.

The turning range of a given arrangement can significantly be extended simply by reducing the sizes of the DFDL. From this and the fact that the limit of the chromatism is defined somewhat arbitrarily we can conclude that a tuning range of about 200 nm can be achieved without changing the refractive index of the dye solutions.

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ПЛАНИРОВАНИЕ РОС ЛАЗЕРА, ВОЗБУЖДЕННОГО АЗОТНЫМ ЛАЗЕРОМ ДЛЯ ШИРОКОЙ ОБЛАСТИ НАСТРОЙКИ

Й. Хедлинг, Ж. Бор и Б. Рац

Область настройки РОС лазера, возбужденного азотным лазером настроенного вращением зеркала, ограничена сдвигом возбуждащих пучков на поверхности кюветы. Определена ось вращения, соотвествующая минимальному сдвигу возбуждающих пучков.