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Winter College on Ultrafast Phenomena

18 February - 8 March 1991

Wavelength Tuning of Distributed Feedback Dye Lasers

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Wavelength Tuning
of Distributed
Feedback Dye
Lasers

Alexander Müller
Max-Planck-Institut
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Chemie
Göttingen
Germany

Spectral Width of a bandwidth-limited Gaussian Pulse:

$$\Delta\nu \cdot \Delta t_p = 0.44$$

$$\Delta\lambda = \frac{\lambda^2}{c} \cdot \frac{0.44}{\Delta t_p}$$

$\lambda = 500 ... 600$ nm

Δt_p	$\Delta\lambda$
100 fs	4 nm
1 ps	0.4 nm
100 ps	4 pm

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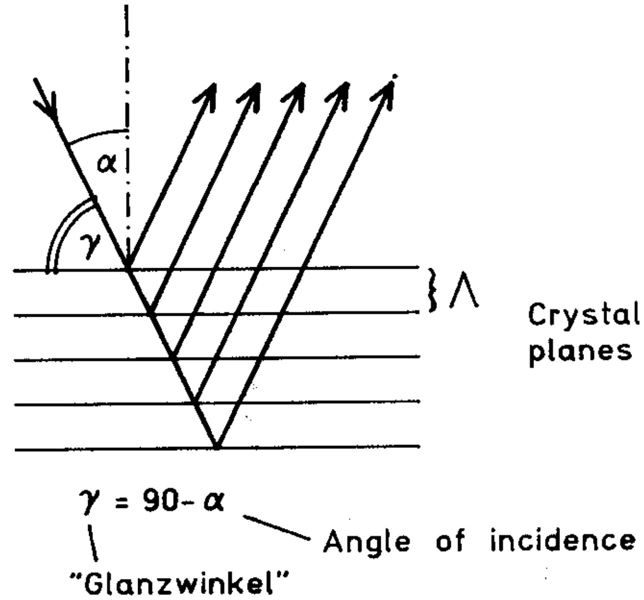
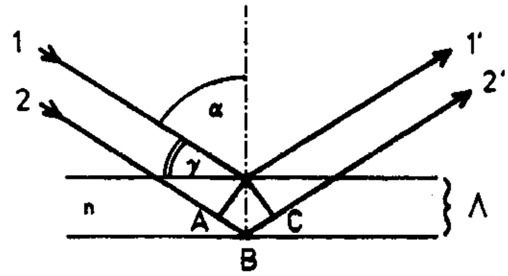
Bragg Scattering



Bragg Scattering



Optical path difference: $\Gamma = (\overline{AB} + \overline{BC}) \times n$

$\overline{AB} = \overline{BC} = n \times \Lambda \times \cos\alpha$

$\Gamma = 2 \times n \times \Lambda \times \cos\alpha$

$\gamma = 90 - \alpha$

Condition for Intensity Maxima

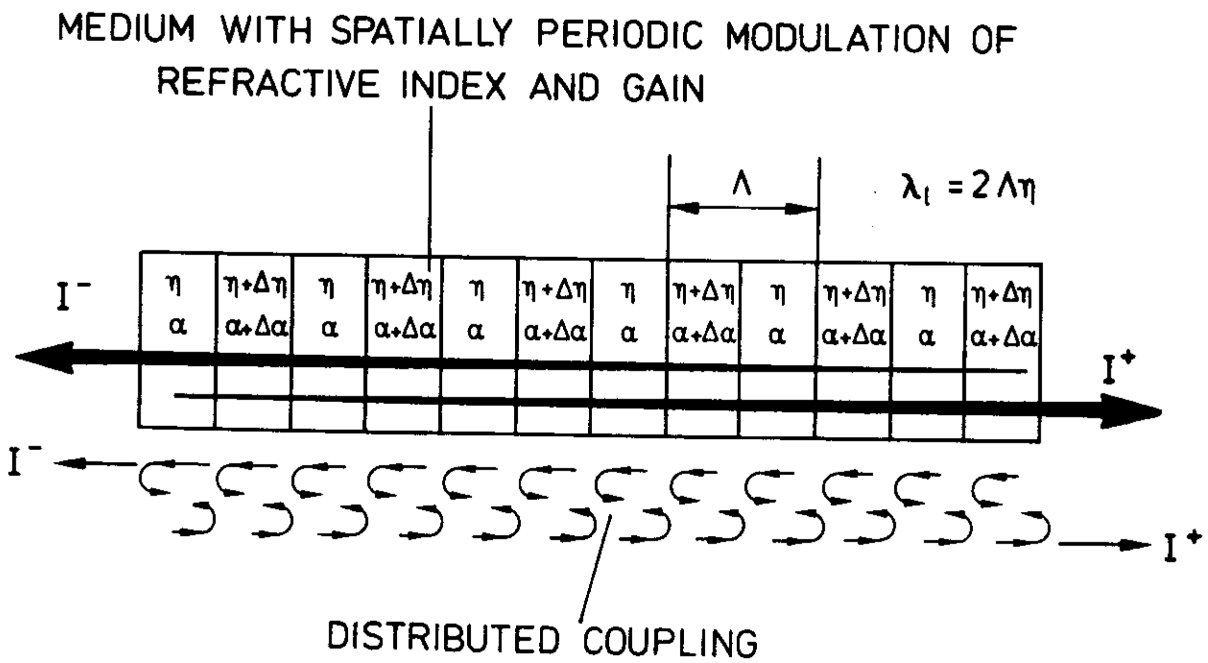
$$\Gamma = 2 \times n \times \Lambda \times \sin\gamma = m \times \lambda$$

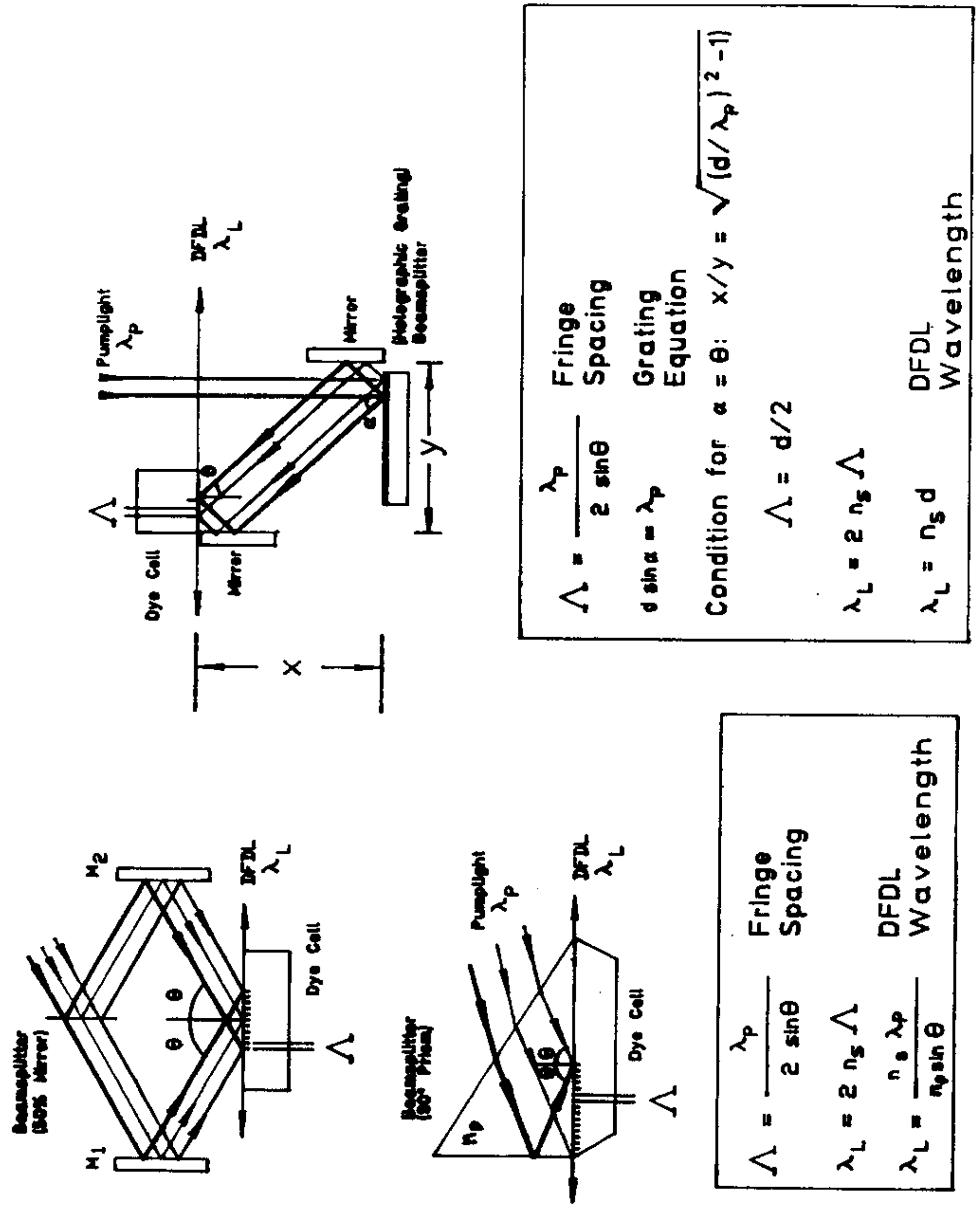
Bragg's Law

$\gamma = 90°$ Normal Incidence $2 \times n \times \Lambda = m \times \lambda$ (m: interference order)

Working Condition of DFDL

PRINCIPLE OF DISTRIBUTED FEEDBACK LASER



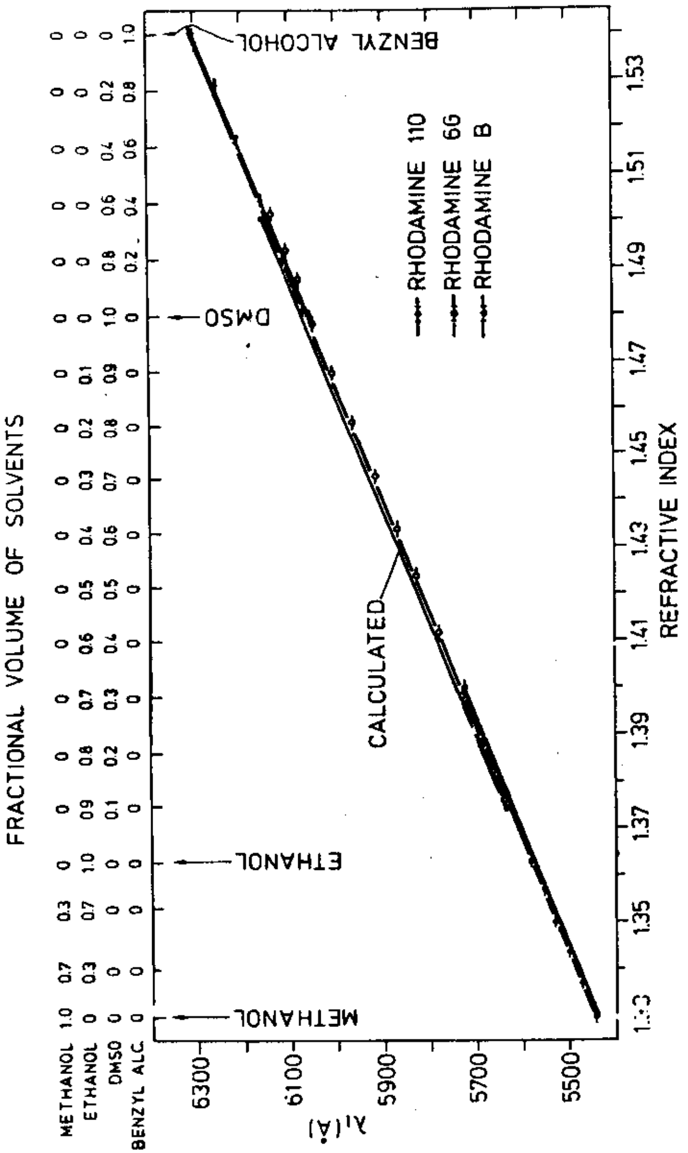


Wavelength Tuning of the Distributed Feedback Dye Laser

$$\lambda_D = \frac{2 \times n_s \times \Lambda}{m}$$

n_s = refractive index of dye solution depends on:

solvent composition
temperature
pressure



Dependence of refractive index n on temperature and pressure is given by the LORENTZ-LORENZ formula (1880):

$$\alpha = \frac{3}{4\pi N}\,\frac{\varepsilon - 1}{\varepsilon + 2} = \frac{3}{4\pi N}\,\frac{n^2 - 1}{n^2 + 2}$$

Maxwell's Relation $\varepsilon = n^2$

α = mean polarizability
ε = dielectric constant
N = number density

Introducing the molar refractivity A

$$A = \frac{4\pi}{3} N_m \alpha$$

$N_m = 6.02 \cdot 10^{23}$ molecules/mole
Avogadro's Number

$$\boxed{A = \frac{4\pi}{3} N_m \alpha}$$

Molar Refractivity

$$\frac{N_m}{N} = \frac{(M)}{\rho}$$

(M) = molecular weight

ρ = mass density

T = absolute temperature

p = pressure

$$\boxed{A = \frac{(M)}{\rho} \frac{n^2-1}{n^2+2} \approx \text{const}}$$

$$\rho = \rho(p) \qquad \rho = \rho(T)$$

$$\boxed{\kappa = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial p}\right)_T} \qquad \boxed{\gamma = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p}$$

$$\gamma = 3\alpha'$$

κ = Compressibility of the liquid

α' = linear } expansion

γ = cubic } coefficient

$$\frac{n^2-1}{n^2+2} = \frac{A}{(M)} \cdot \rho$$

Temperature dependence of n:

$$\frac{d\left(\frac{n^2-1}{n^2+2}\right)}{dn} \cdot \frac{dn}{dT} = \frac{A}{(M)} \cdot \frac{d\rho}{dT}$$

$$\frac{6n}{(n^2+2)^2} \cdot \frac{dn}{dT} = \frac{A}{(M)} \cdot \frac{d\rho}{dT}$$

$$\boxed{\frac{dn}{dT} = \frac{A}{(M)} \cdot \frac{(n^2+2)^2}{6n} \cdot \frac{d\rho}{dT}}$$

$$\lambda_D = 2 \cdot n \cdot \Lambda$$

$$\boxed{\frac{d\lambda_D}{dT} = 2\Lambda \cdot \frac{dn}{dT}}$$

12.2.91 / DFDL10.MCD
Temperaturabhängigkeit der Laserwellenlänge
(vgl. Lusty & Dunn (1987)

$\Phi := 10^{-3}$ dn_s/dT für organ. Lösungsmittel

$\lambda_p := 532 \cdot nm$ Pumpwellenlänge

$\theta := 50 \cdot deg$ Pump-Einfallswinkel

$\frac{\lambda_p}{\sin(\theta)} = 694.477 \cdot nm$

$Delta\_\lambda = d\lambda_L/dT = (d\lambda_L/dn_s)*(dn_s/dT)$

$Delta\_\lambda := \frac{\lambda_p}{\sin(\theta)} \cdot \Phi$ $d\lambda_L/dT$ für den DFDL

$Delta\_\lambda = 0.694 \cdot nm$ pro grad

Liquid	Density	γ	κ
	$g\ cm^{-3}$	K^{-1}	atm^{-1}
Acetone	0.791	$1.43 \cdot 10^{-3}$	$1.26 \cdot 10^{-4}$
Ethanol	0.789	1.10	1.14
Methanol	0.792	1.19	1.20

at 18°C

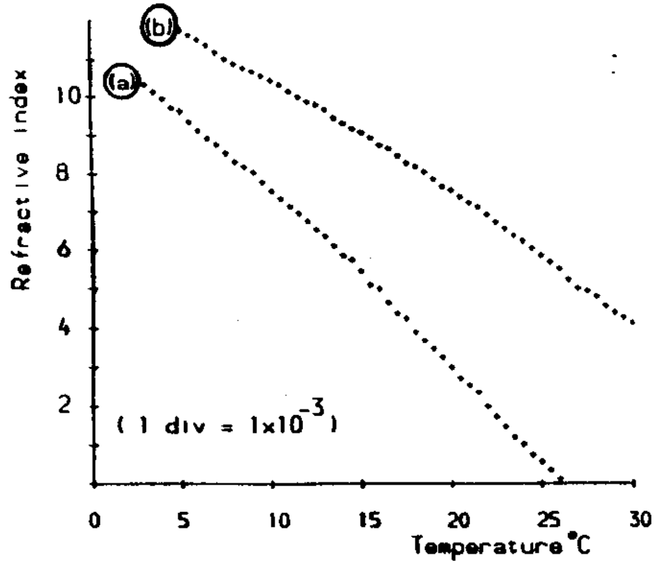


Fig. 1. Refractive index against temperature of *a* methanol, and *b* ethylene glycol. Vertical axis divisions correspond to a change in refractive index of 1×10^{-3} Methanol had the largest dn/dT of any of the solvents measured

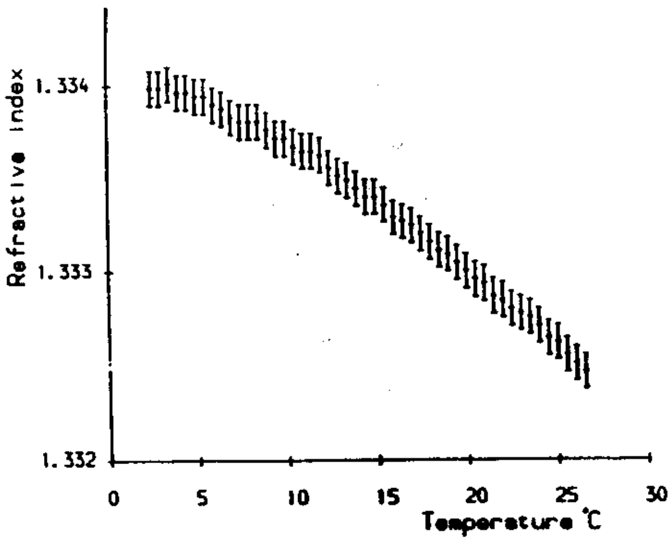


Fig. 3. Refractive index against temperature of pure water. Vertical axis divisions correspond to a change in refractive index of 1×10^{-3}. Around 4 °C refractive index is constant i.e. $dn/dT = 0$

LUSTY AND DUNN (1987)

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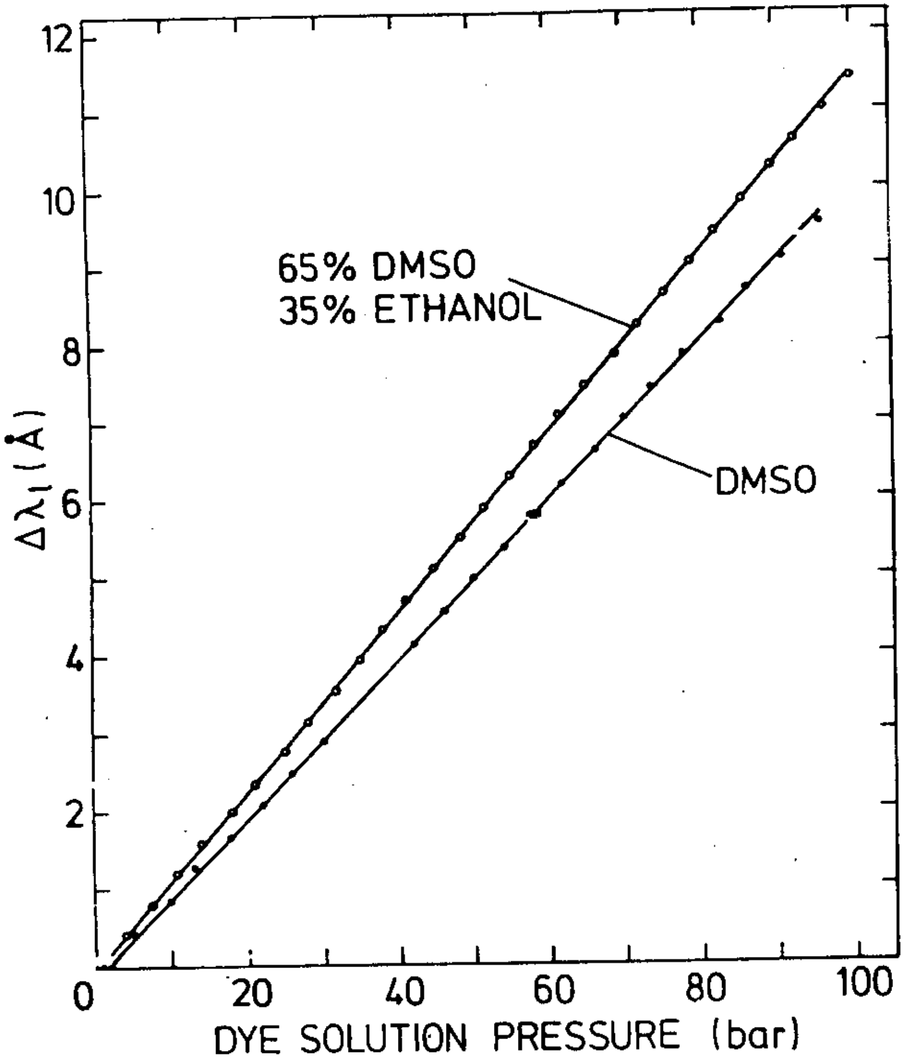
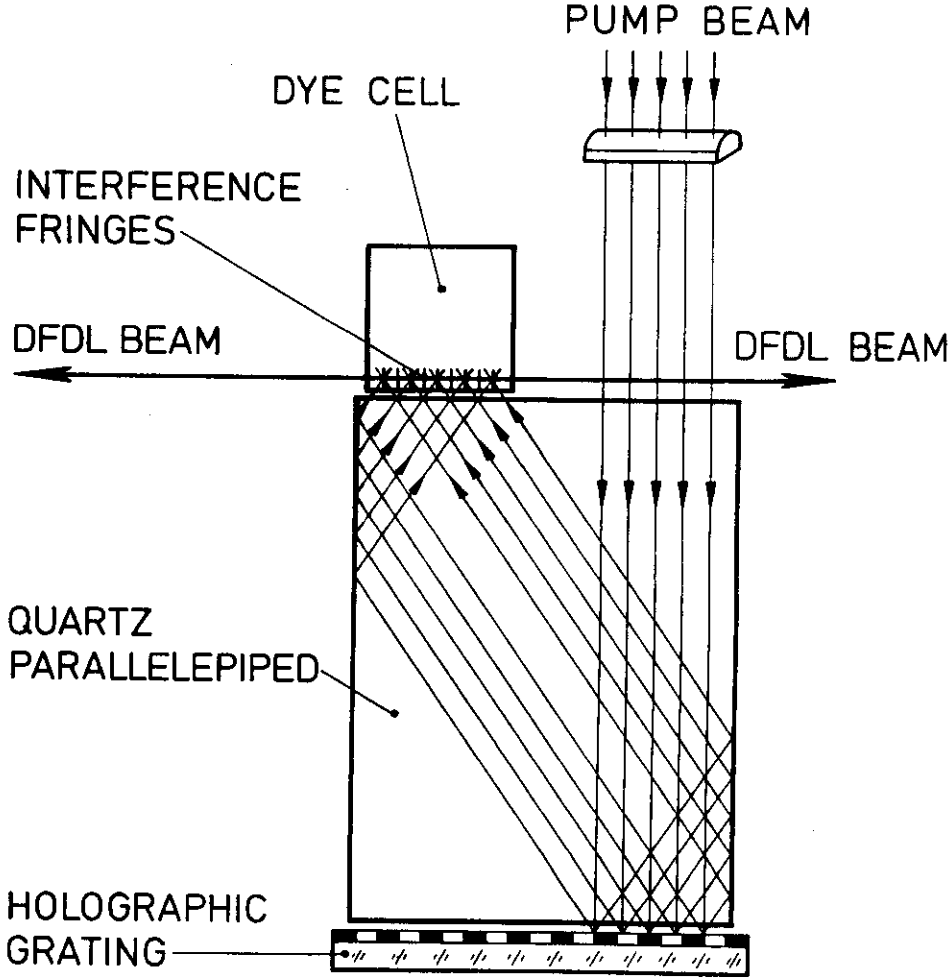
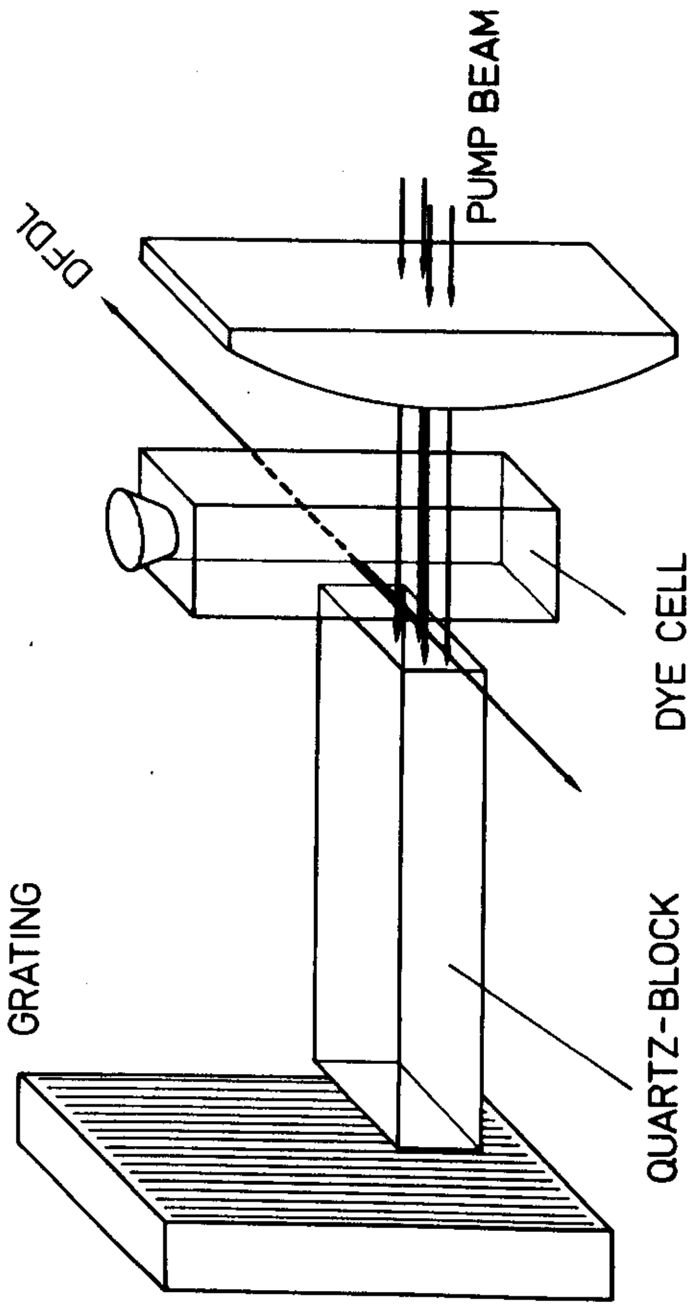
Table 1. Measured values of dn/dT (over range 5–25 °C) for organic solvents. For convenience refractive index data for the individual solvents is given in brackets, and is taken from CRC [8] tabulated values

Solvent	n(20 °C)	dn/dT [-1×10^{-5} K^{-1}] (5–25 °C)
Methanol	(1.327)	46.8(1.1)
Ethanol	(1.360)	43.8(0.4)
Ethylene glycol	(1.431)	30.6(0.3)
Benzyl alcohol	(1.540)	42.0(0.4)
Propylene carbonate	(1.421)	38.0(0.4)
50/50 BA/PC	(1.471)	42.0(0.5)

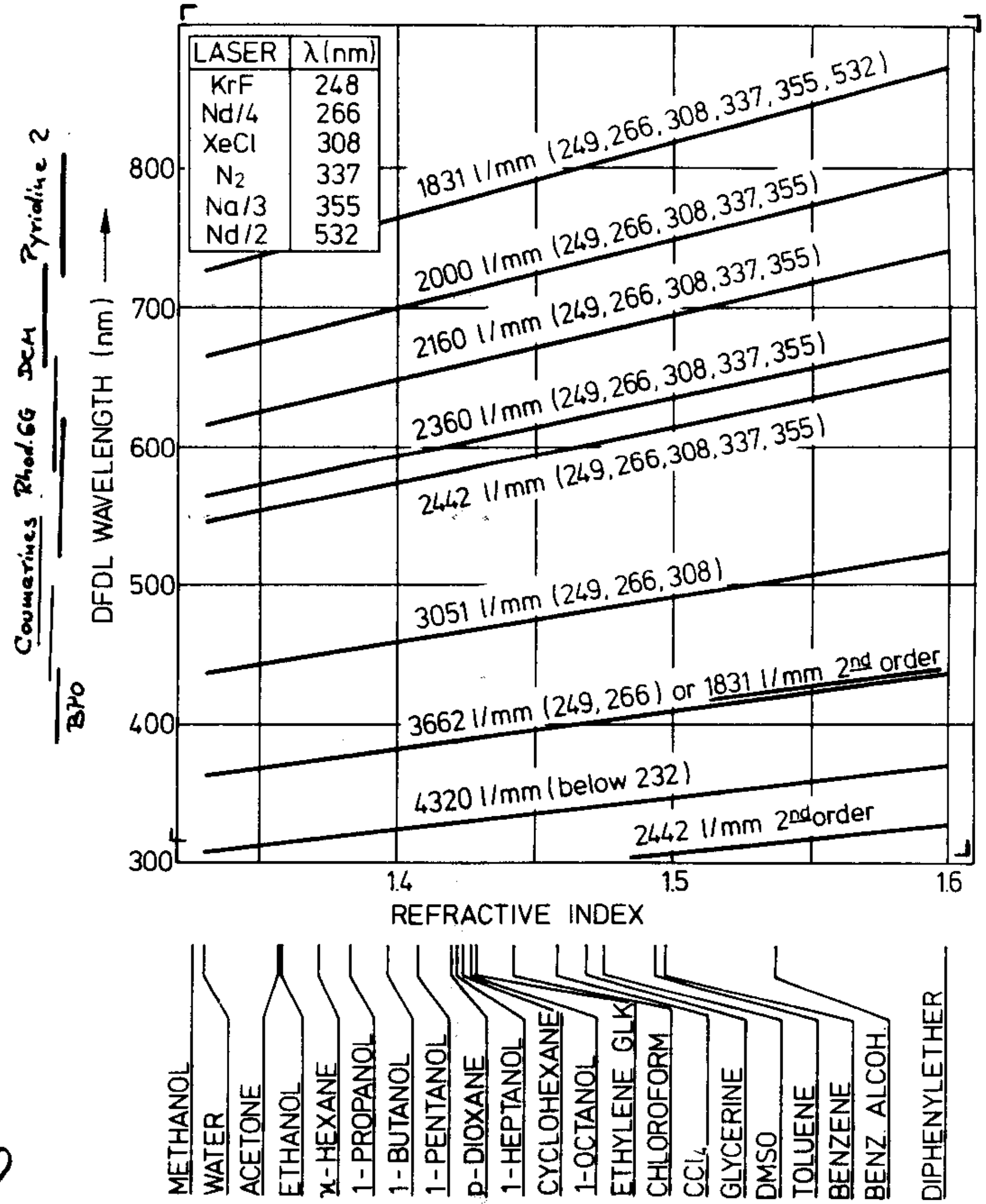
LUSTY AND DUNN (1987)


12
10
8
6
4
2
0
20
40
60
80
100
$\Delta\lambda_l$ (Å)
DYE SOLUTION PRESSURE (bar)
65% DMSO
35% ETHANOL
DMSO


PUMP BEAM
DYE CELL
INTERFERENCE
FRINGES
DFDL BEAM
DFDL BEAM
QUARTZ
PARALLELEPIPED
HOLOGRAPHIC
GRATING



$$\lambda_L = \frac{2 n_s \Lambda}{m} = \frac{2 n_s d}{m}$$



DFDL with holographic grating as beamsplitter

$$\lambda_L = \frac{2\, n_s\, \Lambda}{m}$$

Operation in 2^{nd} order: $m=2$

grating constant: 1831 lines/mm

pump laser: nitrogen
(Lambda Physik M-1000)

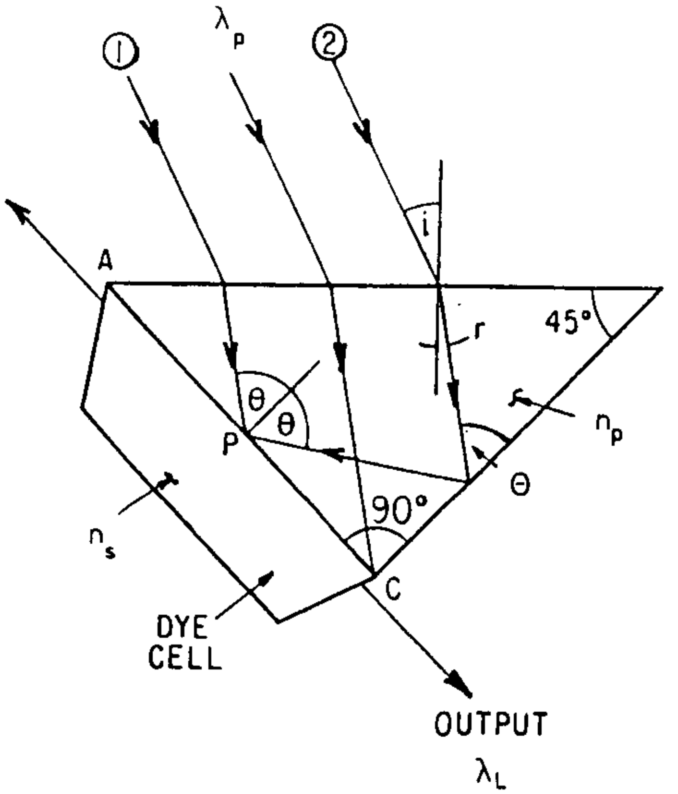
DYE	CONCENTRATION MOL/L	SOLVENT	LASING WAVELENGTH NM
PBD	$5 \cdot 10^{-3}$	38% ETHANOL 62% METHANOL	363
BIBUQ	$1 \cdot 10^{-3}$	80% DIOXANE 20% ETHANOL	383
BIBUQ	$1.5 \cdot 10^{-3}$	100% DIOXANE	388
DPS	$1 \cdot 10^{-3}$	90% TOLUENE 10% ETHANOL	404
STILBEN 1	SATURATED	50% DIMETHYLSULFOXIDE 50% DIPHENYLETHER	413
BIS-MSB	$1 \cdot 10^{-3}$	25% DIOXANE 75% DIPHENYLETHER	421

Wavelength Tuning of the Distributed Feedback Dye Laser

$$\lambda_D = \frac{2 \times n_s \times \Lambda}{m}$$

Λ = Separation of Interference Fringes

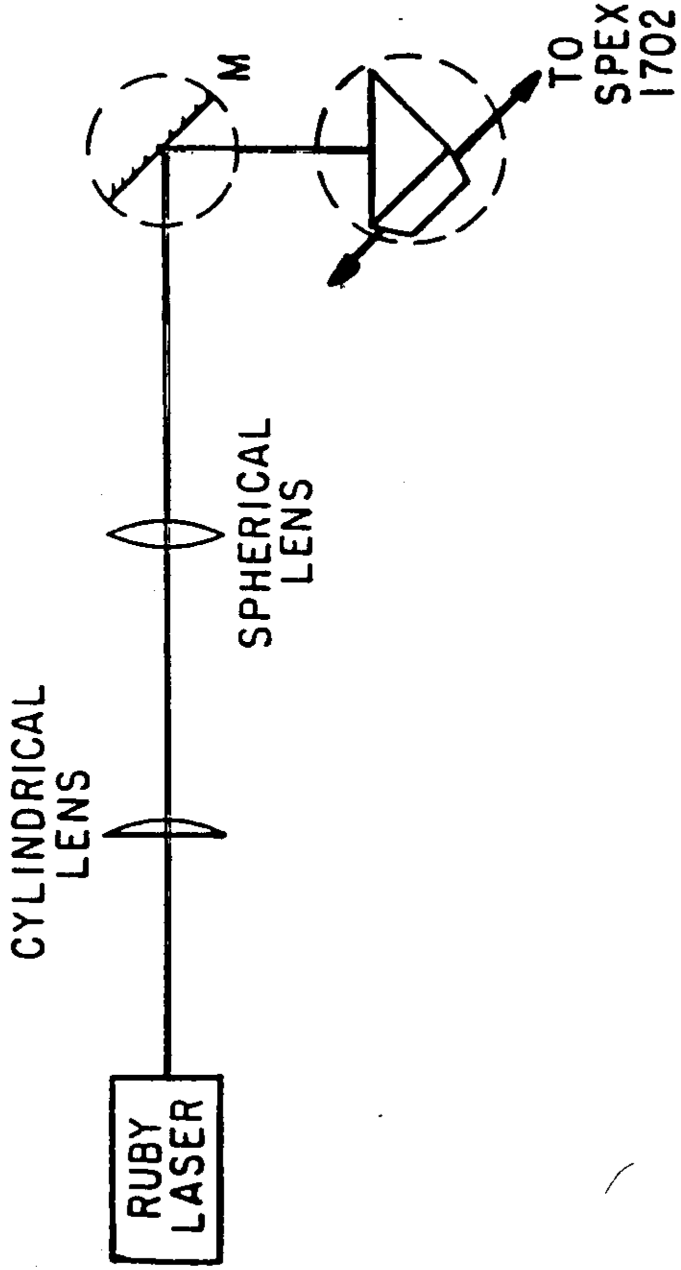
Prism Dye Laser



$$\lambda_L = \frac{n_s \lambda_p}{n_p \sin \Theta} \qquad \Theta = \frac{\pi}{4} + r$$

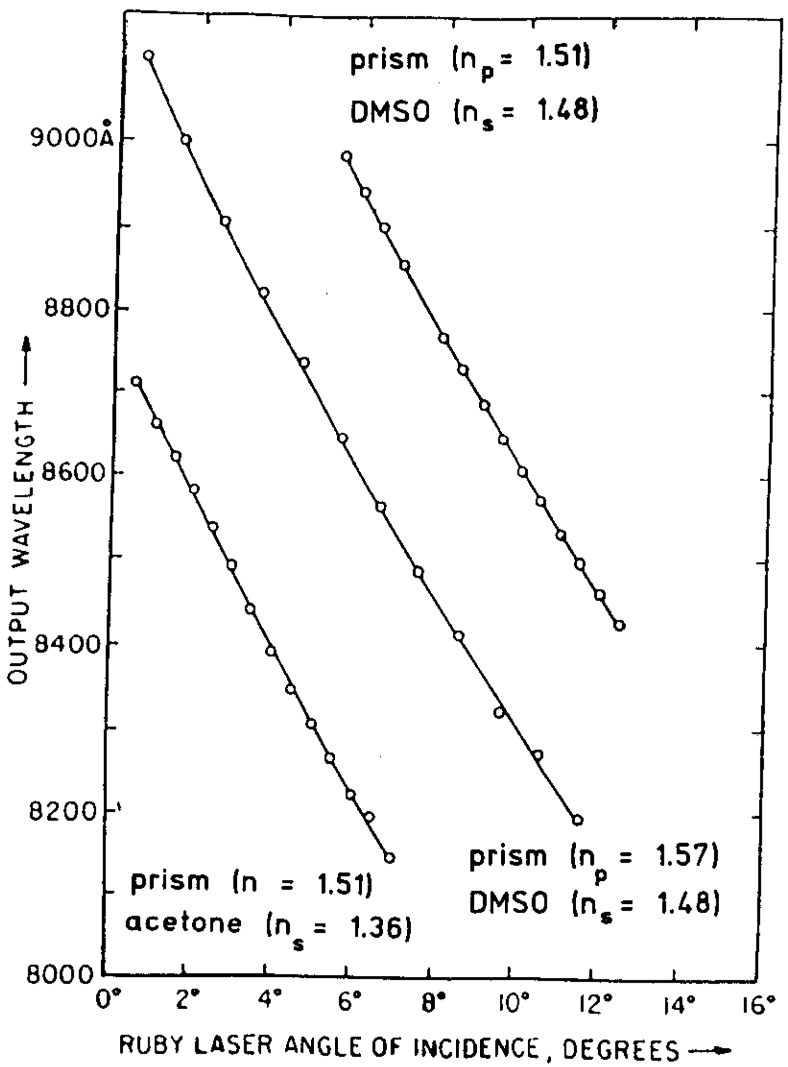
$$\lambda_L = \frac{n_s \lambda_p}{n_p \sin\left[\frac{\pi}{4} + \arcsin\left(\frac{\sin i}{n_p}\right)\right]}$$

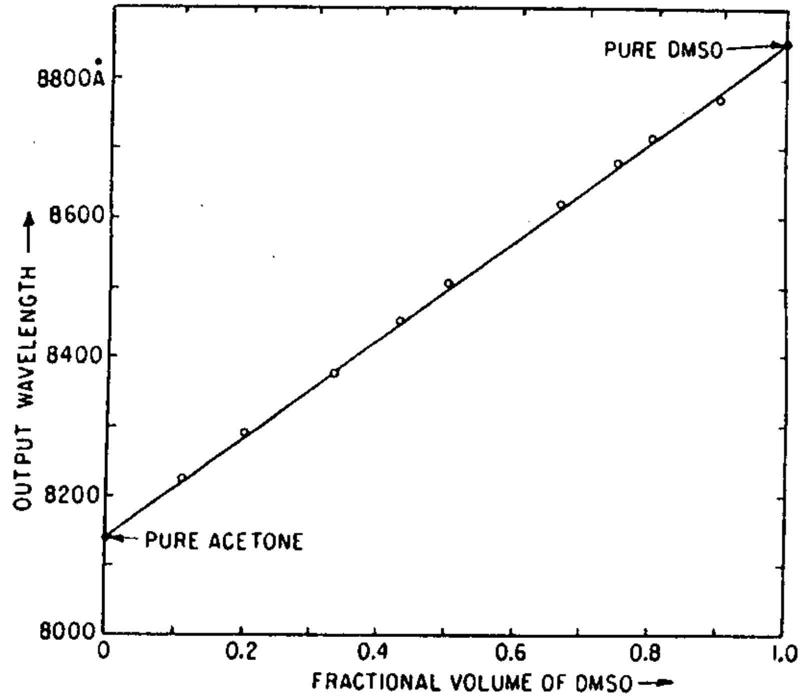
Chandra et al. (1972)



Chandra et al. (1972)

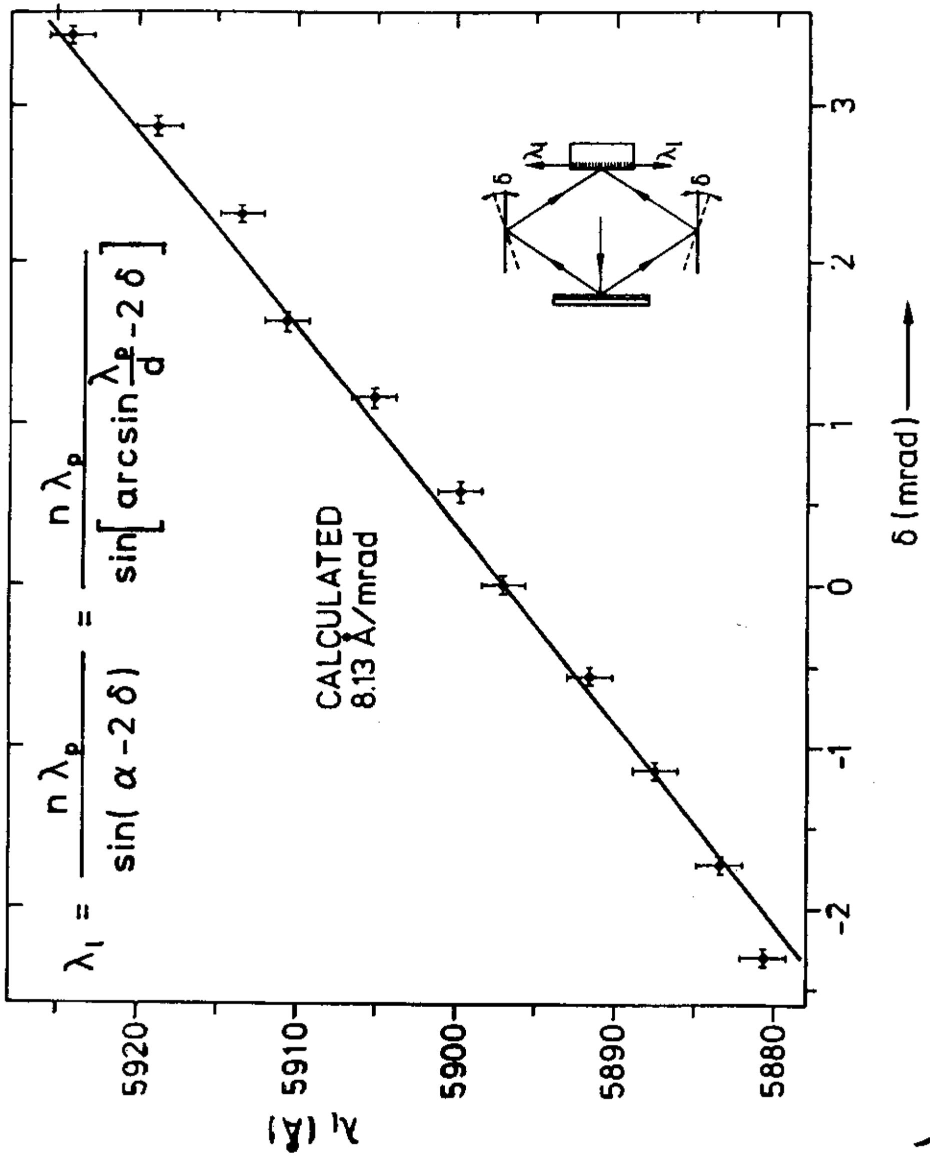
Prism Dye Laser





Chandra et al. (1972)

Chandra et al. (1972)



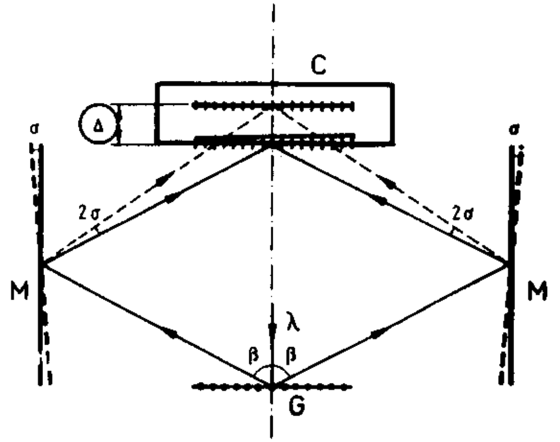


Fig. 4. Displacement of the coherence plane in the dye cuvette, if the mirrors (or prisms) are rotated.

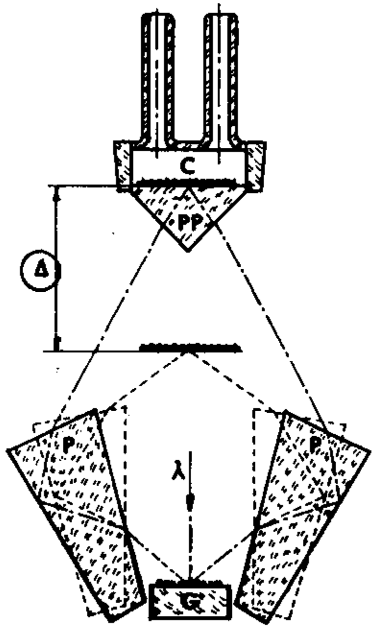


FIG. 2. Displacement of the coherence plane, if prisms P are rotated.

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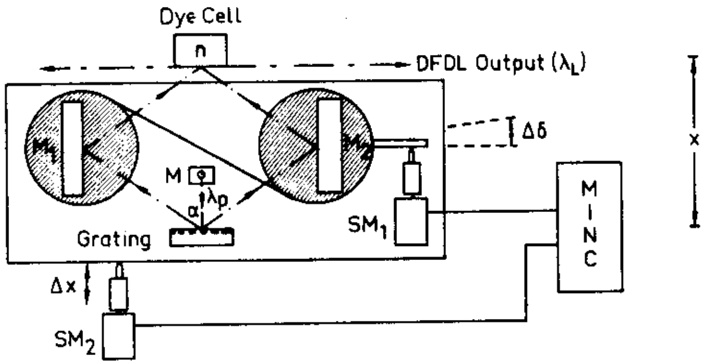
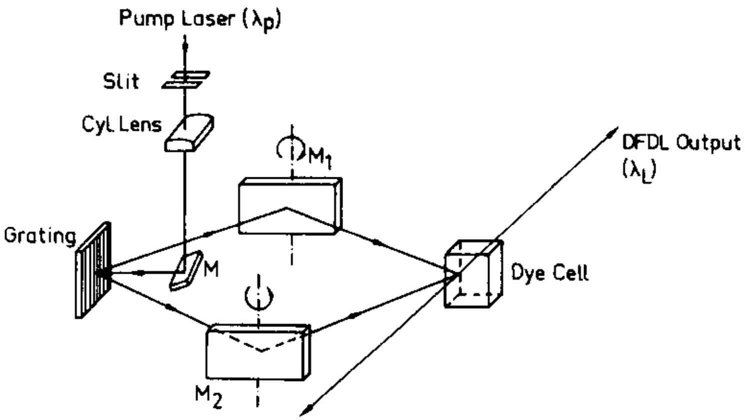
Computer Controlled Distributed Feedback Dye Laser

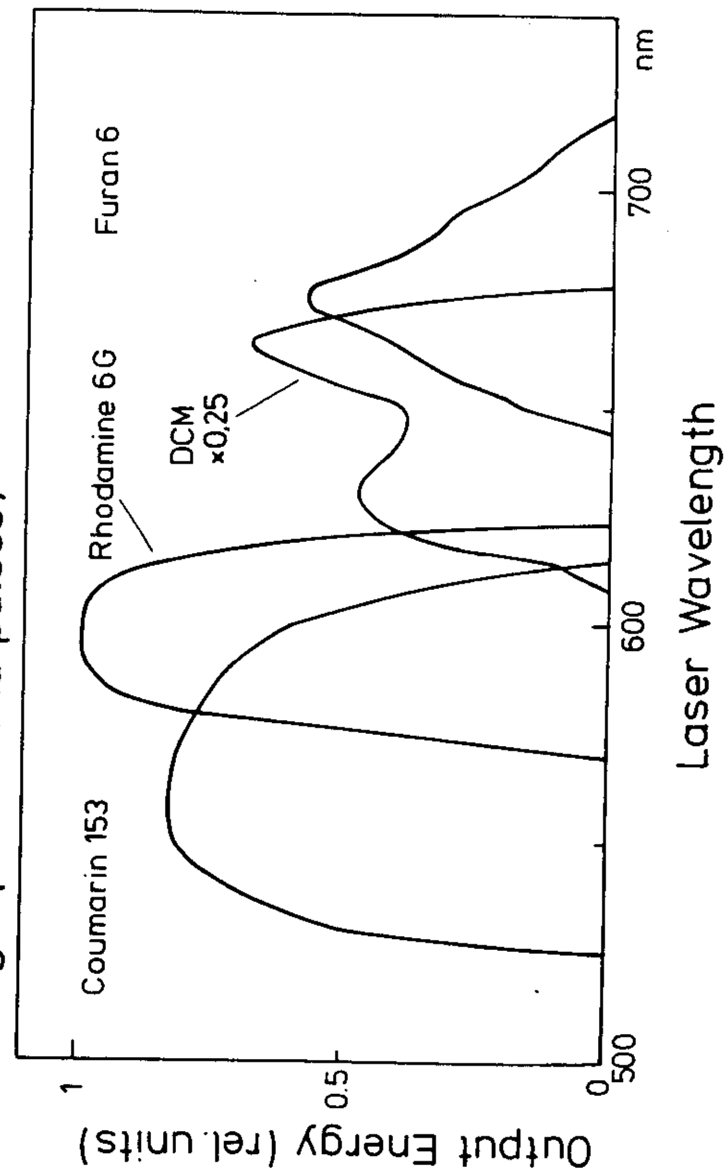


$$\Delta\delta = \frac{1}{2}\left[\alpha - \arcsin\left(n\,\frac{\lambda_p}{\lambda_L}\right)\right]$$

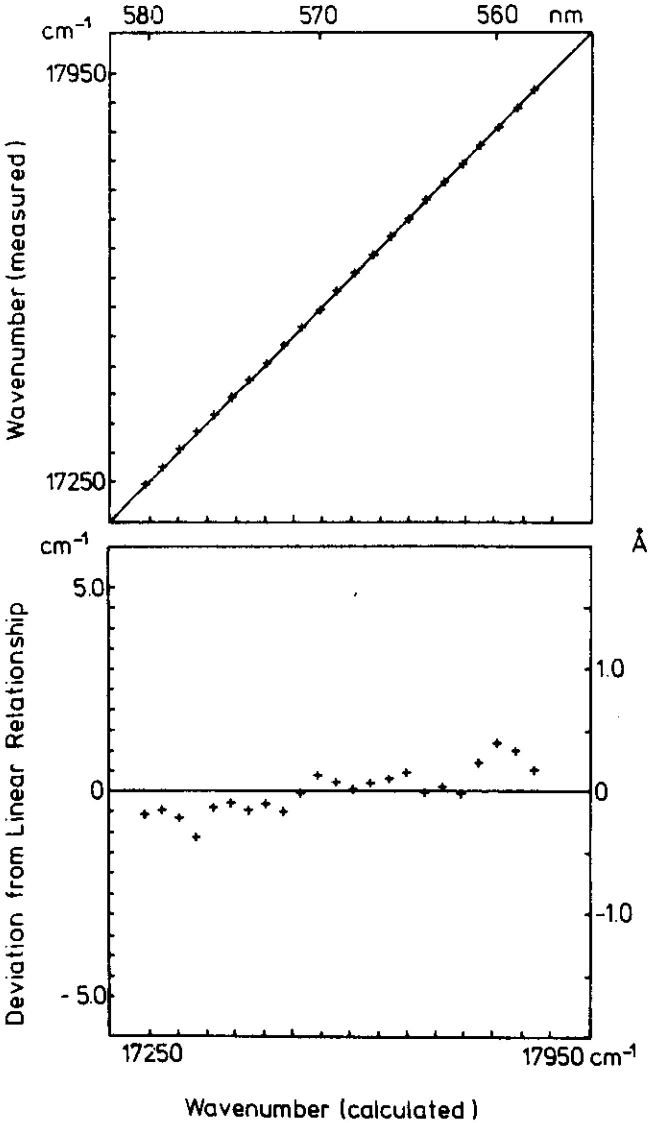
$$\Delta x = \frac{x}{2}\left[tg\,\alpha \cdot tg(90 - \alpha + 2\Delta\delta) - 1\right]$$

$$\alpha = \arcsin\left(\frac{\lambda_p}{d}\right)$$

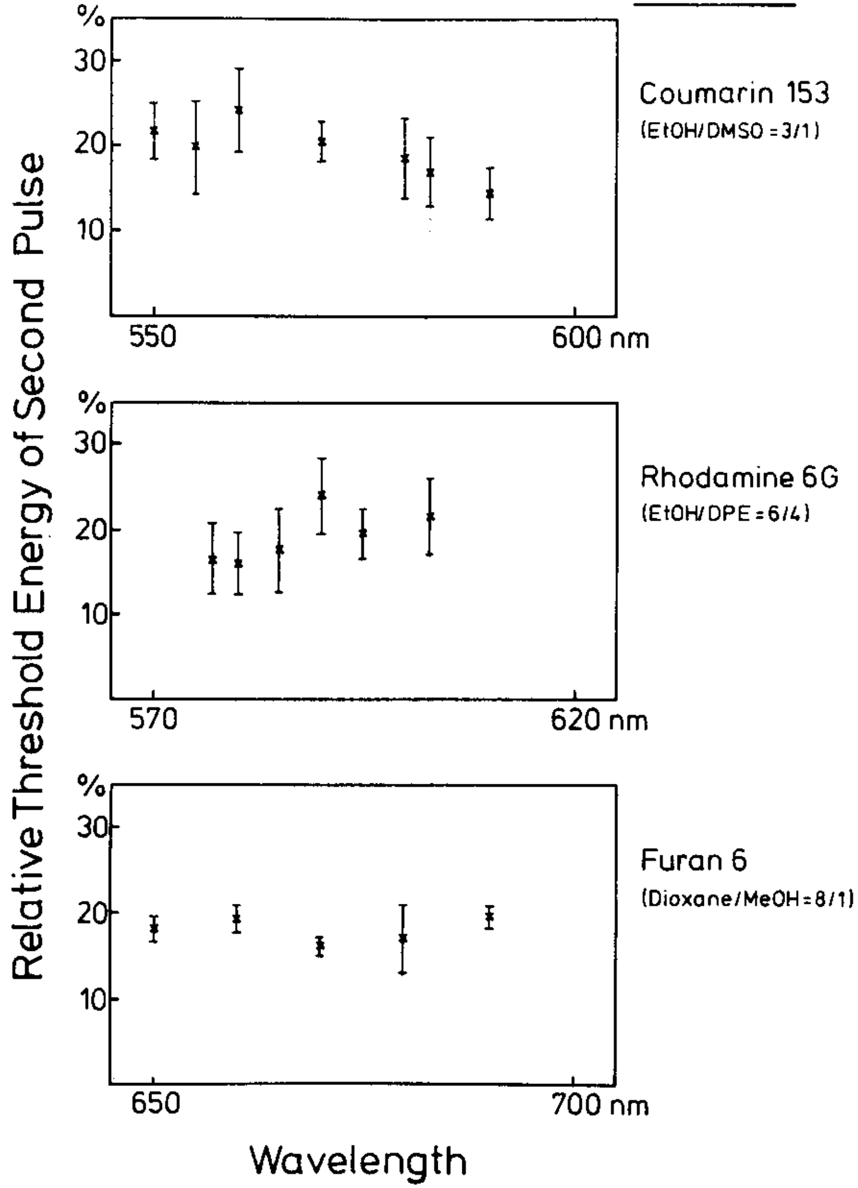


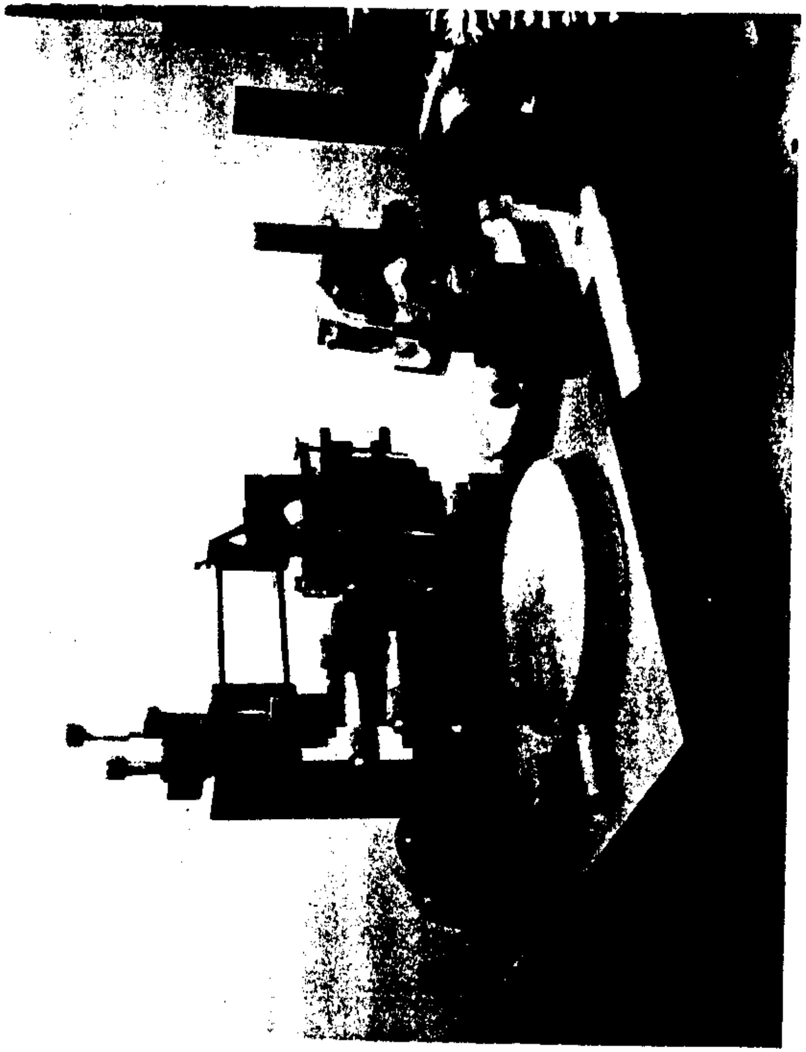


Computer Controlled DFDL
Accuracy of tuning for Coumarin 153



Laser Dyes





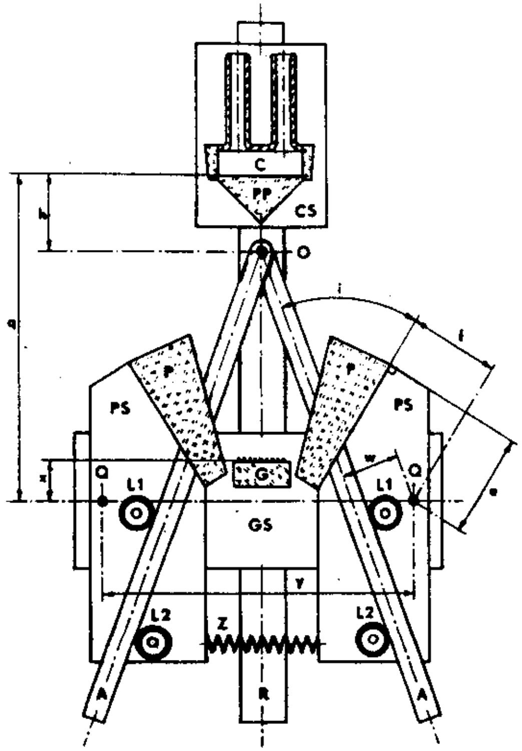


FIG. 3. Mechanical arrangement of the DFDL (see text). JASNY (1986)

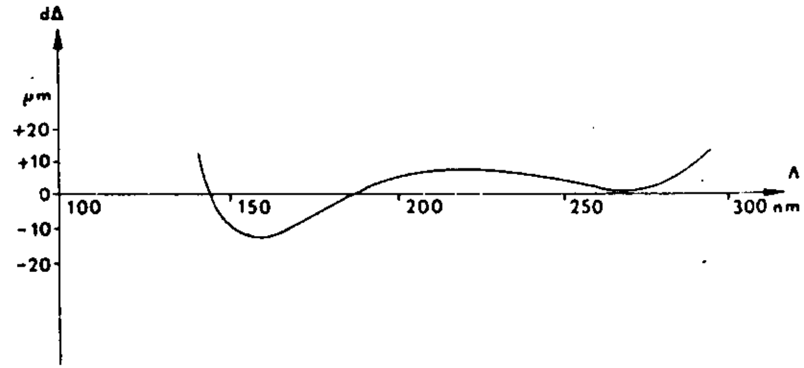
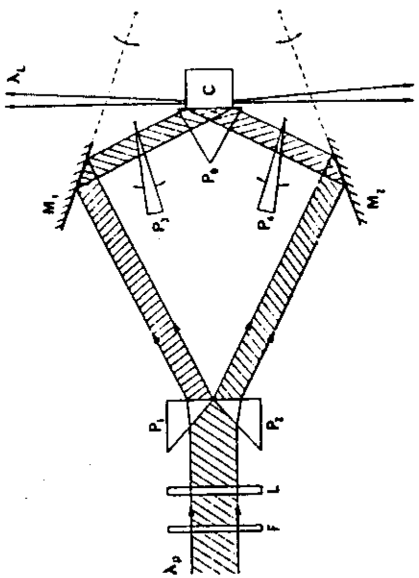
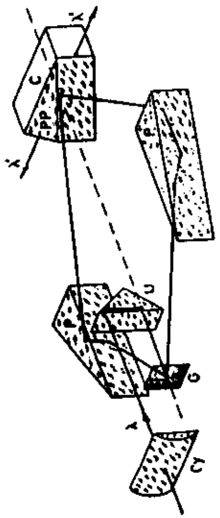


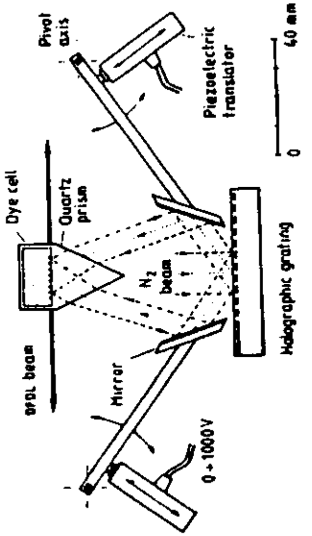
FIG. 4. Displacement error $d\Delta$ (see text), as a function of fringe constant Λ.



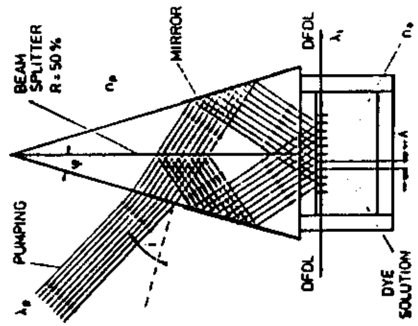
G.M.Gale, P.Ranson, M.Denariez-Roberge
Appl.Phys. B44, 221 (1987)



J.Jasny
Opt.Commun. 53, 4 (1985)

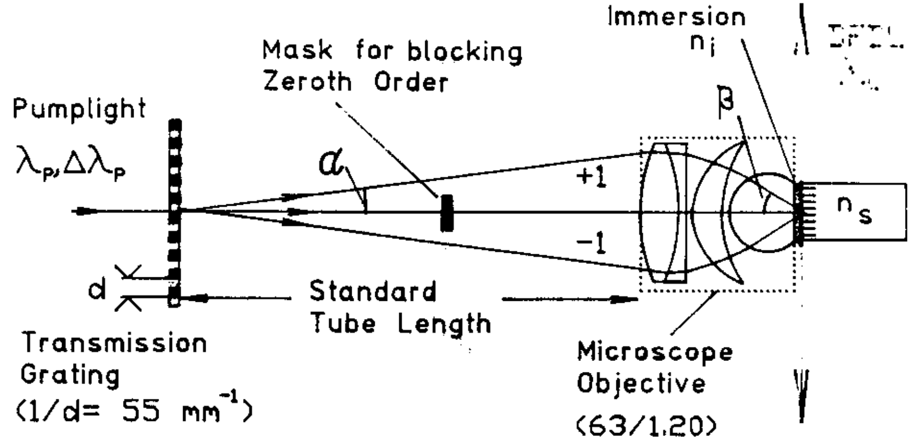


J.Hebling, Zs.Bor
J.Phys.E:Sci.Instr. 17, 1077 (1984)



Zs.Bor, G.Szabo
Appl.Phys. B (1988)

Microscope – DFDL



$$\Lambda = \frac{\lambda_P}{2(n_i \sin\beta)} = \begin{cases} \dfrac{\lambda_P}{2\ NA} \\ \dfrac{d}{2 n_i}\left(\dfrac{\sin\alpha}{\sin\beta}\right) \sim \text{independent on } \lambda_P \end{cases}$$

$$\lambda_L = 2 n_s \Lambda = \begin{cases} n_s \dfrac{\lambda_P}{NA} = 390 \text{ nm (Min)} \quad (n_s = 1.3,\ \lambda_P = 360 \text{ nm},\ NA = 1.20) \\ n_s d \dfrac{\sin\alpha}{n_i \sin\beta} \approx n_s \dfrac{d}{M} \end{cases}$$

Variable Magnification M -> λ_L - Tuning

Szatmari & Schäfer (1988)

Selected Literature on DFDL wavelength tuning:

(1) Zs. Bor, A. Müller : IEEE J. Quant. El. [QE-22], 1524 - 1533 (1986) Review paper

(2) C.V. Shank et al. : Appl. Phys. Lett. [18], 395 (1971)

(3) S. Chandra et al. : Appl. Phys. Lett. [21], 144 - 146 (1972)

(4) Zs. Bor : Opt. Commun. [29], 103 - 108 (1979)

(5) M.E. Lusty, M.H. Dunn : Appl. Phys. [44B], 193 - 198 (1987)

(6) J. Hebling, Zs. Bor : J. Phys. E: Sci. Instr. [17], 1077 - 1080 (1984)

(7) G.M. Gale et al. : Appl. Phys. [44B], 221 - 233 (1987)

(8) J. Jesny : Rev. Sci. Instr. [57], 1303 - 1307 (1986)

(9) S. Szatmari, F.P. Schäfer : Appl. Phys. [46B], 305 - 311 (1988)