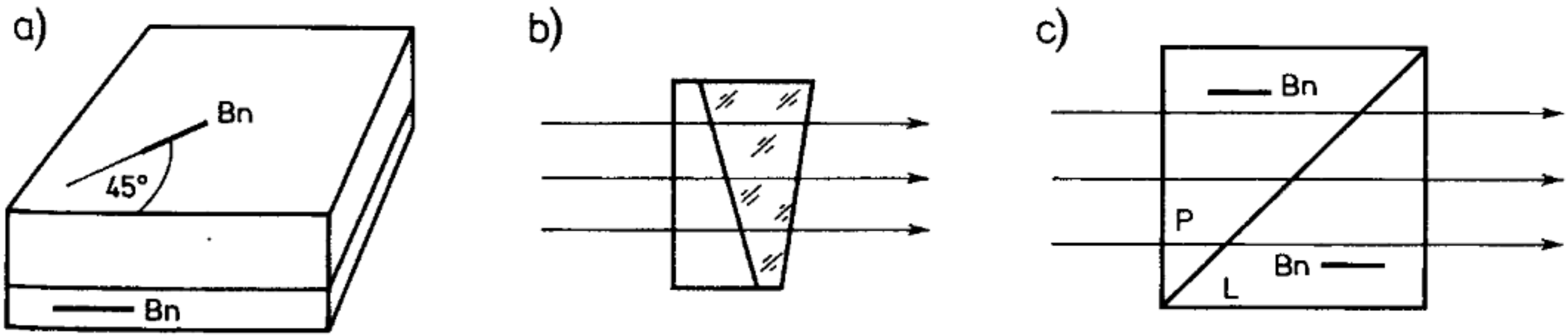
Depolarization of light

Depolarization

- It is not so easy to depolarize light,
- A total depolarization is rather not possible,
- There are some methods to immitate disorder in oscillations of E vector,



Rys. 10.10. a) Depolaryzator Lyota, b) depolaryzator Hanlego, c) depolaryzator Cornu

Depolarization

- Lyott depolarizer
  - Used for depolarization of non-monochromatic light,
  - it consists of two uniaxial plates, where one is twice times thicker than second one,
  - Both are cutted pararelly to the optical axis,
  - The binormal axes forms a 45 degrees angle,
  - When polichromatic linearly polarized light propagates through depolarizer, then each wavelengths gains new polarization,
  - As a result, we get an immitation of depolarized light beam,
  - Redundant polarization is 1%

Hanle depolarizer

- It consists of crystallic wedge, with its axis lays in incidential plane and is aligned under 45 degrees,
- Second glass wedge is for compensation of the beam direction,
- Each ray changes its polarization state depending on thickness of the wedge,
- Redundant polarization is 1%

Cornu depolarizer

- The idea is similar to Henle depolarizer,
- It consists of two wedges made of optically active crystals: one lefthanded and second righthanded,
- The light beam at the output consists of beams with different aximuths but the same ellipticity,

Depolarization of partially coherent light

- Is defined in many ways *(C.Brosseau, R.A. Chipman, S.N. Sasenkov),*
- Is described by many mathematical theories,
- Can be considered as a result of light scattering in optical medium,
- 1997 r. This phenomena was analyzed in context of isotropy,

$$[M] = [M_j] + [M_D]$$

$$[M_D] = \begin{bmatrix} d & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$d = m_{00} - \left[\frac{1}{3}\left[Tr(M^T M) - m_{00}\right]\right]^{\frac{1}{2}}$$

Depolarization of partially coherent light

- For anisotropic depolarization:

$$[M_D] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & m_{11}(n) & 0 & 0 \\ 0 & 0 & m_{11}(n) & 0 \\ 0 & 0 & 0 & m_{33}(n) \end{bmatrix}$$

$$m_{11}(n) = \frac{3 \cdot \left(\frac{7}{10}\right)^n}{2 + \left(\frac{7}{10}\right)^n}$$

$$m_{33}(n) = \frac{3 \cdot \left(\frac{1}{2}\right)^n}{2 + \left(\frac{7}{10}\right)^n}$$

Degree of polarization

$$P = \left[2\left[\frac{\|\mathrm{K}\|_F}{Tr(\mathrm{K})}\right]^2 - 1\right]^{\frac{1}{2}}$$

Coherence of light

- Spatial – transversal,
- Temporal - longitudinal – has influence on depolarization,
- Temporal coherence can be expressed by complex degree of coherence,

$$\gamma(\tau) = \frac{\langle E^*(t)E(t+\tau)\rangle}{\langle |E(t)|^2\rangle}$$

← Complex degree of coherence

$$\gamma(\tau) = \int_0^\infty \hat{G}(v)\exp(-i2\pi v\tau)\,dv$$

← Based on properties of self coherence function

$$\hat{G}(v) = \begin{cases} \dfrac{G(v)}{\int_0^\infty G(v)dv} & dla\ v > 0 \\ 0 & dla\ v \leq 0 \end{cases}$$

Coherence of light

Distribution of spectral light intensity:

- Gauss function $$\hat{G}(\nu) = \frac{2\sqrt{\ln(2)}}{\sqrt{\pi}\Delta\nu}\exp\left[-\left(2\sqrt{\ln(2)}\frac{\nu-\bar{\nu}}{\Delta\nu}\right)^2\right]$$
- Lorentz function $$\hat{G}(\nu) = \frac{2(\pi\Delta\nu)^{-1}}{1+4\left(\frac{\nu-\bar{\nu}}{\Delta\nu}\right)^2}$$

$\bar{\nu} = \frac{c}{\bar{\lambda}}$ Central frequency

$\Delta\nu = \frac{c\Delta\lambda}{\bar{\lambda}^2 - \frac{1}{4}\Delta\lambda} \approx c\frac{\Delta\lambda}{\bar{\lambda}^2}$ Half width of frequency

$\bar{\lambda}$ Central wavelength

$\Delta\lambda$ Shalf width of light

It is correct for quasi-monochromatic light sources

Light coherence

Gaussian light sources

$$\gamma_G(\tau) = exp\left[-\left(\frac{\pi\Delta\nu\tau}{2\sqrt{ln(2)}}\right)^2\right]\exp\left(-i2\pi\bar{\nu}\tau\right)$$

$$\tau_{cG} = \frac{2\sqrt{\ln(2)}}{\pi\Delta\nu}$$

$$\Delta L_G = c\tau_{cG}$$

Lorentzian light sources

$$\gamma_L(\tau) = exp(-\pi\Delta\nu\tau)\exp\left(-i2\pi\bar{\nu}\tau\right)$$

$$\tau_{cL} = \frac{1}{\pi\Delta\nu}$$

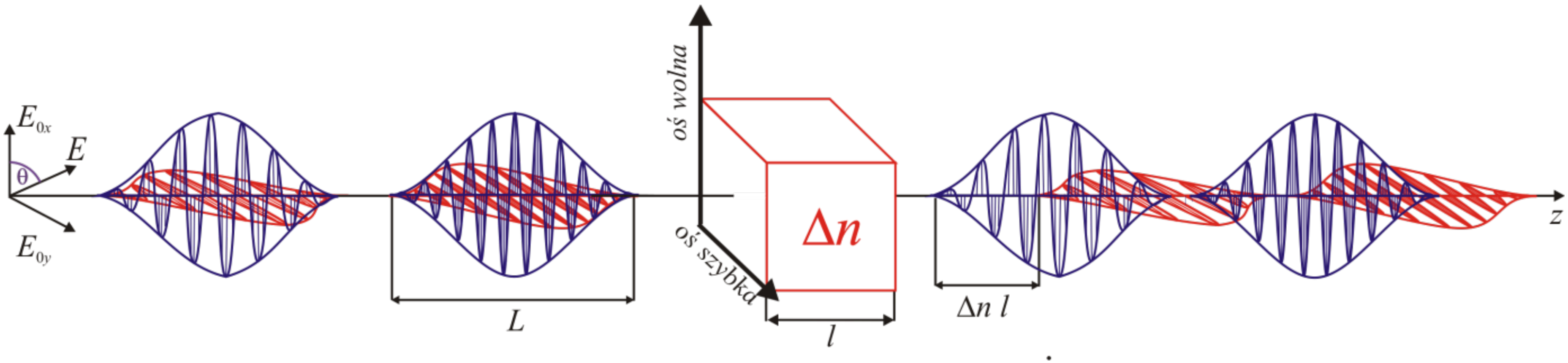
$$\Delta L_L = c\tau_{cL}$$

$$P = \sqrt{1 - \frac{4\det[K]}{(J_{xx}+J_{yy})^2}} = \sqrt{1 - \frac{4(1-|\gamma(\tau)|^2)}{\left(\frac{E_{0x}}{E_{0y}}+\frac{E_{0y}}{E_{0x}}\right)^2}}$$

$$P_G = \sqrt{1 - \frac{4\left(1 - exp\left[-2\left(\frac{\pi\Delta\nu\tau}{2\sqrt{\ln(2)}}\right)^2\right]\right)}{\left(\frac{E_{0x}}{E_{0y}}+\frac{E_{0y}}{E_{0x}}\right)^2}}$$

$$P_L = \sqrt{1 - \frac{4(1 - exp[-2\pi\Delta\nu\tau])}{\left(\frac{E_{0x}}{E_{0y}}+\frac{E_{0y}}{E_{0x}}\right)^2}}$$

Depolarization of light



- light in birefringent medium will experience phase shift in both eigenwaves
- For completely coherent light P = 1,
- for partially coherent light, phase shift may be high enough that P → 0
- as a result of partial temporal coherence (and finished dimension of spectral width) light is propagating in wavepackets,

$$c\tau = \Delta n l$$

Depolarization of light

$$P_G = \sqrt{1 - \frac{4\left(1 - exp\left[-2\left(\frac{\Delta nl}{\Delta L_G}\right)^2\right]\right)}{\left(\frac{E_{0x}}{E_{0y}} + \frac{E_{0y}}{E_{0x}}\right)^2}}$$

$$P_L = \sqrt{1 - \frac{4\left(1 - exp\left[-2\frac{\Delta nl}{\Delta L_L}\right]\right)}{\left(\frac{E_{0x}}{E_{0y}} + \frac{E_{0y}}{E_{0x}}\right)^2}}$$

- a Muller-Stokes formalism extended by depolarization matrix is very suitable for description of depolarization phenomena,.

$$[S^{wy}] = [D_n][M_n]\ldots[D_2][M_2][D_1][M_1][S^{we}]$$

$$[D_n] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & P_c & 0 & 0 \\ 0 & 0 & P_c & 0 \\ 0 & 0 & 0 & P_c \end{bmatrix}$$

Depolarization phenomena

- for linearly polarized light:

$$P_G = \sqrt{1 - \left(1 - exp\left[-2\left(\frac{\Delta nl}{\Delta L_G}\right)^2\right]\right) sin^2(2\theta)}$$

$$P_L = \sqrt{1 - \left(1 - exp\left[-2\frac{\Delta nl}{\Delta L_L}\right]\right) sin^2(2\theta)}$$

where: $\theta = arctg\left(\frac{E_{0y}}{E_{0x}}\right)$

For 45° angle

$$P_{G\,min} = exp\left[-\left(\frac{\Delta nl}{\Delta L_G}\right)^2\right]$$

$$P_{L\,min} = exp\left[-\frac{\Delta nl}{\Delta L_L}\right]$$

Depolarization phenomena

$$[S^{wy}] = [D_n][M_n] \dots [D_2][M_2][D_1][M_1][S^{we}]$$

- depolarization can have an nfluence on results obtained from method)polarizer and QWR)

$$[S^P]_1 = \left[D_{\frac{\lambda}{4}}\right]\left[M_{\frac{\lambda}{4}}\right][M_{0°}][S]$$

$$[S^P]_2 = \left[D_{\frac{\lambda}{4}}\right]\left[M_{\frac{\lambda}{4}}\right][M_{45°}][S]$$

$$[S^P]_3 = \left[D_{\frac{\lambda}{4}}\right]\left[M_{\frac{\lambda}{4}}\right][M_{90°}][S]$$

$$[S^P]_4 = [M_{45°}]\left[D_{\frac{\lambda}{4}}\right]\left[M_{\frac{\lambda}{4}}\right][S]$$

$$[S^P] = \begin{bmatrix} S_0^P \\ S_1^P \\ S_2^P \\ S_3^P \end{bmatrix} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \begin{bmatrix} I(0°,0°) + I(90°,0°) \\ I(0°,0°) - I(90°,0°) \\ 2I(45°,0°) - I(0°,0°) - I(90°,0°) \\ 2I(45°,90°) - I(0°,0°) - I(90°,0°) \end{bmatrix} = \begin{bmatrix} S_0^P|_1 + S_0^P{}_3 \\ S_0^P|_1 - S_0^P|_3 \\ 2S_0^P|_2 - S_0^P|_1 - S_0^P|_3 \\ 2S_0^P|_4 - S_0^P|_1 - S_0^P|_3 \end{bmatrix} = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 P_c \end{bmatrix} \neq [S]$$

$$P_{zmierzone} = \frac{\sqrt{S_1^2 + S_2^2 + P_c S_3^2}}{S_0} = P_{rzeczywiste} \frac{\sqrt{S_1^2 + S_2^2 + P_c S_3^2}}{\sqrt{S_1^2 + S_2^2 + S_3^2}} \leq P_{rzeczywiste}$$

Depolarization in Lithium Niobate $LiNBO_3$

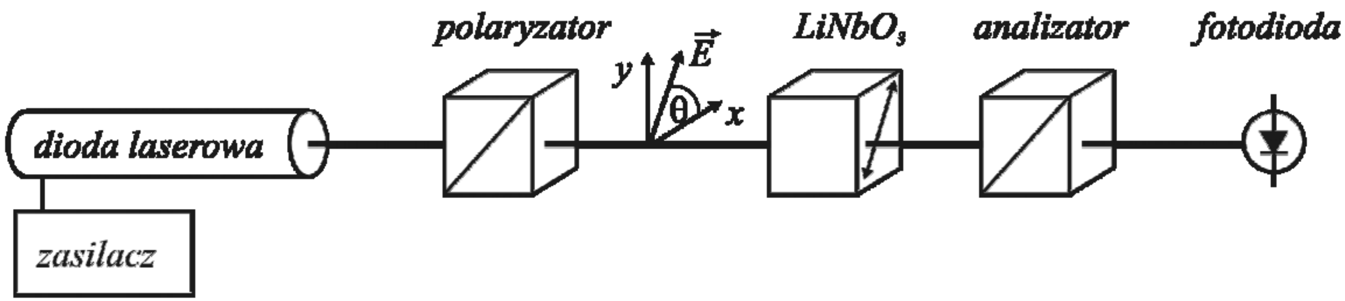
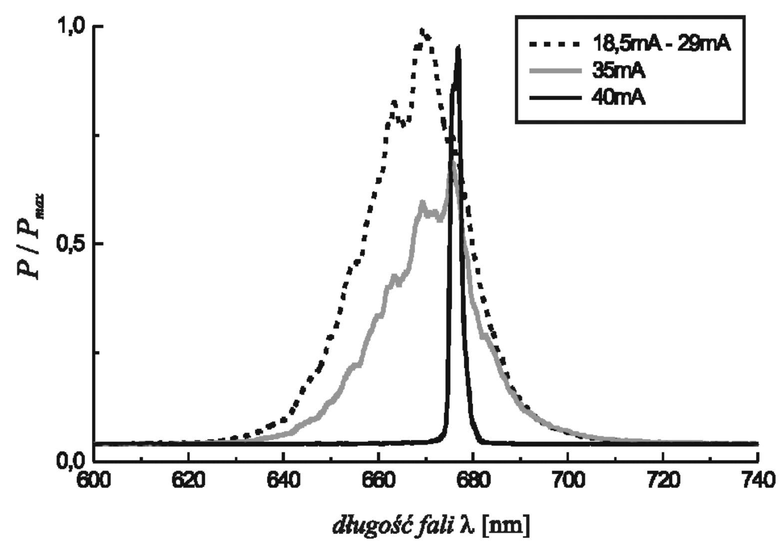


Tabela 3: Wyniki pomiarów depolaryzacji światła częściowo koherentnego w niobianie litu ($LiNbO_3$, Δn=0,086, l=10 mm).

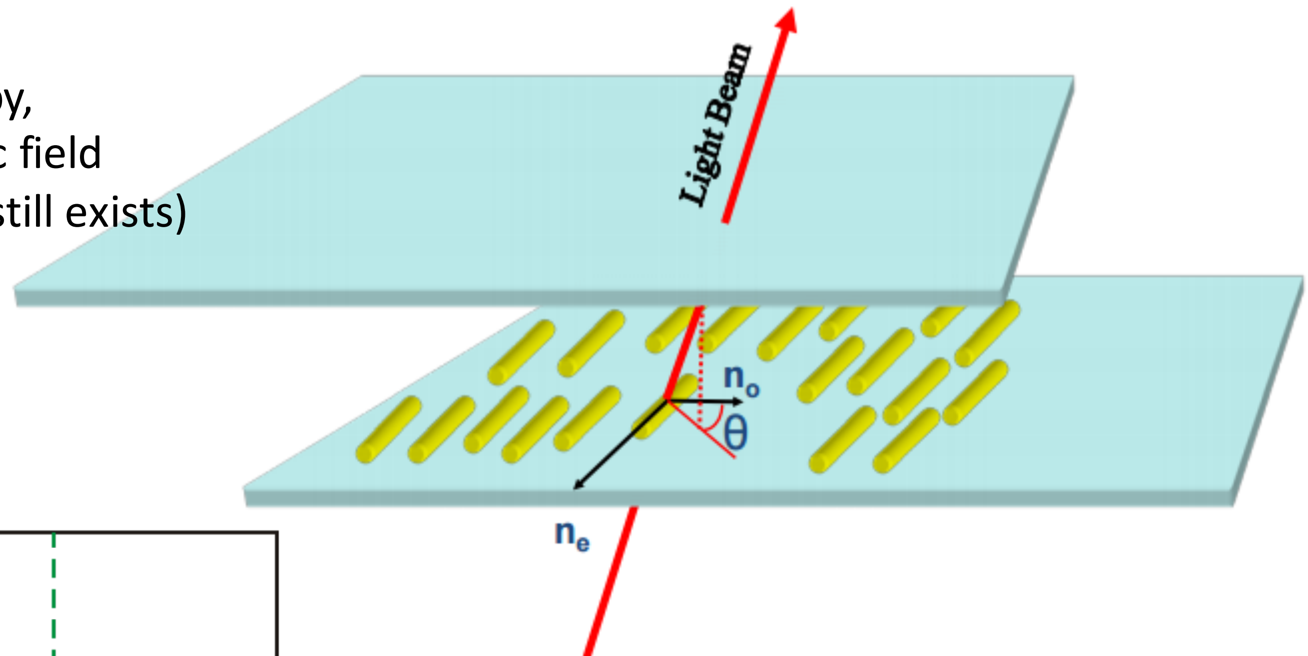
prąd diody laserowej [mA]	Δλ zmierzone [nm]	$\Delta L = \frac{\lambda^2}{\Delta\lambda}$ [μm]	$\Delta n \cdot l$ [μm]	$\frac{\Delta n \cdot l}{\Delta L}$	θ	P_c wyliczone *Gauss **Lorentz	P zmierzone
24	25	18	860	48	0°	$\sim 0^*$	0
					45°	1^*	1
29	25	18	860	48	0°	$\sim 0^*$	0
					45°	1^*	1
37,5	<0,30	> 1600	860	< 0,54	0°	$> 0{,}58^{**}$	0,6±0,1
					45°	1^{**}	1
40	< 0,15	> 3200	860	< 0,27	0°	$> 0{,}76^{**}$	0,8±0,1
					45°	1^{**}	1

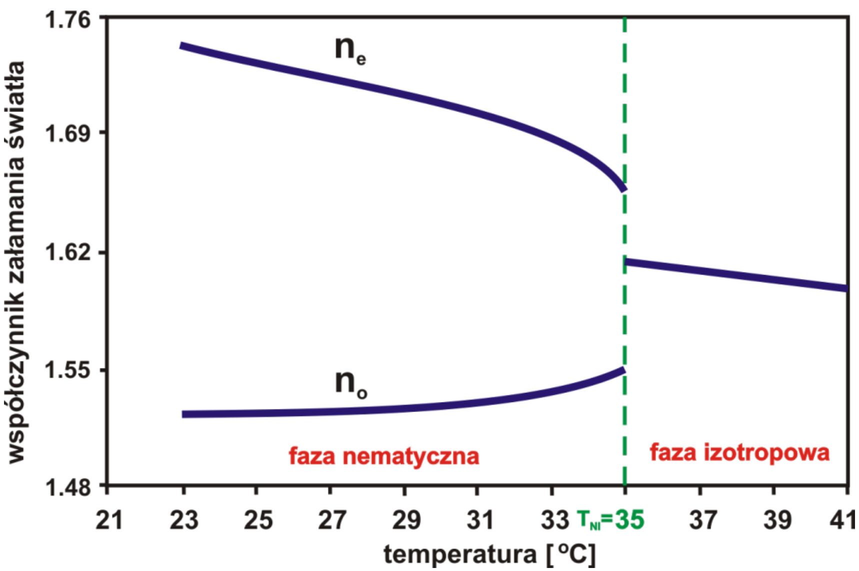


Depolarization in liquid crystals

- Nematic liquid crystals

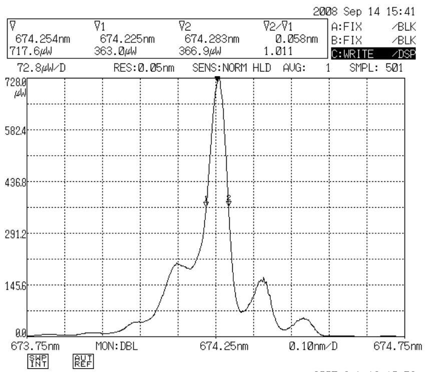
• large optical anisotropy,
• susceptible on electric field
(Frederickzs transition still exists)
• n = 0,05 – 0,5

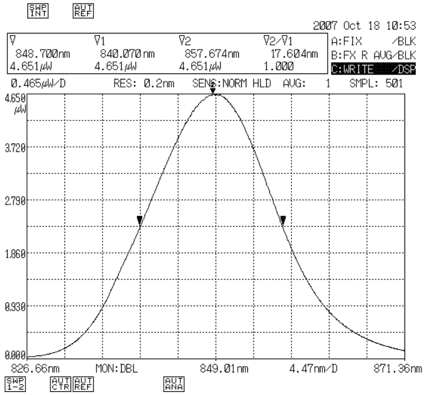


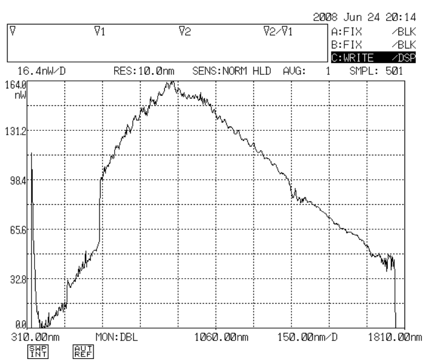


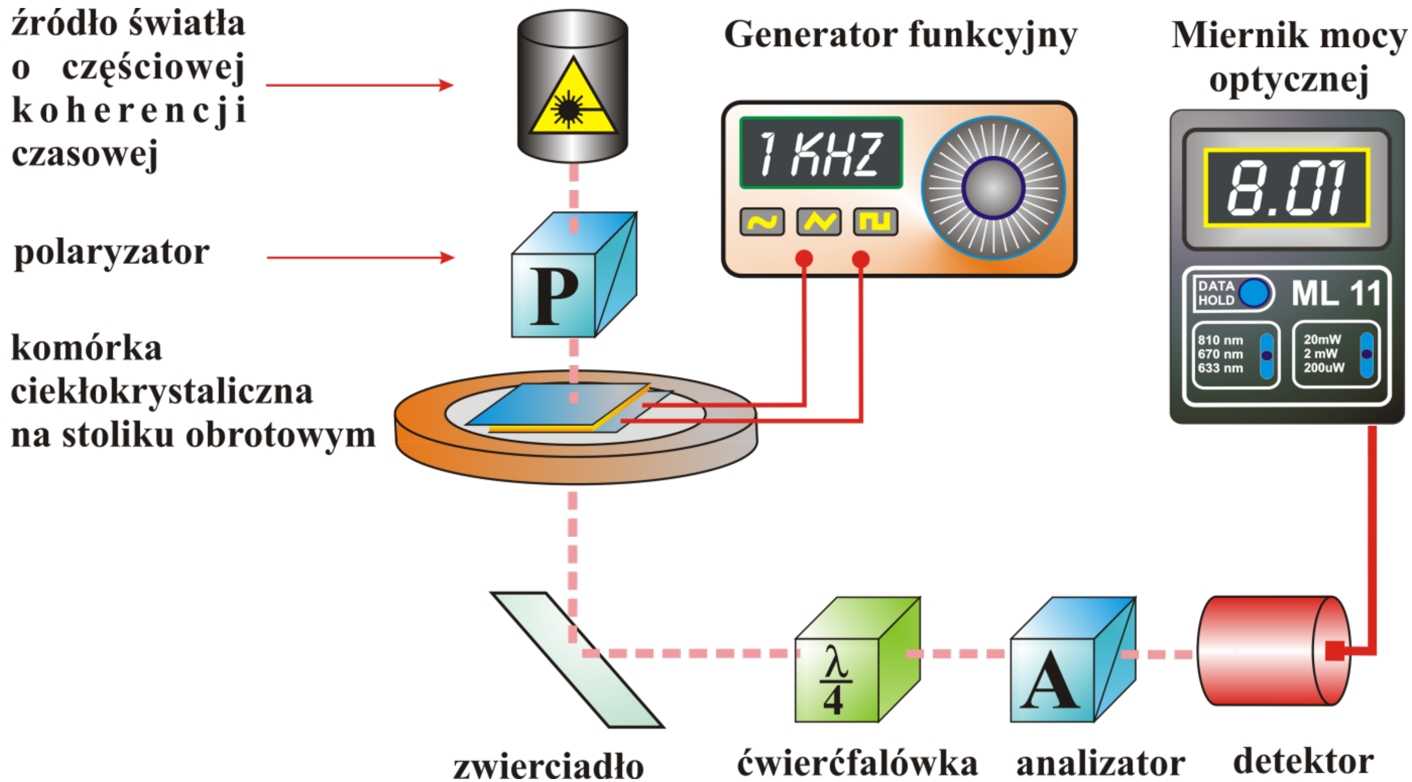
• P. Chatelain (1948) – first experiments on light depolarization in liquid crystals,
• results explained by De Gennes,

Depolarization of light in liquid crystals

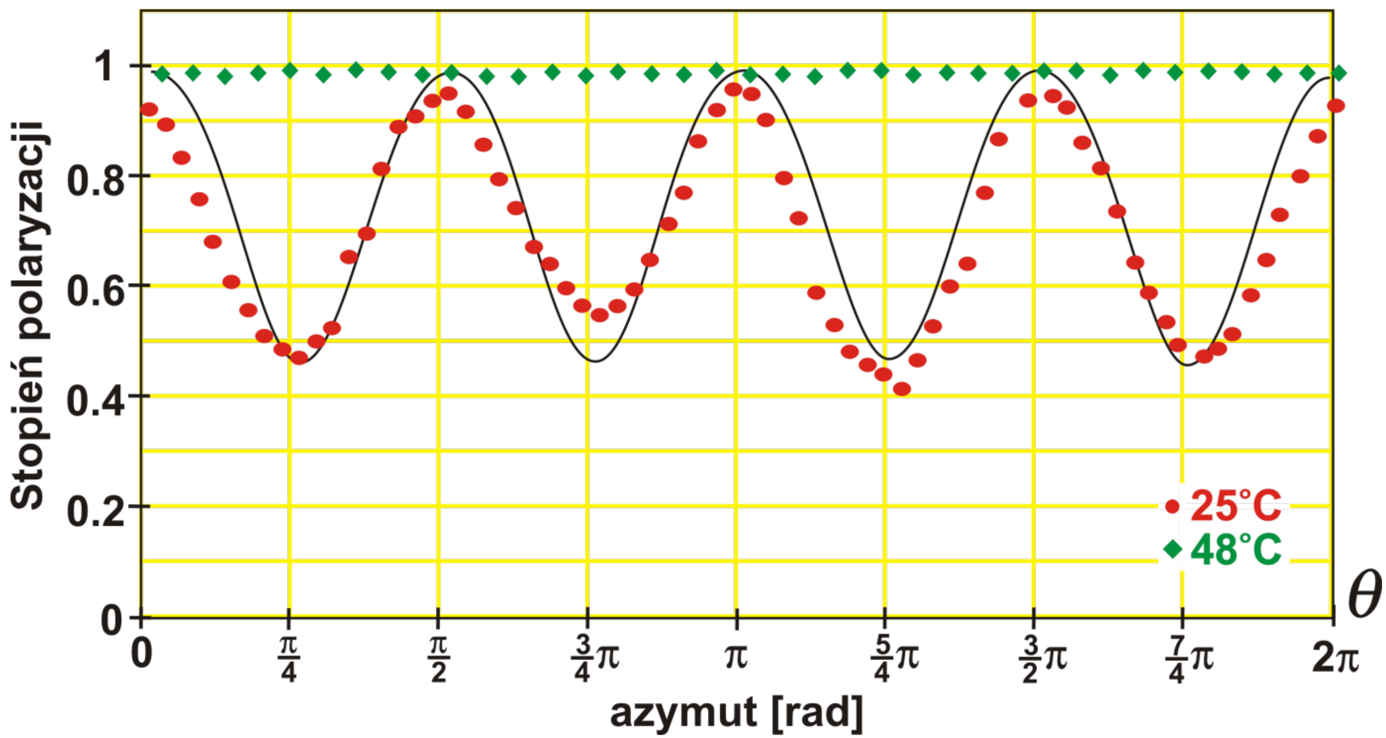






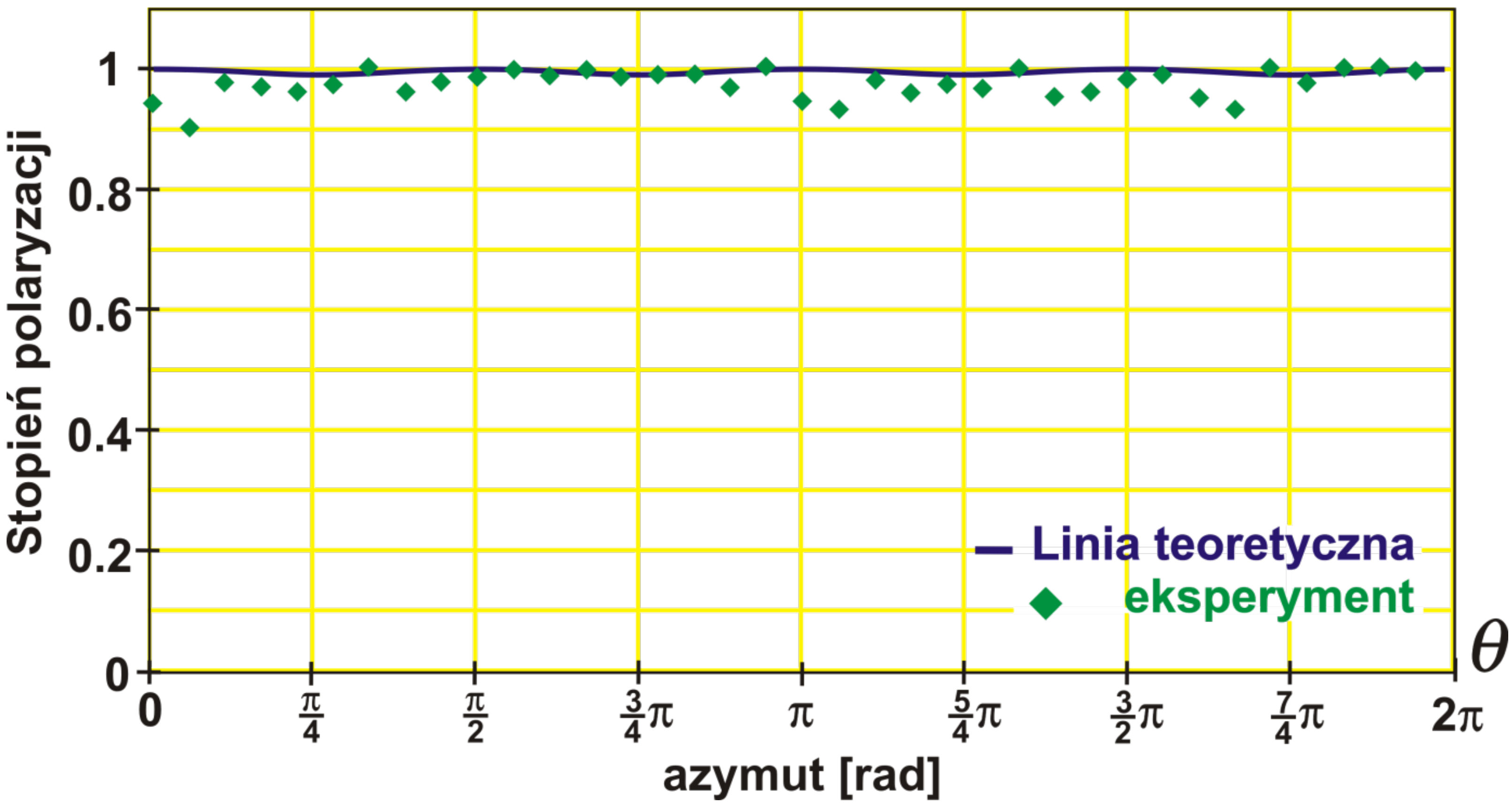


Depolarization of light in liquid crystals



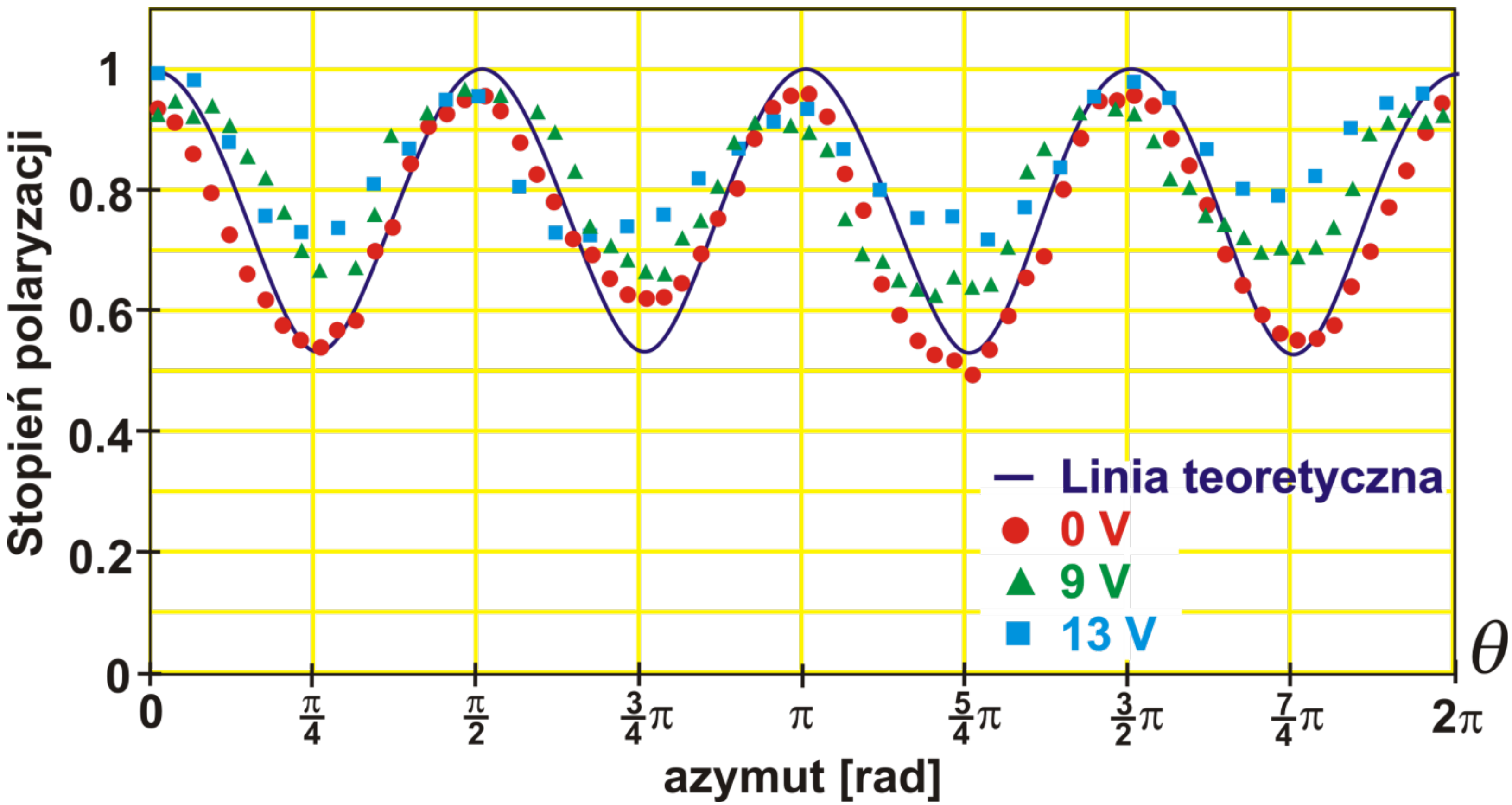
5CB, komórka 80 µm. źr. światla – dioda SLED

Depolarization of light in liquid crystals



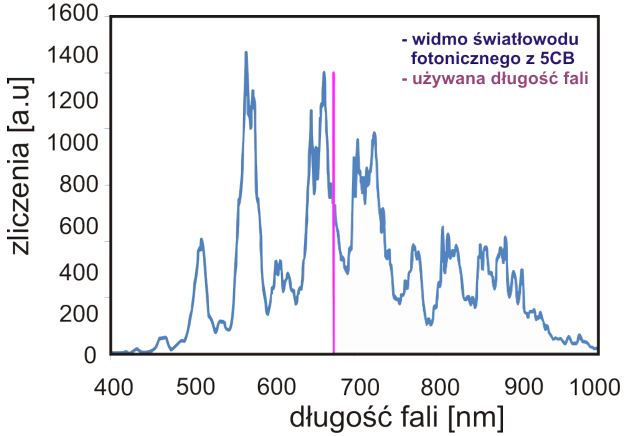
5CB, komórka 80 μm. źr. światla – dioda laserowa

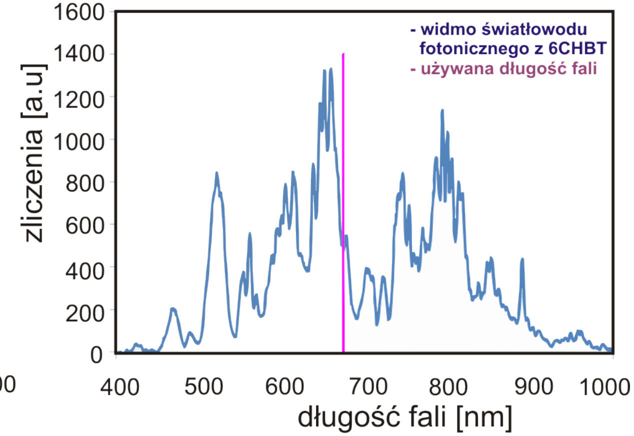
Depolarization of light in liquid crystals

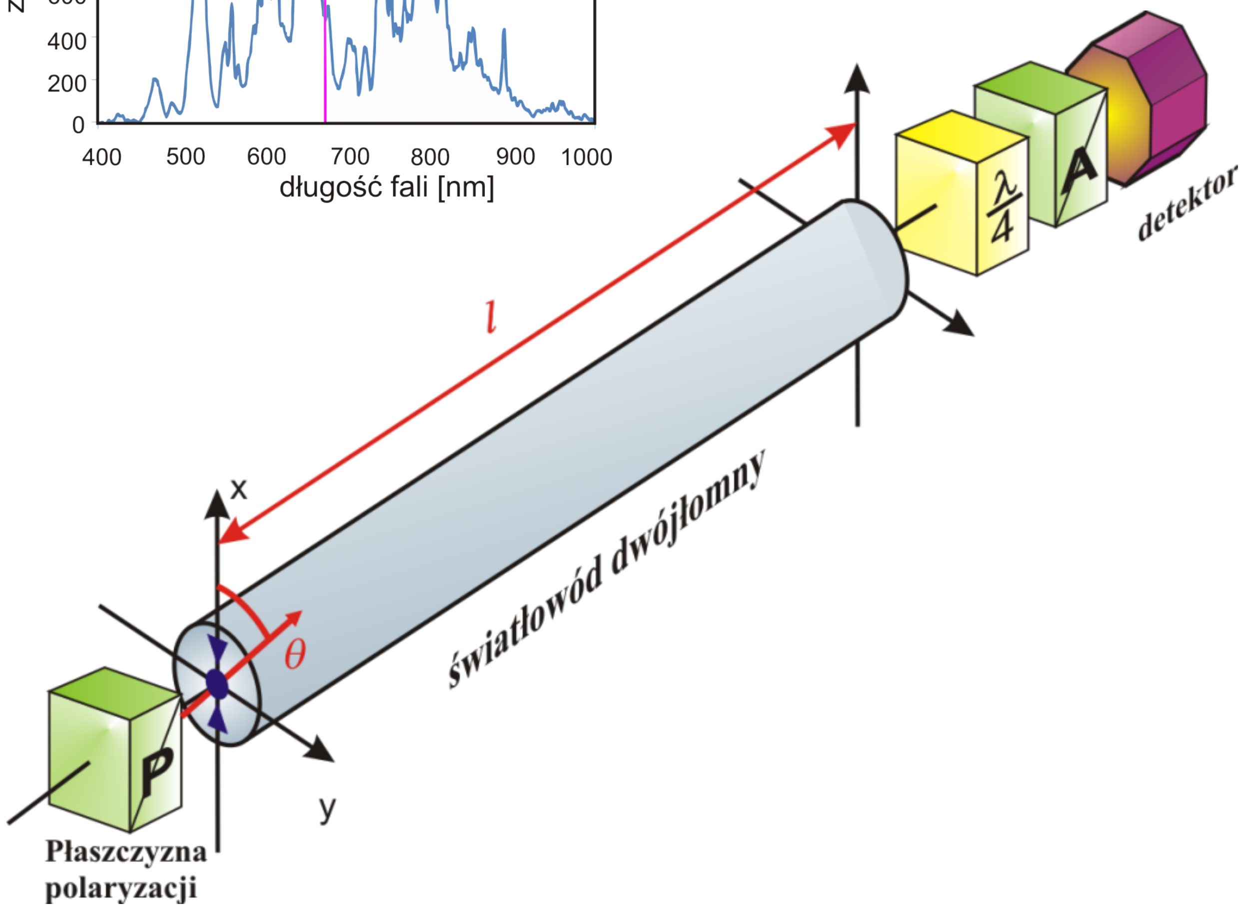


5CB, komórka 80 μm. źr. światla – dioda SLED

Depolarization of light in photonic crystal fibers





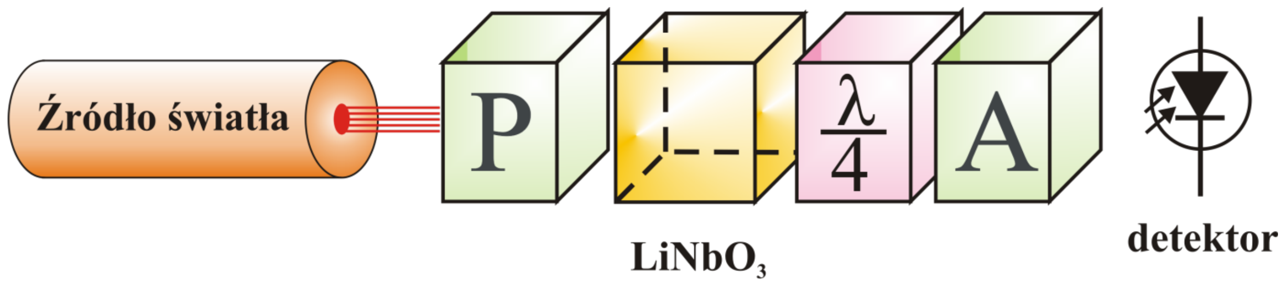


Depolarization of light in photonic crystal fibers

Δλ	Ośrodek		Długość	Azymut	DOP
0,058 nm	Światłowód fotoniczny *070119 P2*		600 mm	0°	0,94
				45°	0,95
	Ciekłokrystaliczny światłowód fotoniczny	5CB	595+5 mm	0°	0,93
				45°	0,35
		6CHBT	594+6 mm	0°	0,96
				45°	0,20
	Klasyczny światłowód HB		1000 mm	0°	0,99
				45°	0,94

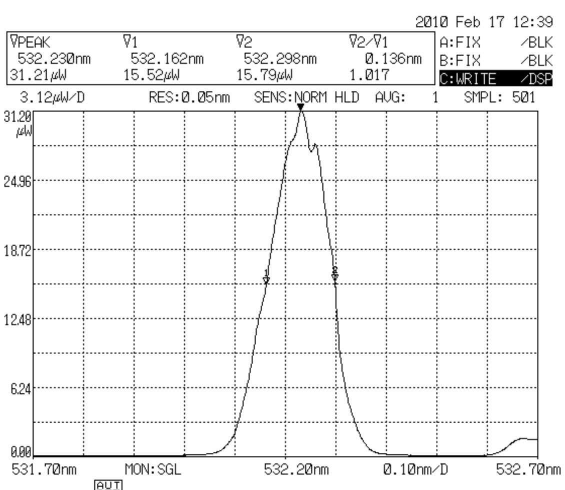
Applications of light depolarization

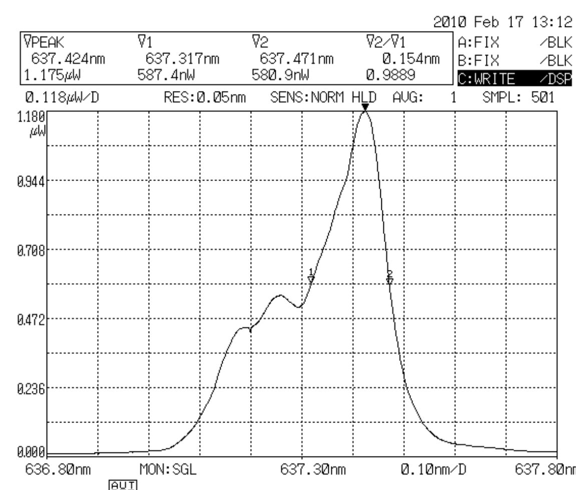
- Measurement of coherence length of light,



$$\Delta L_G = -\frac{\Delta n_{LiNbO_3} \cdot l_{LiNbO_3}}{\sqrt{\ln\left(P_{G_{LiNbO_3}}\right)}}$$

$$\Delta L_L = -\frac{\Delta n_{LiNbO_3} \cdot l_{LiNbO_3}}{\ln\left(P_{L_{LiNbO_3}}\right)}$$



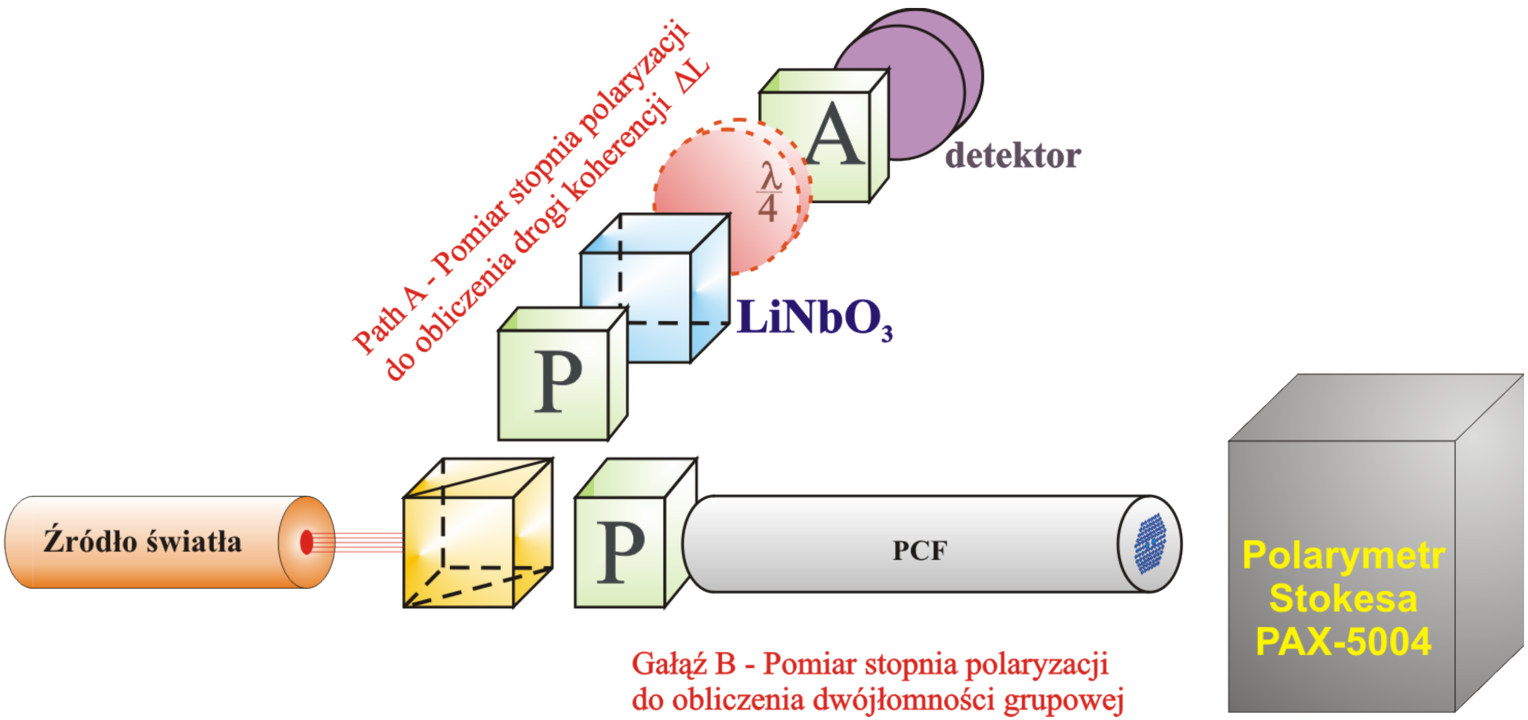


Applications of light depolarization

	Dioda laserowa emitująca zieloną wiązkę (λ= 532,230 nm; Δλ= 0,136 nm)	Dioda laserowa emitująca czerwoną wiązkę (λ= 637,424 nm; Δλ= 0,154 nm)
$\Delta L_L = \frac{\lambda^2}{\Delta\lambda}\frac{1}{\pi}$	$\Delta L_L = \frac{\lambda^2}{\Delta\lambda}\frac{1}{\pi} = 0{,}714 \times 10^{-3} m$	$\Delta L_L = \frac{\lambda^2}{\Delta\lambda}\frac{1}{\pi} = 0{,}839 \times 10^{-3} m$
Metoda depolaryzacyjna	$\Delta L_L = 0{,}662 \times 10^{-3} m$	$\Delta L_L = 1{,}171 \times 10^{-3} m$

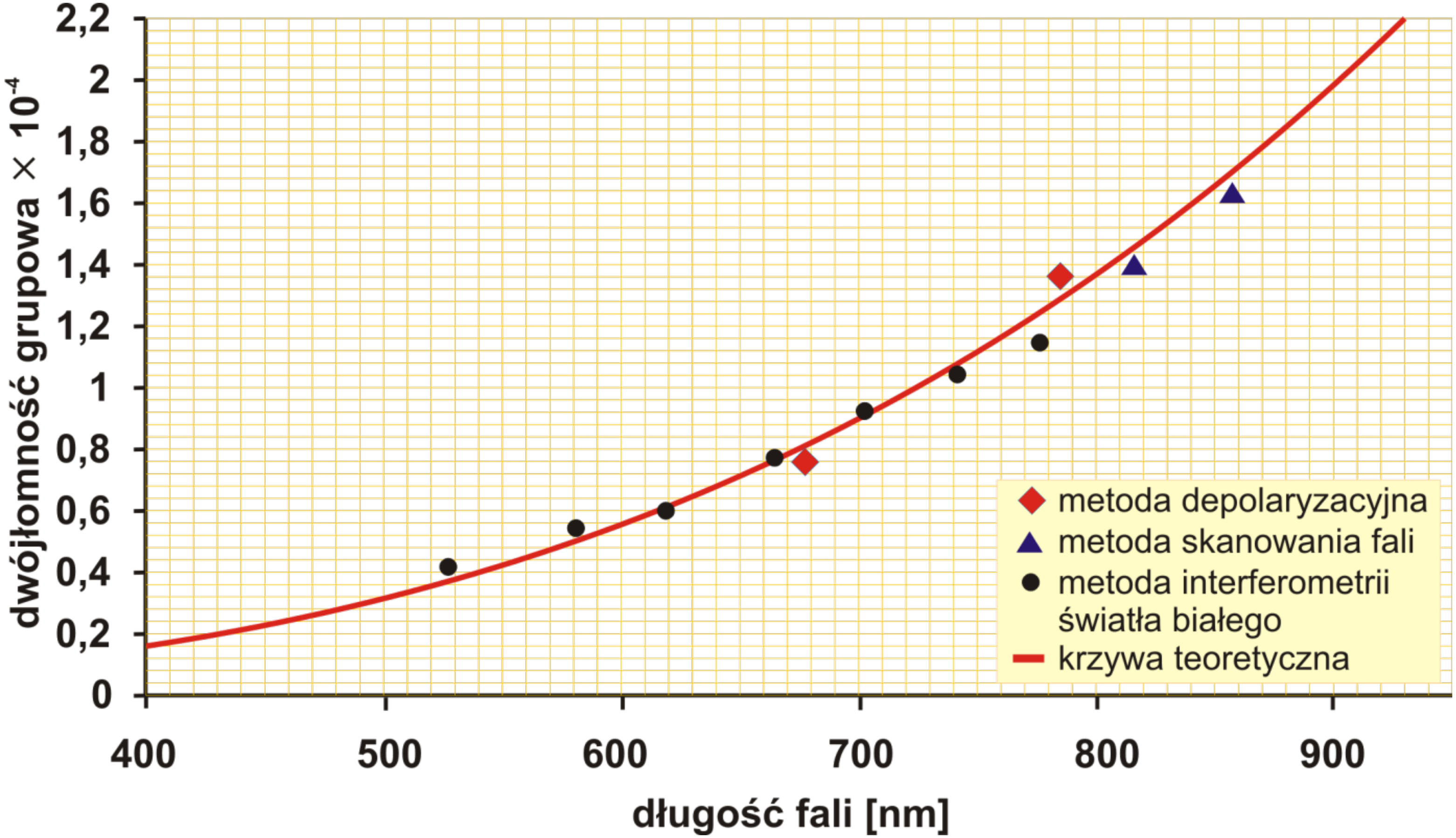
Applications of light depolarization

Group birefringence measurement in photonic crystal fibers,

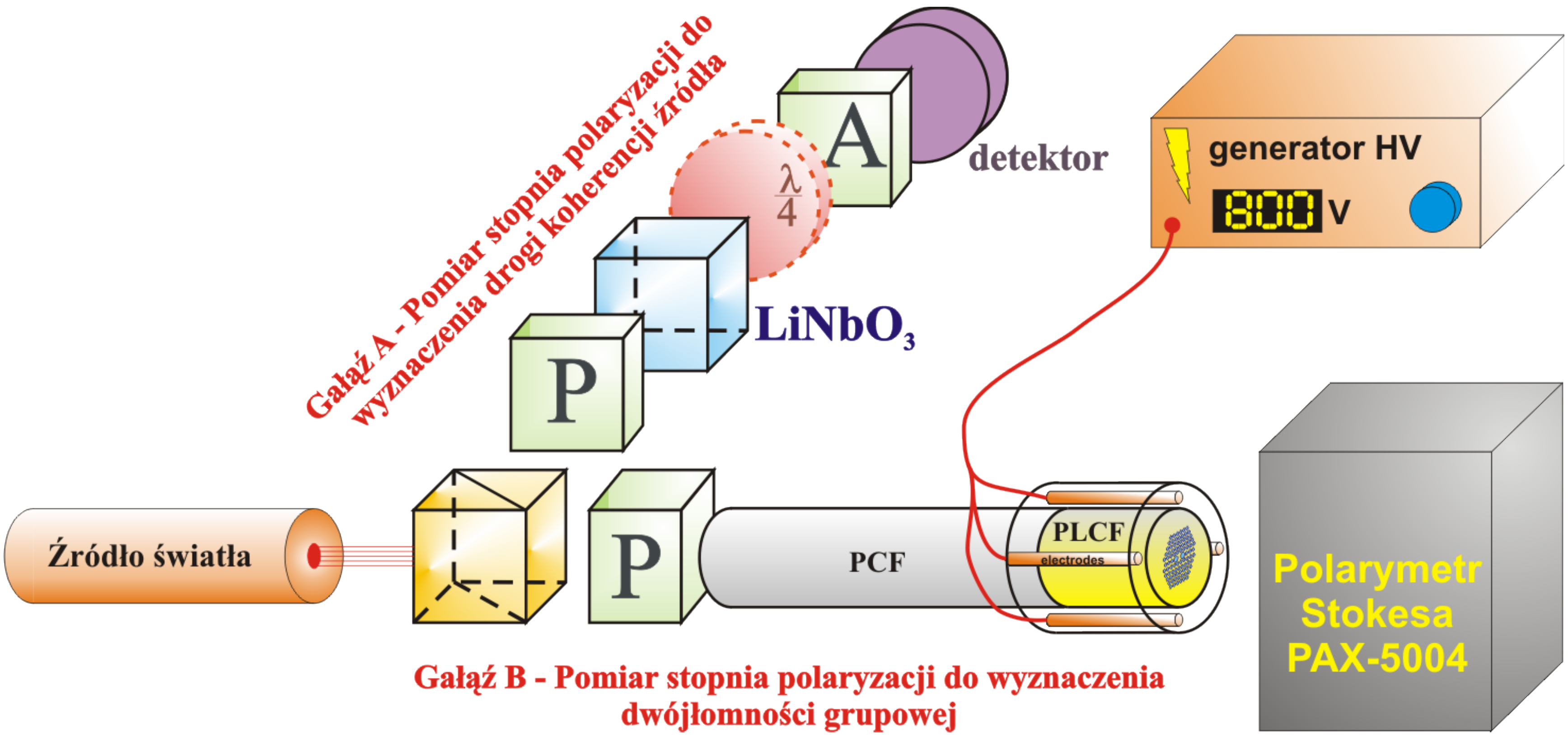


$$G = \Delta n_{eff} = -\frac{\Delta L_L \cdot \ln\left(P_{L_{PCF}}\right)}{l_{PCF}}$$

Applications of light depolarization

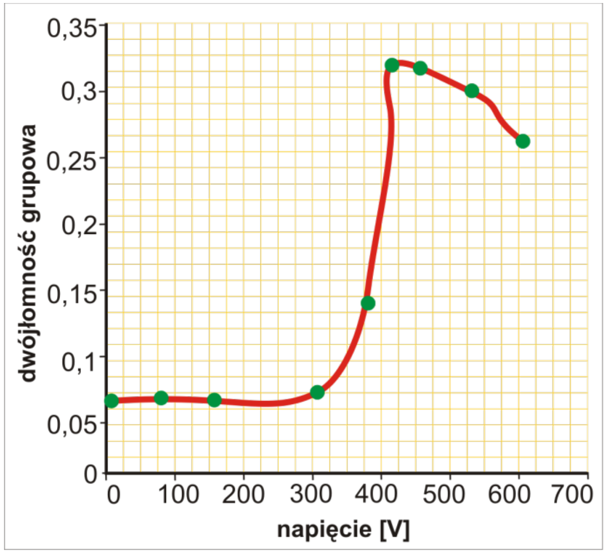


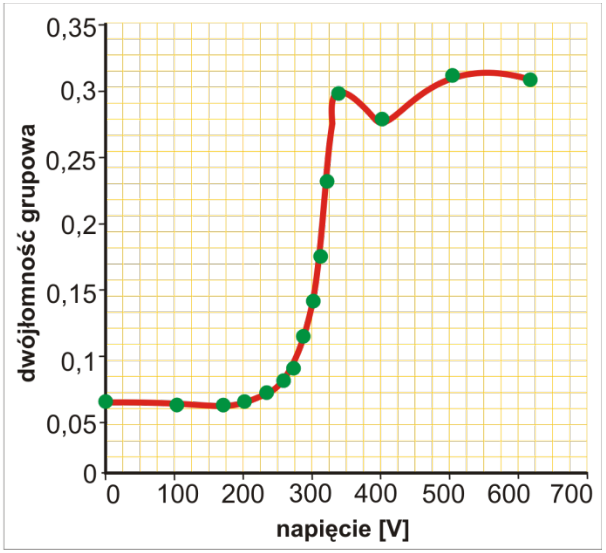
Applications of light depolarization



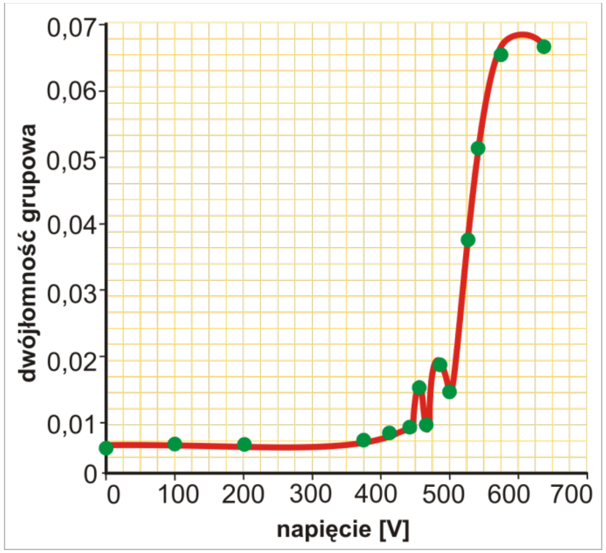
Applications of light depolarization

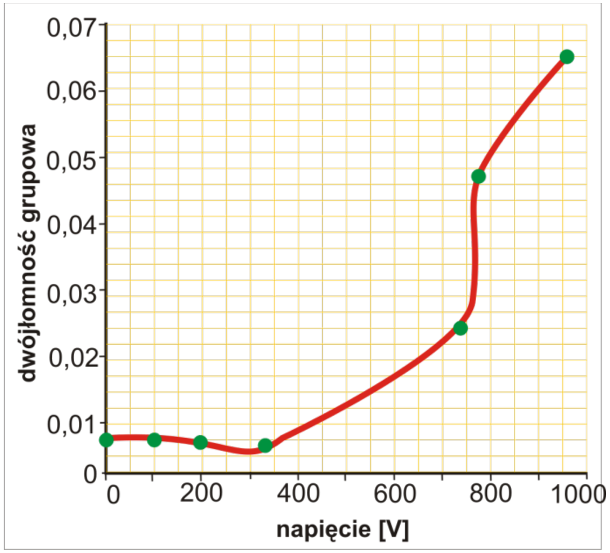
Nd:YAG





PLCF





Influence of depolarization on different optical phenomena

- electrooptical and megnetooptical effects,
- fiber optic sensors,
- influence on polarization dispersion in telecommunication lines,