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NARODOWA STRATEGIA SPÓJNOŚCI

UNIA EUROPEJSKA
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LIQUID CRYSTAL ELEMENTS

The Liquid Crystal Elements ware developed and manufactured by Institute of Applied Physics at Military University of Technology (MUT) in Warsaw, Poland to satisfy all technical requirements that were sent to Institute of Applied Physics at Military University of Technology by Vavilov State Optical Institute in St. Petersburg, Russia on 15 February, 2010.

To approach the solving a problem in diagnostics of a dense plasma (so-called Thomson diagnostics), Institute of Applied Physics at Military University of Technology (MUT) in Warsaw, Poland developed and manufacture the following Special Liquid Crystal Elements) which should be farther investigated in Russian laboratories on:

- Laser Damage Resistance (LDR) of LCC,
- Switching on time (τ_{ON}) of LCC

The Polish Side brings The Russian Side the following Liquid Crystal Elements:

1. **Twisted LCNP3 (TN5, TN7 and TN9) cells (Cells with numbers 5, 7 and 9)**

Twisted **TN5, TN6, TN7, TN8, TN9 and TN10 cells** are generally constructed just the same as it was done in the case of the „Phobos-Ground" project. The TN6, TN7 and TN9 cells operated in transparent "positive TN mode" . The above cells are armed in:

✓	NL rubbed (Nylon 6/6 alignment) layers	in the case of TN5,
✓	PL rubbed (Polyimide SE-130 alignment) layers	in the case of TN7,
✓	SI rubbed (SiO_2) blocking layers	in the case of TN9.

and transparent Porous Indium Tin Oxide (P-ITO) electrodes (with n~1.54 and sheet resistance ρ~2000 $\Omega/\square$) obtained by special deposition,

The schematic cross-section of TN6, TN7 and TN9 cells are shown in Fig. 1.

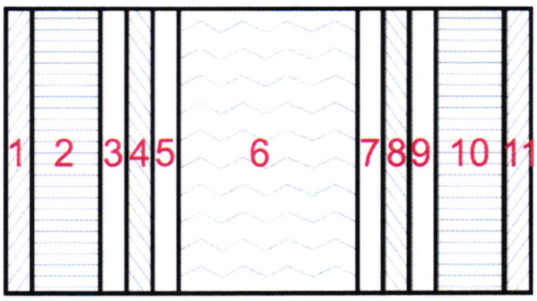

Fig. 1 The cross-section of refractive index matched twisted TN5, TN7 and TN9 cells, where: **1** and **11** are bilayer, dielectric (vacuum deposited) AR layers; **2** and **10** are QP; **3** and **9** are transparent P-ITO electrodes; **4** and **8** are BF (bilayer SiO_2); **6** is LCM3;

5 and **7** are:

✓	NL rubbed (Nylon 6/6 alignment) layers	in the case of TN6,
✓	PL rubbed (Polyimide SE-130 alignment) layers	in the case of TN7,
✓	SI rubbed (SiO_2) blocking layers	in the case of TN5.

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The TN6, TN7 and TN9 cells are filled with new LCM3 (with Δn=0.36 at λ=1.064 μm) for d=2.6 μm thick TN cells working in the first TN interference maximum at λ=1.064 μm. The temperature range of nematic phase of LCM3 is rather broad (from -20 °C to +125 °C).

The material parameters of LCM3 for TN6, TN7 and TN9 cells are following.

Table 1 Material parameters of LCM3 mixture for LCNP3 at 25°C.

Material parameters	LCM3 (W2002) for TN5, TN7, TN9	LCM(W 1825) for Phobos Ground
Temperature transition from Iso to N phase T(I-N)	+125 °C	+136.0 °C
Temperature transition from N to Cr phase T(N-Cr)	-20 °C	-12 °C
Optical anisotropy Δn (for λ=1.064 μm)	0.36	0.37
Ordinary refractive index n_o (for λ=1.064 μm)	1.54	1.53
Dielectric anisotropy Δε□□□(for f=1.5 Hz)□□	23.0	17.0
Perpendicular component of electric permittivity tensor $\varepsilon_\perp$	5.0	4.7
Splay elastic constant K_{11}	21.5 pN	12.5 pN
Twist elastic constant K_{22}	9.7 pN	7.4 pN
Bend elastic constant K_{33}	25.3 pN	32.1 pN
Reduced Twist elastic constant K_{TN},	29.7 pN	16.8 pN
Rotational viscosity□□ γ	250 mPa s	284 mP a s
Bulk viscosity□□ Γ	28 mPa s	31 mPa s
Laser Damage Threshold at λ=1.064 μm, 10 ns	10.5 J/c m^2	9.8 J/cm ^{2}

The optical Transmission T_{QS} of "pure" QP substrate (without any layers) and Transmission T_{LA} of QP substrate covered by all functional (AR, P-ITO, BF and NL) layers are shown in Fig. 2.

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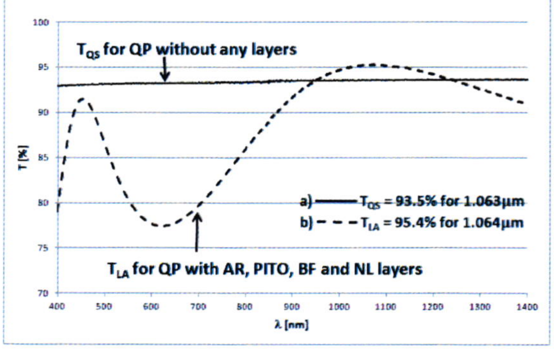

Fig. 2. Transmissions T versus wavelength λ measured by means of digital spectrophotometer: JASCO V670.

a) $T_{QS}(\lambda)$ for "pure" QP substrate (without any layers) – solid line.

b) $T_{LA}(\lambda)$ for QP substrate with all functional (AR, P-ITO, BF and NL) layers – dotted line.

The optical Transmission T of 2.6 LCNP3 (TN6) cell filled with LCM3 is shown in Fig. 3. One notices that the curve describing the stripe of fist interference maximum crated in twisted LCNP3 cell placed between crossed polarizers is a smooth one (without any local interference stripes, as one can see in the case of second maximum). Both smooth character and high transmission (T=97.3% at λ=1.064 µm) of first maximum stripe are the evidences that LCNP3 cell can be regarded as really refractive index matched twisted one for λ=1.064 µm.

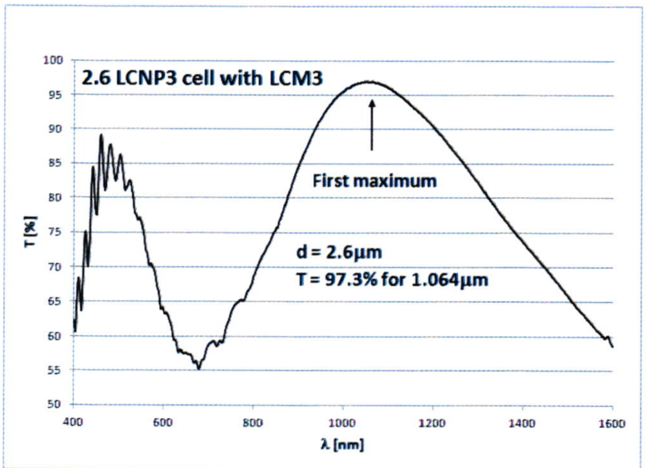

Fig. 3. Transmission T versus wavelength λ of 2.6 LCNP3 cel (TN6 with d=2.6 µm) filled with LCM3 (Δn=0.36 at λ=1.064 µm). T(λ) was recorded when 2.6 LCNP3 cell with LCM3 was placed between crossed polarizers and the plane of polarization of incident light was perpendicular to **n** at the entrance of TN layer. Transmission has got the first maximum (97.3%) at 1.064µm.

To electrically isolate transparent P-ITO electrode (with n~1.50 at λ=1.064 µm) from LCM3 (characterized by n_o=1.54 at λ=1.064 µm), dielectric Blocking Film (BF) was evaporated on P-ITO layer. Since BF consists of two thin (d=λ/2n~360 nm) layers of SiO_2 (with n~1.46) and what is more the refractive indices n of P-ITO and BF as well n_o of LCM3 are nearly the same, BF causes that

Fresnel reflections do not appear at the interface between P-ITO (n~1.50) and BF (n~1.46) and then at the next interface between BF (n~1.46) and LCM (n_o=1.54).

The results of switching on (τ_{ON}) time measured in 2.6 LCNP3 (TN5 with 2.6 μm thick) cell filled with LCM3) at 25°C are presented in Table II. The results shows, that switching on time τ_{ON} smaller than 3 μs in LCNP3 cell (2.6 μm thick) filled with LCM3 (Δn=0.37 for λ=1.064 μm) can be obtained under 200 V pulses. Since the LCNP3 cell is armed in (bilayer SiO_2) BF, the LCNP3 cell is able to work with steering voltages U up to U=300 V. In this case that switching on time τ_{ON} can be much smaller than 2 μs.

Table II. The results of switching on (τ_{ON}) time measured in 2.6 LCNP3 (TN5 cell with 2.6 μm thick) filled with LCM3 (Δn=0.36 for λ=1.064 μm) at 25°C.

Driving voltage [V]	20	40	60	80	120	160	200
Switching on time τ_{ON} [ms]	0.0280	0.0190	0.0095	0.0057	0.0039	0.0033	0.0028

2. Reflective Nematic Liquid Cell LCNP4 (RN3) (Cell with number 3)

The **reflective RN3, RN4 cells** are working in the refractive mod of ECB (Electrically Controlled Birefringence) effect.

The schematic cross-section of RN3, RN4 cells are shown in Fig. 4.

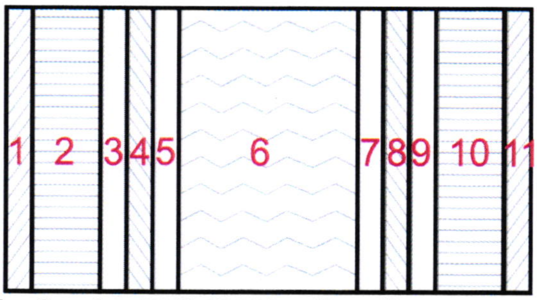

Fig. 4 The cross-section of refractive RN3, RN4 cells, where:

1 and **11** are bilayer, dielectric (vacuum deposited) AR layers; **2** and **10** are QP; **3** and **9** are transparent P-ITO electrodes; **4** is BF (bilayer SiO_2); **6** is LCM3; **5** and **7** are PL (rubbed Polyimide SE-130 alignment) layers, **8** is DM (Dielectric Mirror).

Spectral characteristic of R (reflection coefficient) versus λ (wave length) of DM (dielectric mirror evaporated on PITO) is shown on Fig. 4

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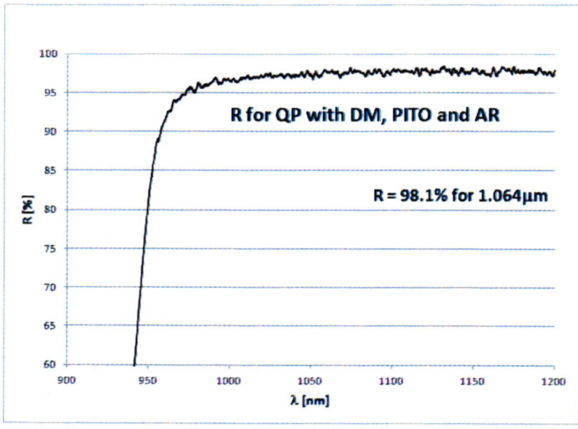

Fig. 4 Spectral characteristic of R versus λ of DM (dielectric mirror evaporated on PITO)

The RN3 and RN4 cells (of thickness d= 2.2µm) are filled with new (W 1974) LCM4 (Δn=0.13 at λ=1.064 µm). LCM4 was tuned for d=2.0 µm thick ECB cell working in the first ECB interference maximum at λ=1.064 µm: $(D\Delta n = 2d\Delta n = 0.13 \times 2 \times 2 \approx 0.53$. The temperature range of nematic phase of LCM4 is from -10 °C to +75 °C.

$$\frac{2D\Delta n}{\lambda} = 2k - 1$$

for k=1 and λ=1.064 µm

$D \cdot \Delta n \sim 0.53$ gdzie D=2d

Dispersion of optical anisotropy $\Delta n(\lambda)=n_e(\lambda)-n_o(\lambda)$ for LCM4 at 25°C is shown in Fig. 5.

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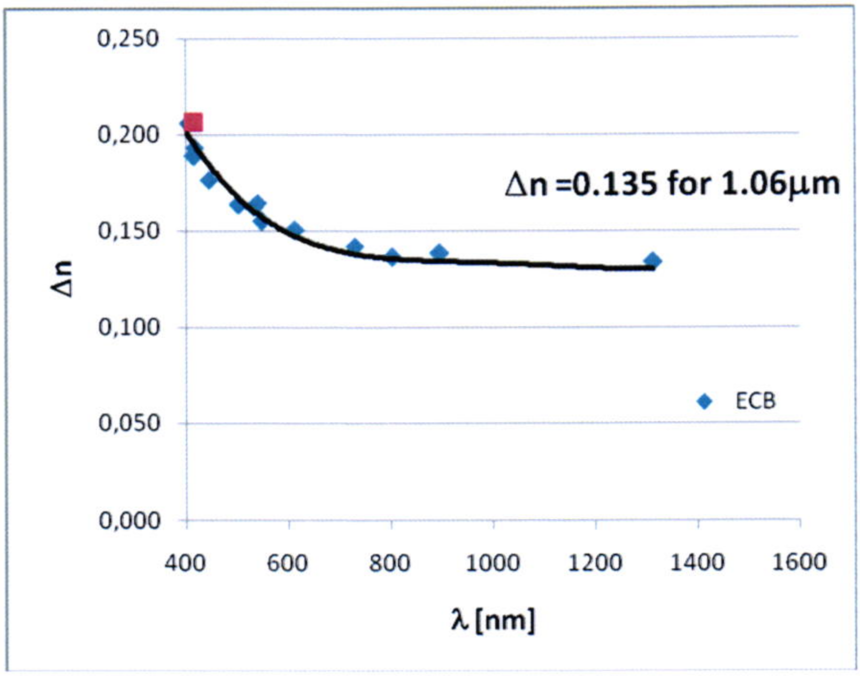

Fig. 5 Dispersion of optical anisotropy $\Delta n(\lambda)$ for LCM4 (W1974) at 25°C.

3. Transmission LCNP5 (RR1 and RR2) cells – LC cell like the "Fabry-Perot" Filter (Cells with numbers 1 and 2)

The **transmission RR1 and RR2 cells** (with two DM - dielectric mirrors) are working on the base of ECB (Electrically Controlled Birefringence) effect.

The schematic cross-section of RR1, RR2 cells are shown in Fig. 6.

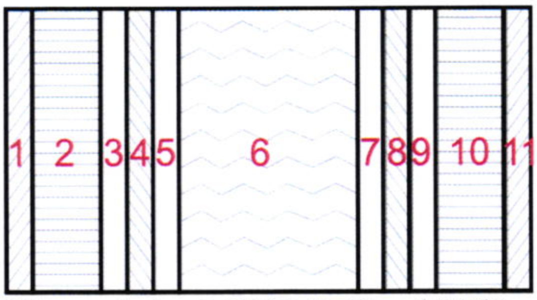

Fig. 6. The cross-section of Transmission LCNP5 (RR1 and RR2) cells, where:
1 and **11** are bilayer, dielectric (vacuum deposited) AR layers; **2** and **10** are QP;
3 and **9** are transparent P-ITO electrodes;
4 and **8** are DM (dielectric mirrors); **6** is LCM3; **5** and **7** are PL rubbed (Polyimide SE-130 alignment) layers.

Spectral characteristic of $R(\lambda)$ of dielectric mirrors DM applied in RR1 and RR2 cells are shown in Fig. 4.

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The RR1 and RR2 cells (of thickness d= 1.8μm) are filled with (W 1974) LCM4 (no=1,48, ne=1,61, Δn=0.13 at λ=1.064 μm).

Fig. 7 shows computer simulation for RR cell of o thickness d=1.8 μm filled with W 1974 (no=1,48, ne=1,61 at λ=1.064 μm) under small electric field E. After applying small electric field E one obtains $n_{e\ EF}$=1,59 and F-P filter (RR cell) is transparent for λ=1.064 μm laser.

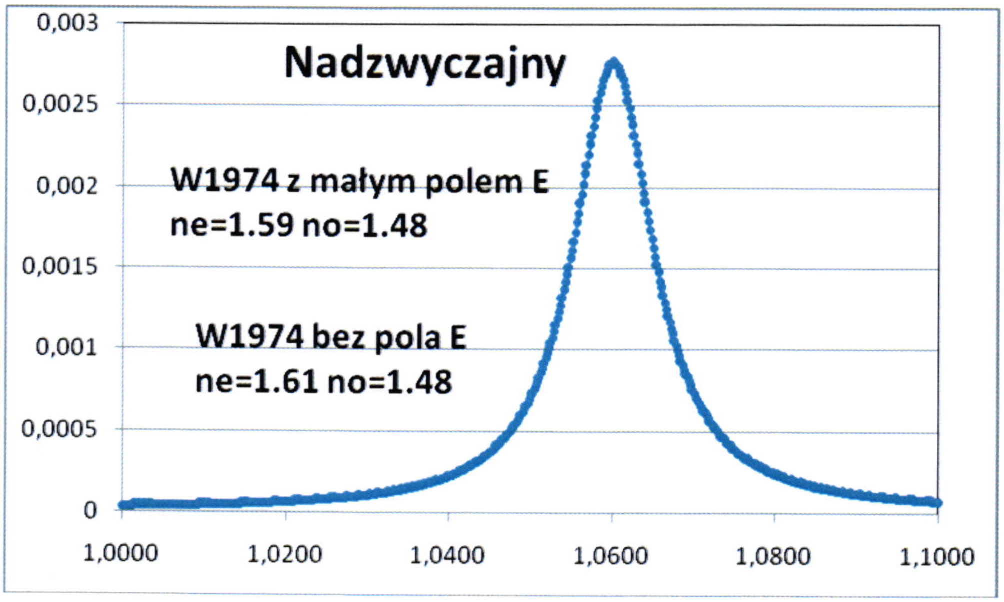

Fig. 7 Computer simulation for RR cell of o thickness d=1.8 μm filled with W 1974 (no=1,48, ne=1,61 at λ=1.064 μm) under small electric field E ($n_{e\ EF}$=1,59).

When E increases, $n_{e\ EF}$ decreases up to $n_{e\ EF}$=1,50 and then F-P filter (RR cell) is non transparent for λ=1.064 μm laser (See Fig.8.)

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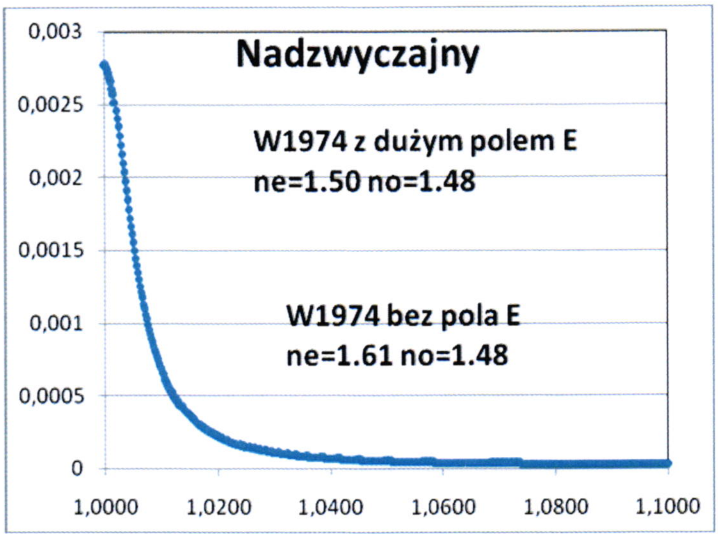

Fig. 8. Computer simulation for RR cell of o thickness d=1.8 μm filled with W 1974 (no=1,48, ne=1,61 at λ=1.064 μm) under high electric field E ($n_{e\,EF}$=1,50).

4. Transmission LCNP3 cells

The layout of such Special Refractive Index Matched Twisted Liquid Crystal Cell (farther called LCNP3) with its main dimensions is given in Fig. 9. All described in common article.

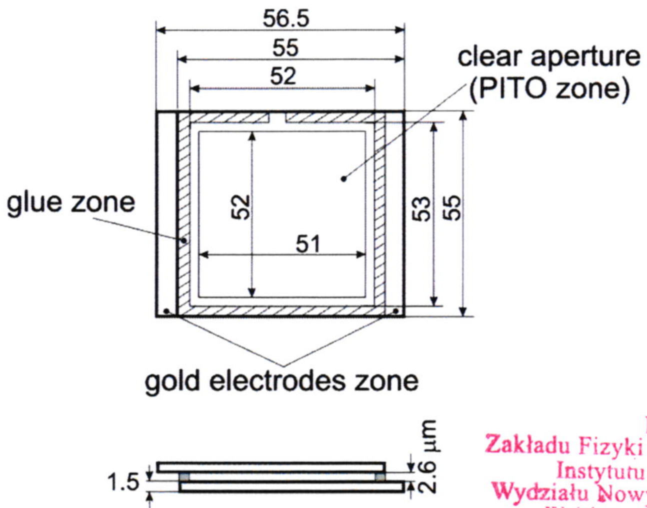

Fig. 8 The layout of LCNP3.

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