Microlasers and Microamplifiers on Liquid Crystals

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Collaborators (with great acknowledgement !)

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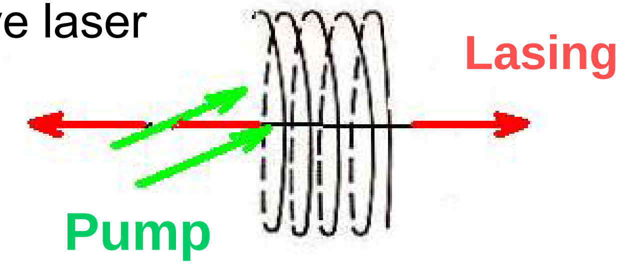
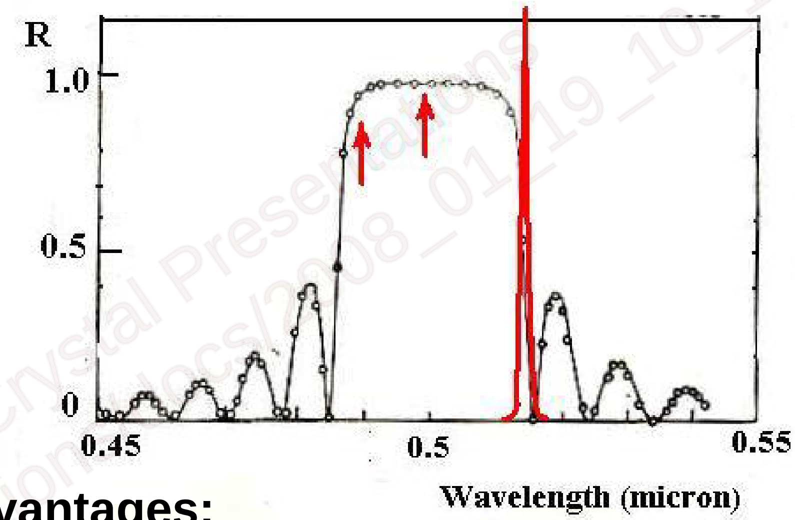
1. **Motivation**
2. **Lasers based on leaky modes in NLC and CLC**
3. **Simple electric field tunable NLC laser**
4. **ASE gain measurements in NLC**
5. **Planar light amplifiers**

1. Motivation: why NLC and why to amplify ?

CLC as lasing medium:
L.Goldberg, J. Schnur, US Patent,3,771,065 (Nov, 1973)
First observation of lasing: I.Il'chishin et al JETP Letters 32, 27 (1980)

DFB-CLC
dye laser





Advantages:

simple, planar, mirrorless;

any wavelength in near UV-Vis-near IR are possible;

sensitive to external agents

Disadvantages:

Low thermal stability (low pump energy density)

Leaky modes do not allow large diameters of pump beam: Low output energy (100 nJ/p)

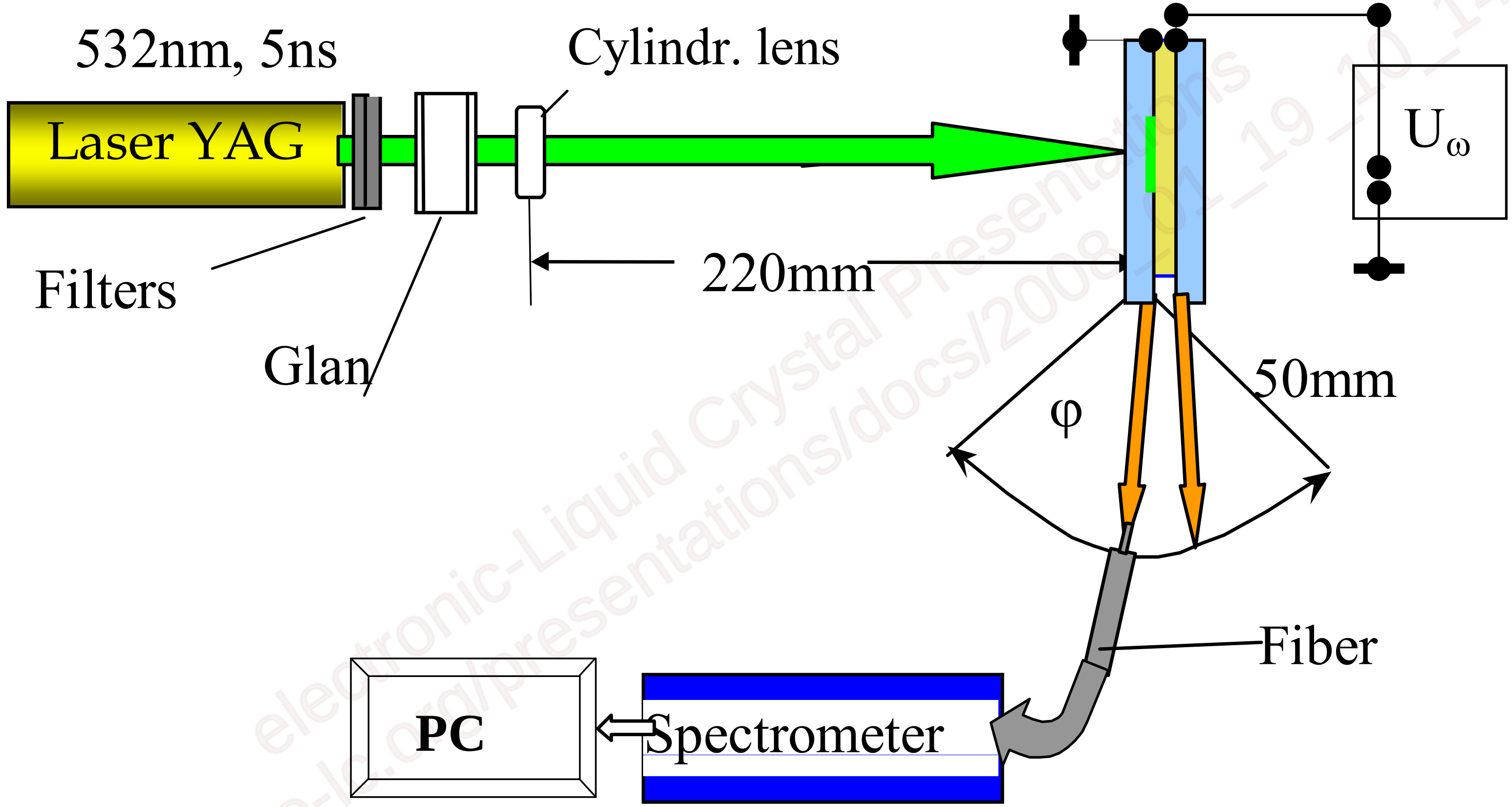
No possibility for tuning by the electric field

E. Tikhonov, M. Bertolotti, F. Scudieri, *Appl. Phys.* 11, 357 (1976).

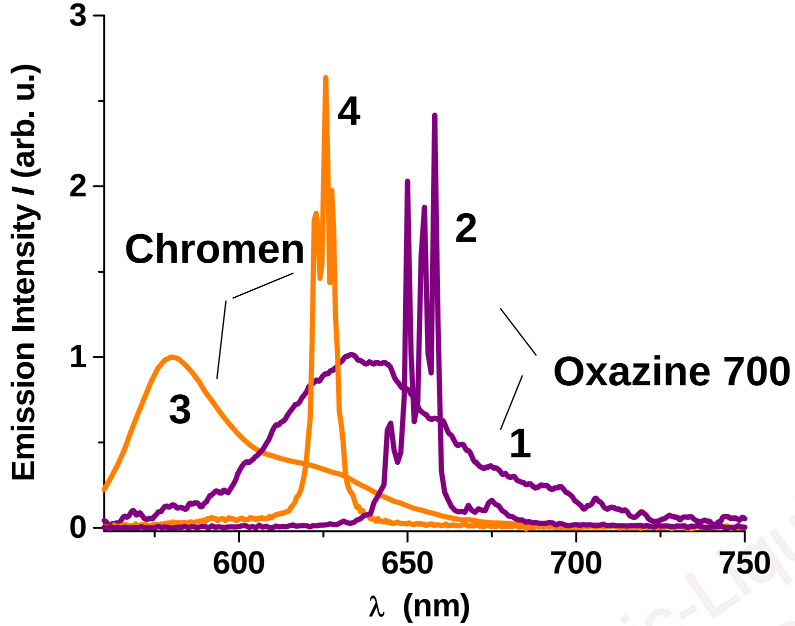
Hence, lasers & amplifiers on NLC !

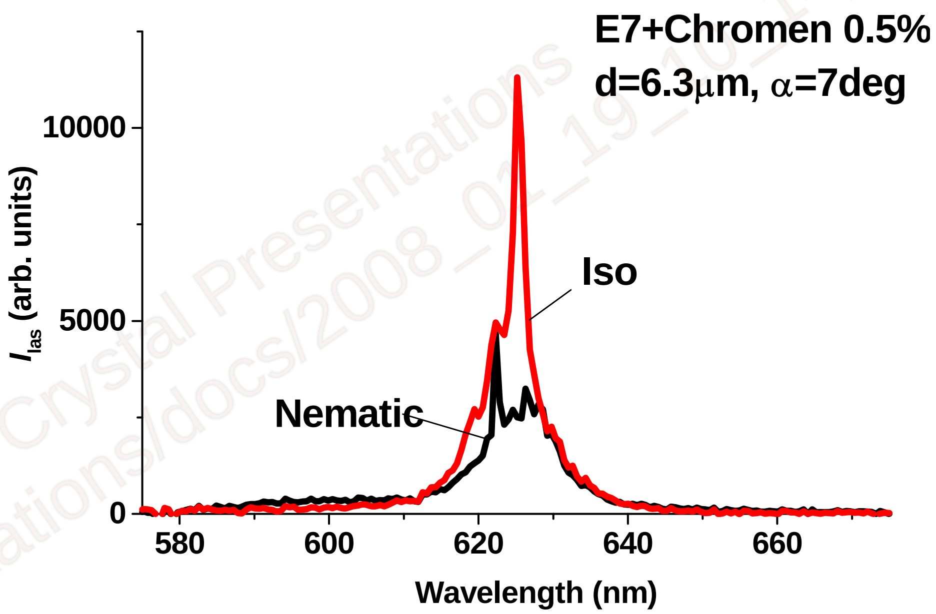
2. Observation of lasing on leaky modes (top view)

a) nematics



Nematic materials: E7 (BDH)+0.5% Chromene (NIOPIK)
Oxazine 700 (NIOPIK)
DCM (Exciton)





Luminescence (1,3) and lasing (2,4); nematic, *d*=6.4±0.5 μm

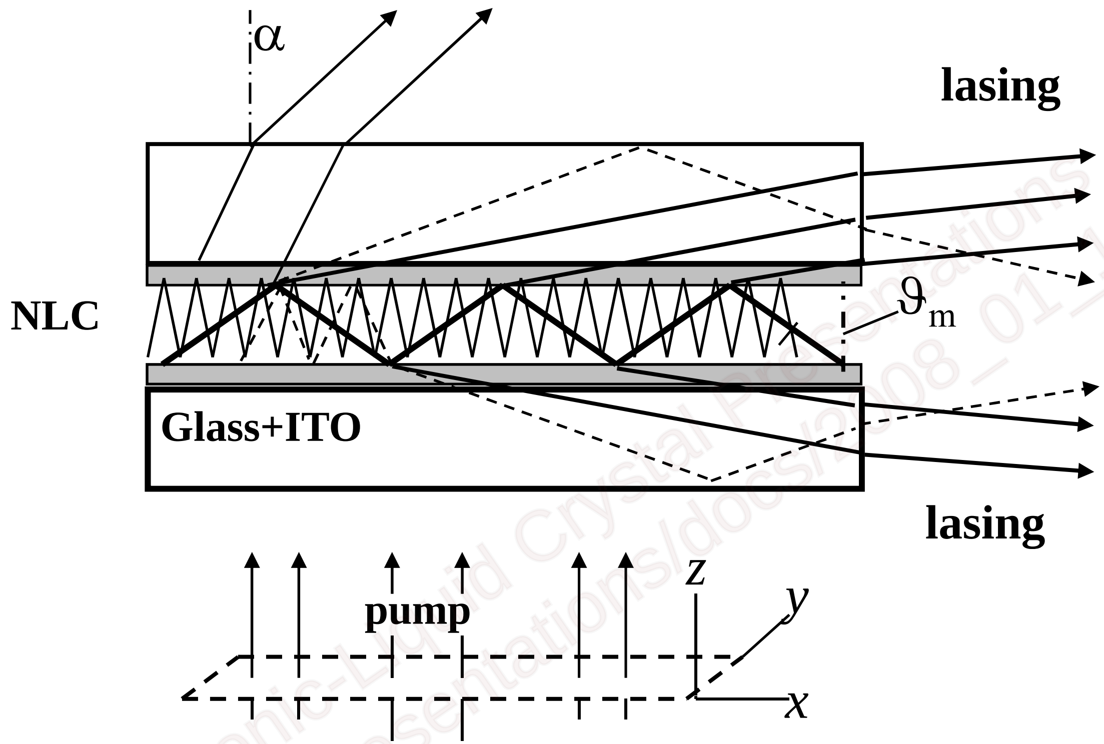
Pump: Chromene *P*= 0.3 mJ/p.cm^2,
Oxazine-700 *P*=1.2 mJ/p.cm^2)

Lasing in "E7 + Chromene"

Nematic and Iso-phase
***P*= 0.3 mJ/cm^{2}pulse**

Emission polarization: close to TM (p), voltage dependence

Waveguide cell and Leaky Modes



Pump beam propagates along the z-direction and forms a 7 x 0.8 mm stripe in the *x*,*y*-plane of the cell. The light amplification appears in the LC layer in the *x*-direction where waves are partially reflected by ITO layers. Amplified modes at an angle close to the total reflection angle leak into glasses, propagate within them and exit from their edges. Which mode has the maximum gain?

Answer:

Our modeling shows that it is the first non-waveguided mode, which escaped into the glass (the most gliding mode within the glass)

This is an additional mechanism of lasing mode selection (the first is narrowing of ASE spectrum, as in traveling wave lasers).

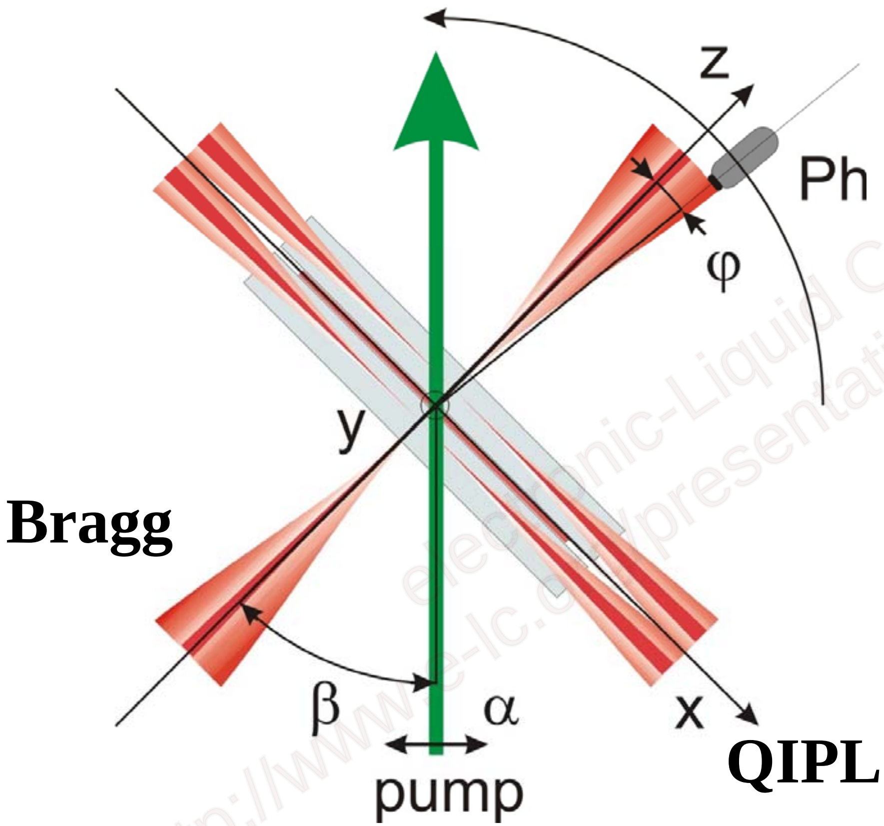
L.M. Blinov et al, Appl. Phys. Lett, **89**, 0311114 (2006)

S.P. Palto, JETP 103, 472 (2006)

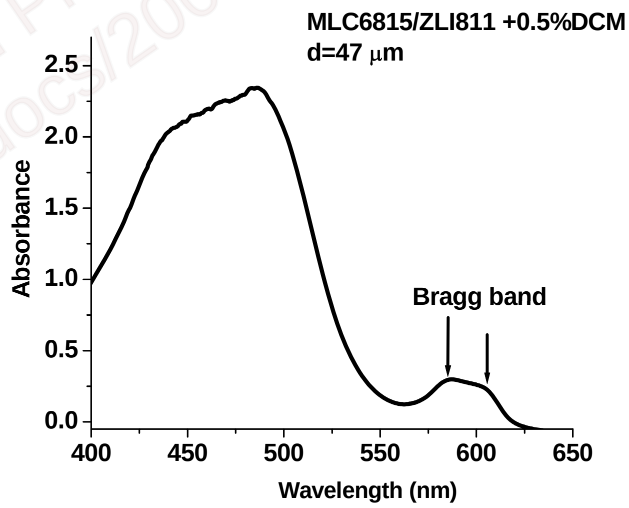
We believe that we observe a new regime of lasing in NLC which is valid also for the isotropic and any other phases of liquid crystals. Let us see what happens in a cholesteric LC

b) Cholesterics liquid crystals: competition between Bragg and Quasi- In-Plane Leaky (QIPL) modes

Geometry (helix axis along z)



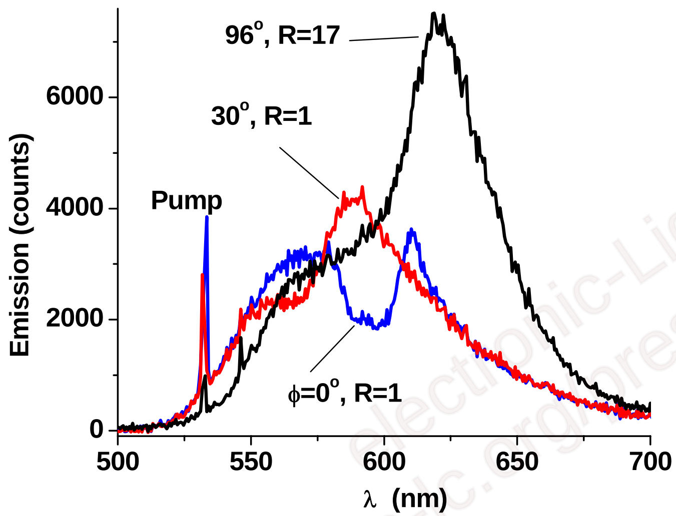
Absorbance spectrum

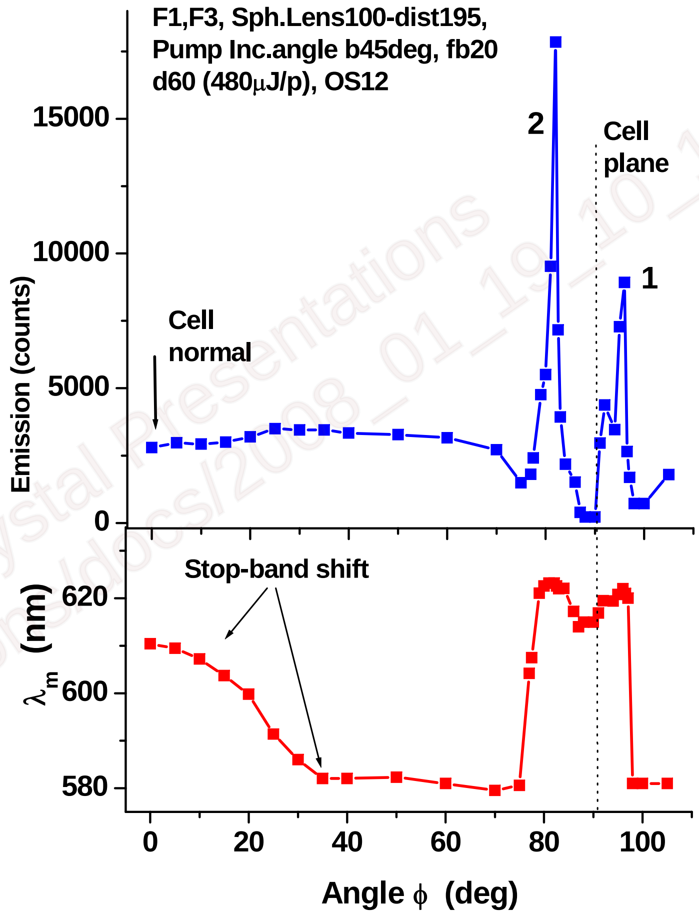


CLC: wide elliptic pump spot

Luminescence: angular dependence

Typical spectra





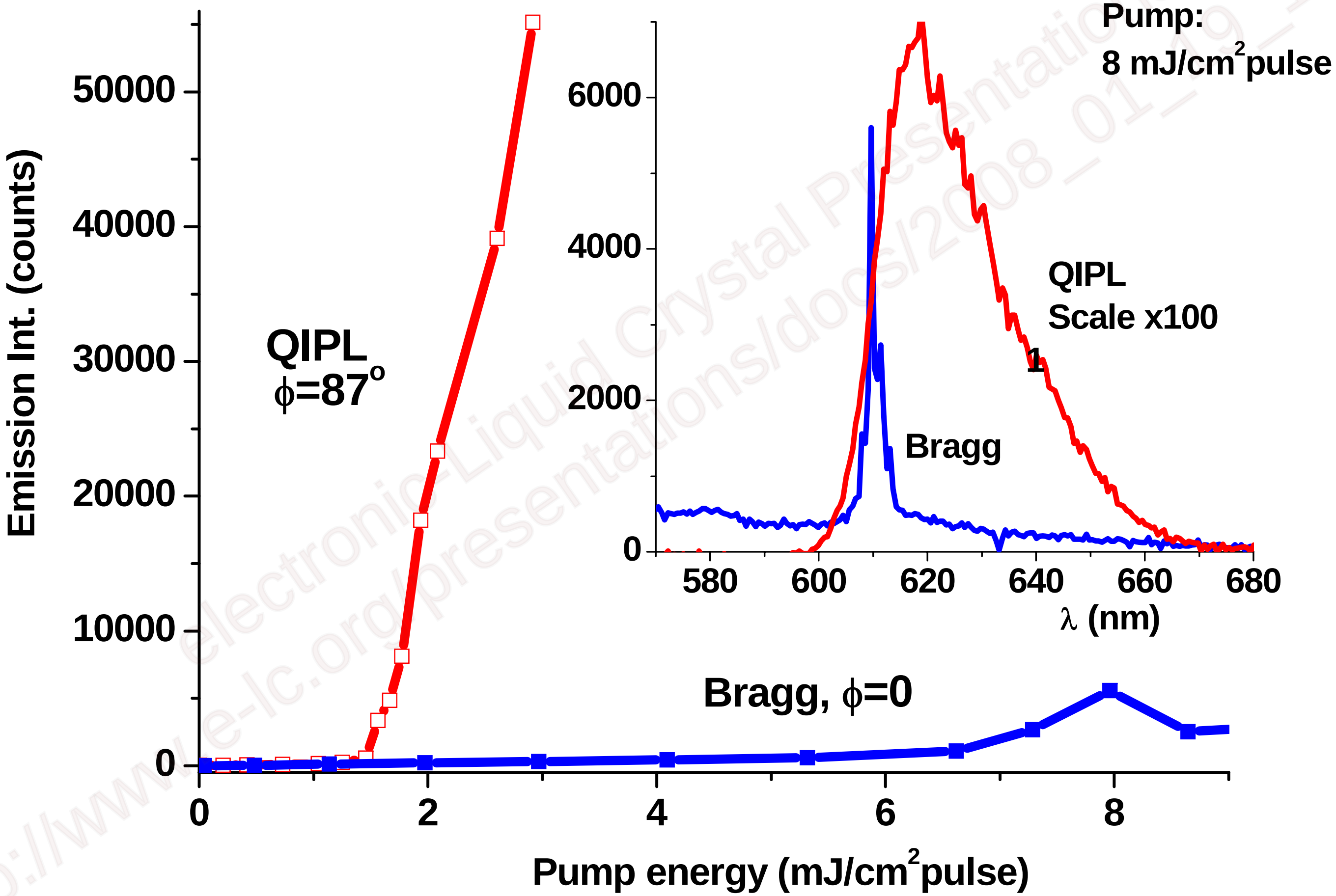
φ is angle of observation, counted from the cell normal

R is polarization ratio

For organic solid films luminescence see: Penzhofer *et al* Opt. Comms. 229, 279 (2004)

CLC: **Cylindrical Lens. Focused beam (7x0.5mm²)**

Spectra and pump dependence of emission intensity in Bragg and QIPL modes



So we can conclude that In CLC, for an expanded pump beam area, the Quasi-In-plane Leaky modes dominate over the Bragg mode (orders of magnitude!)

Leakage of energy must be reduced for DBF LC structures (for example by using multi-channel pump, a kind of "light sieve" or to use amplifiers

L.M. Blinov et al J. Appl. Phys. **101**, 053104-1-6 (2007)

L.M. Blinov et al MCLC **465**, 37-50 (2007)

But what about tuning laser bands by electric field?

In this case CLC is not proper material (CLC helix is not smoothly unwound due to principal limitations, as discussed in my tutorial lecture).

We decided

to follow the work of T. Matsui, M. Osaki et al, *Electro-tunable laser in dye-doped NLC waveguide under holographic excitation*, APL 83, 422 (2003),

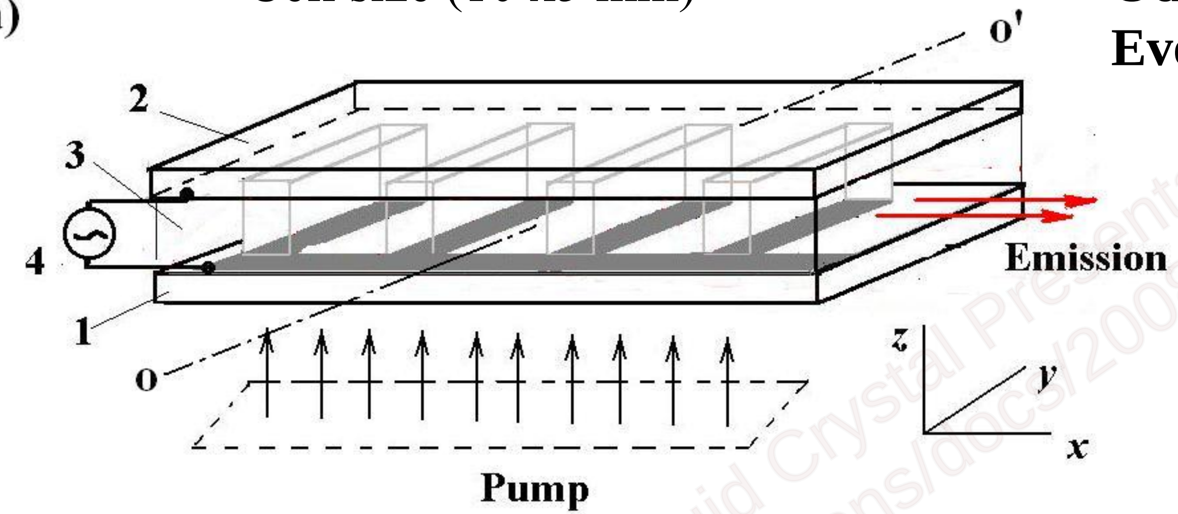
but to do without holography!

3. Simple tunable DFB laser

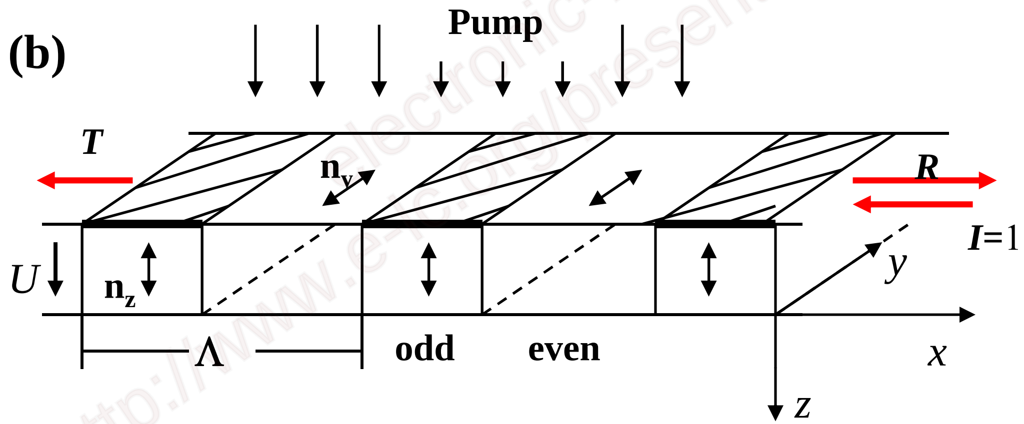
Period is 15 μm (Large !!)
Odd (shadow, *E*): 5 μm
Even (illum, *E*=0): 10 μm

Cell size (10 x5 mm)

(a)



(b)

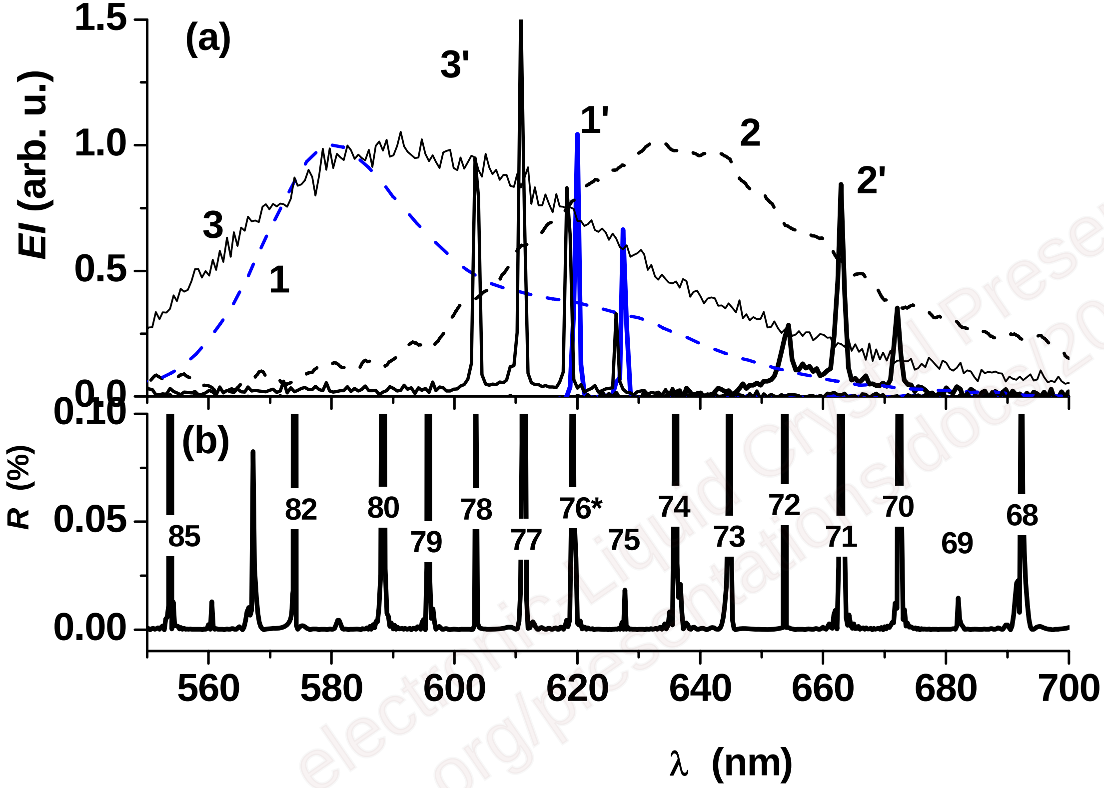


What does electrode mask make?

- modulates gain even without field

- modulates refraction index by field

Laser generation in the isotropic phase of E7/dye (0.5%)



Experiment
n=1.569, Λ=15μm

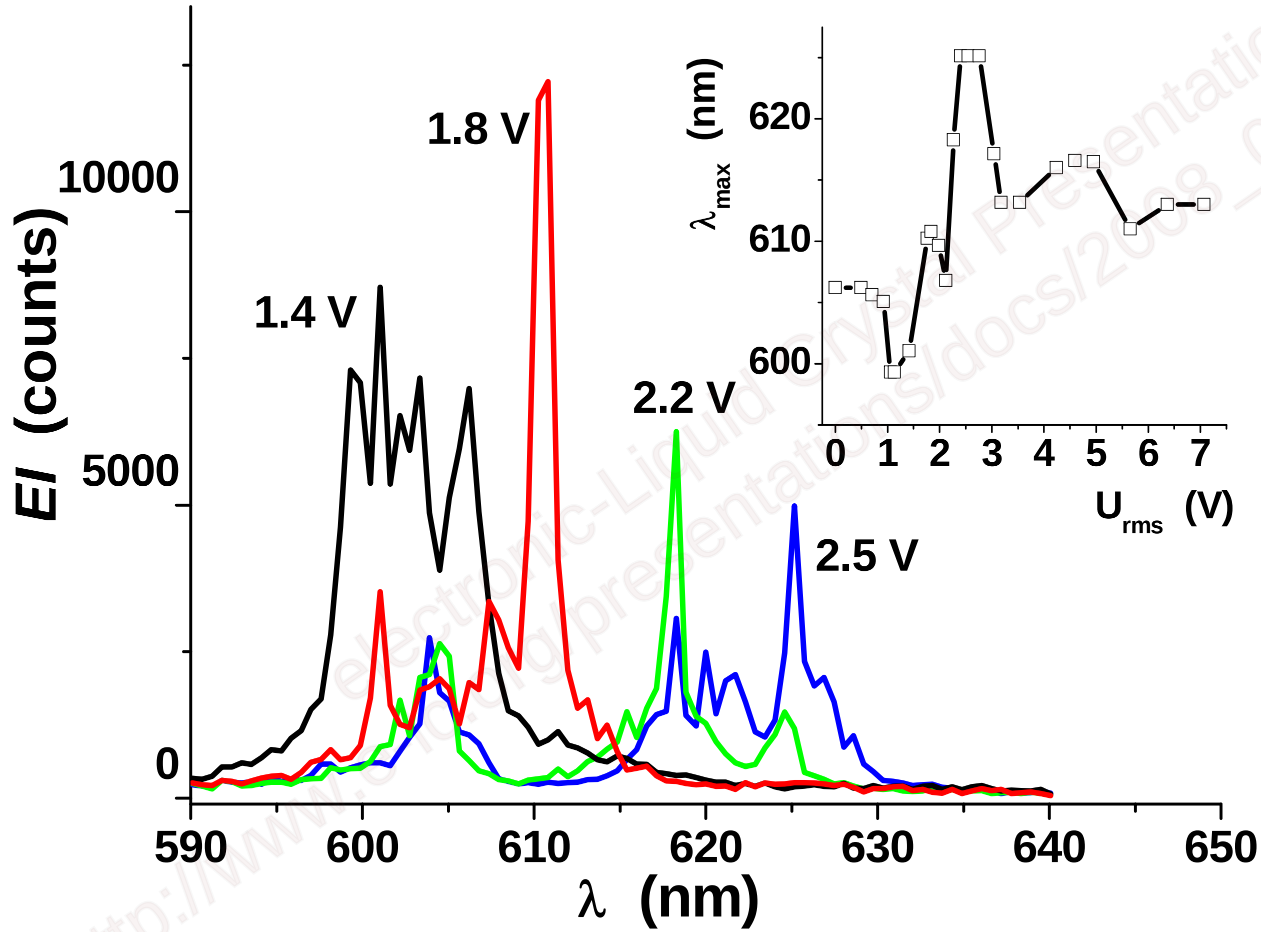
Model
(no fitting
parameters!)

Experimental & calculated lasing spectra
Accuracy is determined by
a) spectrometer resolution (0.6 nm)
b) dependence of *n* on the type of dye

$$\lambda_m = \frac{2 n_{iso} \Lambda \sin\varphi}{m}$$

Evolution of lasing spectra with applied voltage

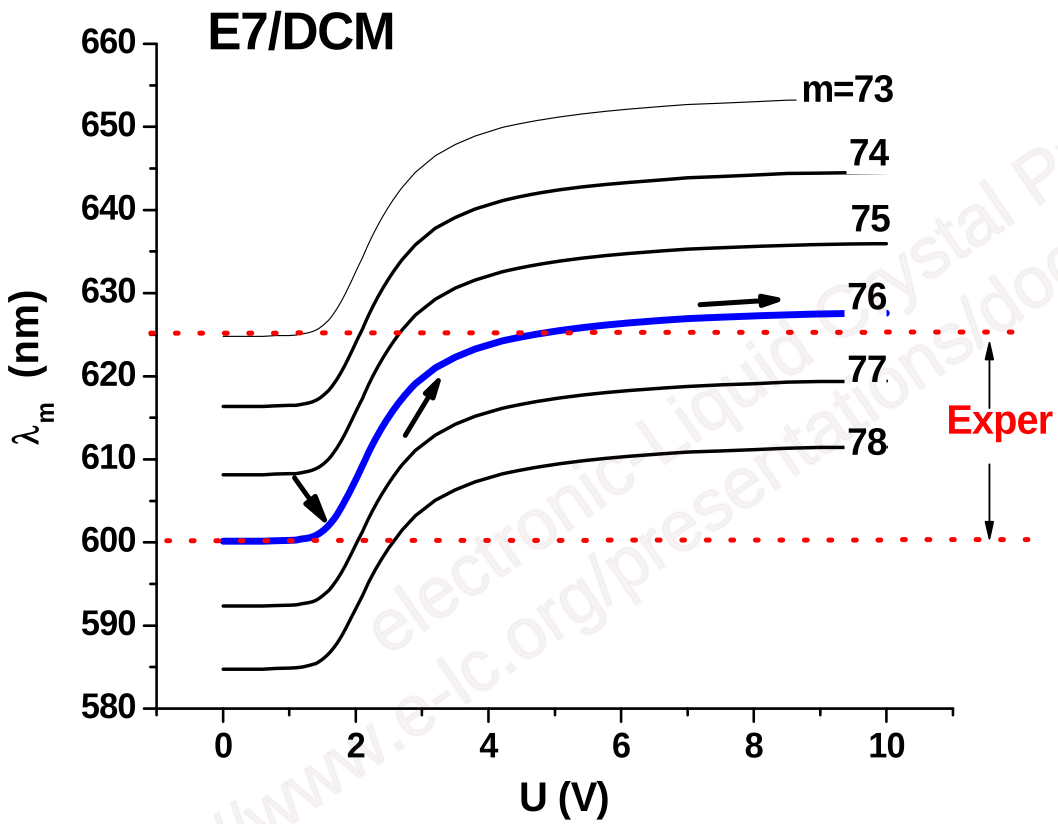
(E7/DCM, nematic, d=1.6 μm, pump1.8 mJ/cm²).



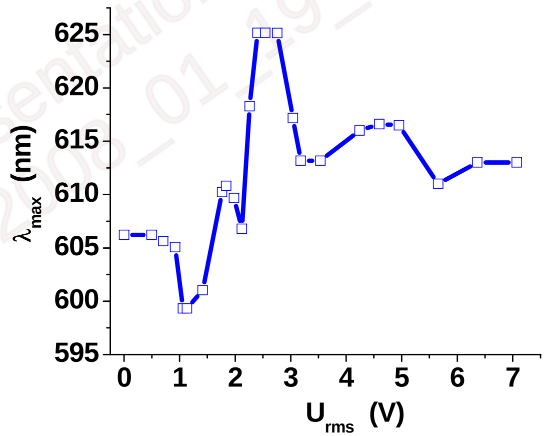
How to understand this trend with increasing voltage?

Calculated voltage dependence of spectral positions of the *z*-polarized Bragg modes of different order *m*

Calculation



Experiment



$$\lambda_m^{y,z}(U) = \frac{2\Lambda n_{y,z}^{av}(U)}{m}$$

Suggested:

simple DFB microlasers with spectral positions of the emission band controlled by an electric field (shift 25 nm)

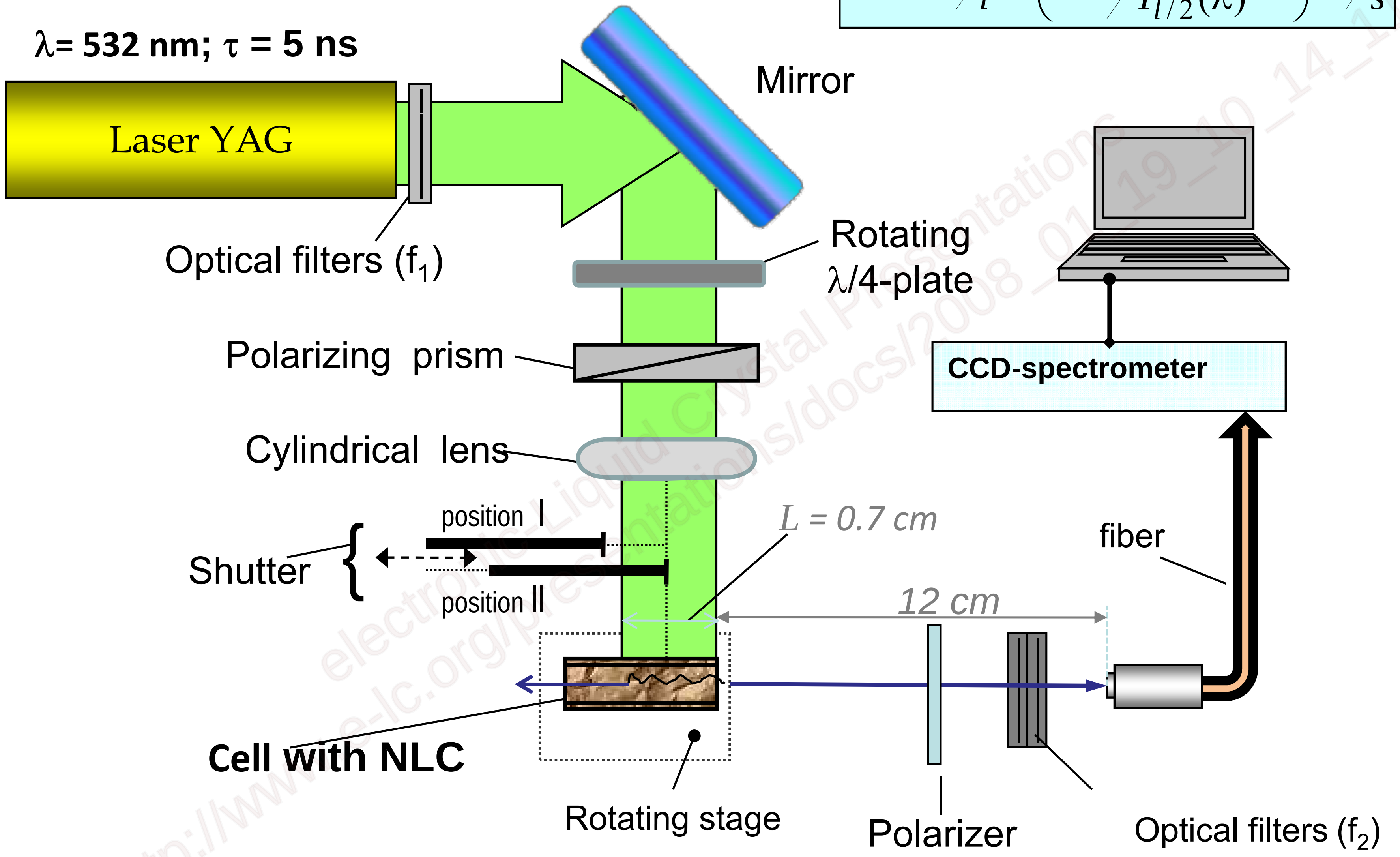
Understood:

the role of the high order resonator modes and the basic mechanism (gain modulation and additional influence of refraction index modulation)

L.M. Blinov et al, Appl. Phys. Lett. **90**, 131103 (2007)
L.M. Blinov et al, J. Nonlinear Opt. Phys. & Mat. **16**, 75-90 (2007)

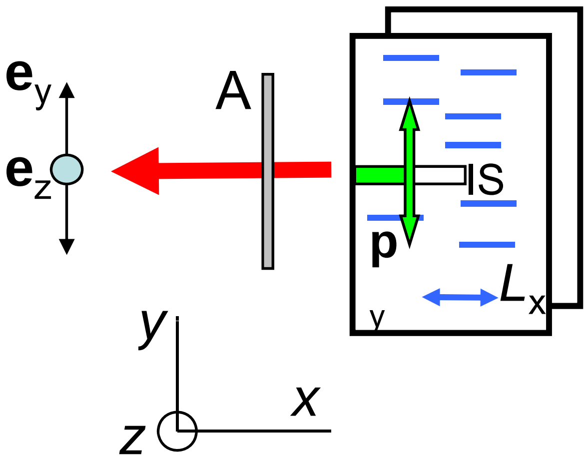
4. ASE gain measurements of dye doped NLC in polarized light with an electric field applied

$$g(\lambda) = \frac{2}{l}\ln\left(\frac{I_l(\lambda)}{I_{l/2}(\lambda)} - 1\right) + \frac{2}{s}$$

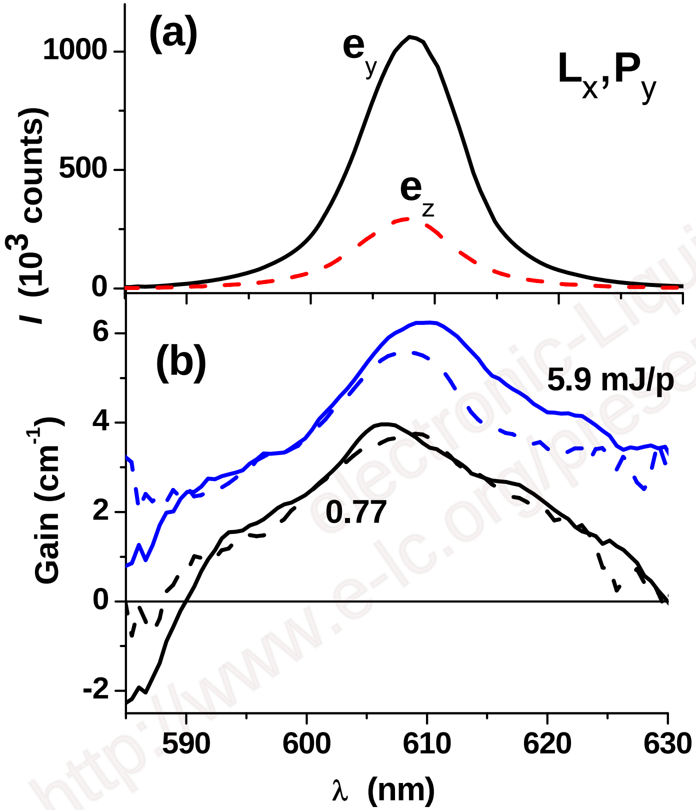


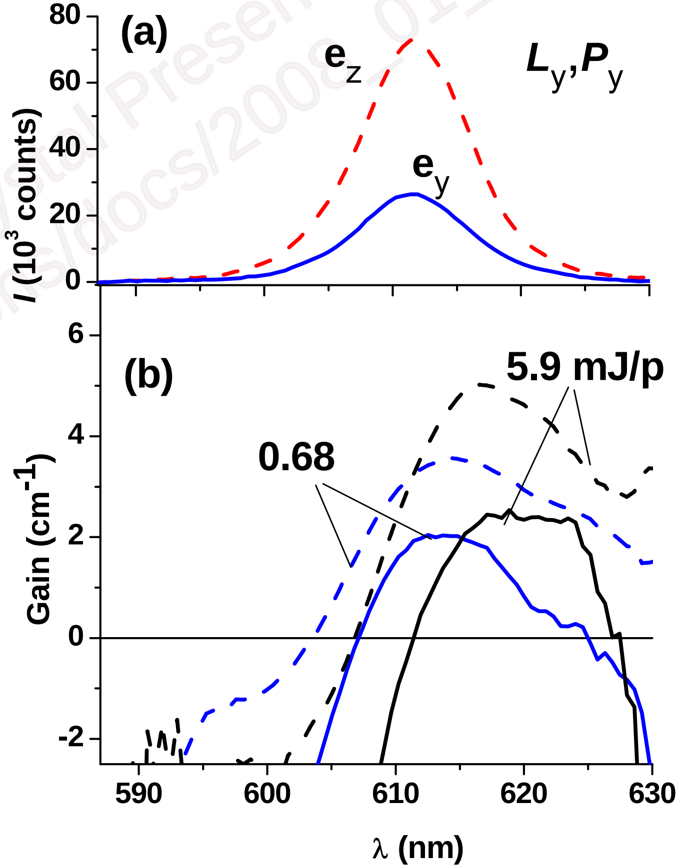
Technique: C.V. Shank et al, *Appl. Phys. Lett. 12, 307 (1970)*

Polarization spectra of gain at variable pump energy per pulse

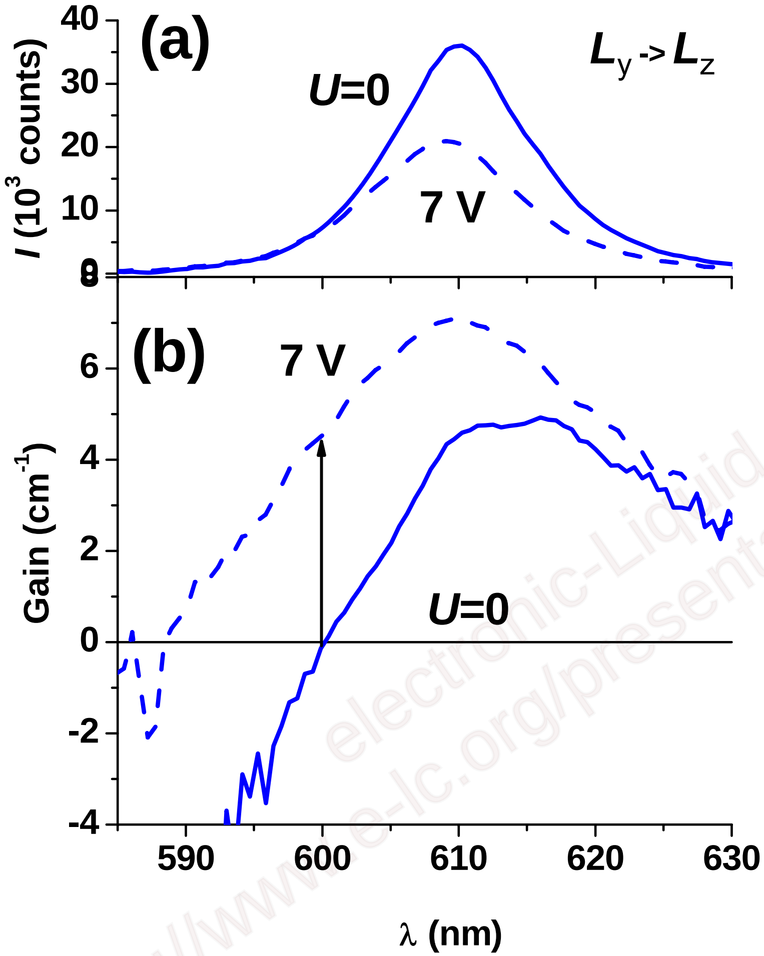


Material: E7 + DCM (0.5%) Cell thickness 27 μm





Field-controlled gain



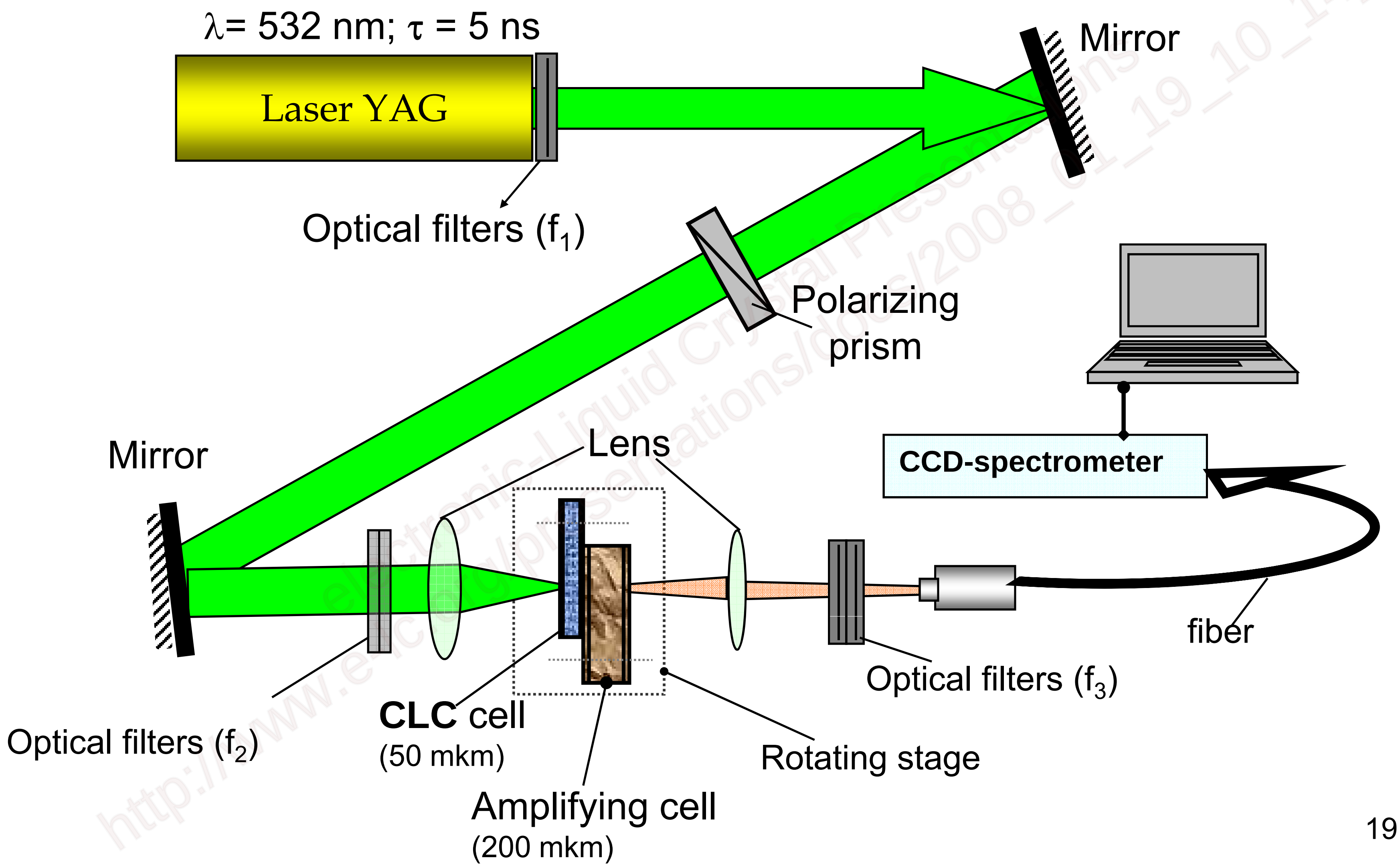
Material: E7 + DCM (0.16%), cell thickness 40 μm

The field reorients the director from planar (y) to homeotropic (z) position

Here we see a possibility to switch the gain from negative to positive, ON and OFF

5. Planar micro-amplifier for CLC laser

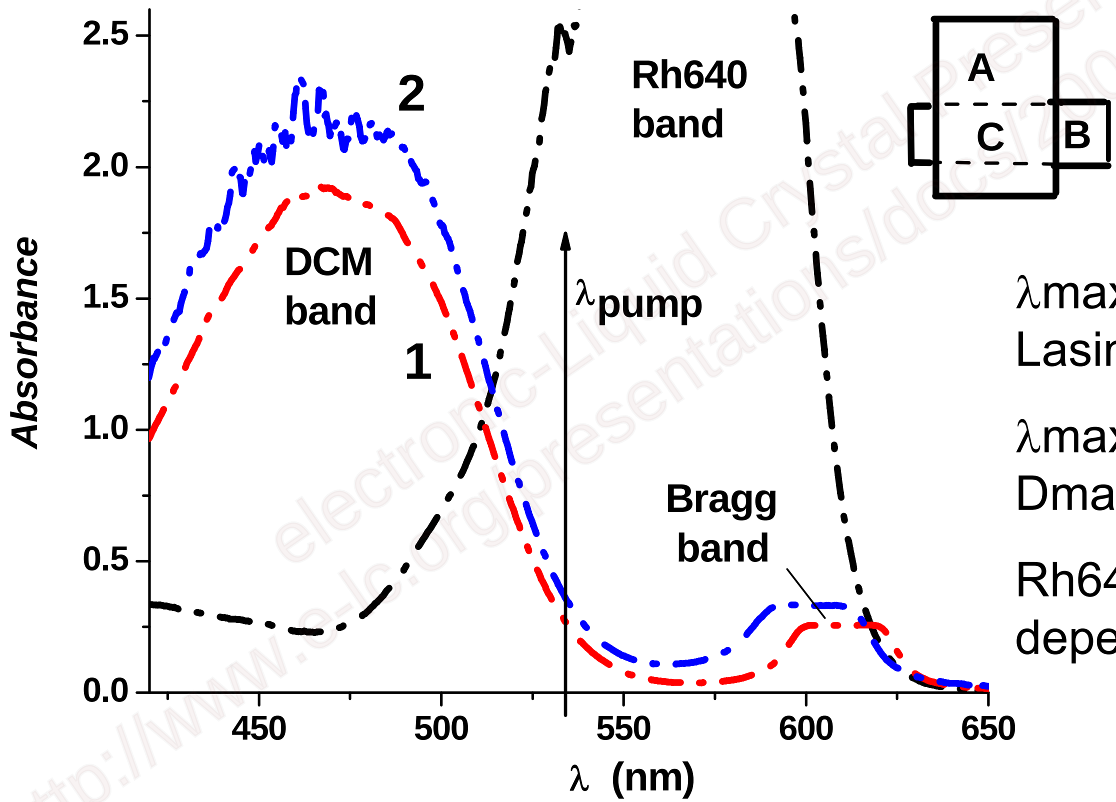
Oscillator: MLC-6815 (Merck) + chiral ZLI-811 (Merck) +DCM 0.5%
Amplifier: Rh640 c=1.05.10^-2 M/L



B1. Absorbance spectra

Red and blue: 50 μm ChLC-DCM cells

Black: 200 μm cell Rh640 dense solution in glycerine (10^{-2} M/L)



λmax(DCM)=467 nm.
Lasing at λ≈ 621 and 614 nm

λmax (Rh640)=573 nm
Dmax=6.4

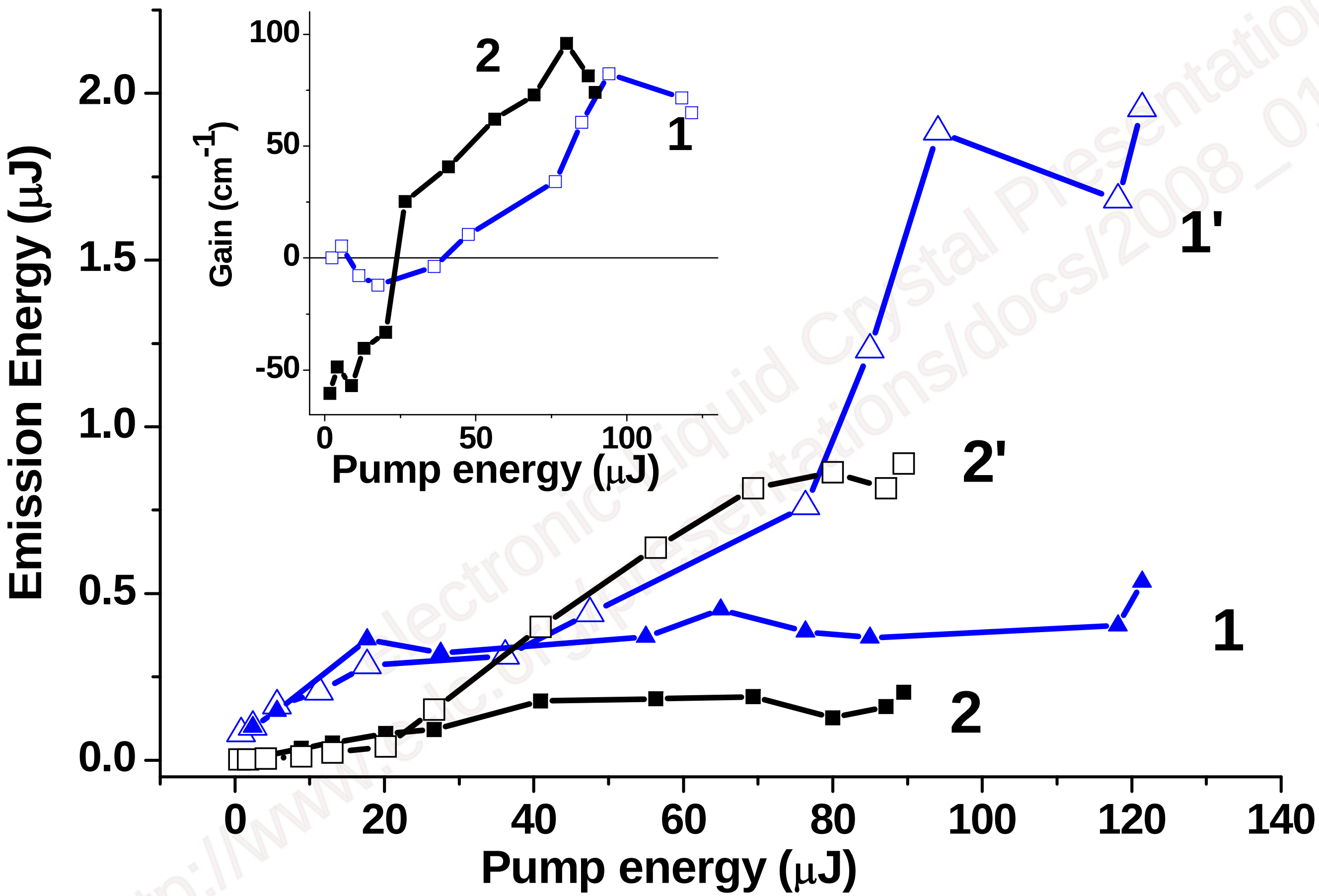
Rh640 ASE at λ≈ 610-613 nm, depends on pump

B2. Laser emission energy and *vs* pump energy

Black: from CLC621 and CLC614 without amplifier

Blue: for same cells with the amplifying Rh Layer

B3. Inset: Gain coefficient at λ=621(1) and 614 (2) nm



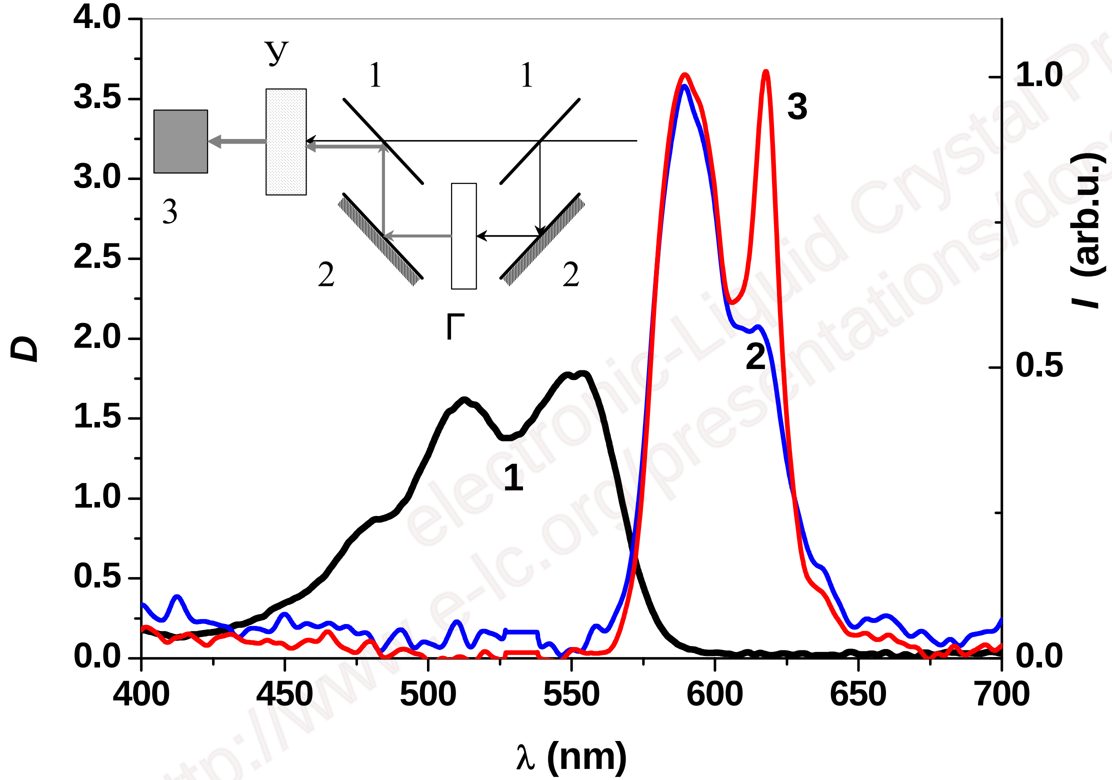
6 times amplification

with locked λ= constant

Pump energy scale W=100 μJ corresponds to W_p= 30 mJ/cm^2 and P_p=6 MW/cm^2.

5b. CLC emission amplification by a nematic cell

Spectra of Ox17 absorption (1) and luminescence at pump 7.4 (2) and 11 (3) mJ/pulse

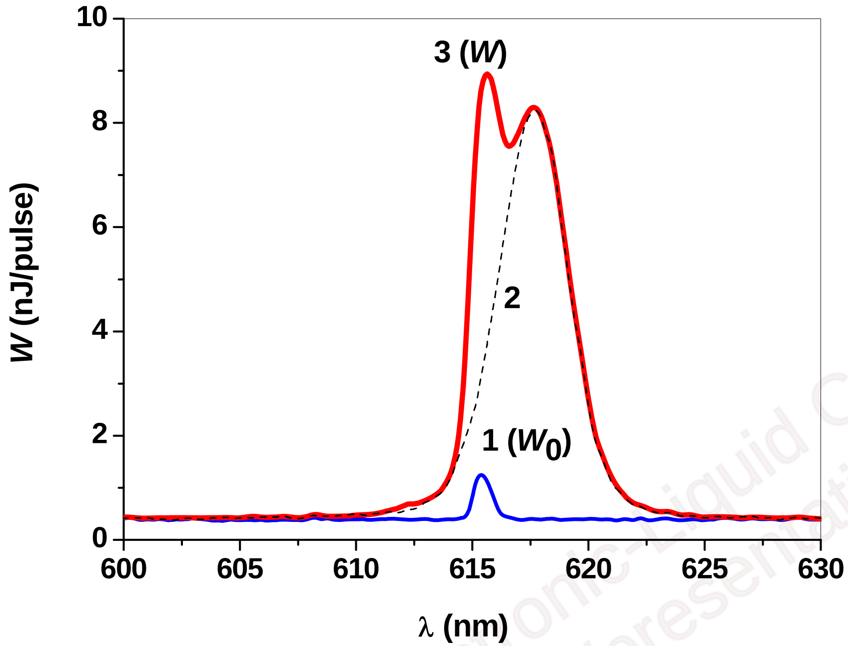


CLC oscillator:
LJK2+Leitsine+
Oxazine 17 (0.3%)
Cell thickness d=30 μm

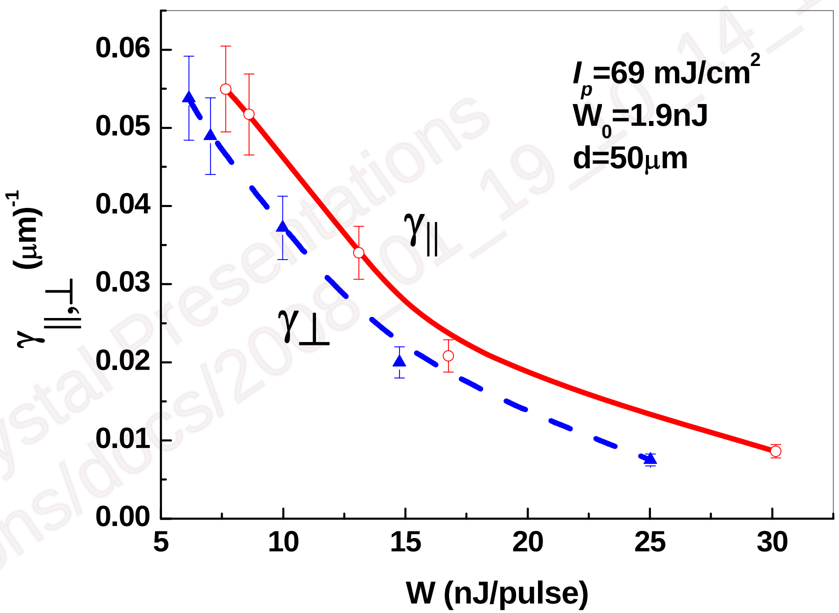
NLC amplifier:
LJK2+Chromene (0.5%)
Cell thickness d=50 μm

Light amplification spectra

Input signal 1.2 nJ, 0utput 9 nJ.



Gain coefficient anisotropy



Max amplification 15

Gain: up to 500 cm^{-1}

Planar amplifier on Rhodamine 645:

L.M.Blinov et al, Appl. Phys. Lett. 91, 161102 (2007)

Amplifier on NLC:

N.M. Shtykov et al, Pis'ma Zh. Eksp. Teor. Fiz. 85, 734-7 (2007)

Conclusion

Lasers:

A new field controllable regime of lasing based on QIPL modes is found in NLC (valid for isotropic and any other LC phases)

At certain geometries of CLC lasers, QIPL modes may have consumed almost all energy of excitation

Simple voltage tunable DFB laser is suggested with interdigitated electrode system, which operates on high order Bragg reflection ($m>70$)

Amplifiers:

Shown a possibility to control the ASE gain magnitude by the electric field using NLCs.

Weak emission of CLC is amplified 6 times by Rhodamine640-glycerin solution in the planar (chip) configuration

Weak emission of CLC is 15 times amplifies by a 50 μm nematic cell

Acknowledgements.

Mr. A. Pane (LiCryL-CNR) and S. Yakovlev (IKRAN) for the help in experiment.
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