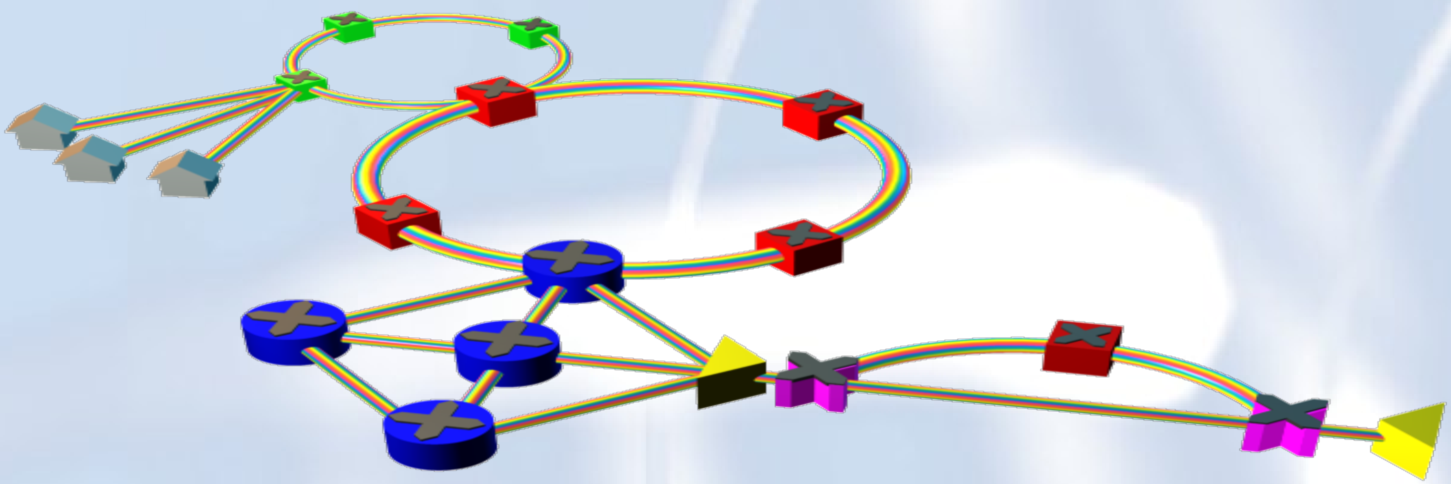
非显示应用：液晶的下一个蓝海?

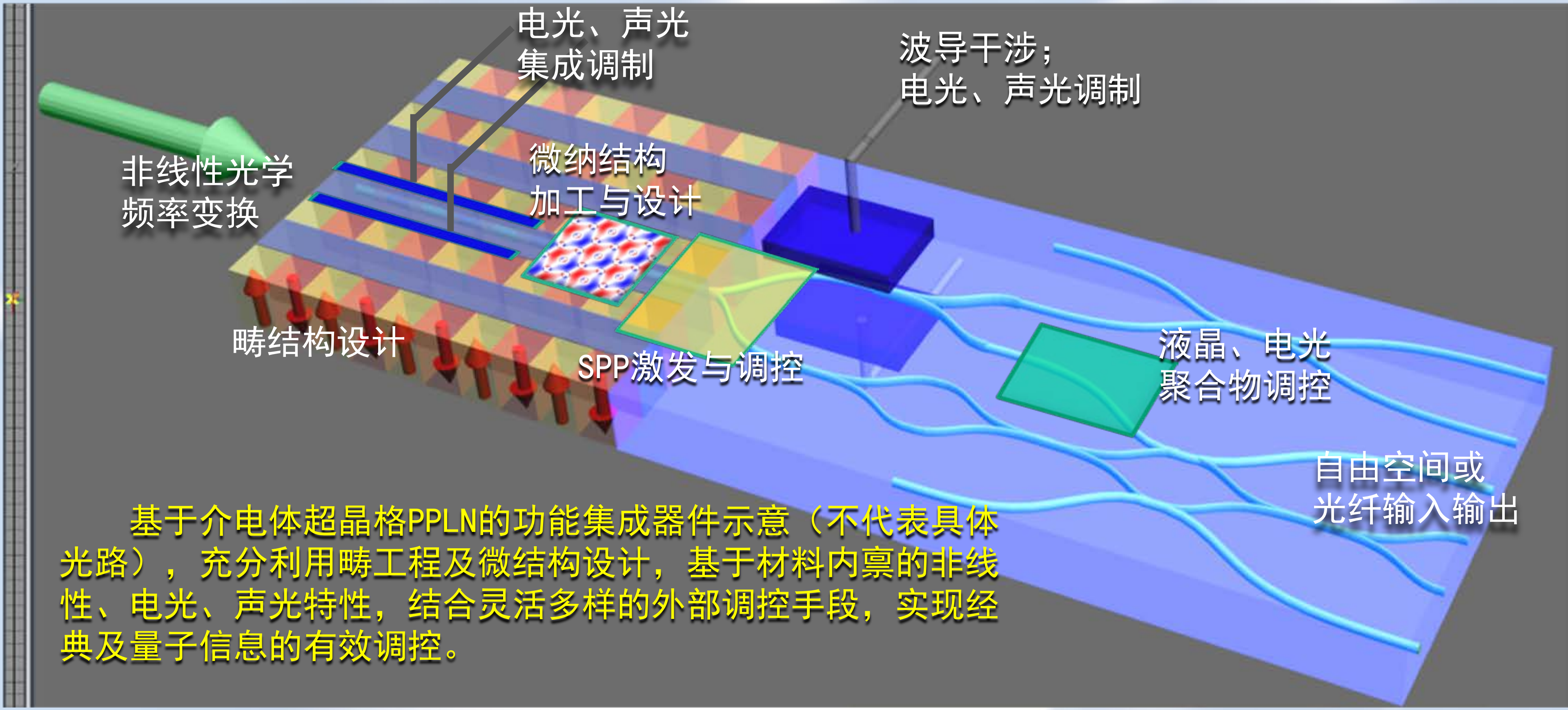
陆延青
南京大学现代工程与应用科学学院
南京大学固体微结构物理国家重点实验室



研究组

http://light.nju.edu.cn

研究基础：介电体超晶格



基于介电体超晶格PPLN的功能集成器件示意（不代表具体光路），充分利用畴工程及微结构设计，基于材料内禀的非线性、电光、声光特性，结合灵活多样的外部调控手段，实现经典及量子信息的有效调控。

*Science **276**, 2004; Science **284**, 1822; PRL **90**, 053903; Sci. Rep **4**, 4812*
*APL **77**, 3719; APL **78**, 1035; APL **85**, 3531; APL **101**, 151109 ; APL **104**, 171110*
*PRA **88**, 063827; PRB **82**, 155107; OE **17**, 11965; OE **18**, 7340; OE **19**, 380*
*OL **35**, 3327; OL **36**, 2533; OL **36**, 4434; …*

报告提纲

I、液晶与液晶显示

II、液晶的非显示应用

无处不在的液晶

1. Handheld

2. Notebook

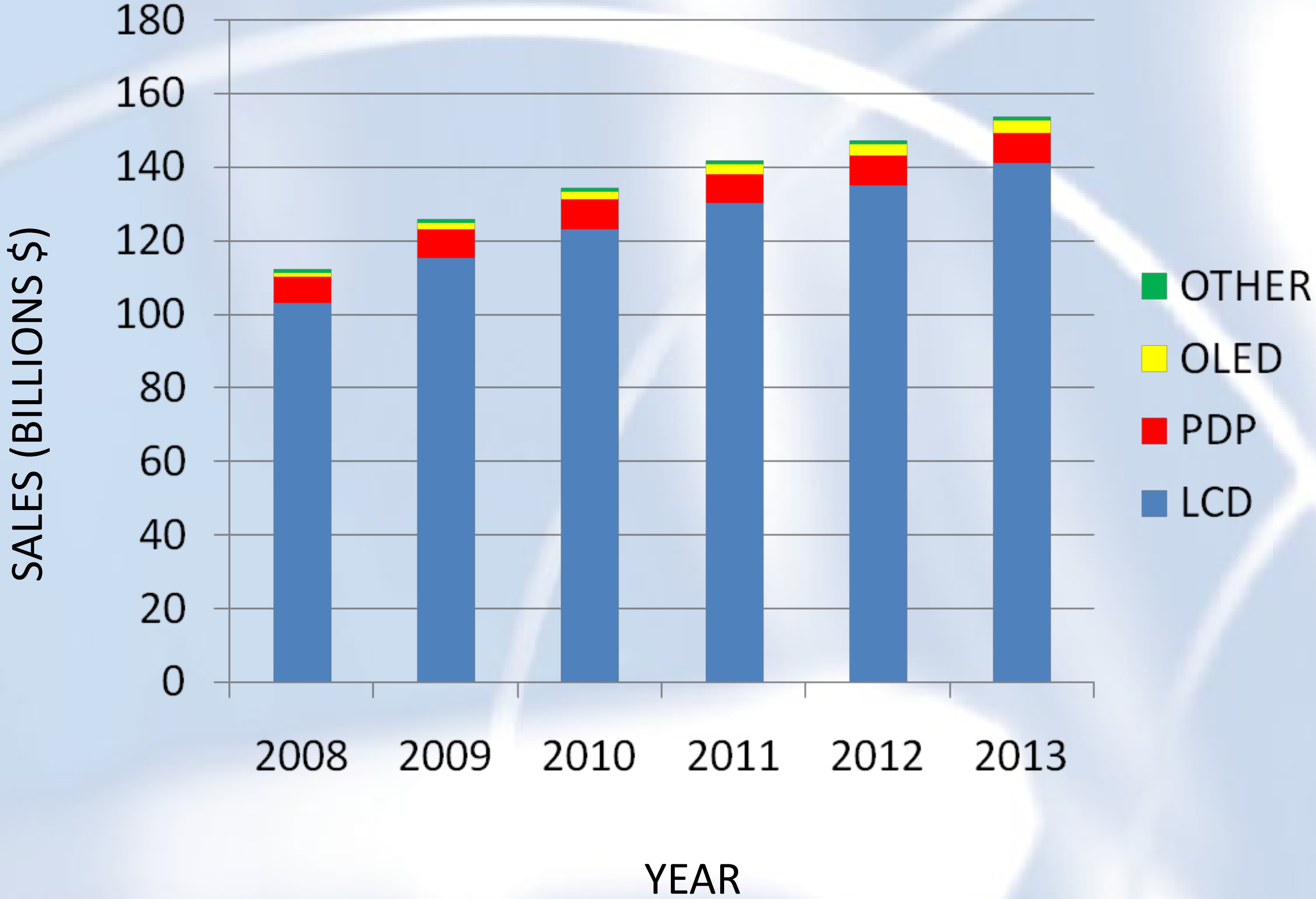
3. Desktop

4. LCD-TV

5. Rear-projection TV

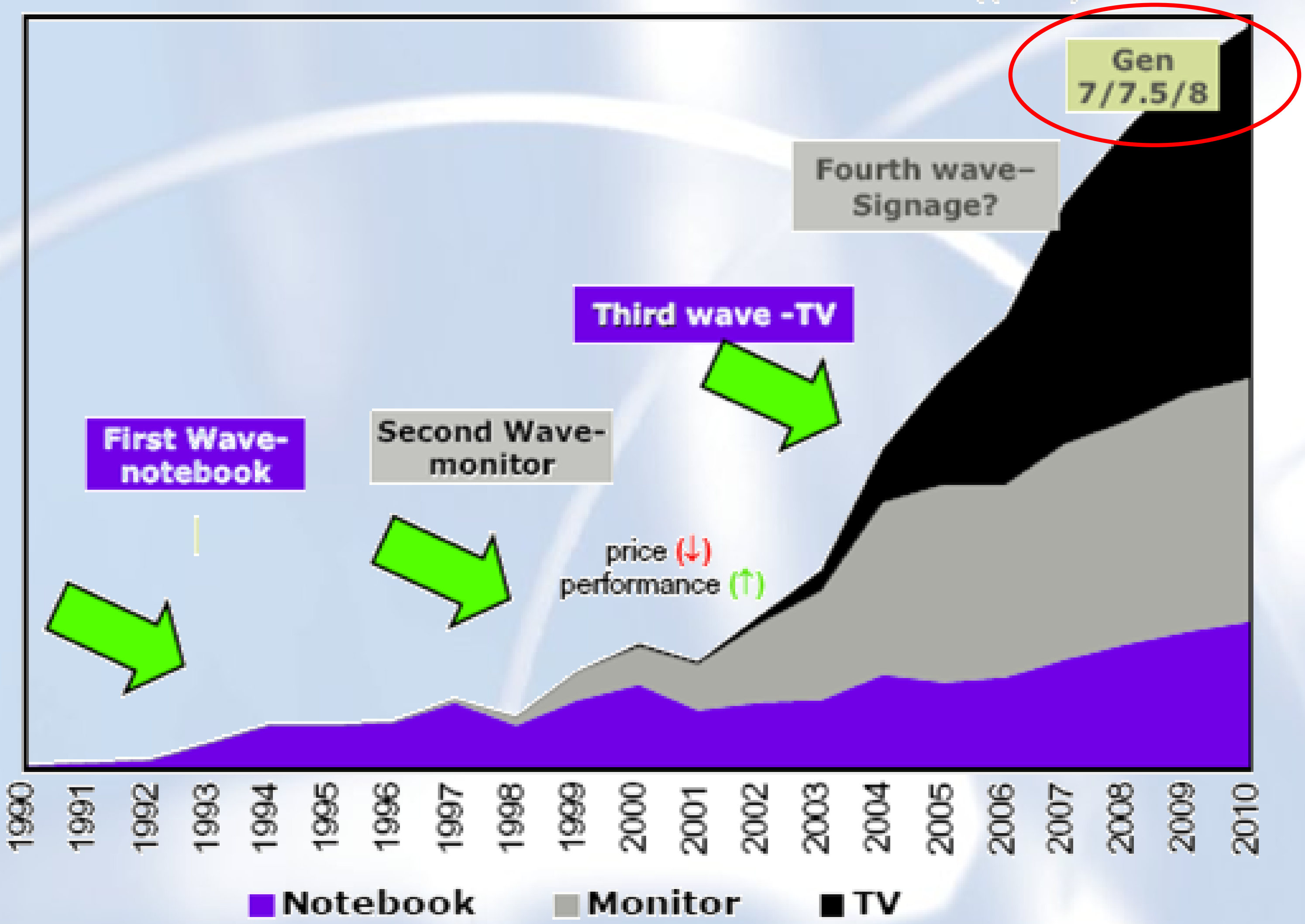
6. Projector

Market analysis: FPD Market

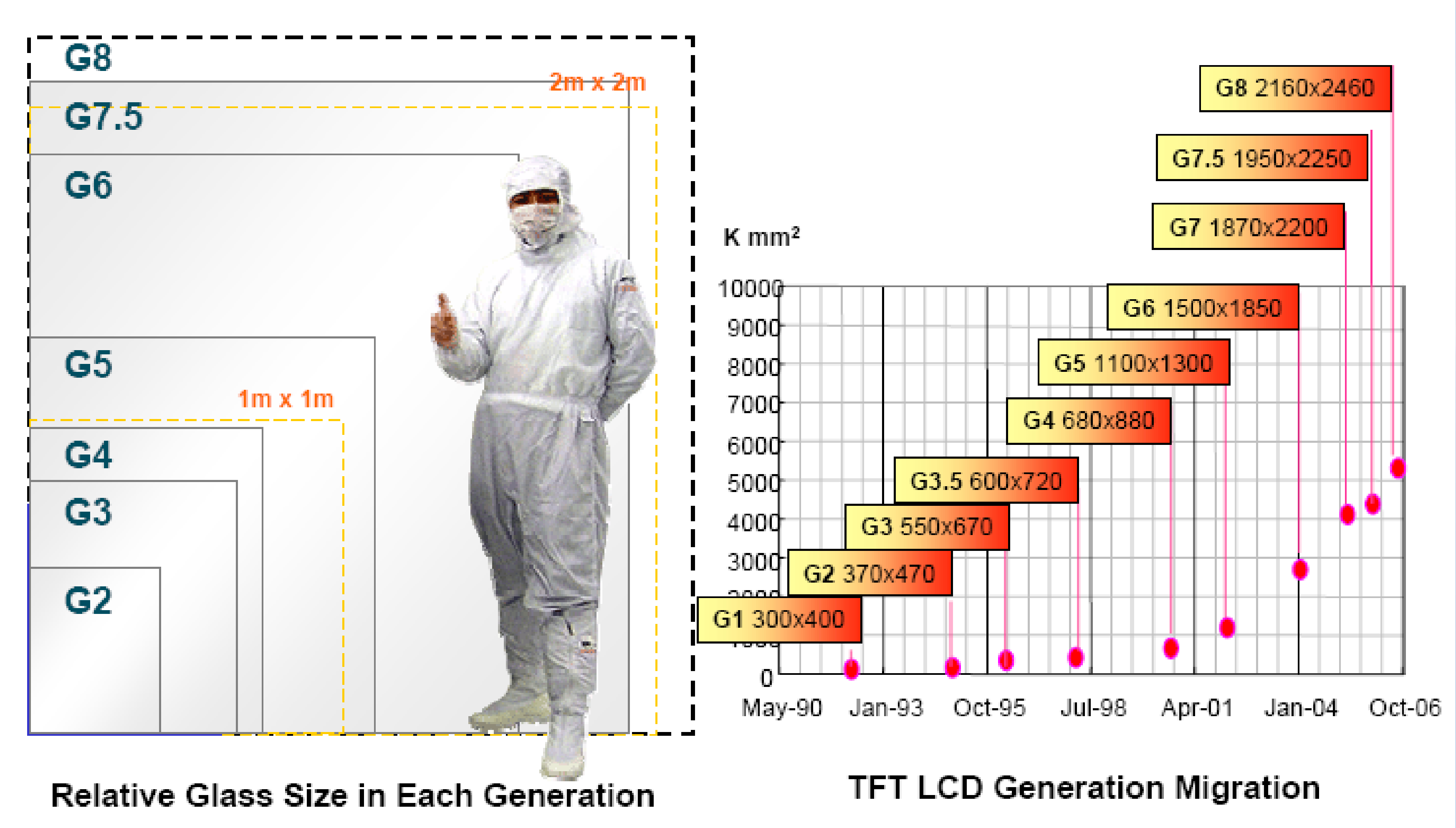


From Display Search Flexible Electronic Displays

LCD win the market, history and trend

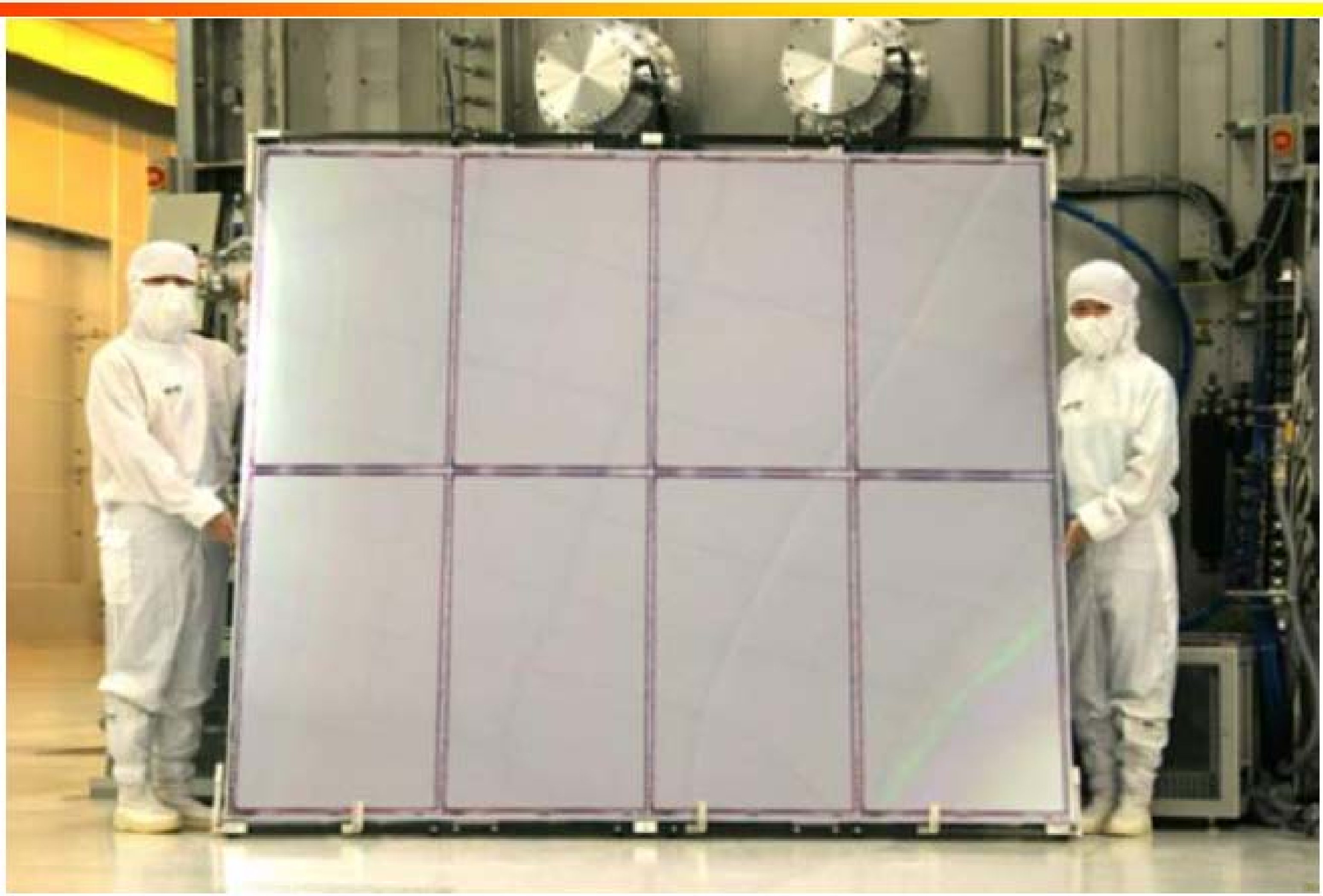


LCD Generation Migration



LCD Generation Migration

2006/08 – Taiwan第一片G7.5產出之42"TV面板



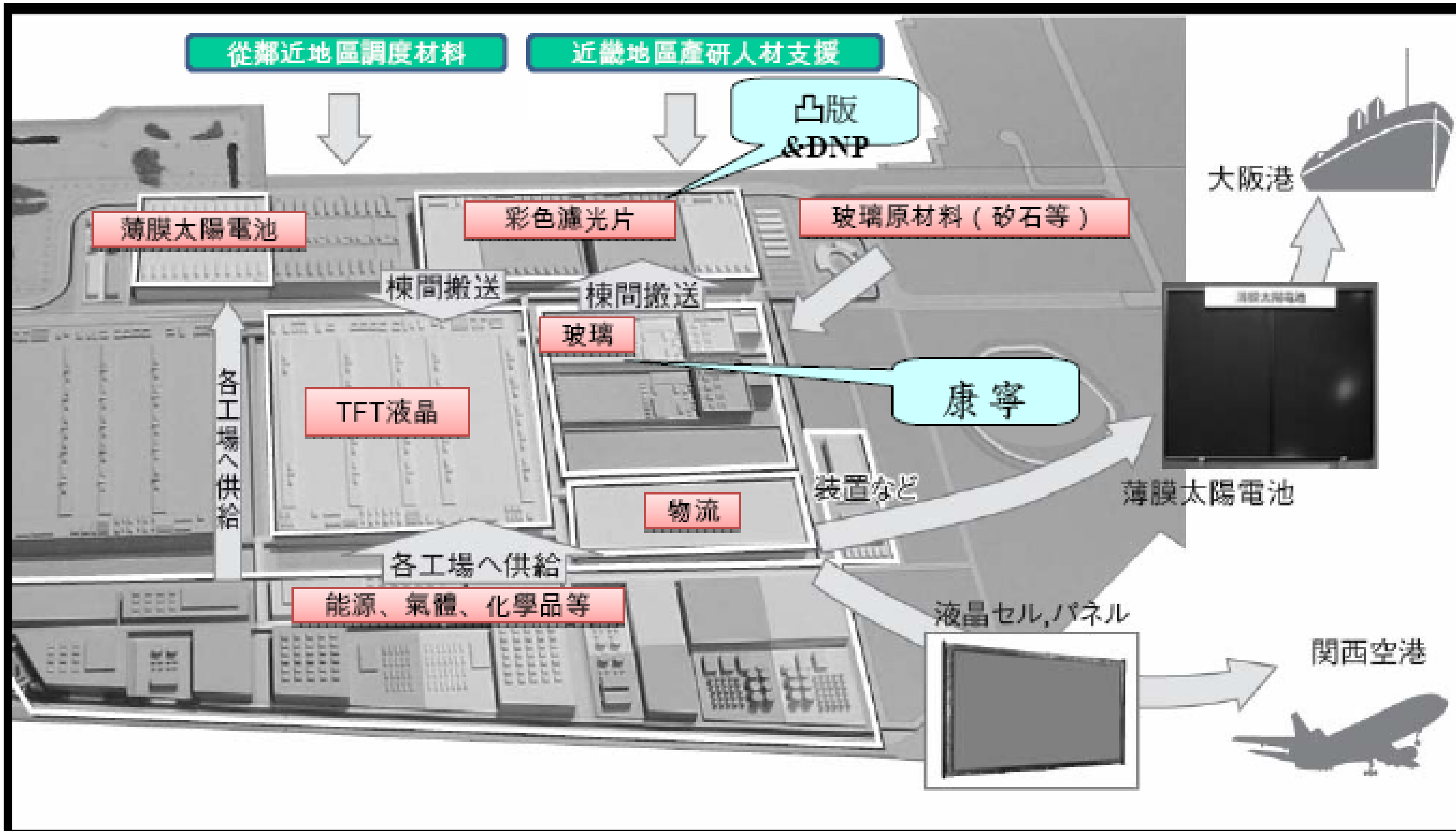
LCD Generation Migration

G7.5 巨大機台

Photo：長達68公尺, 重量 242 噸

LCD Generation Migration

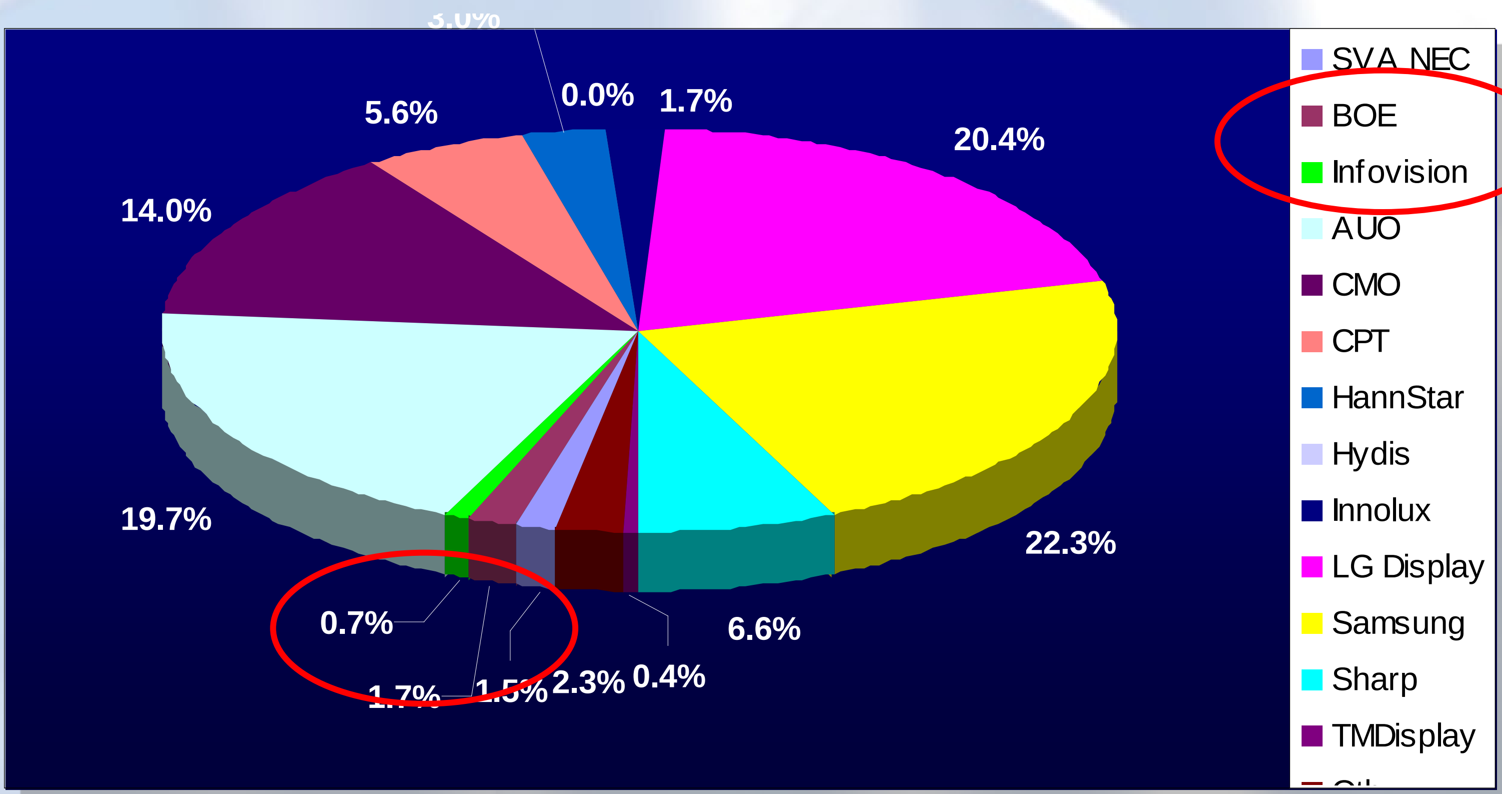
Sharp 於大阪設立十代線



2008年的中国大陆TFT-LCD产业现状

- 我国大陆只有二条TFT-LCD大规模（5代）量产线，总生产能只占全球份额的约3%，处于起步阶段，尚有很大差距

全球大型TFT-LCD制造商份额（2007.5-2008.4，按面积）



12

国家的政策规划

（1）《国家中长期科学和技术发展规划纲要（2006-2020年）》“信息产业及现代服务业”重点领域中的“高清晰度大屏幕平板显示”优先主题

（2）2007年1月23日发布，国家发展和改革委员会、科学技术部、商务部、国家知识产权局2007年第26号令《当前优先发展的高技术产业化重点领域指南（2007年度）》信息类第16项“新型显示器件”的主要内容：大尺寸液晶显示（TFT-LCD）。

目前的中国大陆TFT-LCD高世代线（含规划）

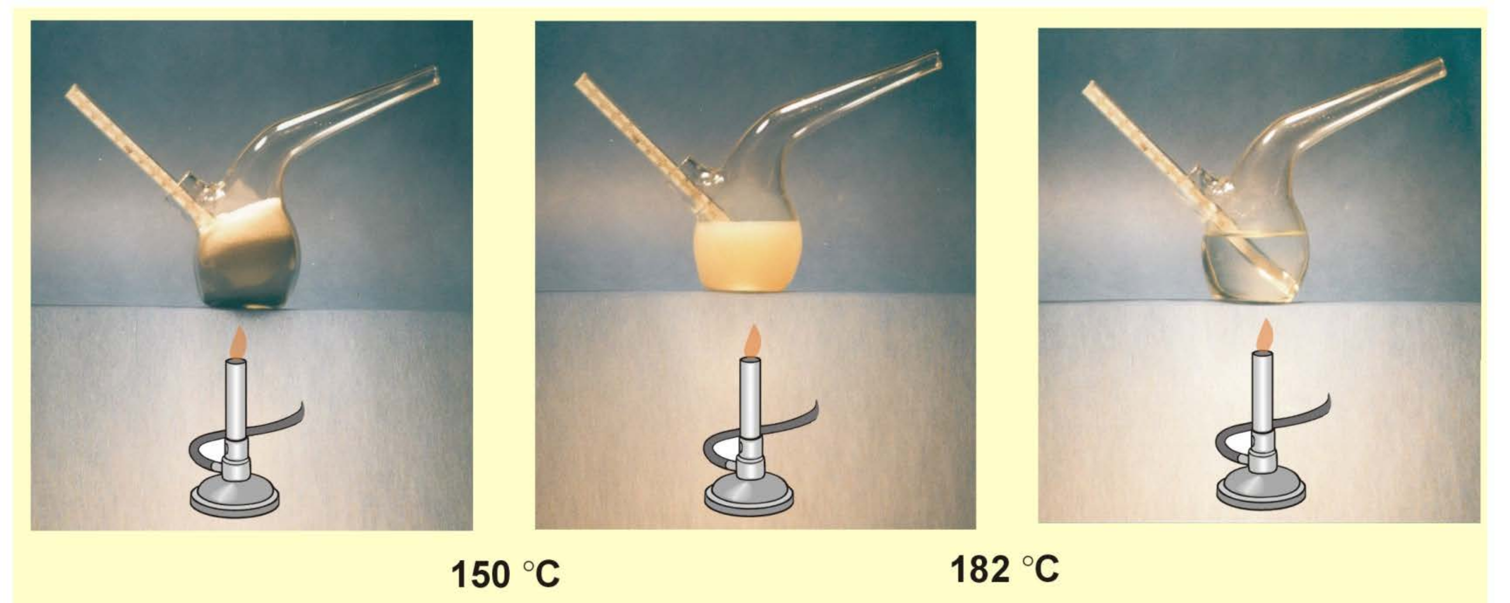
南京液晶谷

江
新生圩港
南京经济技术开发区
龙潭港
栖霞
仙林新市區
液晶谷
市政府
南京市区

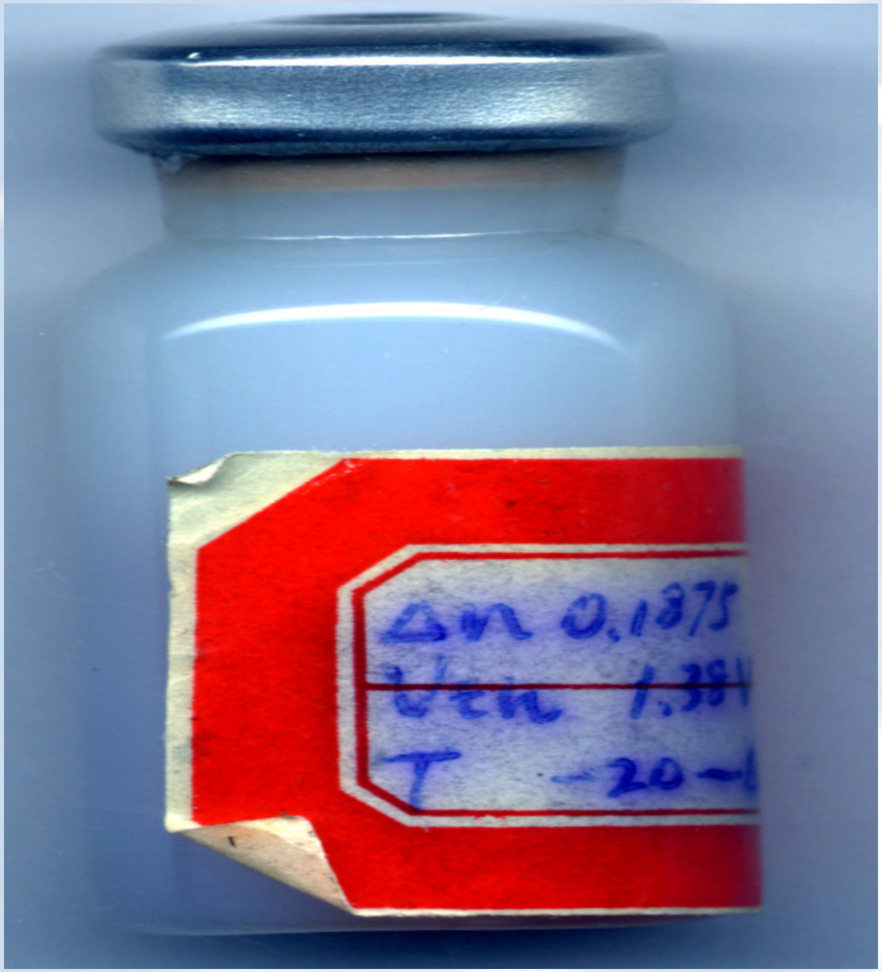
南京市人民政府
南京市人民政府
中国电子信息产业集团有限公司
中国電子情報産業グループ有限公司
日本国夏普株式会社
日本国シャープ株式会社
高世代液晶面板项目签字仪式
高世代液晶パネルプロジェクト調印式

液晶的来源

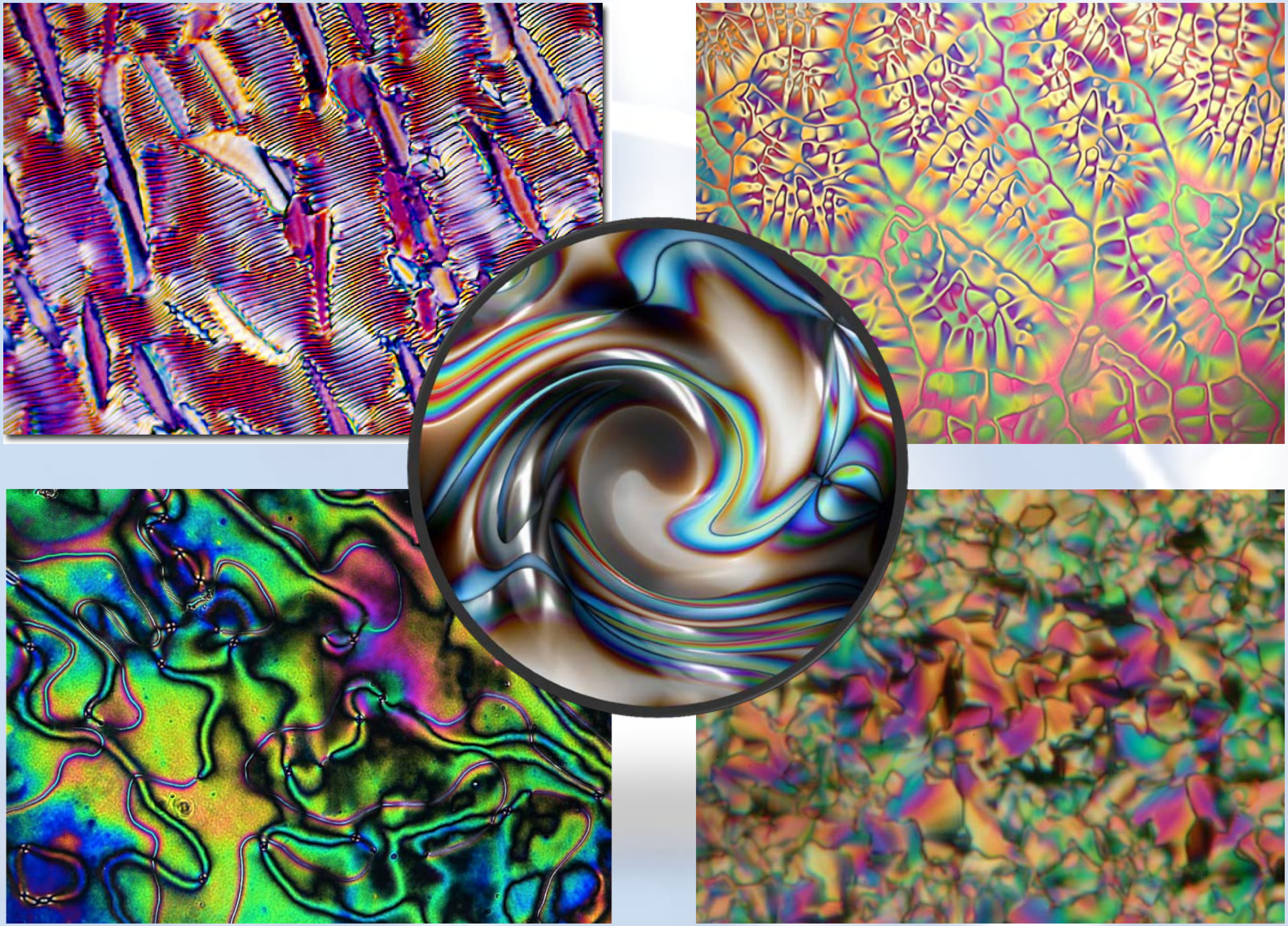
- ✓ 1888年由奥地利植物学家F.Reinitzer发现
- ✓ 将胆甾型结晶的固体通过加热变成透明液体的过程中
- ✓ 在温度升高一定程度时固体开始溶解呈混浊态粘稠液体
- ✓ 在偏光显微镜下发现这个混浊态粘稠液体具有双折射性 --晶体的典型特性
- ✓ 物质的新形态：液态晶体（Liquid Crystal)



液晶材料

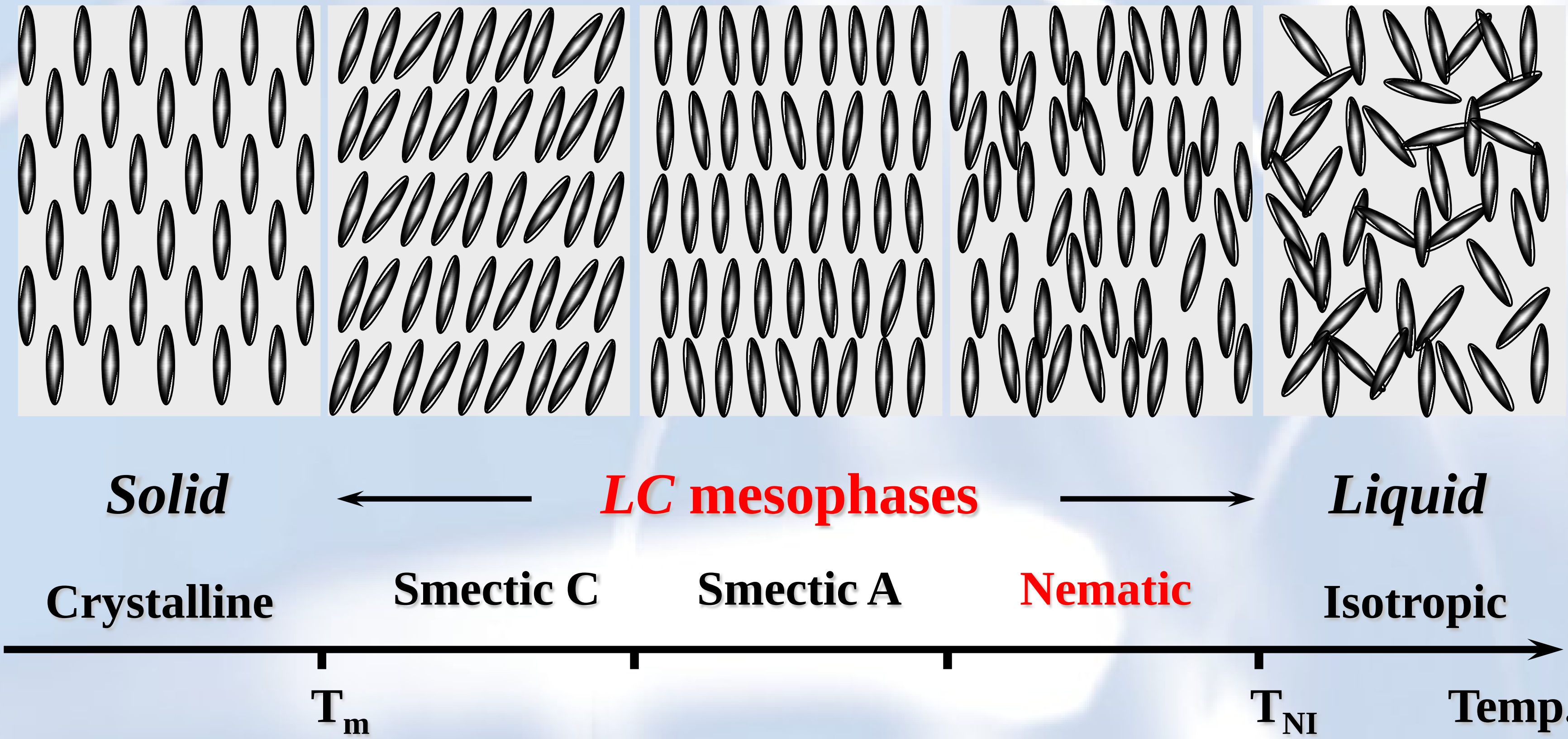


偏光显微镜下的液晶

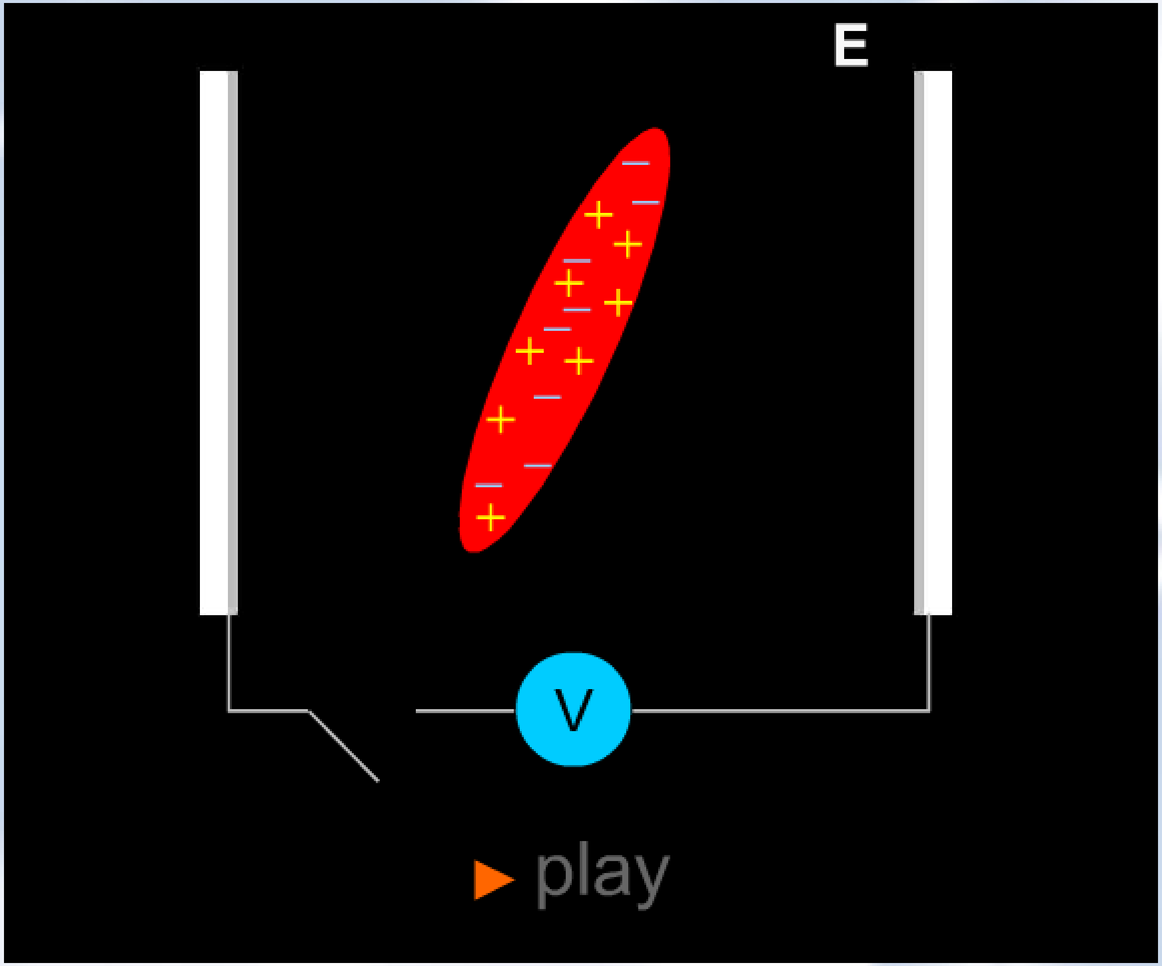


液晶态

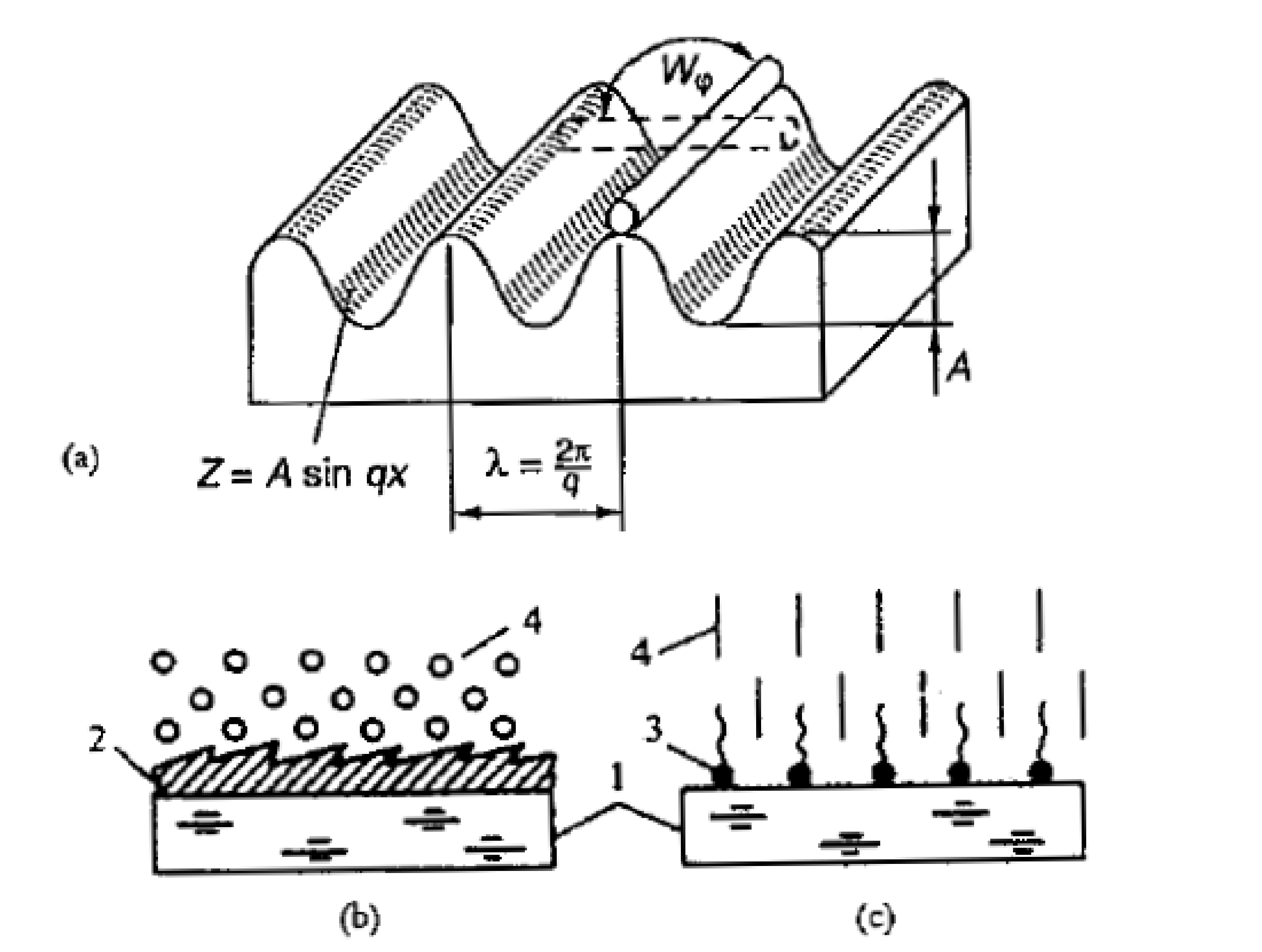
- Solid → Anisotropic Liquid→ Isotropic
- As T increases, order parameter decreases.
  Crystal: S=1; LC: S~0.6-0.8, Isotropic: S=0.



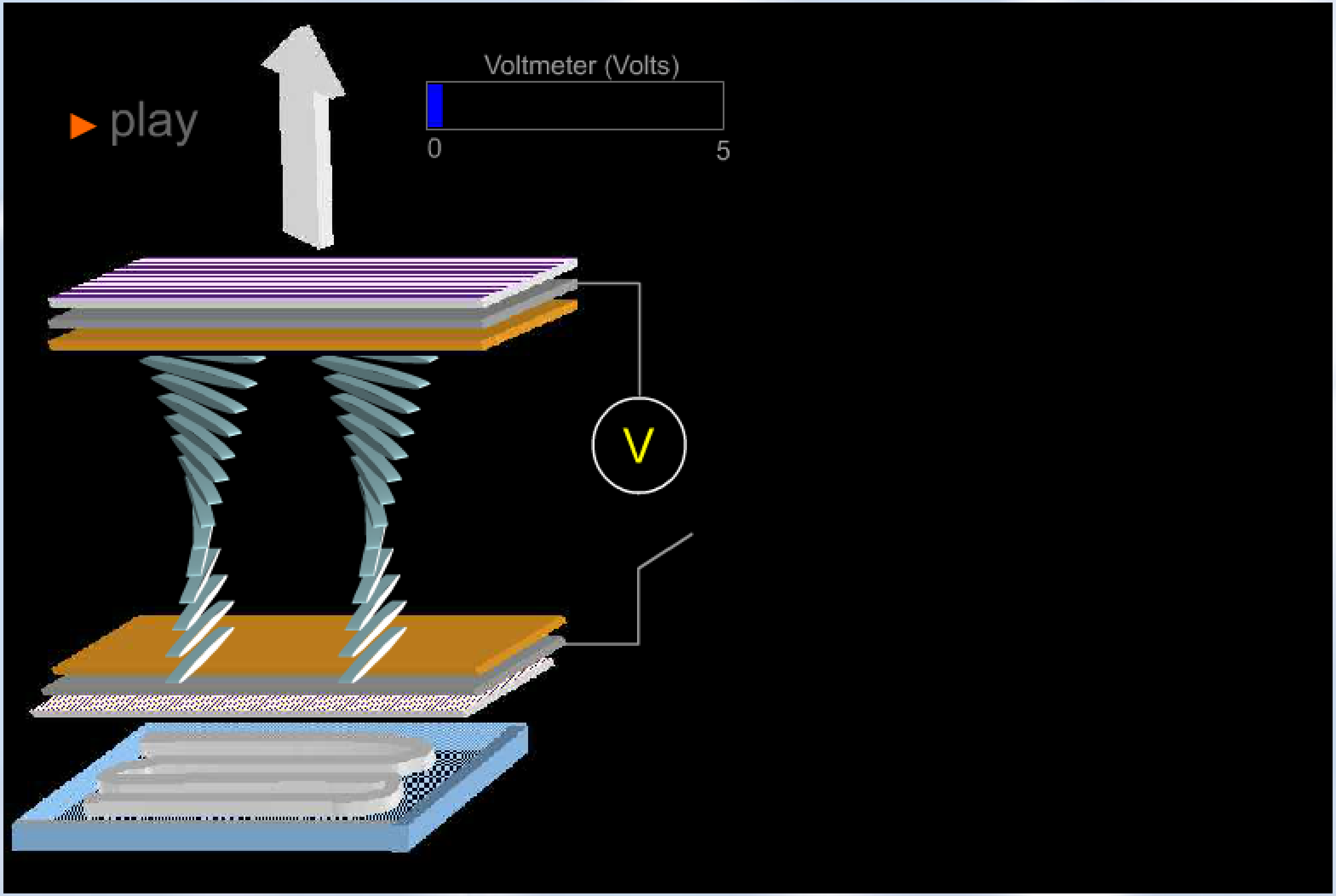
电场下的液晶分子



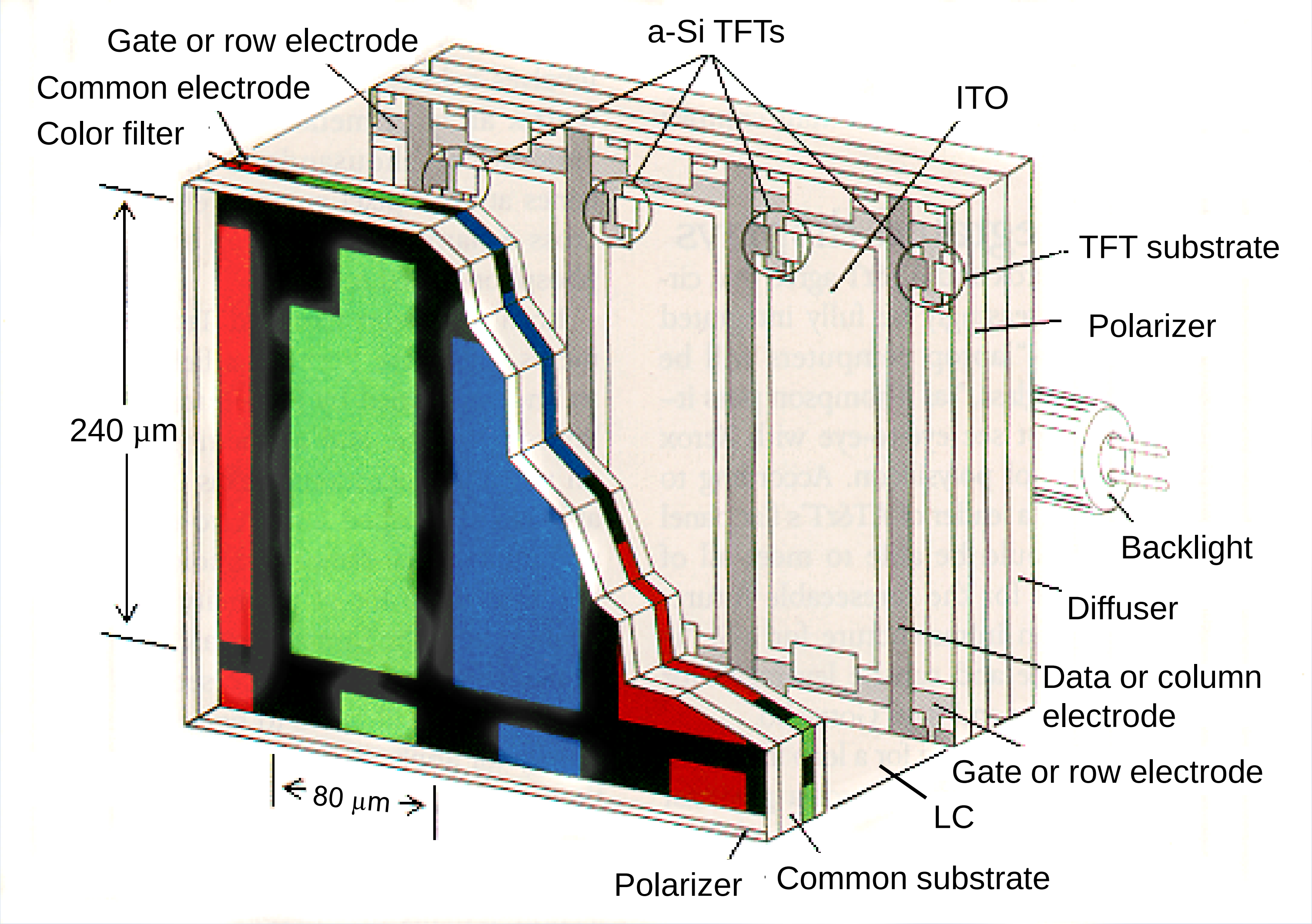
Methods of LC alignment



TN LCD Demo



Transmissive TFT-LCD

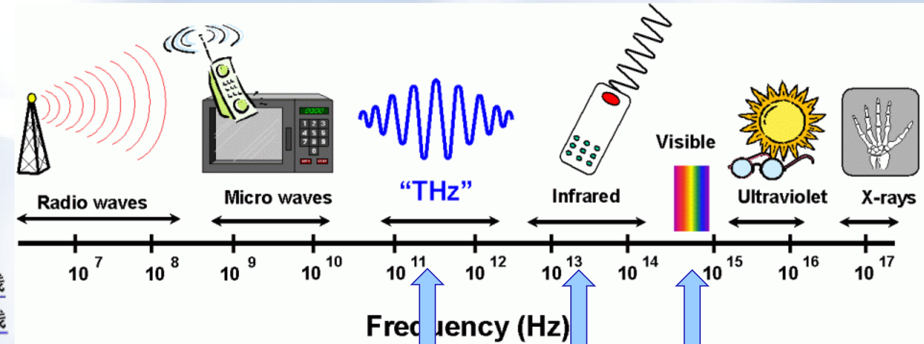


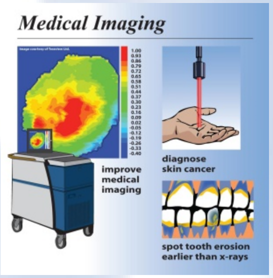
Each pixel is independently driven by a TFT

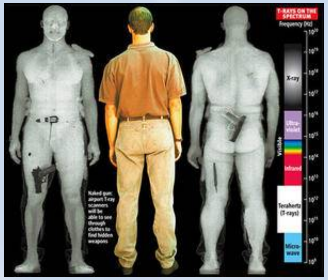
液晶显示

非显示液晶材料及器件：光电产业的新蓝海？

中国液晶显示
高世代线分布







- 在大量高世代面板线建成投产的推动下，中国已经具备了从材料到器件的液晶全产业链
- 液晶可以赋予极宽波段（可见、红外、太赫兹、微波）光电器件以开关、调谐、滤波、偏振控制、波前调控等功能
- 非显示液晶材料及器件：光电产业的新蓝海！

报告提纲

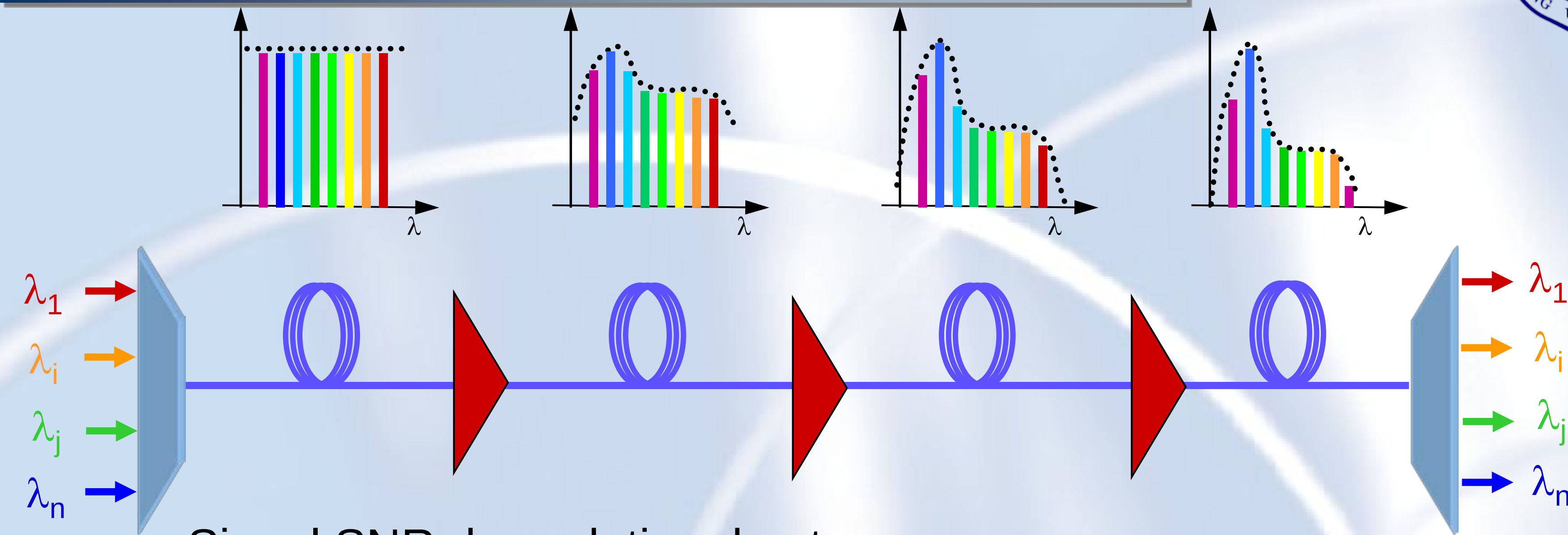
I、液晶与液晶显示

II、液晶的非显示应用

Outline

- ✓ Telecomm as an example for photonic applications
- ✓ LC based VOA (variable optical attenuator)
- ✓ LC based DWDM wavelength blocker
- ✓ LC based diffraction gratings
- ✓ LC based in-line polarizer and fiber-optic sensor
- ✓ LC for tunable THz applications
- ✓ LC for tunable optical vortex generation
- ✓ Other LC's photonic applications

DWDM Networks – an example of adaptation



Signal SNR degradation due to:

- ➪ Non flat spectral response of the EDFA
- ➪ Power dependancy of the response of the EDFA
- ➪ **Wavelength Add & Drop**

* Optical <u>attenuation</u>, <u>switching</u> and <u>equalization</u> functions are critical for a DWDM network.

DWDM networks – components requirements

Components inserted into a network have to be:

- Polarization Insensitive
- Weakly wavelength dependent
- Wide temperature range
  - Storage: -40° C to 85° C
  - Operating: -5° C to 70° C
- Easy to manufacture and low cost
- Easy scalable to various specifications (attenuation range, response time, spectral resolution,…)

⇒ **Can Liquid crystal meet these requirements ?**

LC, advantages

✓ **Advantages:**

1. Switchable Large Optical Birefringence $\Delta n \sim 0.2 - 0.3$.
2. High Transmission at Near-IR Wavelengths, (<0.2 dB loss).
3. No Moving Parts - Long Lifetime.
4. Low Power Consumption.
5. Proven Technology - by Flat-Panel Display Industry.
6. Switching Times from milli- to micro- seconds.
7. Suitable for multi-channel DWDM operation

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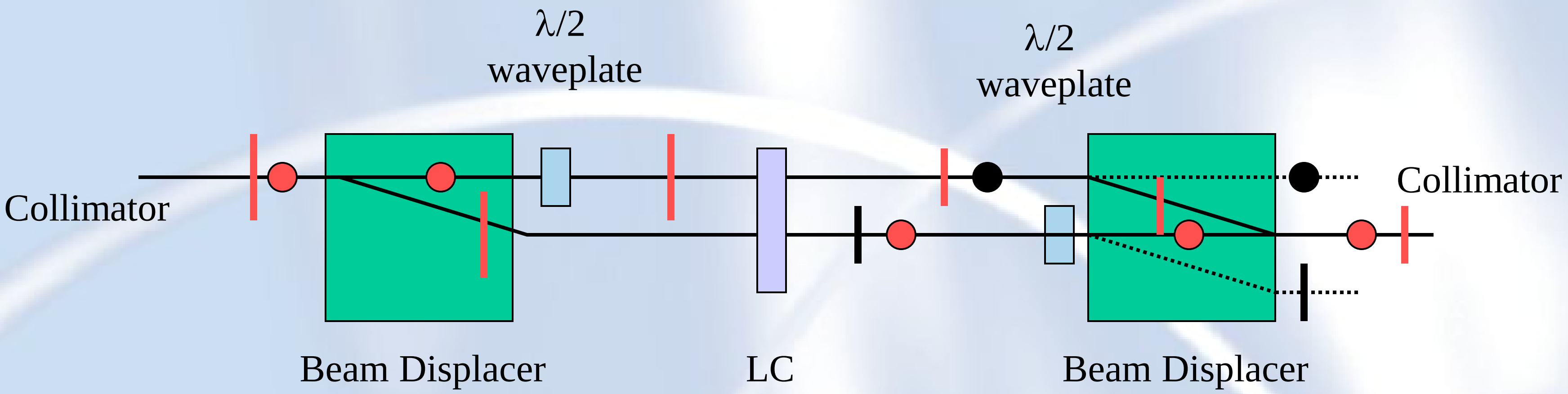
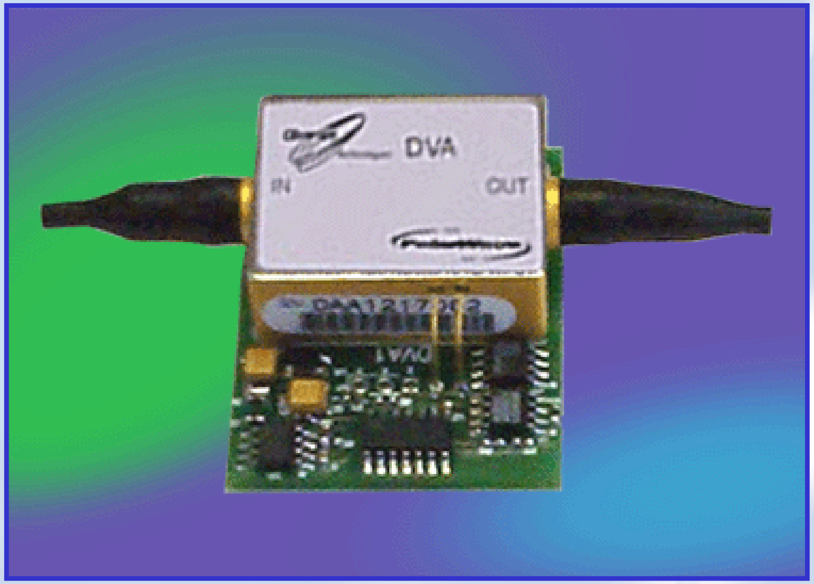
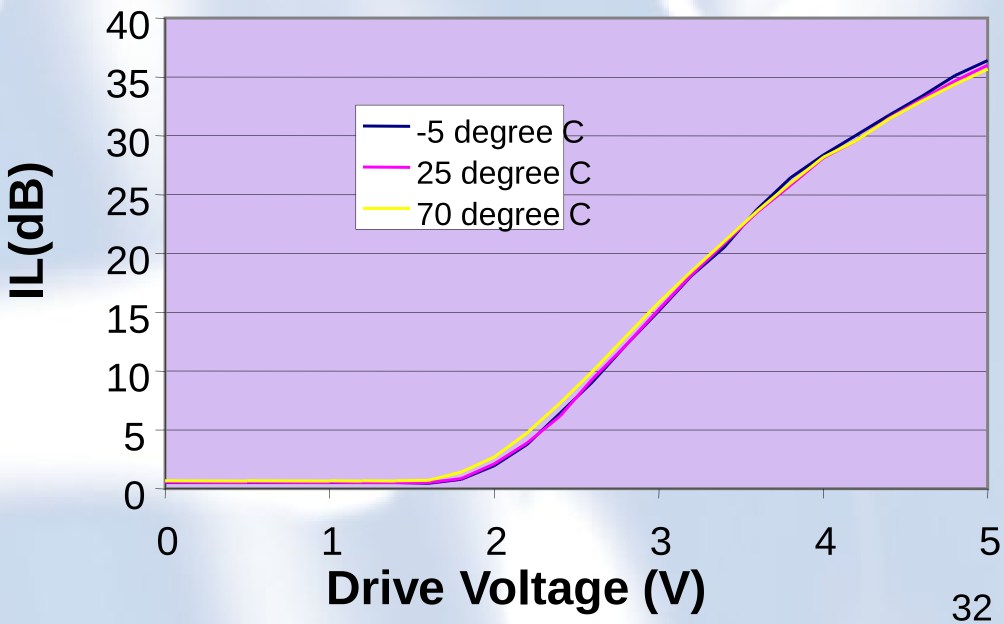
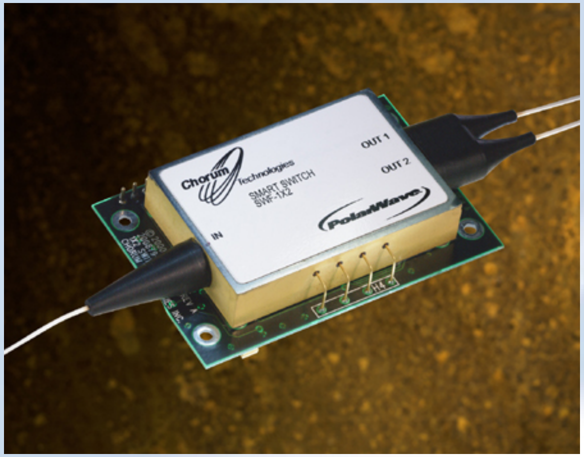
TN LC based VOA (Chorum, EZconn)

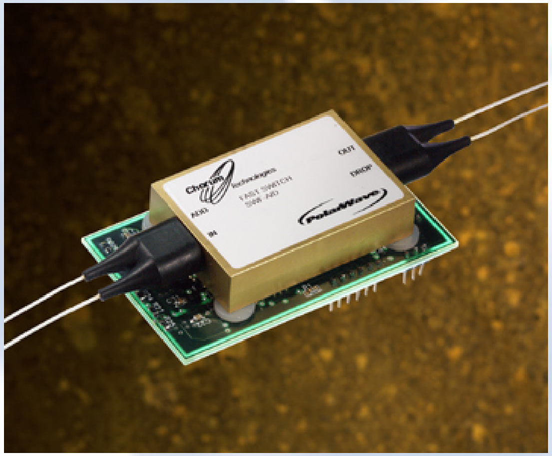






1x2 LC Switch

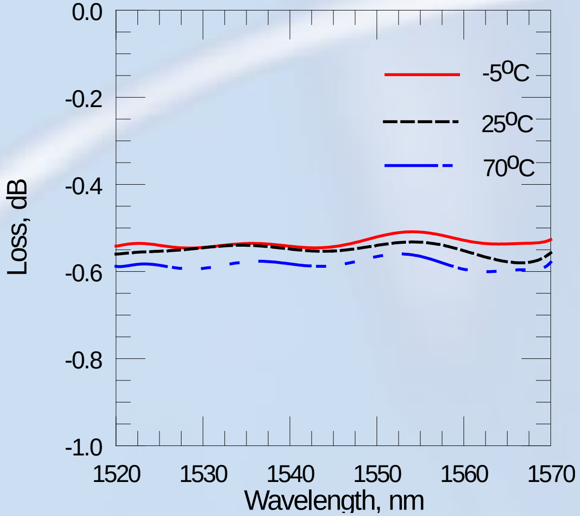




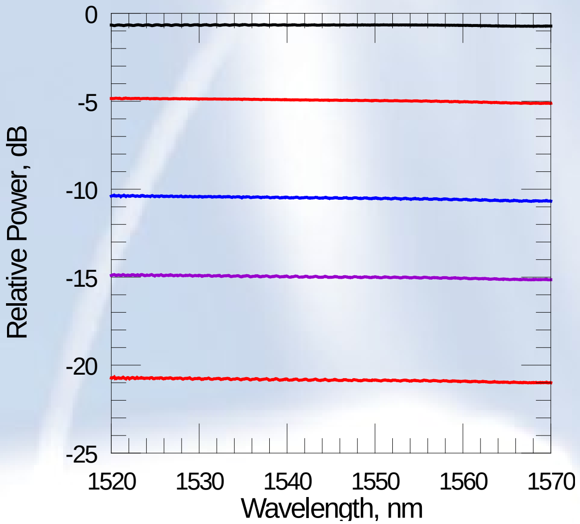
Fast response: Double-cell, PNLC, DFLC, Stressed LC, FLC

TN LC based VOA: Performances (Chorum, EZconn)

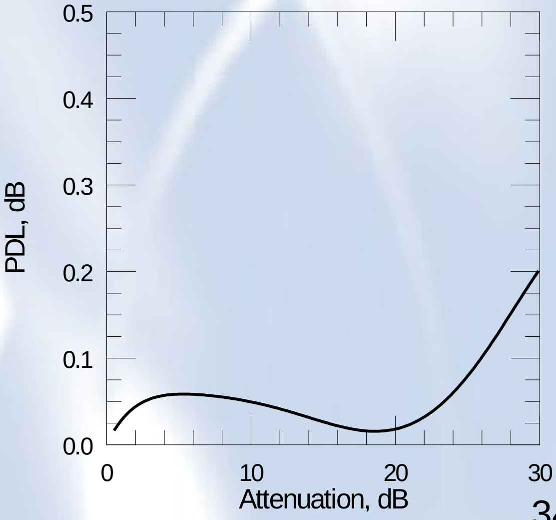
Low insertion loss, highly athermal



Flat spectral response

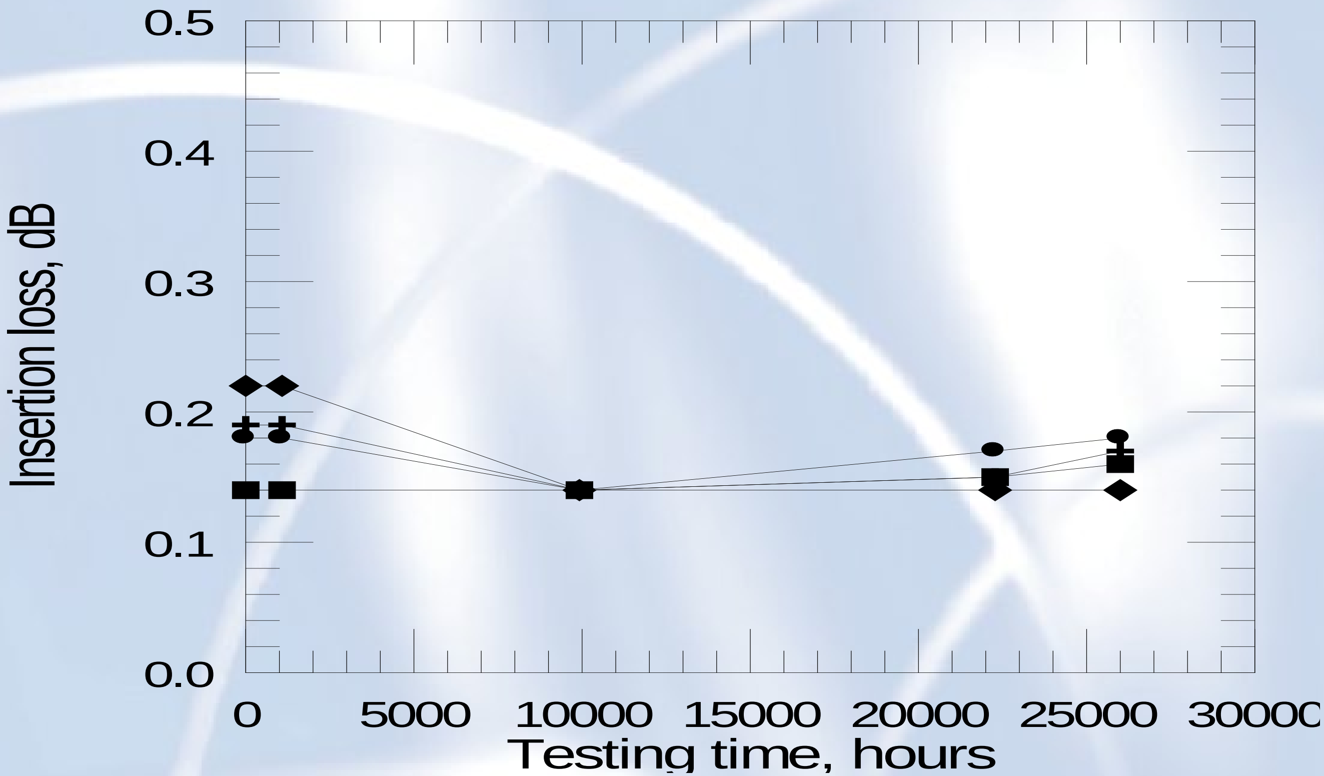


Small polarization dependency



TN LC based VOA: Extensive Aging Test (Chorum)

> 50M cycles
(26000 hours)
@ 90C

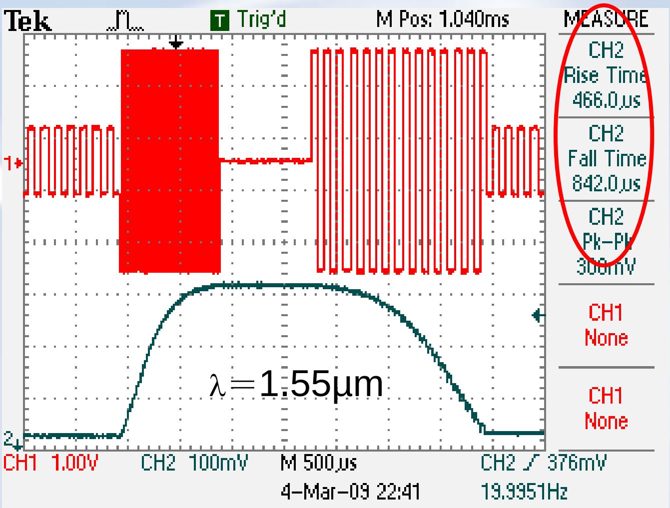


Merits: Reliable, low IL, low PDL, flat spectral response,

Drawback: slow response time.

Speed improvement

1. Thinner cell (Reflective type)
2. Overdrive and undershoot
3. Double-cell
4. Smart electrode design
5. Polymer network, stressed LC, etc.
6. Dual frequency addressing
7. Blue phase LC
8. …

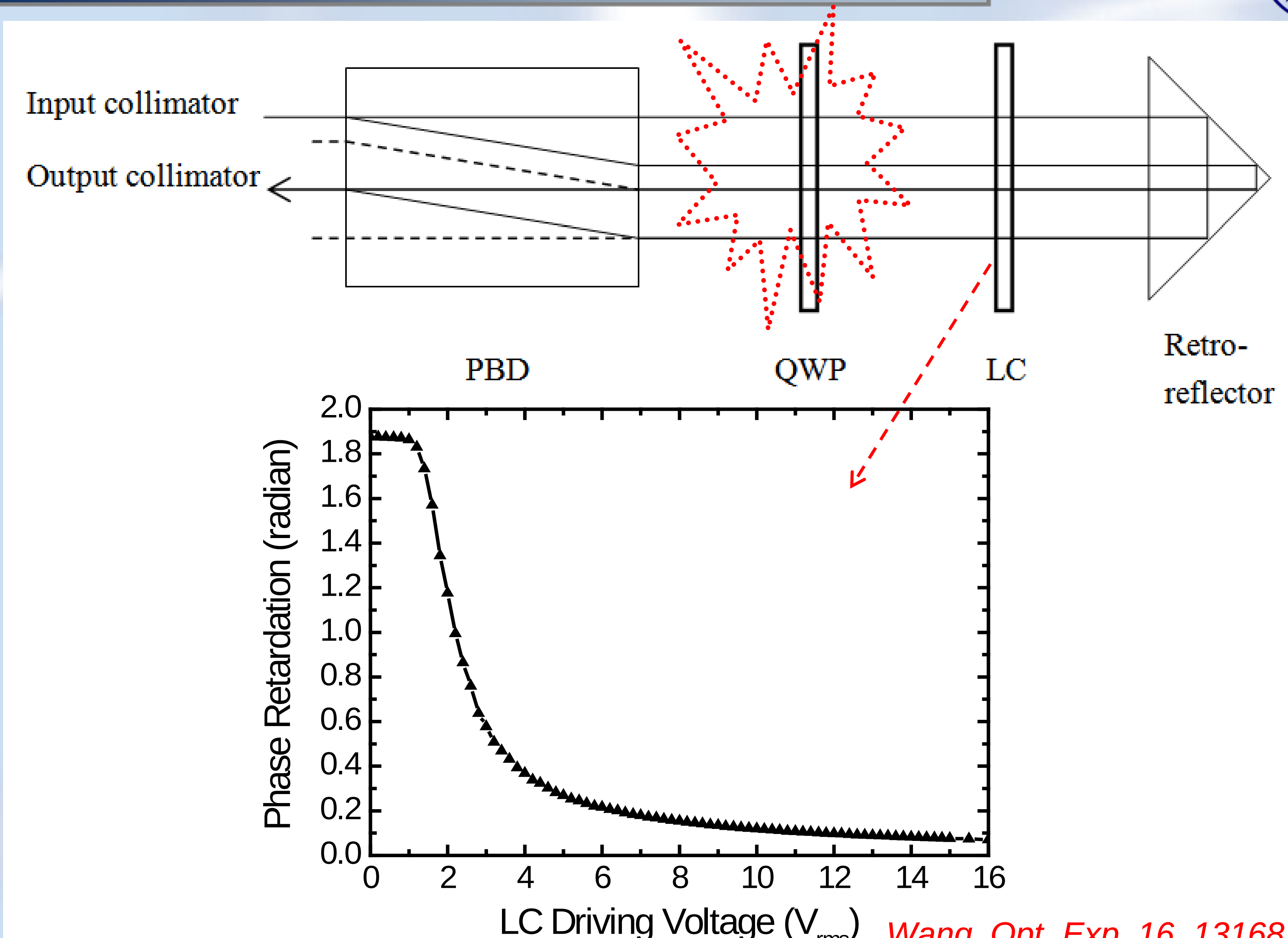


Liang, Jpn. J. Appl. Phys., **44**, 1292-1295 (2005)
Wu, *Applied Optics* **44**, 4394-4397 (2005)
Lu, *Appl. Phys. Lett.*, **85**, 3354-3356 (2004)
Du, Appl. Phys. Lett., **85**, 2181-2183 (2004)
Lu, Opt. Express, **12**, 1221-1227 (2004)
Wu, Opt. Express, **12**, 6377-6384 (2004)

Further improvement:

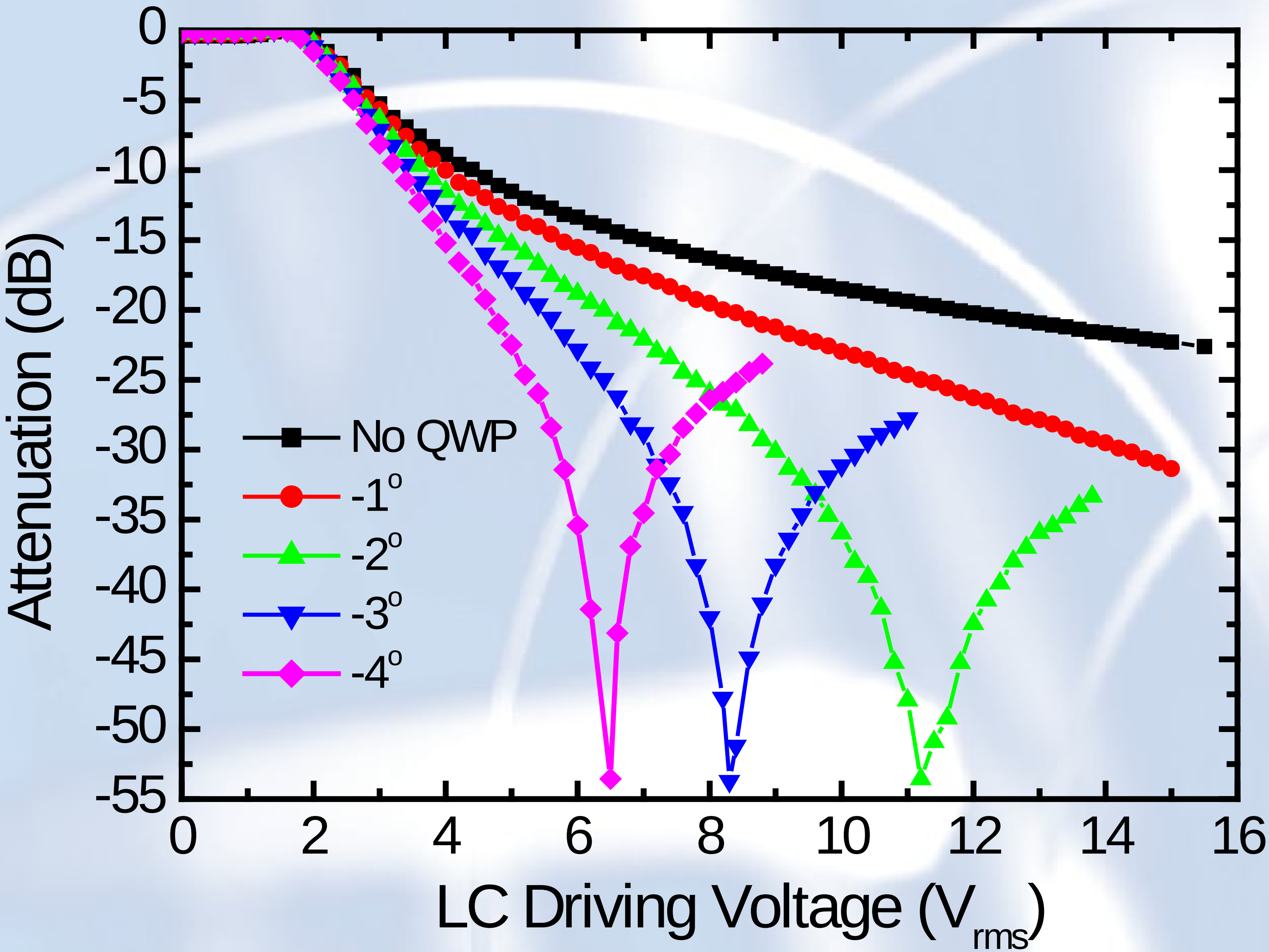
Better performance, low cost, arrayed or multi-channel operation.

A compact ECB LC based VOA with low PDL (NJU)



Wang, Opt. Exp. 16, 13168 (2008)

Voltage-dependent transmittance



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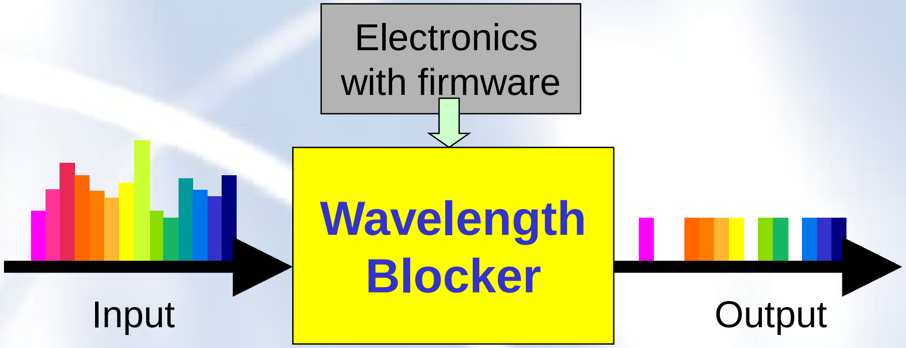
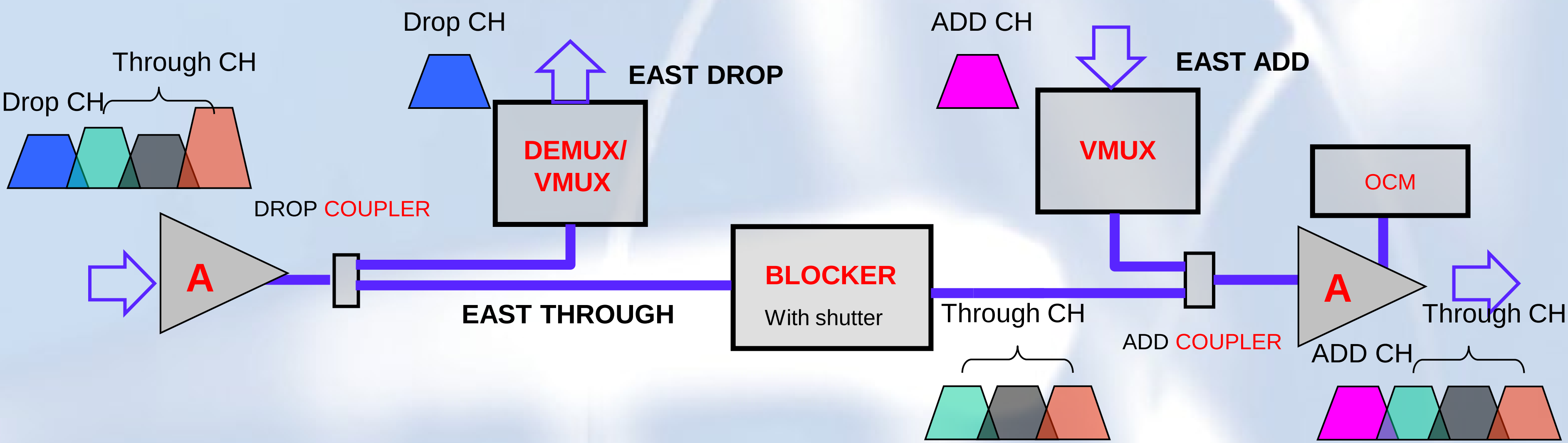
Wavelength blocker and RODAM (NJU)

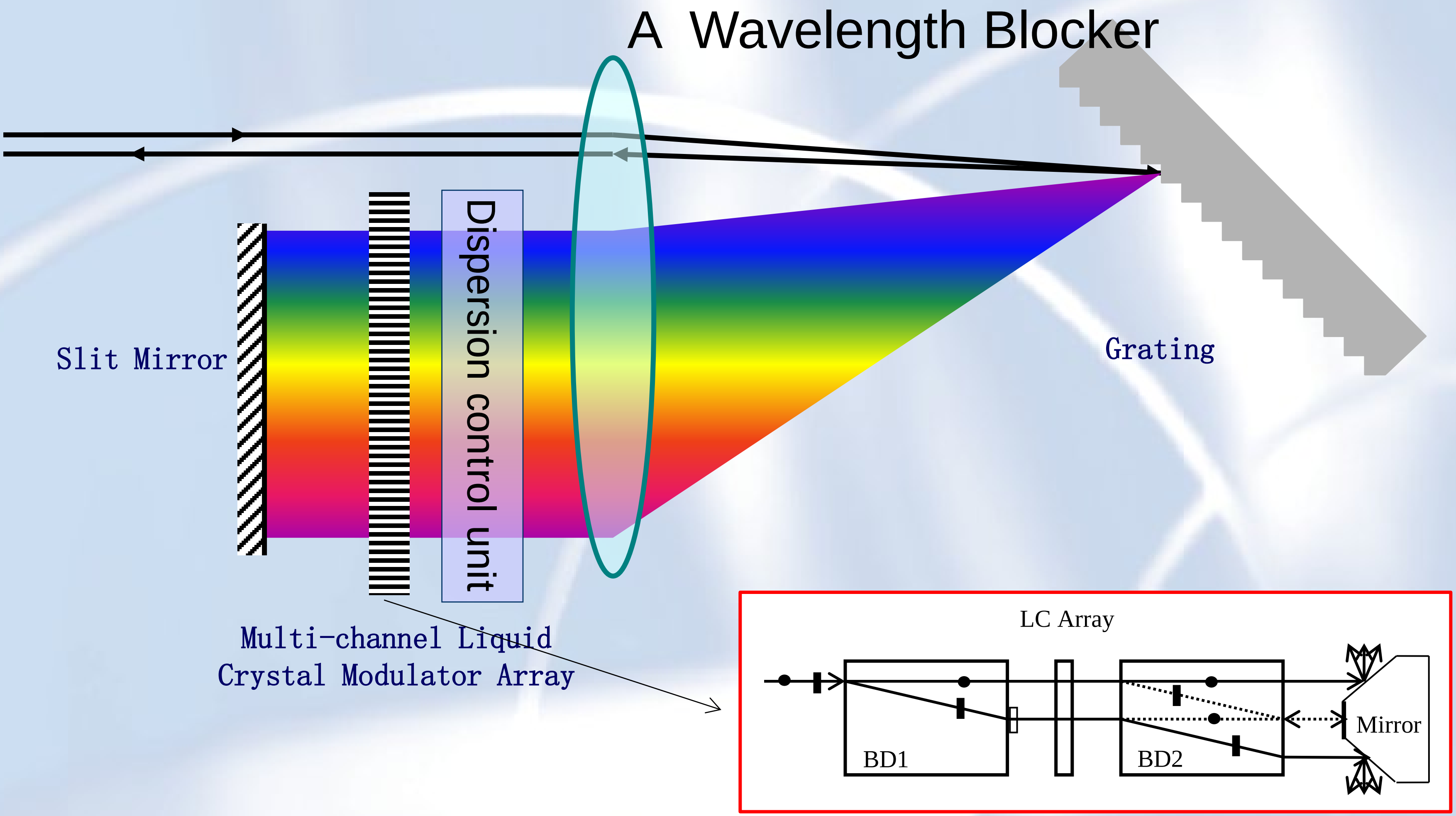
- ✓ λ-blocker is an enabling network element for dynamic optical networks
- ✓ Due to the analog nature of liquid crystals, the same device can be used as channel-based DGFF





A Blocker based RODAM architecture

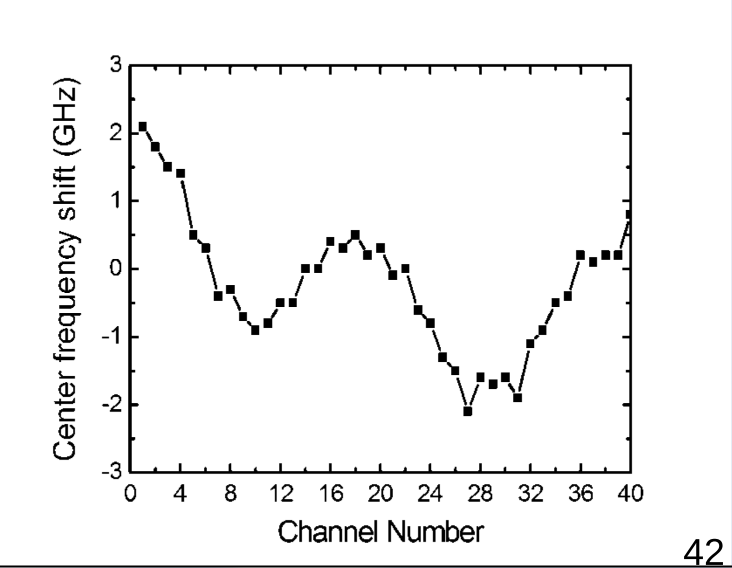
Design Proposal



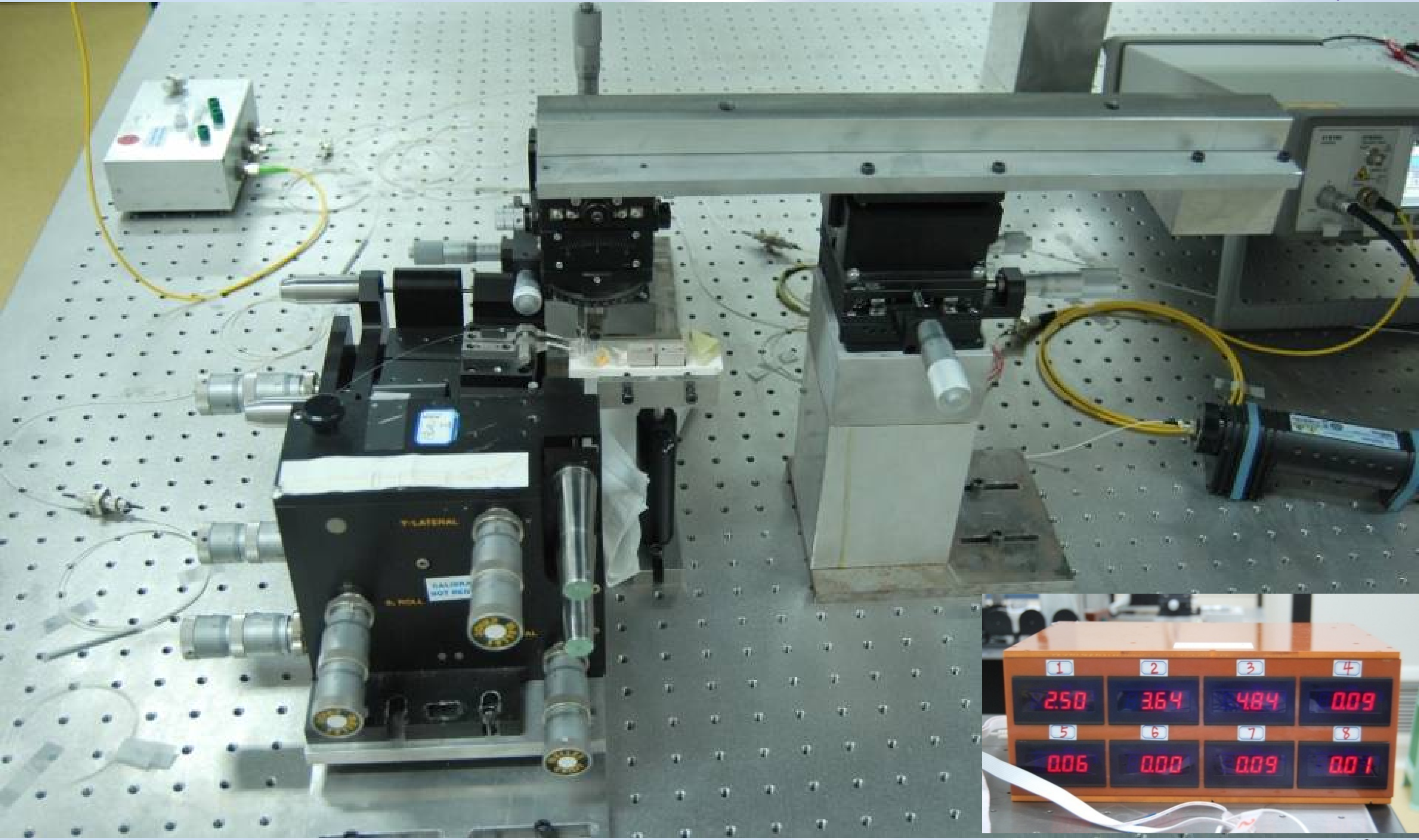
Huang, J. of Lightwave Tech. **28**, 822 (2010)

Optical Design of a 40CH/100G Blocker

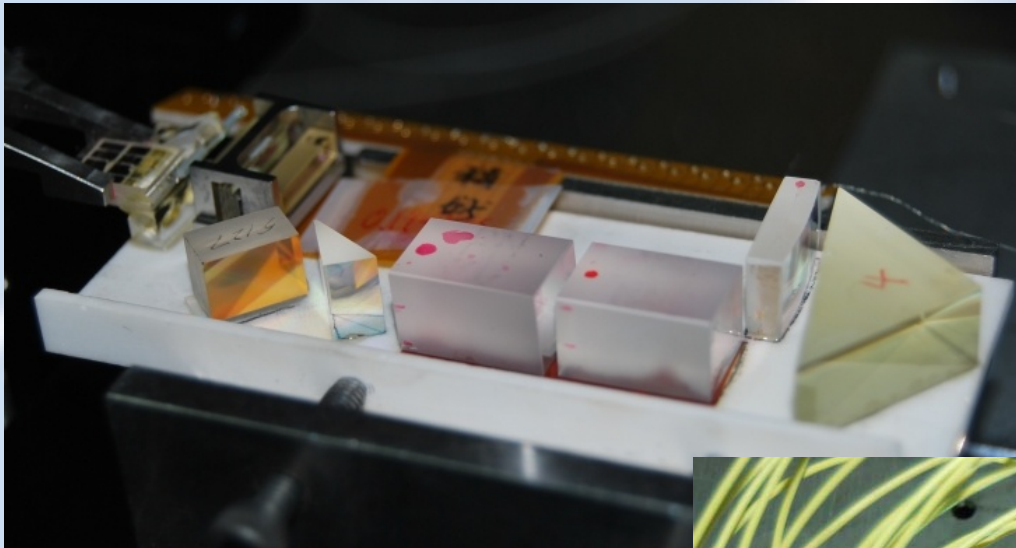
$$\boxed{\frac{dL}{df} = \frac{d\beta \cdot F}{df} = \frac{-cF}{f^2 \Lambda \cos\beta}}$$

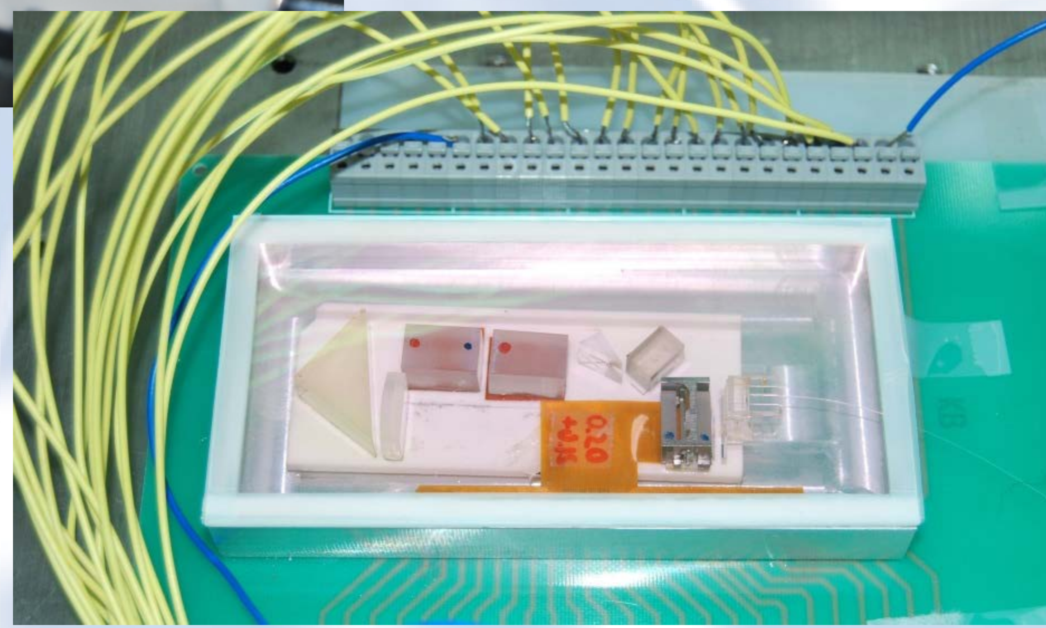


Experimental setup of a 40CH λ-Blocker (NJU)

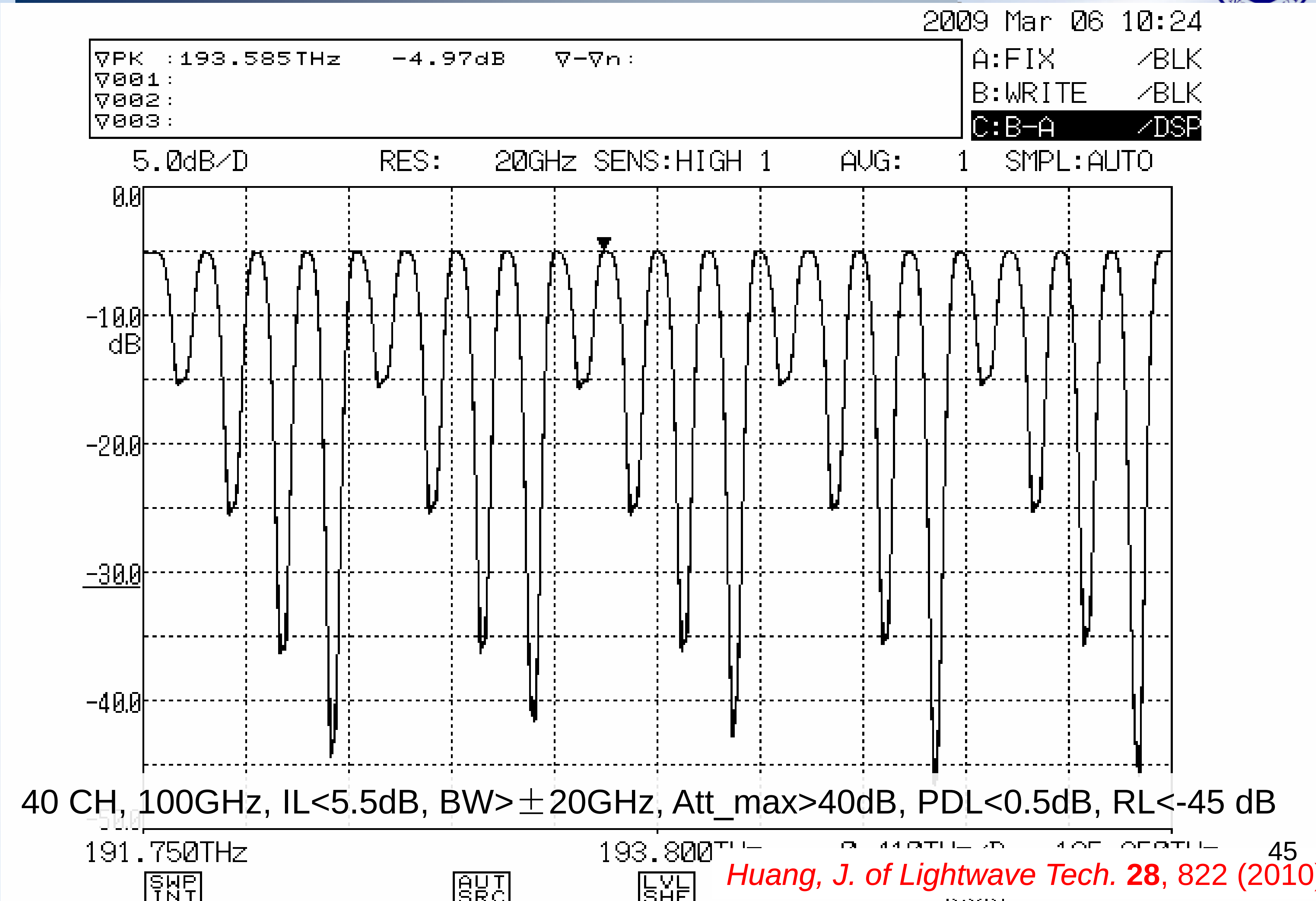


Blocker: Prototype





Spectral response



40 CH, 100GHz, IL<5.5dB, BW>±20GHz, Att_max>40dB, PDL<0.5dB, RL<-45 dB

Huang, J. of Lightwave Tech. **28**, 822 (2010)

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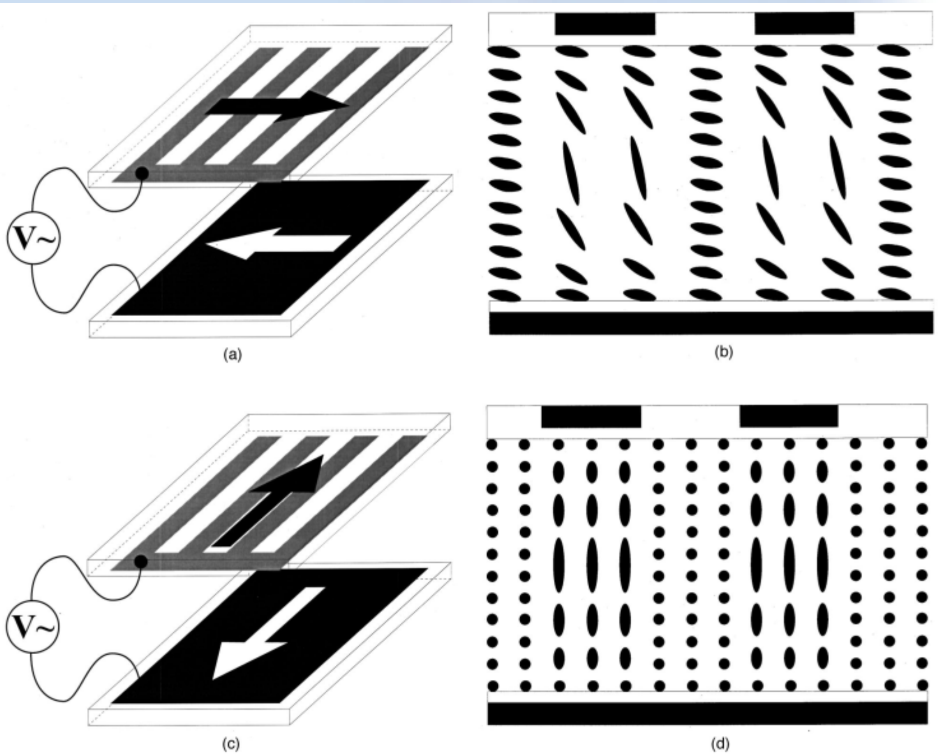
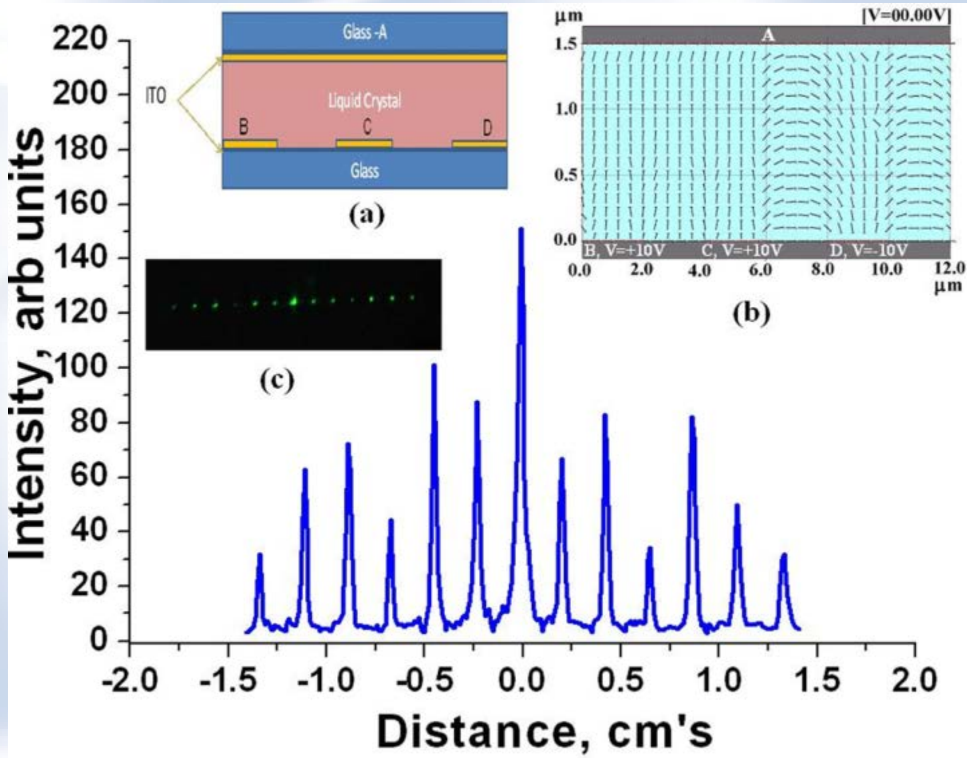
Fabrication strategies- Patterned electrodes

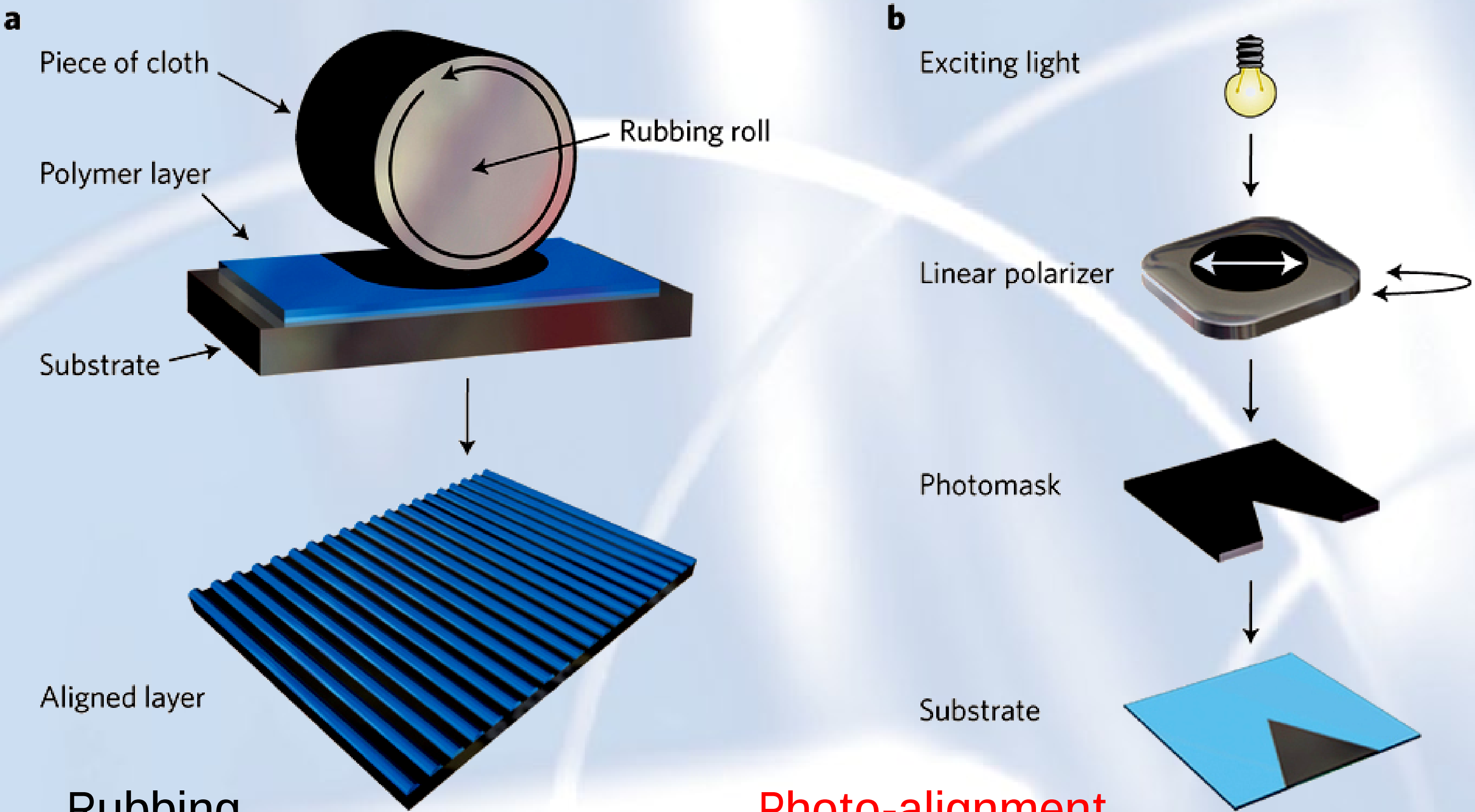




M. Bouvier and T. Scharf.
Opt. Eng. 39, 2129 (2000)
(Switzerland)

Fan *et al*. Appl. Phys. Lett. 100, 111105 (2012)
(Prof. Chigrinov's group)

Rubbing *vs.* Photoalignment for LC devices



Rubbing

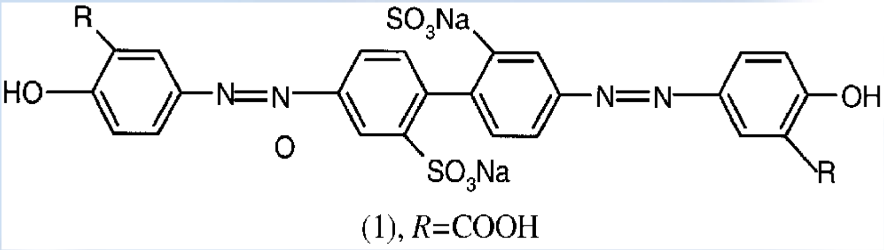
- Particles
- Static charge
- Mechanical damage

Photo-alignment

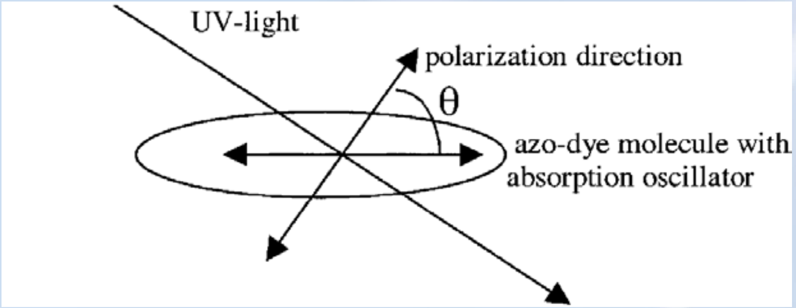
- Non-contact method
- Fine resolution
- Structured/curved surface compatible

Nature Materials, News and Views, 12, 12 (2013)

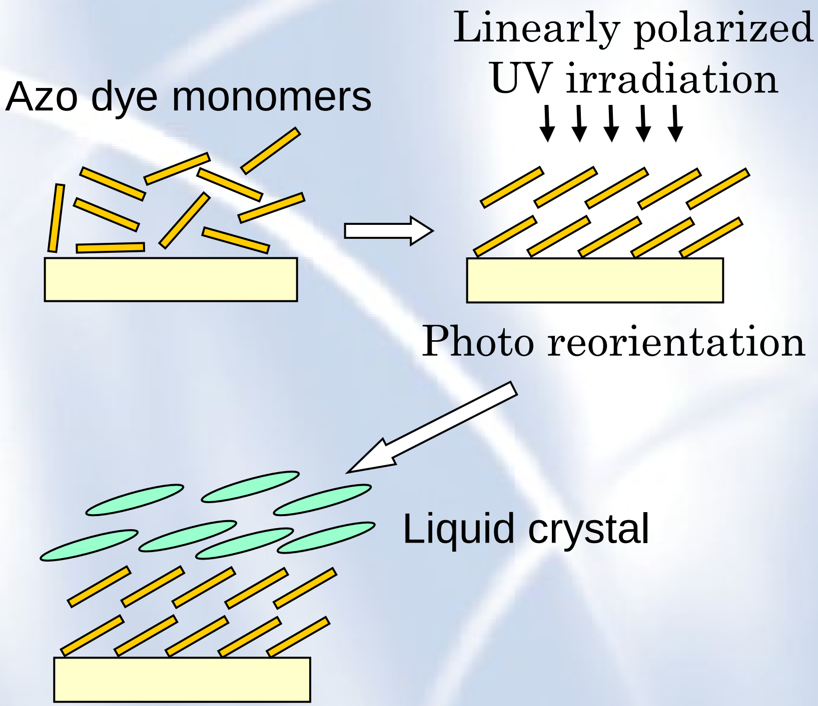
SD1 for Photo-alignment



Sulphonic acid azo dye (SD1) (**DIC**)



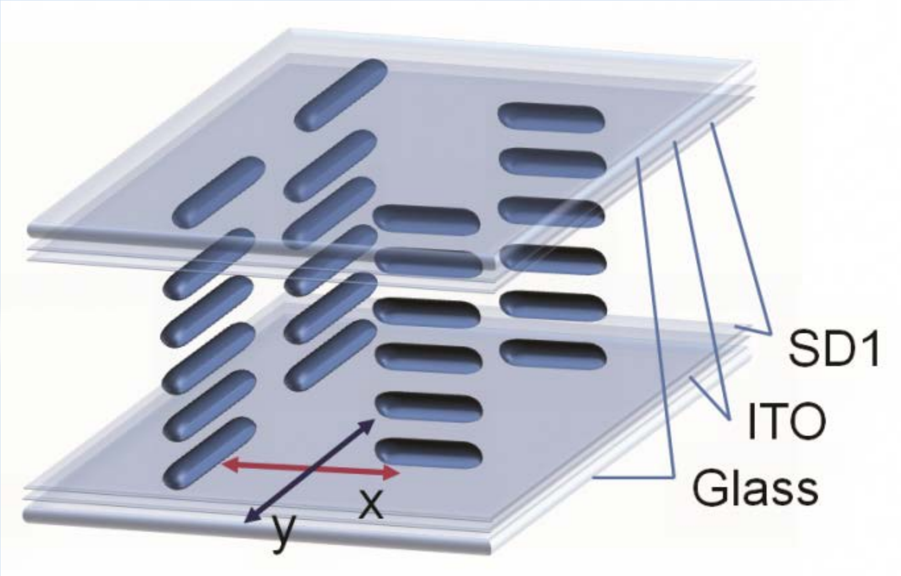
Diffusion model of SD1 reorientation

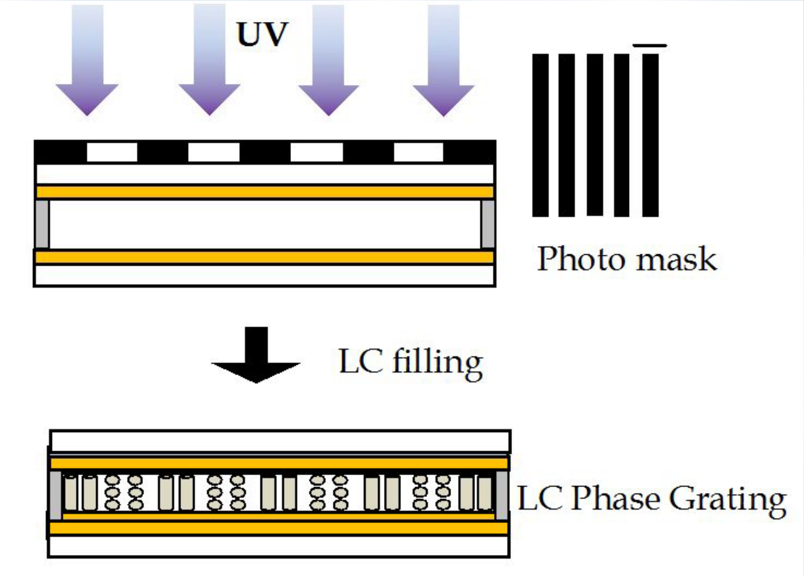


The azo dye molecules would reorient to make their absorption oscillators (chromophores) perpendicular to the polarization of the UV light and further guide the LC directors.

Chigrinov *et al*. *Liquid Crystals,* 29, 1321-1327 (2002)

Orthogonally homogeneous aligned (PA) grating





Procedure:

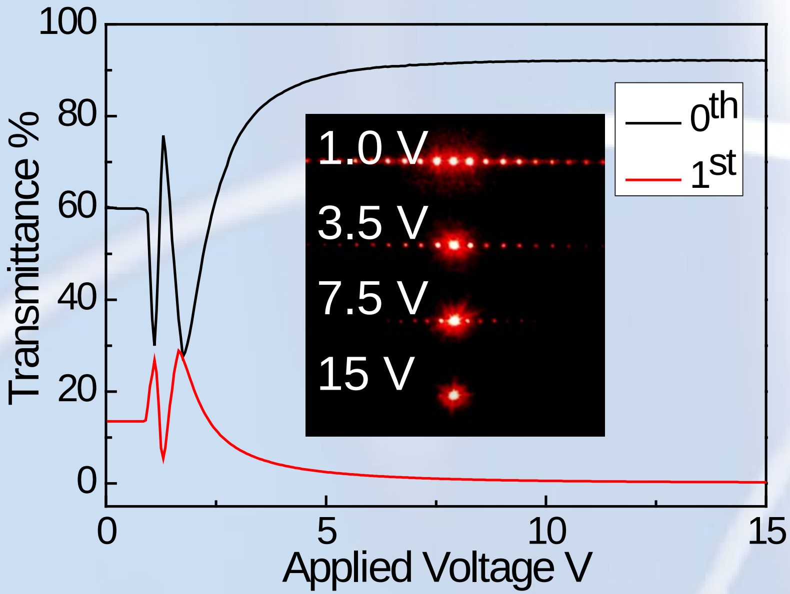
a) SD1 spincoating ;

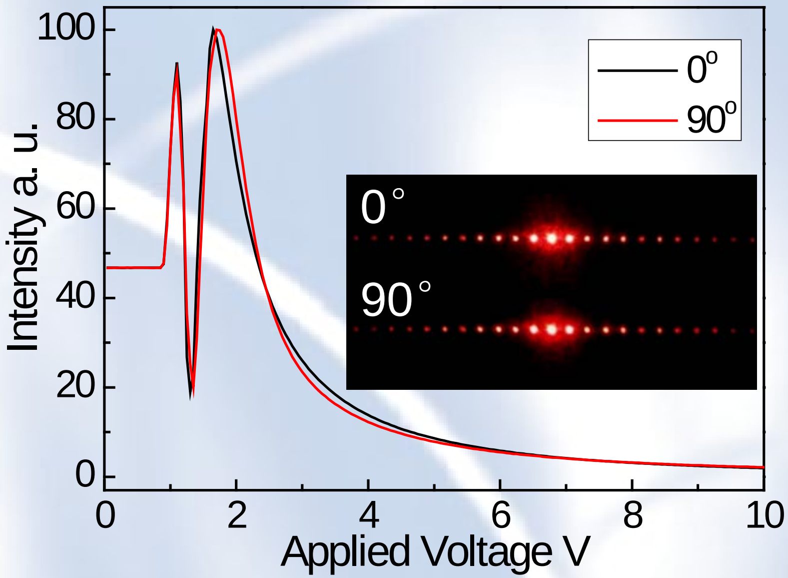
b) Cell fabrication and then the cell is exposed under linearly polarized light with long side parallel to polarization.

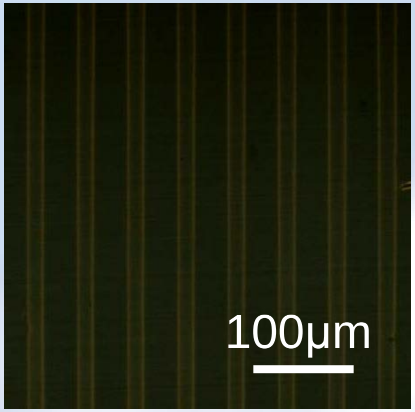
c) The same cell rotates 90º and is exposed again through a grating mask.

Hu *et al.* Appl. Phys. Lett., 100, 111116 (2012)

1D or-PA LC gratings

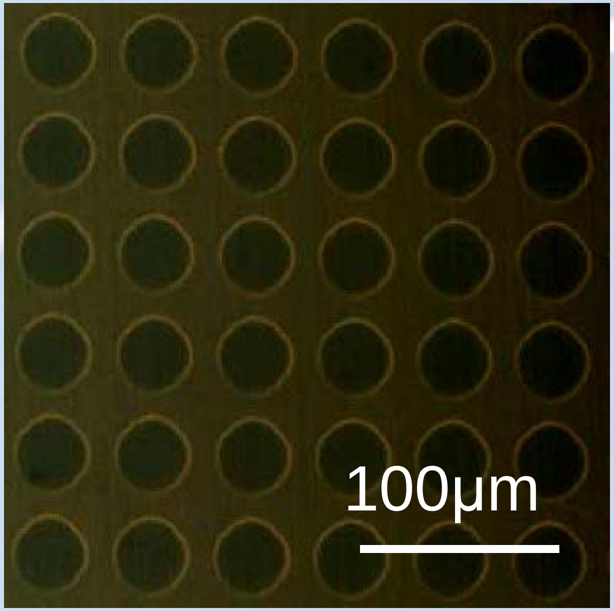


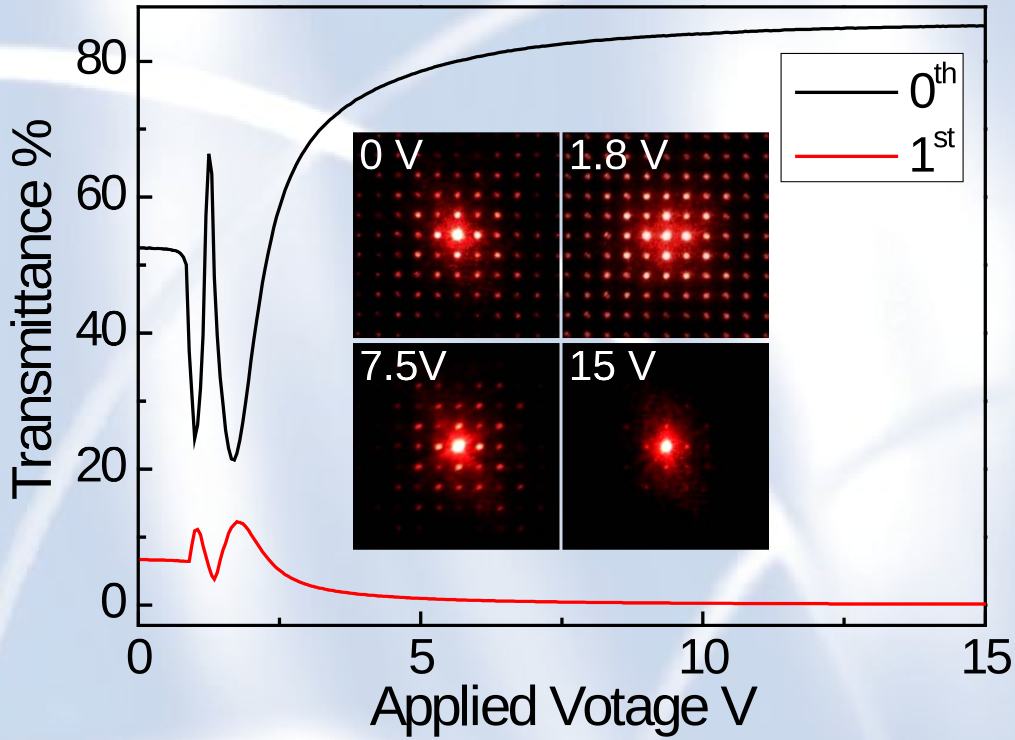




38 diffraction orders could be distinguished with naked eyes at ON state

2D or-PA LC gratings





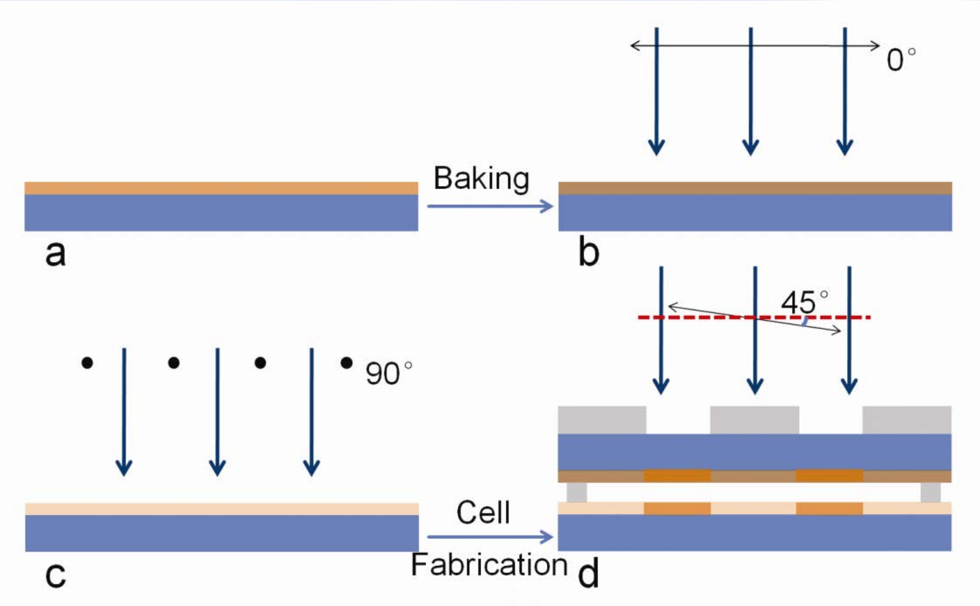
A lower transmittance of 87% is attributed to more domain boundaries and stronger scattering.

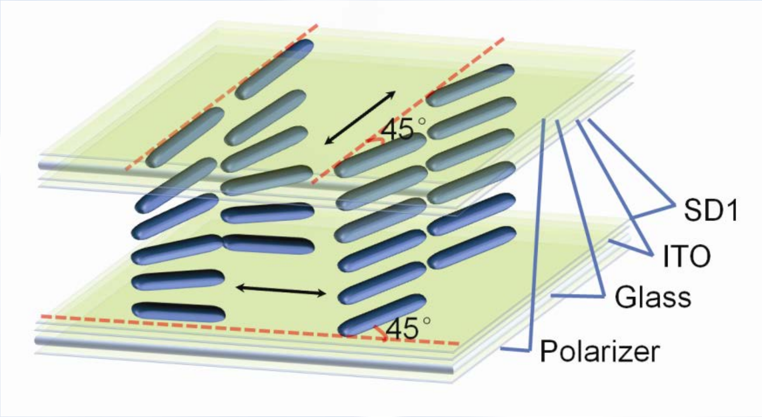
The diffraction efficiency and optical contrast of 1st order is ~ 14% and over 140 respectively.

75.5% of total transmittance energy distributed to diffraction orders at on state.

52

Fabrication of TN/PA gratings





Cell structure of the LC gratings with TN-PA micro arrays.

Procedure:

a) Spin-coating of SD1 and then baking at 100ºC for 10 min

b-c) Bottom and up substrates photoaligning under linearly polarized UV light with orthogonal directions, and then cell fabricating

d) Photopatterning with a cell direction is 45° with respect to the polarization of incident UV light.

Hu *et al. Opt. Express* 20, 5384-5391 (2012)

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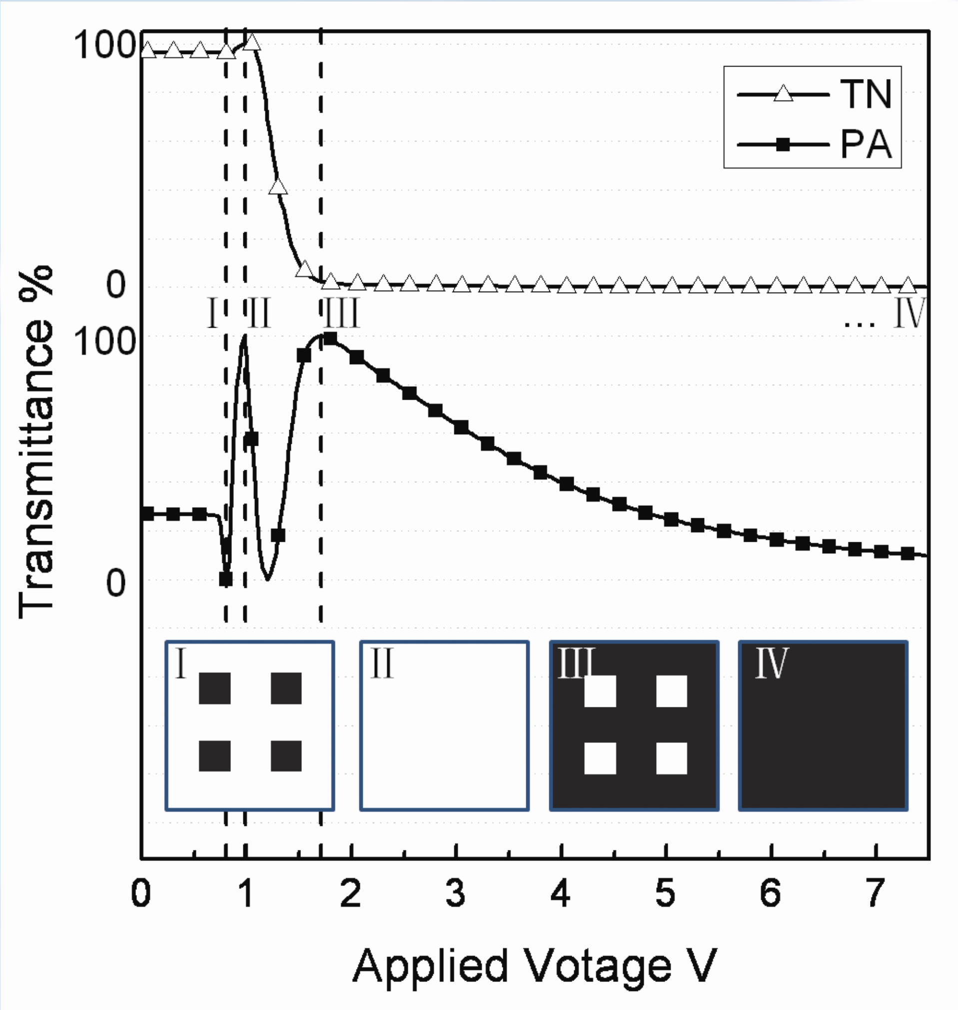
Scheme for TN/PA grating



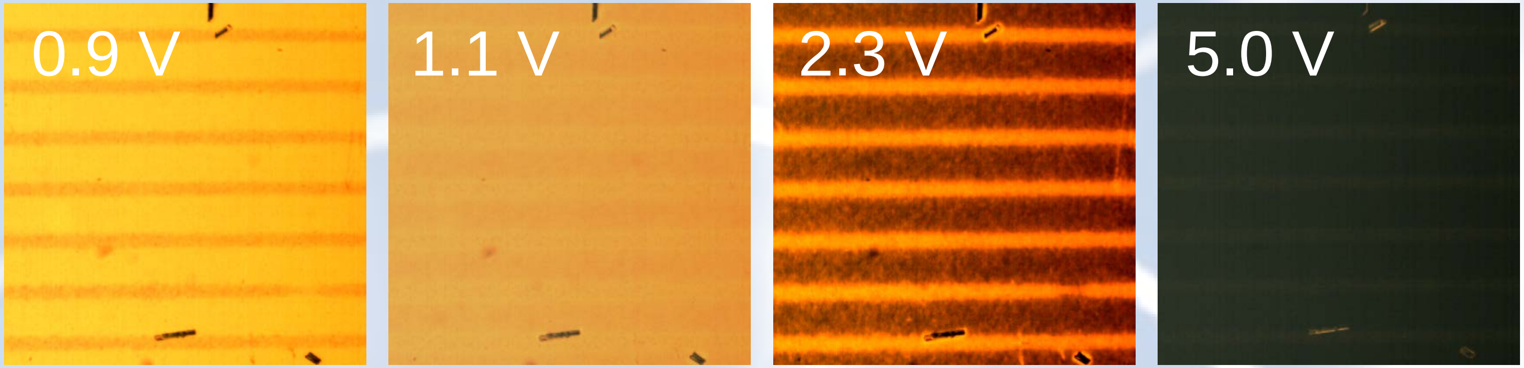
Both TN and PA are typical alignments, but they exhibits different EO properties including voltage-dependent phase changes and transmittances.

Micro 90° TN and PA (45° to the alignment direction of TN) regions are assembled alternately to form gratings. It works based on the combination of phase and amplitude modulation.

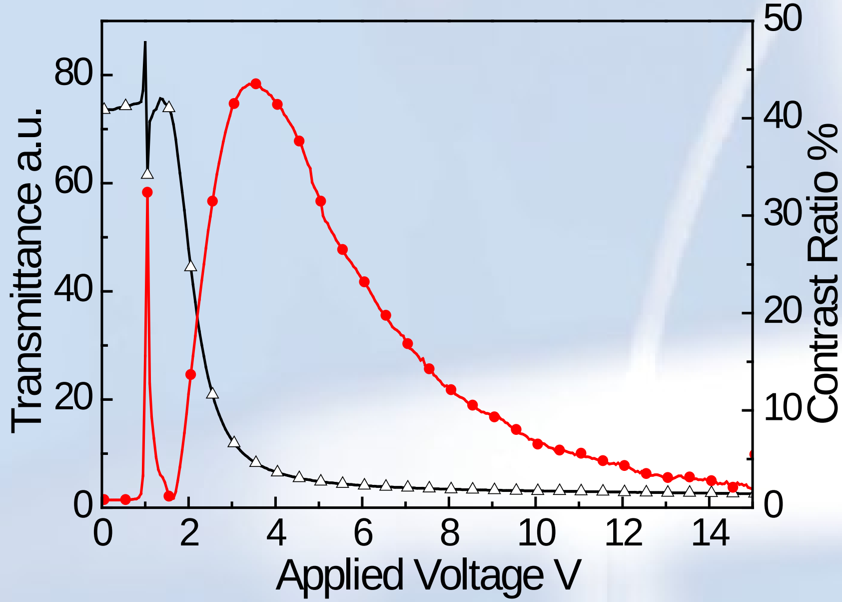
Unique four-state feature of the cell is obtained:

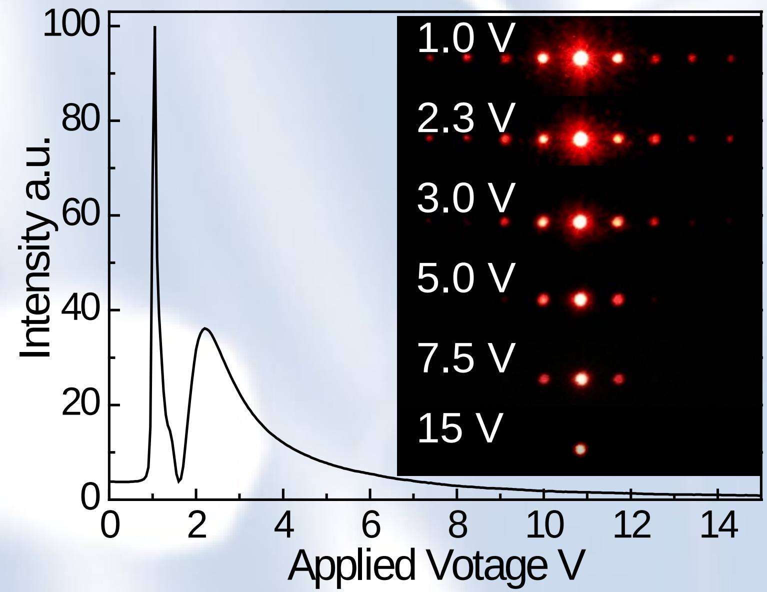
I. Grating A (TN area is brighter than PA area)
II. Uniformly bright state
III. Grating B (PA area is brighter than TN area).
IV. Uniformly dark state

1D TN/PA LC gratings

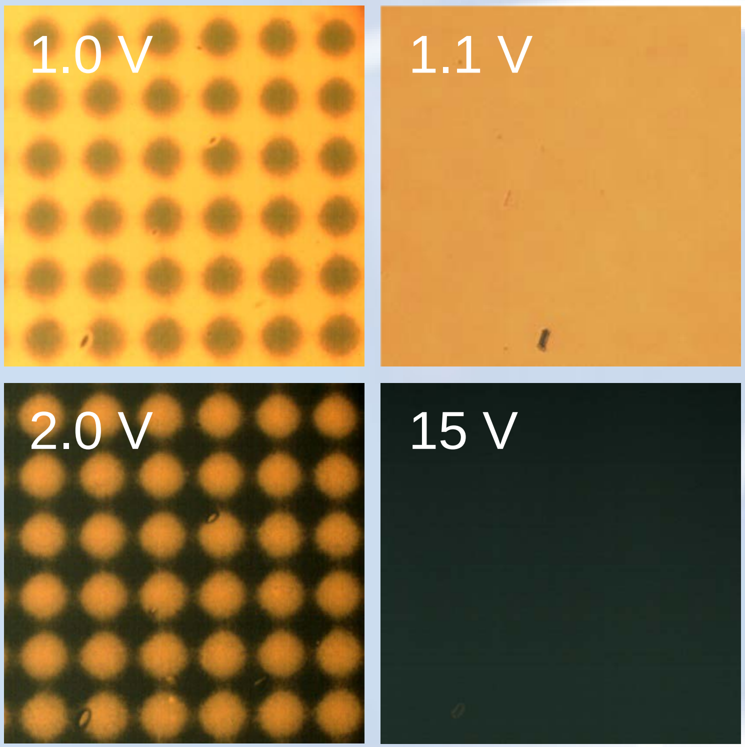


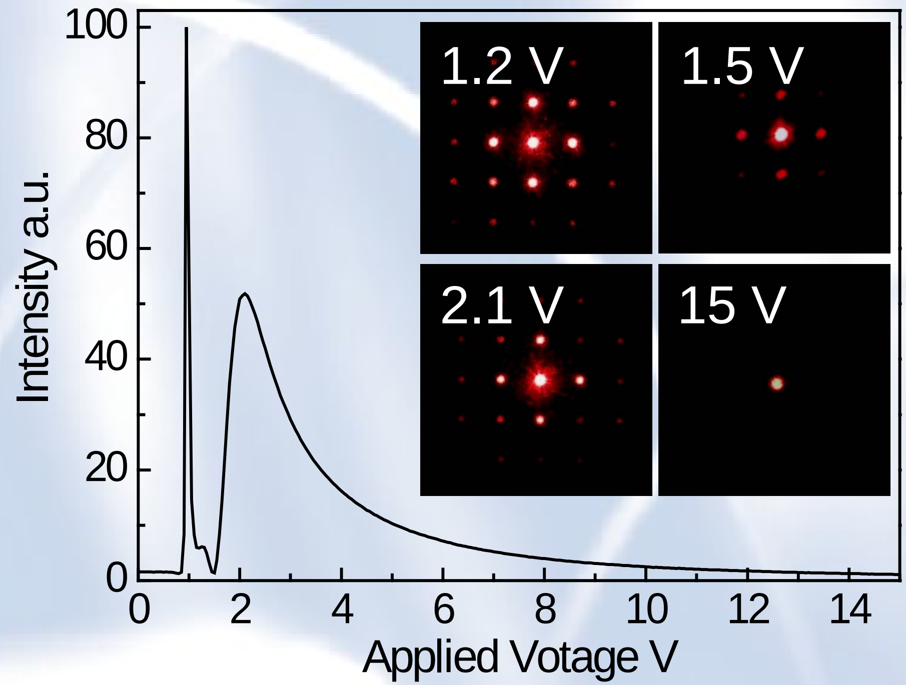
I. Grating A (TN ＞ PA)   II. Bright state   III. Grating B (TN＜PA)   IV. Dark state





2D TN/PA LC gratings





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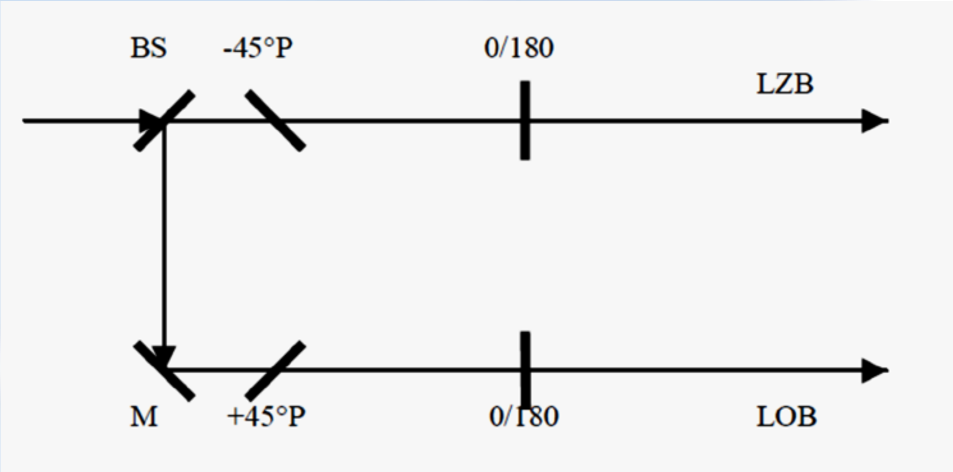
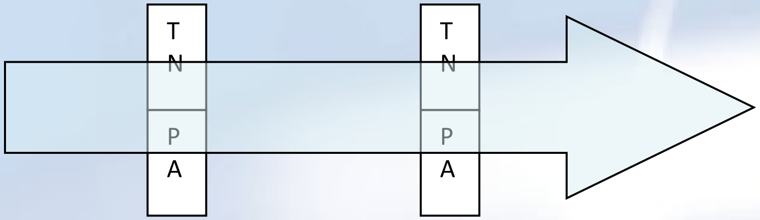
Another possible application: optical logic devices



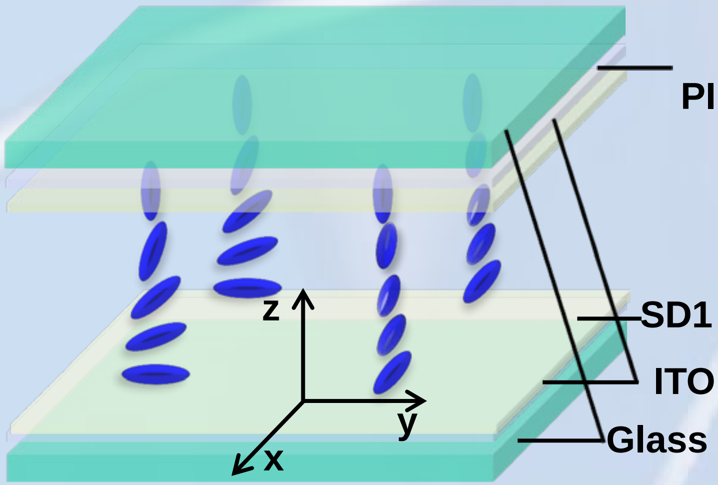
Y. A. Zaghloul, "Complete all-optical processing polarization based binary logic gates and optical processors," Opt. Express **14**(21), 9879(2006)

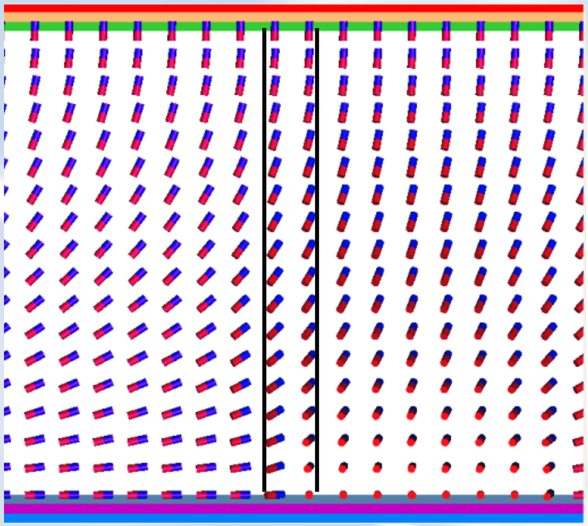


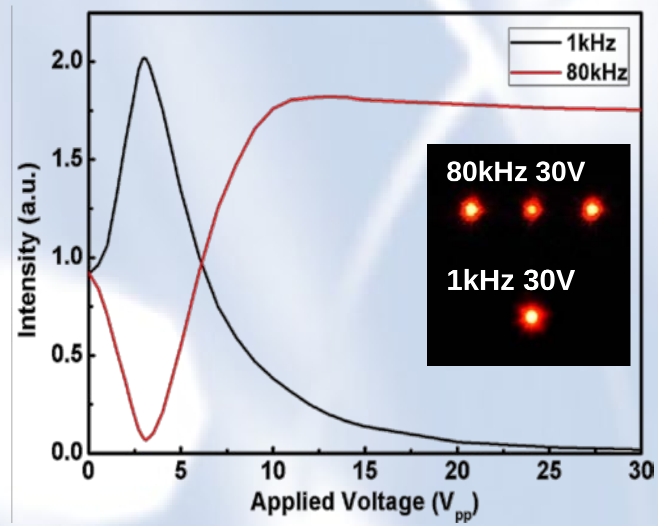
Input \ Voltage		V_I	V_{II}	V_{III}	V_{IV}
0	TN	1	1	0	0
0	PA	0	1	1	0
0	TN	1	1	0	0
1	PA	1	0	0	1
1	TN	0	0	1	1
0	PA	0	1	1	0
1	TN	0	0	1	1
1	PA	1	0	0	1

DFLC + HAN cell gratings

Dual frequency LC + Hybrid alignment



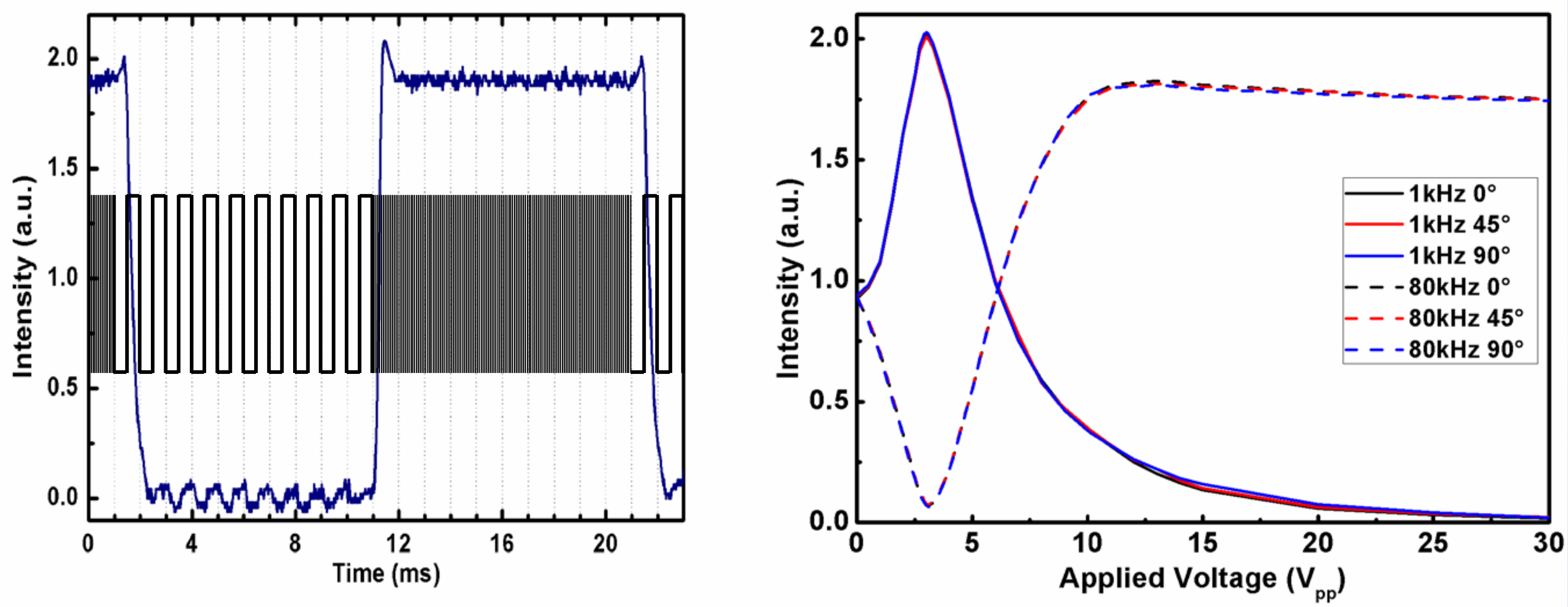




Cell gap: ~ 5 μm
DFLC (HEF951800-100, HCCH)
Δn= 0.19 @ 632.8 nm
Δε= 2.10 @ 1KHz
Δε= −2.02 @ 80 kHz
fc ≈ 45 kHz

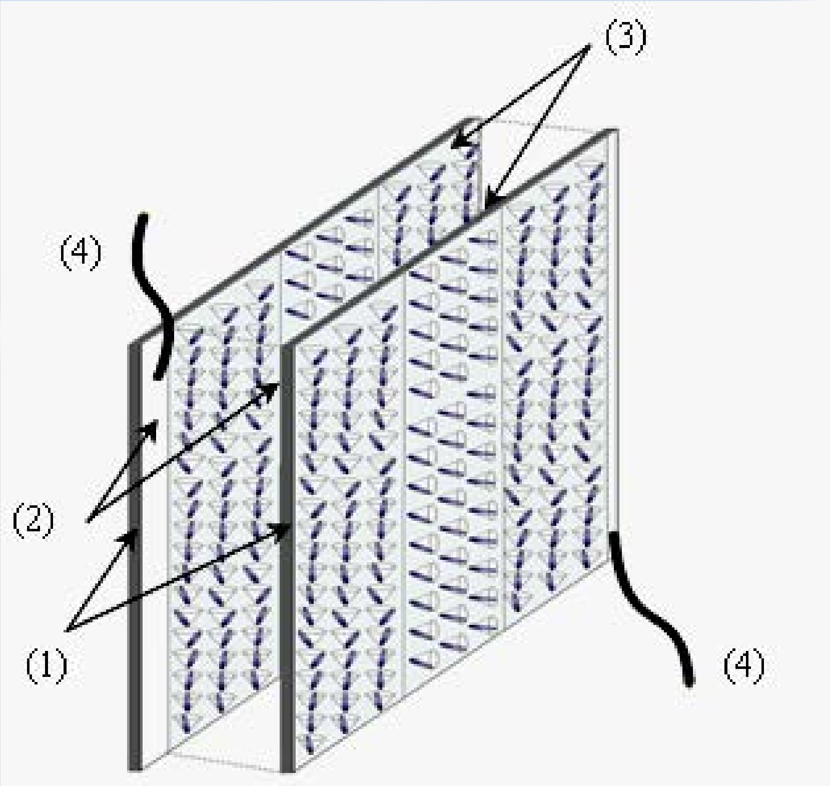
X. W. Lin *et al. Opt. Lett.* **37**, 3627 (2012)

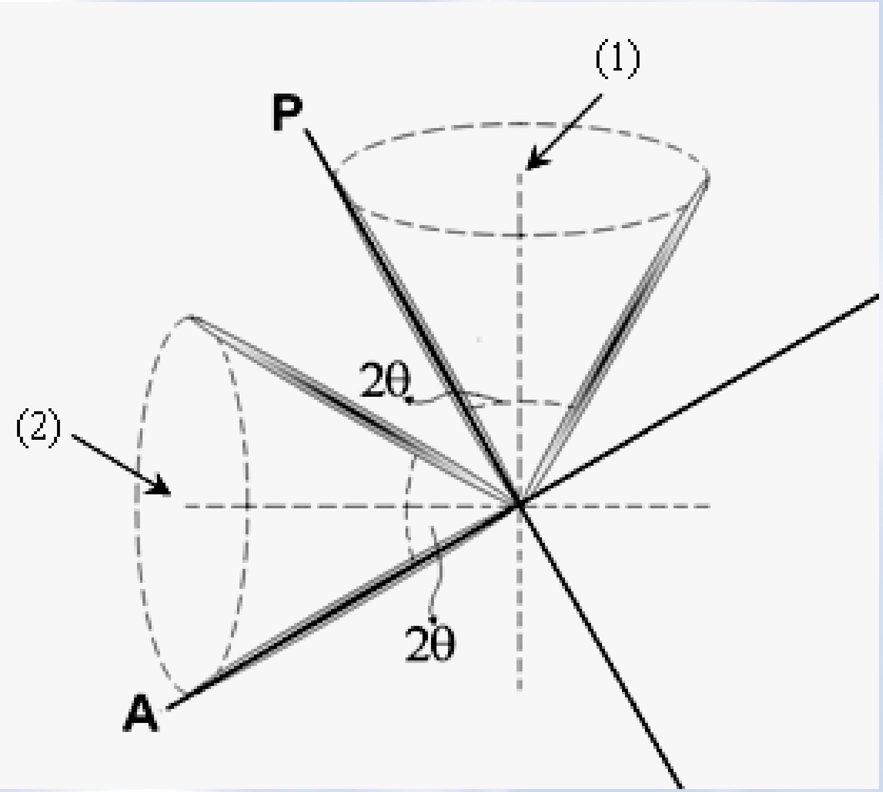
Fast switching and Polarization independency



The switch ON/OFF time are measured to be **350 μs** and **600 μs** respectively, both of which have reached submillisecond scale. Moreover, the grating is polarization independent for normally incident light. And the measured extinction ratio of 1st diffraction order is over 20dB.

Fast switching FLC gratings

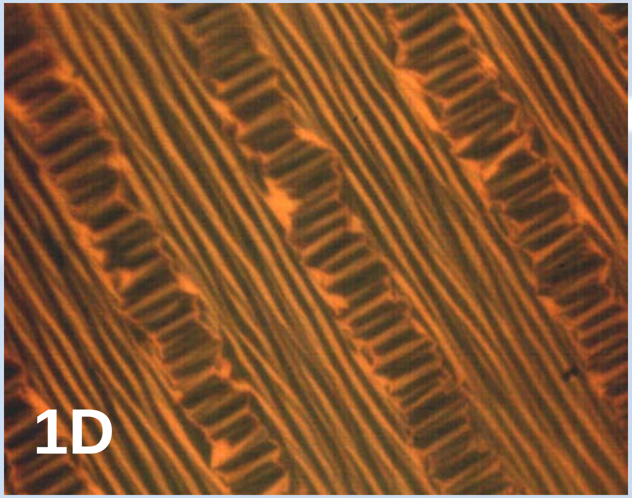


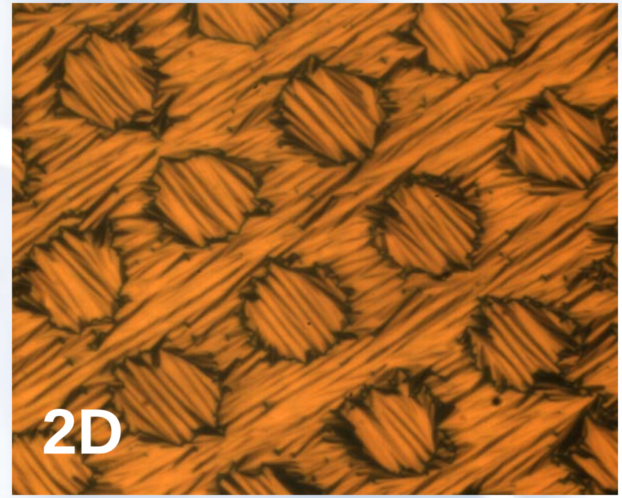


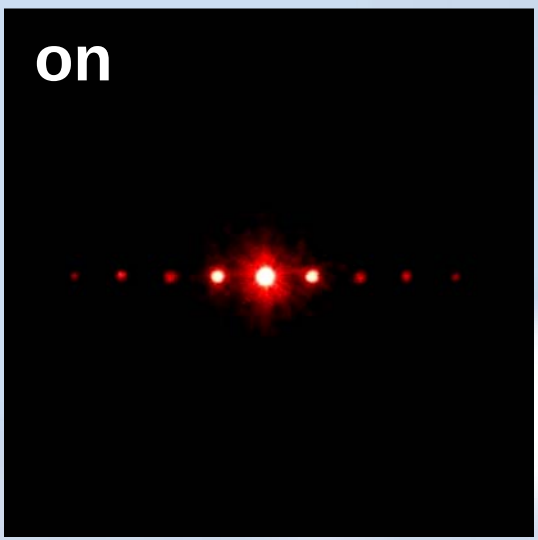
a FLC grating cell with electrically suppressed helix electro-optical mode with FLC pitch less than the LC cell gap.

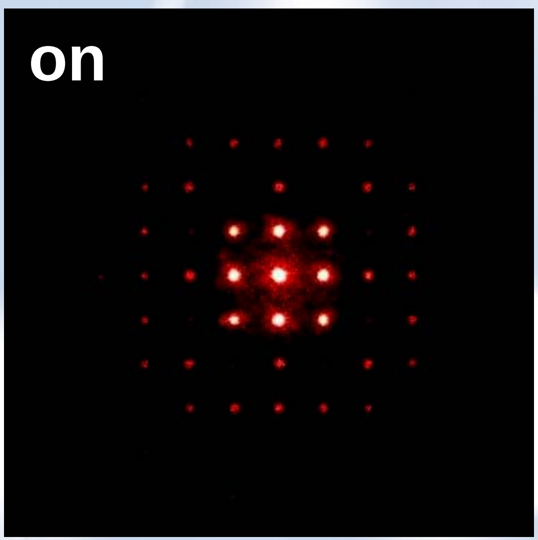
A. K. Srivastava, W. Hu, V. G. Chigrinov, A. D. Kiselev and Y. Q. Lu
Appl. Phys. Lett., **101**, 031112 (2012)

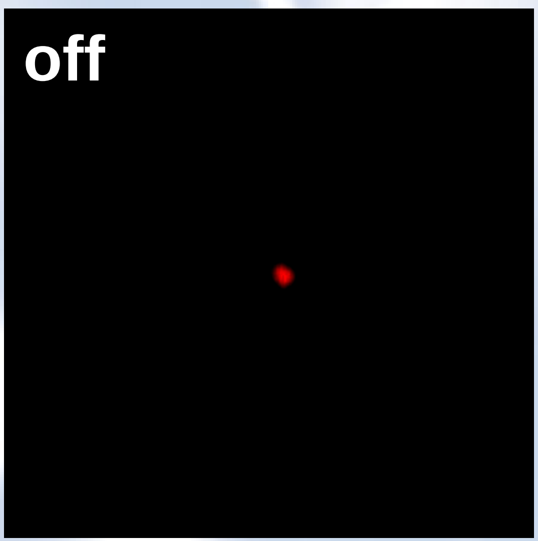
1D and 2D FLC gratings





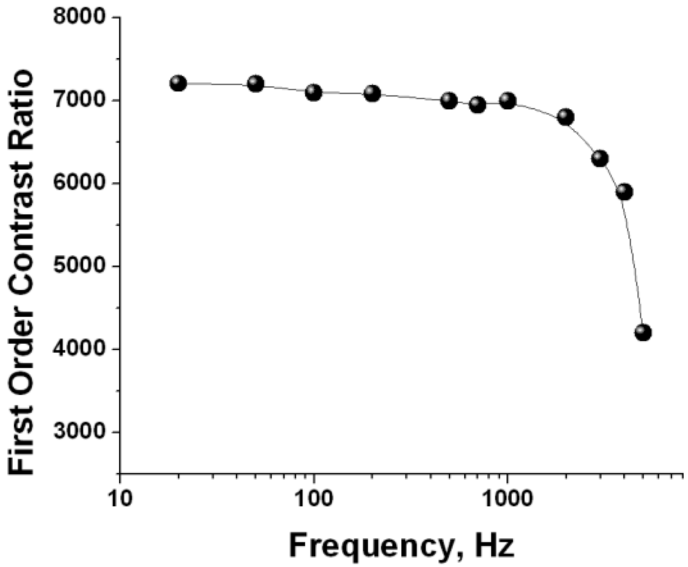


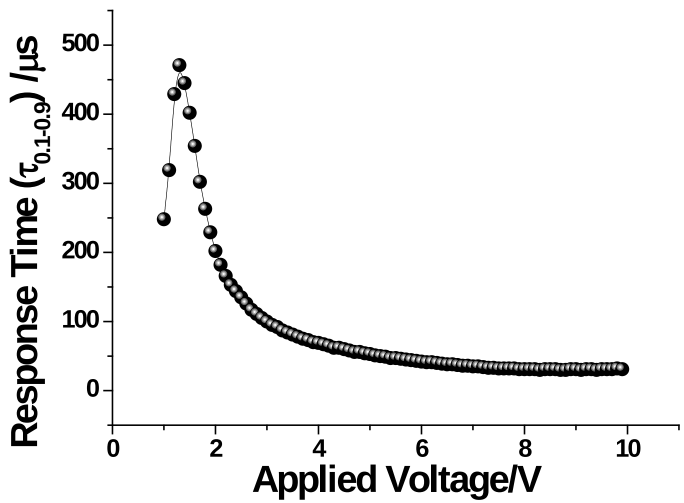


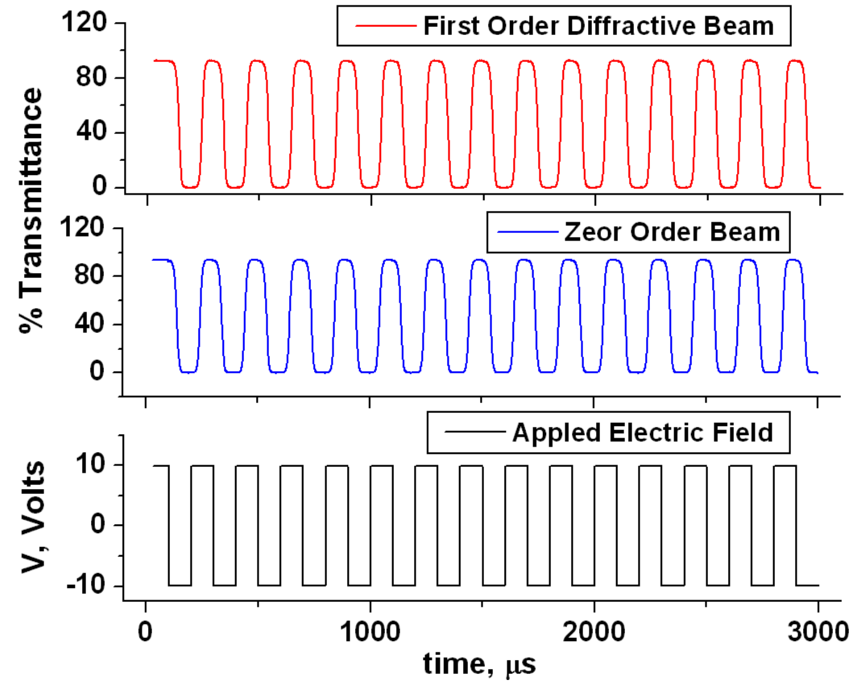


FLC FD4004N (DIC) , tilt angle θ: 22.05°, Cell gap: 1.5 μm, Grating period: 50 μm

Fast switching

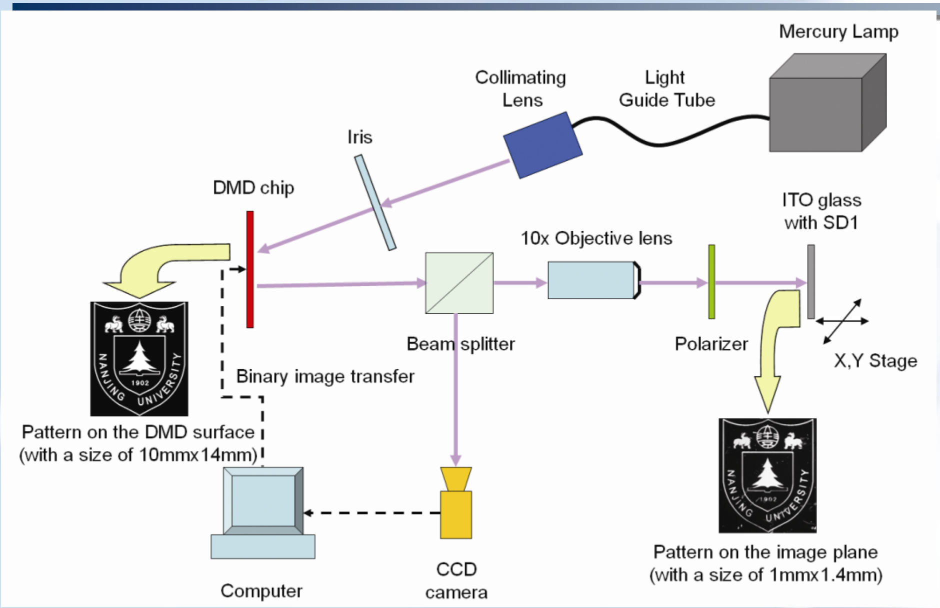


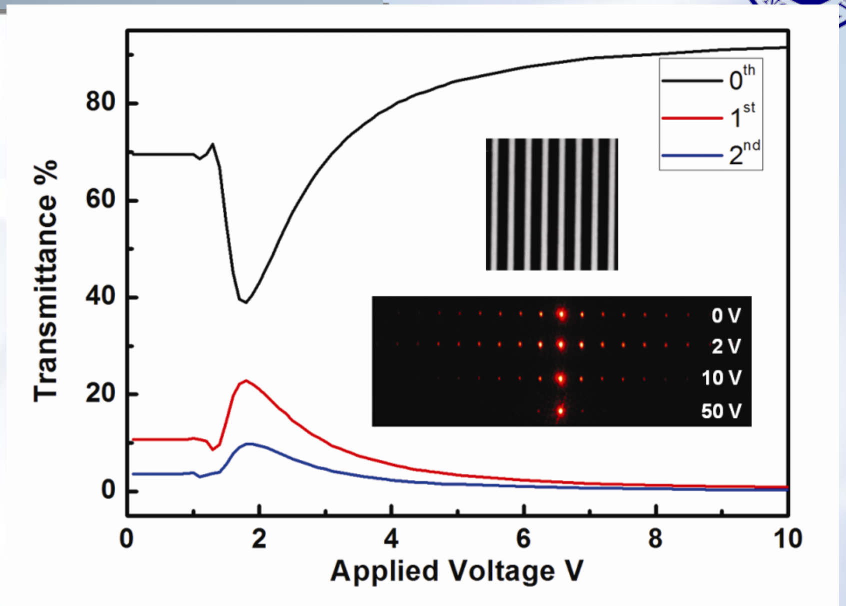


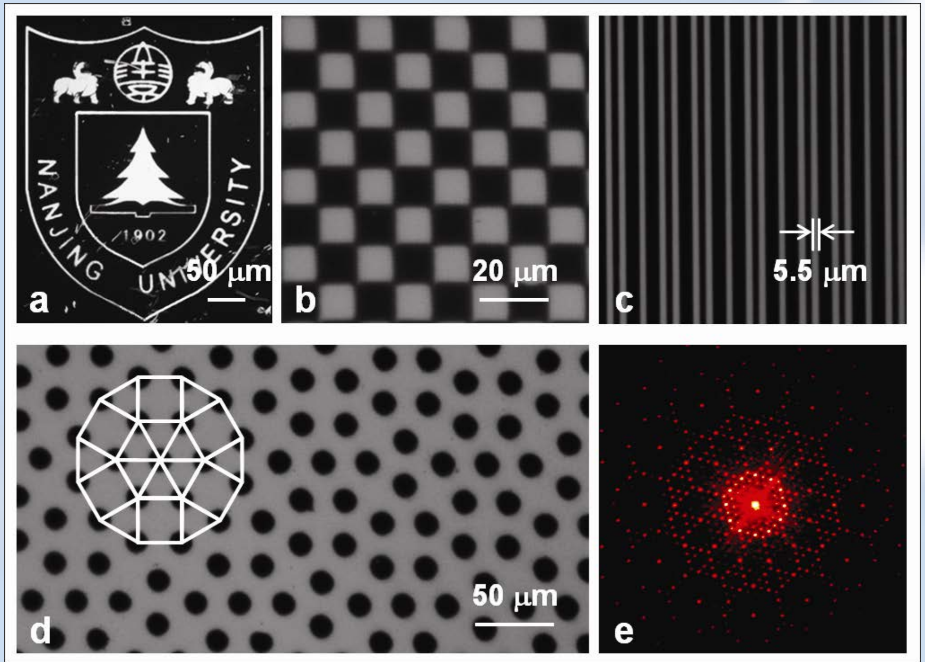


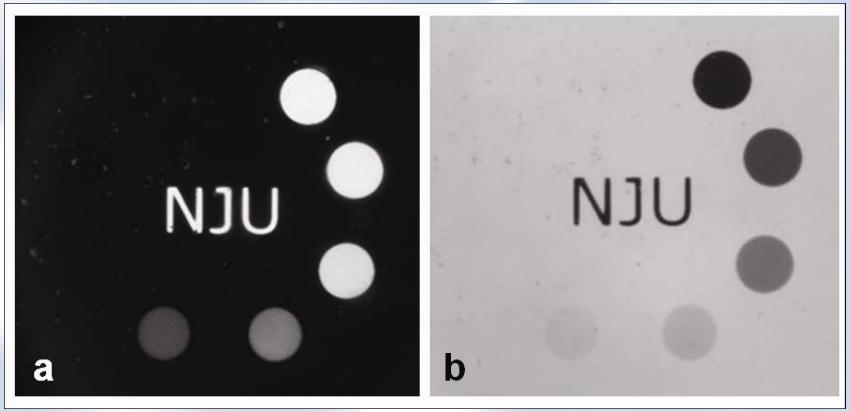
Such gratings show very high optical contrast of 7000:1, fast EO response down to **10 μs**, and perfect EO modulation up to frequency of **5 kHz** at the electric field of 7 V/μm.

Arbitrary photo-patterning in LC alignments









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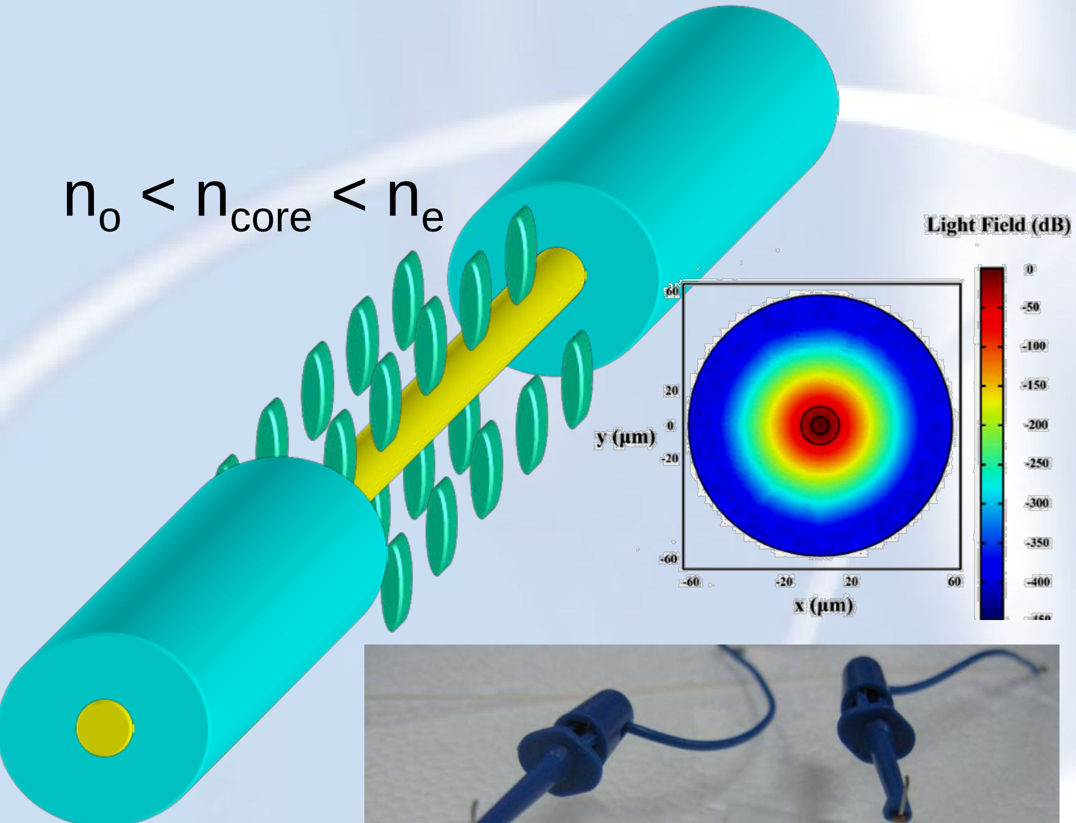
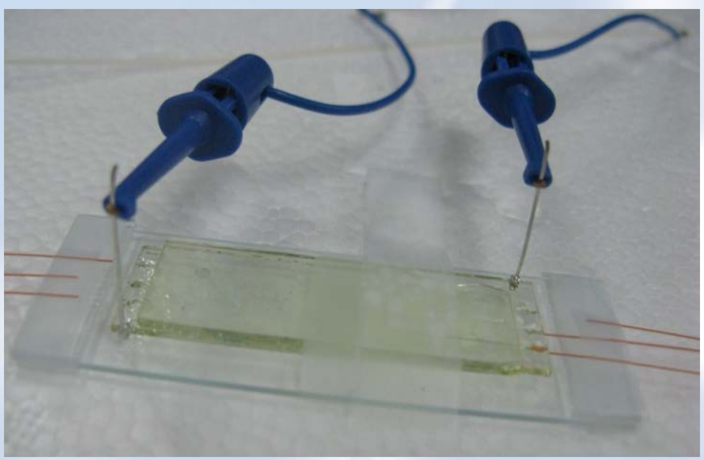
Outline

- ✓ Telecomm as an example for photonic applications
- ✓ LC based VOA (variable optical attenuator)
- ✓ LC based DWDM wavelength blocker
- ✓ LC based diffraction gratings
- ✓ LC based in-line polarizer and fiber-optic sensor
- ✓ LC for tunable THz applications
- ✓ LC for tunable optical vortex generation
- ✓ Other LC's photonic applications

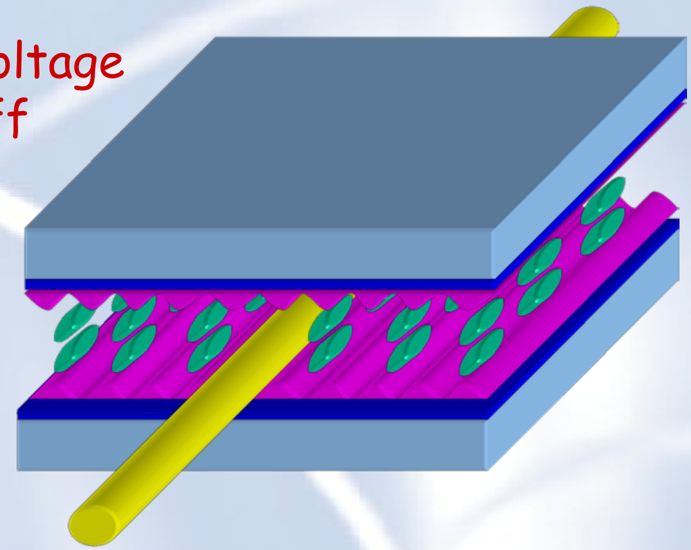
LC cladding microfiber as an in-line polarizer

$n_o < n_{core} < n_e$

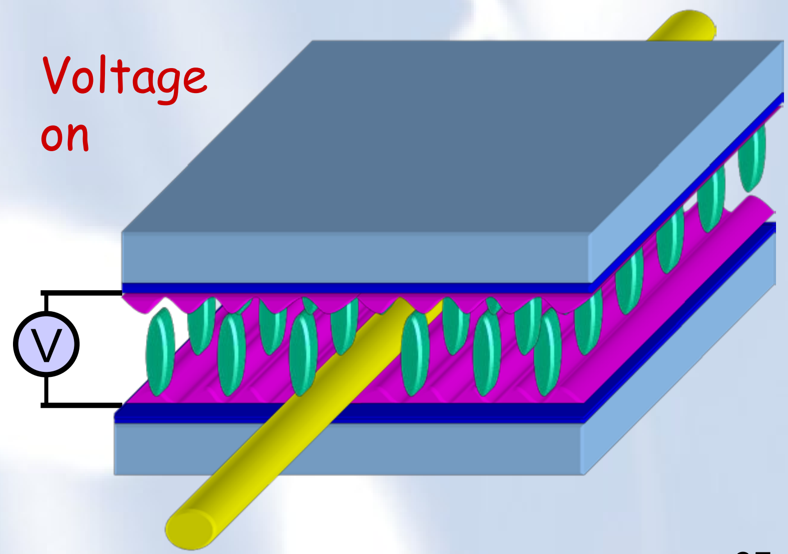




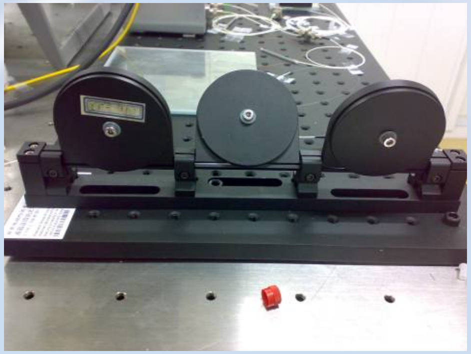
Voltage off

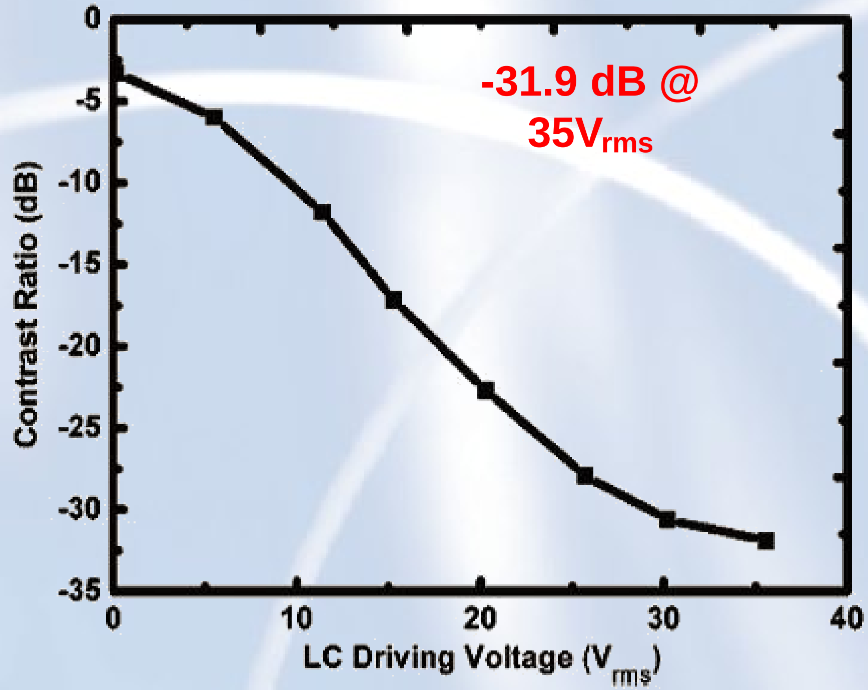


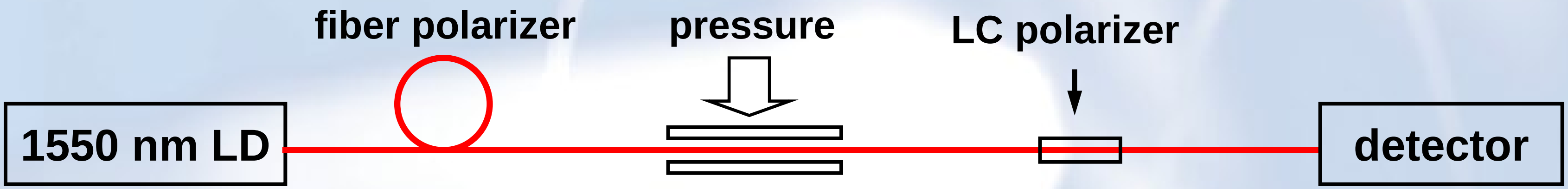
Voltage on



LC cladding microfiber as an inline VOA & polarizer

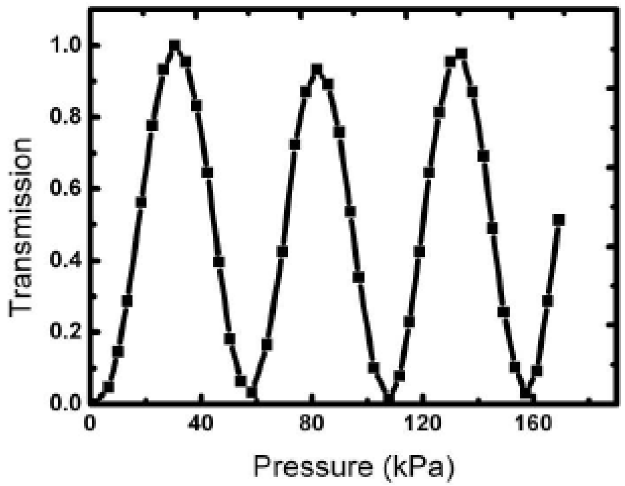






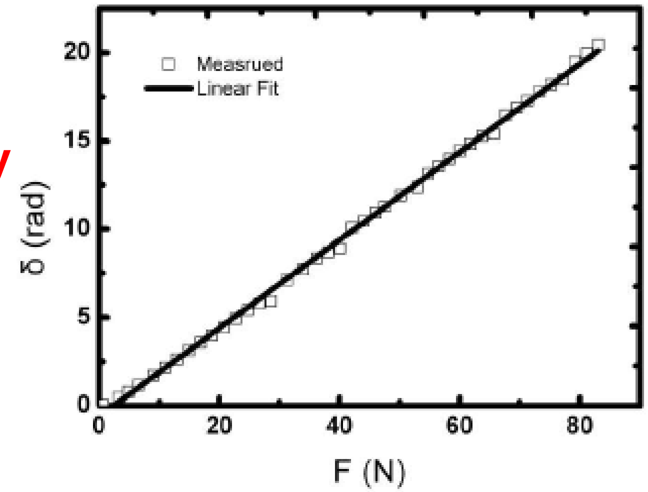
J. Feng et. al., IEEE Photonics Journal, **2,** 292-298 (2010)

LC cladding fiber for pressure sensing



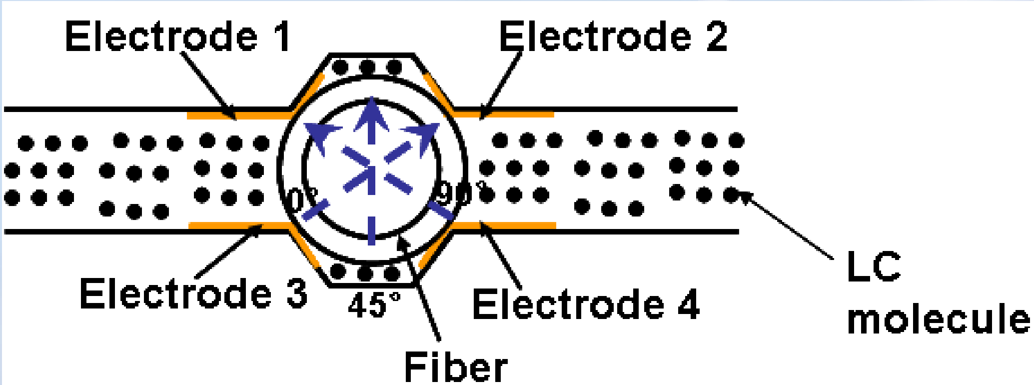
(a)

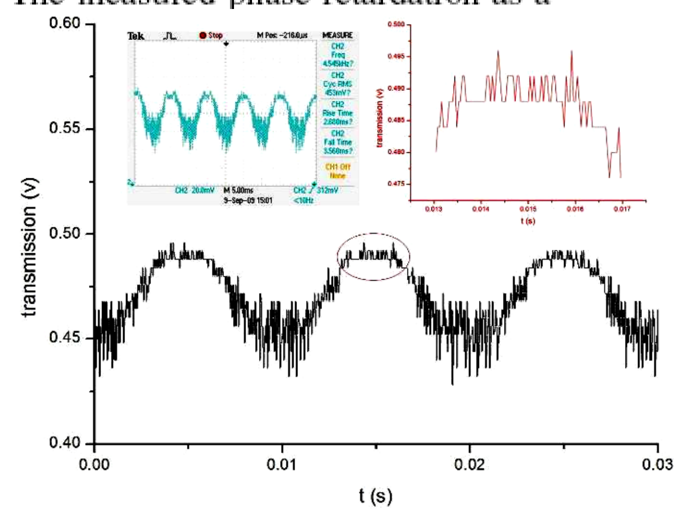
Sensitivity dδ/dF = 0.25 rad/N



(b)

Fig. 5. (a) The pressure induced transmission change. (b) The measured phase retardation as a function of the applied force. The solid line is a best-fit cu





J. Feng et. al., IEEE Photonics Journal, **2,** 292-298 (2010)

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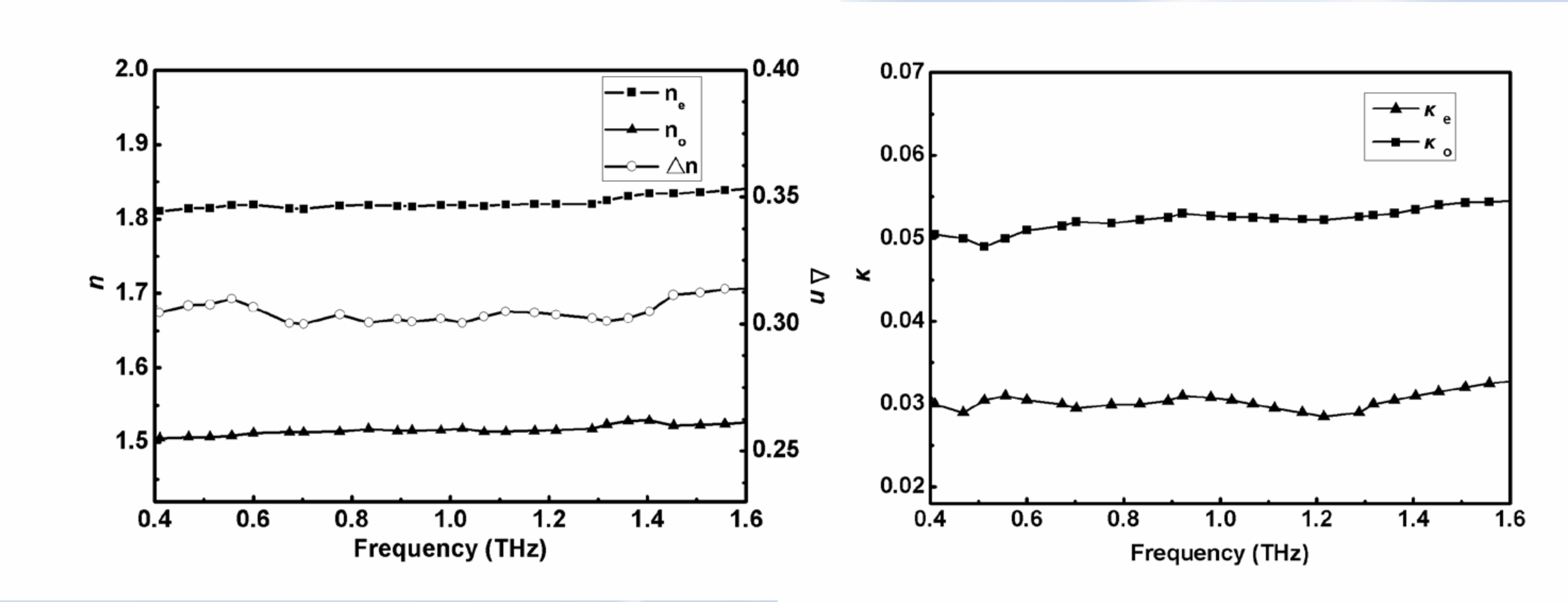
Challenges of tunable LC devices for THz apps.

- The commonly used conductive ITO layer is highly absorptive in THz range.
(New transparent conductive electrodes in THz band)
- The dispersion of LC induces a comparatively low birefringence.
(New highly birefringent LC mixture in THz band)
- Cell gap should be much larger than that in visible region, large operation voltage, slow response and poor pre-alignment.
(New cell structure, new LC alignment)
(e.g., *Prof. CL Pan's group: 570 μm-thick cell, QWP @ 1THz, - Opt. Lett. 31, 1112 (2006)).*

Self-developed large birefringence LC in THz range



Collaborated with Prof. Xiao Liang in Tsinghua Univ.

Frequency-dependent birefringence Δ*n* and refractive indices: real part *n* (a) and imaginary part *κ* (b) of a fluorinated phenyl-tolane based nematic mixture NJU-LDn-4.

Wang, *Opt. Mater. Express*, **2**, 1314 (2012)

Large birefringence LC material in terahertz range

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Home > Liquid-crystal material has large birefringence for terahertz radiation

Liquid-crystal material has large birefringence for terahertz radiation

10/05/2012
By John Wallace
Senior Editor

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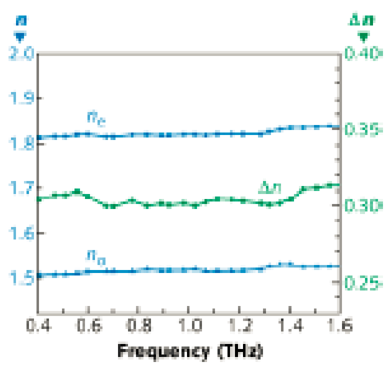
Liquid crystals (LCs) are commonly used at visible wavelengths, but it turns out that these materials can be used for optical devices at terahertz frequencies, too. A group at Nanjing University (Nanjing, China) and Tsinghua University (Beijing, China) is using a fluorinated phenyl-tolane-based nematic LC mixture between two thin fused silica plates (rubbed for LC orientation) as a birefringent material for radiation in the 0.4 to 1.6 THz range. The materials have a mean birefringence of 0.306 over that range, reaching a peak at 0.314 at 1.6 THz.



The gap between the two 0.7-mm-thick plates was 0.127 mm, and for testing the assembly was immersed in a nitrogen atmosphere to avoid water vapor absorption. Terahertz time-domain spectroscopy (THz-TDS) was used to characterize the material, with the refractive-index effects of the fused silica itself measured first and then subtracted out from the subsequent data. Both real and imaginary components of the ordinary (n_o) and extraordinary (n_e) refractive indices were measured (the real portion is shown here). The imaginary part of birefringence, which is associated with the absorption coefficient, showed low absorption over the whole testing range. The LC material has potential for fast tunable terahertz optical devices. Contact Xiao Liang at liangxiao@tsinghua.edu.cn.

Subject: Top Downloads in Liquid Crystals from Optical Materials Express

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We hope that you enjoy this collection.

Large birefringence liquid crystal material in terahertz range

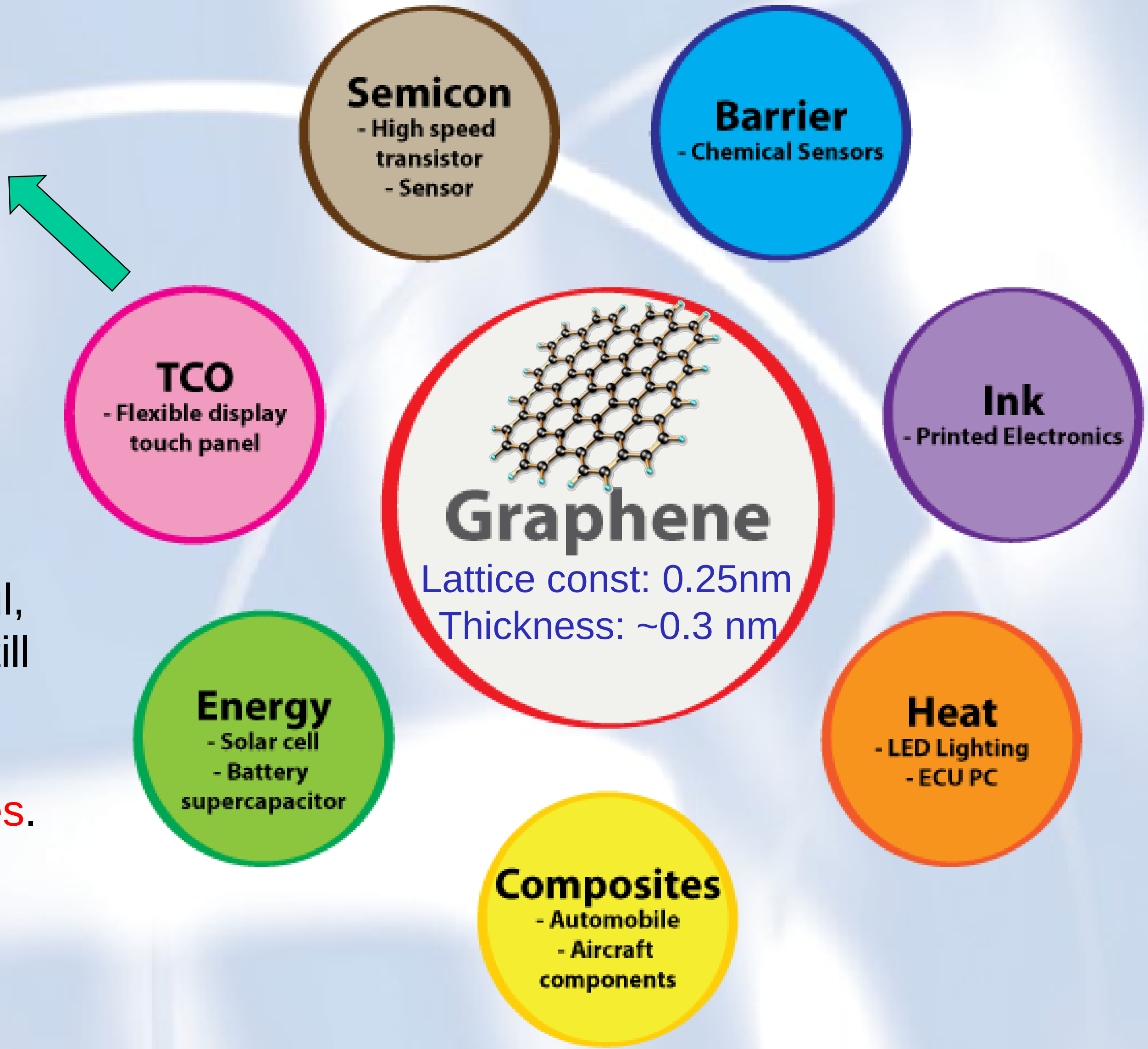
Abstract | Full Text: PDF | Enhanced HTML

Optical Materials Express, Vol. 2 Issue 10, pp. 1314-1319 (2012)
Wang, Lei; Lin, Xiao-wen; Liang, Xiao; Wu, Jing-bo; Hu, Wei; Zheng, Zhi-gang; Jin, Biao-bing; Qin, Yi-qiang; Lu, Yan-qing

We develop a fluorinated phenyl-tolane based nematic mixture NJU-LDn-4 and evaluate its frequency-dependent birefringence utilizing terahertz time domain spectroscopy (THz-TDS). A large mean birefringence of 0.306 is obtained in a broad range from 0.4 to 1.6 THz, with a

Top downloads in Liquid Crystals from *Optical Materials Express*

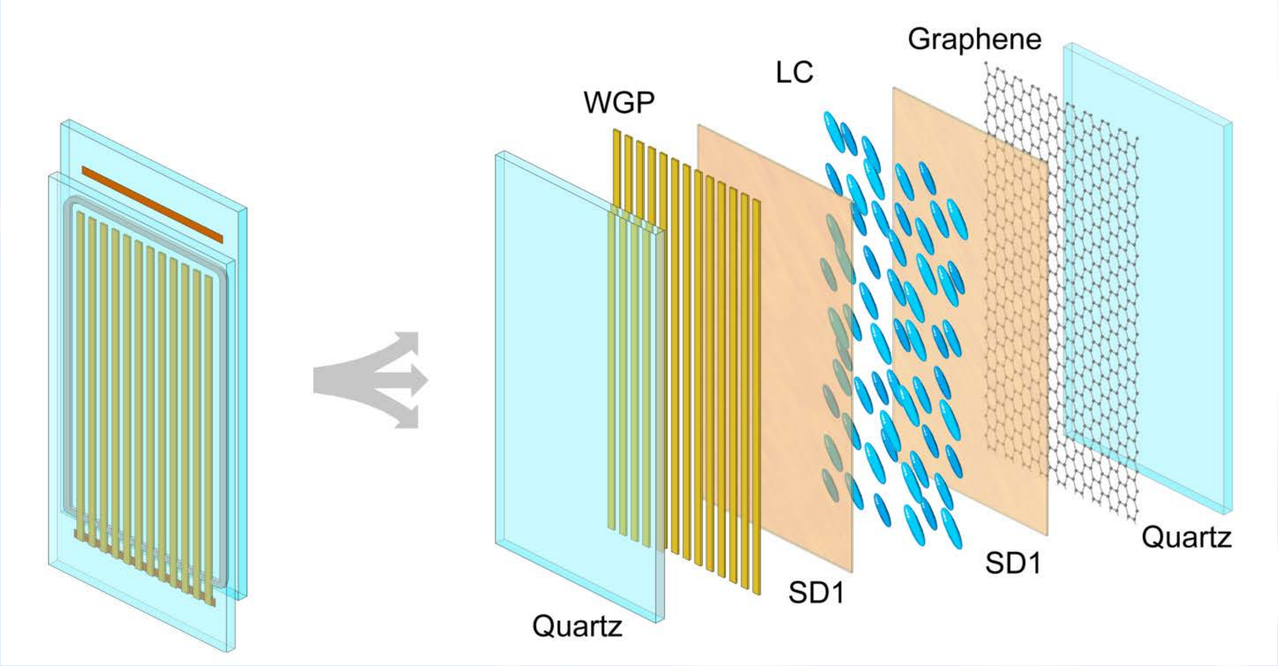
New electrode material: Graphene

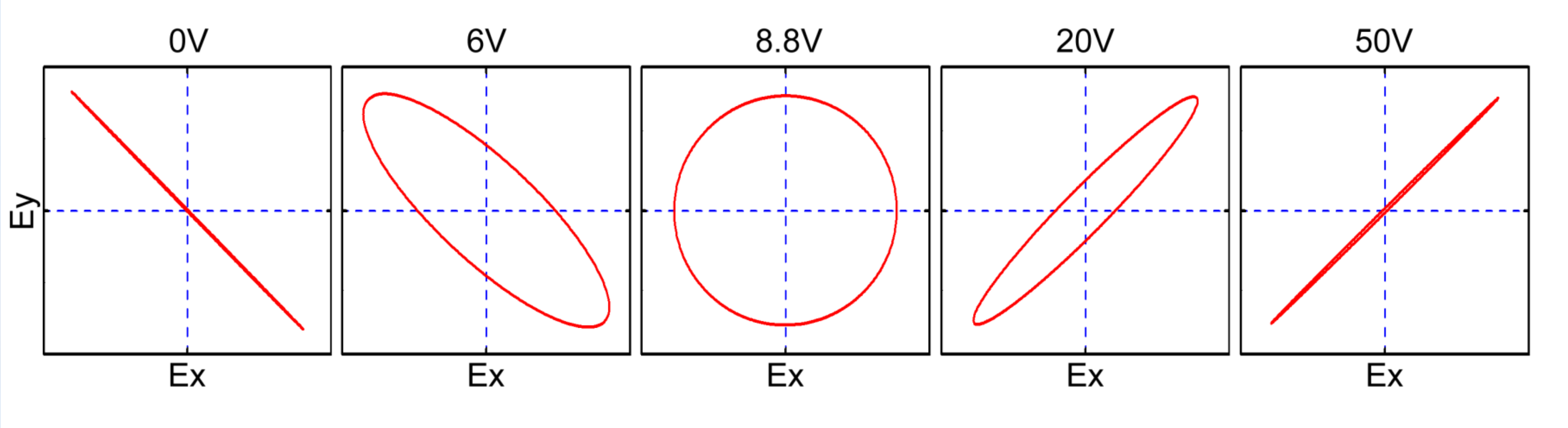


The self-polarizing function of sub-wavelength metallic gratings is very useful, but, sometimes we still need polarization independent transparent electrodes.

A new candidate:
Graphene

Our tunable THz LC waveplate with graphene electrode





Outline

- ✓ Telecomm as an example for photonic applications
- ✓ LC based VOA (variable optical attenuator)
- ✓ LC based DWDM wavelength blocker
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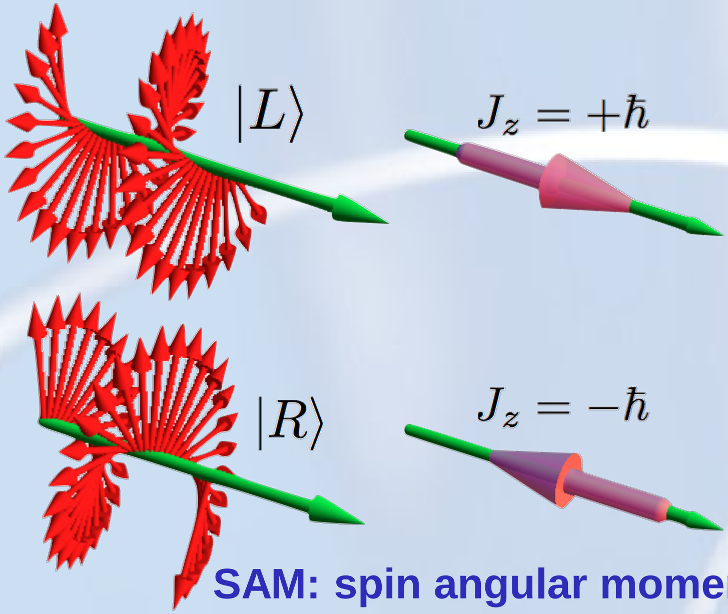
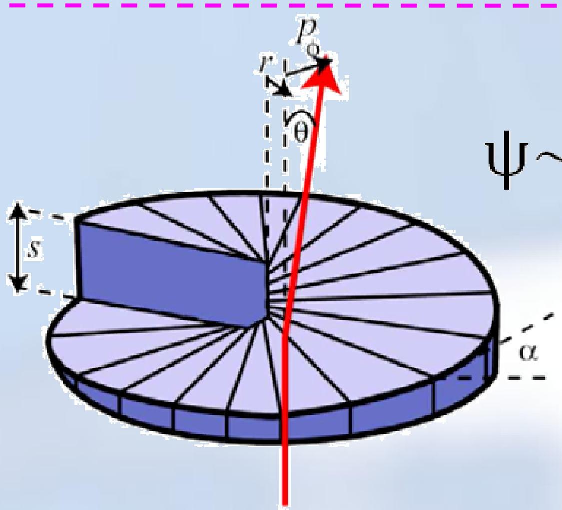
Optical vortex and orbital angular momentum



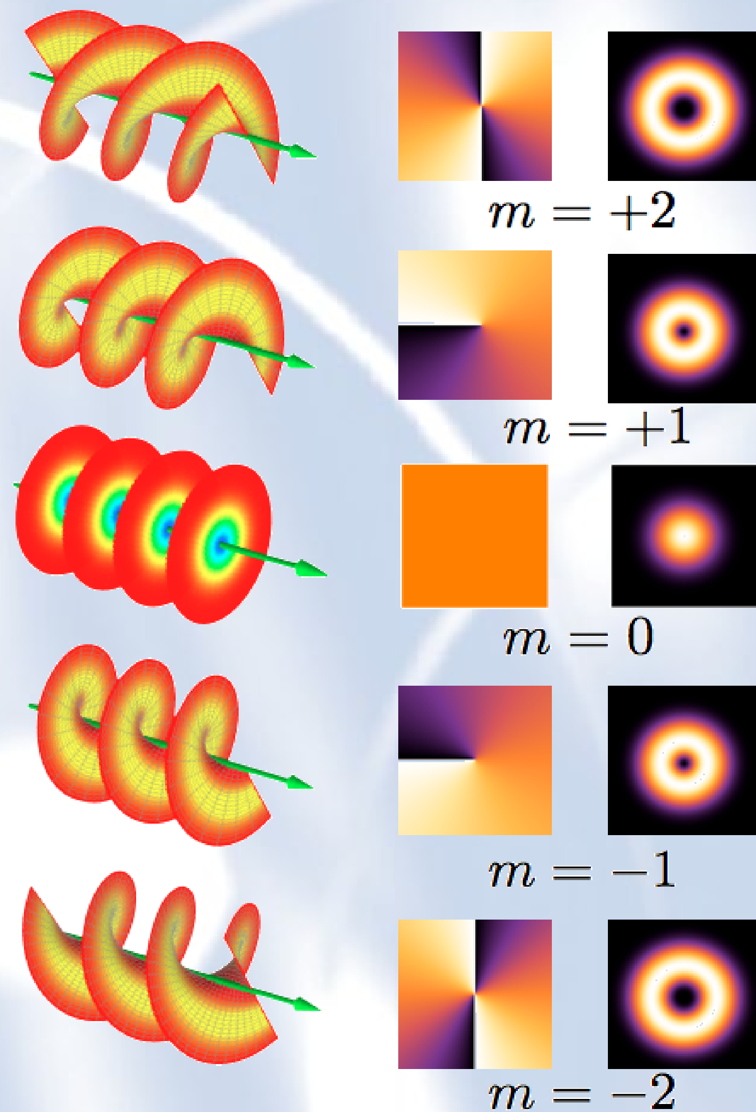
SAM: spin angular momentum



$$\psi \sim e^{im\phi} e^{-r^2}$$

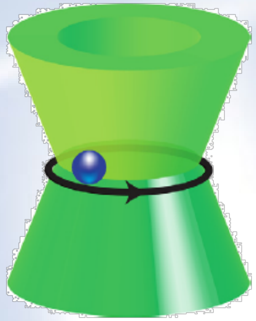
OAM: orbital angular momentum

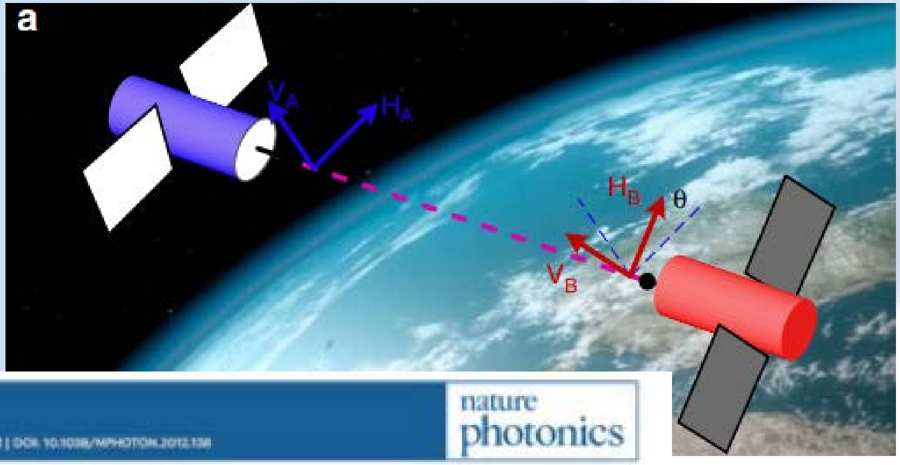
Optical Vortices with OAM



Interesting applications of optical vortex beams

- ✓ Optical tweezers: trapping and rotation
- ✓ OAM multiplexed optical comunications
- ✓ Satellite-based quantum communication
- ✓ Fast data manipulation in quantum computing
- ✓ Extrasolar planets observation
- ✓ Cryptography
- ✓ Fundamental tests of quantum mechanics
- ✓ …






ARTICLES

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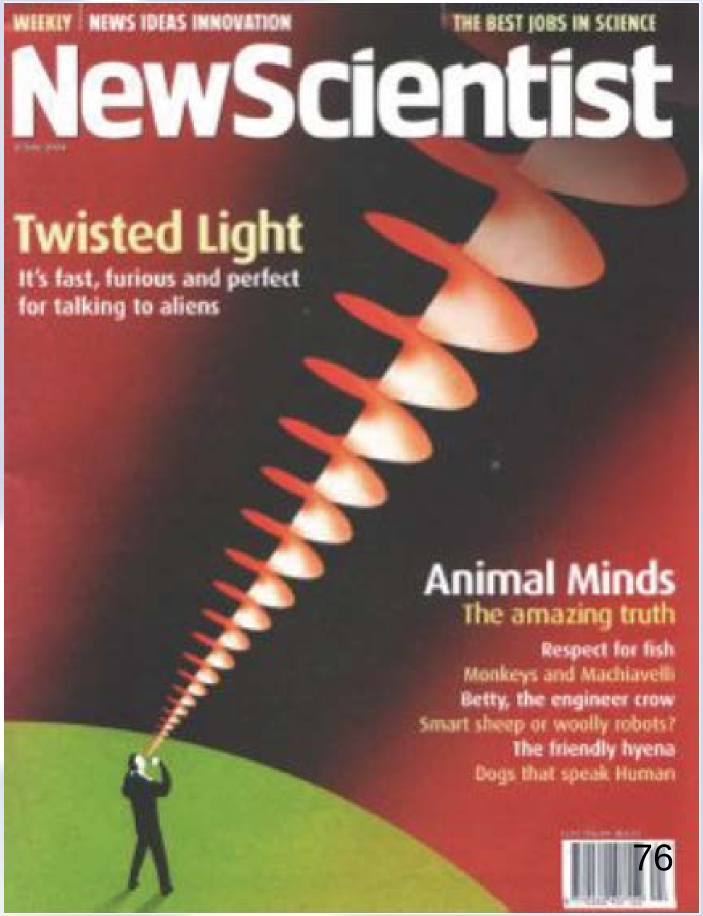
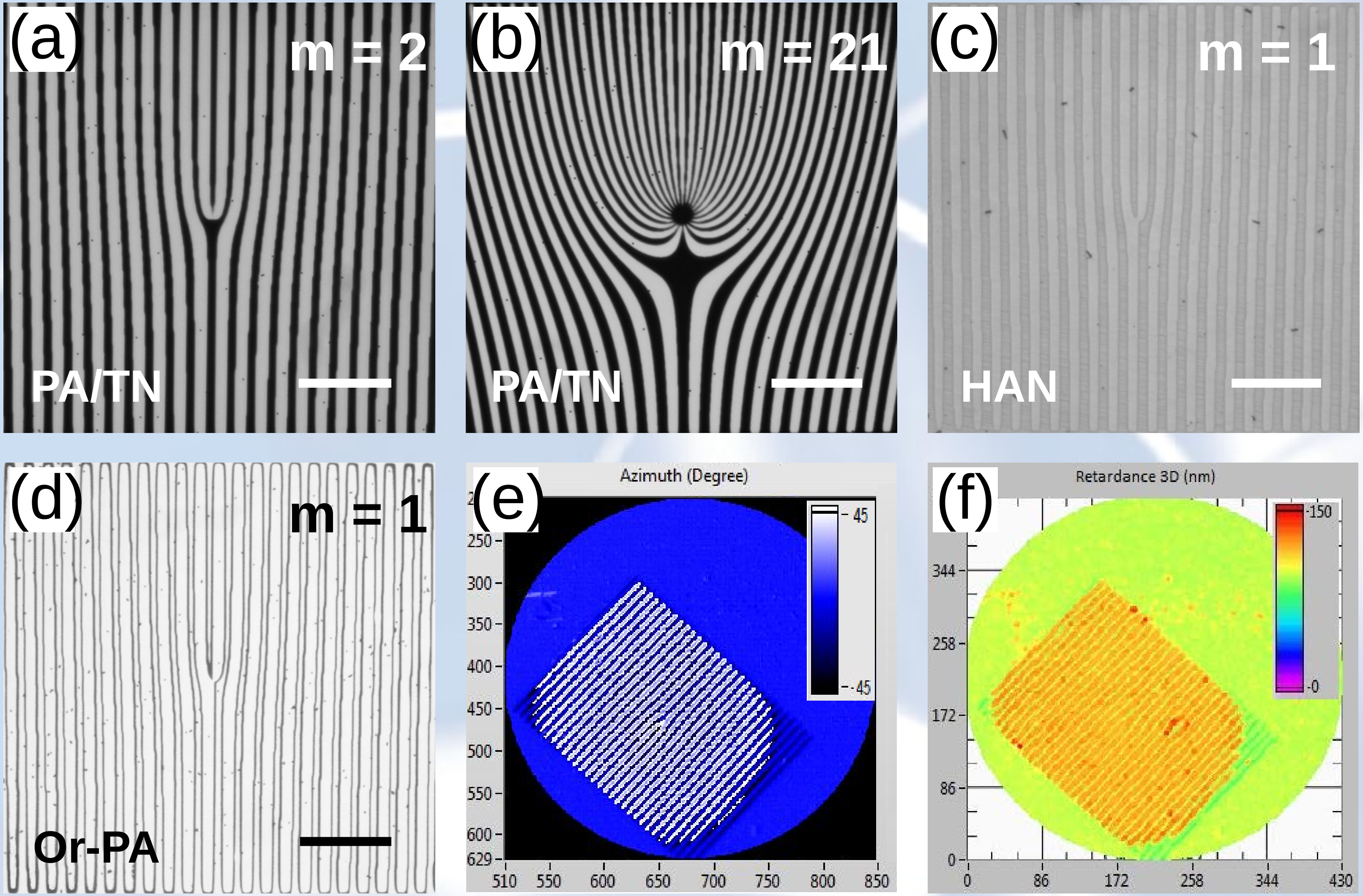
Terabit free-space data transmission employing orbital angular momentum multiplexing

Jian Wang[1,2*], Jeng-Yuan Yang[1], Irfan M. Fazal[1], Nisar Ahmed[1], Yan Yan[1], Hao Huang[1], Yongxiong Ren[1], Yang Yue[1], Samuel Dolinar[3], Moshe Tur[4] and Alan E. Willner[1*]



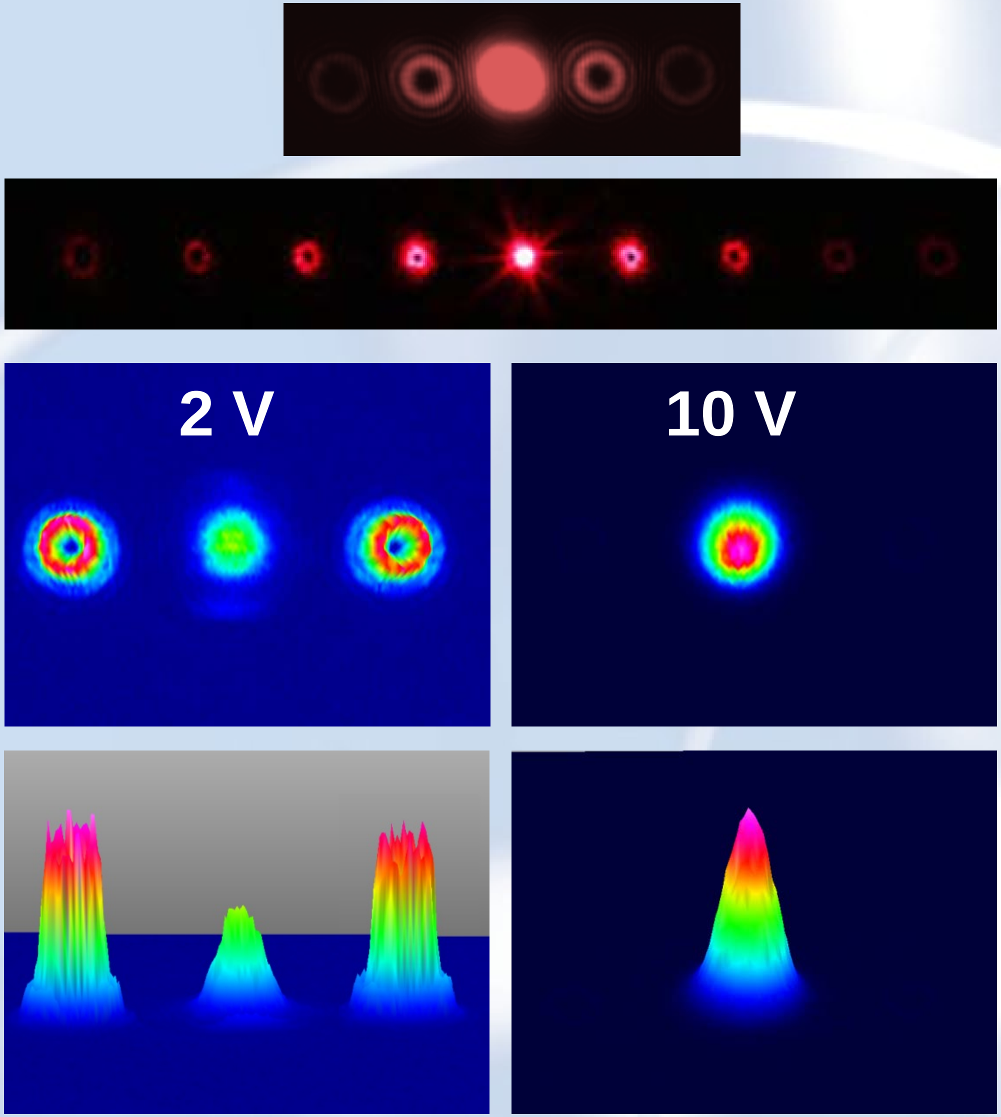
LC fork grating with various alignments

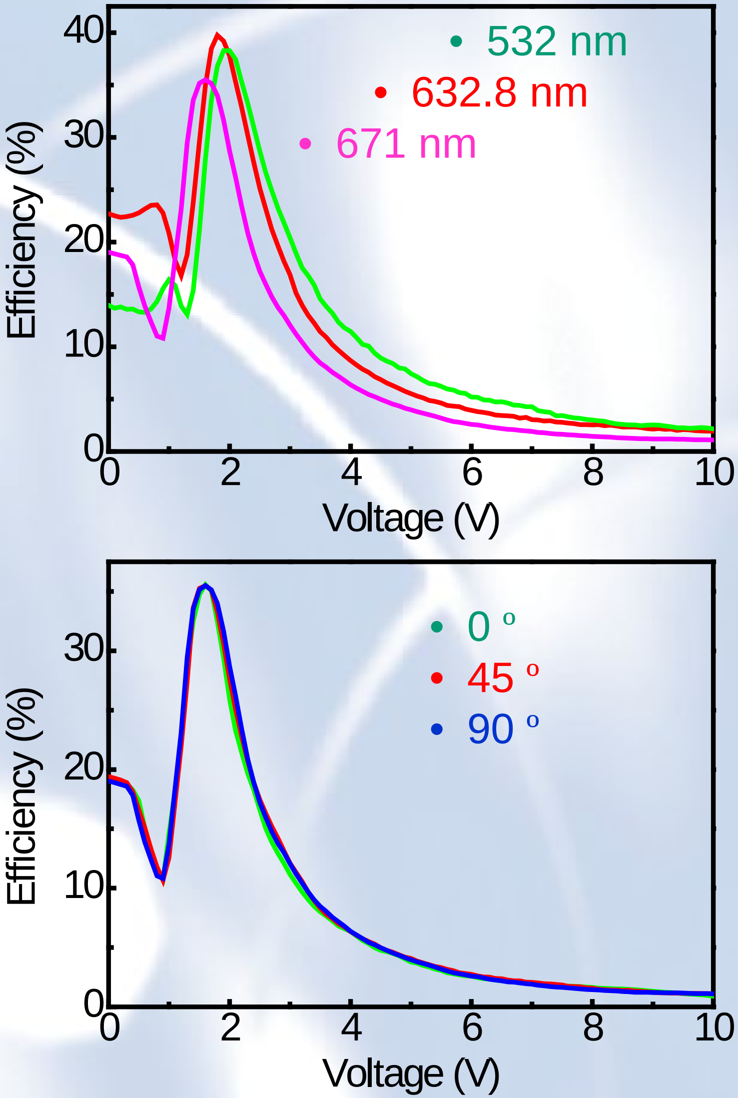


LC: E7　Cell gap: 4 μm　Scale bar: 100 μm

B. Y. Wei et al., *Advanced Materials* **26**, 1590–1595 （2014）

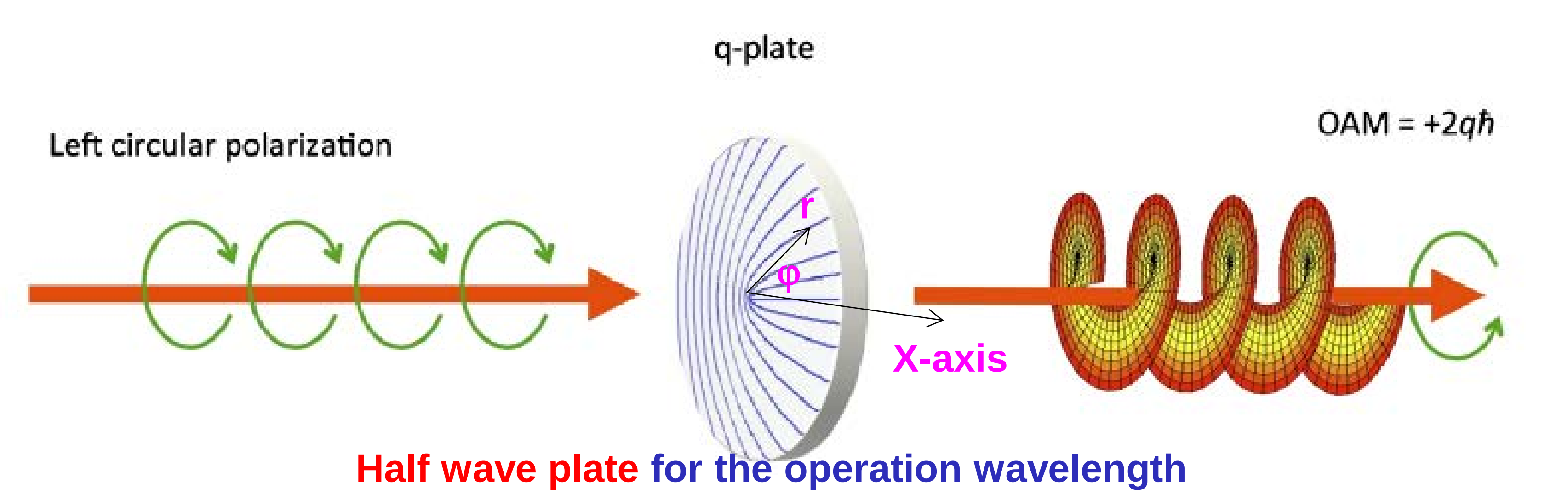
EO tunable optical vortices (HAN cell)





B. Y. Wei et al., *Advanced Materials* **26**, 1590–1595 （2014）

Liquid crystal Q-plate for tunable vortex generation

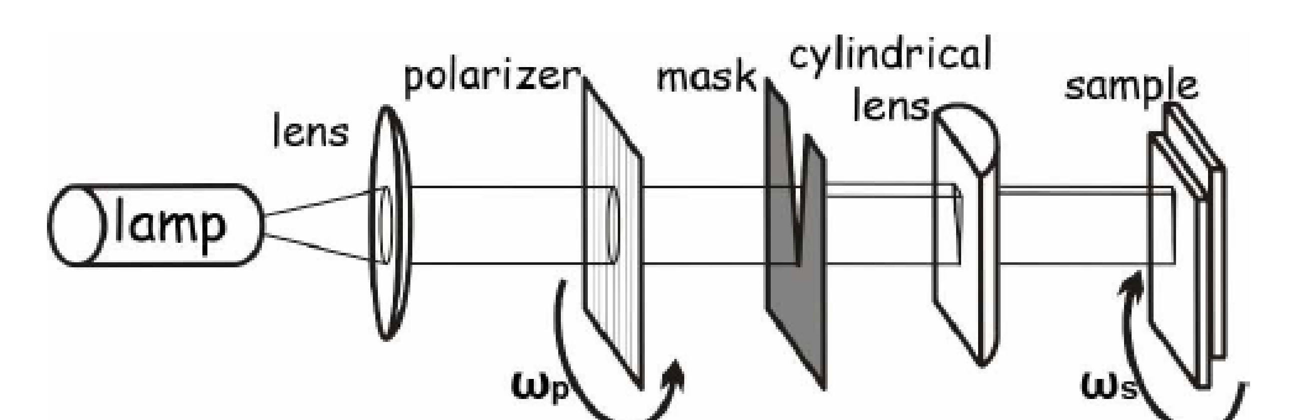


For a specific Q-plate pattern: $\alpha(r,\varphi) = q\varphi + \alpha_0$

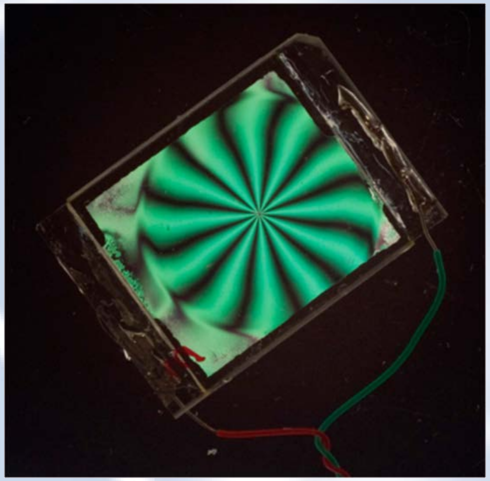
$$\Delta\phi(x,y) = \pm 2\alpha = \pm 2q\varphi + (\pm 2\alpha_0) = m\varphi + \text{cost.}$$

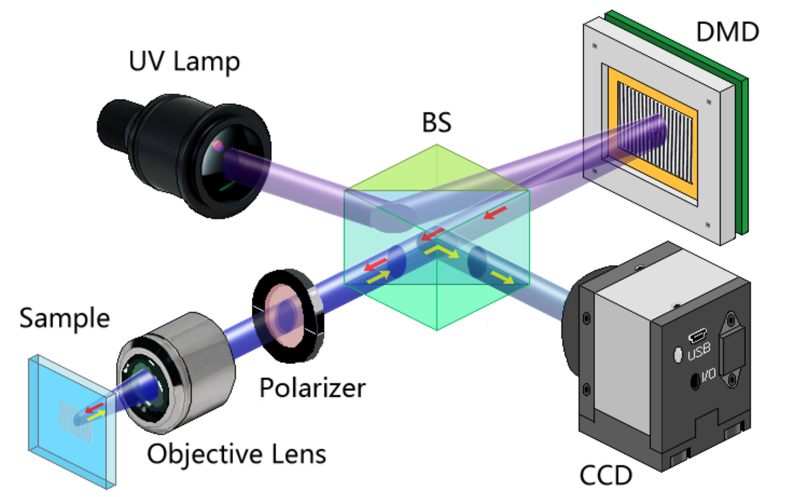
Vortex phase with m=±2q

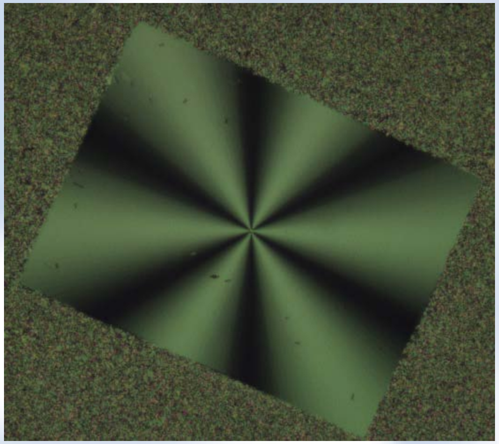
Fabrication of Liquid crystal Q-plates

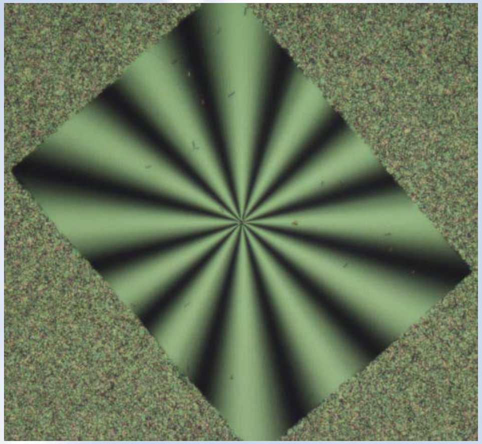


Opt. Express, 19, 4085 (2012)









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LC’s other photonic applications

- ✓ LC tunable FP filter/laser
- ✓ LC based random laser
- ✓ LC tunable metamaterials
- ✓ LC based soliton
- ✓ LC based nonlinear optical frequency converter
- ✓ LC tunable plasmonic devices in different bands
- ✓ LC based electrocaloric effect
- ✓ …

1991年诺贝尔物理奖得主，法国著名的物理学家P. G de Gennes 教授在《液晶物理学》的中译本（1990年）序言中写道: “液晶最初是100年前由德国学者发现的，后来法国的Georges Friedel建立了结构分类的基本方案，美国人最先注意到液晶在显示器件应用的潜在重要性，今天的液晶的应用技术大部分掌握在日本人手中……”

下一个　韩国　台湾　中国大陆?!

寻找液晶产业的新蓝海！

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http://light.nju.edu.cn