The Abdus Salam International Centre for Theoretical Physics
United Nations Educational, Scientific and Cultural Organization
IAEA International Atomic Energy Agency

2037-10

Introduction to Optofluidics

1 - 5 June 2009

Two case studies on liquid crystal reorientation based applications: holographic data storage and nanotube reorientation

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GEBZE INSTITUTE OF TECHNOLOGY

MAGNETIC MATERIALS
OPTICS AND LASERS
LIQUID CRYSTALS
SENSORS
QUANTUM ELECTRONICS
NANOTECHNOLOGY
SPINTRONICS
LOW TEMPERATURE PHYSICS

SCOPE OF THE TALK

LIQUID CRYSTAL SYSTEMS
FOR DYNAMIC HOLOGRAPHY

LASER INDUCED DIELECTRIC
SPECTROSCOPY OF LC. SYSTEMS

LIQUID CRYSTAL – NANOTUBE
DISPERSIONS

ORGANIC ELECTRONICS BASED
INSPIRATIONS

Liquid crystals

Liquid crystal displays (LCD) are found everywhere:

- wristwatches, pocket calculators
- mobile phones
- digital cameras
- desktop and laptop systems
- flat panel television
- …….

These range from simple black&white 7-segment displays to highly sophisticated, full colour, high resolution screens and micro-displays.

Future applications are likely to include:

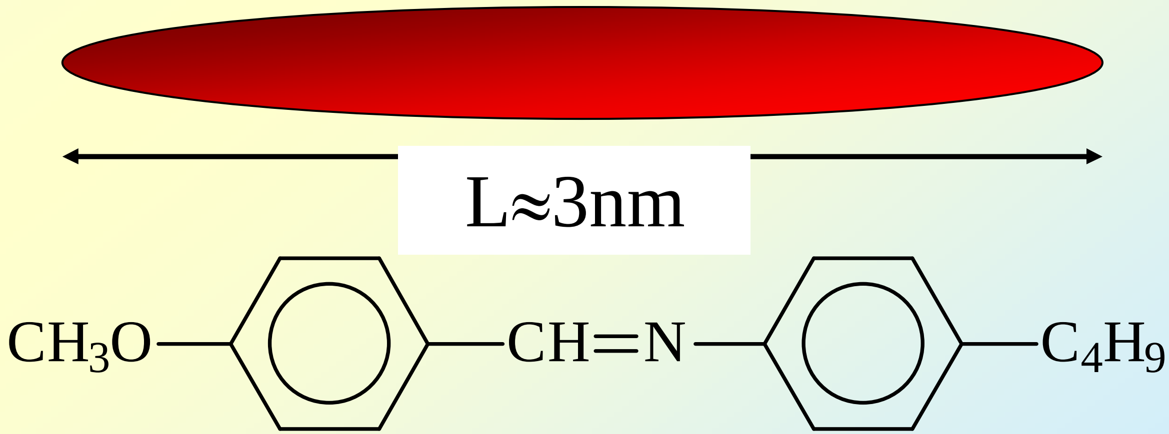
- adaptive optical elements
- 3D holographic displays
- devices in telecommunication
- “electronic paper”
- varieties of sensors
- biological recognition systems

But, what really are liquid crystals ?

Liquid crystals are:

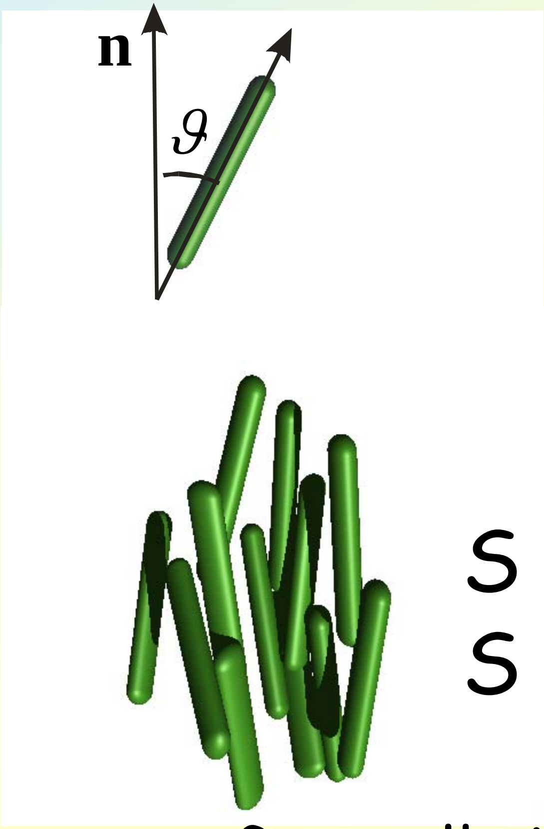
- partially ordered fluids
- thermodynamically located between the liquid and the solid state
- anisotropic liquids, with anisotropic properties
- self-organised systems

Their occurrence is observed for shape-anisotropic molecules:



Many different types of liquid crystal phases are known. Here we will only introduce the most basic ones.

Nematic:



- only orientational order of the long molecular axis

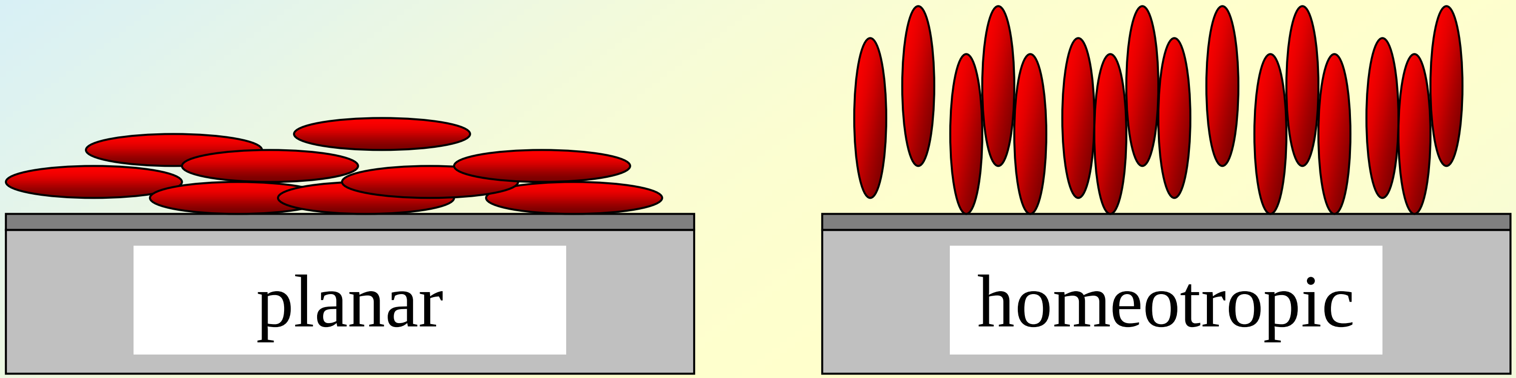
$$S = \frac{1}{2}\langle 3\cos^2\vartheta - 1\rangle$$

$S = 0$ no orientational order (isotropic)

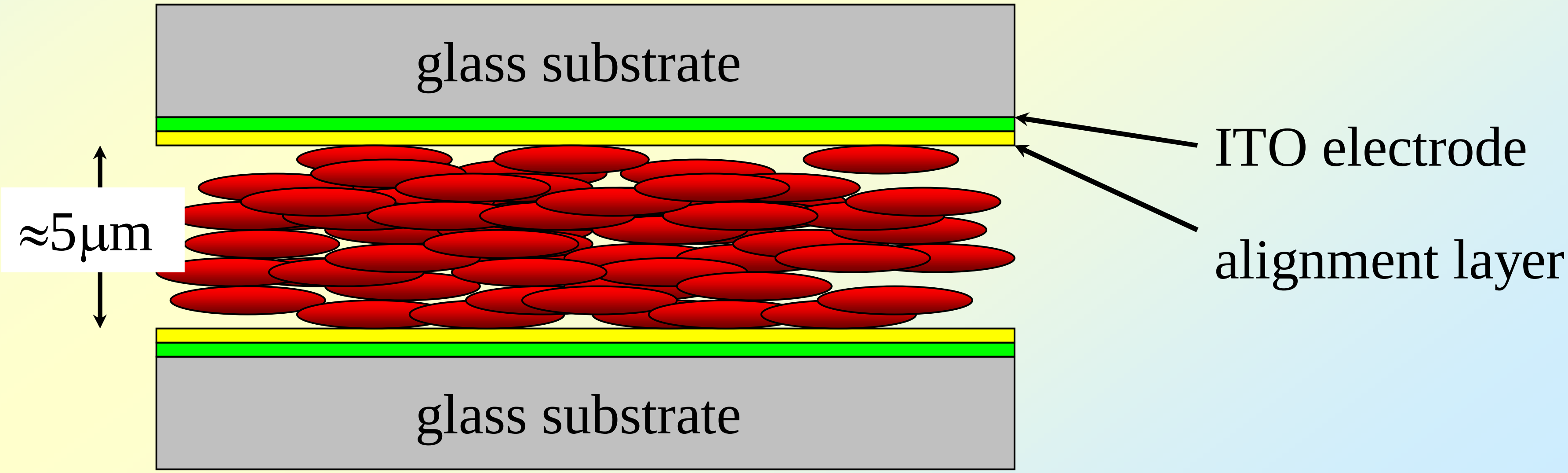
$S = 1$ perfect order

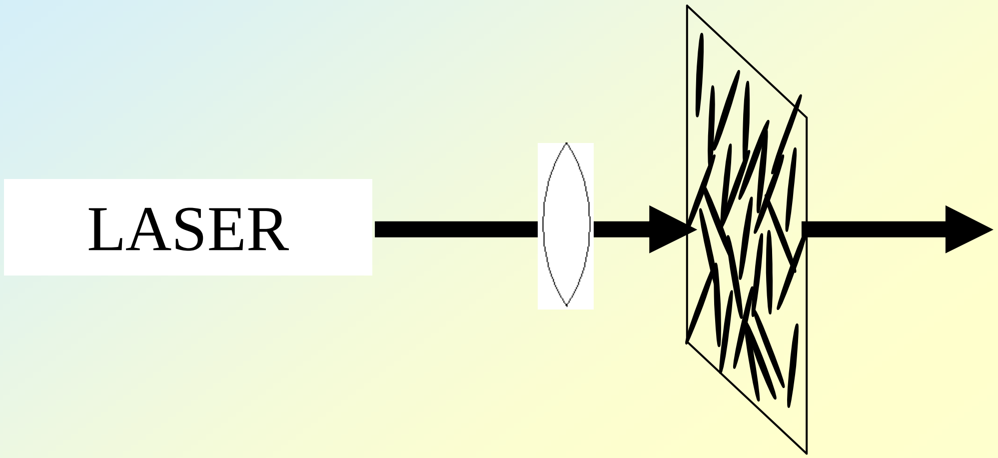
Generally it is S=0.5-0.7, depending on temperature

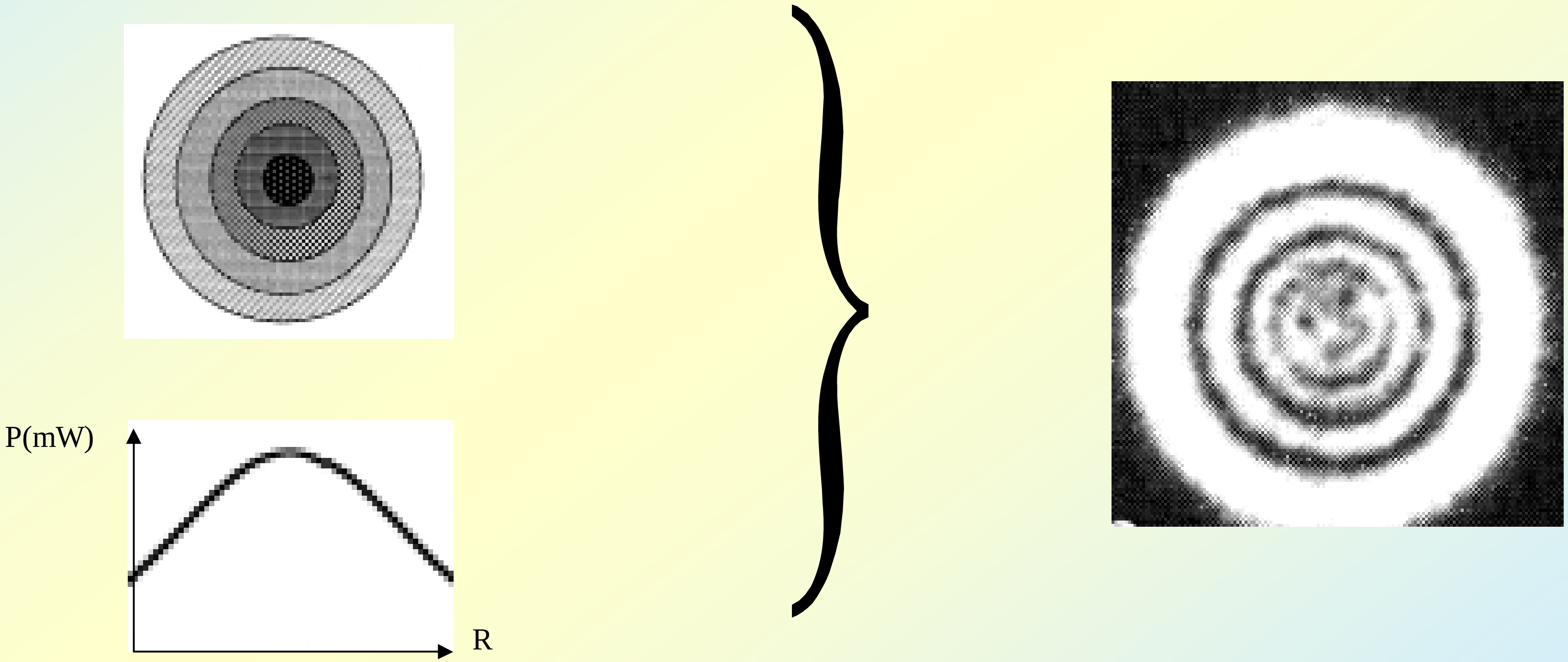
Nematic liquid crystals can easily be aligned uniformly through interactions with treated surfaces



Standard liquid crystal sandwich cell:

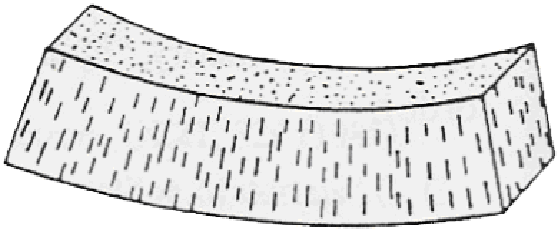




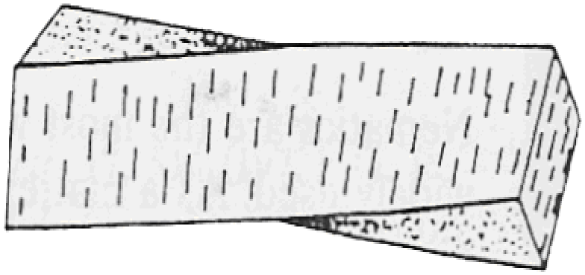


‘Self focusing’

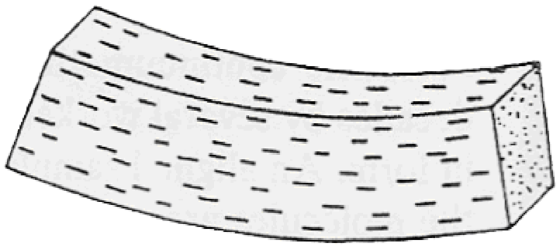
Light Scattering


Egilme

$$F_1 = \frac{1}{2}K_1(\nabla.\hat{n})^2$$


Burulma

$$F_2 = \frac{1}{2}K_2(\hat{n}.\nabla\times\hat{n})^2$$

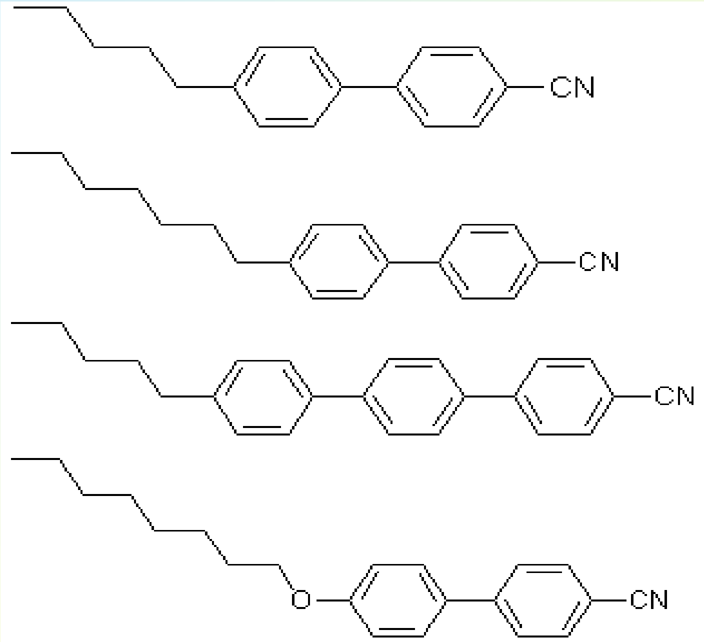

Bükülme

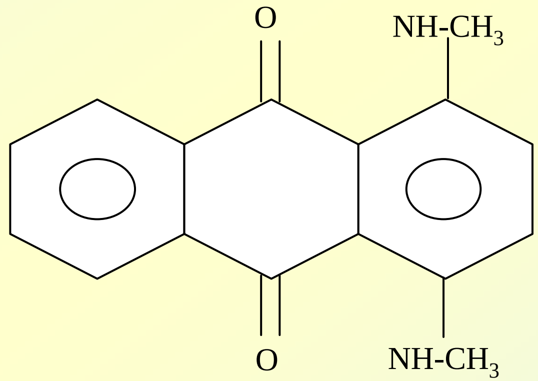
$$F_3 = \frac{1}{2}K_3(\hat{n}\times(\nabla\times\hat{n}))^2$$

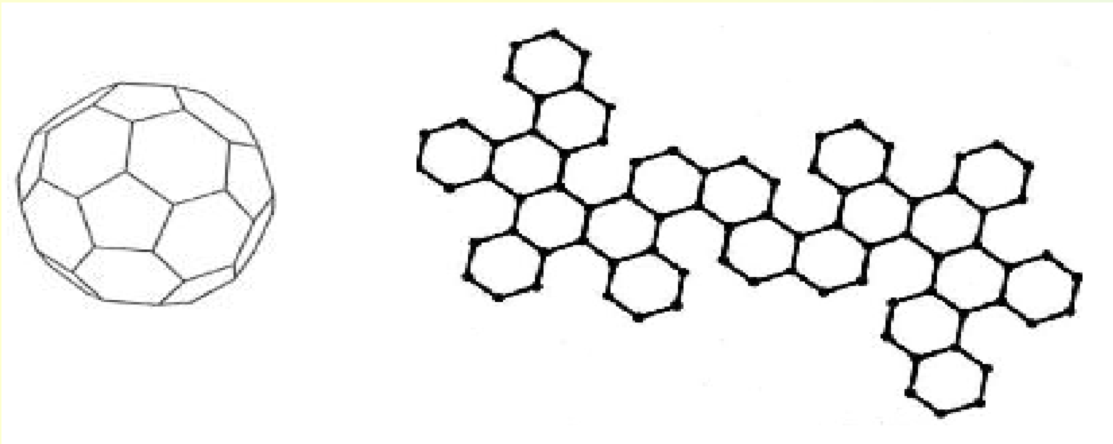
Free Energy

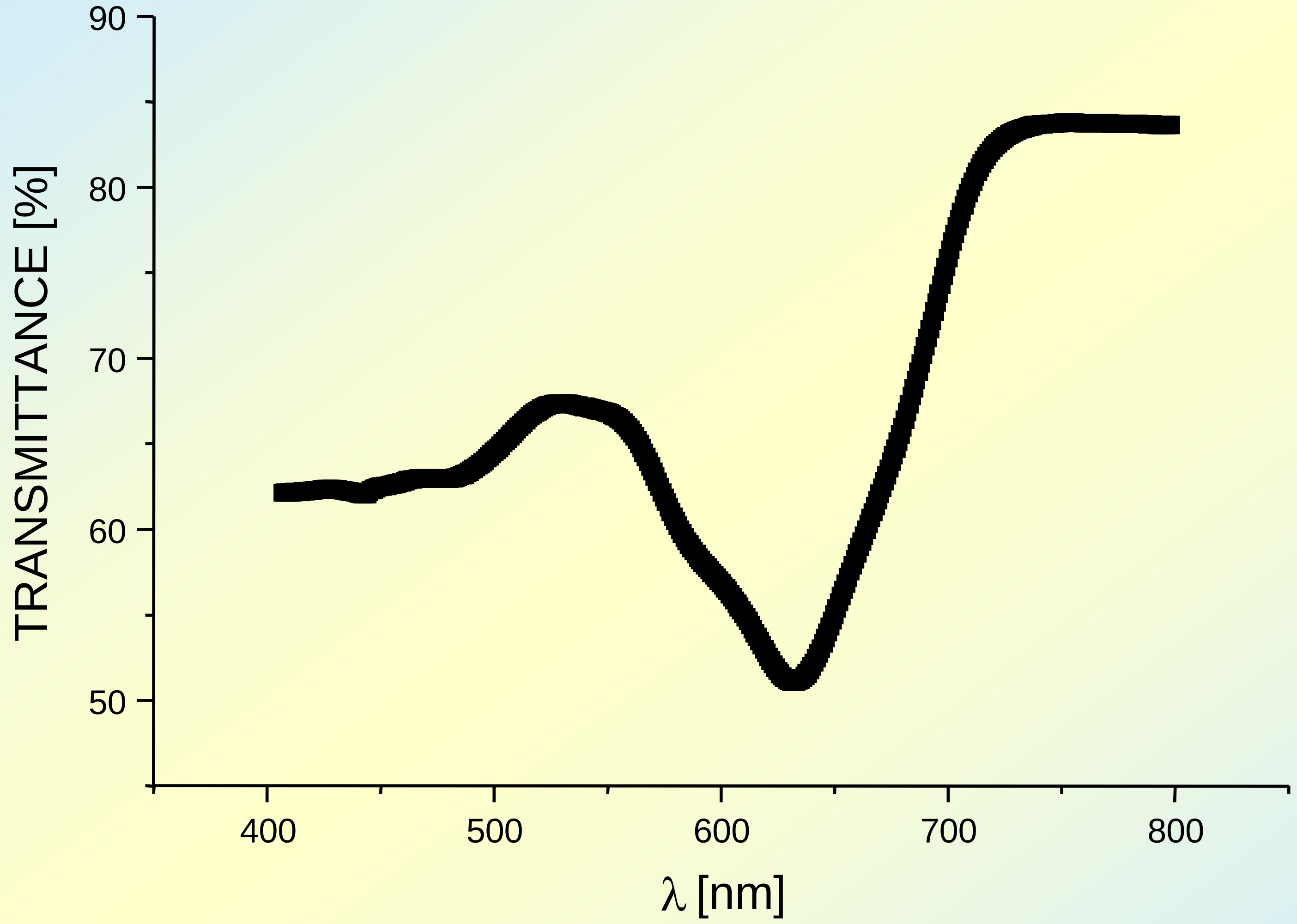
$$F_T = \frac{1}{2}K_1(\nabla.\hat{n}) + \frac{1}{2}K_2(\hat{n}.\nabla\times\hat{n})^2 + \frac{1}{2}K_3(\hat{n}\times\nabla\times\hat{n})^2$$

I	II	III	IV
Pure E7	**1 % DB14 in E7**	**1 % C60 in E7**	**0.5 % DB14 + 0.5 % C60 in E7**

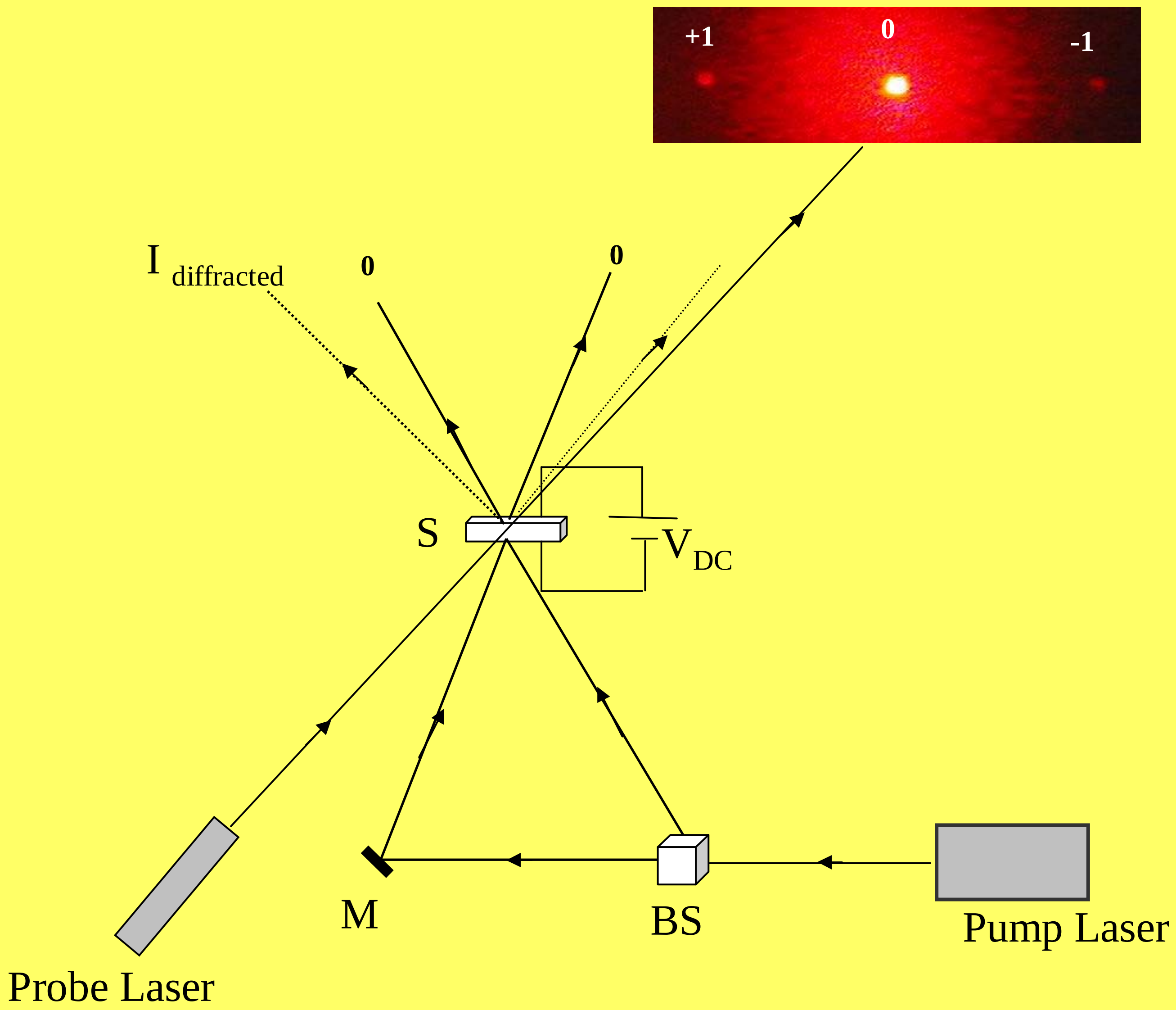


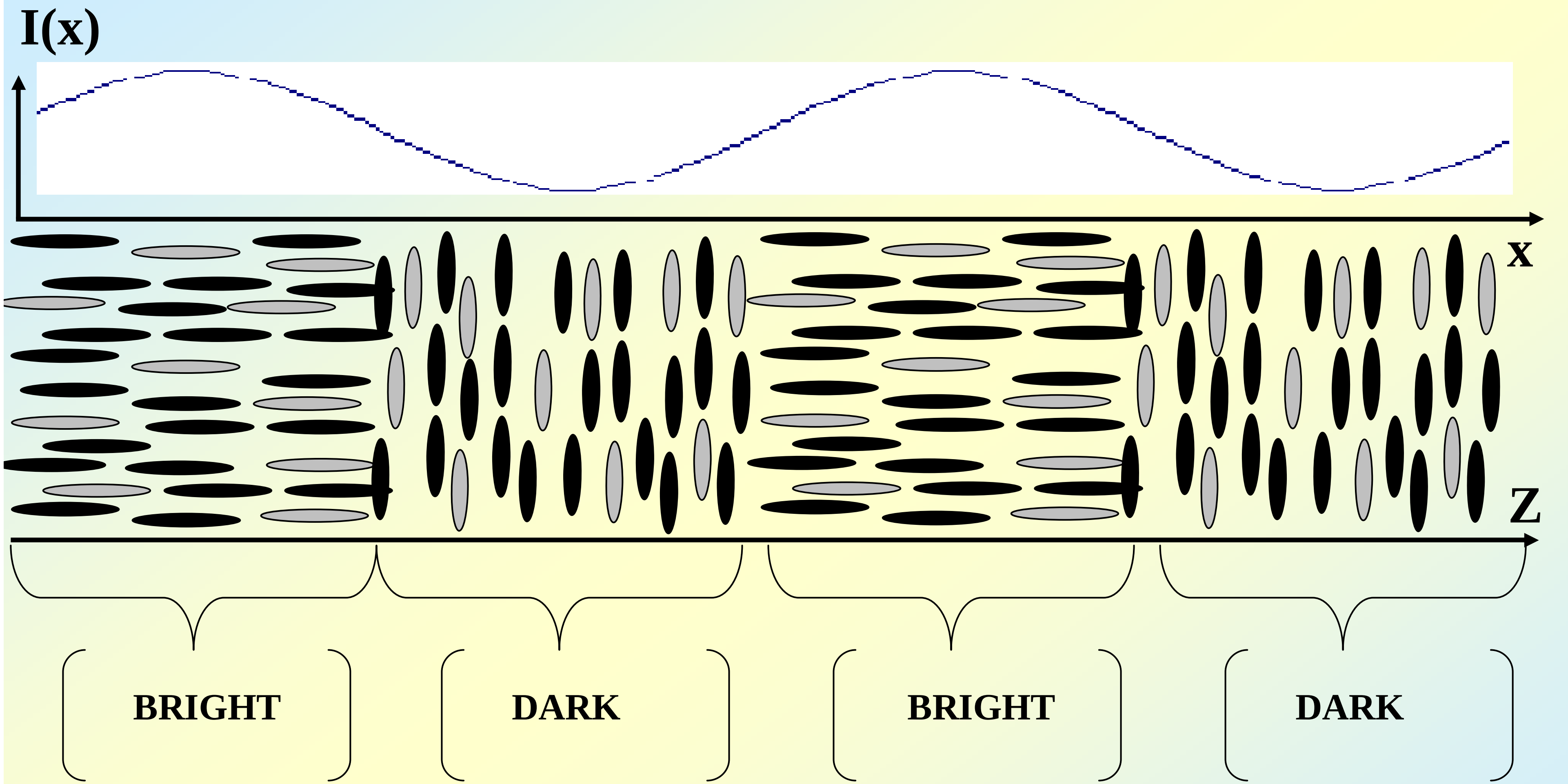


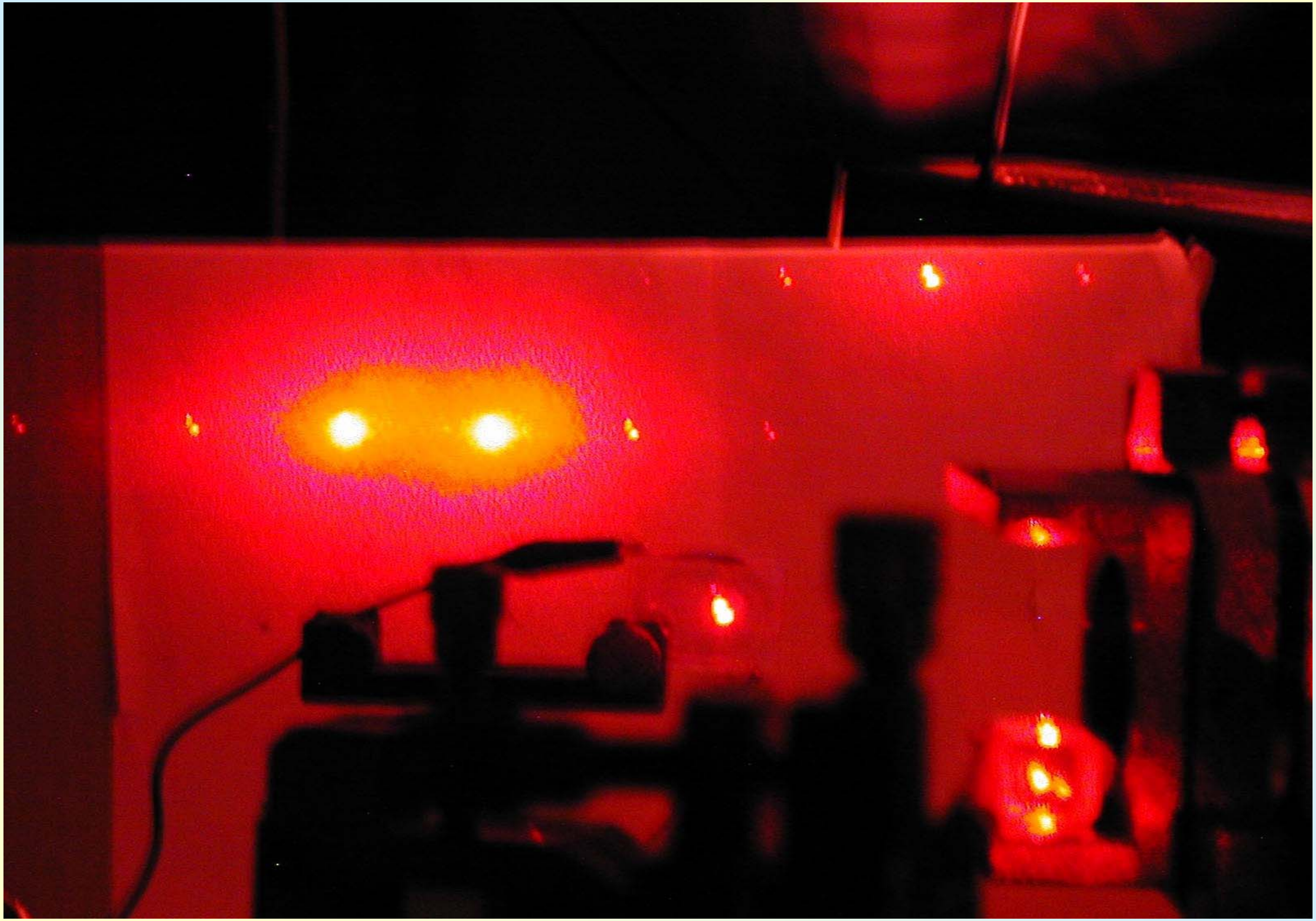


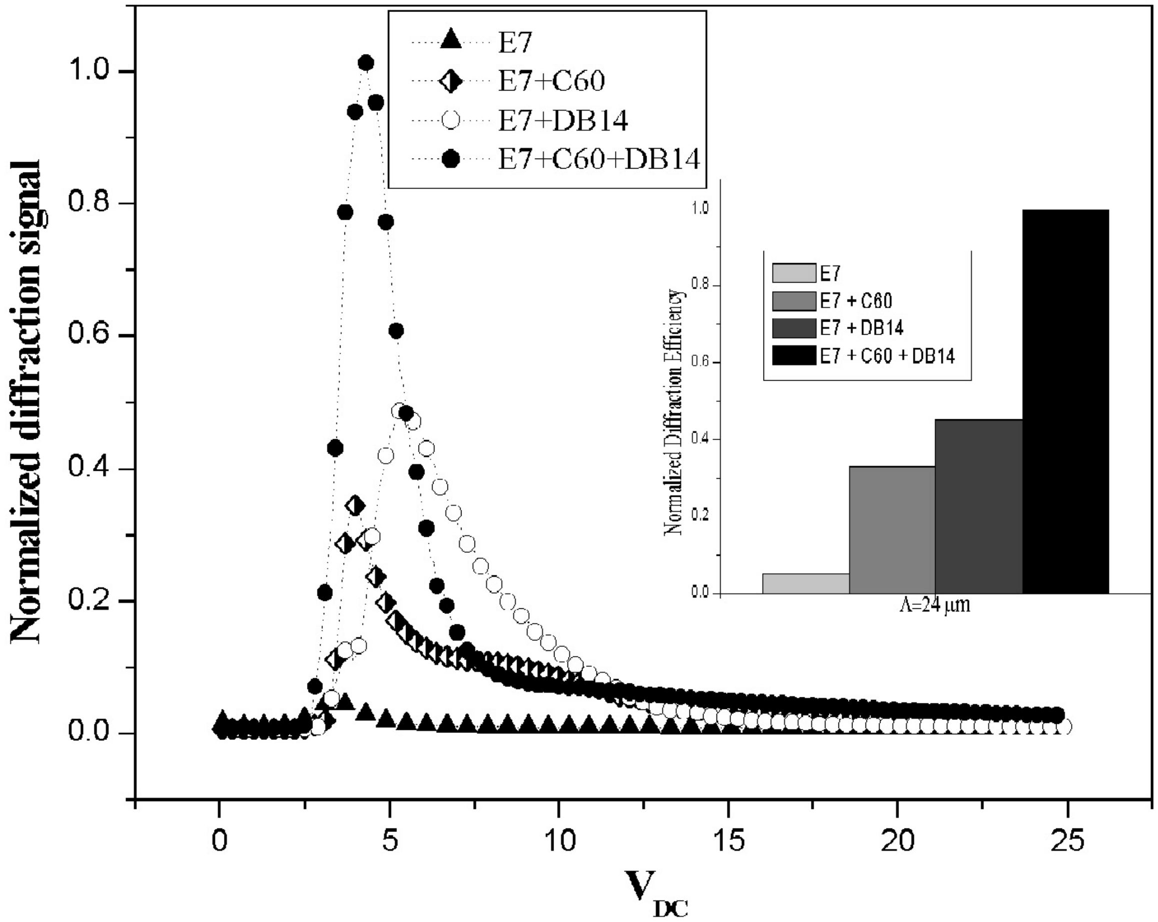


90
80
70
60
50
TRANSMITTANCE [%]
400
500
600
700
800
λ [nm]

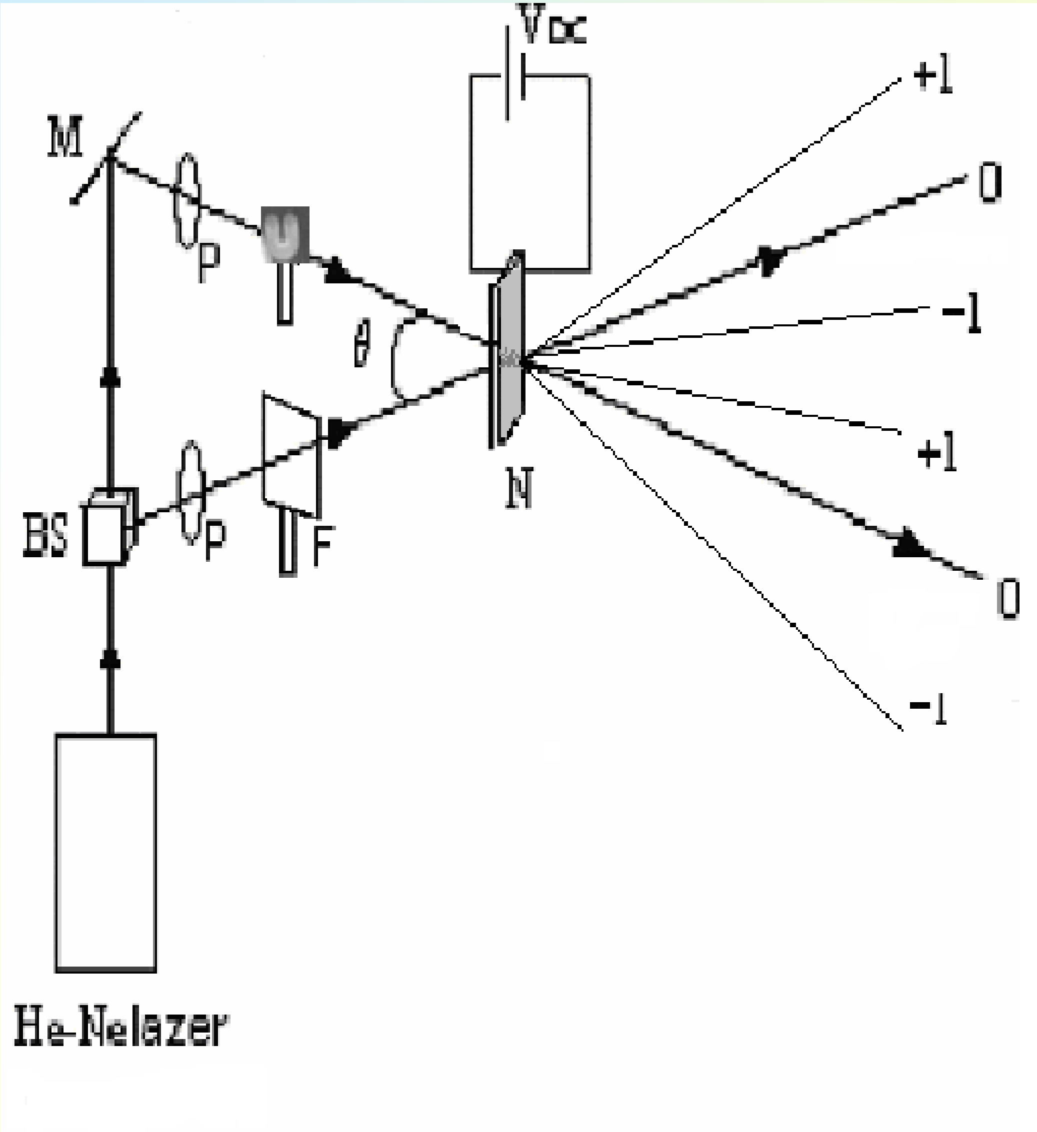

+1
0
-1
I diffracted
0
0
S
V DC
M
BS
Pump Laser
Probe Laser


I(x)
x
Z
BRIGHT
DARK
BRIGHT
DARK





S. Eren San et.al. Synthetic Metals 142 (2004) 283-286


V DC
+1
M
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θ
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BS
P
F
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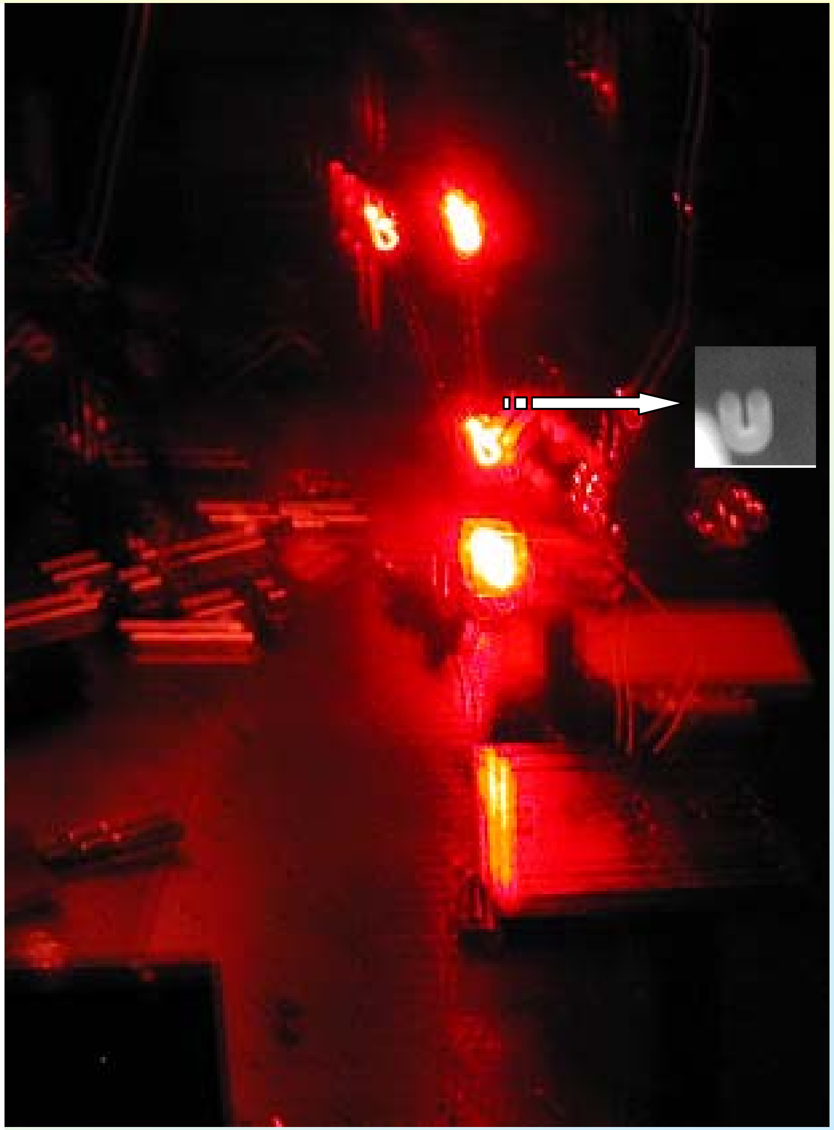
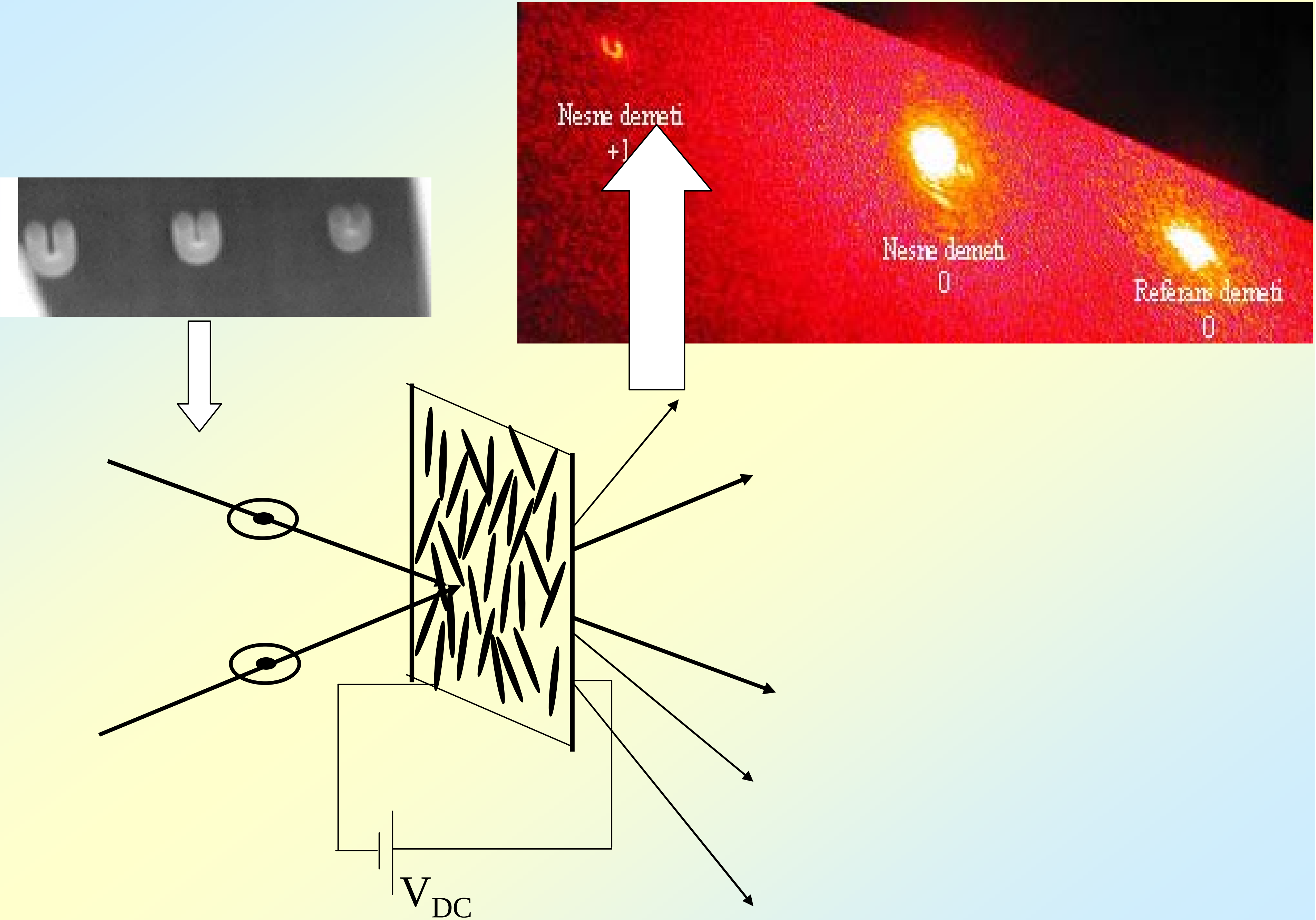
0
-1
He-Nelazer




Nesne demeti
+1
Nesne demeti
0
Referans demeti
0
V DC

Laser induced dielectric spectroscopy of a hybrid liquid crystal composite made up of methyl red and fullerene C60

Motivation

- Light-molecule & voltage-molecule interaction mechanisms (A tool for understanding the molecule scale events in such systems
- Optimization basis for new designs

  (Opto-electronic applications: displays, optical switches, holographic mediums, phase retarders, filters etc.)

Outline

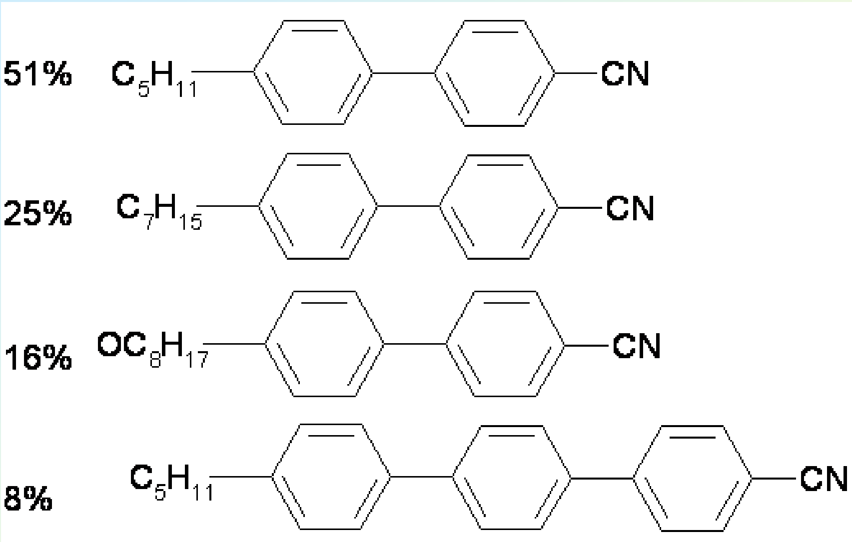
- Liquid Crystals
- Doping
- Dyes (Methyl Red)
- Fullerene
- Application

- Material
- Experimental
- Results

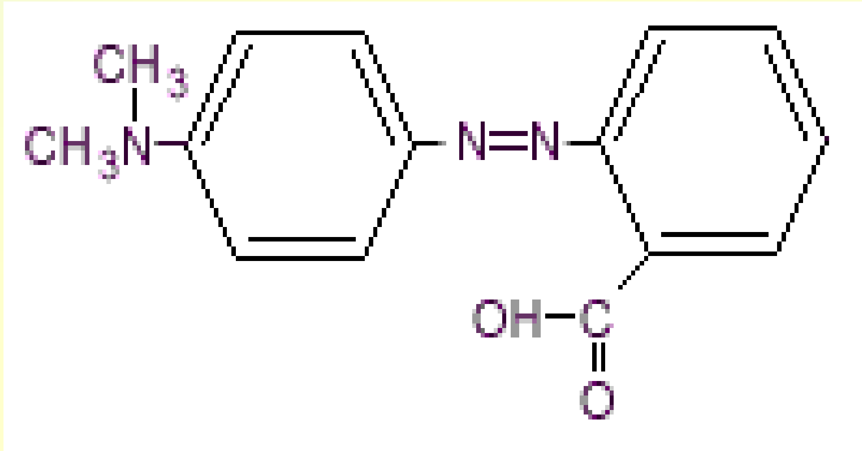
Dielectric Spectroscopy

HP4194A IMPEDANCE GAIN PHASE ANALYZER

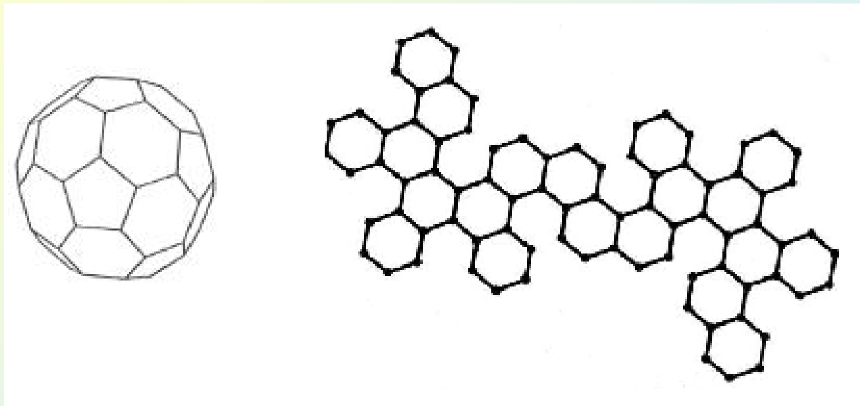
E7



MR



C60



I (MR)	II (MR+C60)
1 % MR in E7	0.5 % MR + 0.5 % C60 in E7

Diffraction efficiency

Fig3

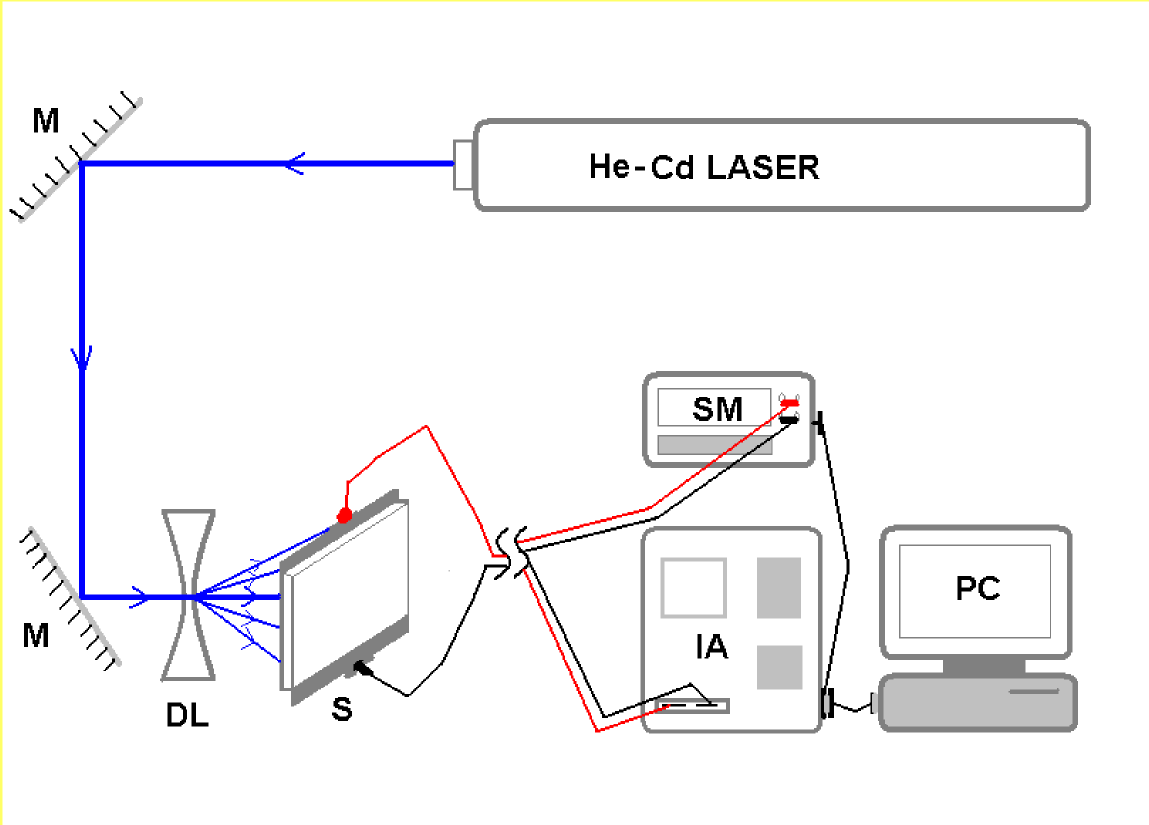
S. Eren San, Oğuz Köysal, ***Displays, Volume 24 , Pages 209-212***

Experimental set-up

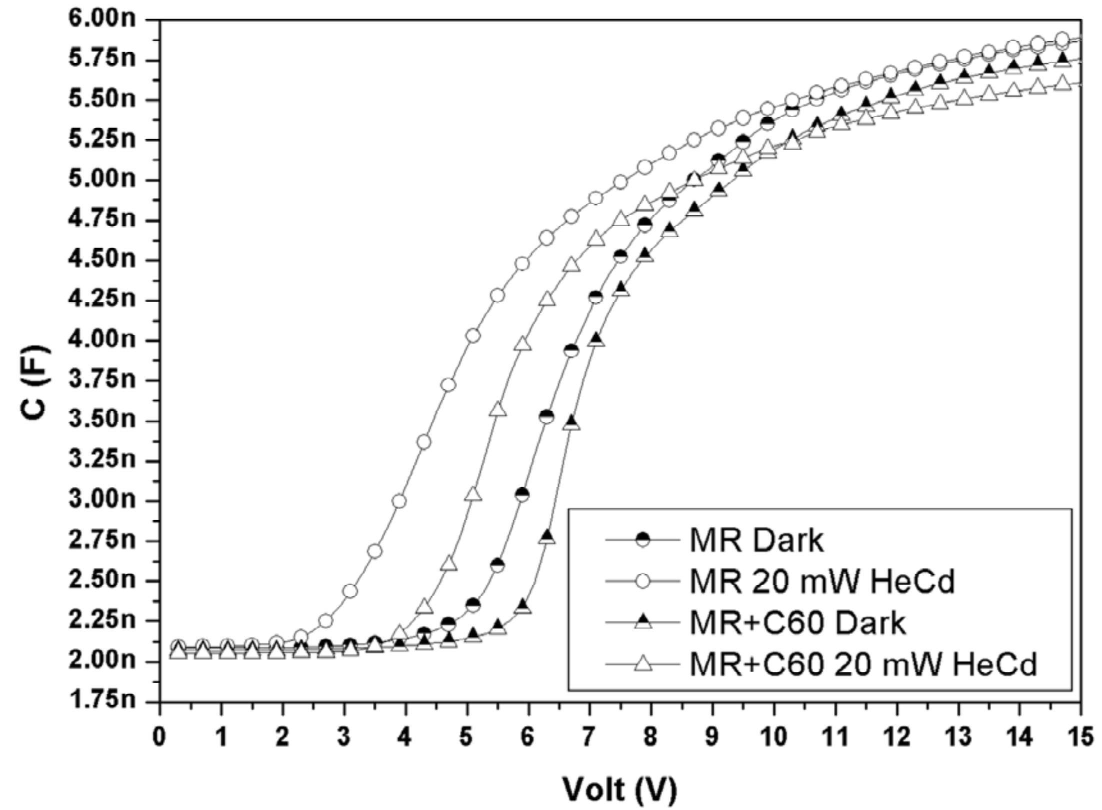
• 10k Hz spot frequency whose rms amplitude is ~ 495 mV

• 20 mW He-Cd λ=441.6 nm

•The time lag between successive measurements was arranged to be at the order of 10 seconds



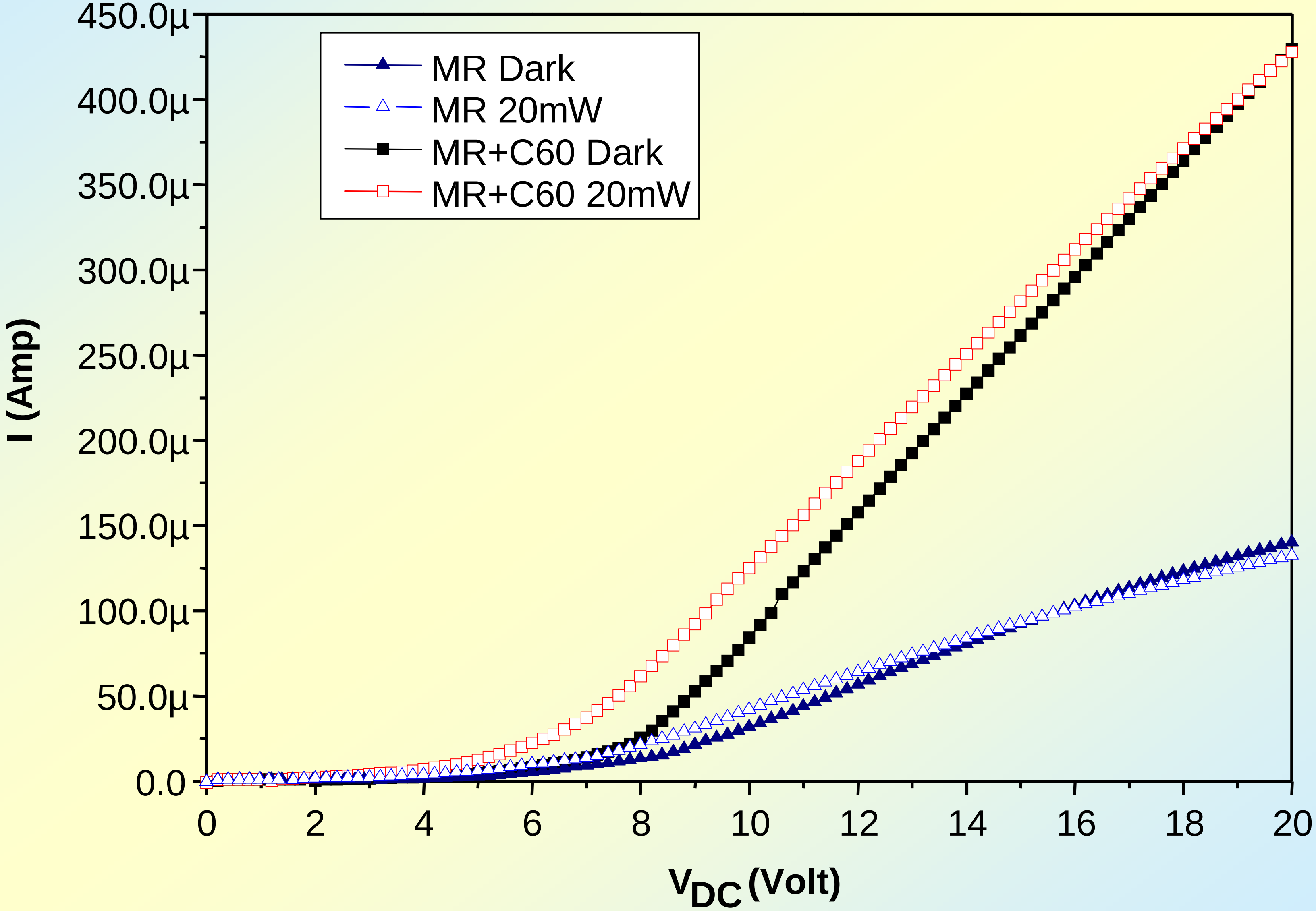
Capacitance measurements



$$C = \varepsilon_0 . \varepsilon . \frac{A}{d}$$

Δε	MR	MR+C60
Dark	12.68	12.44
20 mW HeCd	10.56	9.87

I / V plot of samples under dark and illuminated circumstances.



Results

- C60 doping enlarges the bandwidth of impedance peak while it gets narrower by **laser pumping**
- Switching voltage was shifted to lower values as the **laser pumping** occurs
- The lowest amount of capacitance was acquired by **MR+C60 doped sample** after the saturation threshold
- The **MR+C60 doped sample has superiority over the others** according to the satisfied $\Delta\varepsilon$ value both in dark and in illuminated conditions. Decreasing trend of $\Delta\varepsilon$ value is also explicit **under the laser illuminated case**
- $\Delta\varepsilon$ is inferred from the extreme values (Capacitance graph) (Dielectric constant along the director axis is larger than that of it along the axes perpendicular to the director) $\Delta\varepsilon>0$ So our system to be determined as **p-type**
- **Laser illumination** increases the **photoconductivity** in both of the samples as it also shifts the switching voltages of reorientation to lower voltage values.

Dielectric spectroscopy of a hybrid composite; constituted by doping a side-chain liquid crystalline polymer; in laser induced circumstances

Material

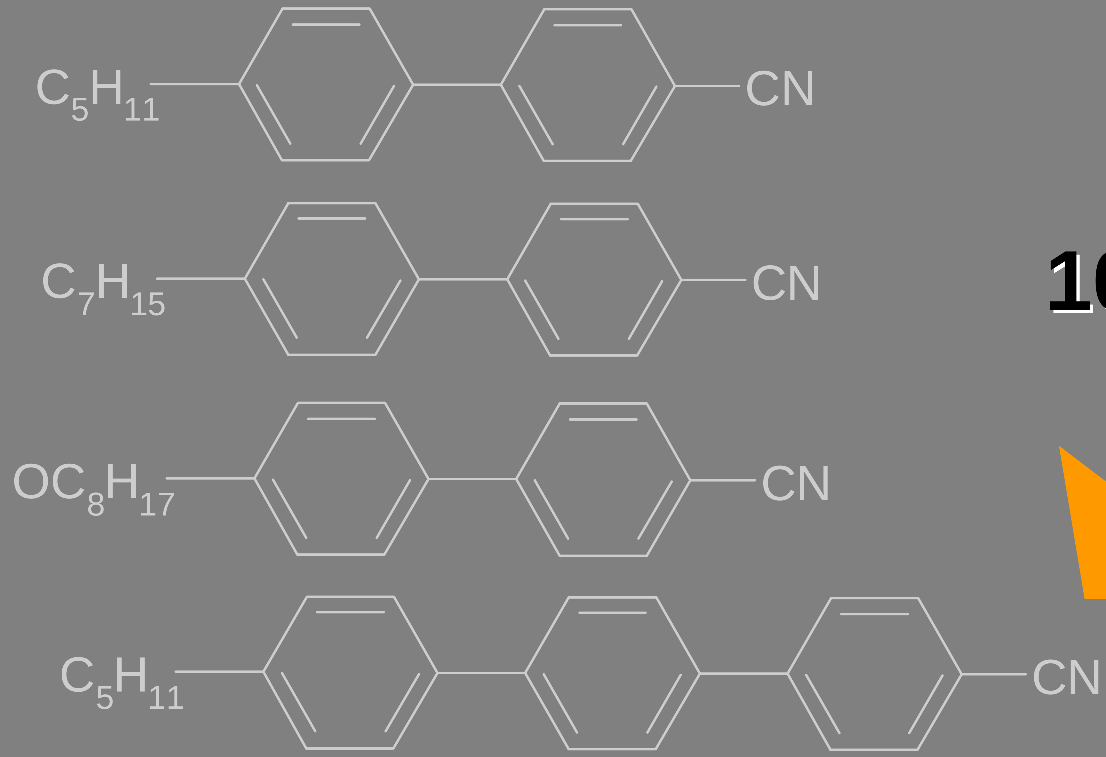
E7

51%

25%

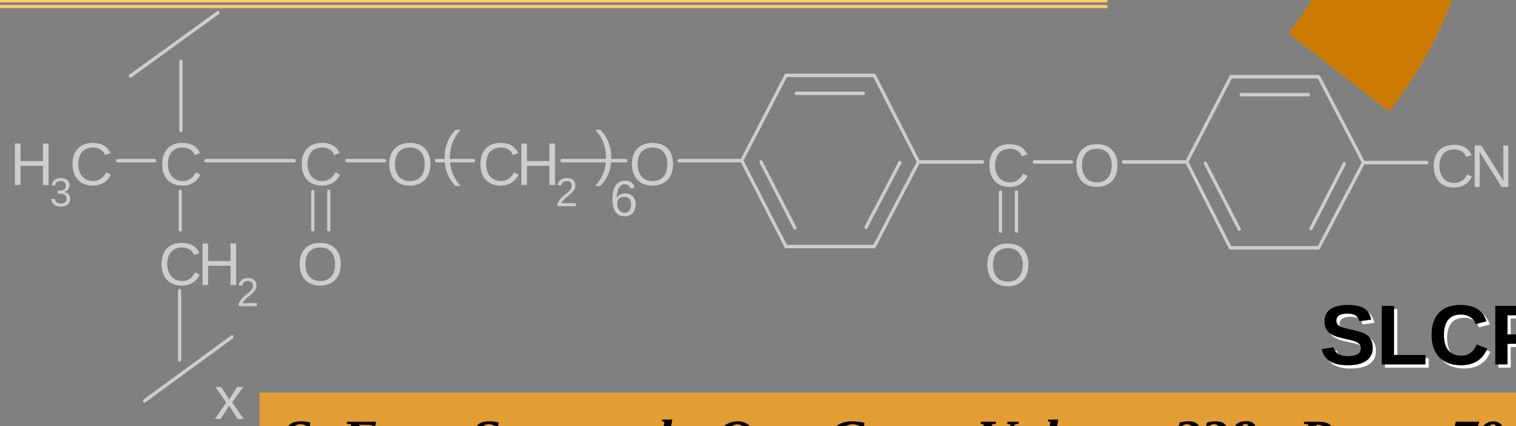
16%

8%



10 % SLCP in E7

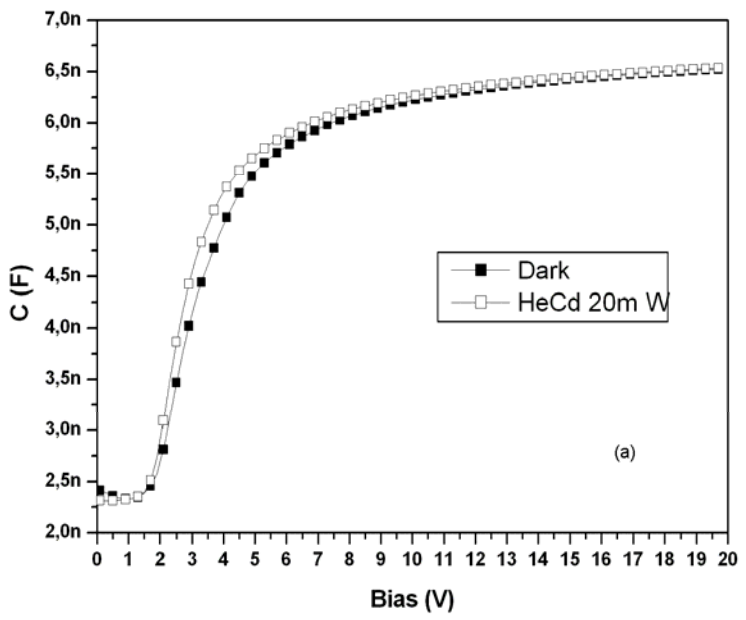
wt/wt



SLCP

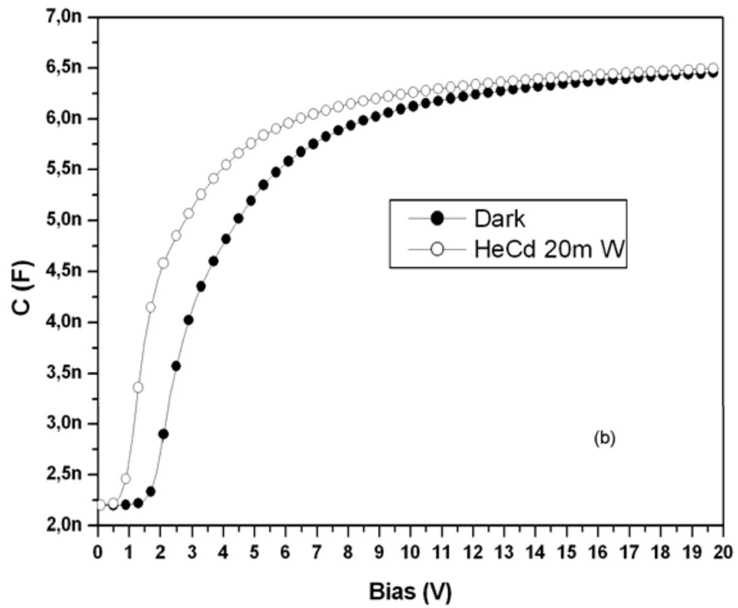
S. Eren San et al. Opt. Com., Volume 238 , Pages 79-84

Dependency of capacitance on DC voltage

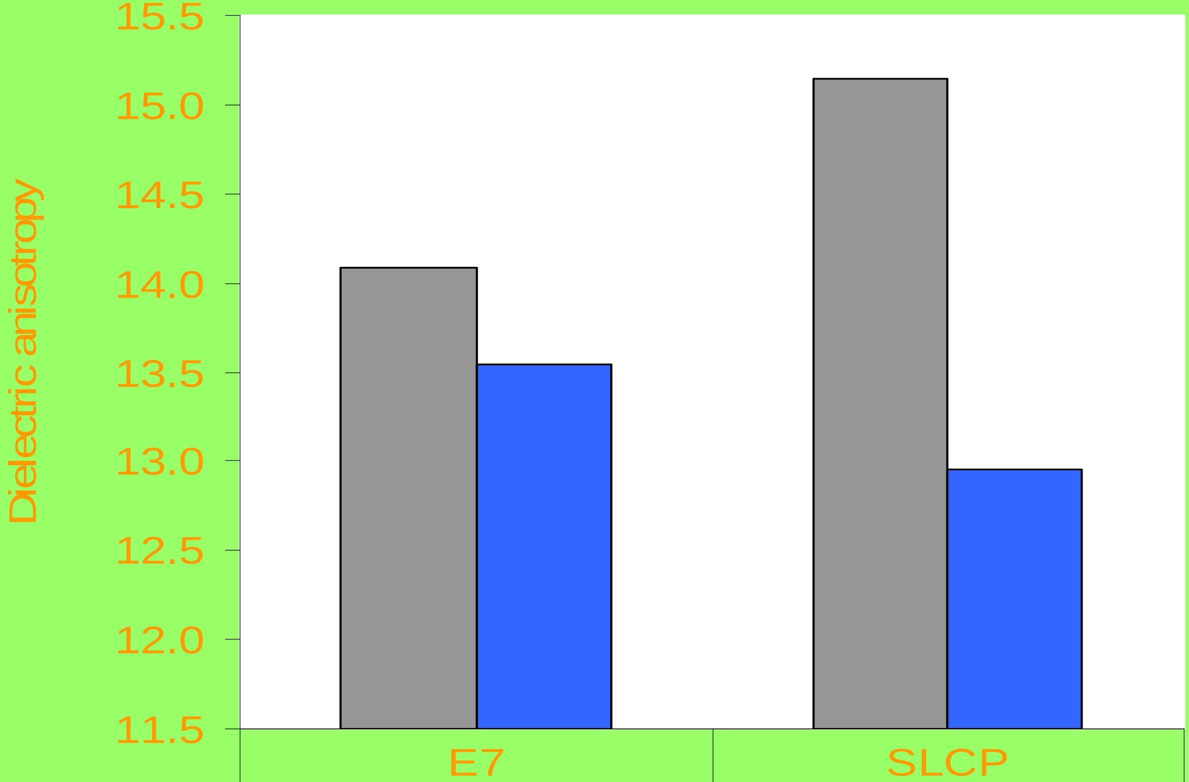


E7

SLCP

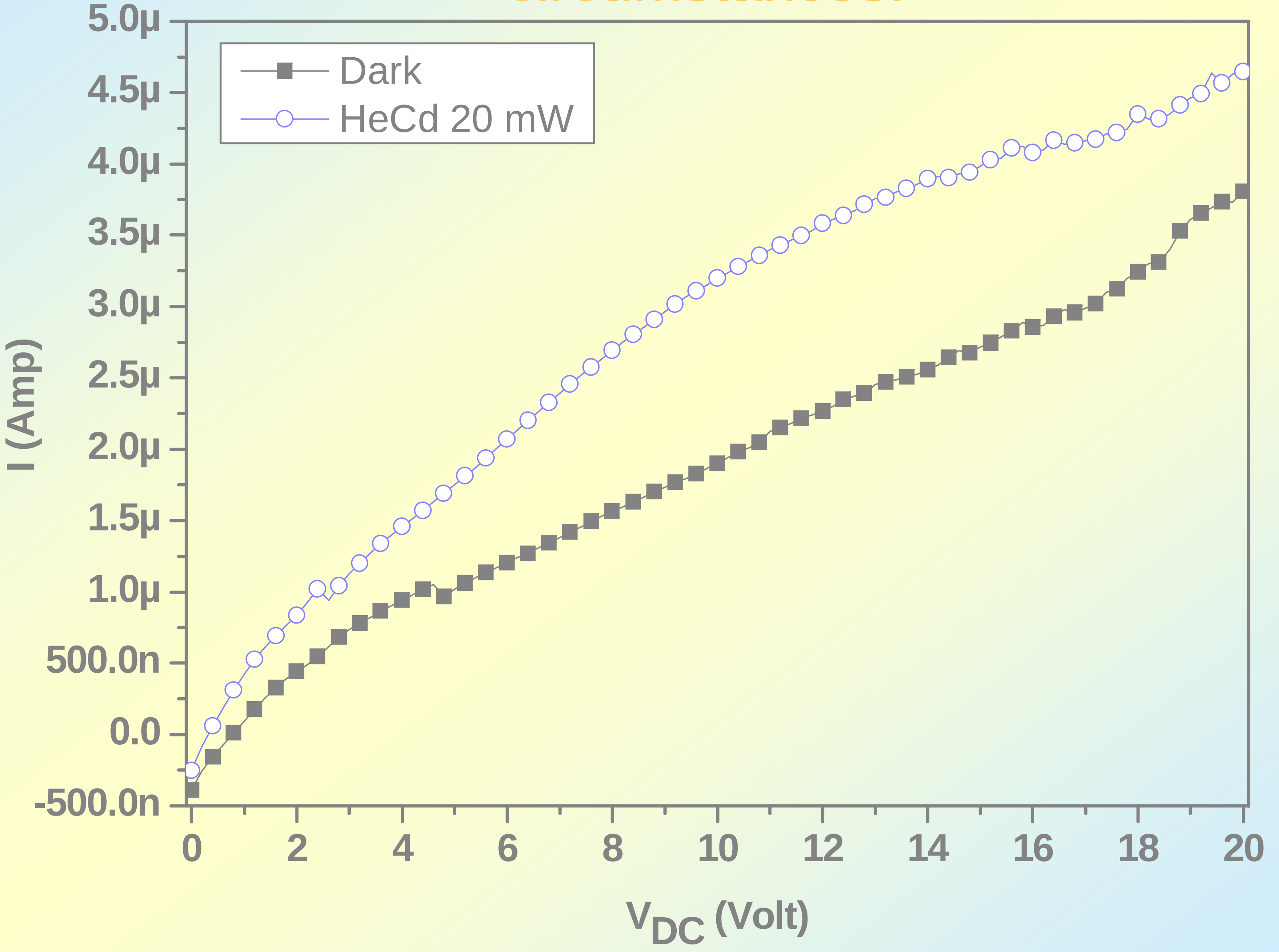


$$C = \varepsilon_0 . \varepsilon . \frac{A}{d}$$



	E7	SLCP
Dark	14.08	15.15
20m W HeCd	13.54	12.95

I / V plot of SLCP under dark and illuminated circumstances.



Results

- **Laser pumping** causes a considerable decrease on the required amount of voltage for saturation in **SLCP**
- $\Delta\varepsilon$ value of **SLCP** is more and its response to **laser illumination** is larger than **pure E7**; the minimum dielectric anisotropy case holds for the **illuminated SLCP** sample
- **Laser pumping** has a noteworthy effect on the conductivity in **SLCP**

S. Eren San et.al. Journal of Non-Crystalline Solids 351 (2764-2767

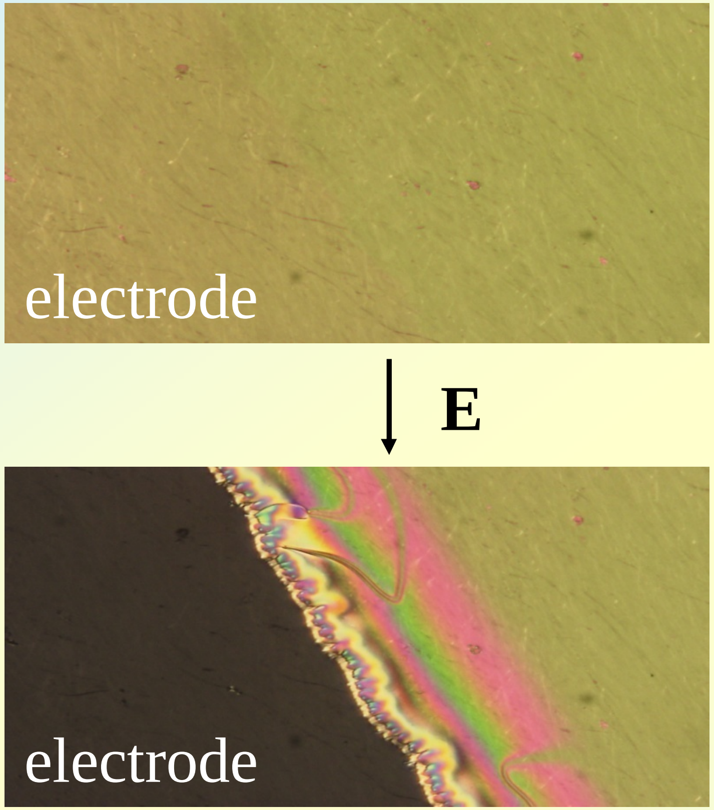
Liquid crystal – nanotube dispersions

Contents

- Combining two modern materials
- Reorienting nanotubes
- Possible applications

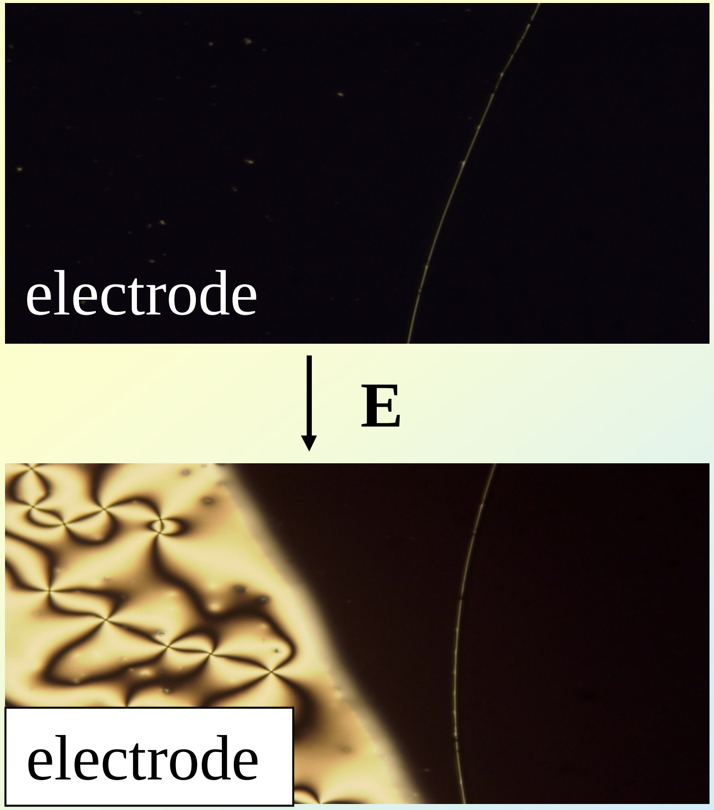
The liquid crystal director n (optical axis) can be reoriented by application of external fields: electric, magnetic, mechanical, optic …

E7 ($\Delta\varepsilon > 0$)



planar → homeotropic

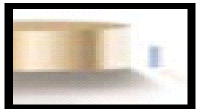
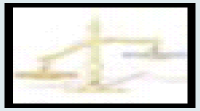
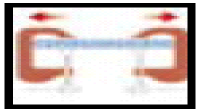
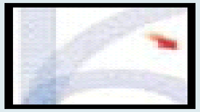
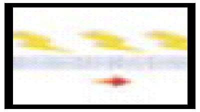
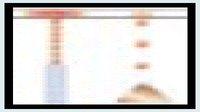
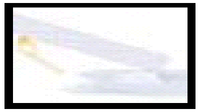
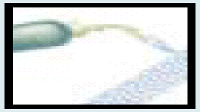
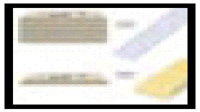
ZLI-2806 ($\Delta\varepsilon < 0$)



homeotropic → planar

Properties of Carbon Nanotubes

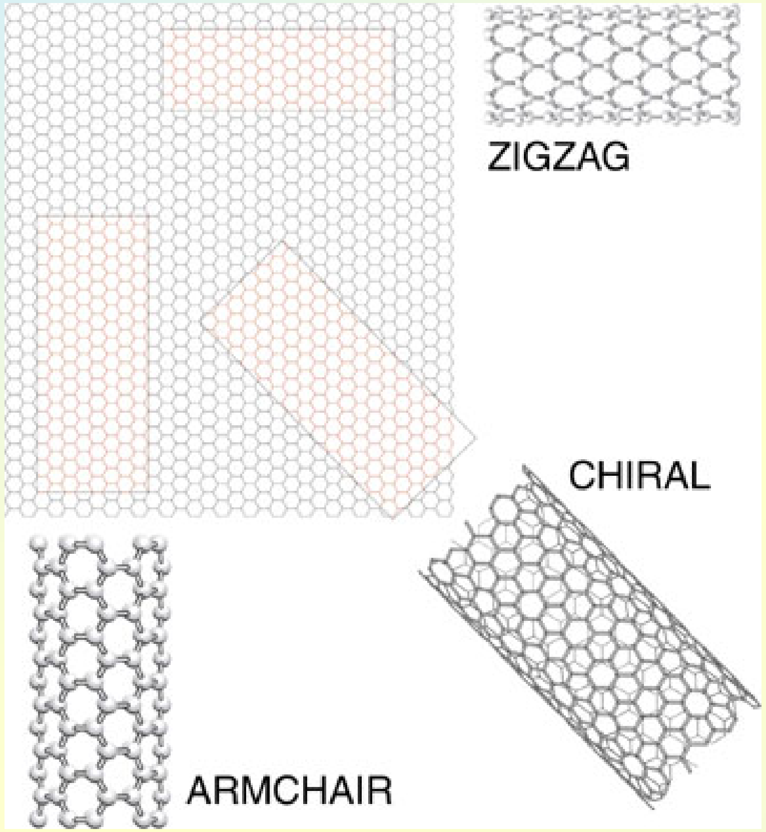
Going to Extremes

	PROPERTY	SINGLE-WALLED NANOTUBES	BY COMPARISON
	Size	0.6 to 1.8 nanometer in diameter	Electron beam lithography can create lines 50 nm wide, a few nm thick
	Density	1.33 to 1.40 grams per cubic centimeter	Aluminum has a density of 2.7 g/cm^3
	Tensile Strength	45 billion pascals	High-strength steel alloys break at about 2 billion Pa
	Resilience	Can be bent at large angles and restraightened without damage	Metals and carbon fibers fracture at grain boundaries
	Current Carrying Capacity	Estimated at 1 billion amps per square centimeter	Copper wires burn out at about 1 million A/cm^2
	Field Emission	Can activate phosphors at 1 to 3 volts if electrodes are spaced 1 micron apart	Molybdenum tips require fields of 50 to 100 V/µm and have very limited lifetimes
	Heat Transmission	Predicted to be as high as 6,000 watts per meter per kelvin at room temperature	Nearly pure diamond transmits 3,320 W/m-K
	Temperature Stability	Stable up to 2,800 degrees Celsius in vacuum, 750 degrees C in air	Metal wires in microchips melt at 600 to 1,000 degrees C
	Cost	$1,500 per gram from BuckyUSA in Houston	Gold was selling for about $10/g in October

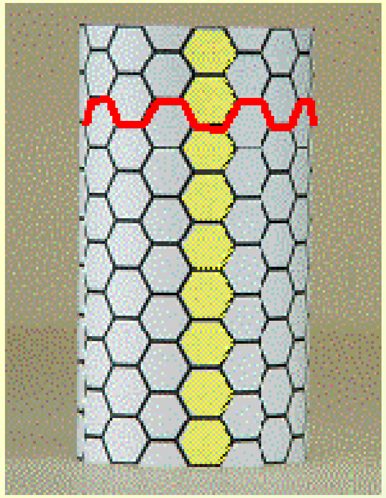
LAURE GRACE

There are two basic forms: **single-wall nanotubes** (SWNT):

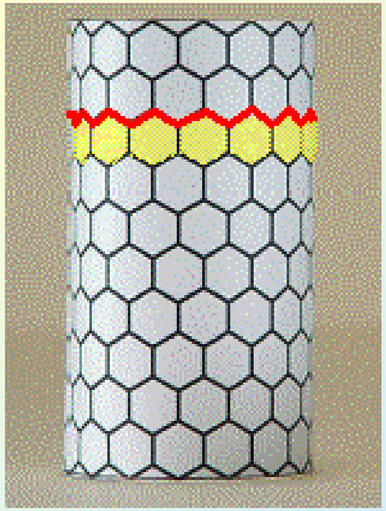
Basically: rolled up sheets of atomic carbon



http://www.seas.upenn.edu/mse/images/



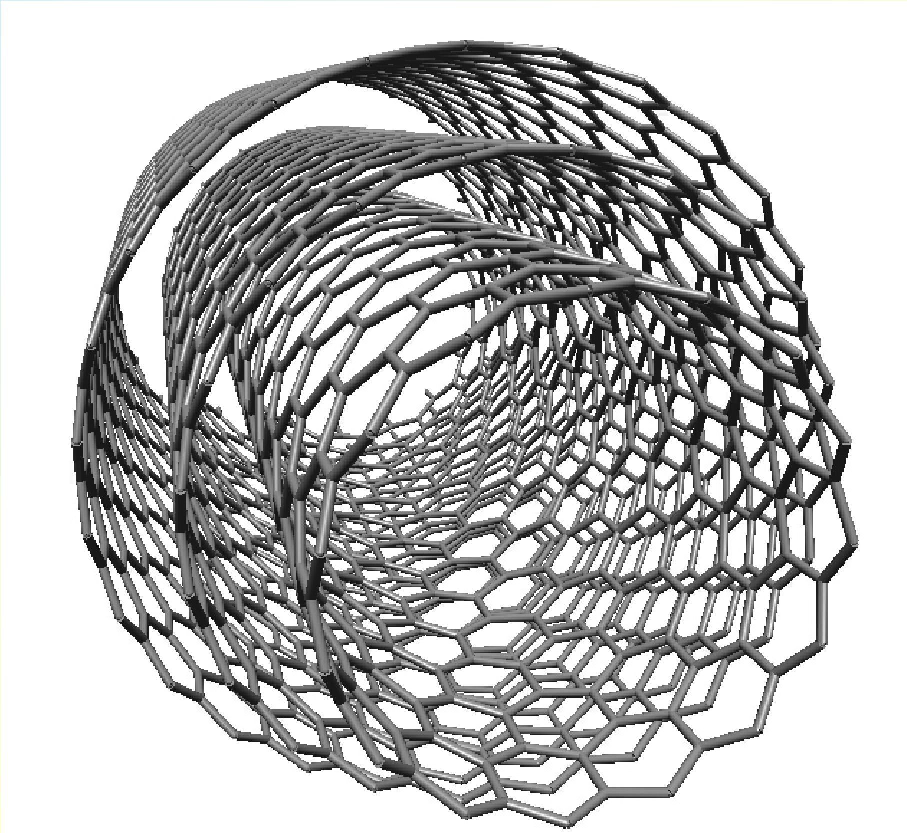
armchair



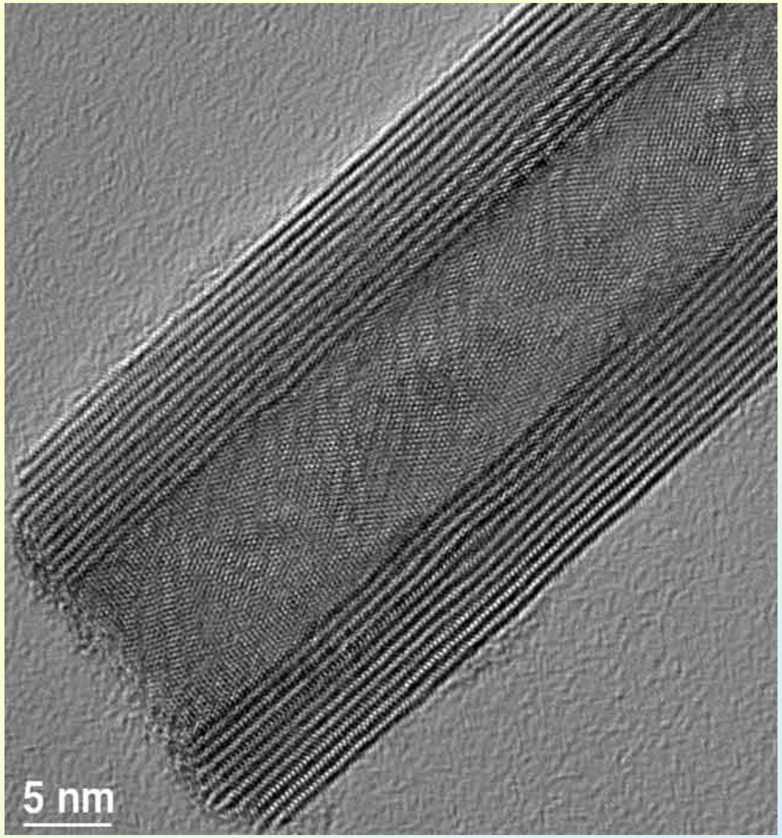
zigzag

http://www.arc.eee.tut.ac.jp/research/nanotube/paperfold/pic/

and **multi-wall nanotubes** (MWNT):



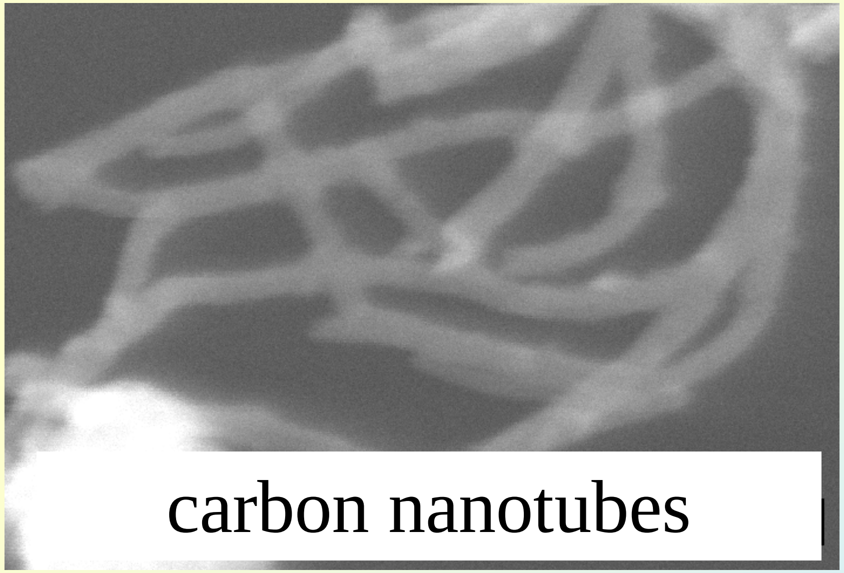
http://www.ahwahneetech.com/technology/images/



http://www.weizmann.ac.il/materials/msg/

Combining two modern materials

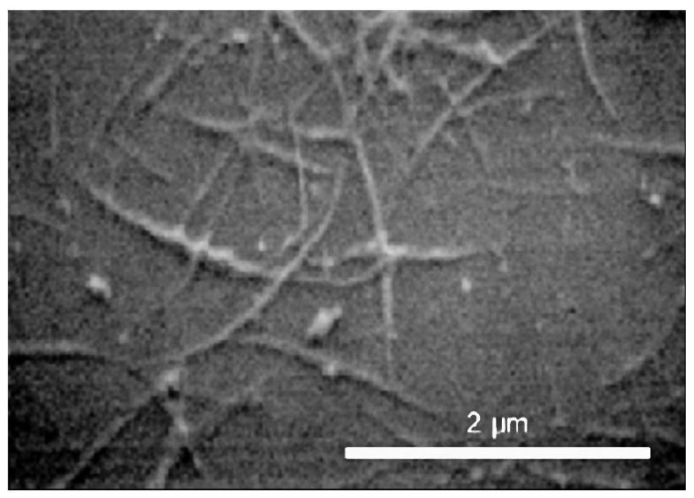
+

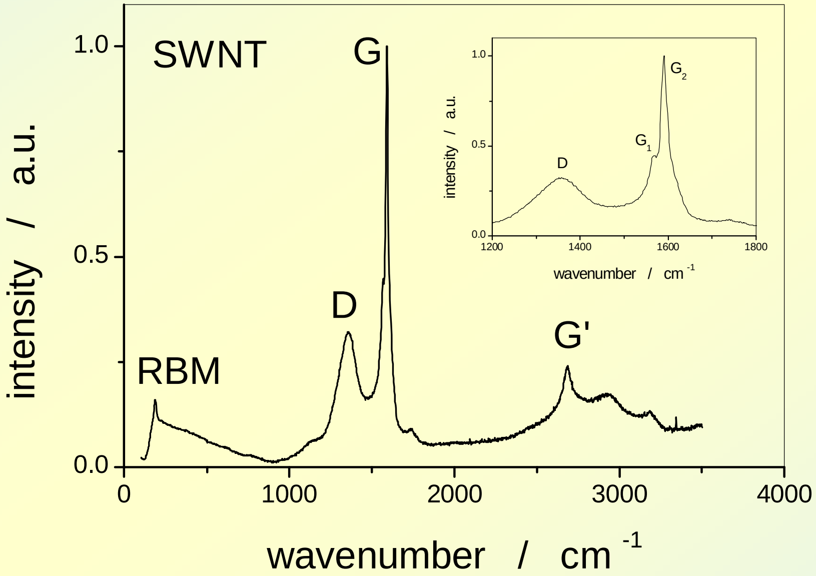


- mixing at low nanotube concentrations (<0.1%)
- use of spectroscopically pure solvents
- ultra-sonification for at least half an hour

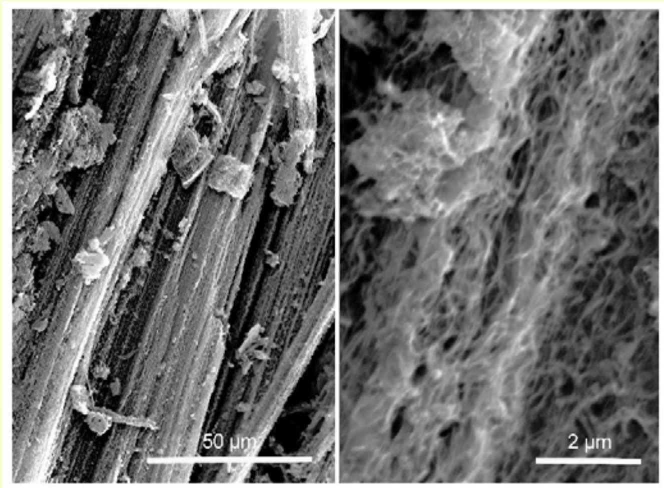
Characterisation of nanotubes

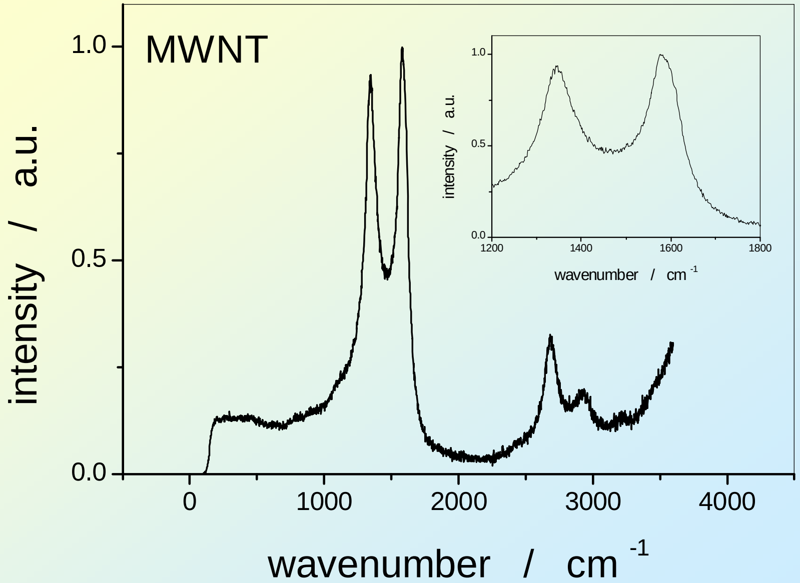
Single wall nanotubes





Multi-wall nanotubes

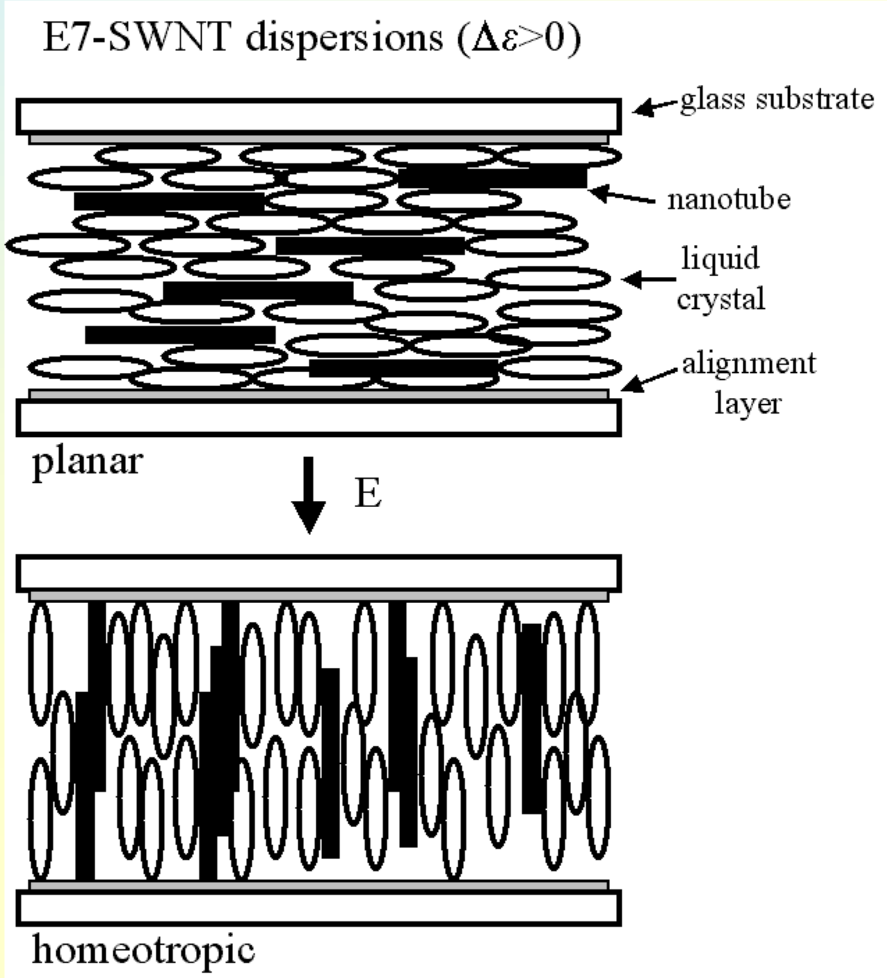


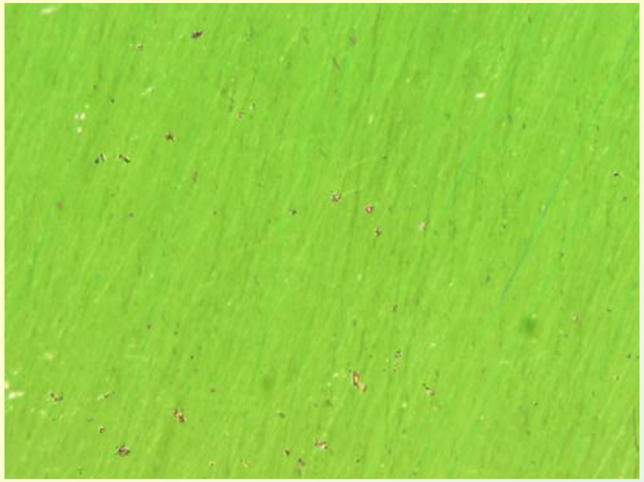


Re-orienting nanotubes

Liquid crystal - single-wall nanotube dispersions:

LC: nematic E7 positive dielectric anisotropy $\Delta\varepsilon>0$



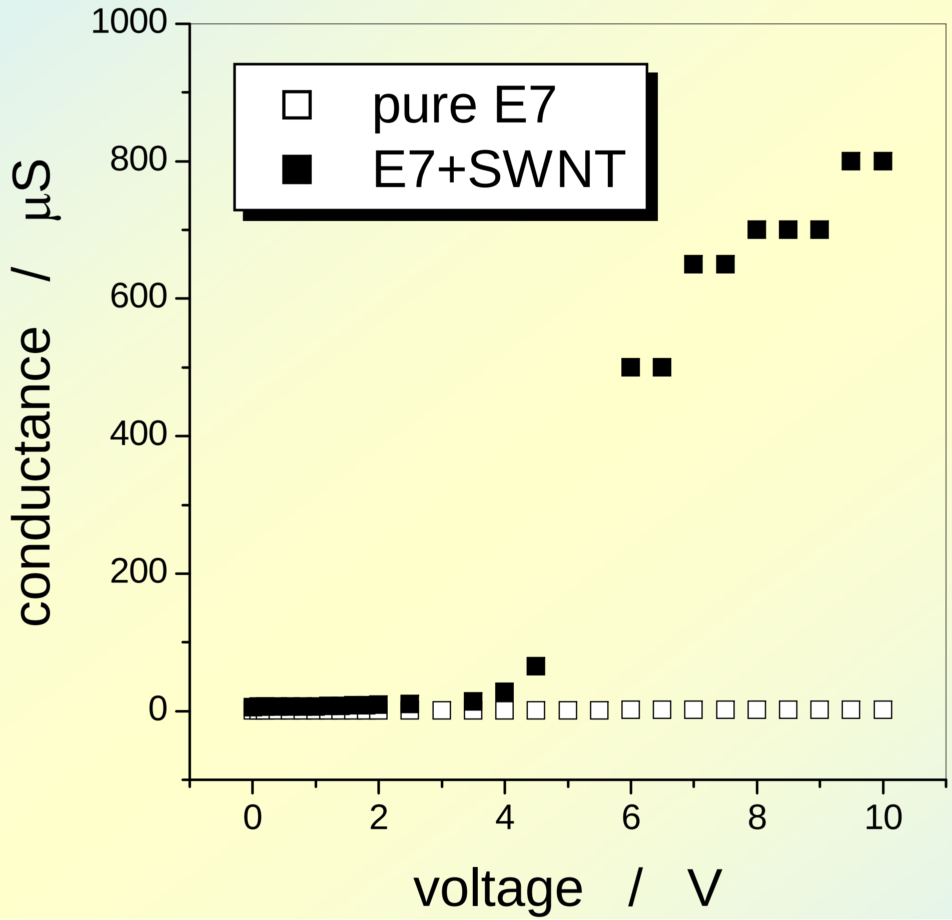


electrically steered

• The liquid crystal re-orientation is easily verified by polarising microscopy. Also capacitance measurements are employed for double check.

• But how can we verify that also the nanotubes are re-oriented?

→ conductance measurements

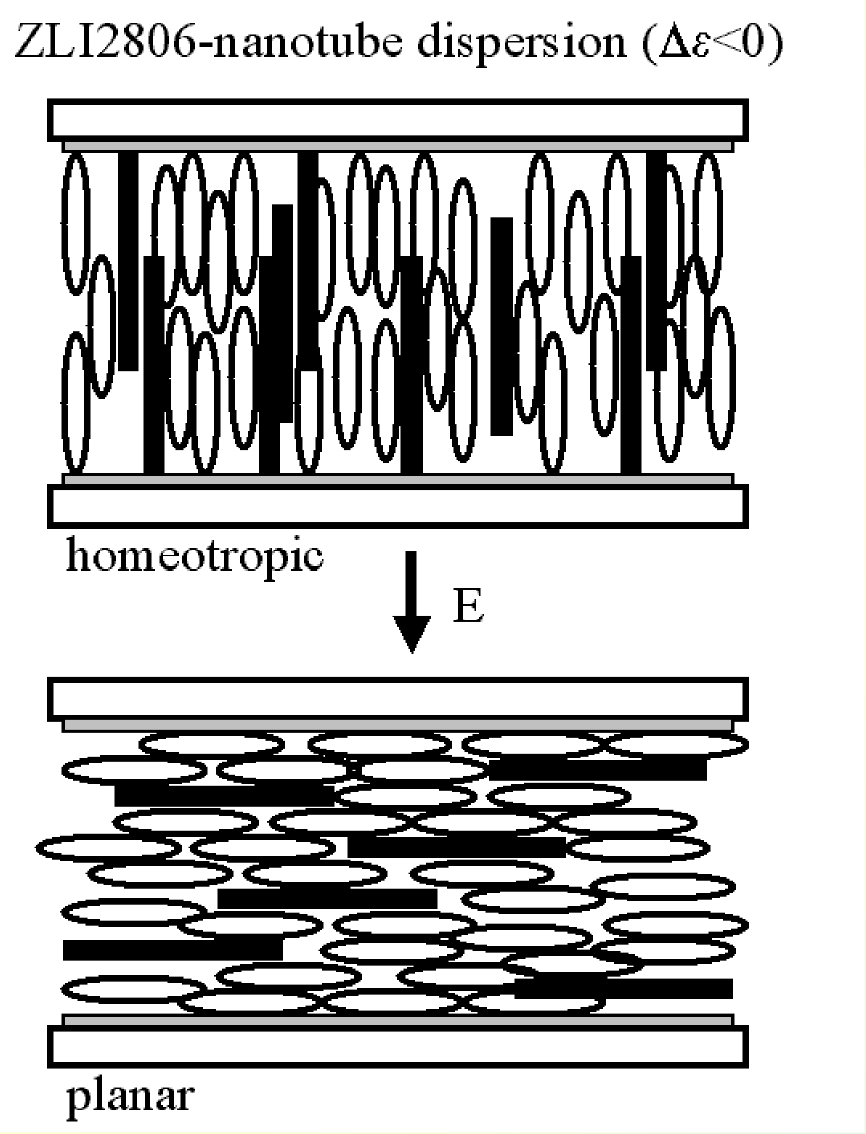


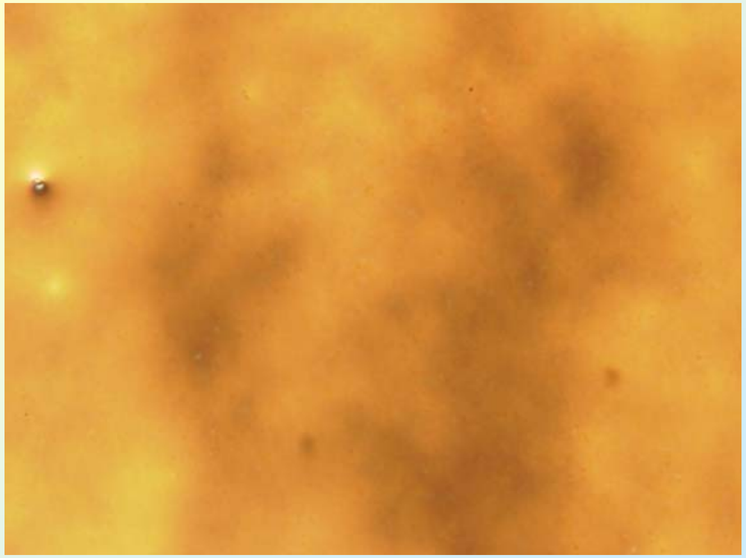
• The conductance of the LC-nanotube dispersion increases drastically, as the threshold voltage for the liquid crystal Freedericksz transition (planar to homeotropic) is exceeded.

→ Nanotubes re-orient from the non-conductive in-plane orientation to the conductive out-of-plane orientation.

The counter-experiment: ***electrically steered***

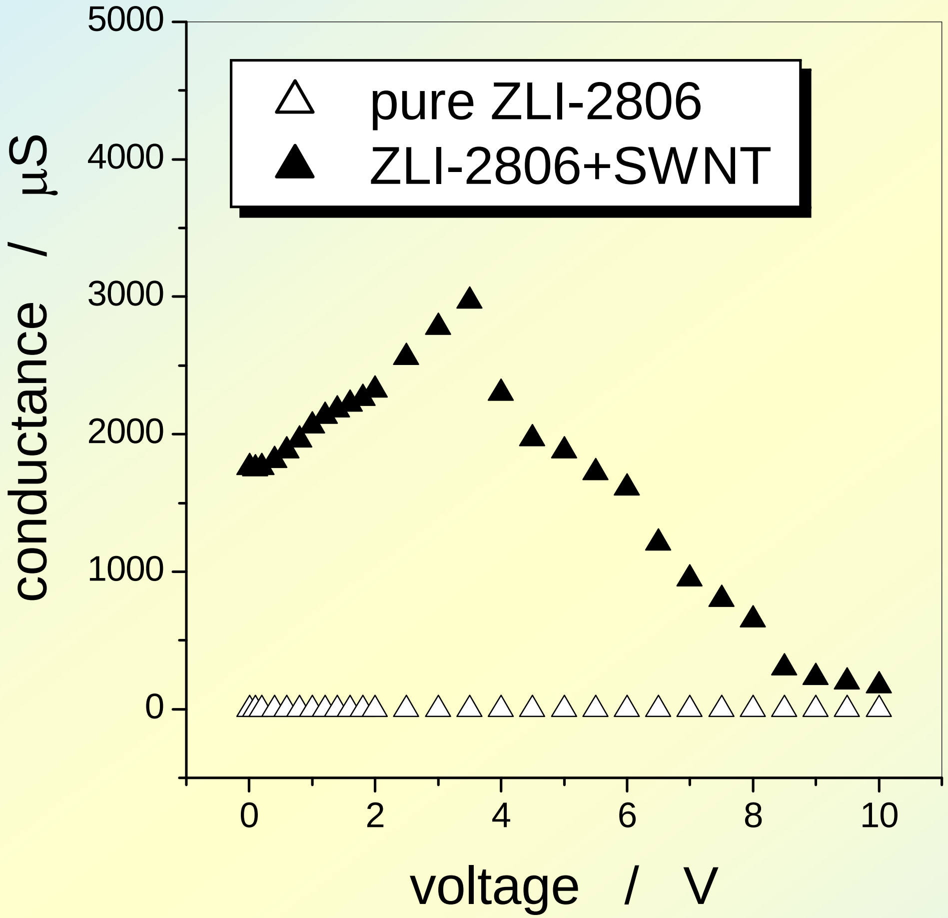
LC: nematic ZLI-2806 negative dielectric anisotropy, $\Delta\varepsilon<0$





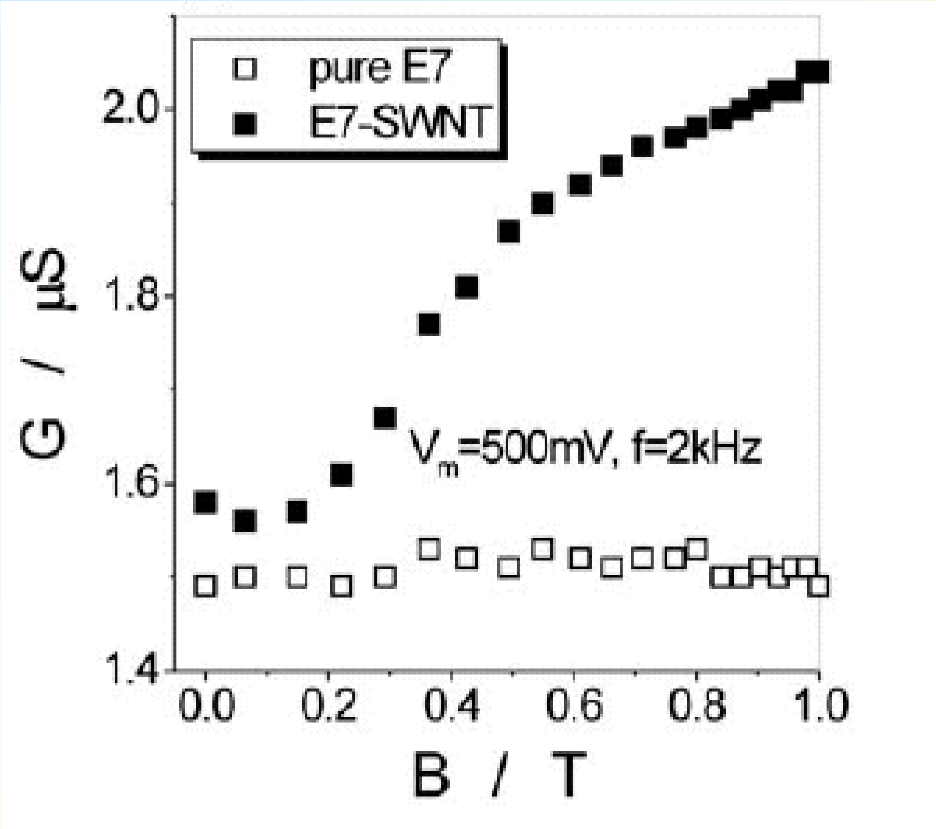
electrically steered

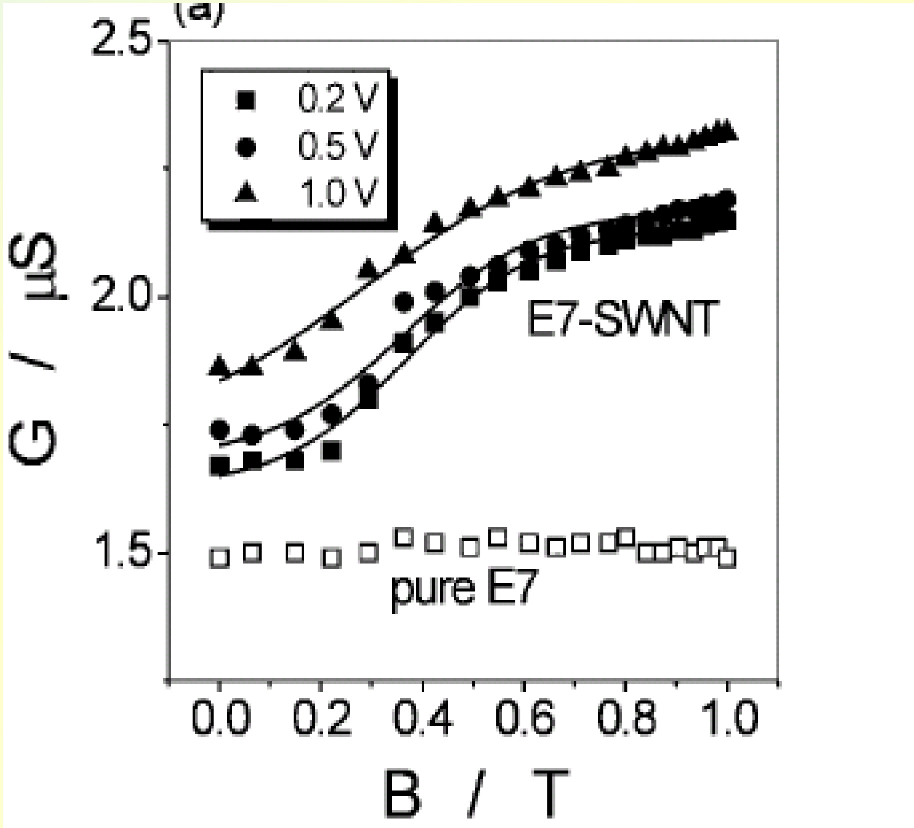
Conductance measurements:



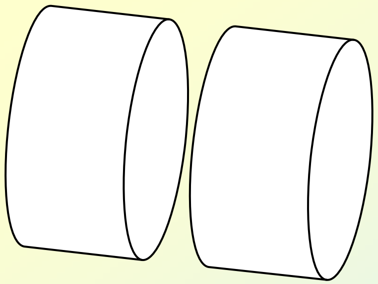
• The conductance of the LC – nanotube dispersion strongly decreases, as the threshold voltage for the liquid crystal homeotropic to planar transition is exceeded.

→ Nanotubes re-orient from the conducting to the non-conducting orientation.



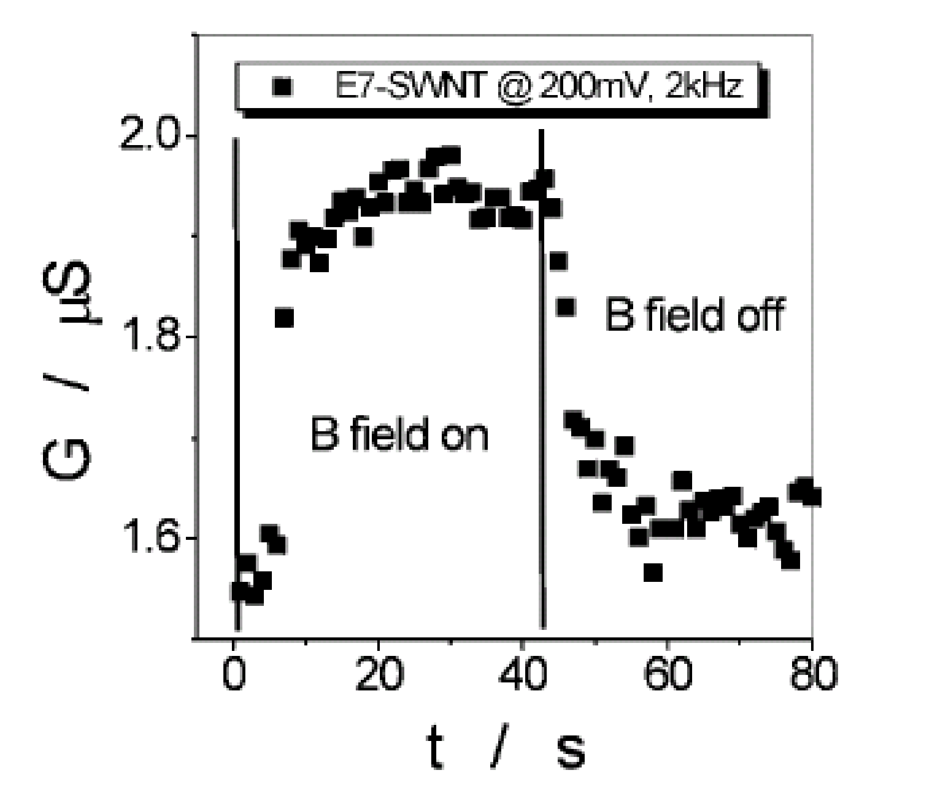


1 Tesla

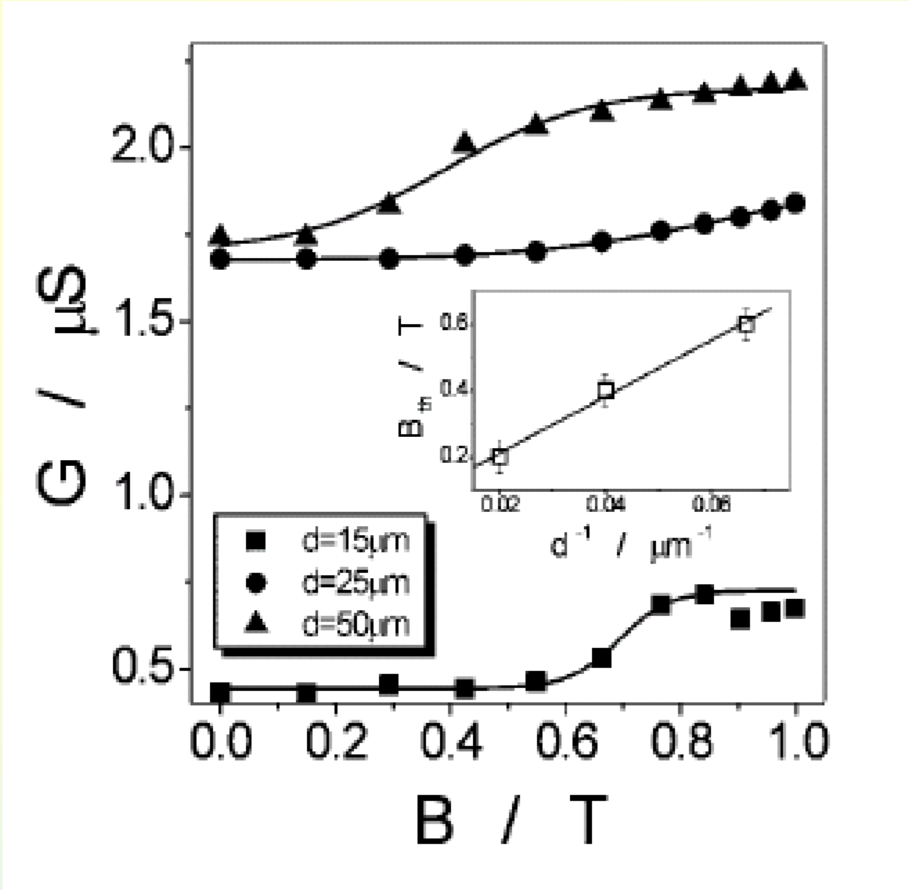


magnetically steered

I. Dierking, S. Eren San et.al. Appl. Phys. Lett. 87, 233507



magnetically steered



⇨ **The anisotropic liquid crystal environment imposes orientation onto the dispersed nanotubes.**

⇨ **A change of the liquid crystal director field causes an elastic torque on the dispersed nanotubes.**

⇨ **The dispersed nanotubes are re-oriented through *elastic interactions* with their host**

Note that:

The reported conductivity behaviour is NOT observed in the isotropic phase of E7 or ZLI-2806, nor in glycerine!

Possible applications

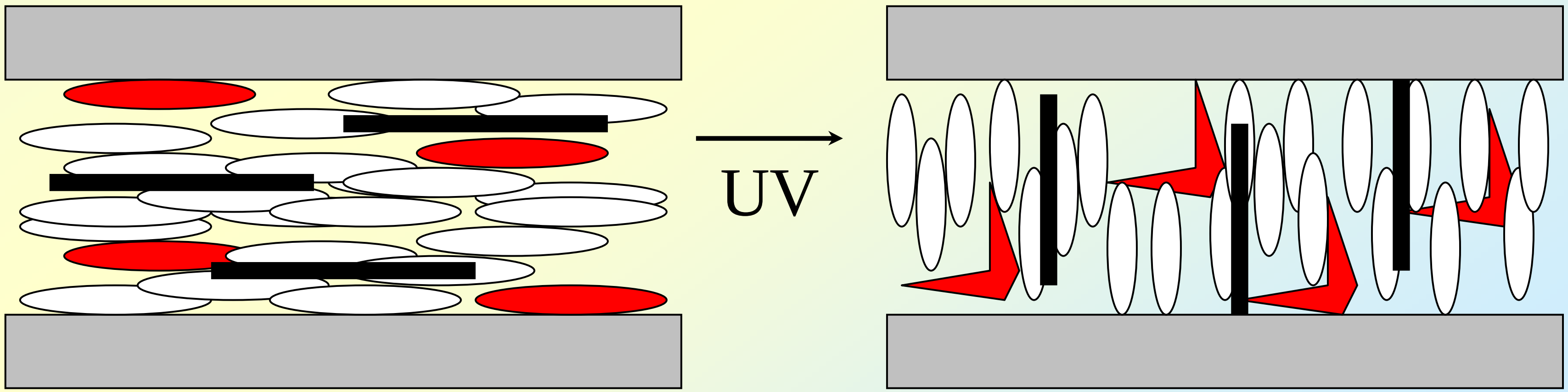
electrically steered liquid crystal – nanotube switches, in both OFF-ON (planar-homeotropic) and ON-OFF (homeotropic-planar) configuration. Note that the electric threshold voltage is **independent** on cell gap. → **Nano-electronics ...** ?

magnetically steered liquid crystal – nanotube switches, OFF-ON (planar-homeotropic) configuration . → **Magnetic field sensors ...** ?

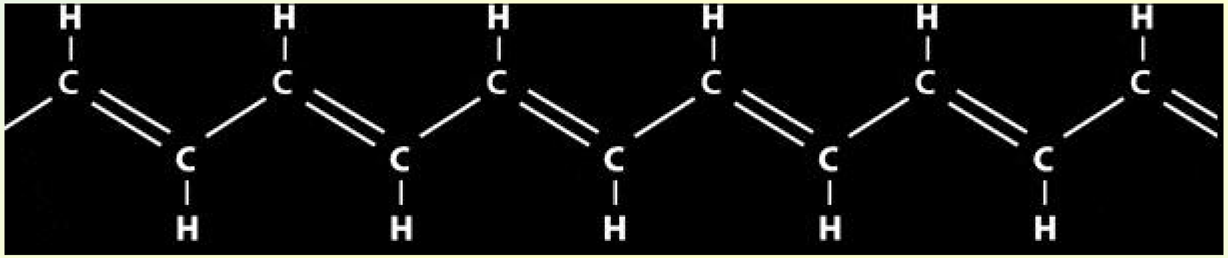
One can also think of **optically steered** electric switches:

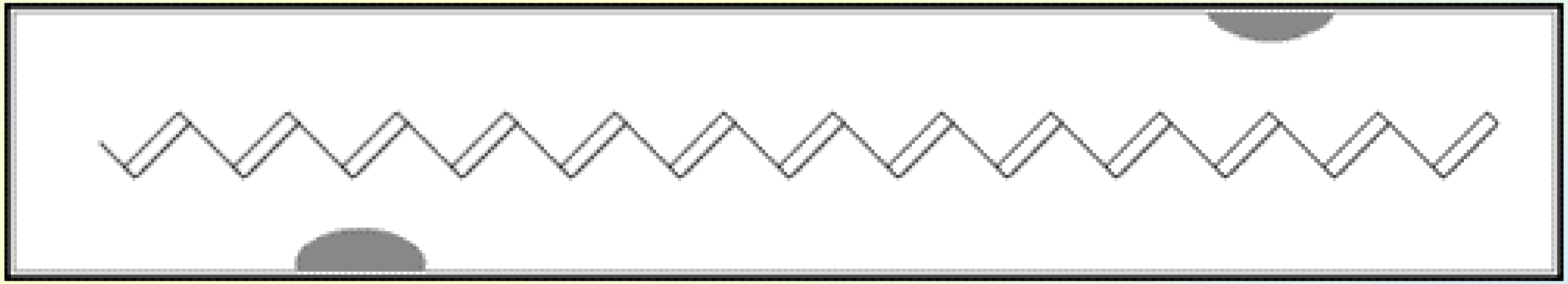
- dope the liquid crystal with special azo-compounds
- illumination with UV light causes molecular cis-trans isomerisation
- this in turn causes a macroscopic reorientation of the liquid crystal from planar to homeotropic
- thus switching from a non-conducting to a conducting state

→ **LC-nanotube UV sensors … ?**



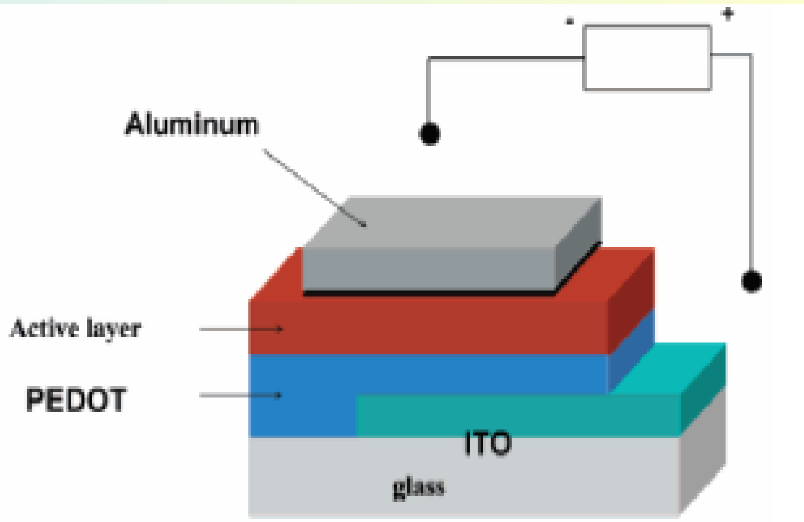
Conjugated polymers

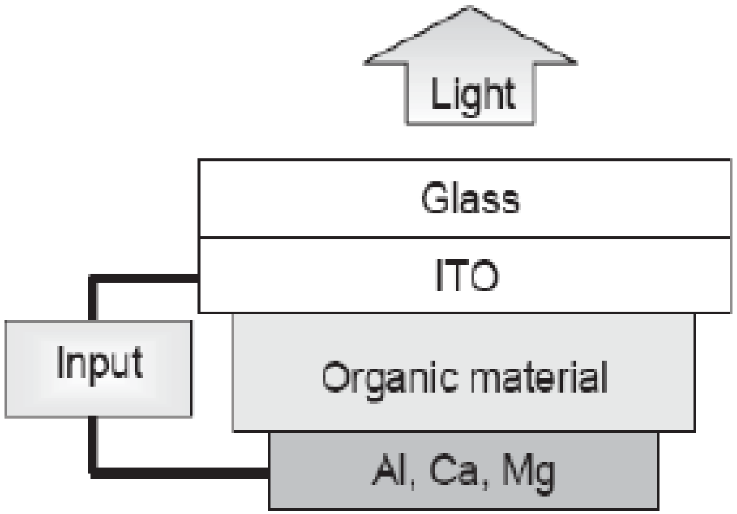




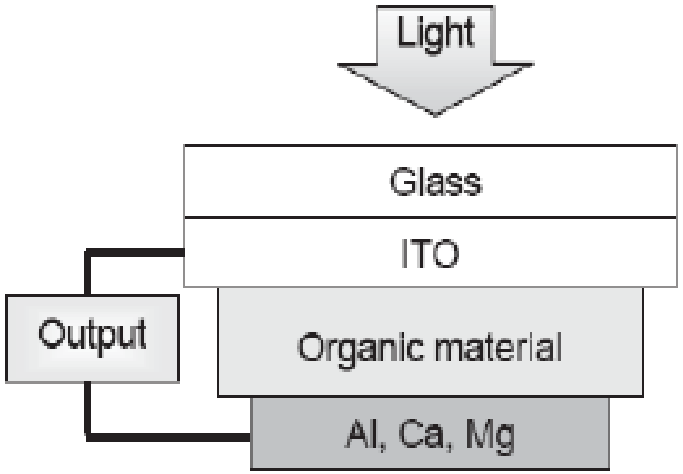
Organic Electronics

- OLEDs
- Organic Solar Cells OSCs
- OFETs
- LCs for OFETs





LED mode



Photovoltaic mode

Ongoing with preliminary results:

Analogy from pipes to circuits

OSC+OFET Light to Voltage to Light (wavelength switch)

OSC+OFET Light to Voltage to Current (sensors or light induced control)

LC FETs

Acknowledgements for CNT work

• My coworker: **Dr. I. Dierking,**

University of Manchester.

• Our colaborators: **Dr. Giusy Scalia, Dr. Piero Morales**

Unità Tecnico Scientifica, Materiali e Nuove Tecnologie (ENEA)

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[1] *Adv. Mater.*, **16**, 865, (2004).

[2] *J. Appl. Phys.*, **97**, 044309, (2005).

[3] *Appl. Phys. Lett.* **87**, 233507, (2005).

THANK YOU