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Optical Control of Surface Anchoring and Reorientation of Liquid Crystals via a Plasmon-Enhanced Local Field

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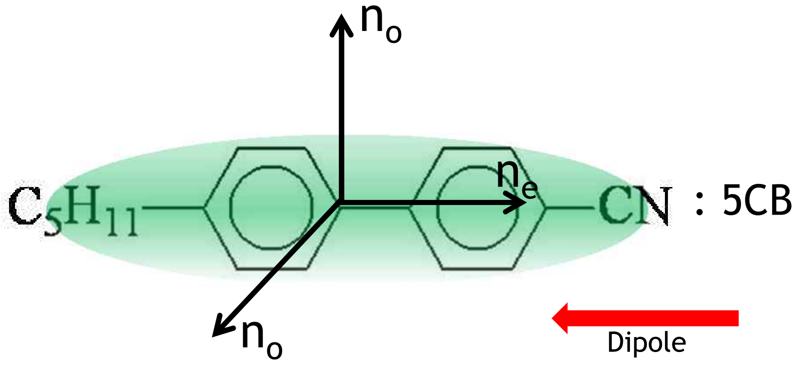
Presenter : Woongmo Sung

LIQUID CRYSTAL : WHAT IT IS

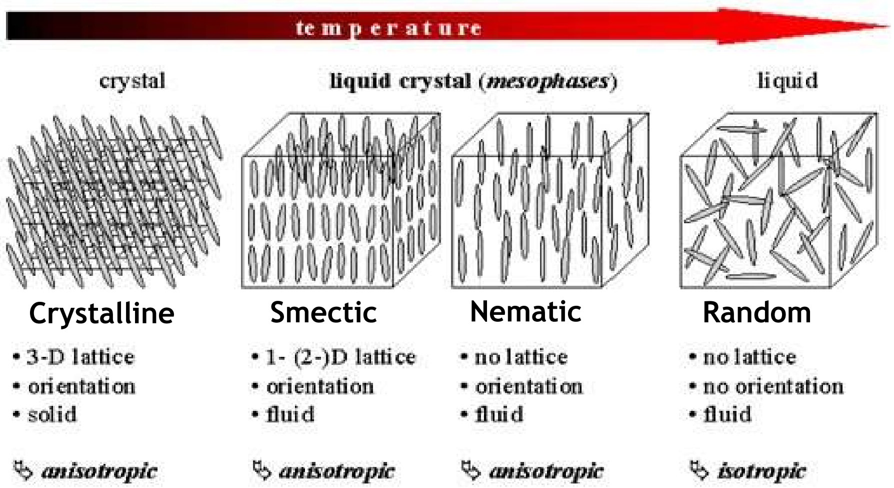
Typical LC molecule



Carrying electric and magnetic dipole moment

Optically anisotropic

LC Phases



http://www-g.eng.cam.ac.uk/CMMPE/lcintro1.html

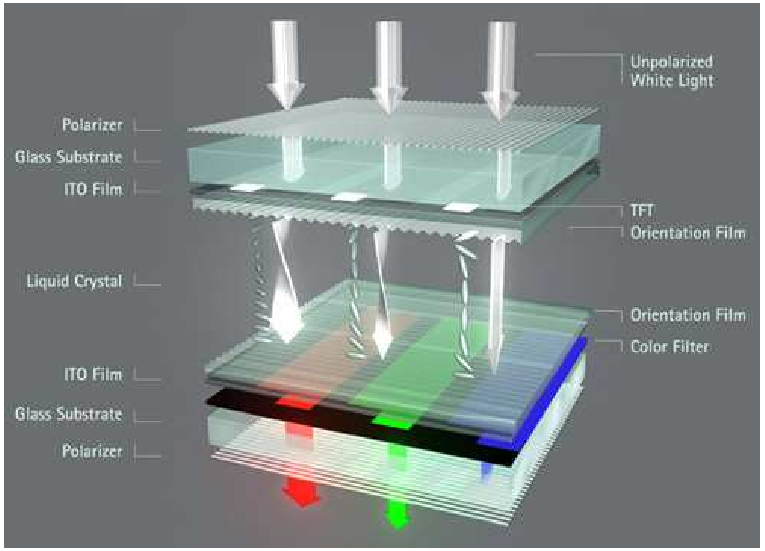
LIQUID CRYSTAL : APPLICATION

Liquid Crystal Thermometer

http://www.edmundoptics.com/testing-targets/calibration-standards/temperature-sensitive-liquid-crystal-sheets/1642

➡ Alignment of liquid crystals in the sheet changes optical path length

LCD (Liquid crystal Display)



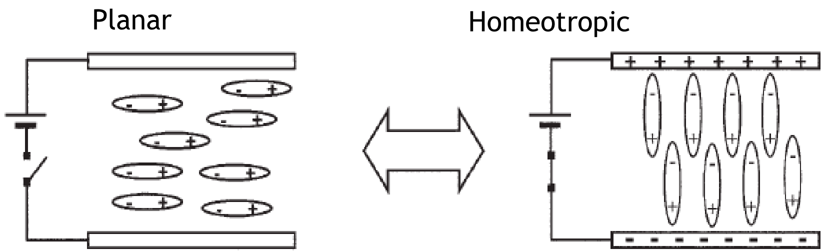
http://www.fokus-technologies.de/technology_en.phtml

➡ Alignment of liquid crystals can be changed by electric field, it gives rotation of polarization

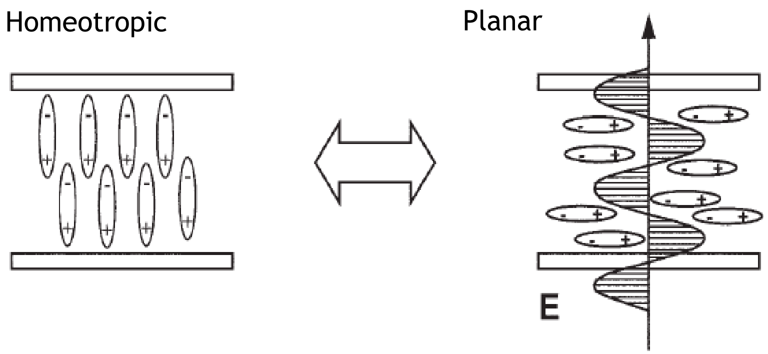
LIQUID CRYSTAL : FRE´EDERICKSZ TRANSITION (FT)

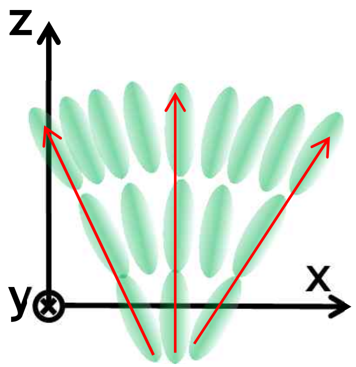
Definition: Threshold Phenomenon of LC alignment in external E-field

A) Electrical Freedericksz Transition



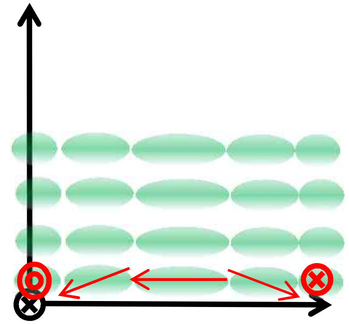
B) Optical Freedericksz Transition





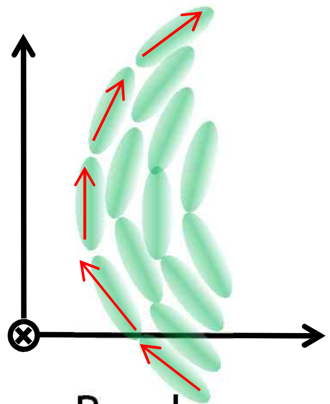
Splay

$\nabla \cdot \hat{n} \neq 0$



Twist

$\nabla \times \hat{n} \parallel \hat{n}$



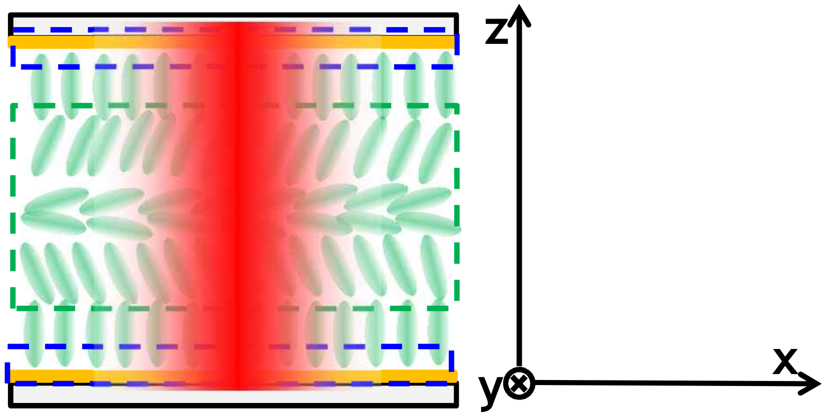
Bend

$\nabla \times \hat{n} \perp \hat{n}$

$$F = F_V + U_{E,DC} = [\frac{1}{2}K_1[\nabla \cdot \hat{n}]^2 + \frac{1}{2}K_2[\hat{n} \cdot (\nabla \times \hat{n})]^2 + \frac{1}{2}K_3[\hat{n} \times (\nabla \times \hat{n})]^2] - \frac{1}{2}\vec{D} \cdot \vec{E}$$

LIQUID CRYSTAL : OPTICAL FT IN LC CELL

Depends strongly on interaction between substrate (e.g. polymer) and LC molecules



$$f = \underbrace{\frac{1}{2}\left[(k_{33}\cos^2\theta + k_{11}\sin^2\theta)\left(\frac{d\theta}{dz}\right)^2\right]}_{(1)} - \underbrace{\frac{I}{c}n(\theta)}_{(2)} + \underbrace{\frac{1}{2}[\delta(z) + \delta(d-z)]\sum_{n=1}^{\infty} W_{2n}\sin^{2n}\theta}_{(3)},$$

$$n(\theta) = n_o n_e/(n_0^2\sin^2\theta + n_e^2\cos^2\theta)^{1/2}, \quad (1)$$

<Free energy inside of LC cell>

(1) Splay and bending energy of bulk LC

(2) Energy of electromagnetic field in LC cell

(3) Surface anchoring energy (SAE) → Orientation depends strongly on interaction between substrate (e.g. polymer) and LC molecules

Motivation: Making Low Optical FT Level

Optical threshold intensity

$$\left(\frac{I_{\mathrm{th}}}{I_0}\right)^{1/2}\tan\left[\frac{\pi}{2}\left(\frac{I_{\mathrm{th}}}{I_0}\right)^{1/2}\right]=\frac{dW_2}{\pi k_{33}}, \qquad (2)$$

$$I_0 = ck_{33}[n_e^2/n_0(n_e^2-n_0^2)](\pi^2/d^2)$$

➡ For given intensity of light, threshold magnetic field is,

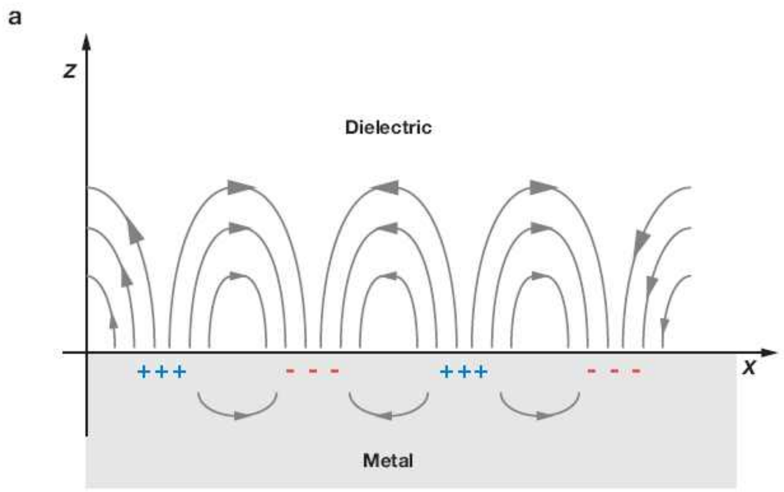
$$\left[\left(\frac{H_{\mathrm{th}}}{H_0}\right)^2+\frac{I}{I_0}\right]^{1/2}\tan\left\{\frac{\pi}{2}\left[\left(\frac{H_{\mathrm{th}}}{H_0}\right)^2+\frac{I}{I_0}\right]^{1/2}\right\}=\frac{dW_2(I)}{\pi k_{33}}. \quad (3)$$

$$H_0 = (\pi/d)(k_{33}/\chi_a)^{1/2}$$

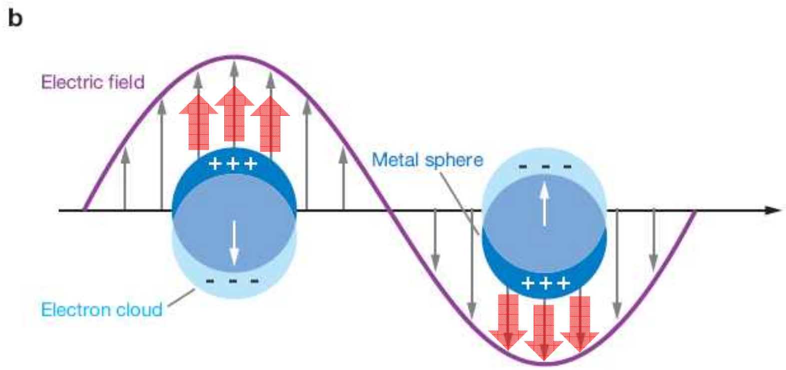
➡ In order to lower H_{th}, *I* should be increased or W_2 should be reduced.

➡ How about local field enhancement?

MOTIVATION: LOCAL FIELD ENHANCEMENT (SPR)



Collective motion of charges in conducting medium surface (Surface Plasmon Polariton) creates additional electric field.



In the limit of a<λ, external AC electric field (e.g. light) drives electrons in conducting surface causing local electric field enhancement.

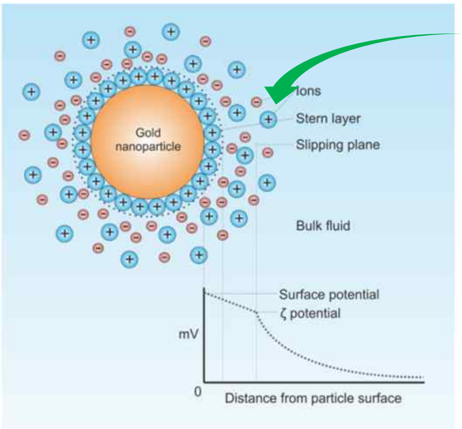
$$\mathbf{E}_{out}(x,y,z) = E_0\hat{\mathbf{z}} - \left[\frac{\varepsilon_{in}-\varepsilon_{out}}{(\varepsilon_{in}+2\varepsilon_{out})}\right] a^3 E_0 \left[\frac{\hat{\mathbf{z}}}{r^3} - \frac{3z}{r^5}(x\hat{\mathbf{x}}+y\hat{\mathbf{y}}+z\hat{\mathbf{z}})\right].$$

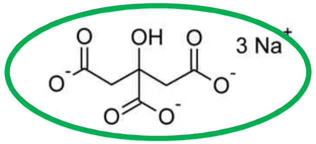
E_{out} will be maximized when $\varepsilon_{out} = -2\varepsilon_{in}$.

EXPERIMENT: SAMPLE PREPARATION

Preparation of Au nano particles

<Chlorauric Acid, $HAuCl_2$ >

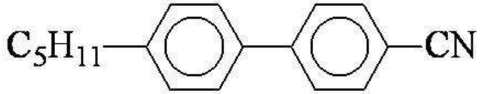




Reducing agent

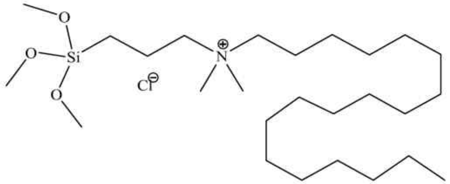
- Precipitation occurs after forming ~nm size Au particles

<Liquid Crystal>

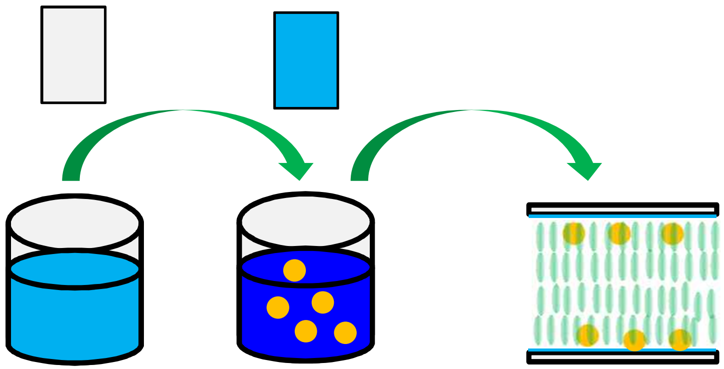


: 5CB

<Surface Coupling Agent>

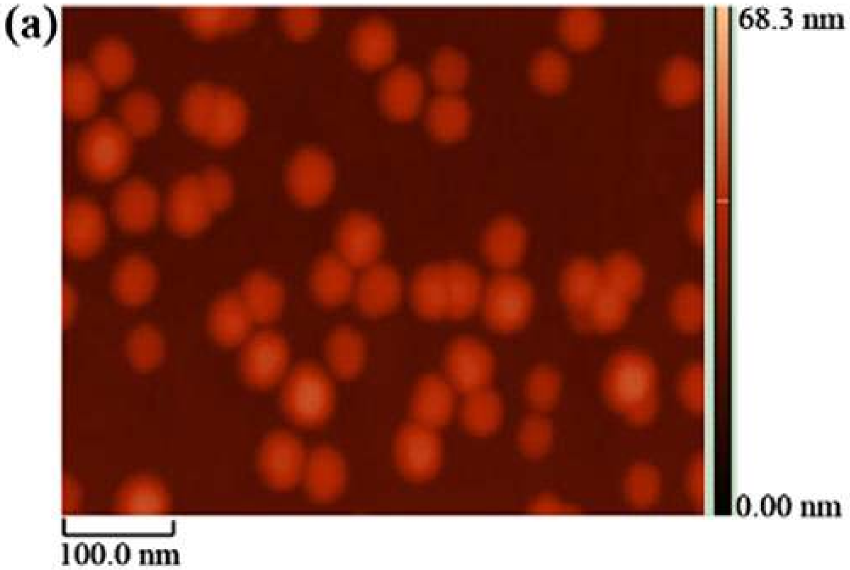


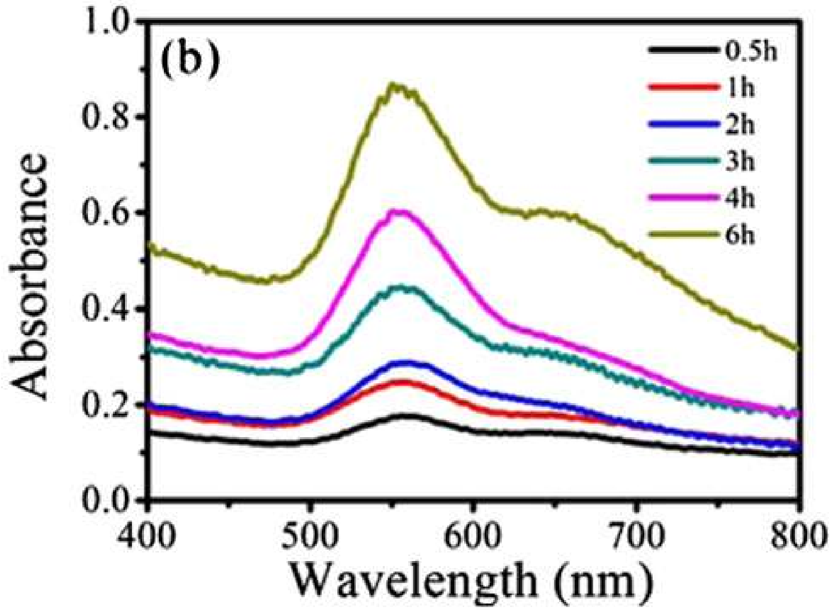
: DMOAP



DMOAP solution   Au particle solution   LC cell

EXPERIMENT: SAMPLE PREPARATION





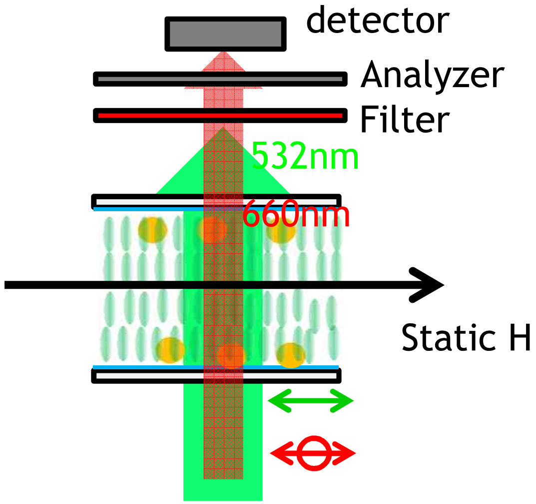
- Size of Au nano particle was confirmed by AFM (2h)

- Absorption peak appears near ~ 550nm originated from local plasmon resonance of single Au nano particle

- Shoulder around ~ 680nm correspond to absorption band of aggregates

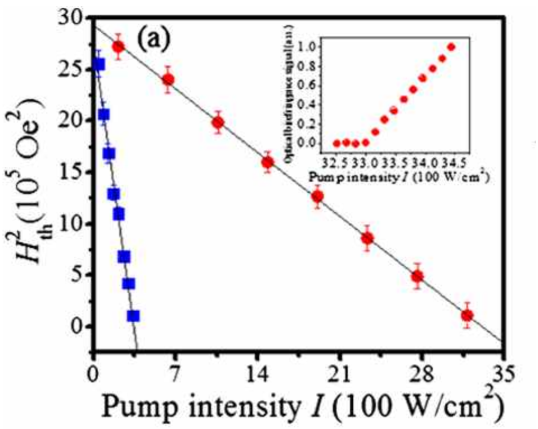
Experiment: Measurement of H_{th} in FT

Experimental Description – Magnetic-optical pump method



→ H_{th} was recorded when optical birefringence showed up.

Experiment - H_{th} measurement with varying pump intensity

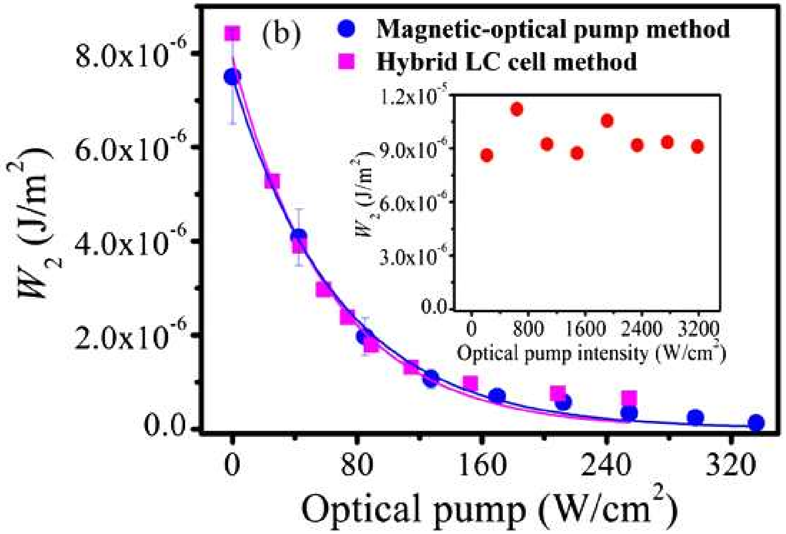


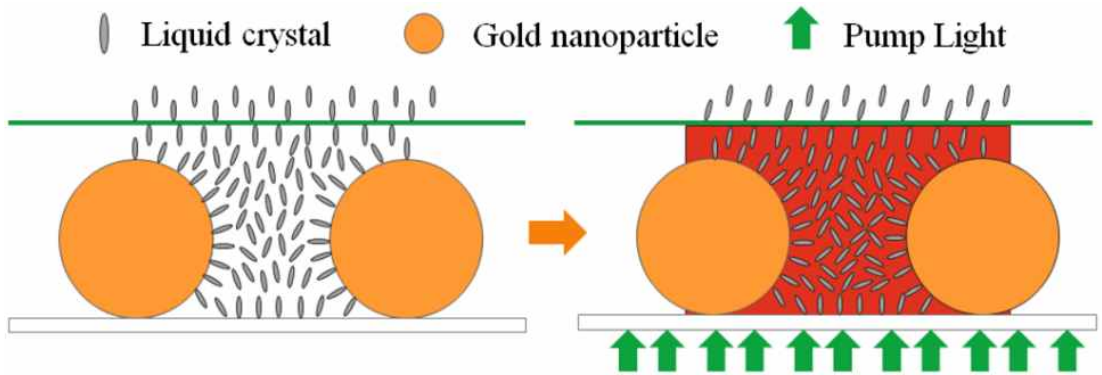
→ H_{th} was reduced more than one order of magnitude in the case of Au deposited LC cell.

$$\left[\left(\frac{H_{th}}{H_0}\right)^2+\frac{I}{I_0}\right]^{1/2}\tan\left\{\frac{\pi}{2}\left[\left(\frac{H_{th}}{H_0}\right)^2+\frac{I}{I_0}\right]^{1/2}\right\}=\frac{dW_2(I)}{\pi k_{33}}. \quad (3)$$

EXPERIMENT: MEASUREMENT OF H_{TH} IN FT

Analysis – Intensity dependence of SAE



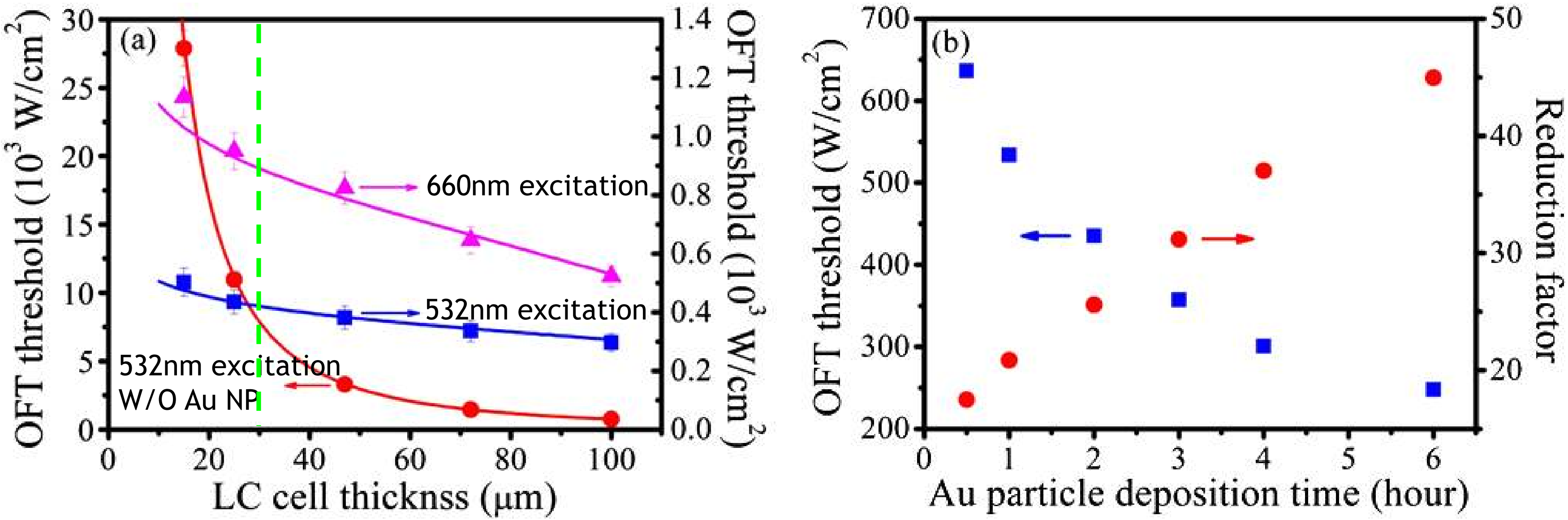


<Suggested Model – SAE relaxation by local field>

Steep reduction of H_{th} is originated from re-alignment of LC molecules near Au nano particle where local field is enhanced as ~30times of incident field.

EXPERIMENT: SIZE AND AUNP DEPENDENCE

Experiment - I_{th} measurement without external H field



*Dielectric constant of 50nm Au nanoparticle,

- $\varepsilon_{in} = -5.2 + 2.3i$ (532nm)

  $\varepsilon_{in} = -10.0 + 1.1i$ (660nm)

*Refractive index of 5CB,

- $n_e \sim 1.7$

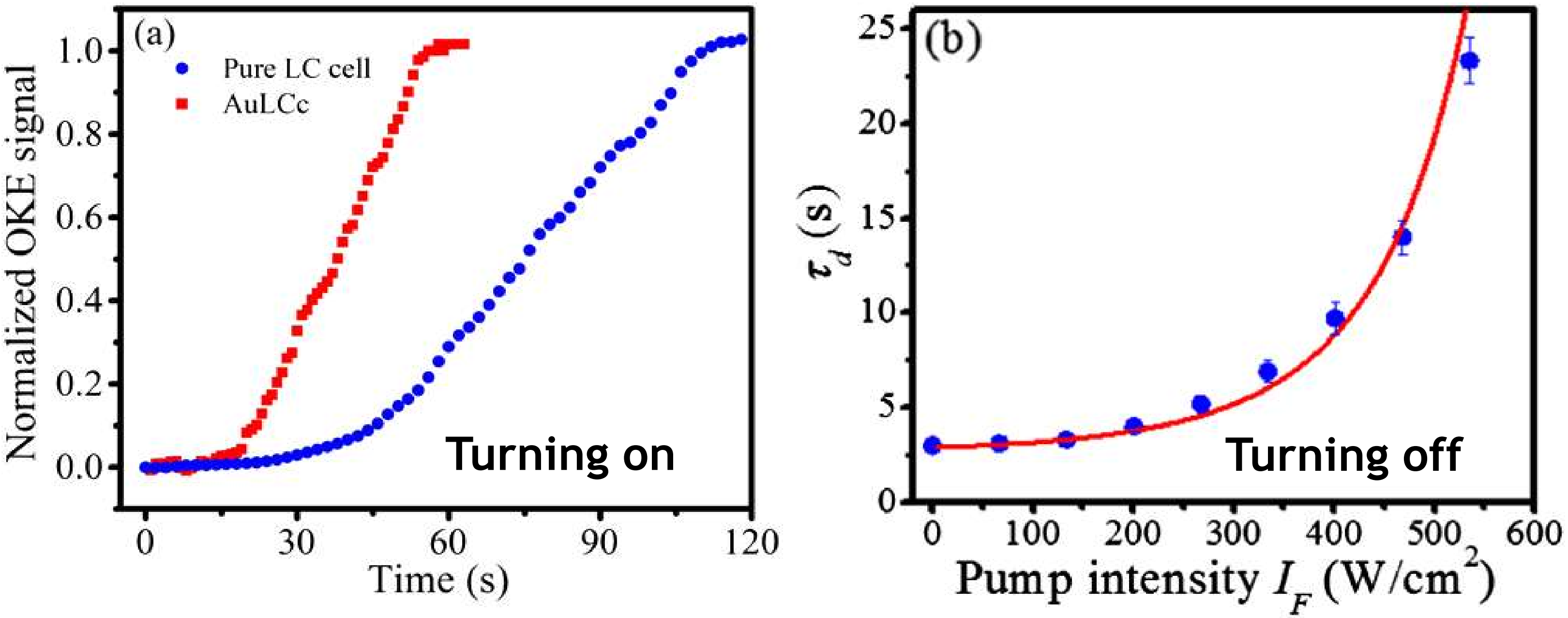
  $n_o \sim 1.5$ in visible range.

Coefficient gets larger in 532nm

$$\mathbf{E}_{out}(x,y,z) = E_0\hat{\mathbf{z}} - \left[\frac{\varepsilon_{in} - \varepsilon_{out}}{(\varepsilon_{in} + 2\varepsilon_{out})}\right] a^3 E_0 \left[\frac{\hat{\mathbf{z}}}{r^3} - \frac{3z}{r^5}(x\hat{\mathbf{x}} + y\hat{\mathbf{y}} + z\hat{\mathbf{z}})\right].$$

EXPERIMENT: SWITCHING BEHAVIOR

Additional Experiment – Turn on/ off behavior of LC cell



- Faster turning on behavior of Au LC cell was observed.
- τ_d was consistent with theoretical prediction.

$$\tau_d = \gamma d'^2 / k_{33}\pi^2, d' = d + 2b = d + 2(k_{33} / W_2)$$

$$W_2(I) = W_{2,0} \exp(-I / I_{sat})$$

CONCLUSION AND SUMMARY

- Optical Freeddericksz transition was observed in Au nano particle embedded 5CB LC cell.

- H_{th} was drastically reduced by local field enhancement causing surface anchoring energy relaxation.

- Switching on/off behavior of AuNP LC cell was measured, and its response is faster than pure LC cell.