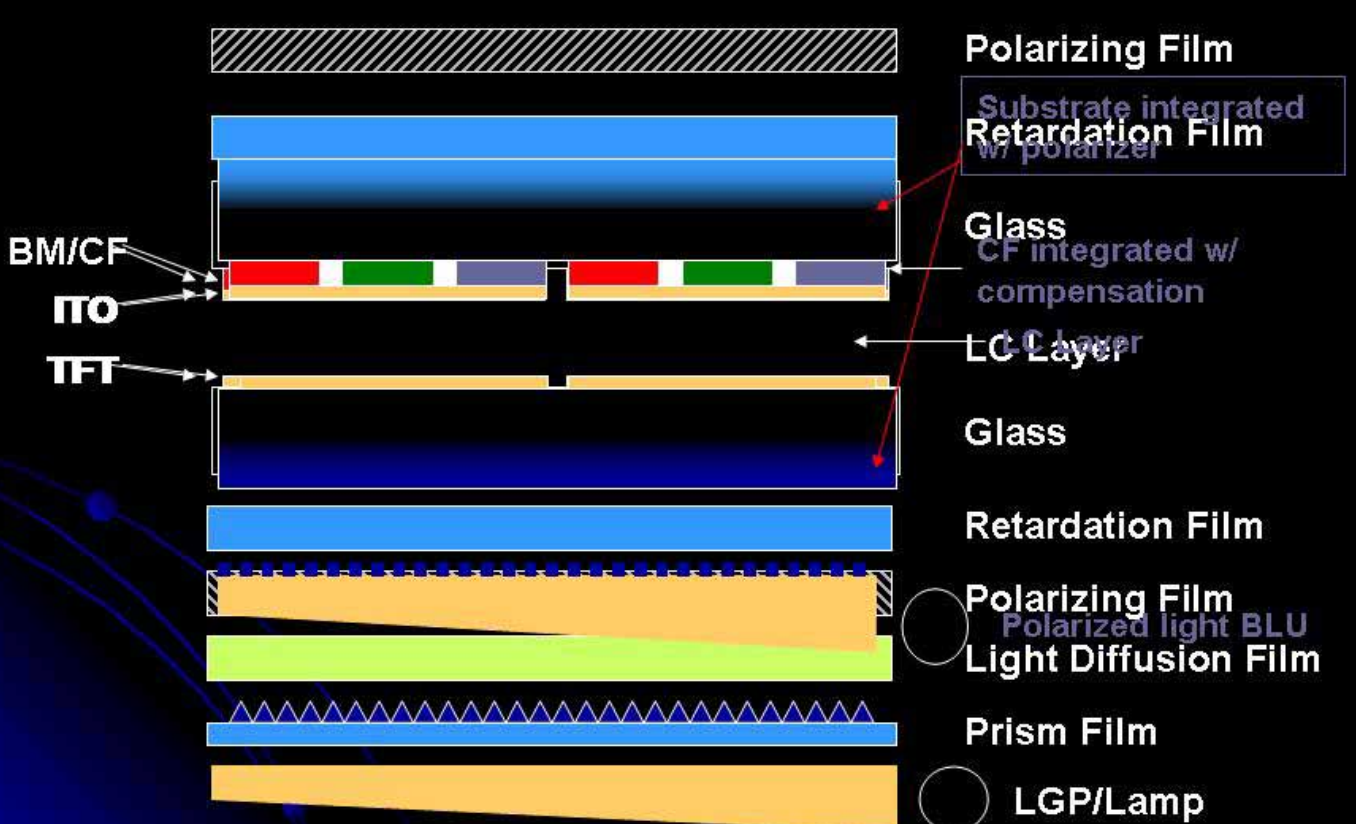
偏光膜的原理與應用

時間：2005.Nov. 2.(三.) --- 14:20~17:20
地點：台灣大學 應用力學研究所 一樓 113室

郭惠隆

薄膜LCD組成架構



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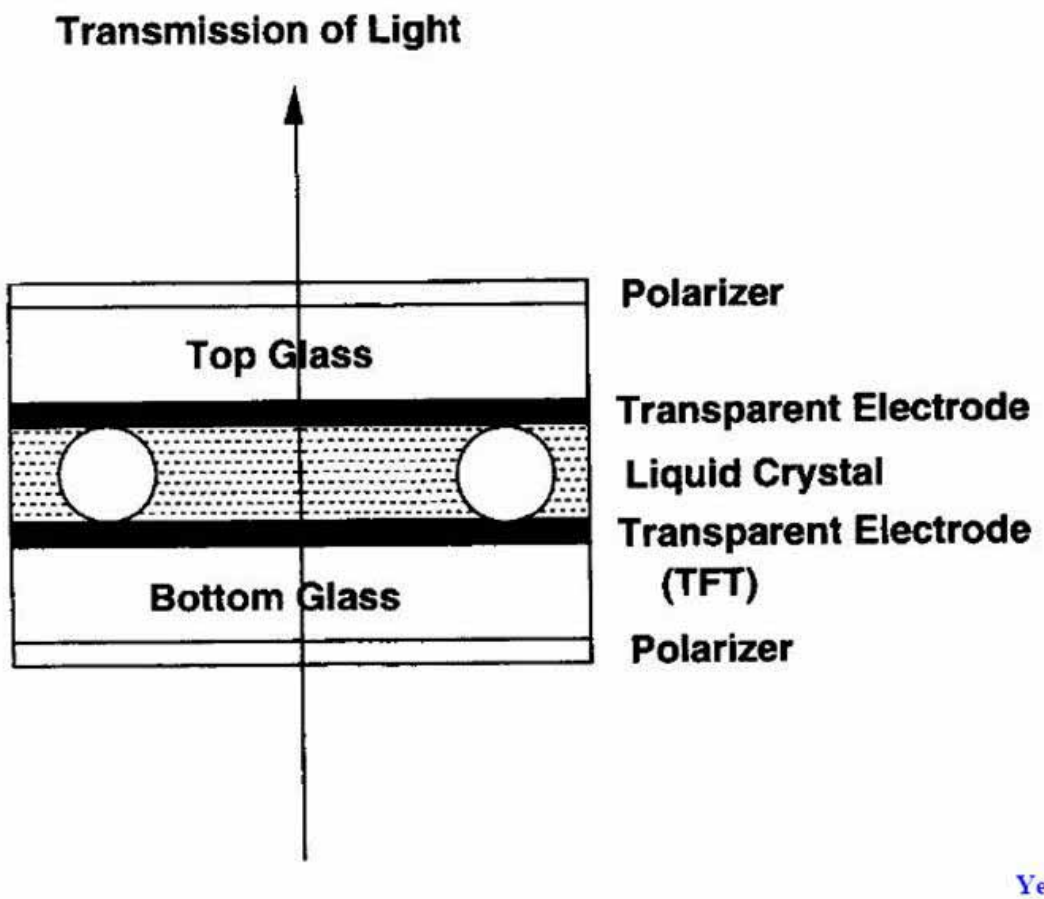
講題內容

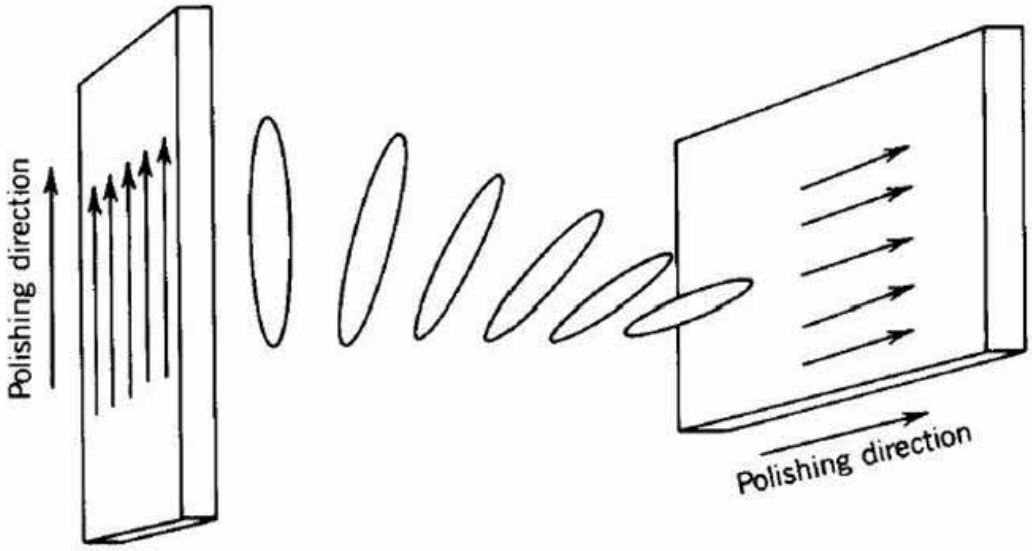
- 偏光膜與顯示器
- 偏光簡介
- 偏光膜之種類與原理
- 偏光膜之製造
- 偏光膜的附加功能

Basic Components of LCD



Yeh & Gu

Twisted Nematic Liquid Crystal

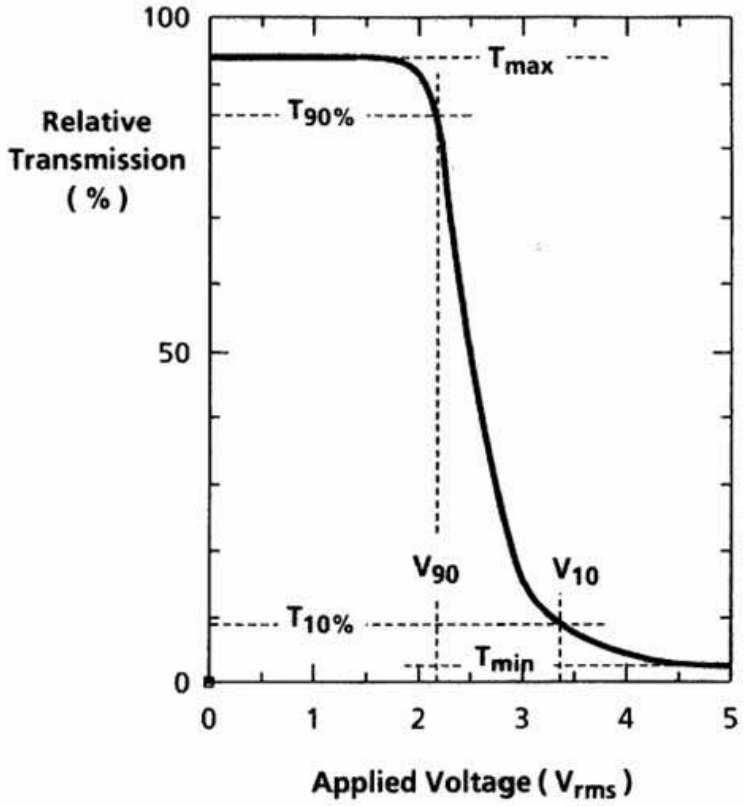


Saleh & Teich

Figure 6.5-2 Molecular orientations of the twisted nematic liquid crystal.

- **Nematic Liquid Crystals** on which a twist is imposed by external forces such as Boundary conditions
  - Thin layer of LC between two glass plates polished in perpendicular directions

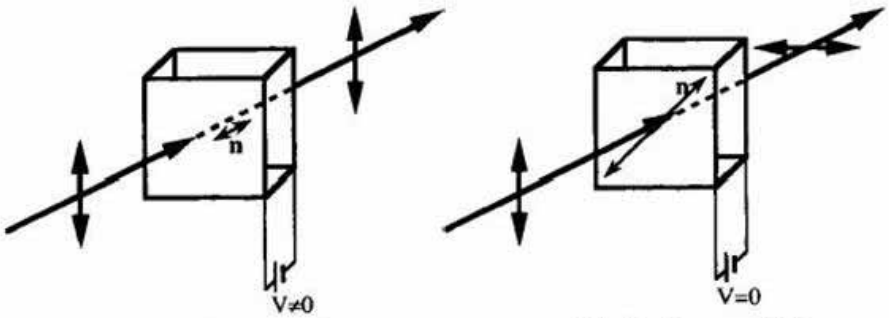
Electro-optic Response of TN-LC Cell



- V_{10}, V_{90}
- Contrast ratio = T_{max} / T_{min}
- Gray scale

Steemers, SID Seminar Notes 1994

Liquid Crystal Cell

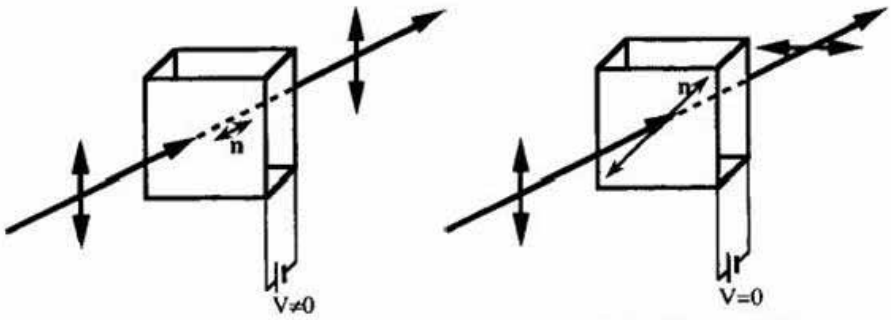


(a) Voltage On (b) Voltage Off

Yeh & Gu

- LC material fills space between electrodes
- Thickness kept uniform using glass fibers or plastic balls
  - A few microns
- Without any external field, ordering of LC determined by anisotropic boundary conditions
- Electrical anisotropy allows control of ordering and orientation of molecules by external field
  - Rod-like molecules aligned parallel to E-field to minimize electrostatic energy

Liquid Crystal Cell

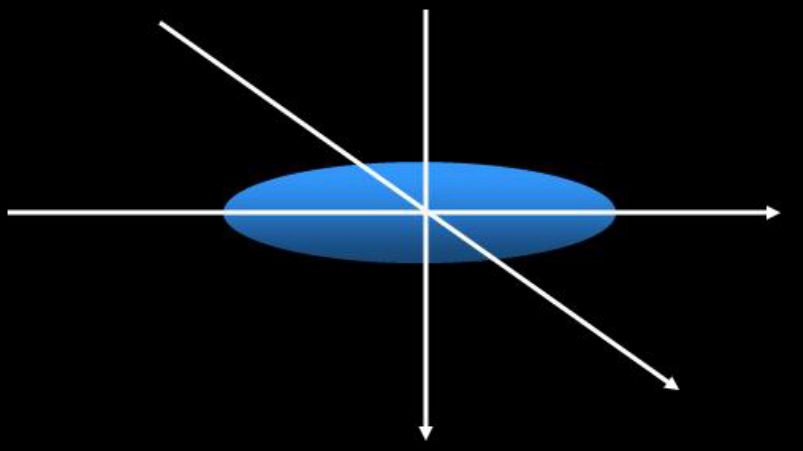


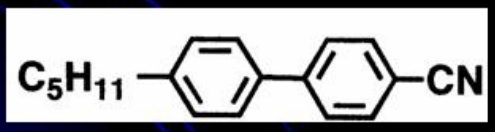
(a) Voltage On (b) Voltage Off

Yeh & Gu

- As a result of the ordering of molecule (nematic phase) LC exhibits a strong optical birefringence
- Two modes of optical propagation with unique pahse velocities
  - Relative phase retardation
- Polarization state of incoming polarized light is modified.
- Sandwiching the LC cell between a pair of cross polarizers leds to intensity modulation by applied voltage
  - Dielectric anisotropy
  - Optical birefringence

液　晶



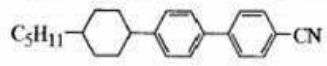
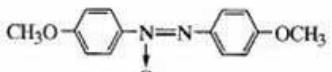
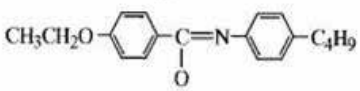
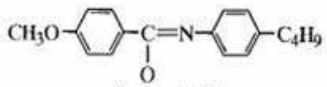
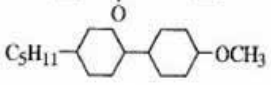
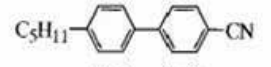


- Alignment
- Polarized light

Properties of Liquid Crystals

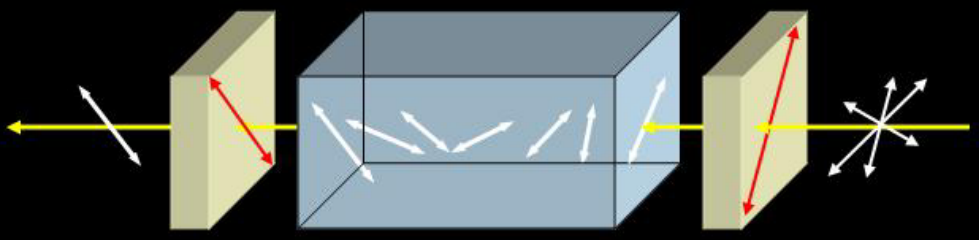
- LC is state of matter intermediate between solid and amorphous liquid
  - Liquid with ordered arrangement of molecules
  - Molecules with **orientation order** (like crystals) but lack **positional order** (like liquids)
- Organic substances with anisotropic molecules that are highly enlongated or flat
- Ordering leads to **anisotropy** of
  - **Mechanical properties**
  - **Electrical properties**
  - **Magnetic properties**
  - **Optical properties**

Table 1.1. Liquid Crystal Materials

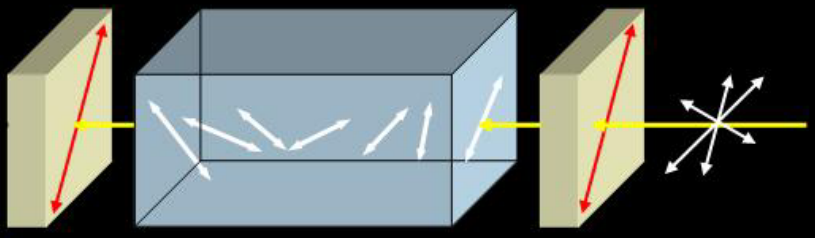
Name	Formula	Nematic Range (°C)
BCH-5		96–219
PAA		118–135.5
EBBA		35–77
MBBA		22–47
CCH-501		29–36.8
5CB		24–35
6CB		15–29

Yeh & Gu

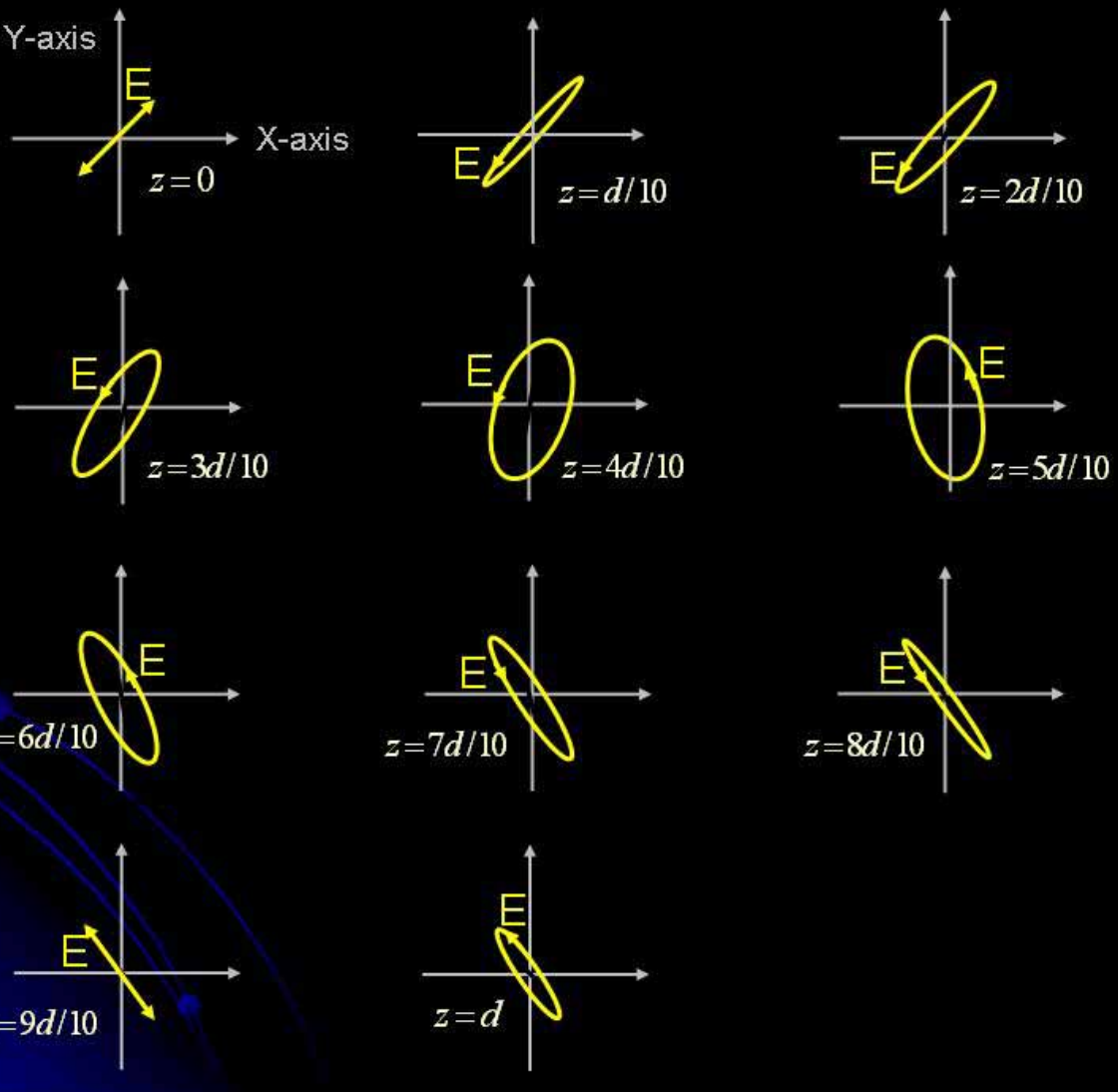
90°液晶顯示器



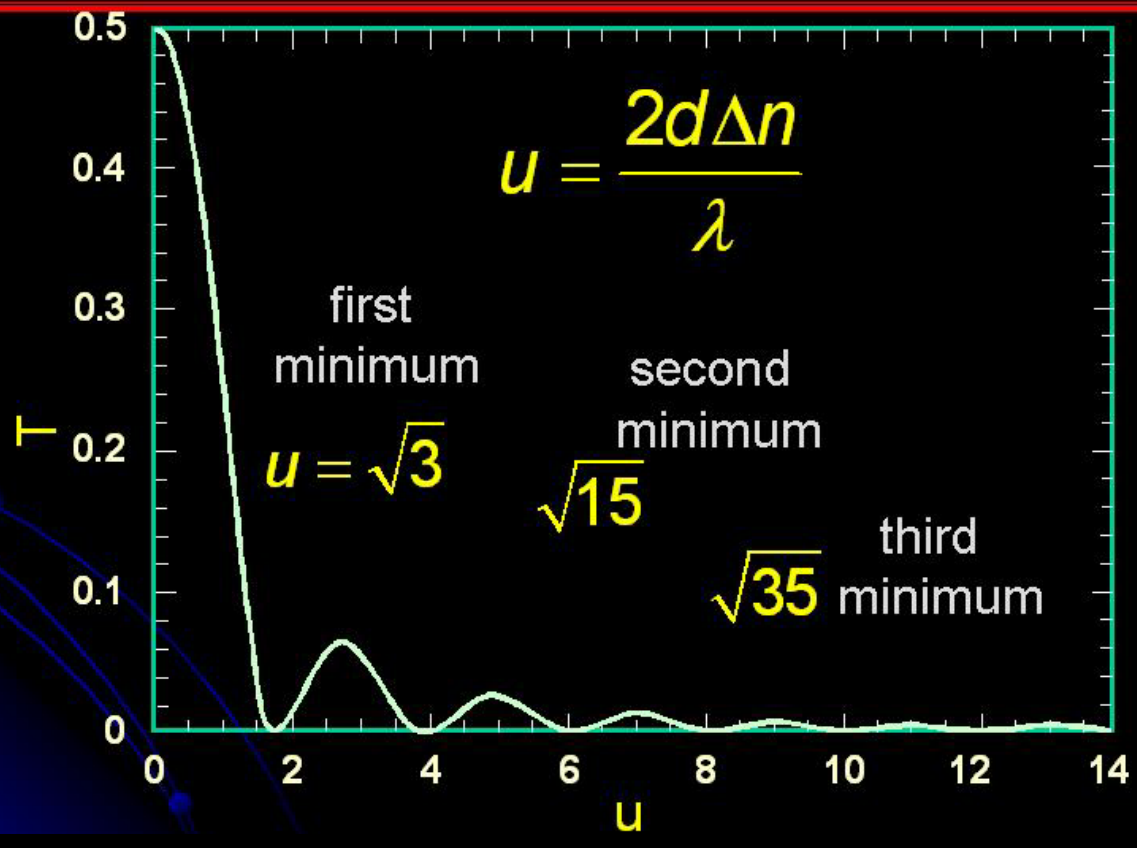
Normal White Mode



Normal Black Mode



LCD的暗態設計



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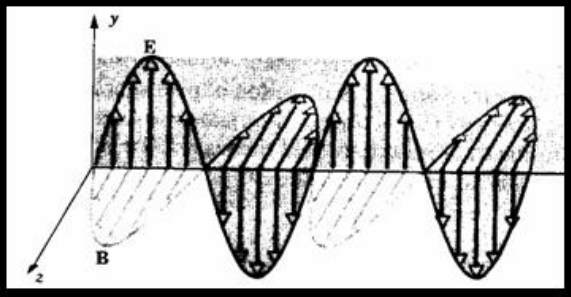
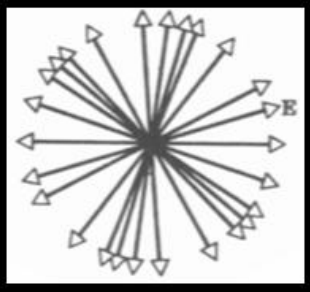
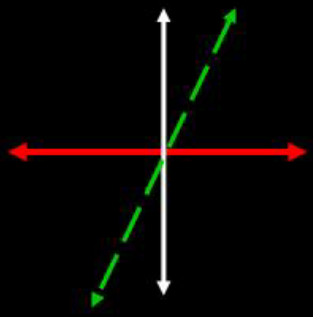
自然光





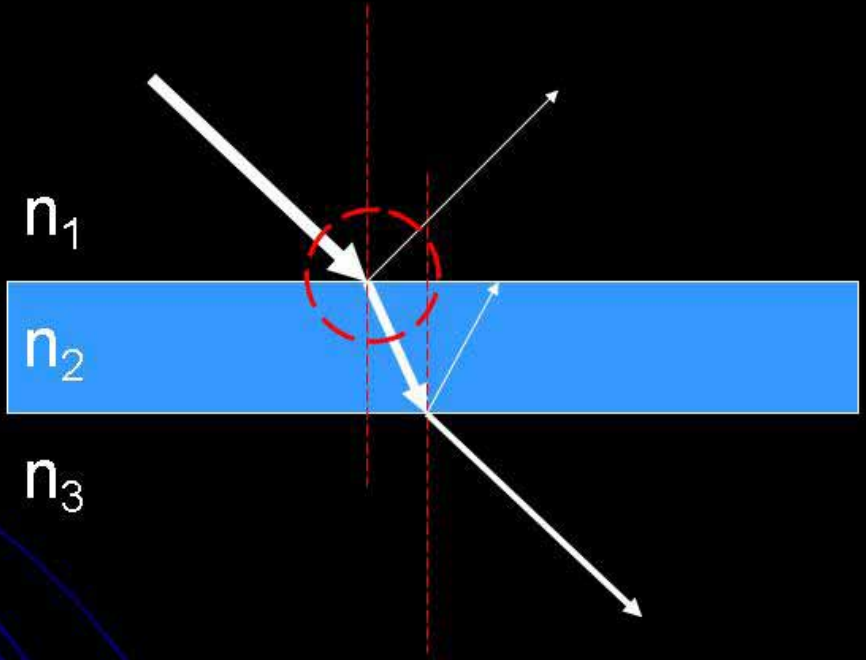


電磁波，在傳播方向上電場與磁場相互直交振動

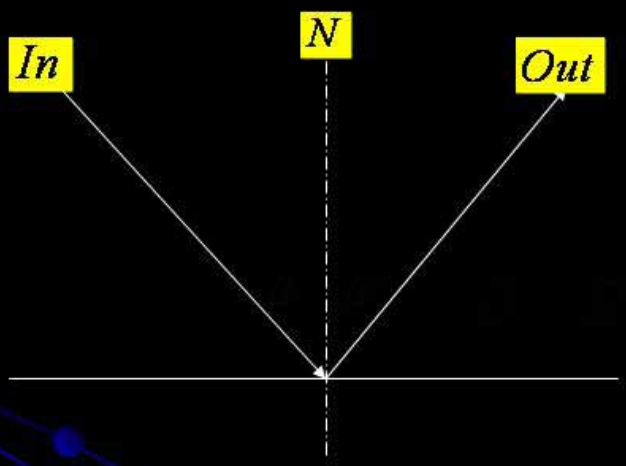
E_x, E_y, δ 隨時變化

界面之光學現象(1)

1.穿透
2.反射
3.折射



反射定律



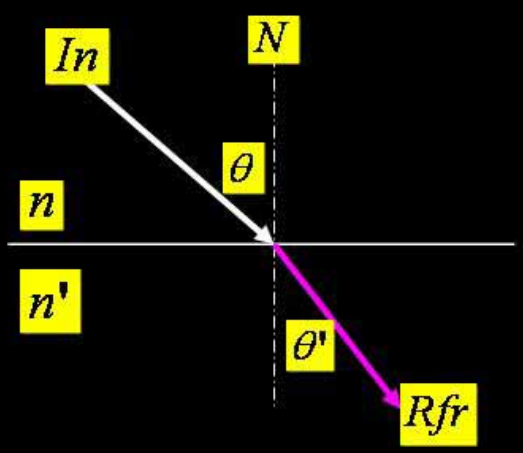
In 入射光

N 法線

Out 反射光

$$R = \left(\frac{n_1-n_2}{n_1+n_2}\right)^2 + \left(\frac{n_3-n_2}{n_3+n_2}\right)^2 + \cdots$$

折射定律-- *Snell's law*



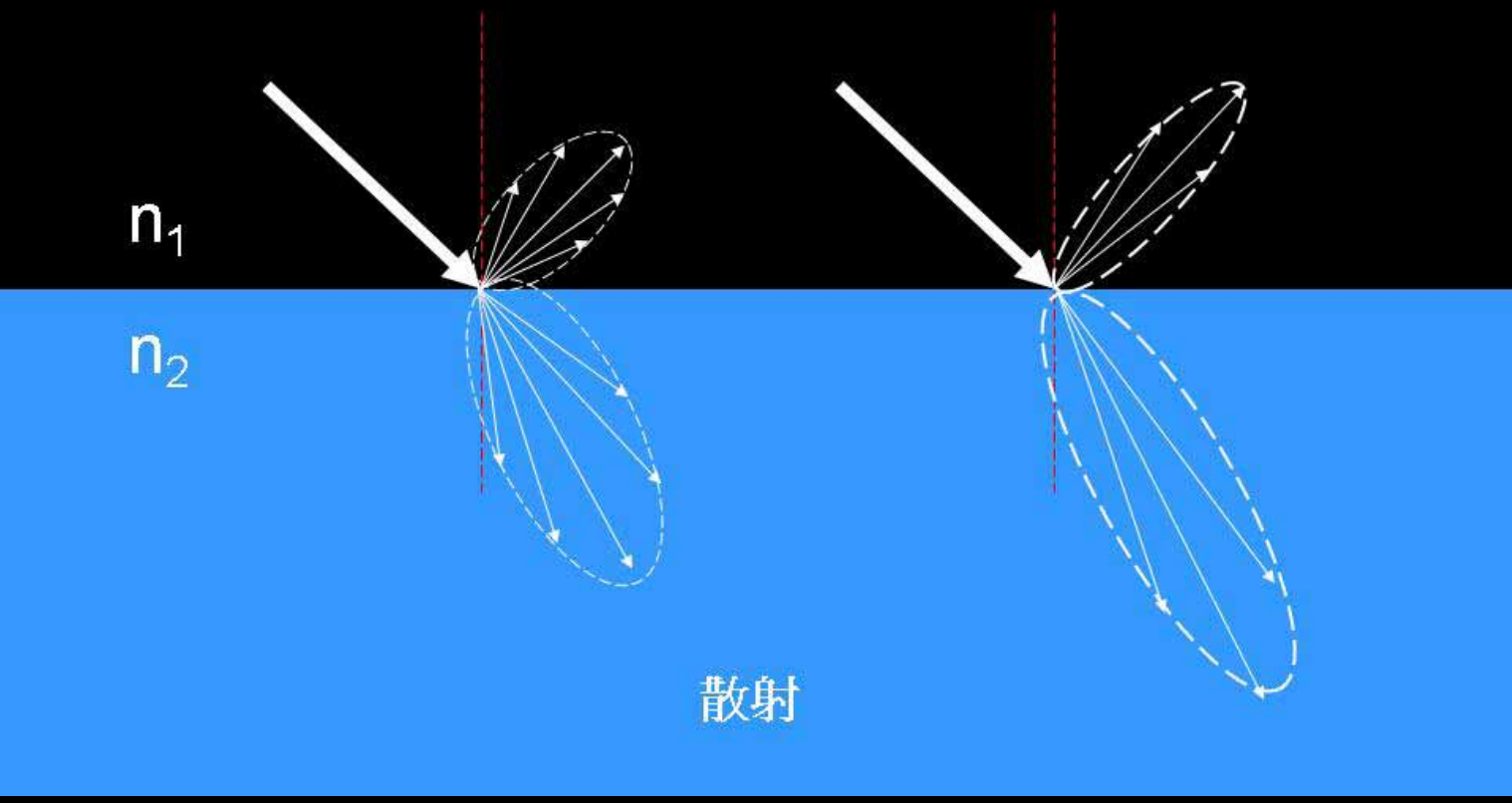
In 入射光

Rfr 折射光

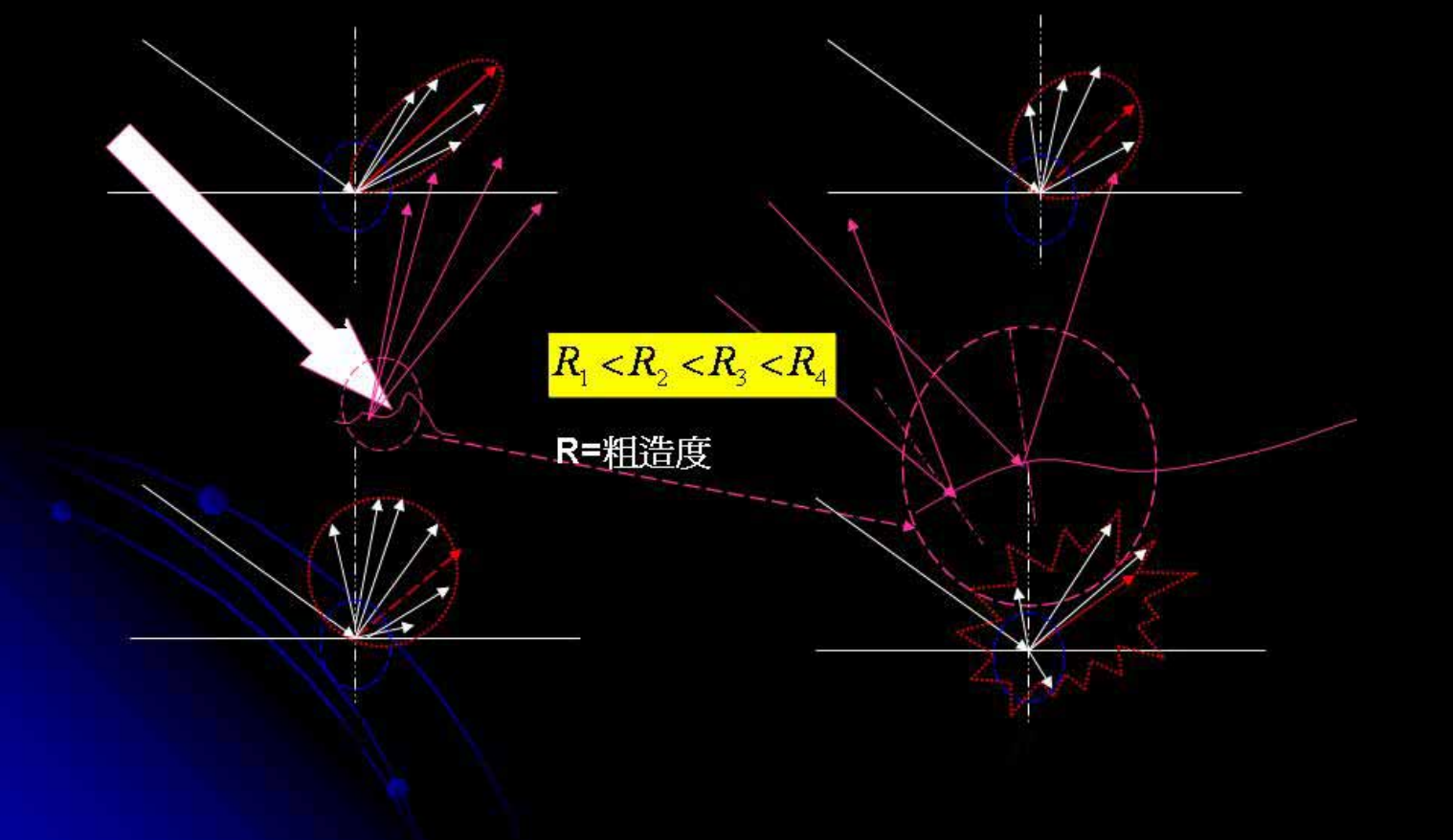
N 法線

$$n \sin\theta = n' \sin\theta'$$

界面之光學現象(2)



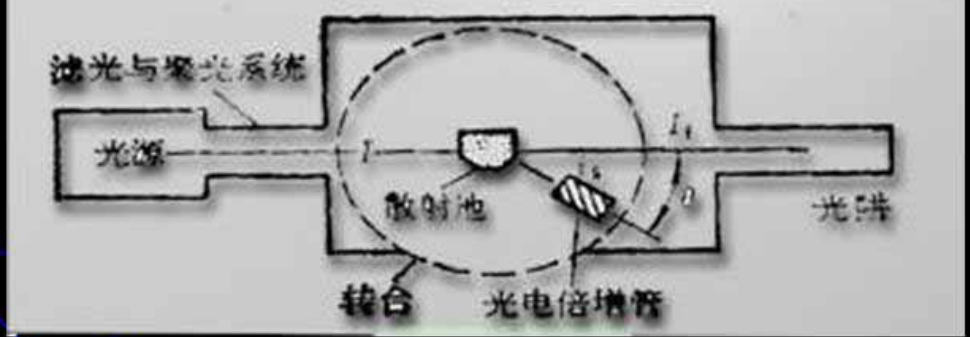
微粒子與粗超表面的散射



瑞利散射公式

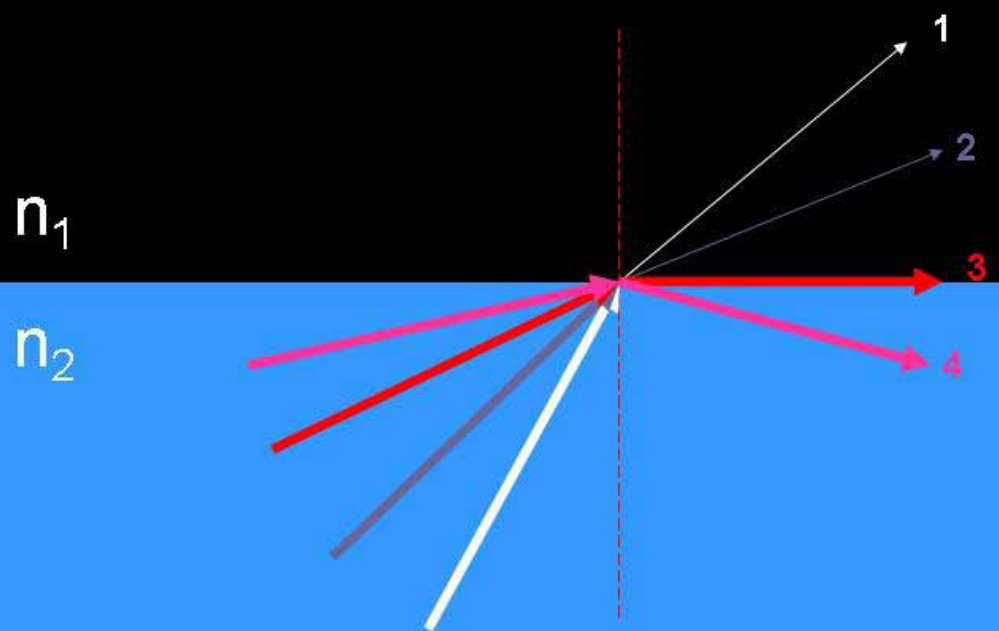
瑞利公式

$$R_\theta = \frac{I_\theta r^2}{I} = \frac{9\pi^2 N_0 V^2}{2\lambda^4}\left(\frac{n_1^2 - n_0^2}{n_1^2 + 2n_0^2}\right)^2 (1+\cos^2\theta)$$



- R_θ 稱爲散射角 θ 處的瑞利比
- r是散射距離，
- I_θ 是散射角爲 θ ，距離爲r時的散射光強度，
- N_0是單位體積中散射質點數，
- V是質點的體積，
- n_1爲分散相的折射率，
- n_0是介質的折射率，

界面之光學現象(3)



全反射

全反射現象

Snell's law：$n\sin\theta = n'\sin\theta'$

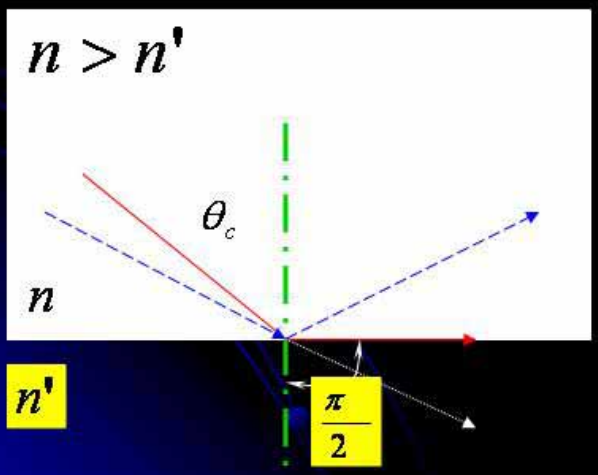
當 $\theta' = \frac{\pi}{2}$

$$\Rightarrow \sin\theta = \left(\frac{n'}{n}\right)\sin\left(\frac{\pi}{2}\right)$$

$\sin\left(\frac{\pi}{2}\right) = 1$

$$\Rightarrow \theta_c = \sin^{-1}\left(\frac{n'}{n}\right)$$

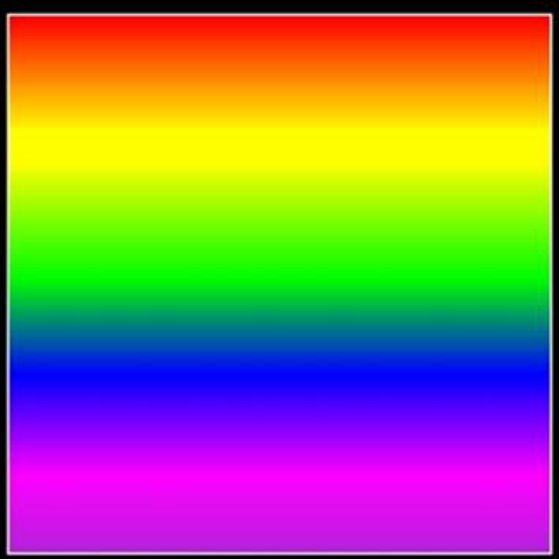
Critical angle

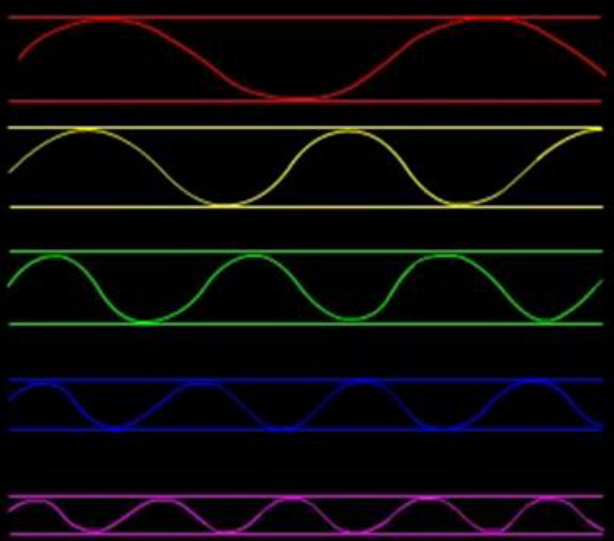


$\Rightarrow \theta > \theta_c$ 全反射發生

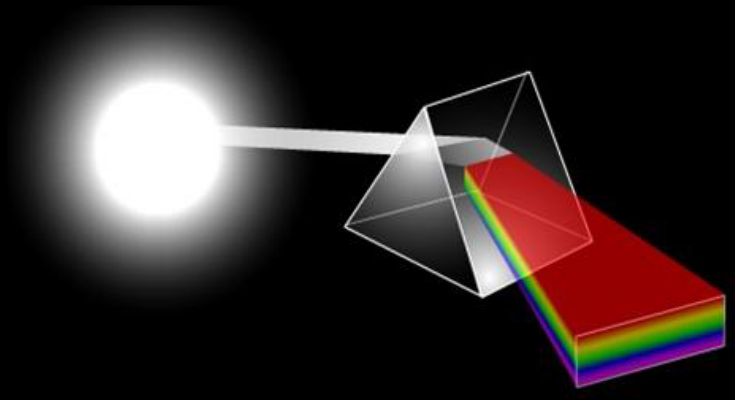
$\theta < \theta_c$ 折射現象

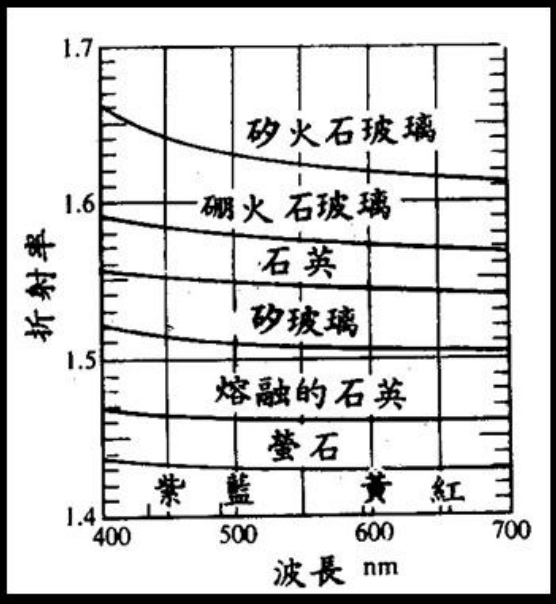
色彩與波長

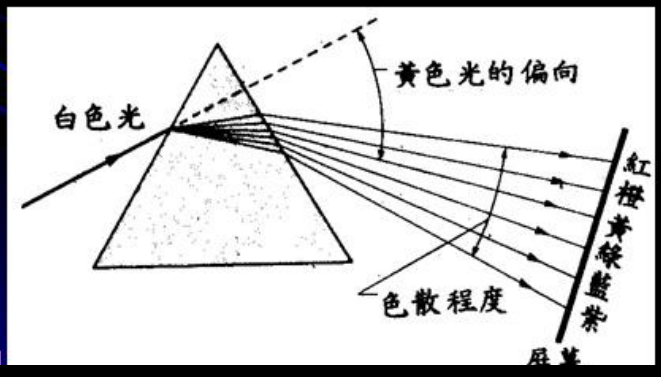




色散現象







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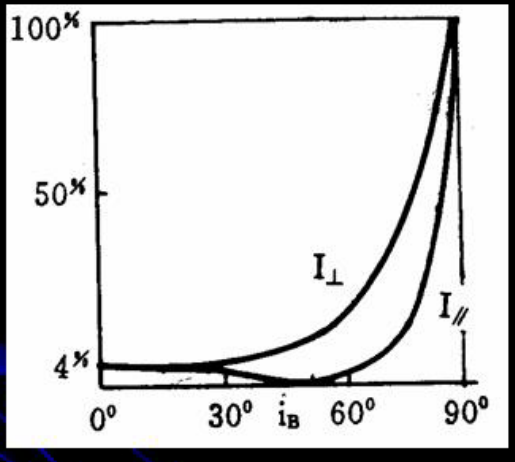
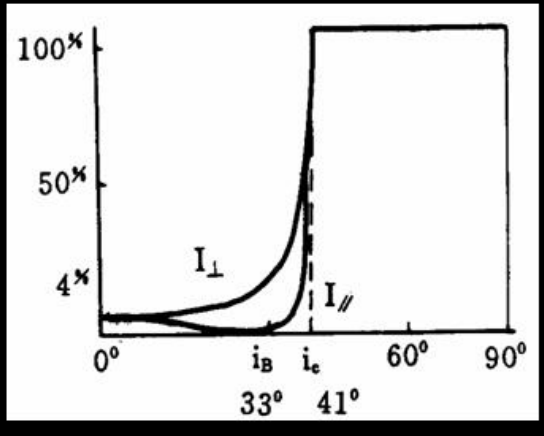
Brewster's angle

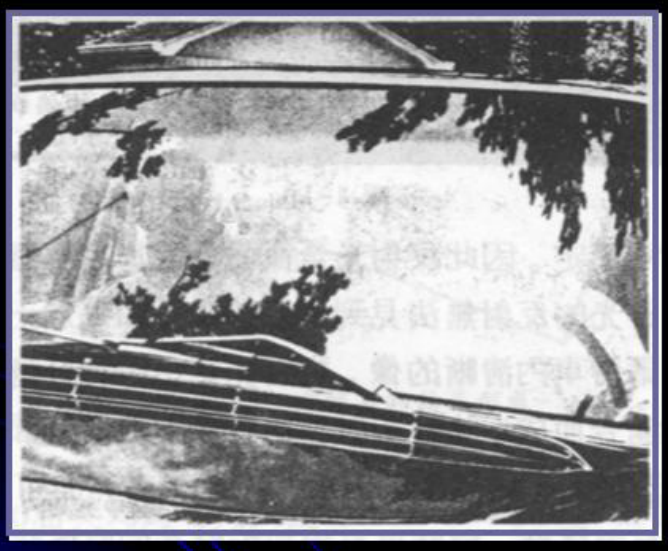


L ⟶ H



H ⟶ L

偏光現象



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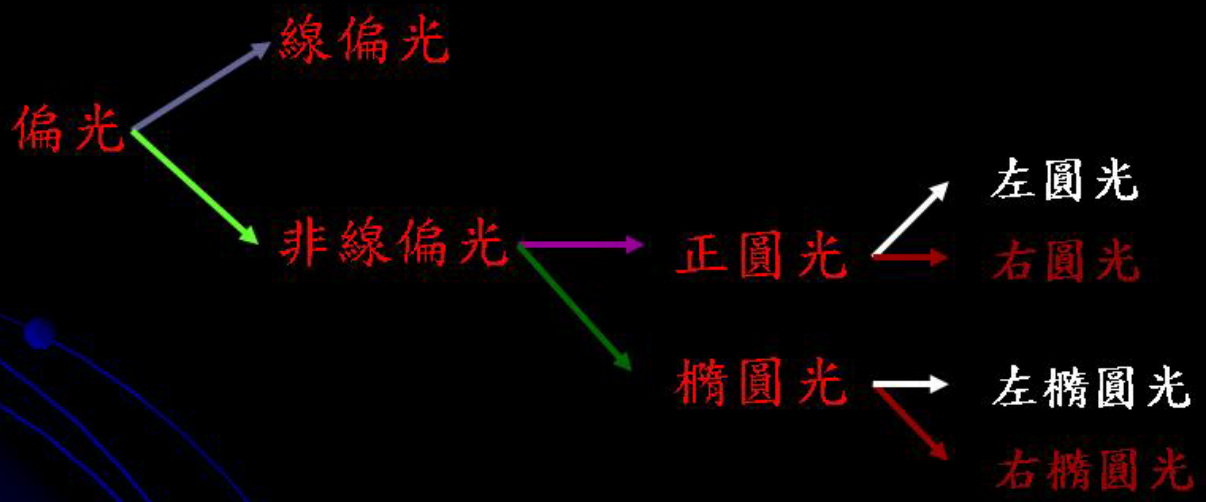
偏光現象

透過水平偏光片觀察水面

透過垂直偏光片觀察水面

偏光種類



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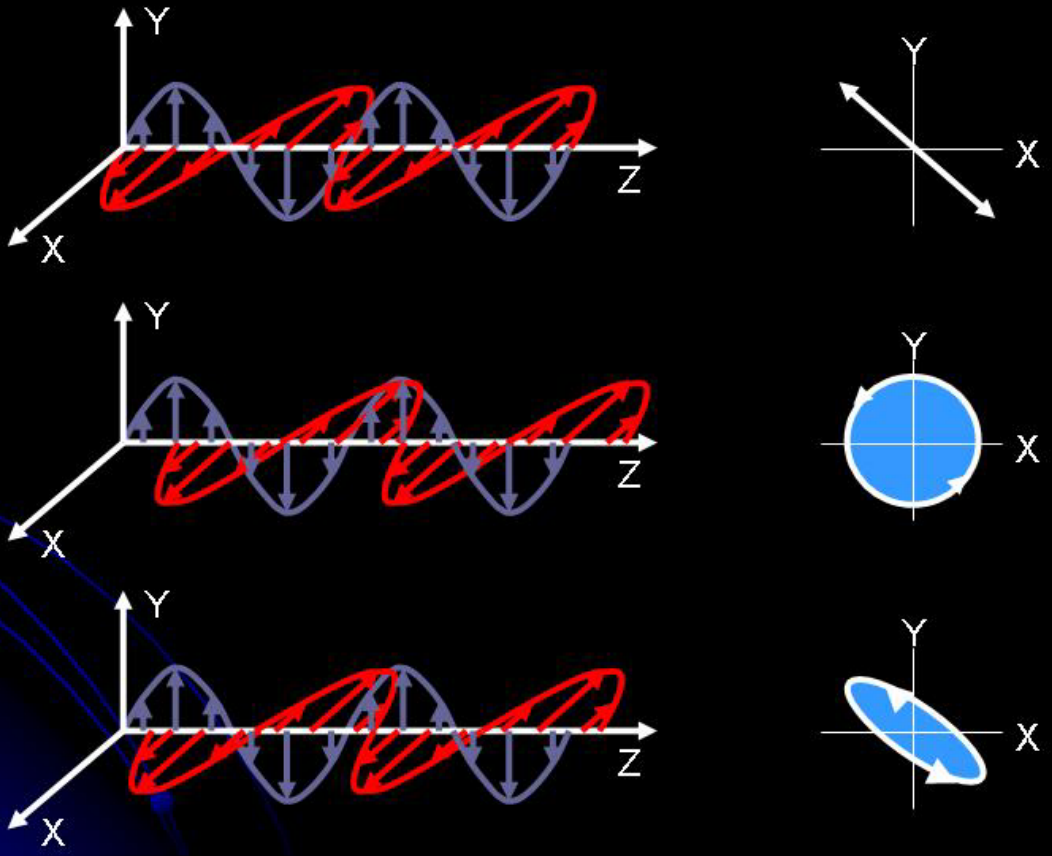
偏 振 光



如何描述一單色光？

可直接觀測的量

→亮度（光強）

→傳播方向

→色彩（波長）

虛擬的狀態

→相位（phase)

→偏光態

Maxwell's equation

$$E = E_0 e^{i(kz-wt)},$$

其中 $e^{i\phi} = \cos\phi + i\sin\phi$

$\kappa = 2\pi/\lambda$, $w = 2\pi\nu$

E 是向量，數值為 $|E_0|^2$

ν =頻率

λ =波長

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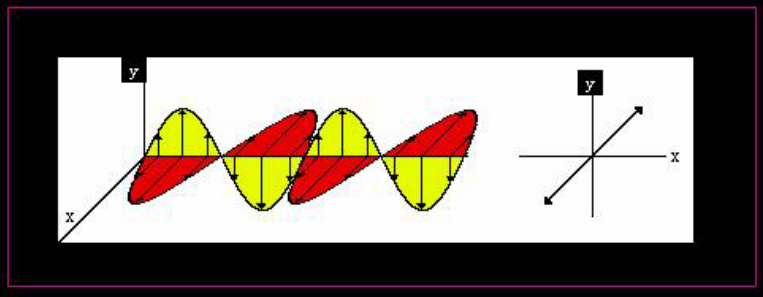
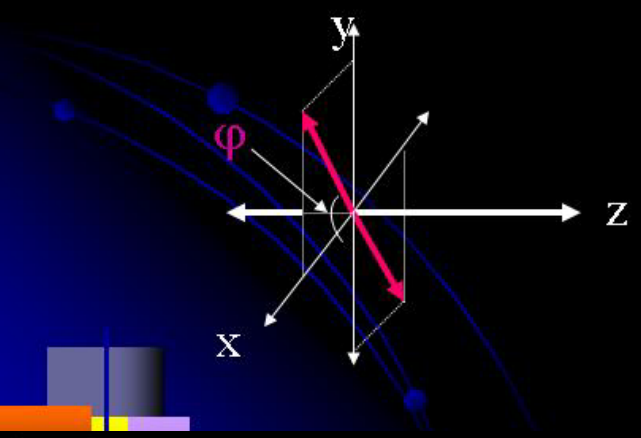
偏極化光的描述

- Jones Vectors
- Stokes Vectors
- Poincare Sphere
- Adiabadic Waveguiding

線性偏光





$E = E_x + E_y$

$E_x = A_x E_x e^{i(kz-wt)}$

$E_y = A_y E_y e^{i(kz-wt+\delta)}$

δ = E_x與E_y的相位差

= 0, 1, 2.. for LP

$\tan \varphi = E_y / E_x$

φ = 偏向角

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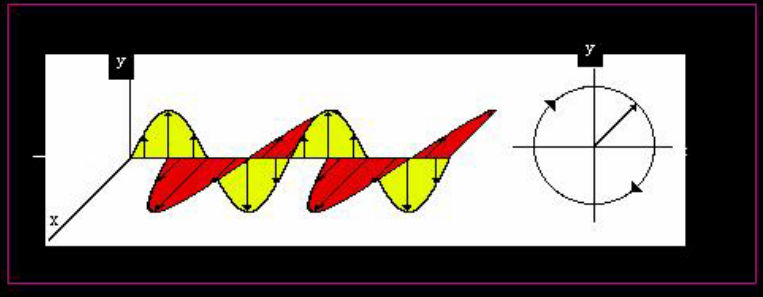
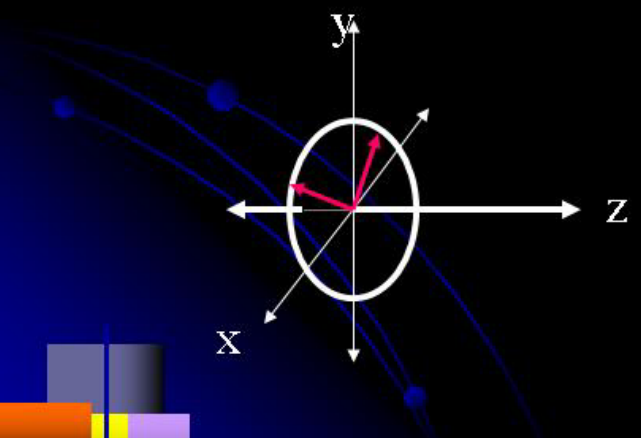
圓偏光





$E = E_x + E_y$

$E_x = AxE_x e^{i(kz-wt)}$

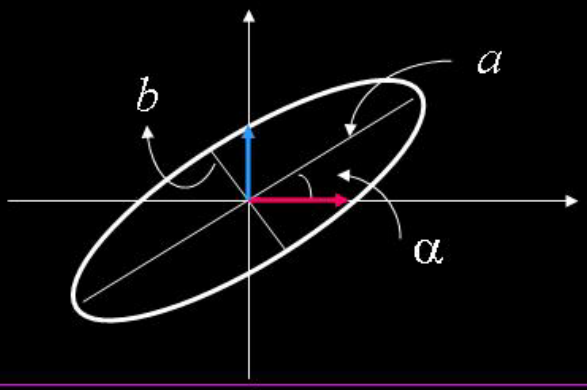
$E_y = AyE_y e^{i(kz-wt+\delta)}$

For CP

$\delta = \pm n\pi/2$, n=1, 3, 5..

$|E_x| = |E_y|$

橢圓偏光



$$(Ex/Ax)^2+(Ey/Ay)^2-2(\cos\delta/AxAy)ExEy=\sin^2\delta$$

$E_x \neq E_y$

$$\tan(2\alpha) = (2\,AxAy/\,Ax^2-Ay^2)\cos\delta,$$

$$\tan\beta = b/a$$

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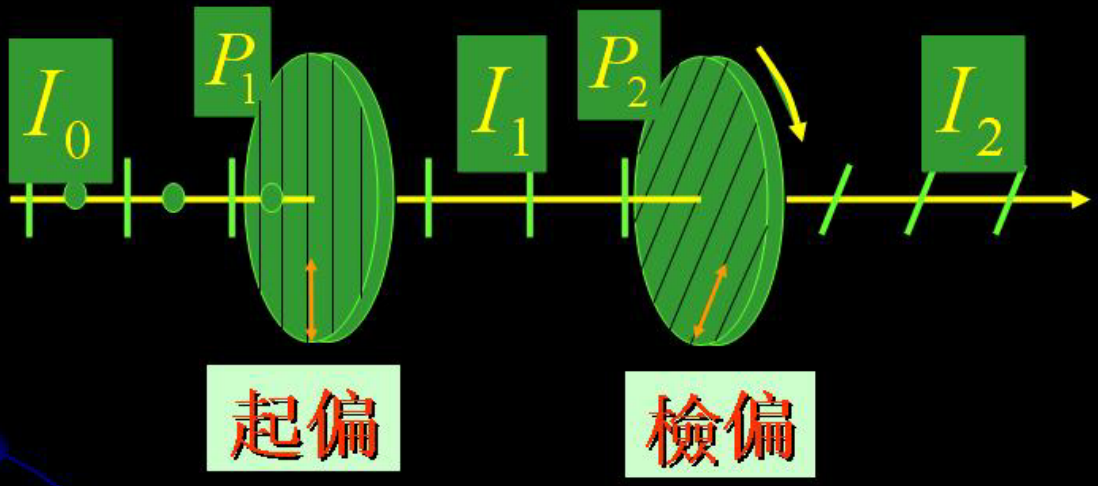
檢偏與起偏



自然光通過偏光片後成為偏光，稱為起偏

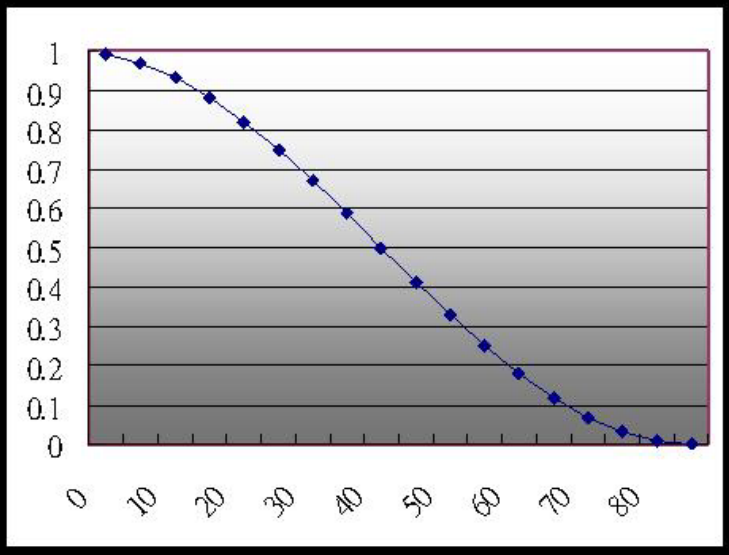
利用偏光片檢查偏光度，稱為檢偏

Malus's Law

將兩片Polaroid type polarizer交疊，
其光穿透度遵守如下公式：

$$E_T = E_o \cos\theta$$

$$I_T / I_o = \cos^2\theta$$



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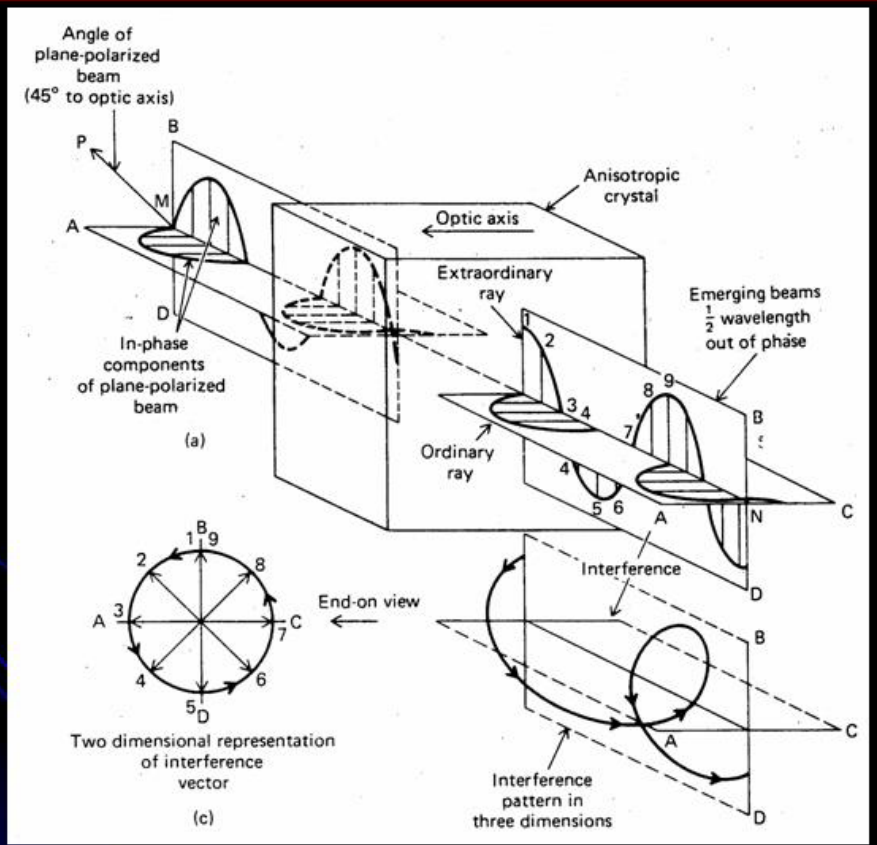
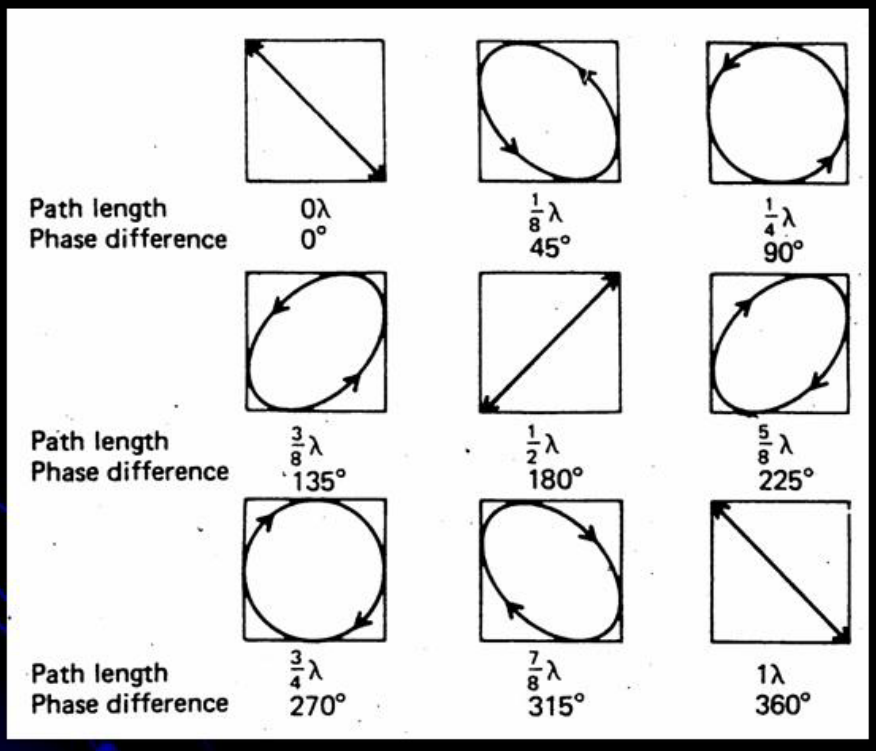
圓偏光與異向性物質



偏光的週期變化



偏光膜的原理與應用

講題內容

- 偏光膜與顯示器
- 偏光簡介
- 偏光膜之種類與原理
- 偏光膜之製造
- 偏光膜的附加功能

LCD對偏光膜之特性需求

- 廣波長範圍偏光效應
  （至少涵蓋全可見光範圍）
- 表現高偏光度
  （至少99.5%以上）
- 高透光度
  （與偏光度有關連性）
- 環境安定性
  （高溫高濕環境1000小時以上）
- 其他附加功能
  （耐刮、抗反射……）

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現有偏光膜種類
(依組成之材質分)

- 碘系偏光膜
- 染料型偏光膜
- 金屬材質偏光膜
- 共軛烯高分子偏光膜

偏光產生的方法

- 物質之二色性：單晶材料或微晶體軸向排列
- 平面反射法：控制光源入射角度
- 雙折射法：直交之偏光具有不同之光特性
- 散射法：物質具有雙折射性，光在主光軸行進

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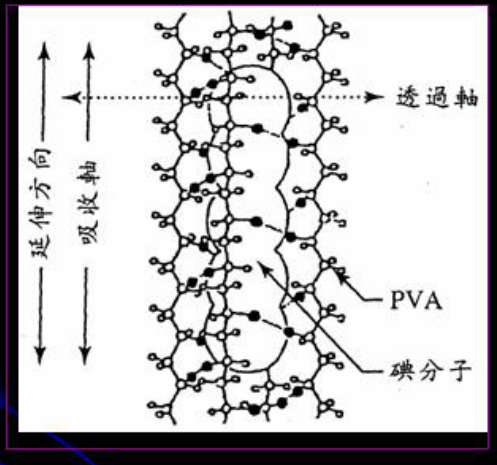
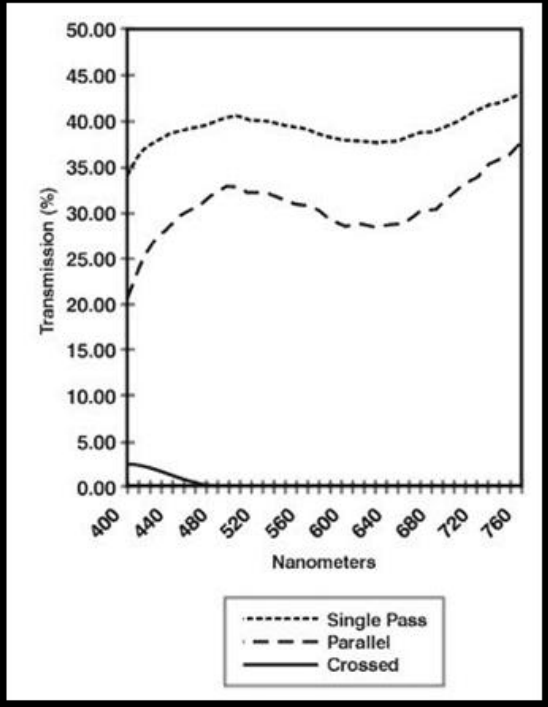
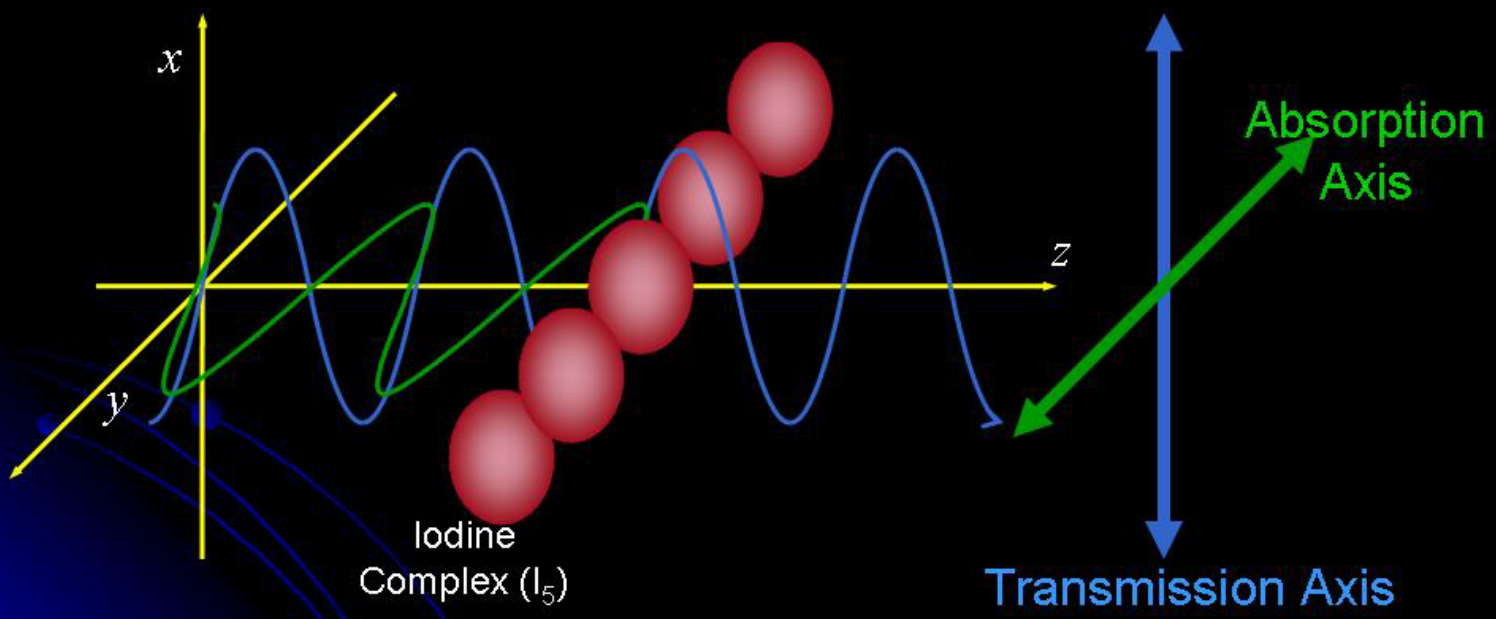
二色性法





- Invented by E.H. Land in 1928
- polarisability~100%, transmittance~40%

二色性法(2)



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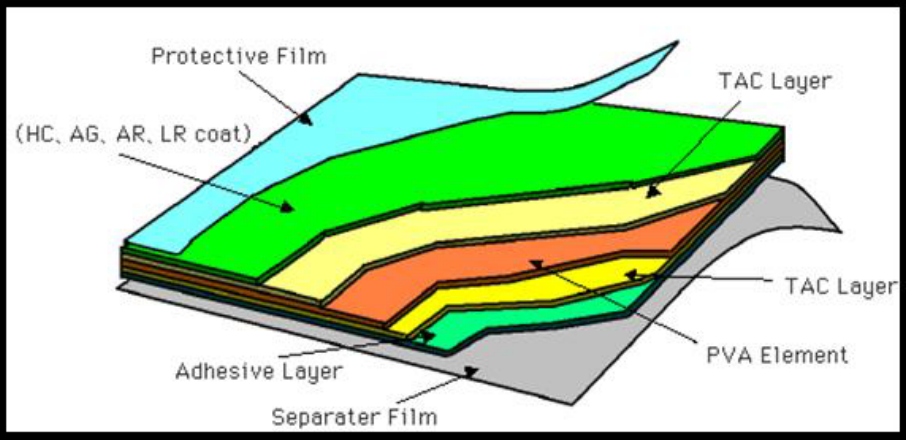
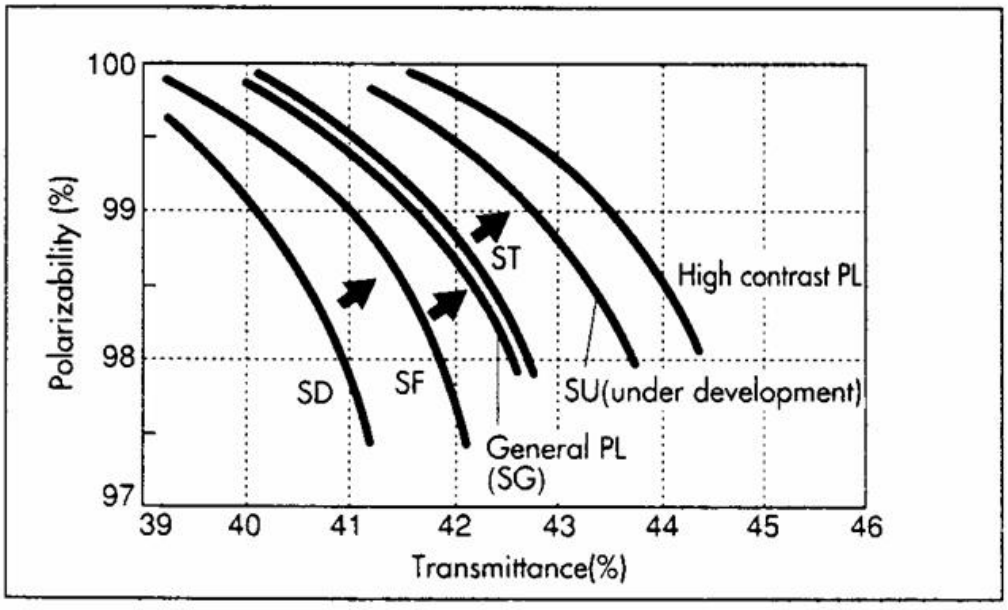
偏光膜組成材料及功能



層 別	構 成	材 料	功 用
1	表面保護膜	PE、PET	偏光膜的保護
2	保護層	Triacetyl Cellulose	偏光膜的支持及保護
3	偏光基體	10-20μm PVA 拉伸 3~5 倍並滲透碘或染料分子	偏光機制
4	保護層	Triacetyl Cellulose	偏光膜的支持及保護
5	黏著劑	EVA or polyacrylate	LCD 基板黏貼
6	分離膜	PET	黏著劑的保護

偏光膜之偏光率與穿透率



取自住友化學產品目錄

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染料系偏光膜之性能

●Optical Characteristics of Dyestuff Grade

Grade		Optical property	
		Transmittance (%)	Polaizability (%)
SF grade	SF-1812AP	38.0	99.9
	SF-18X2AP	39.5	99.7
	SF-1822AP	40.0	99.5
	SF-18Y2AP	41.0	98.5
	SF-1832AP	42.0	97.5
ST grade	ST-1812AP	38.0	100.0
	ST-18X2AP	39.5	100.0
	ST-1822AP	40.0	99.9
	ST-18Y2AP	41.0	99.7
	ST-1832AP	42.0	99.0

取自住友化學產品目錄

Nitto偏光片的分類

Type		Polarizer	Protective layer	Transmittance of Axis Single(%)	Polarizing efficiency(%)
F	General purpose	Iodine	TAC	44.6	95.7
FW	Whitening type	Iodine	TAC	44.5	97.6
G	High polarizing efficiency type	Iodine	TAC	41.5	99.97
EGW	Whitening type and high polarizing efficiency type	Iodine	TAC	44.0	99.6
HEG	High transmittance and high polarizing type	Iodine	TAC	43.2	99.95
SEG	Super transmittance and high polarizing efficiency type	Iodine	TAC	44.1	99.95
TEG	Thinner type	Iodine	TAC	44.1	99.95
Q	Medium durability type	Iodine	TAC-Acrylic resin (dual layer)	39.0	99.5
QE	High durability type	Dye	TAC-Acrylic resin (dual layer)	40.9	88.6

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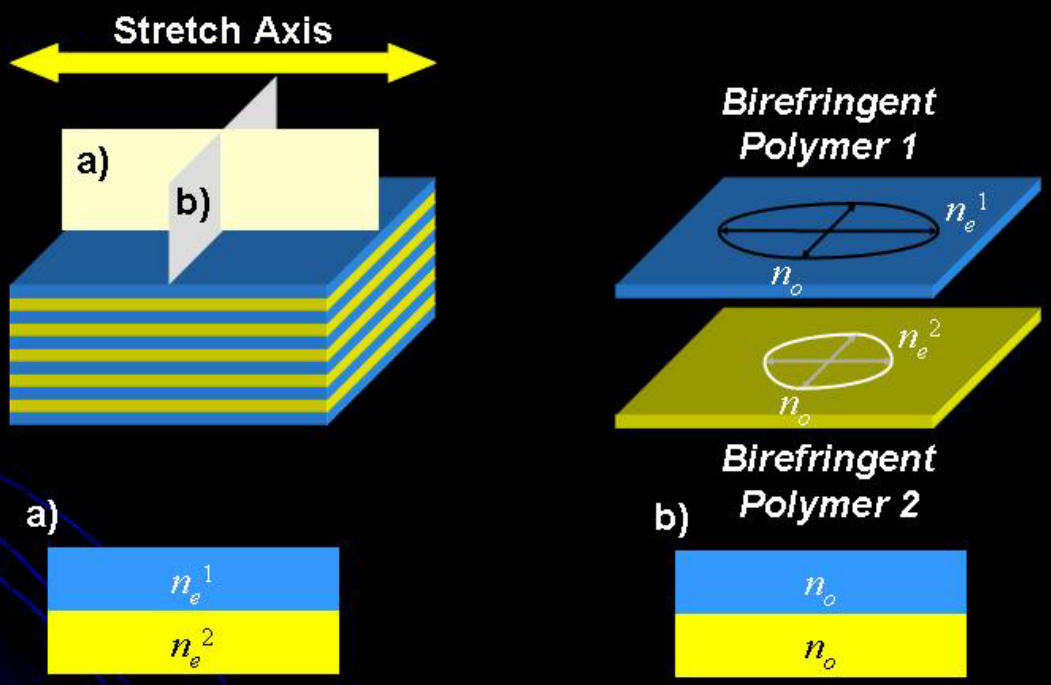
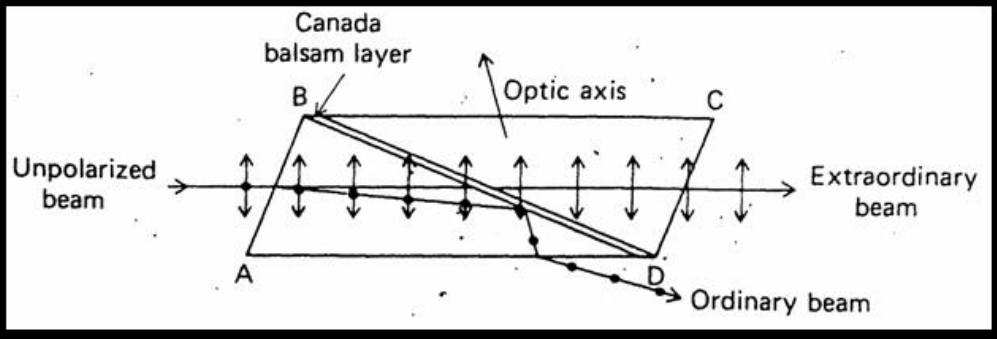
反射式偏光片(1)



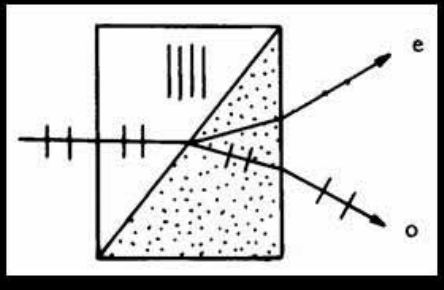
雙折射法



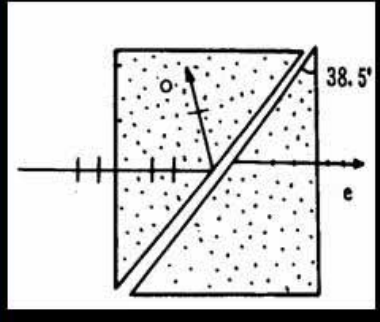
Nicol

Crystal	n_o	n_e
Calcite	1.6583	1.4864
Quartz	1.544	1.553
Ice	1.306	1.307

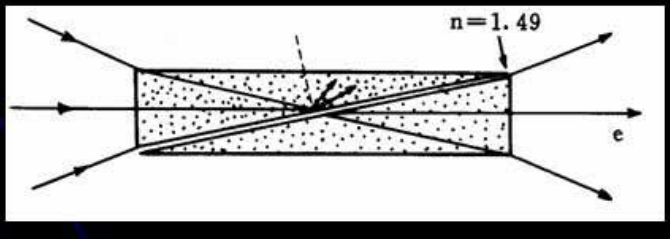
更多雙折射晶體



Rochon



Foucault



Glan-Thomson

偏光膜的原理與應用

講題內容

- 偏　光　簡　介
- 偏光膜與顯示器
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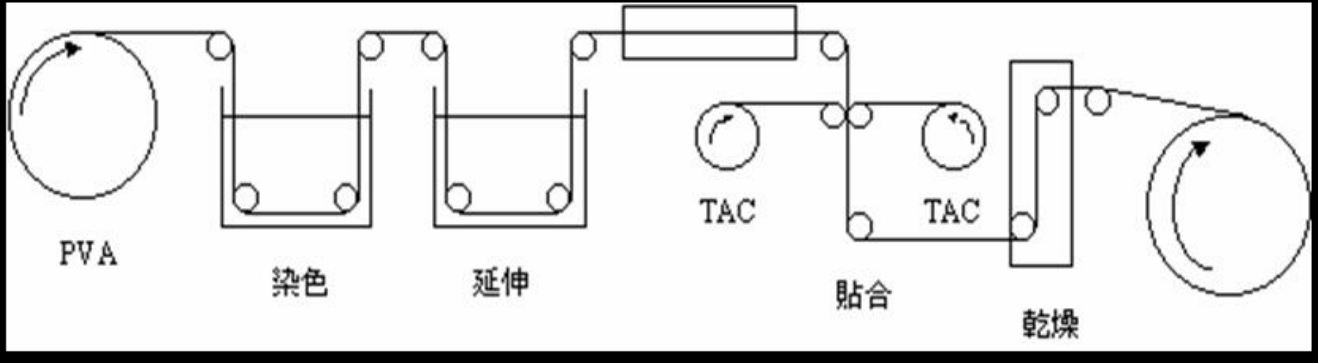
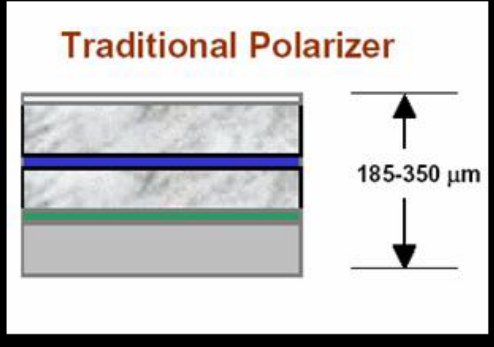
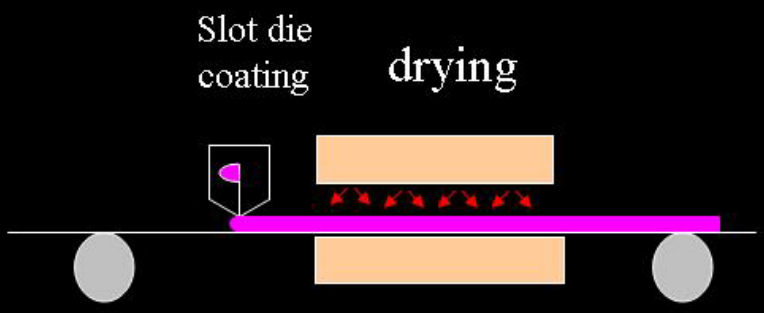
偏光片之拉伸製程

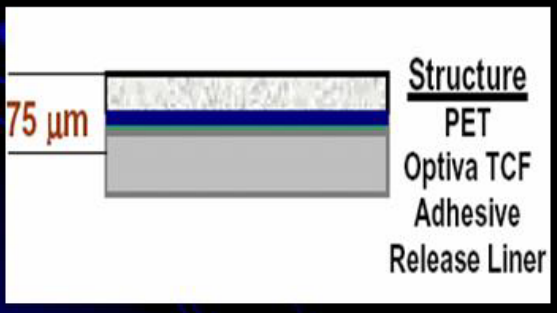


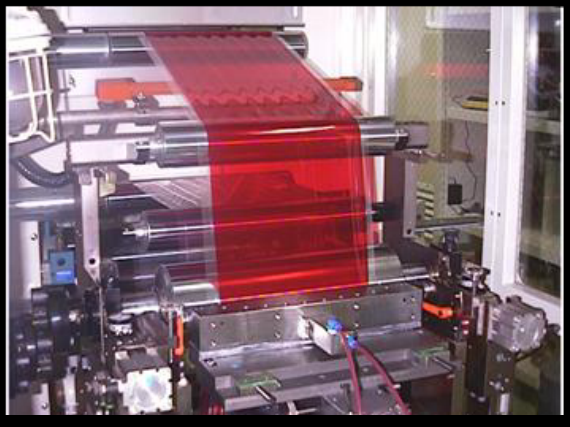
1.PVA膜在染色槽中含浸可起偏的成分(例如 碘離子、染料)
2.在拉伸槽中做精密延伸使偏光膜產生光學異方性
3.經過烘箱烘乾後兩測以TAC膜貼合
4.經過最後的乾燥後、收捲起來
5.加上黏附用的光學膠及上下保護膜、總厚度約爲0.185-0.35mm



偏光片的塗佈製程







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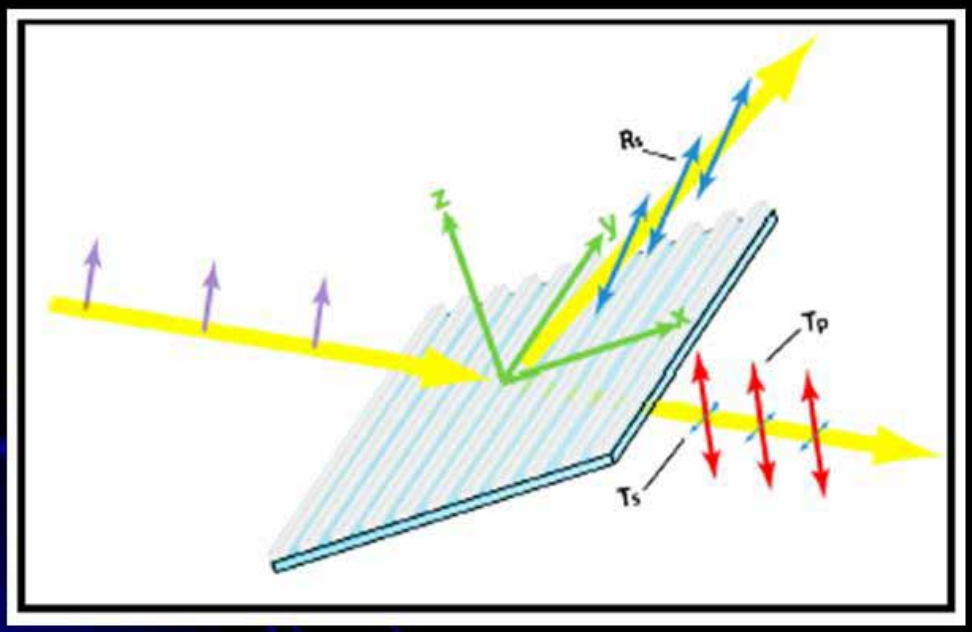
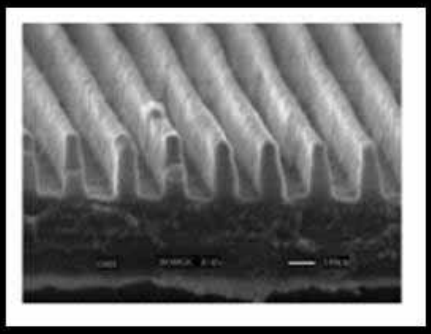
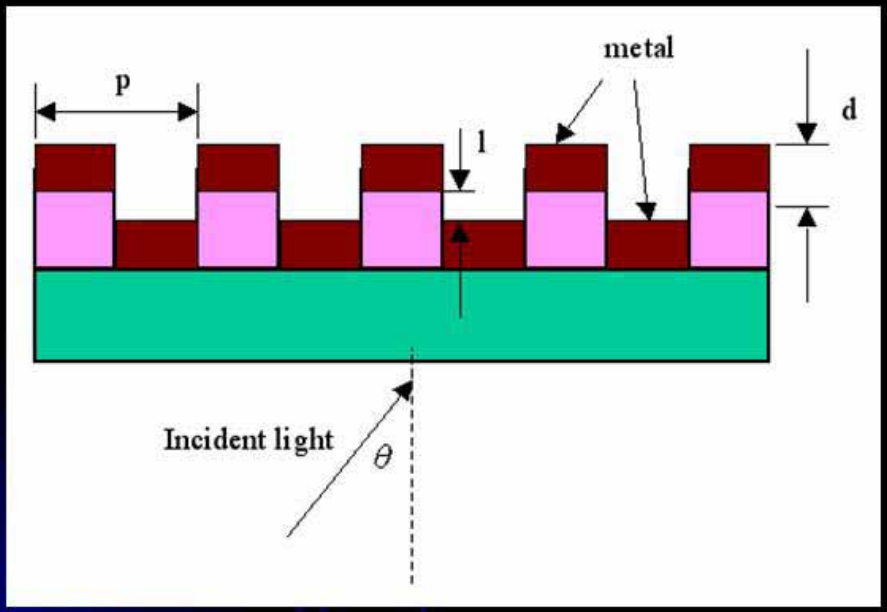
Optiva's TCF 運作原理

金屬光柵式偏光板





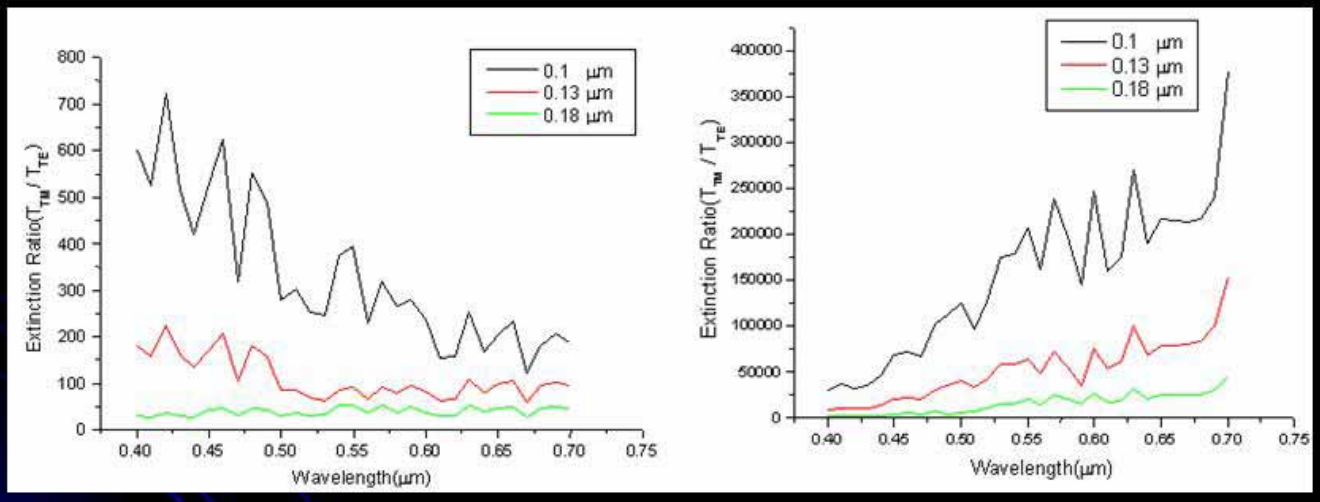
MRL 雙層金屬型偏光片



Parameters:
- pitch of grating
- light incident angle
- gap of metal layers
- metals
- line/space ratio

光柵型偏光片的模擬

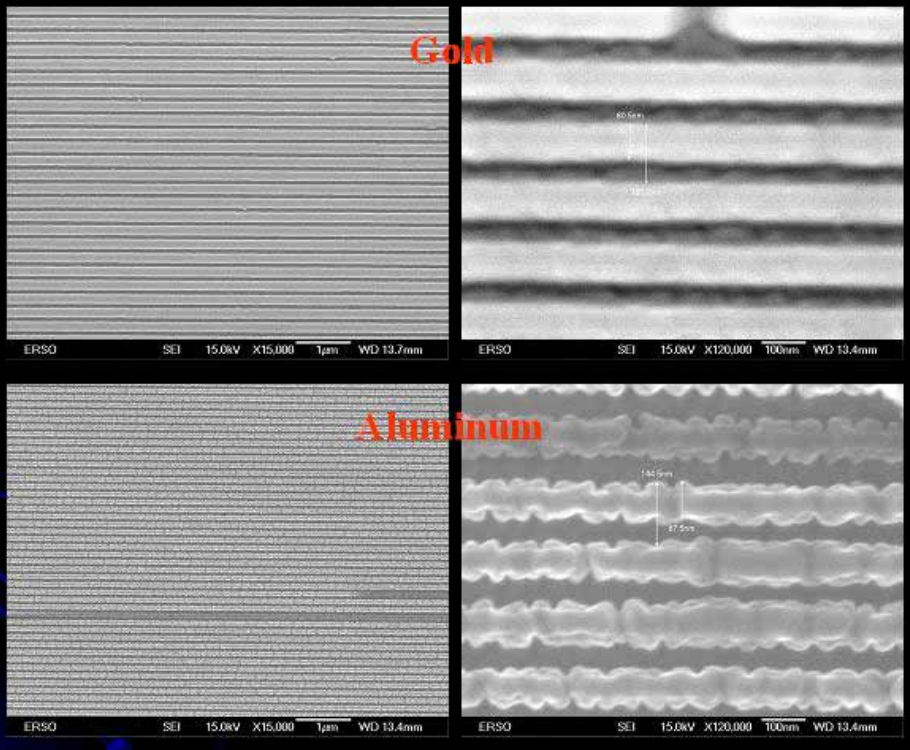
Commercial available software of "G-Solver" (from Grating Solver Development) to calculate the relationship of diffraction efficiency and feature size of the nano-grating structures.



Extinction ratio of the single layer metal nano-grating polarizer as a function of wavelength for different grating pitch.

Extinction ratio of the double layer metal nano-grating polarizer as a function of wavelength for different grating pitch.

雙層金屬偏光片SEM圖



偏光膜的原理與應用

講題內容

- 偏　光　簡　介
- 偏光膜與顯示器
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- 偏光膜的附加功能

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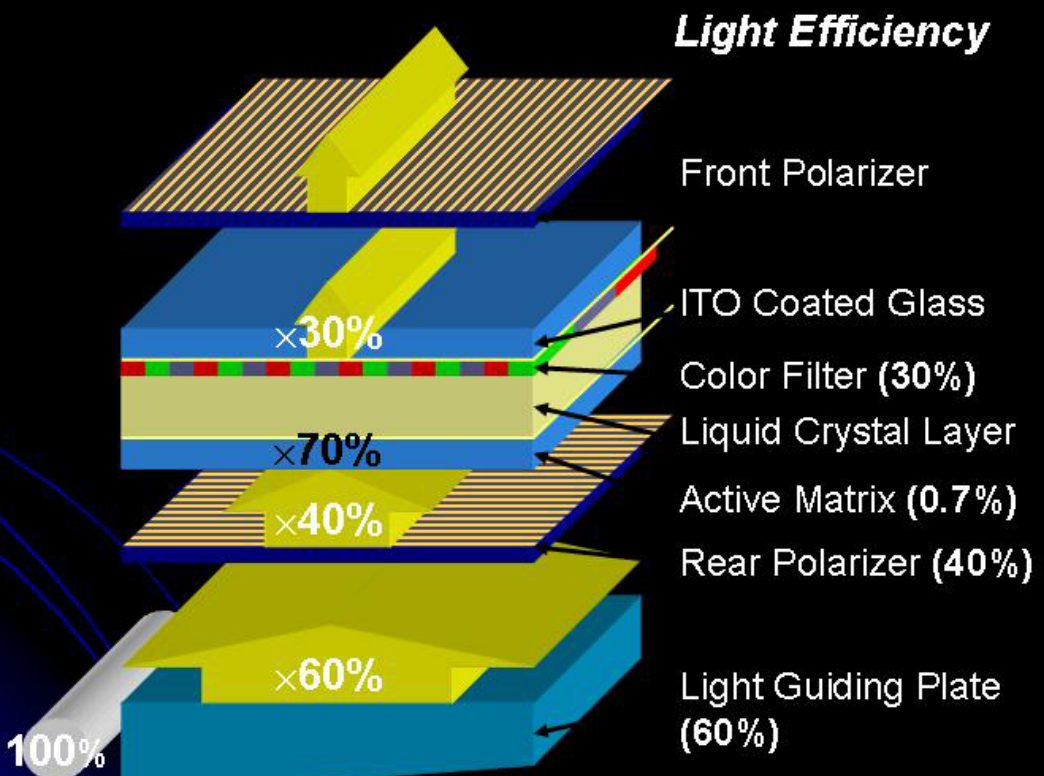
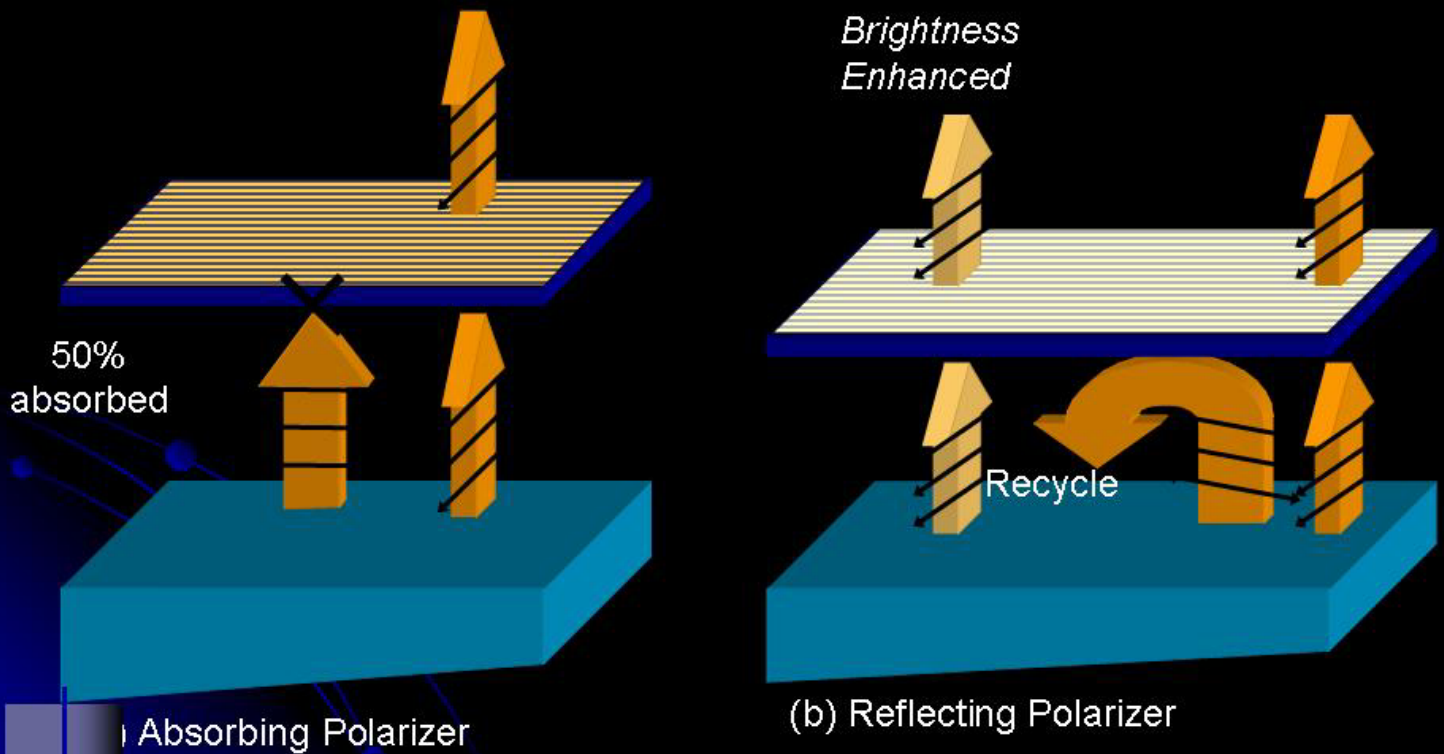
增亮(1)

Light Efficiency in LCDs

$0.60 \times 0.40 \times 0.70 \times 0.30 = \mathbf{0.05}$



偏光轉換法



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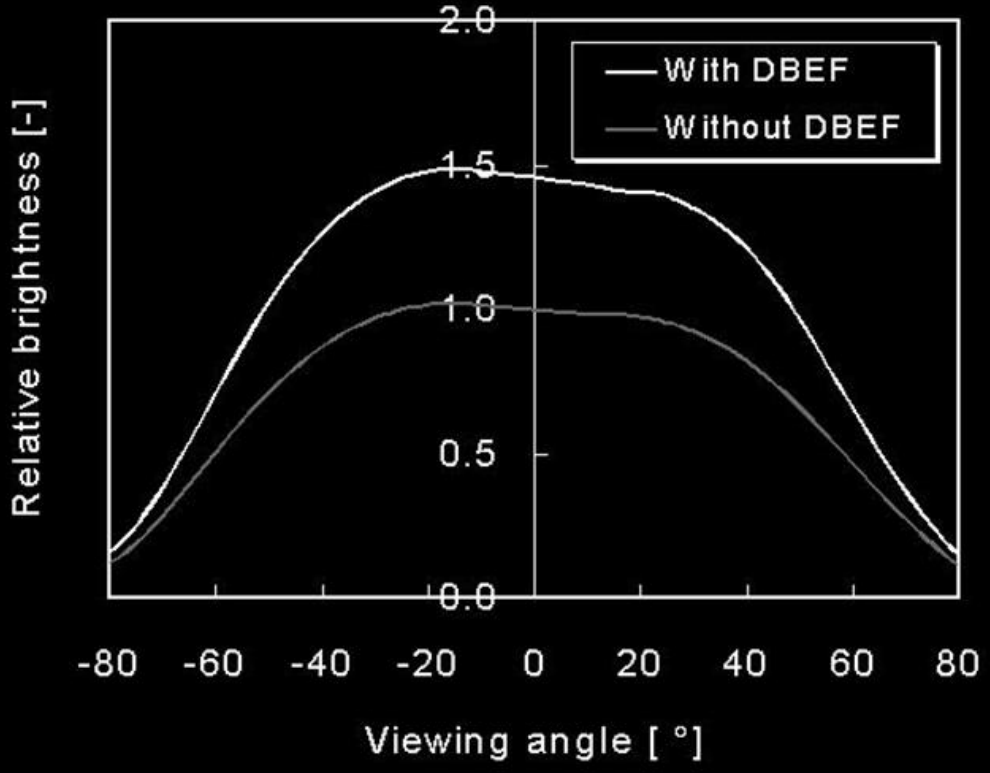
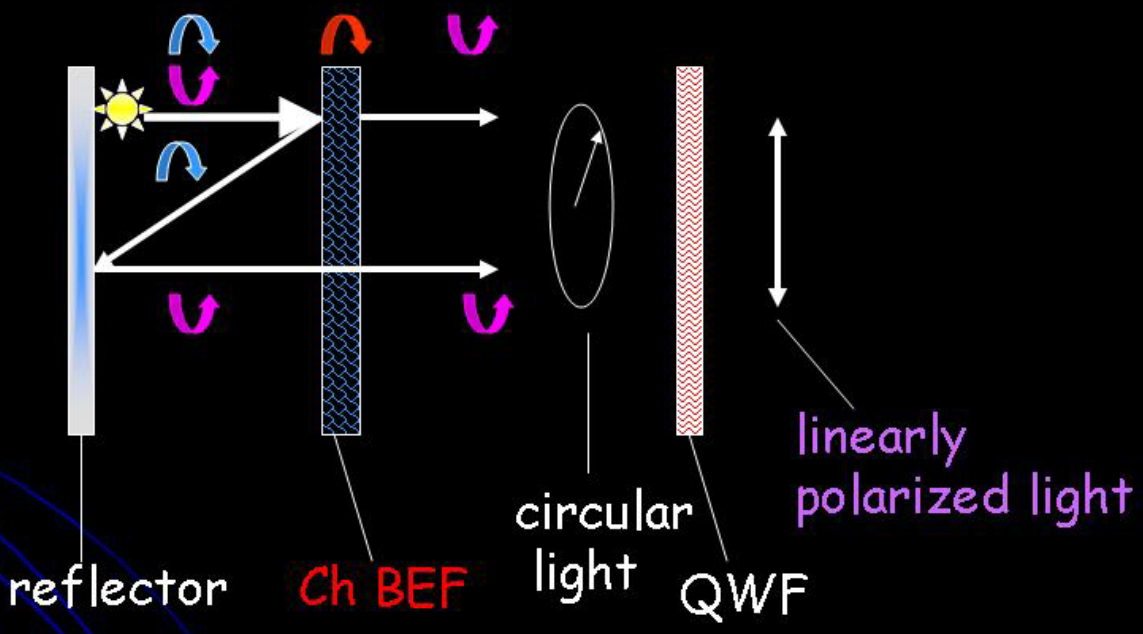
DBEF增亮效能



Cholesteric LC Brightness Enhancing Film



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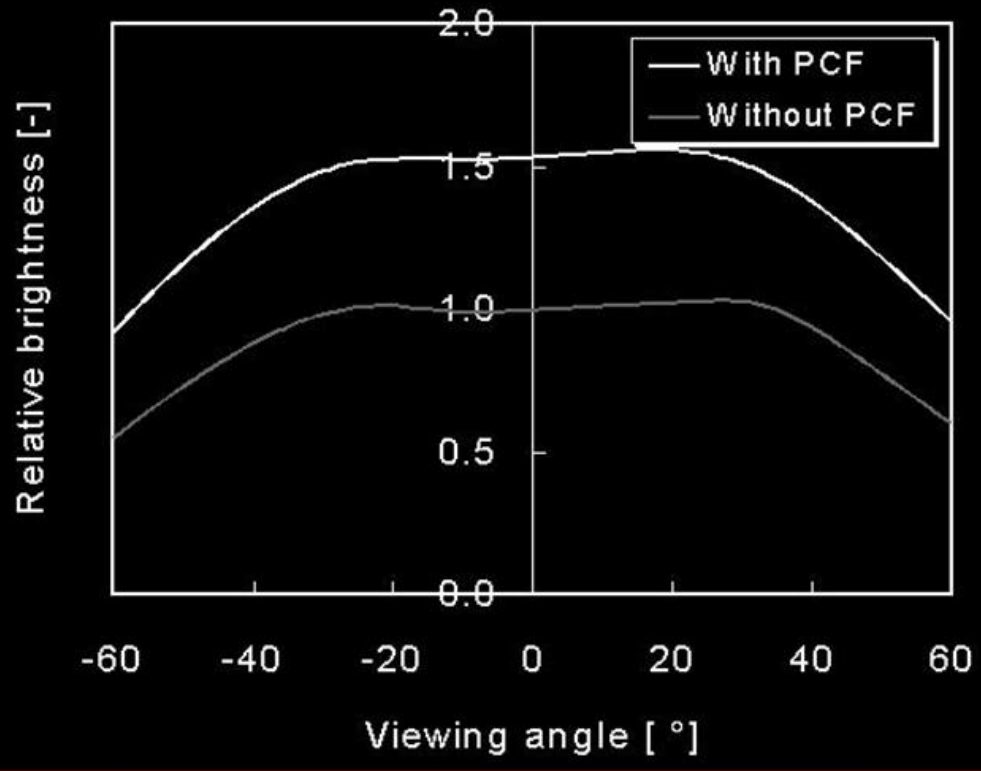
NIPOCS增亮效能



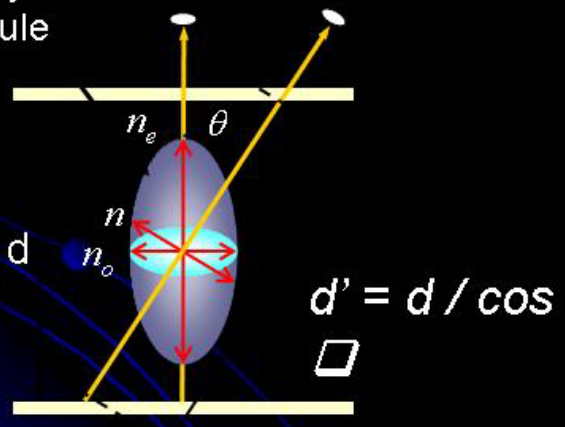
Viewing Angle Compensation Film

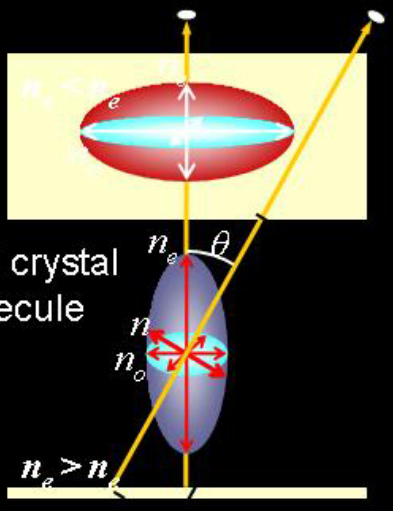
Retardation Differences

In Viewing Angles

C – Plate Compensation

Liquid crystal molecule





Liquid crystal molecule

Biaxially Stretched Polymer Film (C-Plate)

LC Cell

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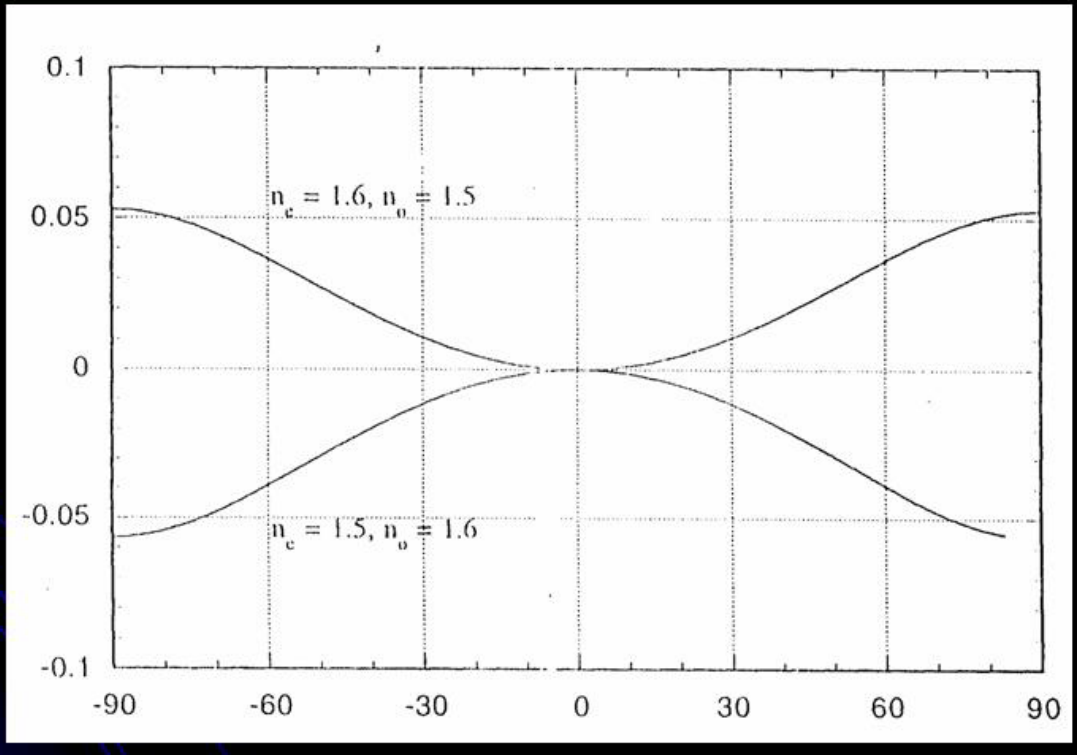
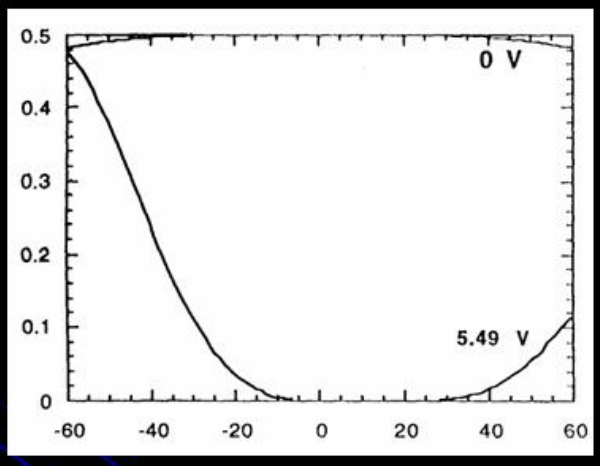
LCD廣視角膜補償原理概念



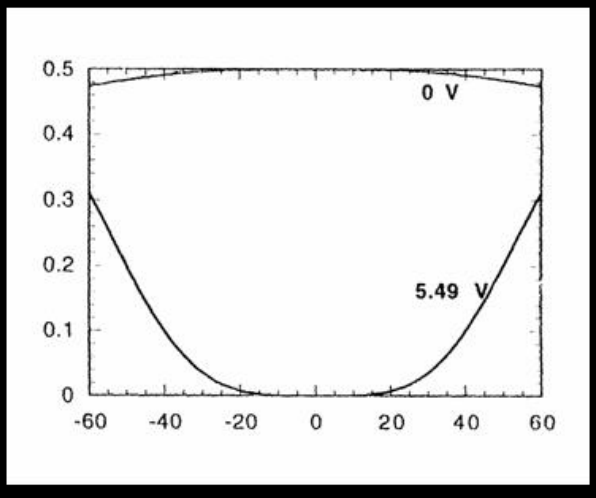
NW TN-LCD之視角特性
(Un compensated)

T



Viewing angle
(vertical)

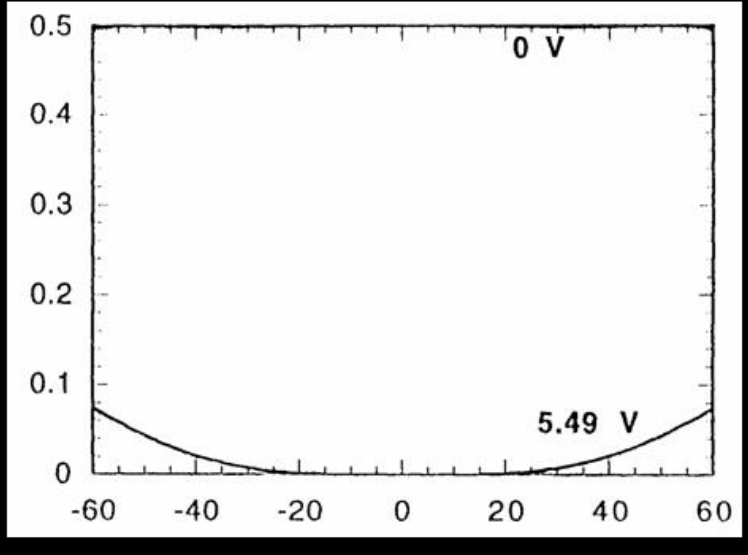
T



Viewing angle
(horizontal)

NW TN-LCD之視角特性
(Compensated/optical symmetry adjustment)

Transmmitance



Viewing angle
(horizontal)

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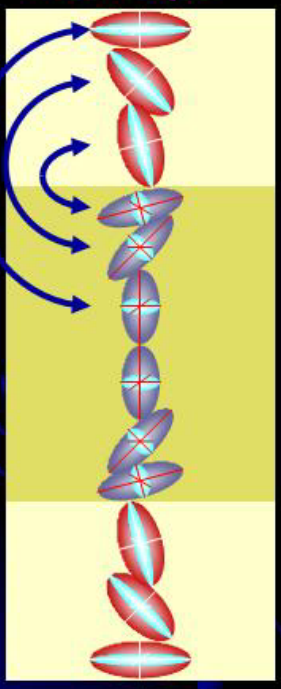
Wide View Film
(FUJIFILM)

Concept

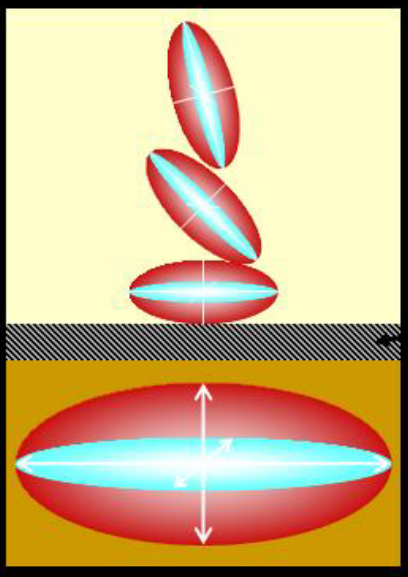


Compensation Film

TN-LC Cell

Compensation Film

Structure of the Wide View Film



Compensation Film

Alignment Layer

Substrate (TAC)

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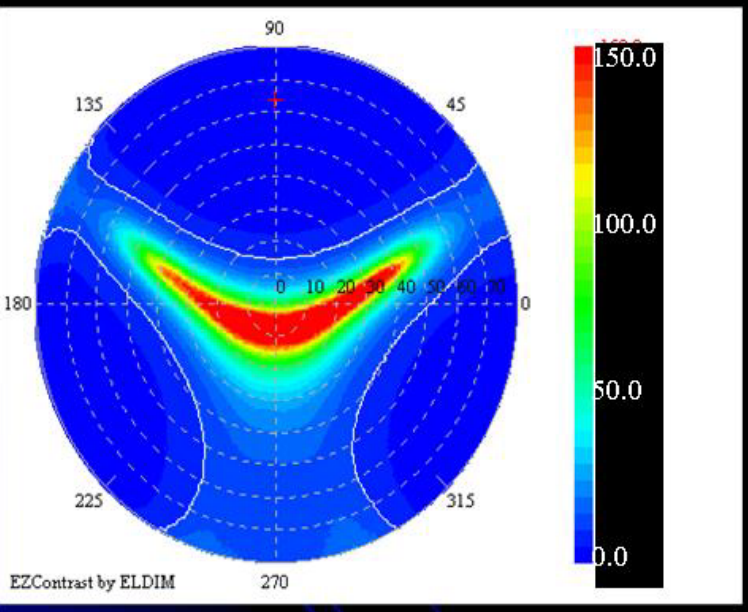
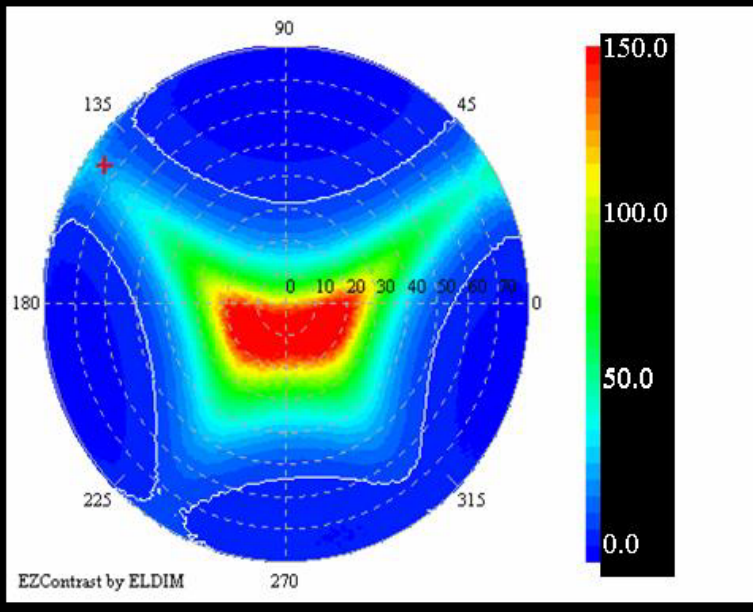
廣視角補償膜

Viewing Angle Improvement with the Wide View Film



補償前



補償後

膽固醇型液晶(Cholesteric ; Ch) I

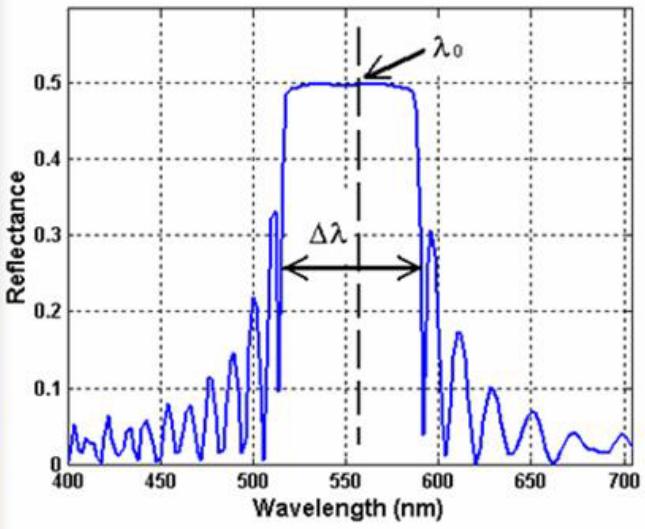
- 具有向列型液晶和層型液晶的特徵。
- 具有不對稱中心，又被稱為Chiral Nematic。
- 節距(Pitch):其節距大小大約與可見光的波長相同，可見光通過時會產生布拉格反射(Bragg reflection) 。

What is Cholesteric Liquid Crystal?

- Cholesteric liquid crystal has rod-like molecules in planar structure that are spiral arranged.
- This chiral structure has a periodicity P_o, which is known as the pitch length.

Why Cholesteric Liquid Crystal?

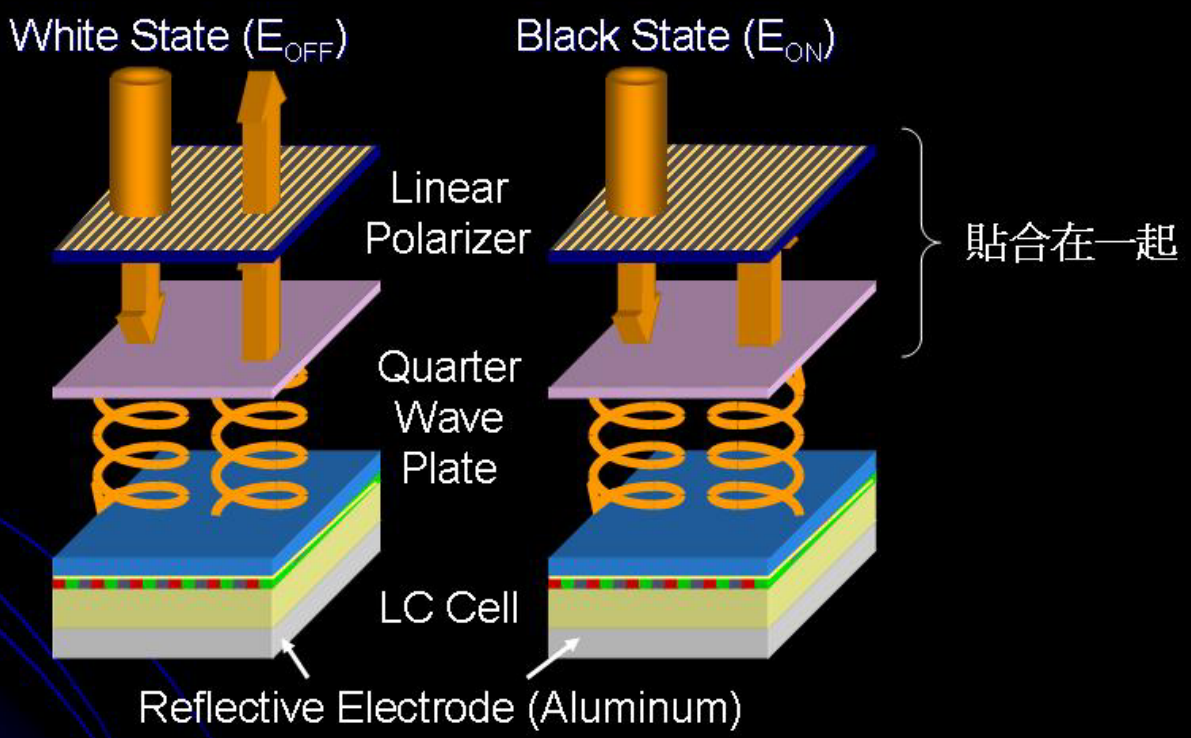
Bragg reflection.



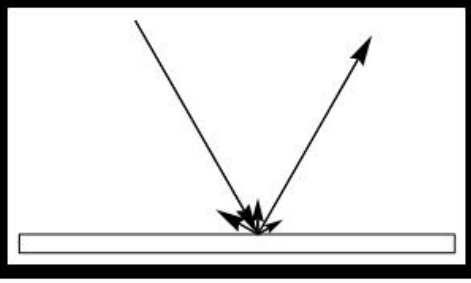
- For left-hand cholesteric liquid crystal,
  - ✓ only left-hand circularly polarized (LCP) incident light is strongly reflected.
  - ✓ the central reflected wavelength according to Maxwell theory is at
    $$\lambda_0 = nP_0 \cos\theta,$$
  - ✓ the reflected bandwidth is
    $$\Delta\lambda = \Delta n \cdot P;$$
  - ✓ the other is transmitted without significant reflection.

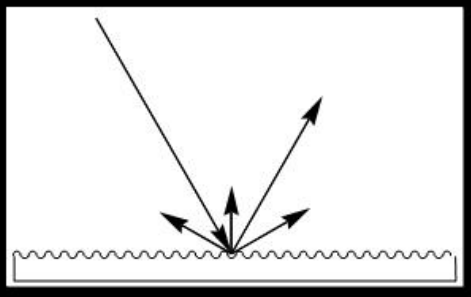
However, only 20-30 nm is effectively reflected in natural state.

反射式LCD用偏光片

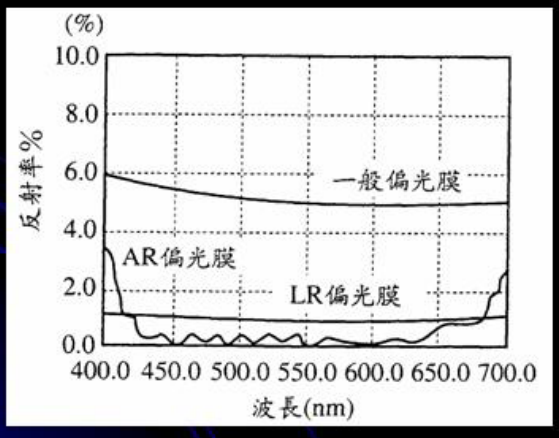


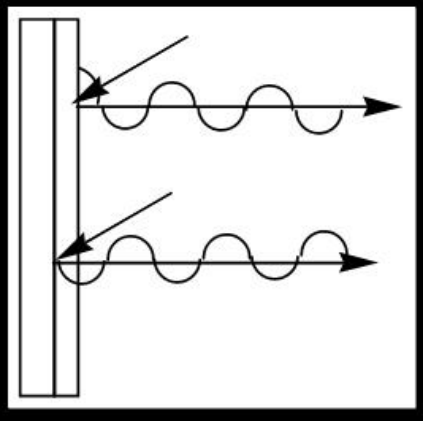
AG 及 AR 處理





Antiglare



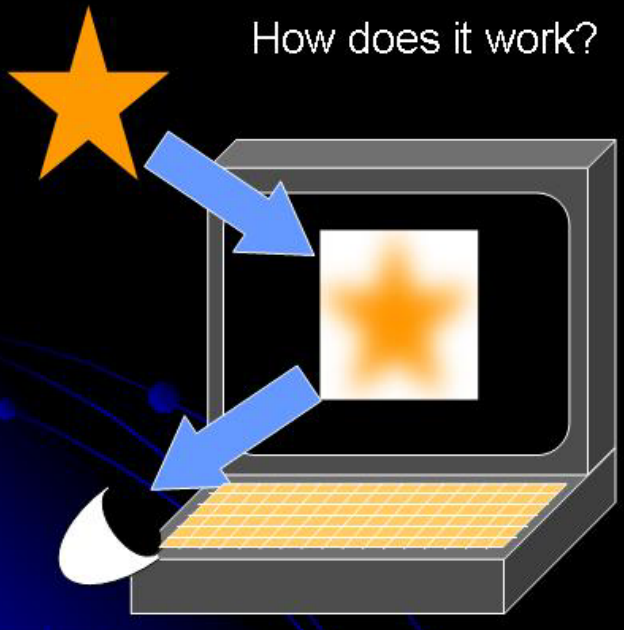


Antireflection

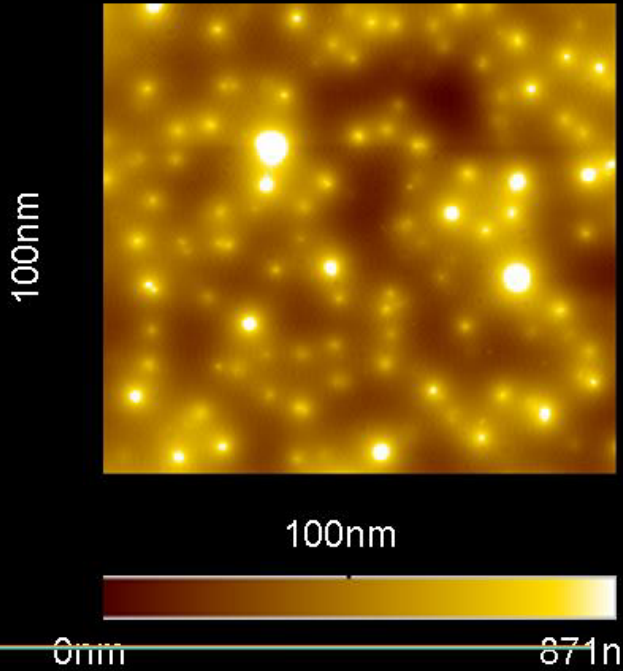
工業技術研究院
工業材料研究所
Industrial Technology Research Institute
Materials Research Laboratories

Anti–Glare Film

How does it work?

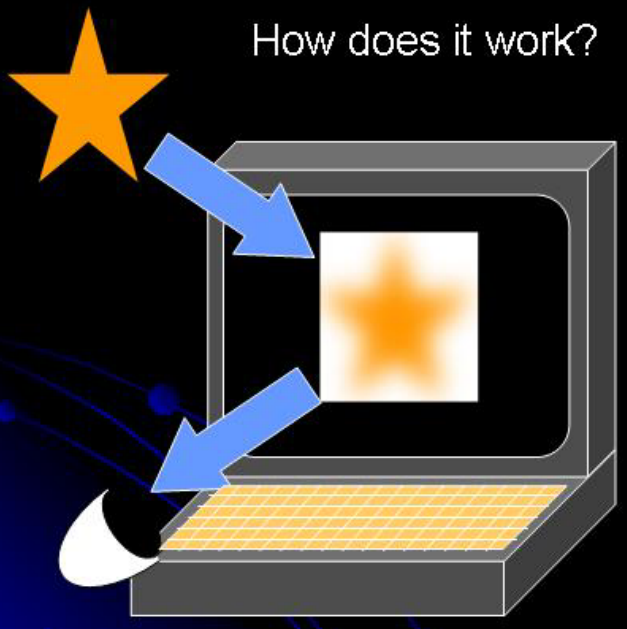


Surface structure of AG Film

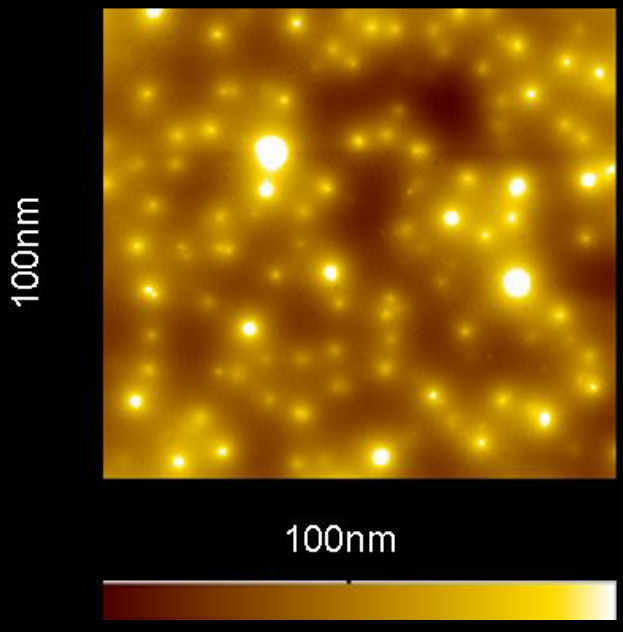


Anti–Glare Film

How does it work?



Surface structure of AG Film



謝謝各位

請指教