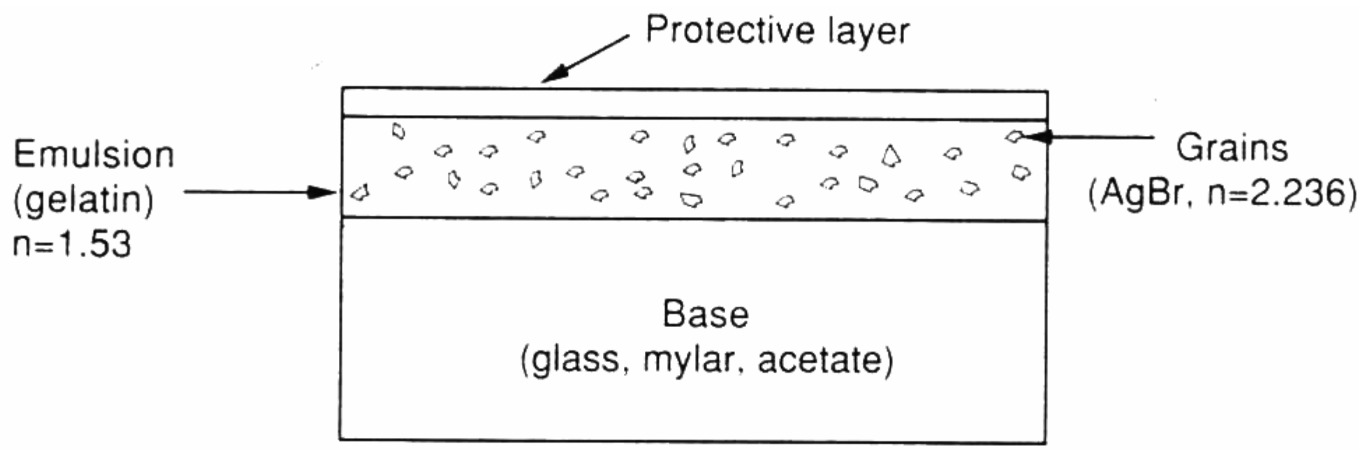
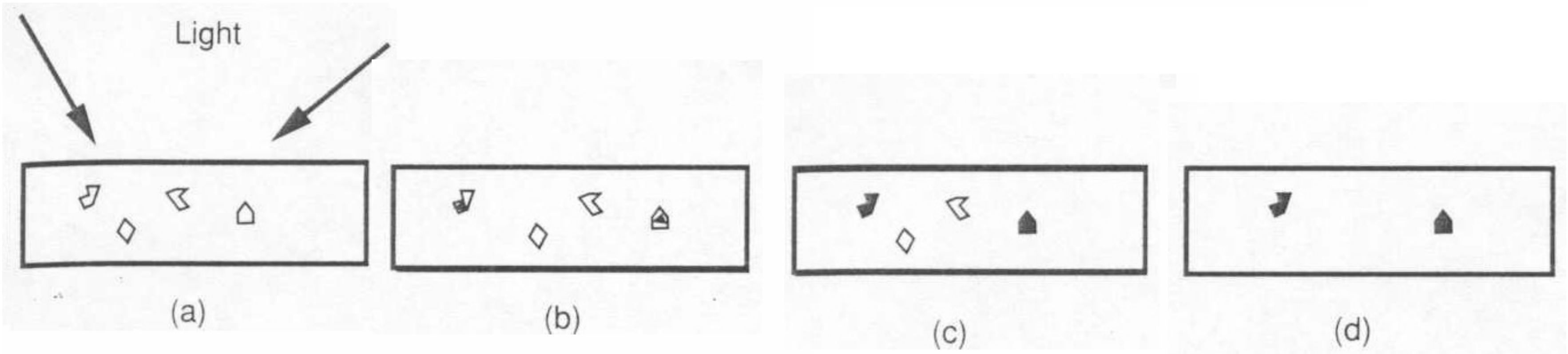
7. Wavefront Modulators and Detectors

Photographic Film (I)





Exposure Latent image After development After fixing

Photographic Film (II)

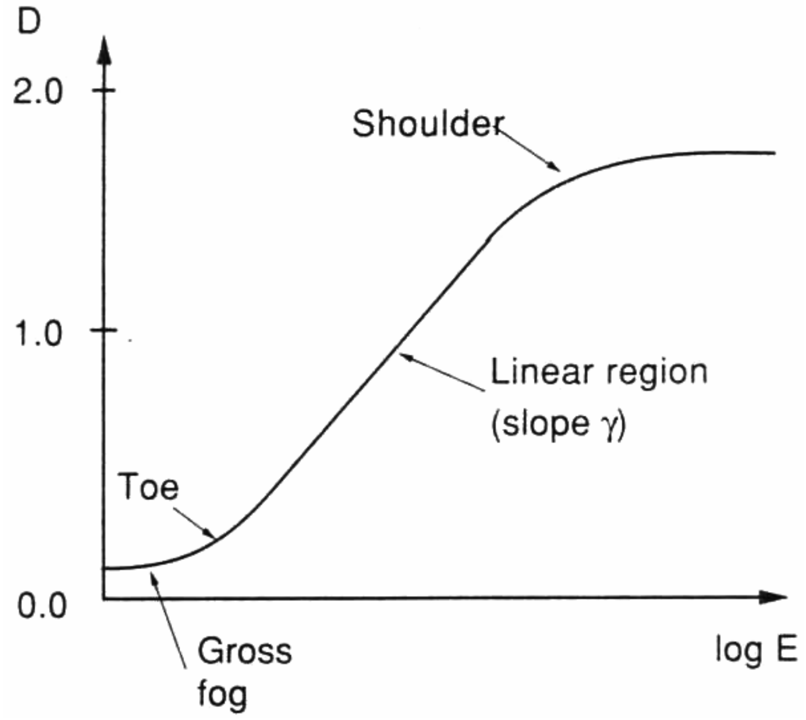
- Exposure $E(x,y) = I(x,y)T$

- Intensity Transmittance

$$\tau(x,y) = \underset{\text{average}}{\text{local}} \left\{ \frac{I \ \text{transmitted at} \ (x,y)}{I \ \text{incident at} \ (x,y)} \right\}$$

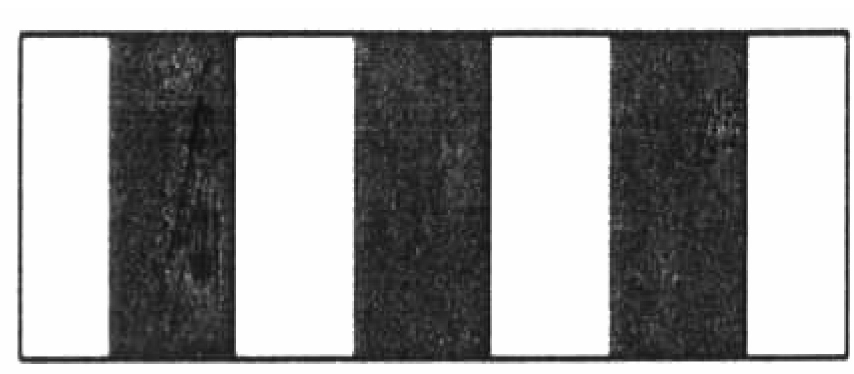
- Photographic density

$$D = \log_{10}\left(\frac{1}{\tau}\right)$$

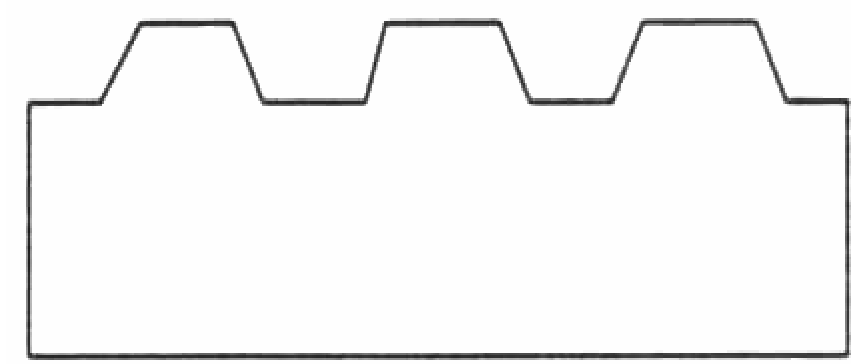


Hurter–Driffield curve

Bleaching of Photographic Emulsions



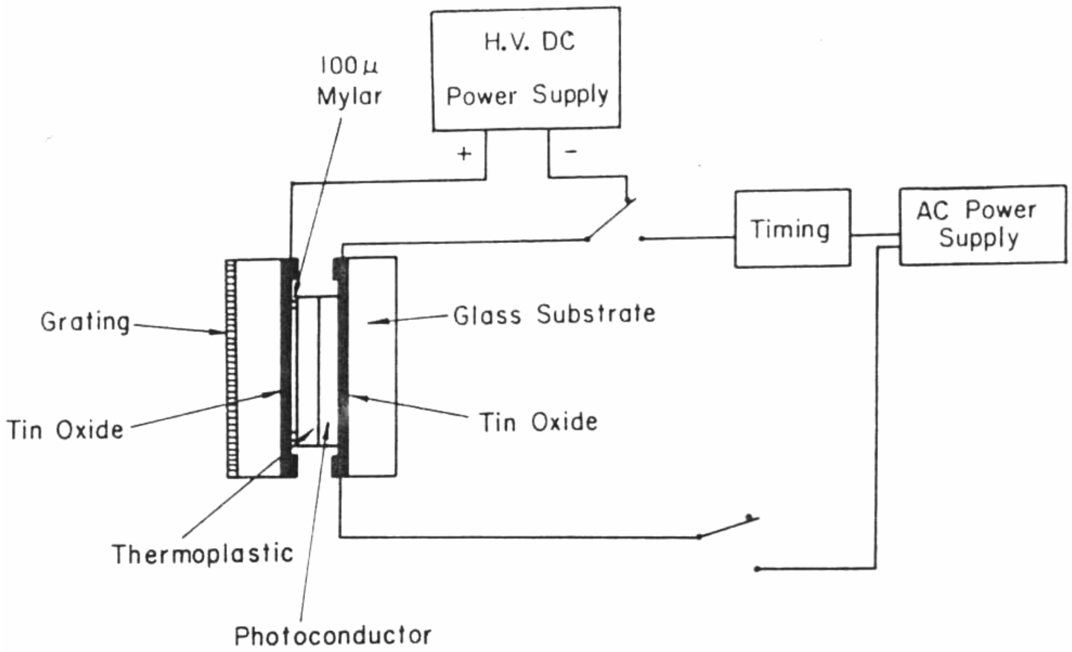
(a)

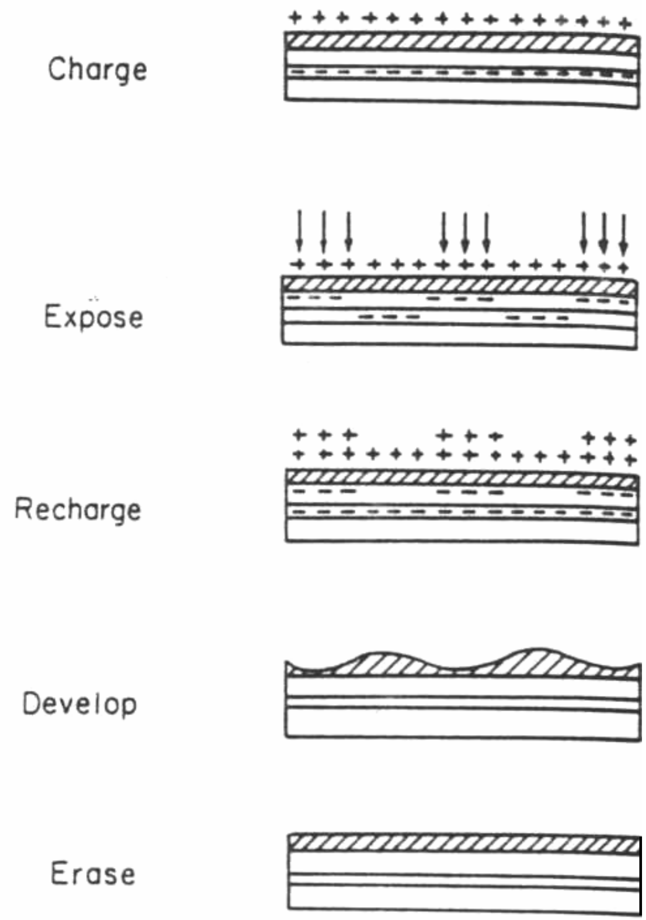


(b)

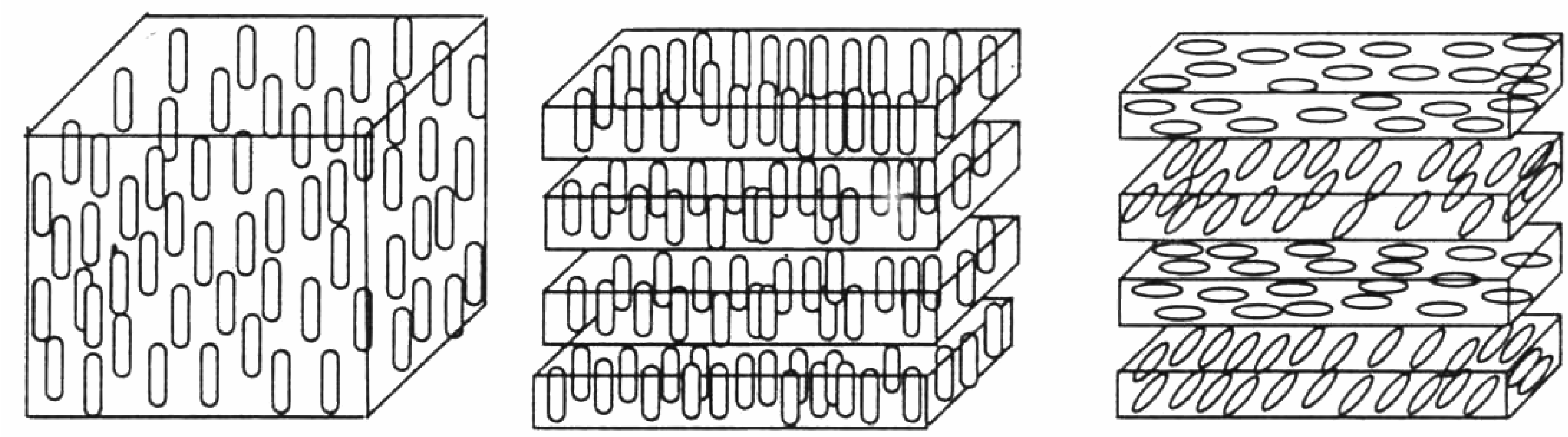
Tanning bleach

Photoplastic Device





Liquid Crystal (I)

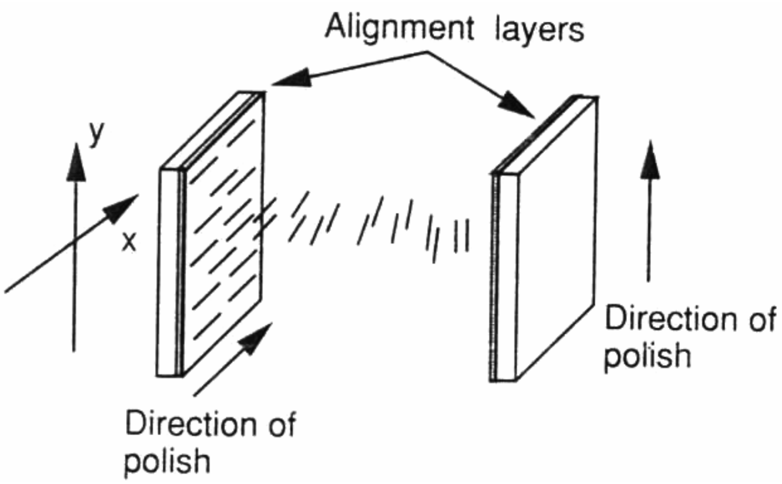


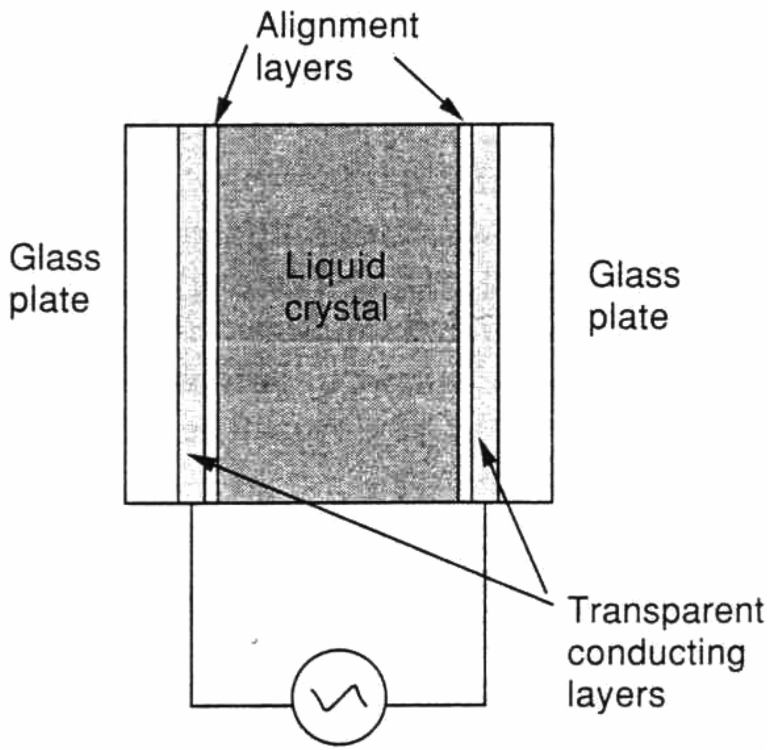
(a) Nematic LC

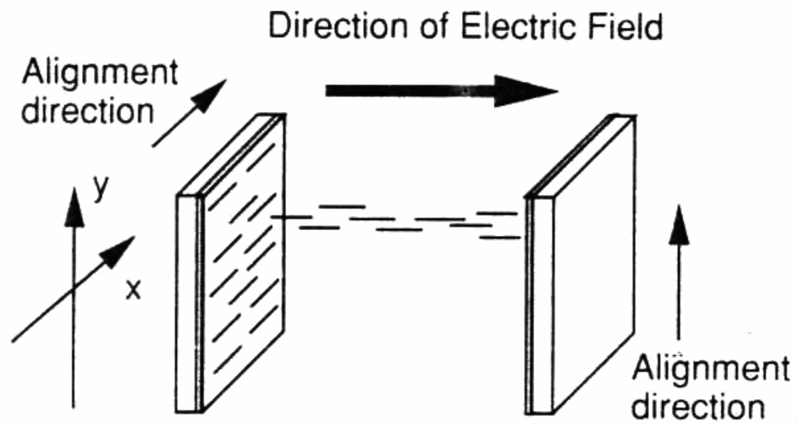
(b) Smectic LC

(c) Cholesteric LC

Liquid Crystal (II)

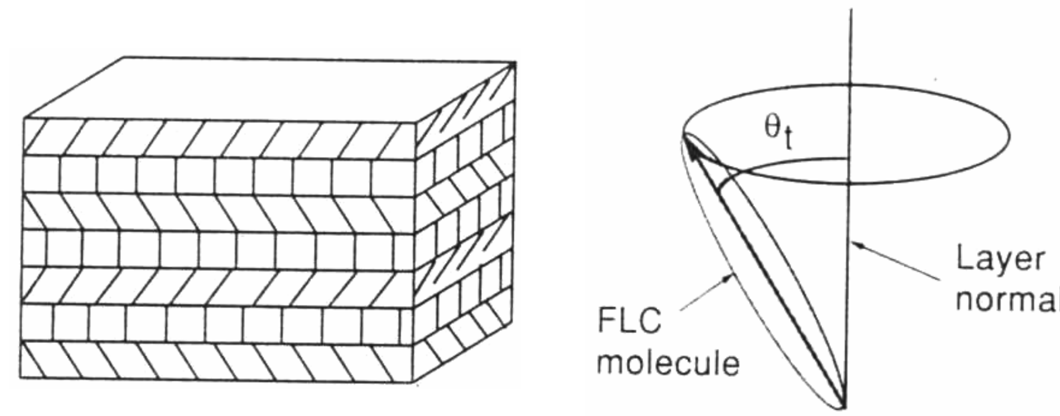


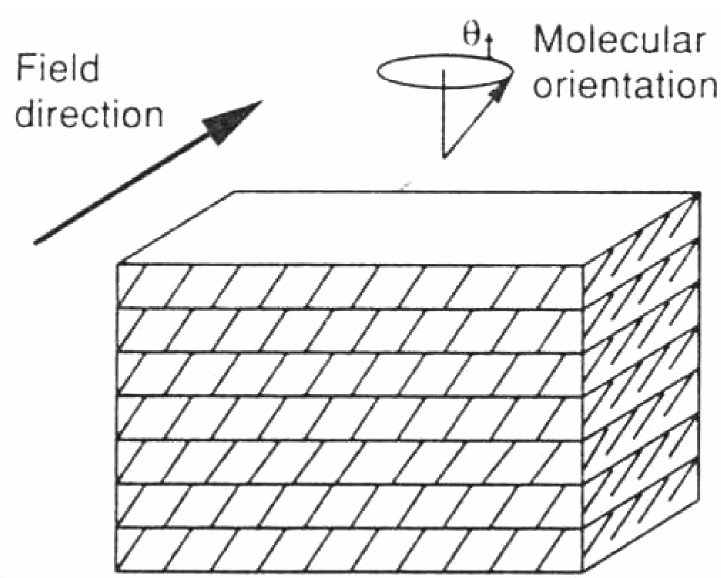


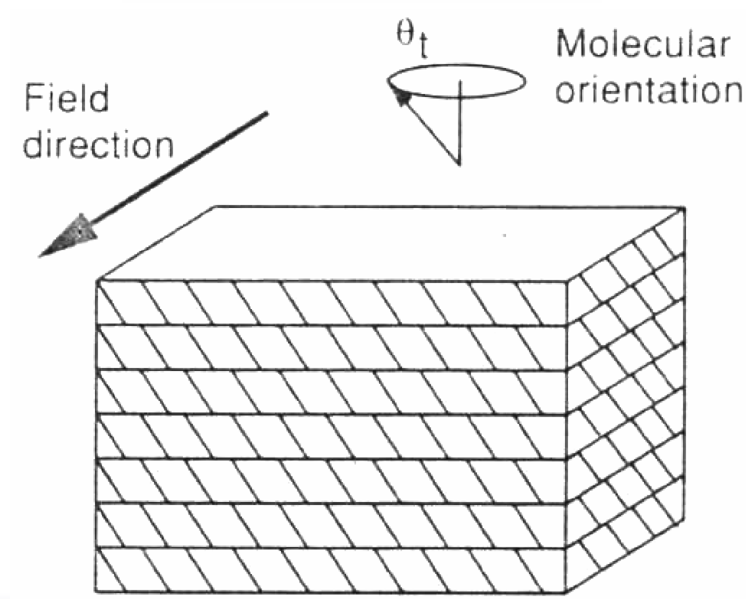


Liquid Crystal (III)

Ferroelectric
liquid crystal







Jones Calculus (I)

$$\vec{U} = \begin{bmatrix} U_X \\ U_Y \end{bmatrix}$$

$$\text{Linearly polarized in the } x \text{ direction}: \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$\text{Linearly polarized in the } y \text{ direction}: \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$\text{Linearly polarized at} +45 \text{ degrees}: \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

$$\text{Right-hand circularly polarized}: \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -j \end{bmatrix}$$

$$\text{Left-hand circularly polarized}: \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ j \end{bmatrix}$$

$$\vec{U}' = \mathbf{L}\vec{U} = \begin{bmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{bmatrix} \vec{U}$$

Jones Calculus (II)

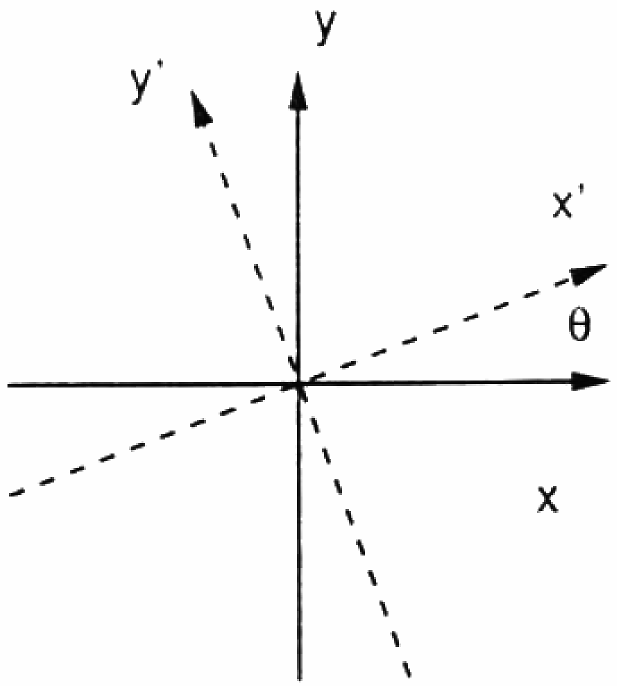
$$\mathbf{L} = \mathbf{L}_N \cdots \mathbf{L}_2 \mathbf{L}_1$$

$$\mathbf{L}_{rotate}(\theta) = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

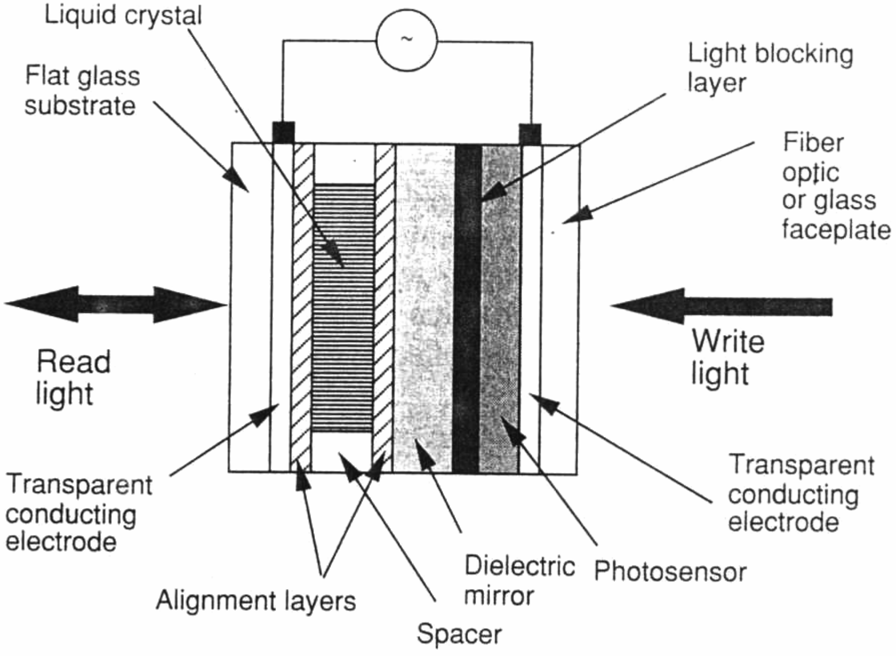
$$\mathbf{L}_R(\theta) = \mathbf{L}_{rotate}(-\theta) = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

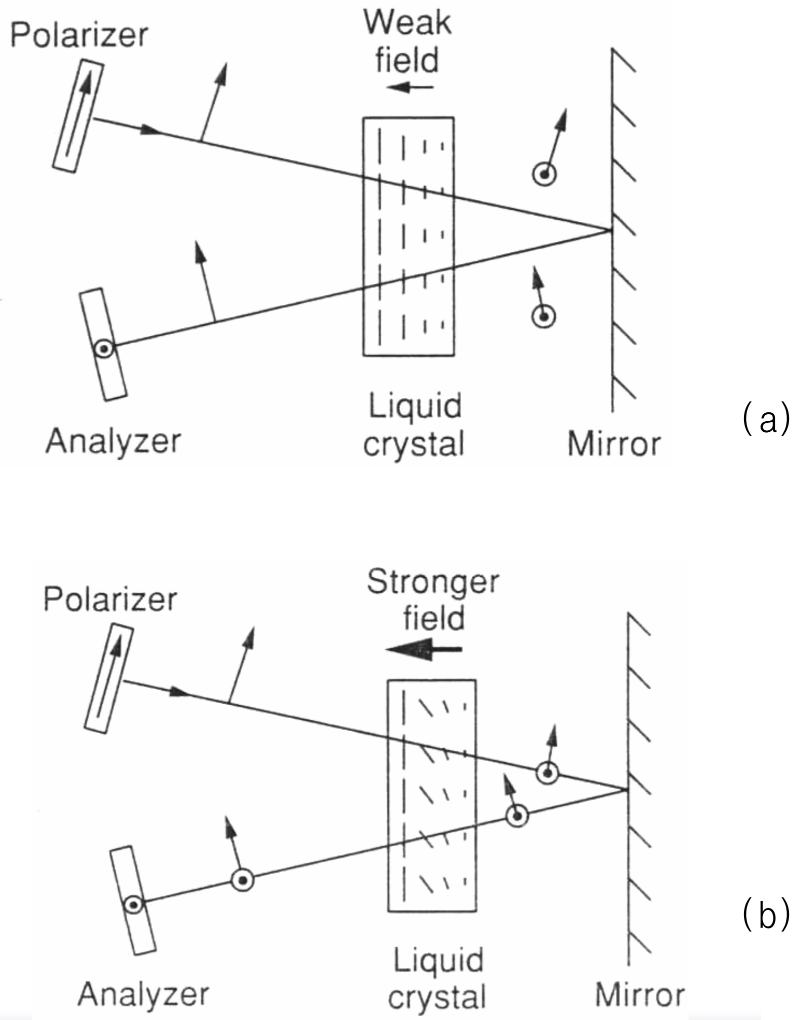
$$\mathbf{L}_{retard}(\Delta) = \begin{bmatrix} 1 & 0 \\ 0 & e^{-j\Delta} \end{bmatrix}$$

$$\Delta = \frac{2\pi(n_X - n_Y)d}{\lambda_0}$$

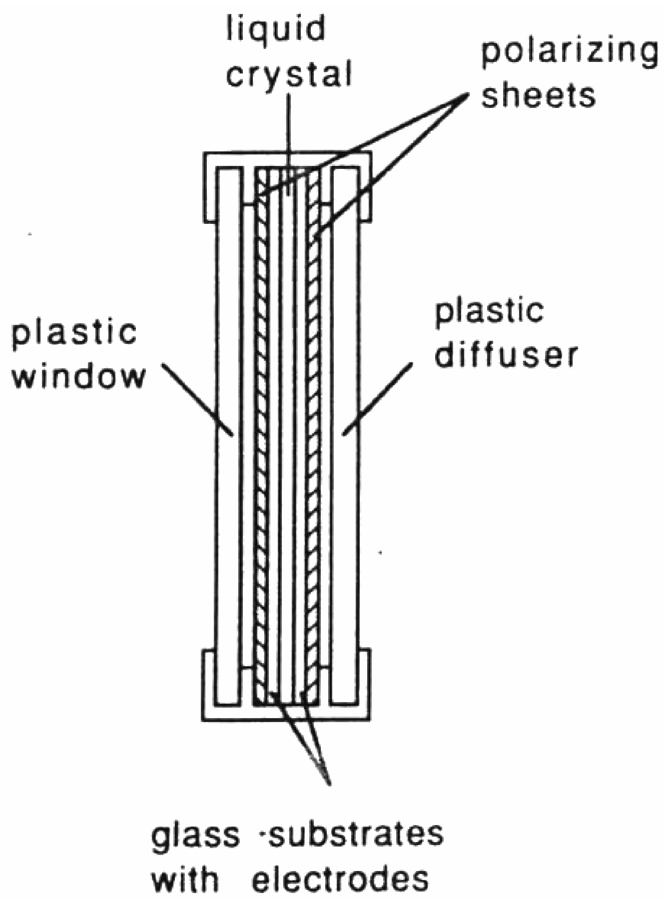


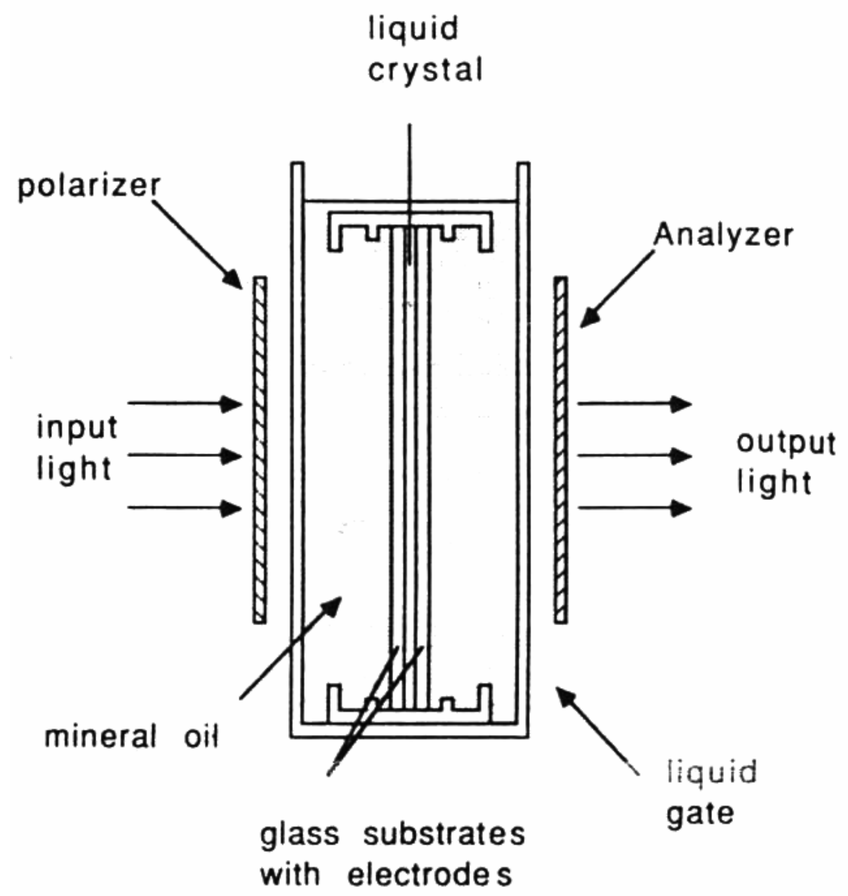
Liquid Crystal Light Valve





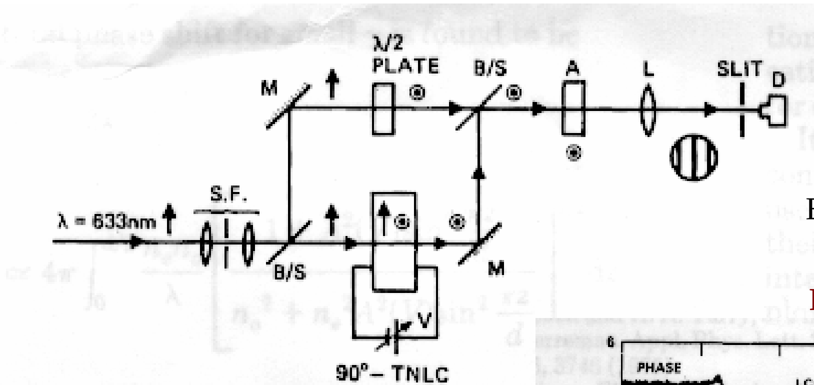
Liquid Crystal TV

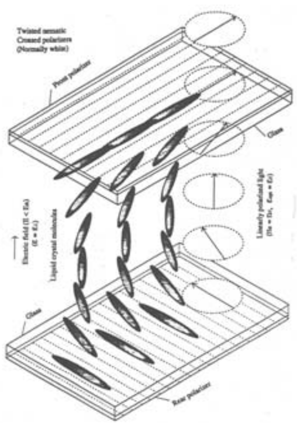




Liquid Crystal Modulators

- Amplitude and Phase modulation
  - ✓ N.Konforti et al., Opt. Lett. **13**, 251 (1988)



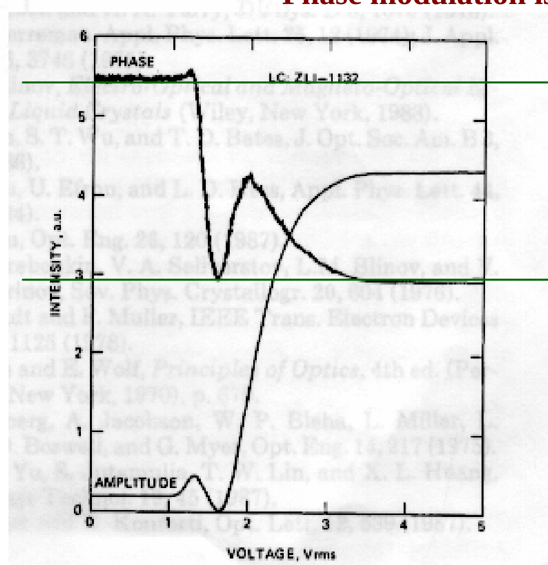


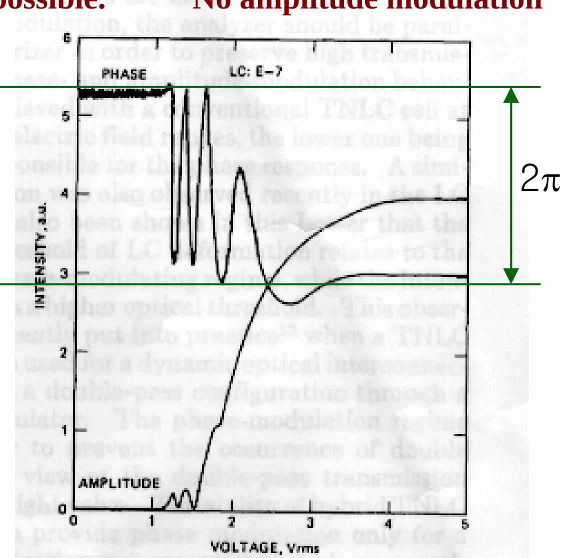
Freedericksz transition threshold < V < Optical threshold

Tilt angle increases as V increases while twist angle remains unchanged.

Effective birefringence is reduced. → **Phase modulation is possible.**

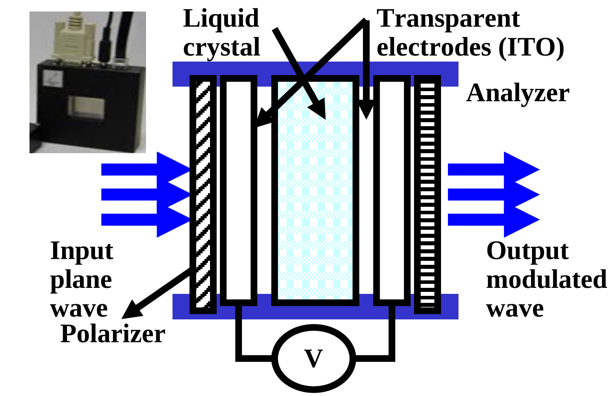
Waveguiding effect still exists. → **No amplitude modulation**

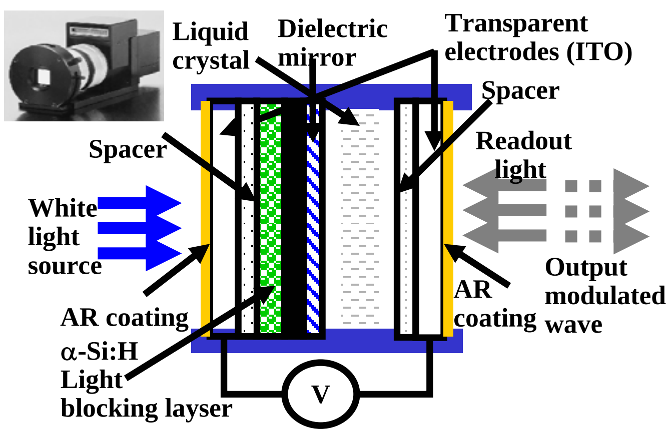




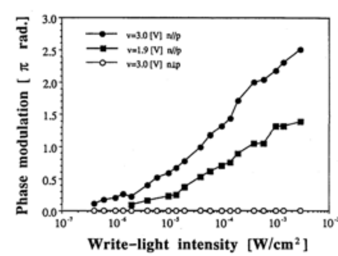
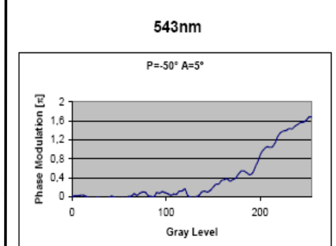
Phase-Type Spatial Light Modulators

- Dynamic encoding
  - ✓ Phase-type SLMs



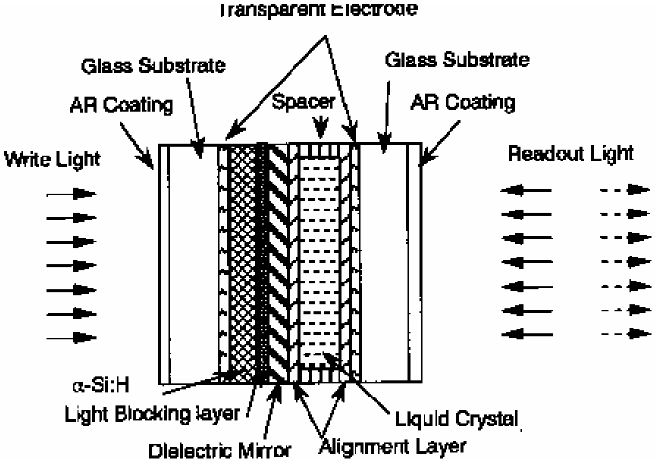


Comparison of specifications of the phase-type SLMs

	PPM X-8267	LC2002
Manufacturer	Hamamatsu	HoloEye
Efficiency	Reflection (30%)	Transmission (20%)
Active area	20×20mm	26.2×20mm
Pixels	1024×768	832×624
Pitch	26×26μm	32×32μm
Modulation mode	Amplitude, phase	Amplitude, phase
Phase modulation	2π @ 632.8nm (He:Ne)	2π @ 532nm (Nd:YAG)
Frame rates	60Hz, max	60Hz, max
Contrast ratio	200:1	200:1
Modulation curve		

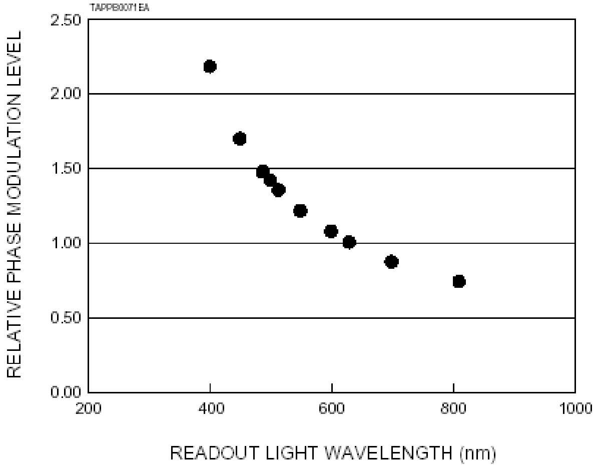
Phase-Type Spatial Light Modulators

- Operation spec. of the phase modulator
  - ✓ PPM X-8267 SLM
    - – PAL-SLM (Parallel Aligned Nematic Liquid Crystal SLM
    - – An electrical signal input type LCD
    - – An optical image transmitting element (FOP or lens)
    - – A write-in laser(LD, 50mW@690nm)
    - – Phase modulation depends on readout light wavelength



Detailed specifications of the X-8267

Parameter		X8077	X8267	Unit
Features		· FOP optical transmitting. · Most compact model. · Compact LD module built-in. · Output image without pixel structure.	· More control point with an XGA type LCD. · Compact LD module built-in. · More compact than that the former VGA type model. · Output image without pixel structure.	—
Input signal (IBM PC/AT [Windows/DOS])		VGA	XGA	—
Number of control pixels		Approx. 230 000	Approx. 590 000	pixels
Effective image area		20 × 20 (Four corners rounded)		mm
Optical image transmitting element		FOP	Lens	—
Phase modulation level (readout light wavelength: 633 nm) (A)		2 π		radian Min.
Maximum display spatial resolution		12	19	Lp/mm
LCD	Display type	Active matrix monochrome 1.3-inch LCD		—
	Display mode	Transmission mode, normally-white, TN type		—
	Number of pixels (H × V)	644 × 488	1024 × 768	—
Input voltage		85 to 132		V ac
Power consumption		40	45	VA
Dimensions (W × H × D)		55 × 58.7 × 82.5	80 × 93 × 226.3 (B)	mm
Weight		Approx. 450	Approx. 1600	g



Phase-Type Spatial Light Modulators

- Cautions and Test of the phase modulator
  - ✓ Cautions
    - – The intensity of read light should be kept below 200 mW/cm^3.
    - – Be sure to operate at temperature below 40°C, and avoid high humidity
    - – Only the center of 768×768 pixels is effective
    - – Transmission: 30%
  - ✓ Test result
    - – Driving voltage: ±3.0V 1KHz
    - – Readout light : Laser diode (λ=633nm)
    - – Write light : Laser diode (λ=690nm)

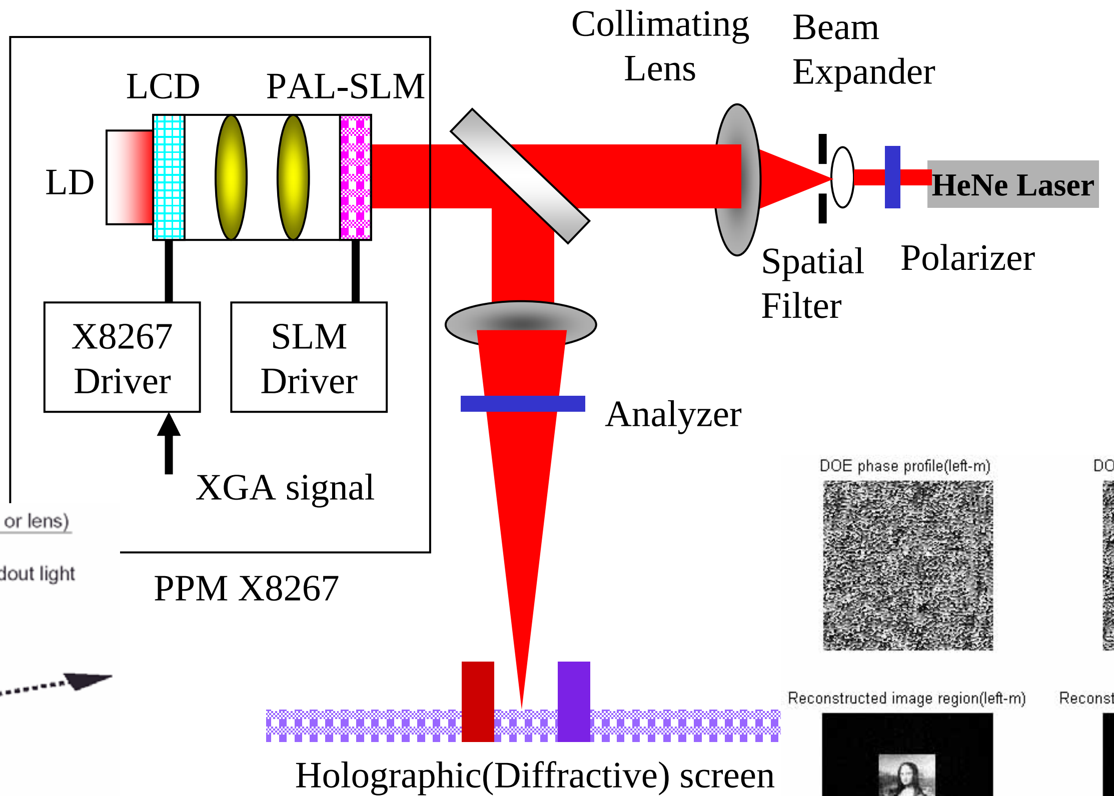
Items	Test results
Sensitivity of π modulation	20μW/cm²
Phase modulation	3.5π radians (write-light intensity : 1mW/cm²)
Response time	rise < 40 ms
	fall < 50ms
Spatial resolution	> 46 lp/mm

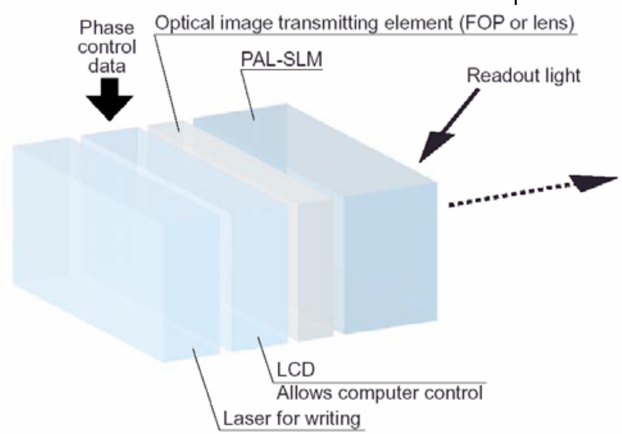
Use of Phase-Type SLM

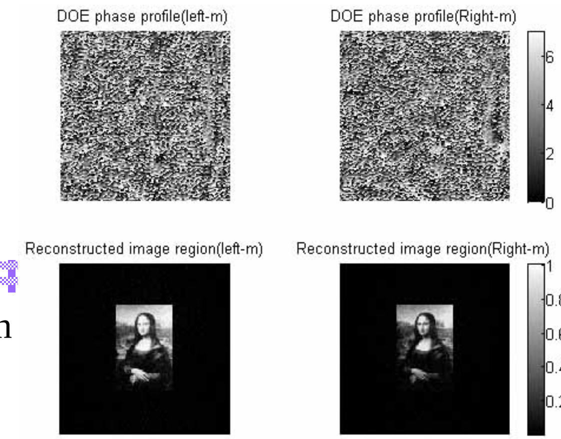
- ❑ Dynamic encoding
  - ✓ Computer-generated holographic stereogram

Stereoscopic 3D contents

Movie, Game,
Aviation,
Education, Medical
service,
Remote control,
…

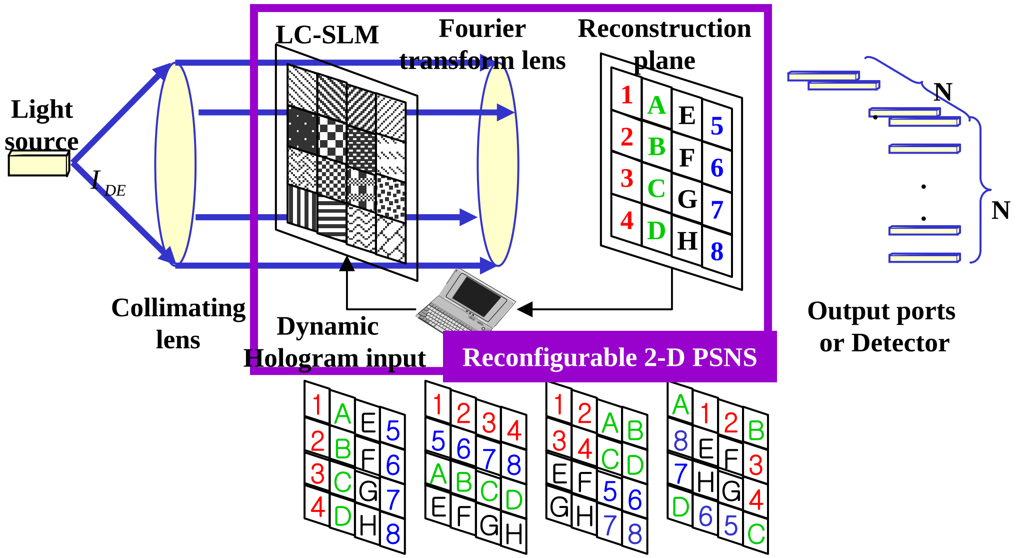


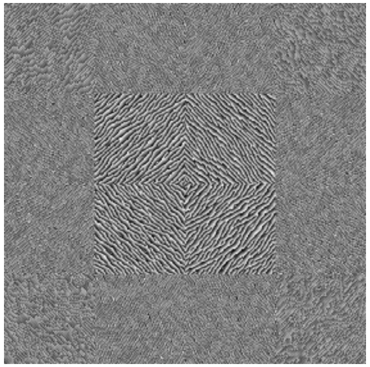


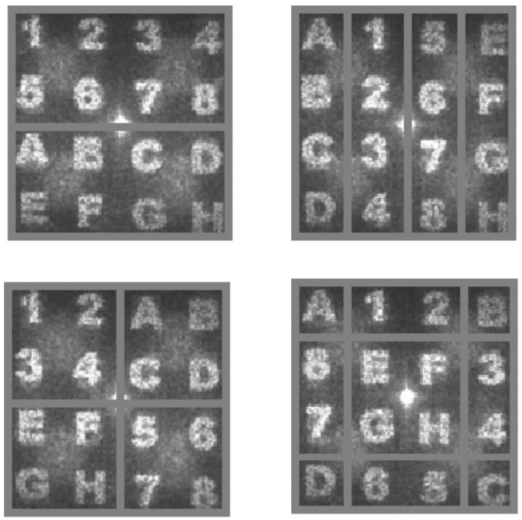


Use of Phase-Type SLM

- Dynamic encoding
  - ✓ 2D reconfigurable PSNS: K. Choi and B. Lee, *IEEE PTL* 17, 687 (2005)



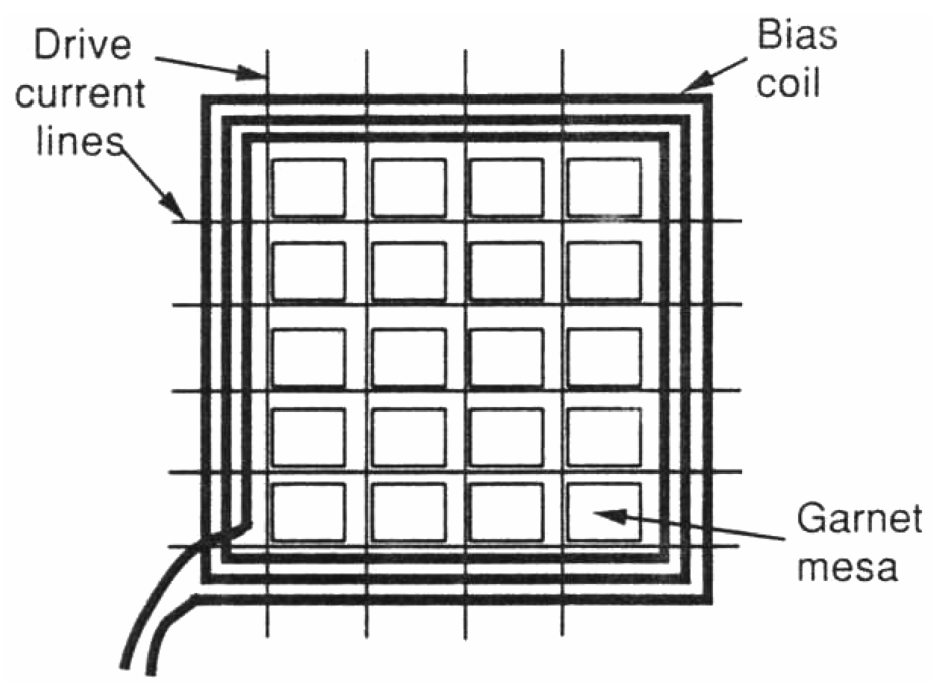


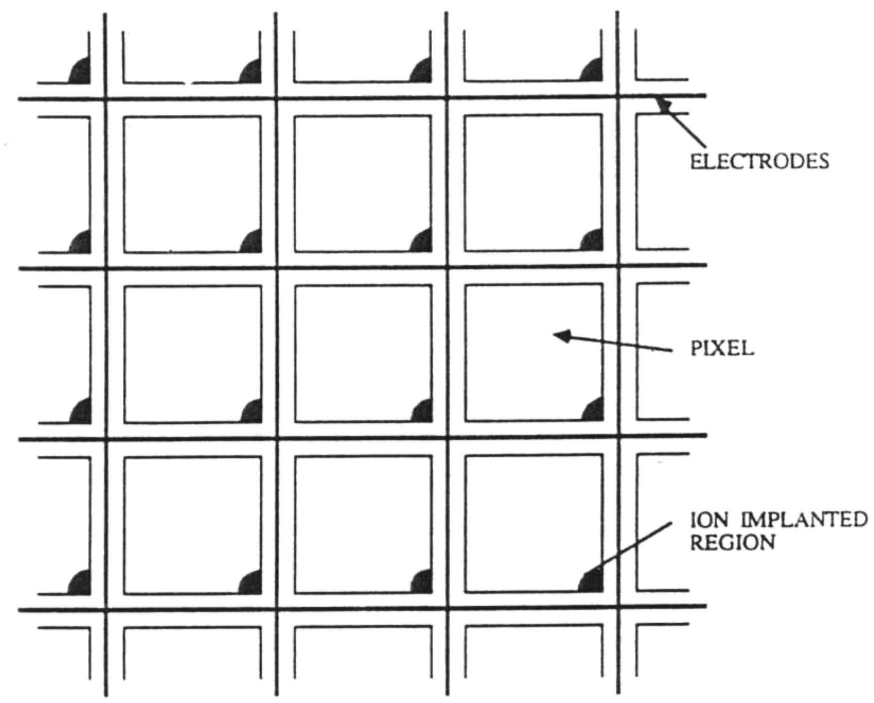


Performance factors	Phase holograms		
	Directional hologram	Hologram for character image	Combined hologram
I_{DE} [%]	98.36	88.25	86.80
Uniformity [%]	0.22	4.84	5.03
RMS error	0.0167	1.2511	1.4433
SNR [dB]	17.79	8.76	8.18

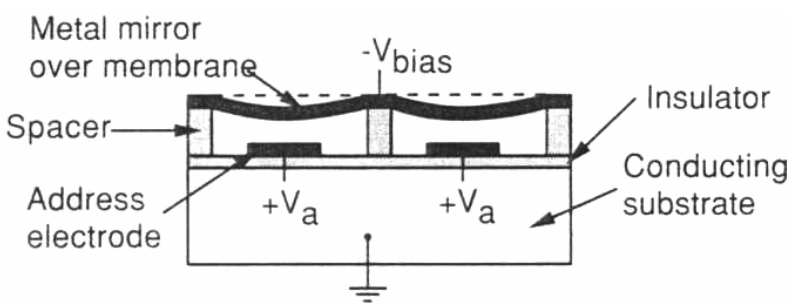
Magneto-Optic Spatial Light Modulator

- Using Faraday rotation

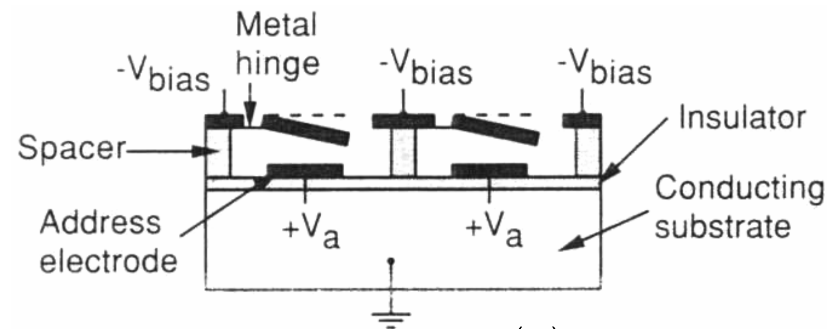




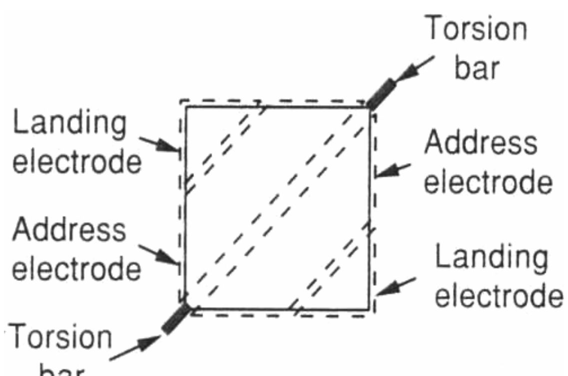
Deformable Mirror SLM



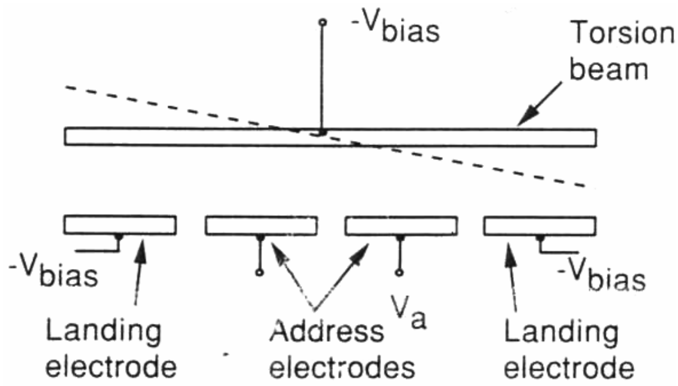
(a)



(b)



(a)

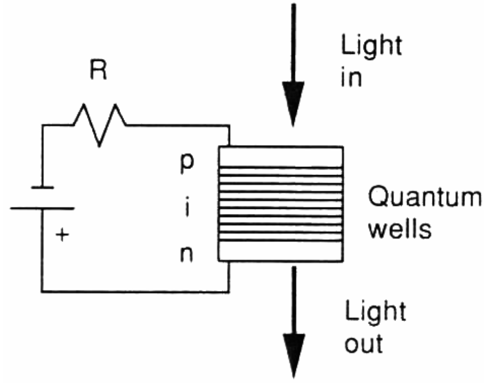


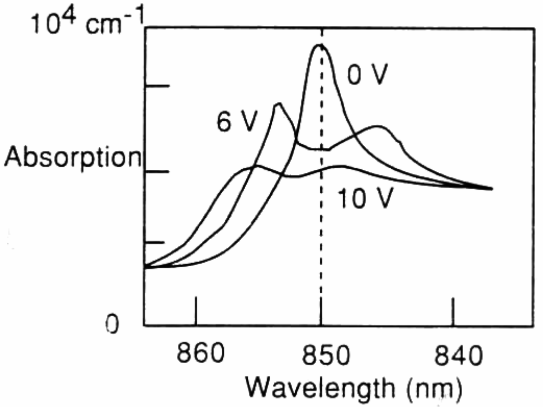
(b)

Lucent Tech.

Multiple Quantum Well SLM

- Self-electro-optic effect device (SEED)
  - Quantum-confined Stark effect (QCSE)





- Symmetric SEED (S-SEED)