CENTER FOR DISPLAY RESEARCH

Hong Kong University of Science & Technology

Progress in Microdisplay Optics

H S Kwok, H F Li and H C Huang

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SPIE Meeting, Jan 2000

Microdisplay optics

- LCOS LCD mode
- Projector optics - PBS, color separation filters, color recombination filters, projection lens
- Lamp - spectrum, collimation, polarization conversion, homogenizer
- Near eye optics - aspheric lens

Optical budget

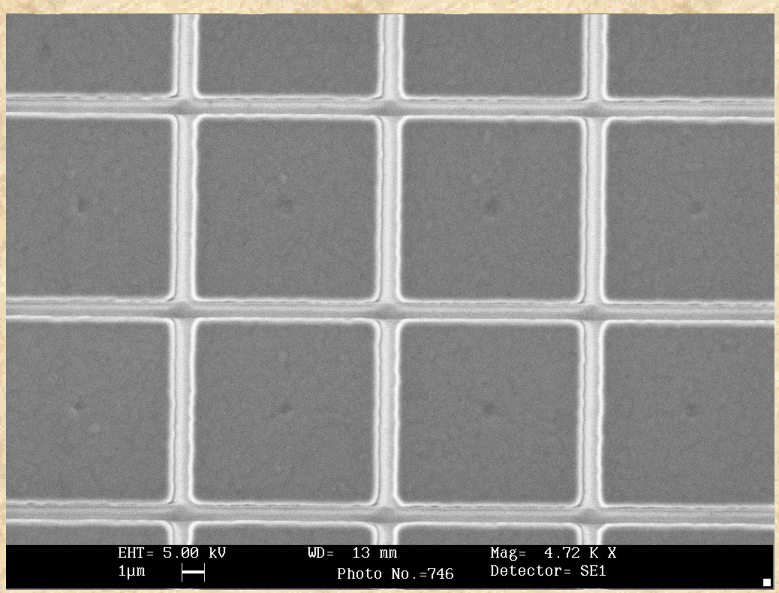
- 9600 Lm is available from a 150W arc lamp
- 1200 Lm can be projected in the best DLP and transmittive LCD systems, <800 Lm for LCOS
- Why? Limited acceptance angle of the optical elements (etendue or F# matching)
- Improvement can be made from the lamp side (smaller divergence angle), and/or from the optical elements side (larger acceptance angles)

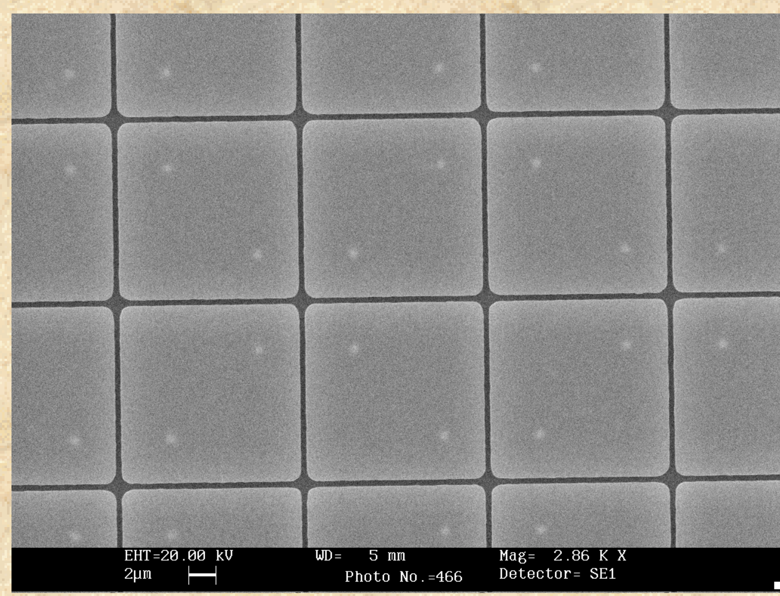
LCOS fabrication

- **Front-end for electrical functions**
  - ¤ Full integration of display drivers and DAC
  - ¤ High breakdown voltage techniques
  - ¤ Standard 0.5 μm CMOS process
- **Back-end for optical performance**
  - ¤ Surface planarization by CMP and light shield
  - ¤ High reflectivity final metal with special surface treatment
  - ¤ Pixels gap filling techniques
  - ¤ Modified 0.35 μm CMOS process

3M2P process

SEM pictures of pixels





- DVD resolution (704x576)
- 9.6 µm pixels
- 86% fill factor
- Direct view

- XGA resolution (1024x768)
- 13.8 µm pixels
- 91% fill factor
- Projection

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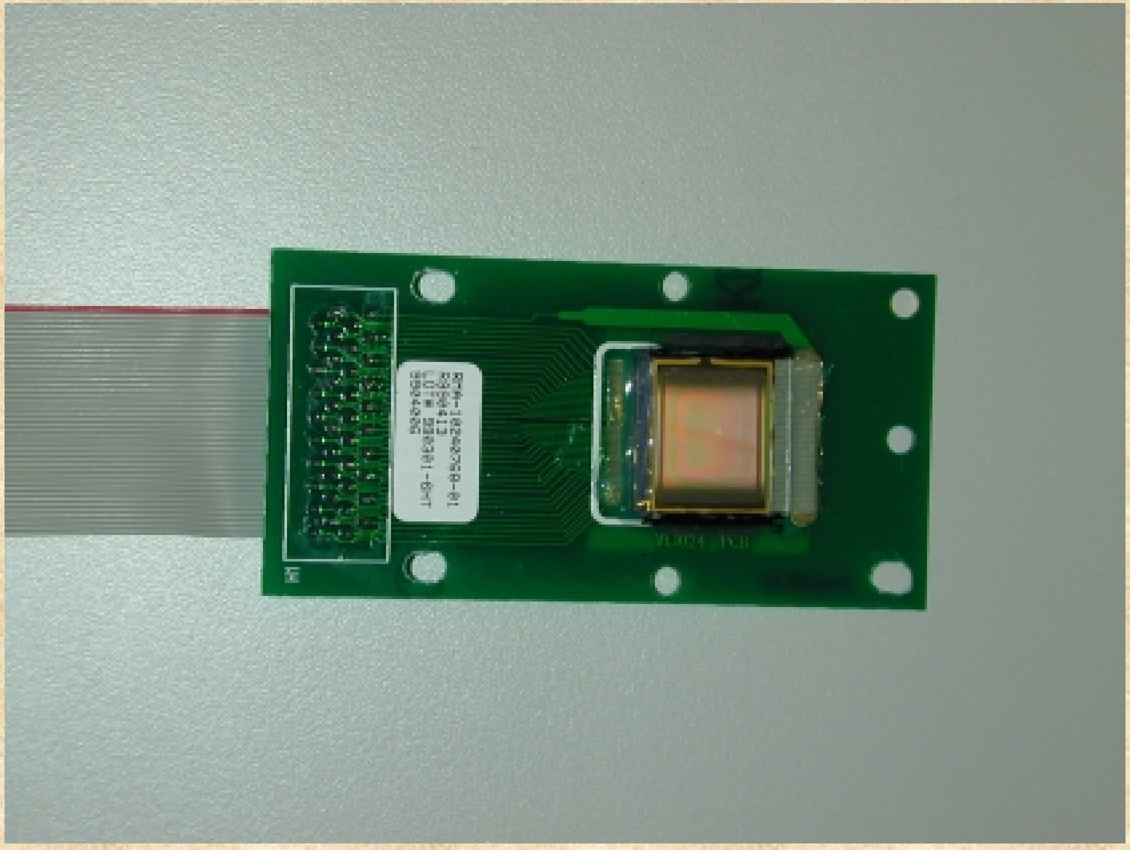
Packaged LCOS panel



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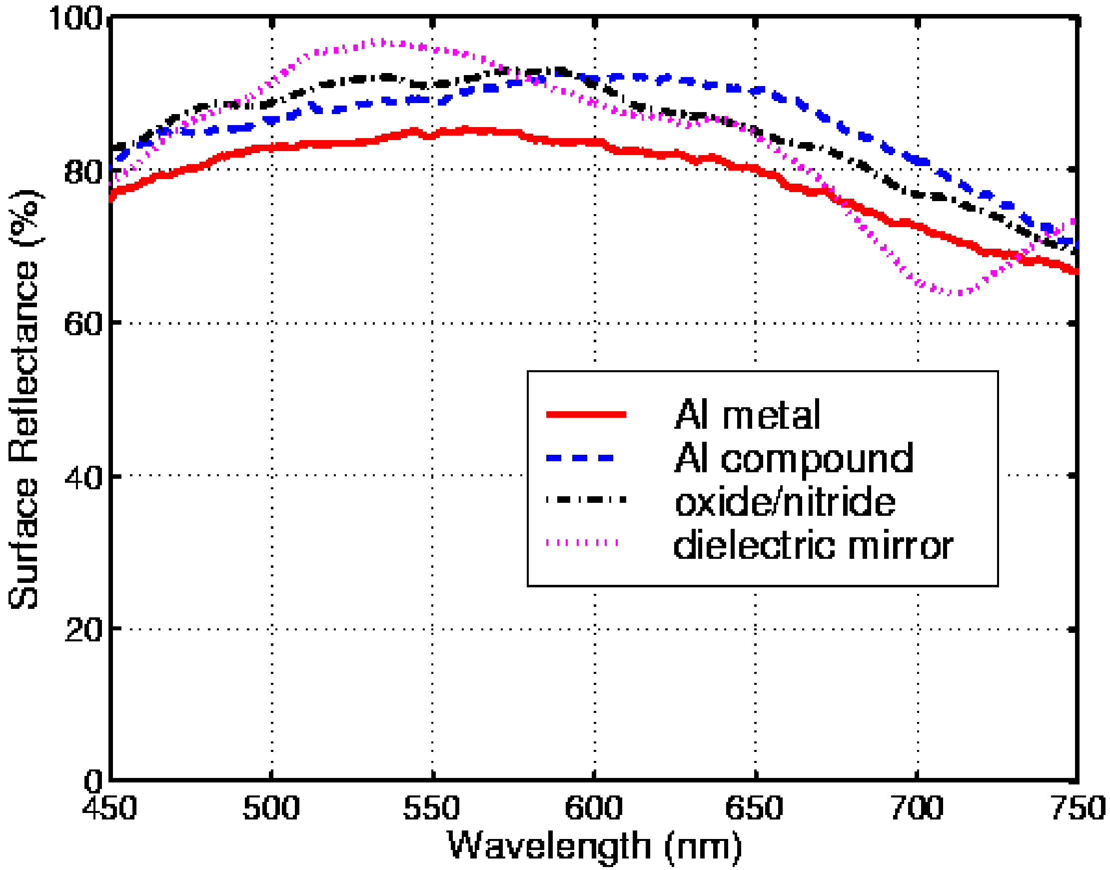
Surface reflectance



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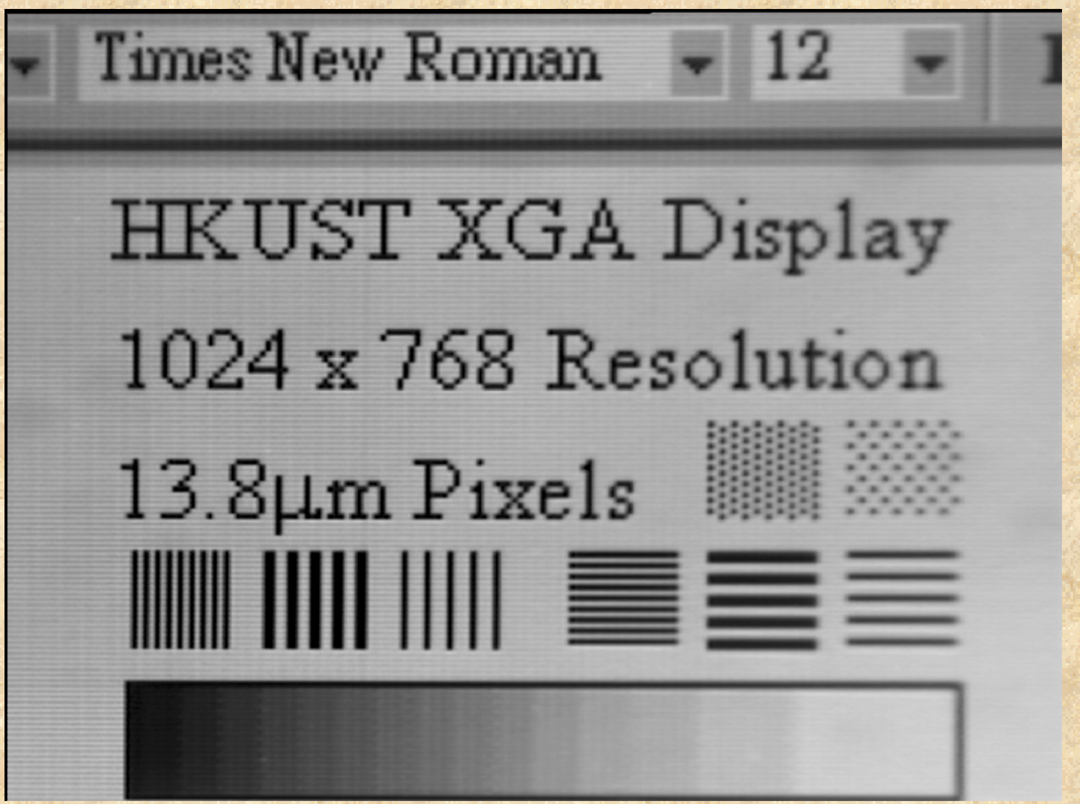
Resolvable pixels showing stability



No timing jitter - advantage of digital driving scheme

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Projected image on the screen

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Projected image on the screen

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LCOS LCD optical modes

- Traditional LCLV - 45^o hybrid field effect (HFE) mode (Hughes)
- Normally white operation - TN-ECB mode (Sonahara 1989)
- MTN (Wu 1995)
- MTB (Kwok 1997)
- Other LCD modes in use: VA, ferroelectric, PDLC, ….

Unified picture of all reflective LCD modes

Observation:

At any voltage $T = T(\alpha, \gamma, \phi, \delta)$

For a single polarizer reflective display

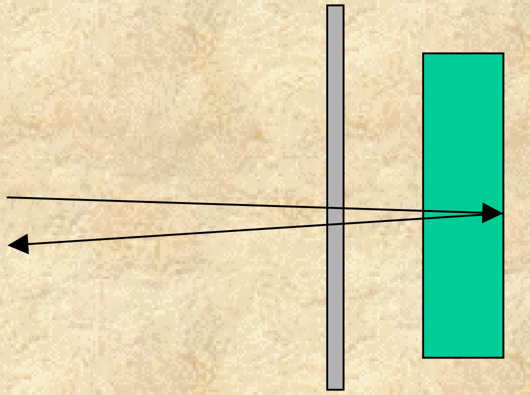
$$R = R(\alpha, \phi, \delta)$$

Therefore, T or R can be plotted as a function of 2 variables by fixing the third or fourth variable - parameter space

Reflective displays

For reflective display with one polarizer

$$R = \left| \begin{pmatrix} \cos\alpha & \sin\alpha \end{pmatrix} \bullet R \bullet M^{*} \bullet R^{-1} \bullet M \bullet \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix} \right|^{2}$$



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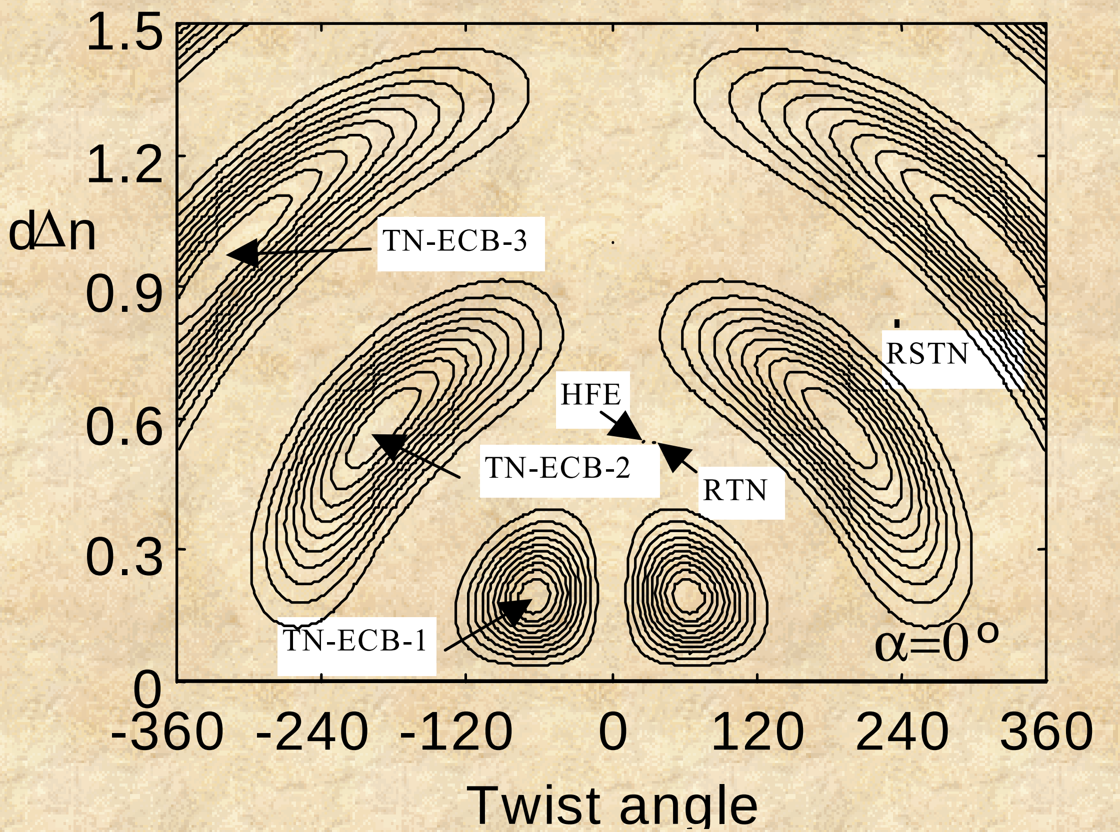
Parameter Space Diagrams for Reflective Displays



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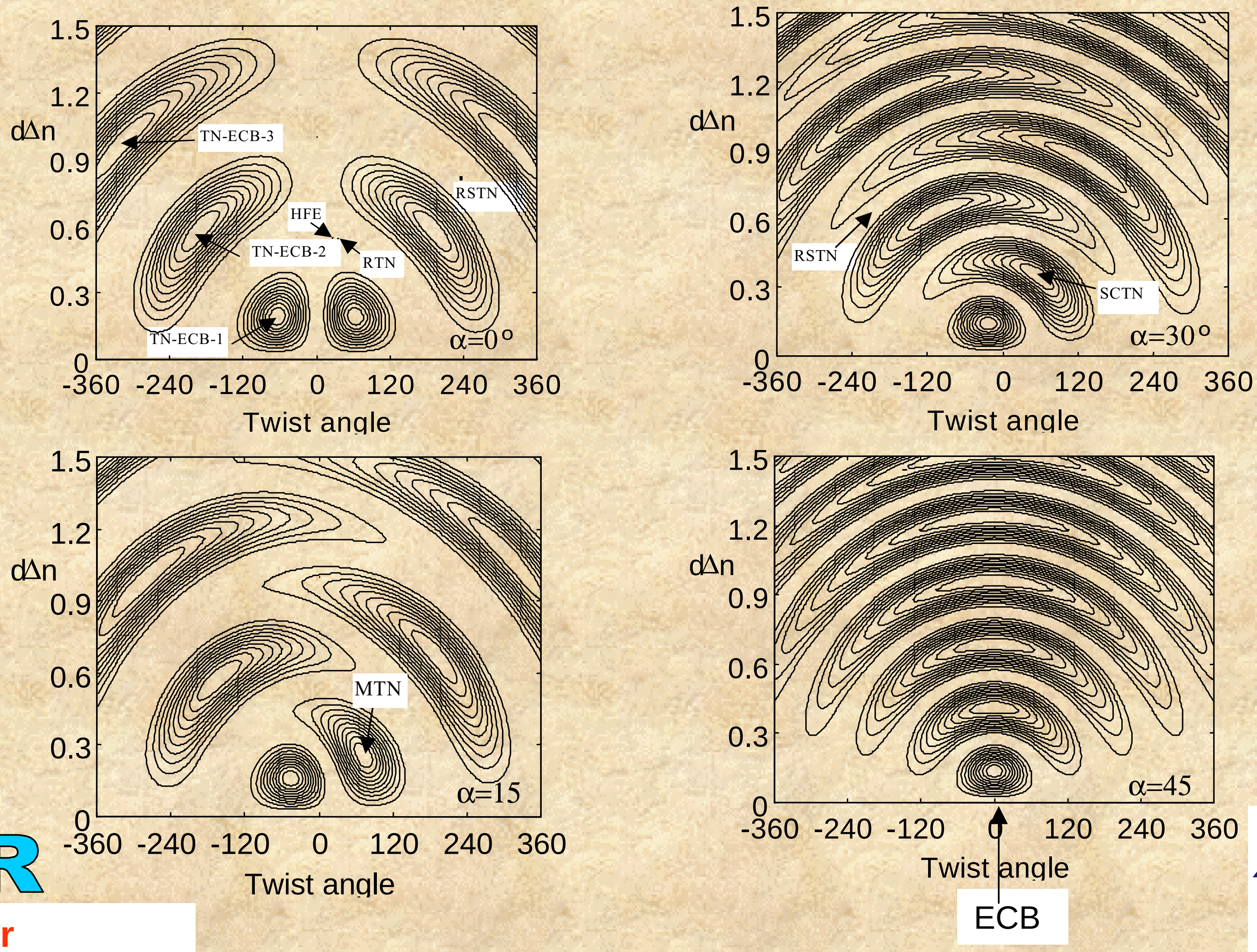
Parameter Space Diagrams for Reflective Displays - effect of change in polarizer angle



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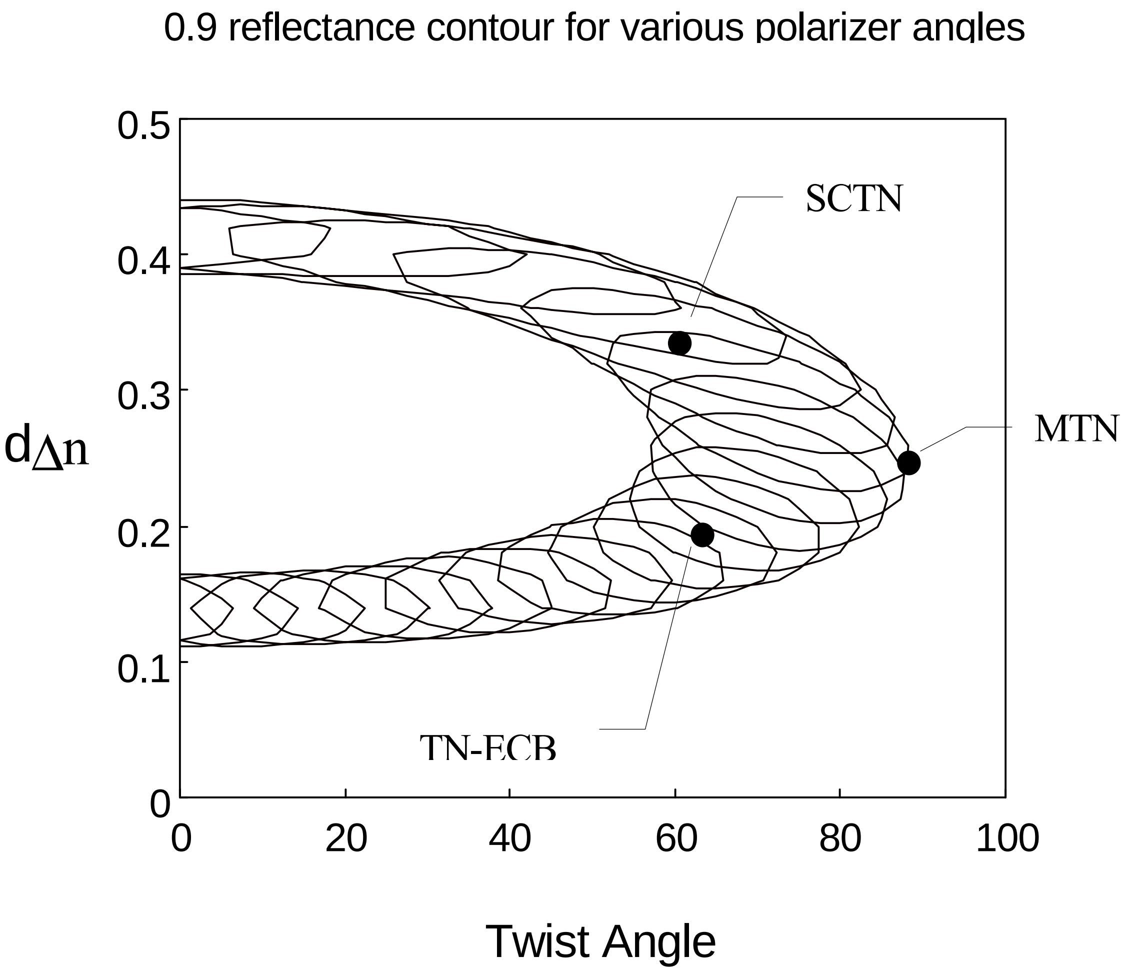
Relationship between various MTB modes

(Mixed TN-Birefringence modes)



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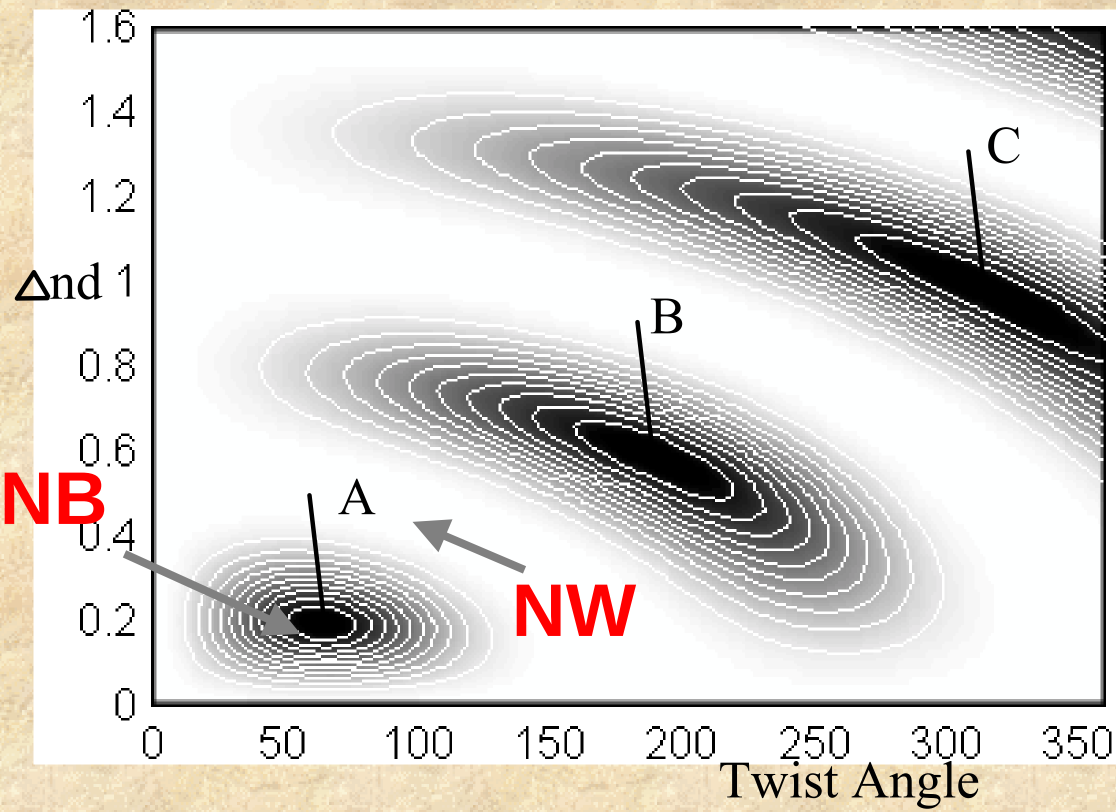
Both NW and NB modes are possible
(//-// polarizers)



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NB or NW can be reversed by changing polarizers. Better nomenclature: In-well and out-of-well modes

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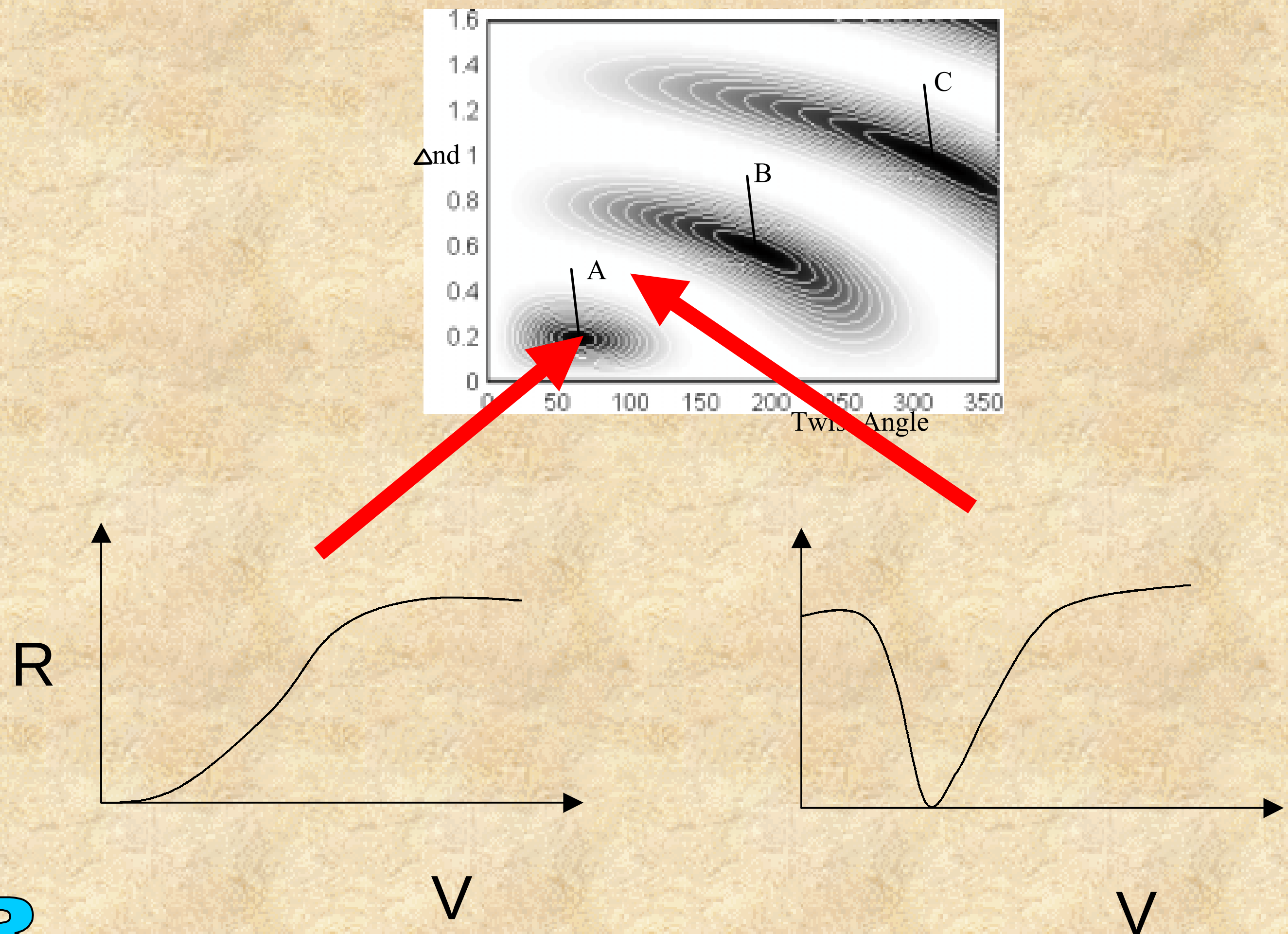
Electro-optic curve of in-well and out-of-well modes



//-// polarizers

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In-well and out-of-well modes

	Normally white (NW)	Normally black (NB)
Direct view	Out-well, dark state at intermediate voltage	In-well, bright state at high voltage
Projection	In-well, dark state at high voltage	Out-well, bright state at intermediate voltage

Note: No retardation film

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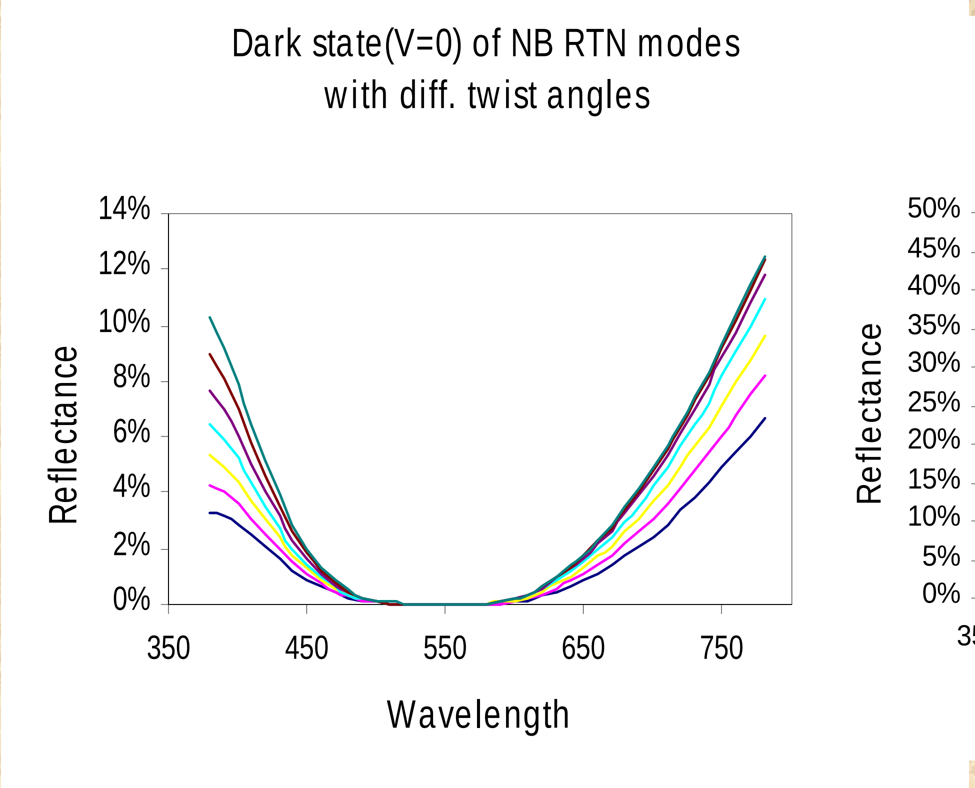
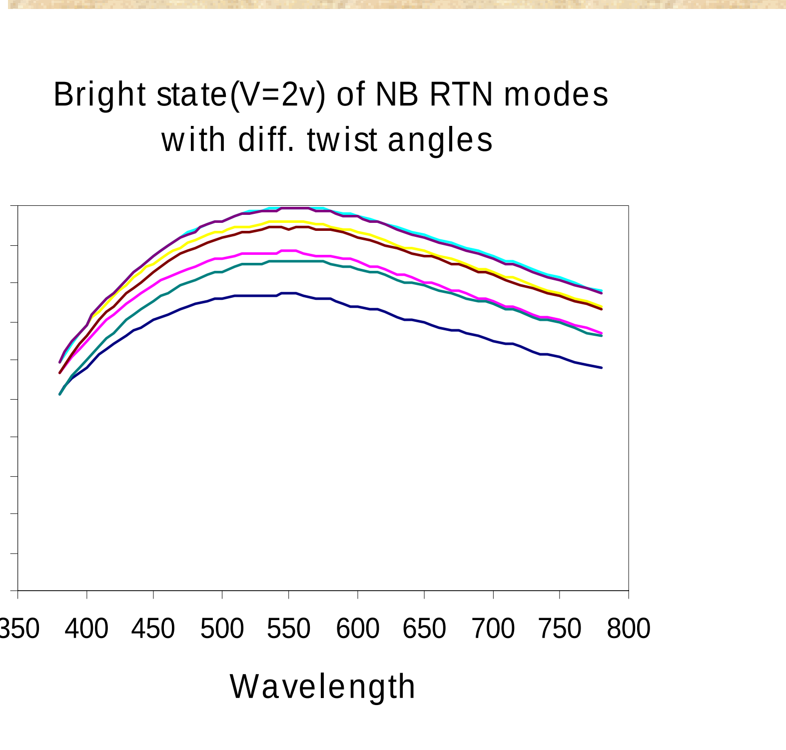
Normally black modes with PBS (Out-of-well modes)





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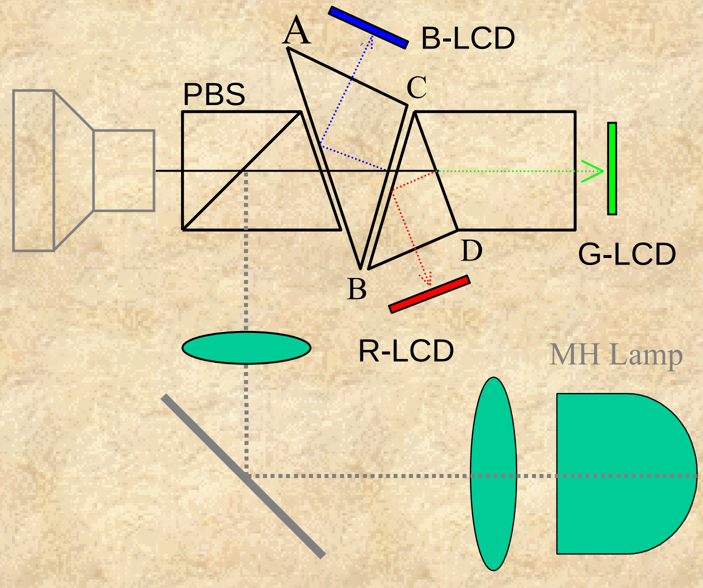
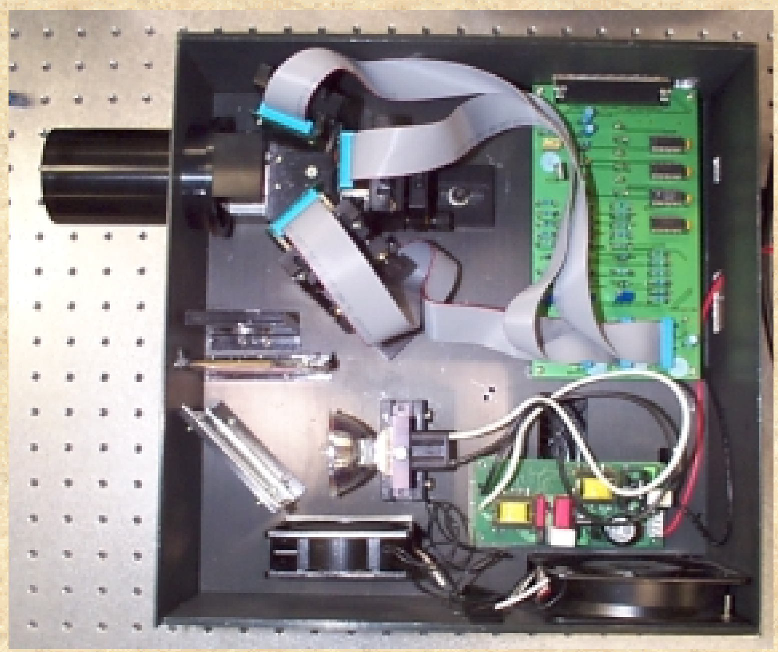
Optical engine





- New PBS + new trichroic prism assembly (TPA)

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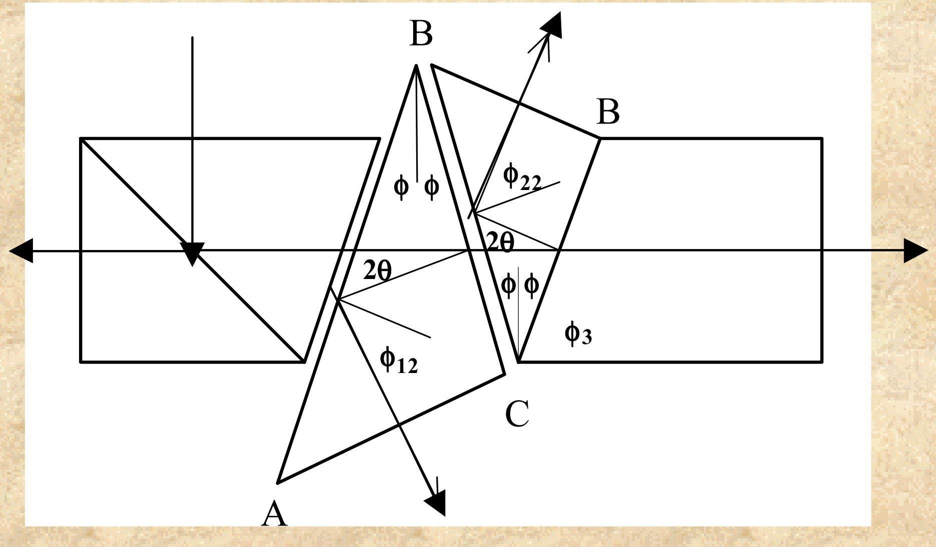
New TPA reduces s-p split of dichroic coating



Angle of incidence reduced to 16°.
(Traditional Philips prism has AOI of >24°)

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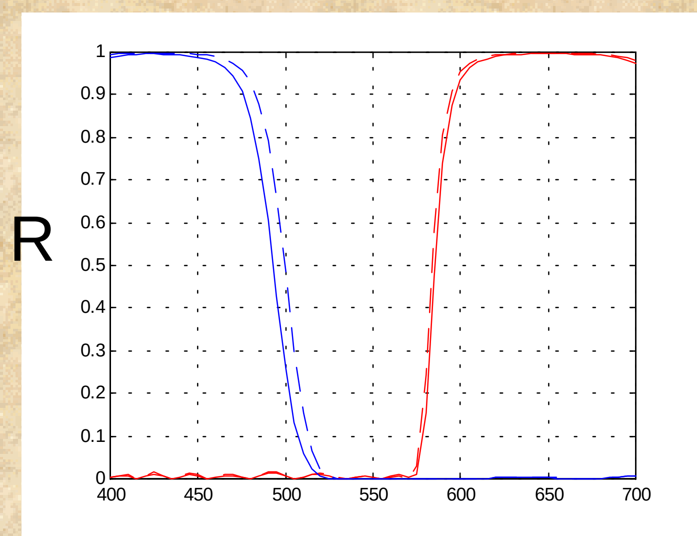
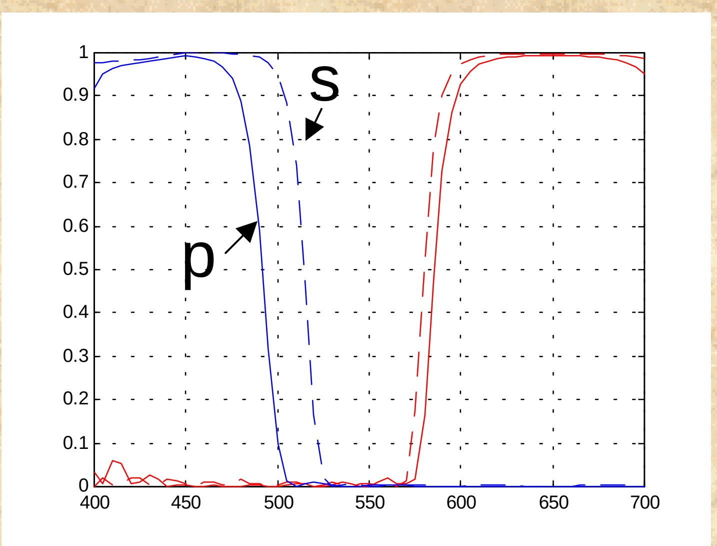
Calculated results for θ = 16º and 30º





Why is s-p split important?

Color fidelity, light efficiency

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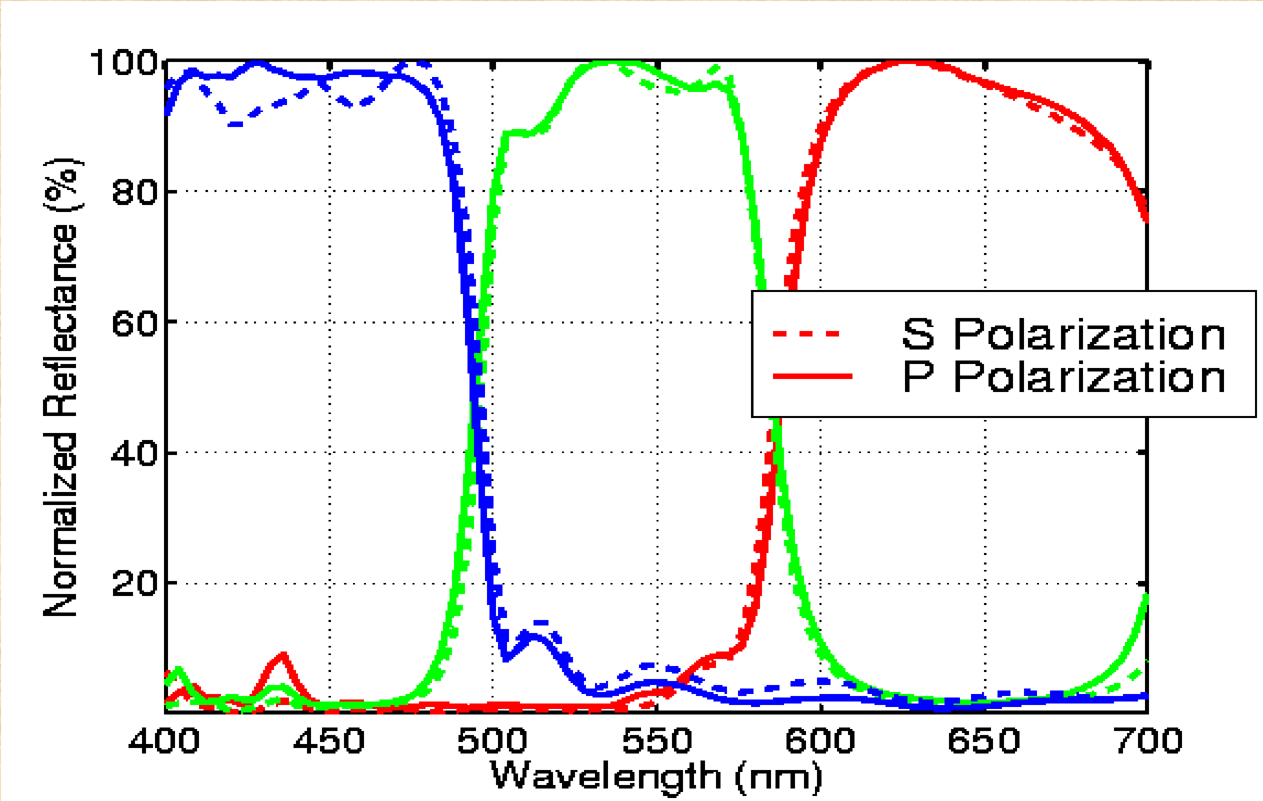
Good Color Fidelity for TPA

- Experimental Results



Negligible S-P Polarization Split

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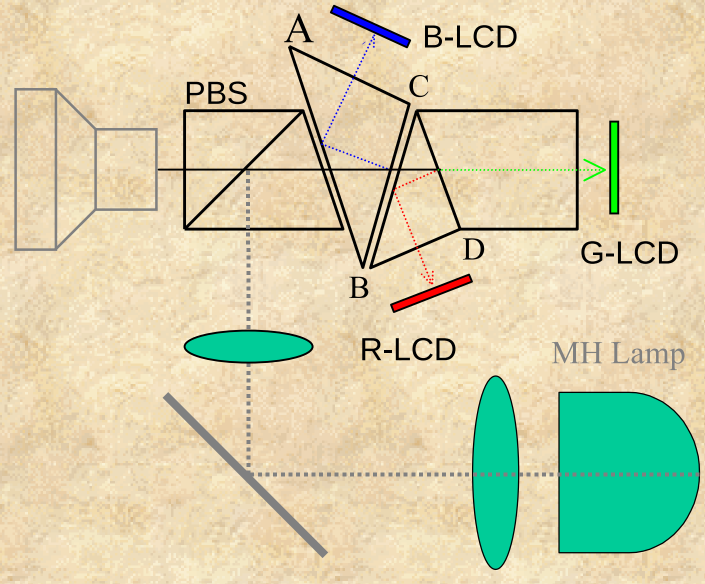
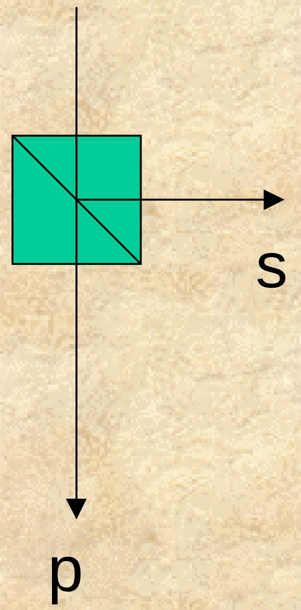
Acceptance angles of optical coatings in PBS and TPA

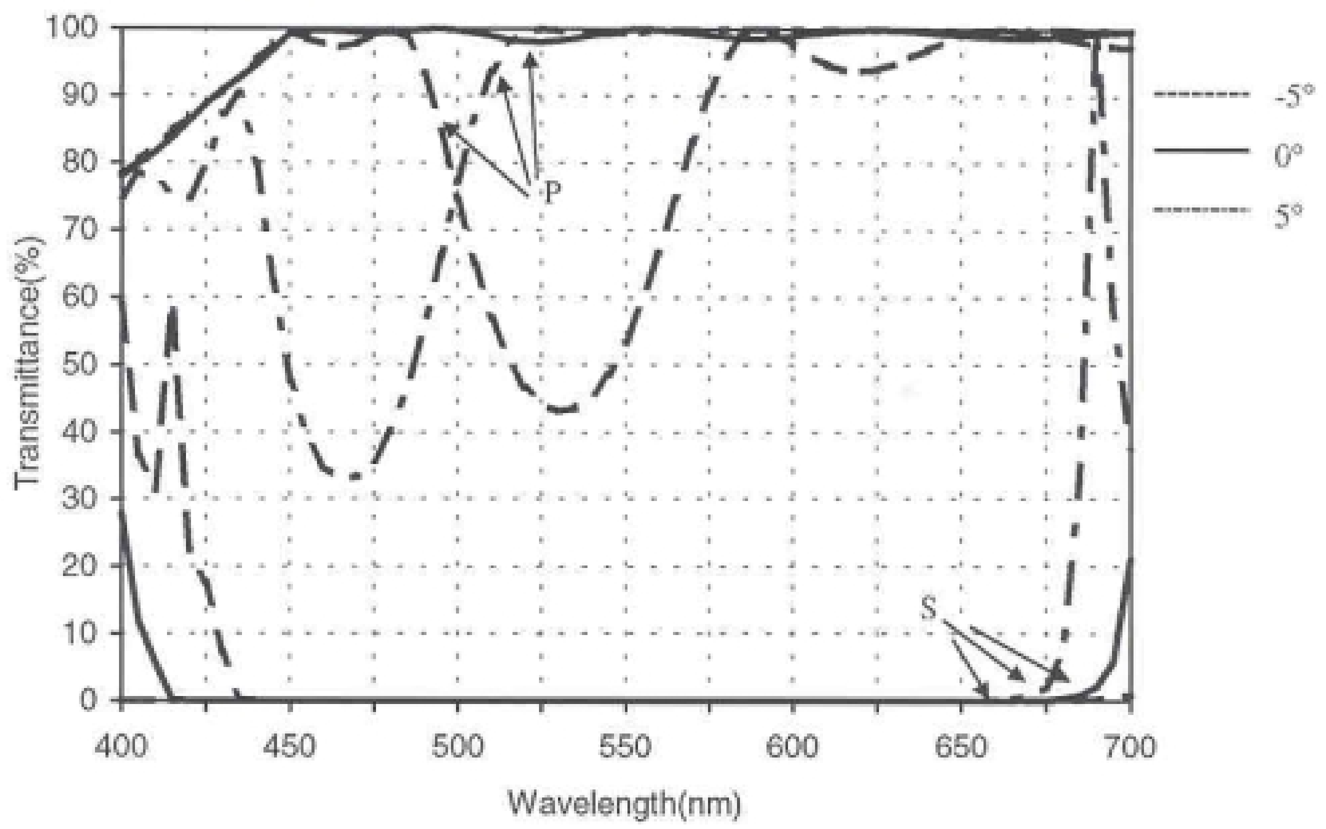
Acceptance angle: F/3.8 optics => ±5° in glass



PBS, dichroic filters, LCOS panels

Broadband, large acceptance angle PBS is difficult to achieve





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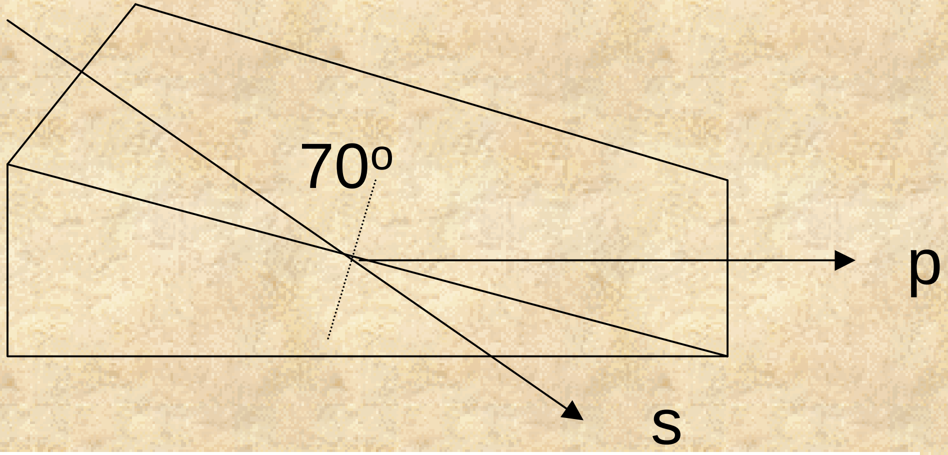
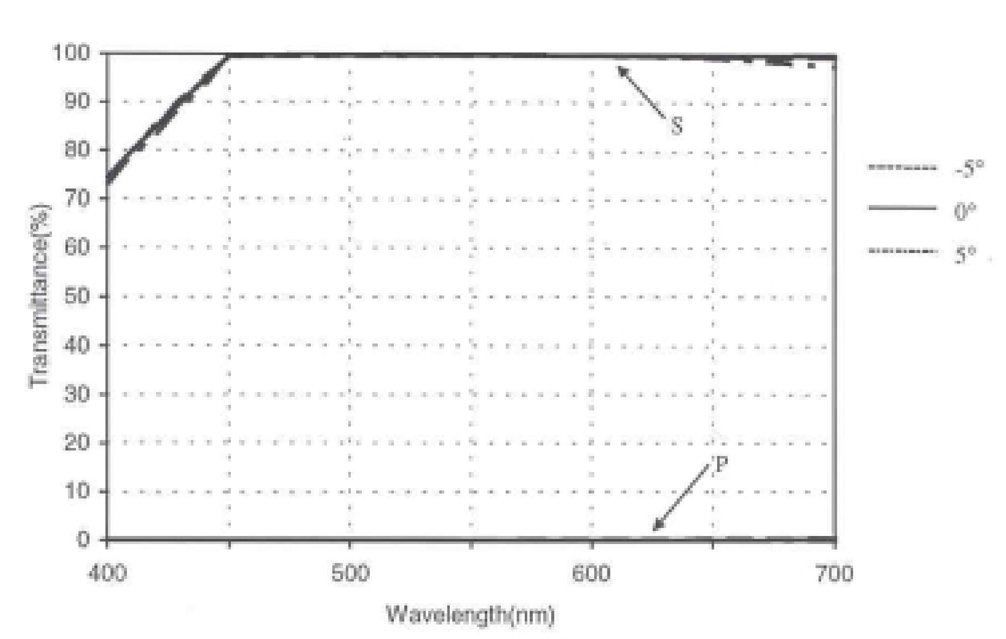
New PBS - Li design





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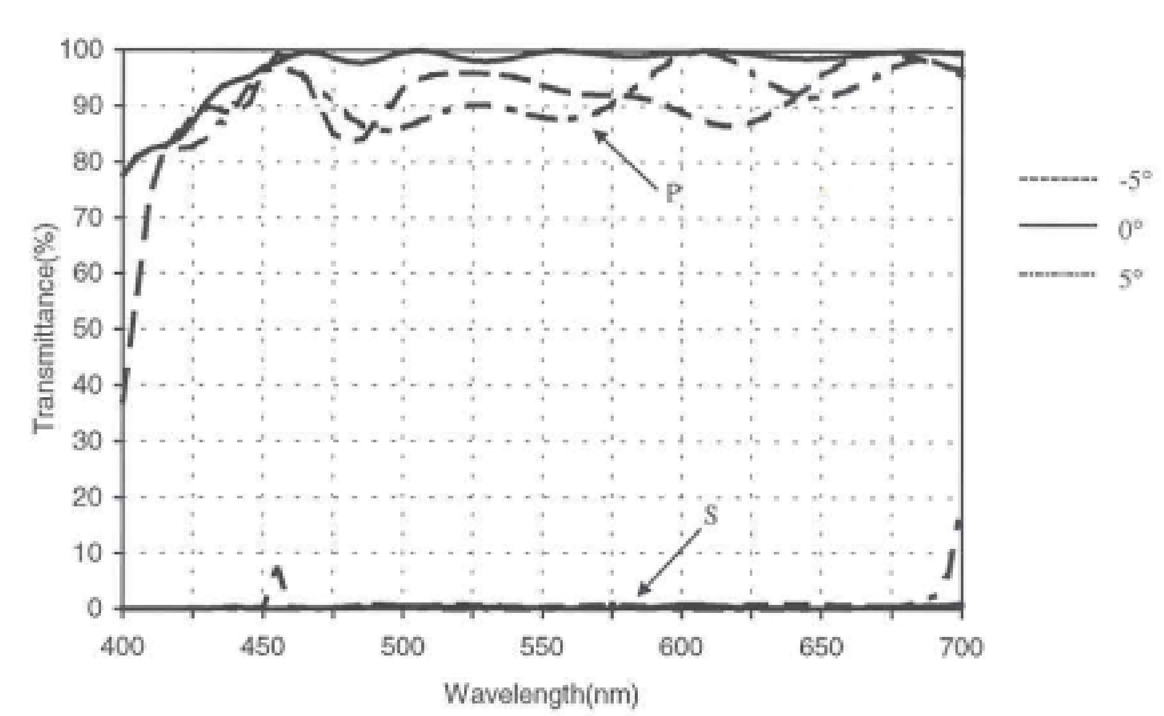
New PBS (52º)



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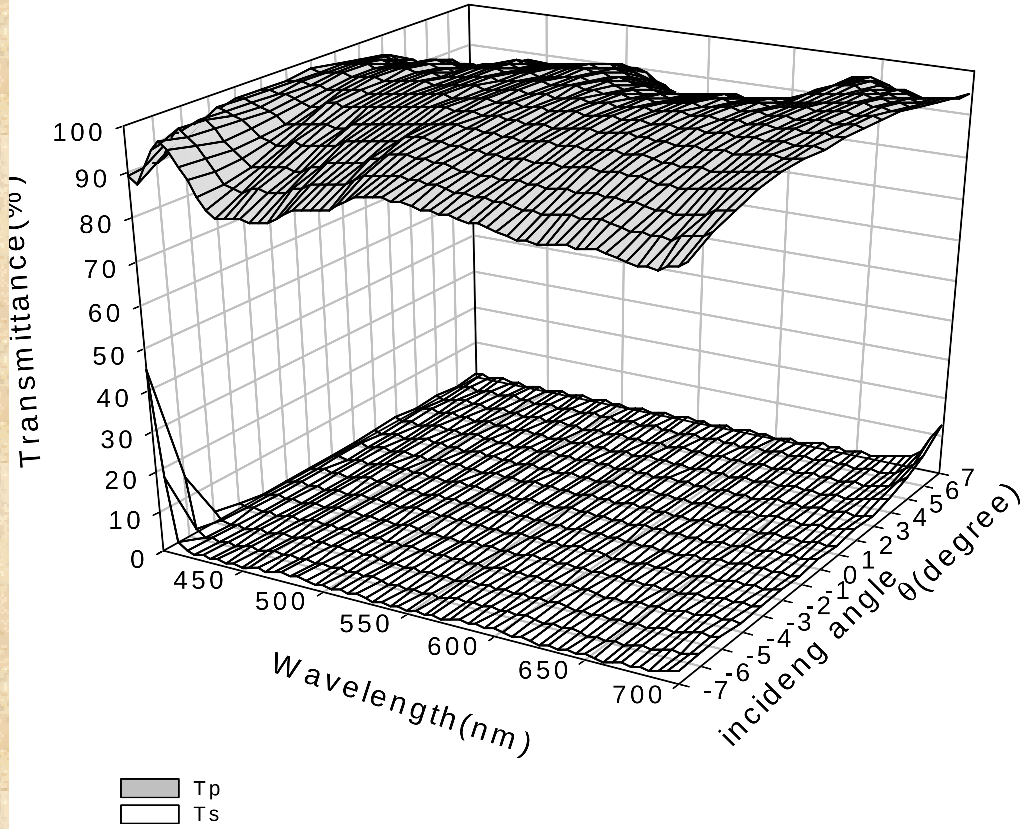
More detailed data for 52° PBS



Coating: 25 layers

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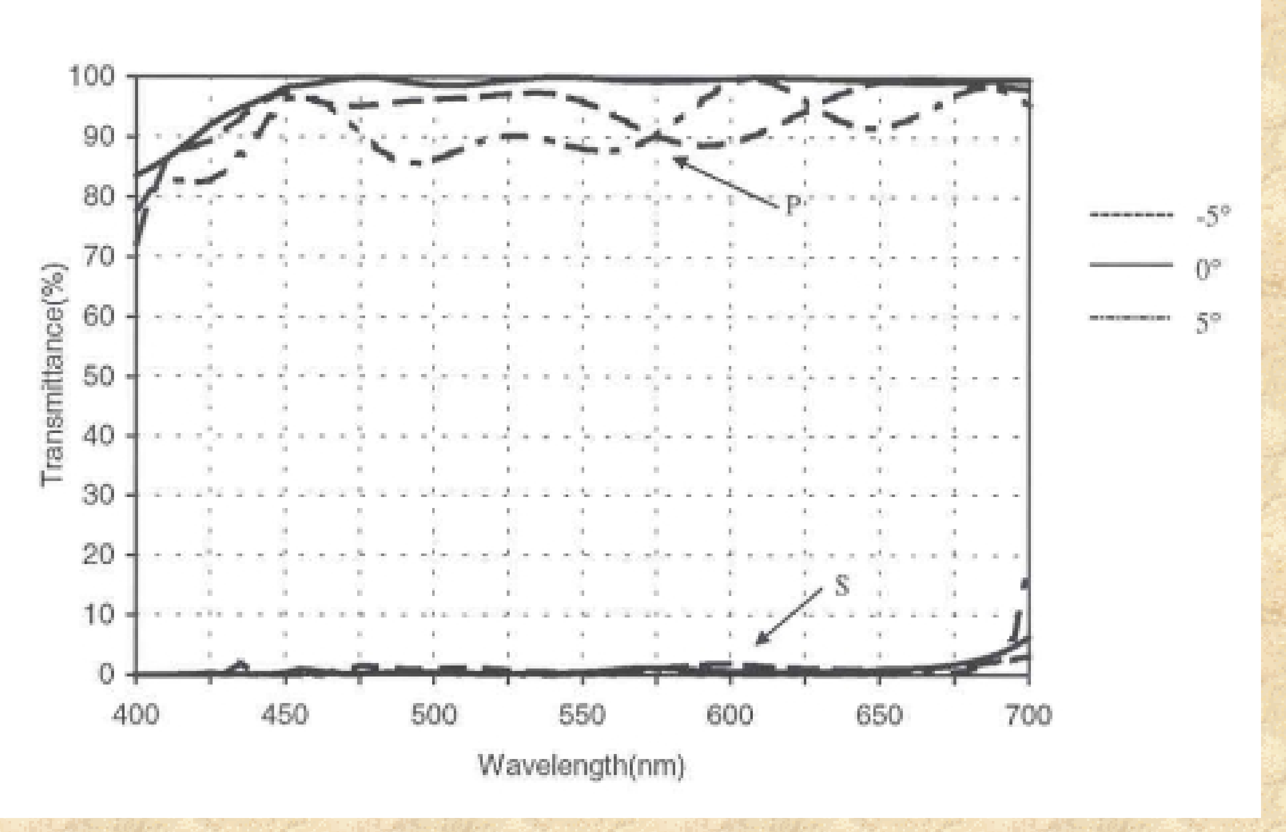
New PBS (45º)



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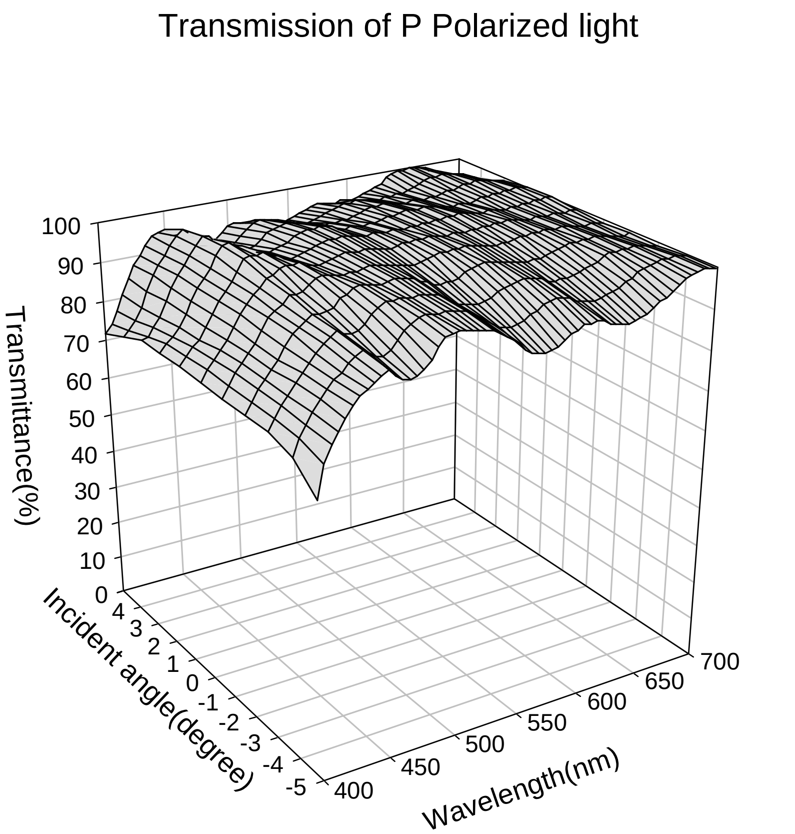
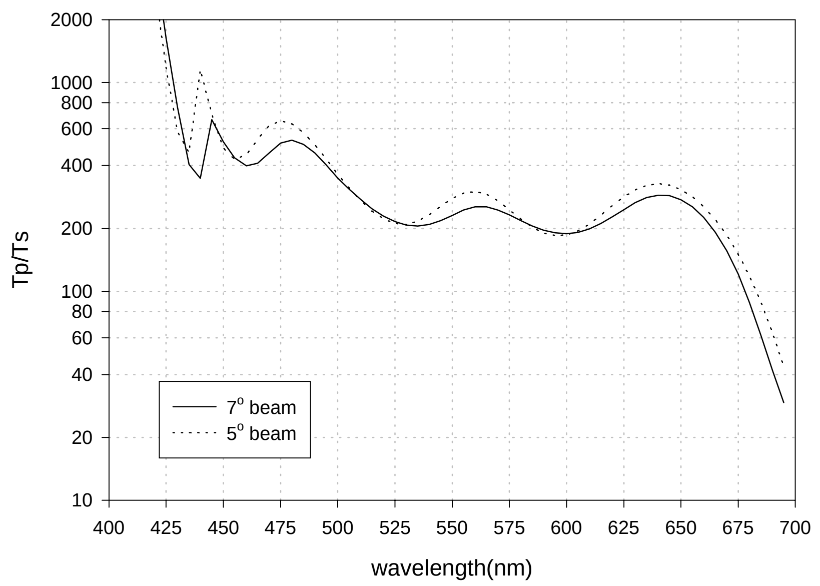
More detailed data for 45º PBS





Coating: 19 layers

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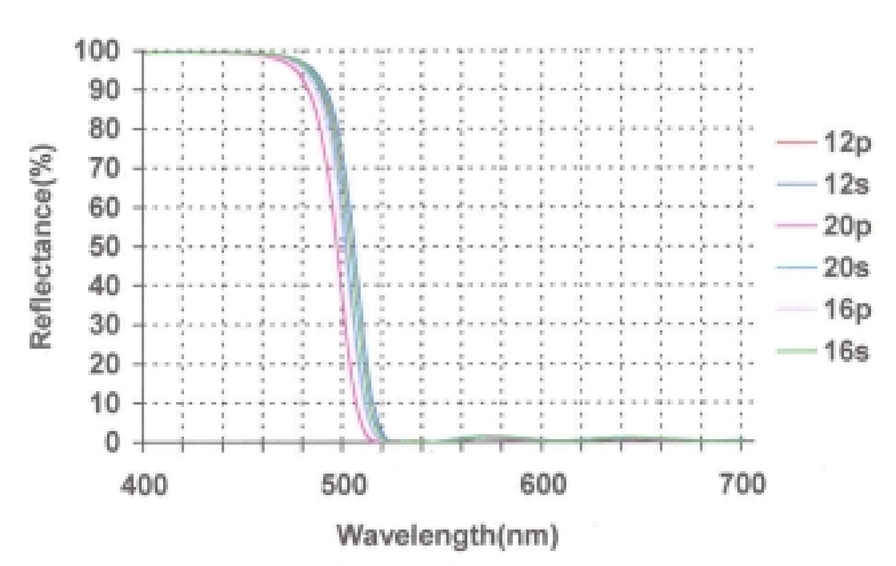
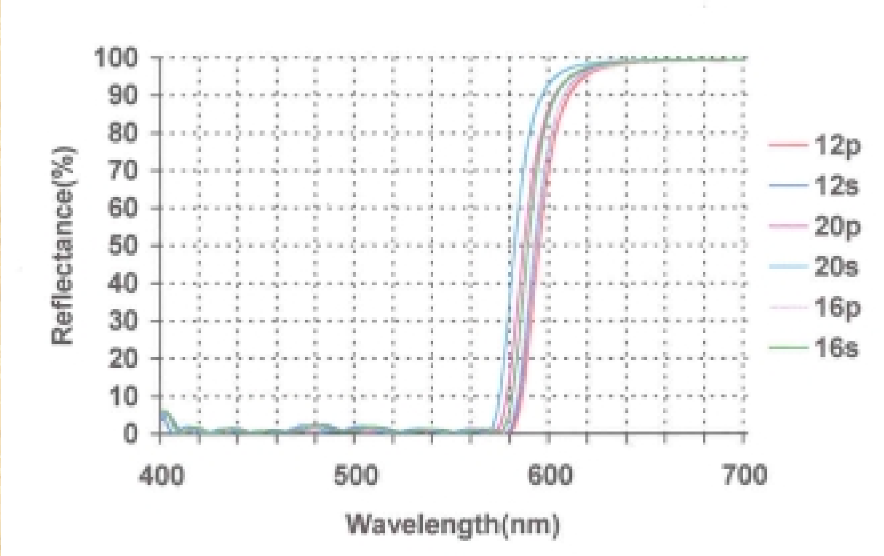
Color separation/recombination coatings





Color shift of 10nm. Loss of color fidelity and some intensities

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Color saturation measurements

Green not quite green

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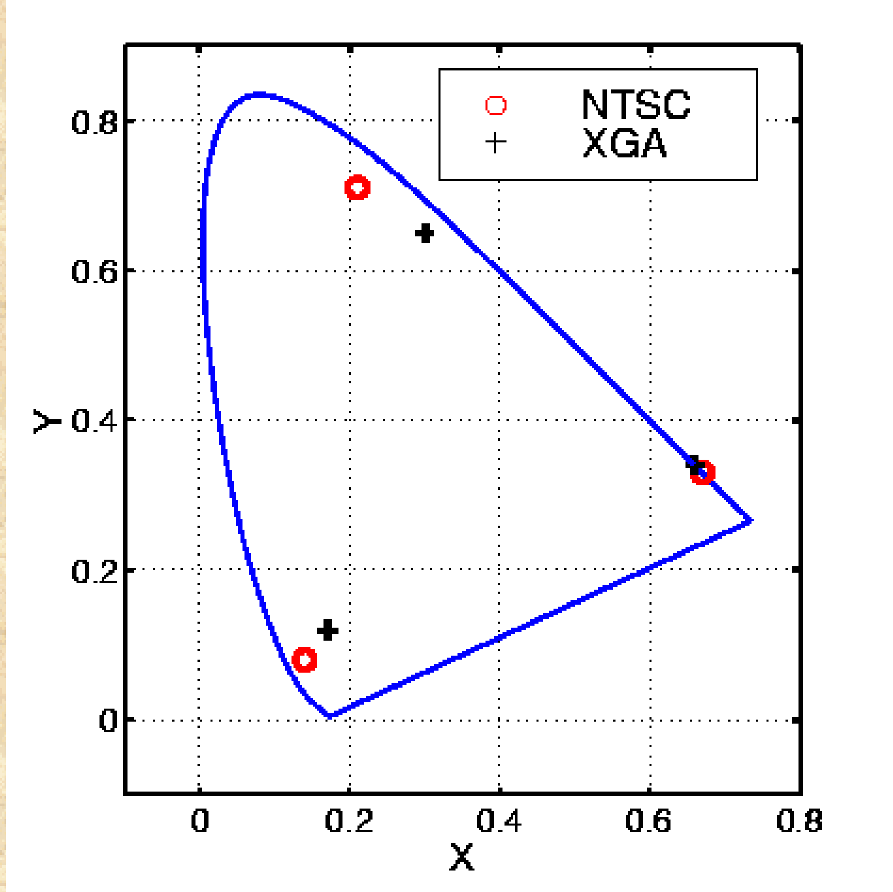
Measured color coordinates



Includes the effects of the halogen light source and the TPA.

Cannot be improved no matter how hard we tried!

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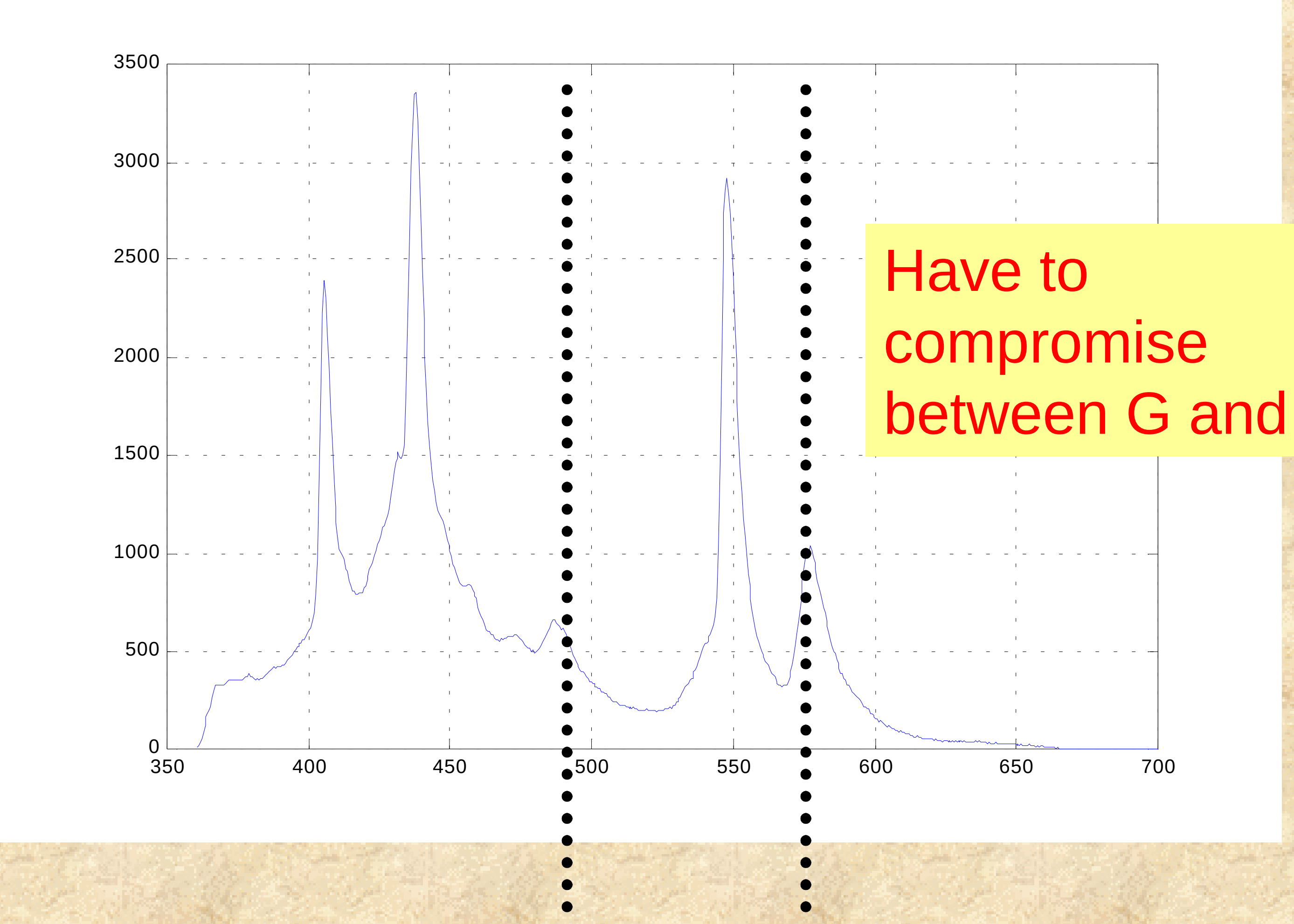
Color saturation is not quite NTSC

Reason: the UHP lamp does not have enough red color output!

*Same problem no matter which color separation/recombination scheme is used

120 W Philips UHP lamp output spectrum



Have to compromise between G and R

Other arc lamps are no better!

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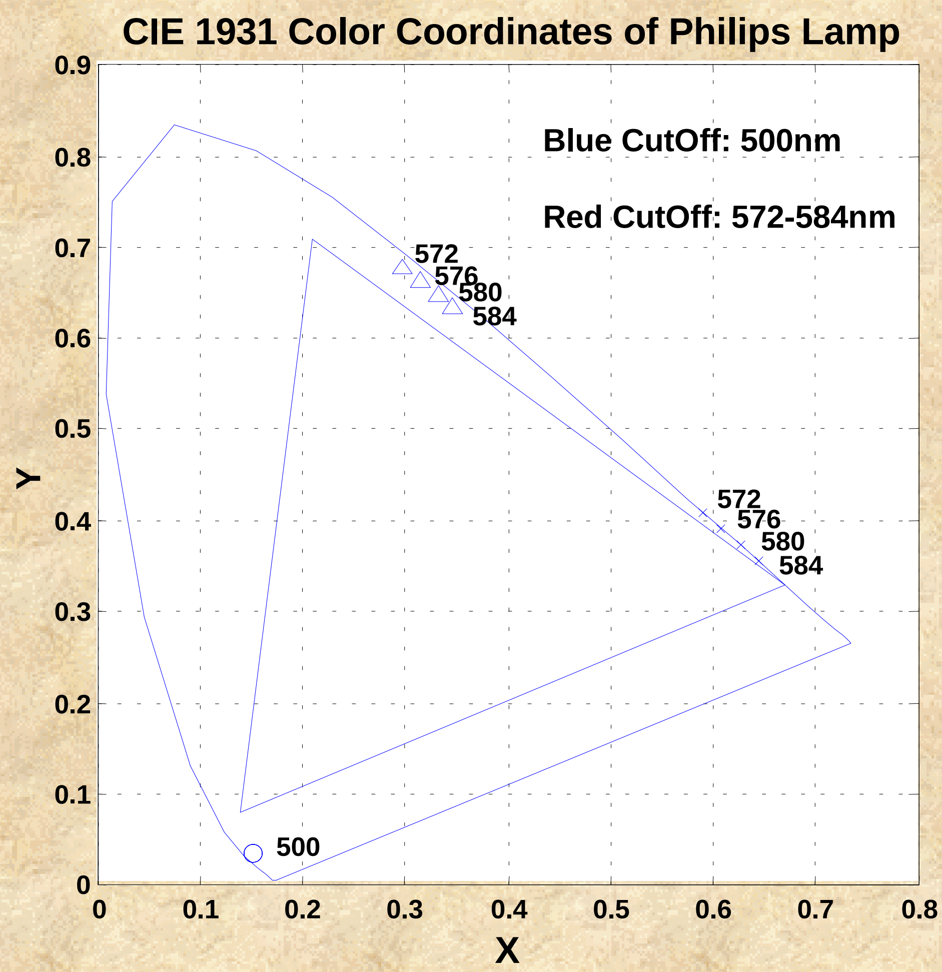
Color coordinates as a function of λ_{cutoff}



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Need more red continuum emission

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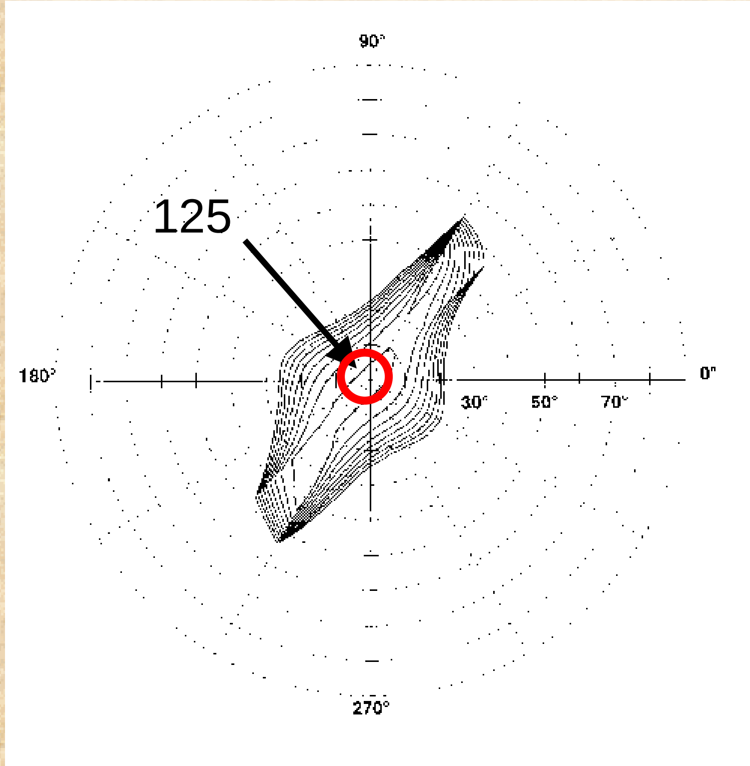
Acceptance angle of LCOS panels

- Not an issue with present PBS designs (10^o acceptance angle)

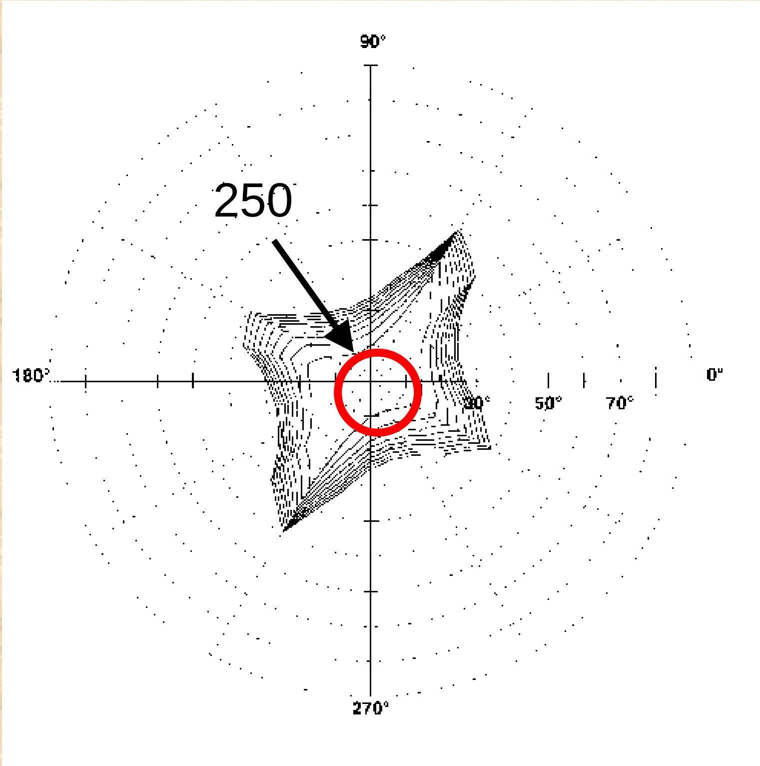
- Strongly dependent on operating voltages and LCD modes

Viewing angle of MTB mode
- importance of operating voltage



3V

± 4º for CR = 125



4V

±10º for CR = 250

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Projected image on screen

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Summary

- Much detailed optimization needed for LCOS projectors
- Steady progress is being made to improve the acceptance angle of all the optical elements and this has direct implication on the system brightness (optical efficiency)
- Improvement is also made from the lamp side - smaller etendue