Business Innovation in Optics and Photonics

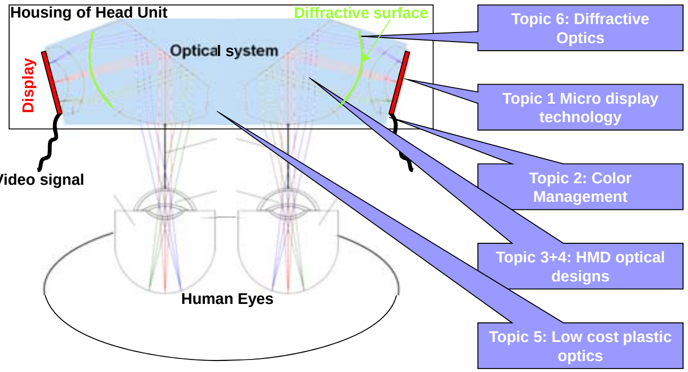
Course Section 2

Technology Introduction

Prof. Dr. Uli Lemmer
Light Technology Institute (LTI)
Karlsruhe Institute of Technology (KIT)

Dr. Markus Weber
Carl Zeiss AG

HMD Systems set-up with 6 technology topics related to optics and photonics



Group Task: For each technology topic, one group has to prepare and hold a 10' presentation and lead a 5' discussion

Technology Basics to be summarized and presented by 6 Groups

Introduction to display technology

Group 1: Micro-Display Technology LCD vs. OLED

Introduction to color management

Group 2: Color Management

Introduction to HMD optics: Key parameters and their mutual dependencies

Group 3: HMD - Optical Designs I: “cinemizer approach”

Group 4: HMD Optics Design II: “Planar approach”

Group 5: Low Cost Plastic Optics for Consumer Products

Group 6: Diffractive Optics

DATA GLASSES

Gruppe A	Gruppe B	Gruppe C
Nehemia Girma Terefe	Johannes Fischer	Christina Kelegkouri
Bohui Wang	Justus Zorn	Bernd Bertschinger
Ibrahim Dursun	Tobias Harter	Mario Planeck
Abel Gil Villalba	James Boettiger	Li Pan
Soumya Sunder Dash	Xavier Borrega	Tobias Lutz
Michael Rommel	Dejenie Birile Gemeda	

CINEMIZER

Gruppe D	Gruppe E	Gruppe F
Nitish Tripathi	Jingyi Zhang	Dagmawi Alemayehu Bekele
Aparajita Srivastava	Benedikt Bäuerle	Naresh Kotadiya
Elena Rachkova	Stephan Prinz	Kemal Juned Nassir
Carlos A. Rios-Ocampo	Alexander Lochbaum	Yuan Gao
Tuan Anh	Xiaoying Tan	Mahmood Joz Tavasoli
Philipp Brenner	Nico Bolse	

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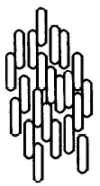
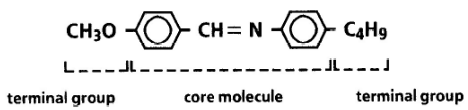
Display technology basics: What is an LCD ?
… a Liquid Crystal Display.



Nematic liquid Crystal

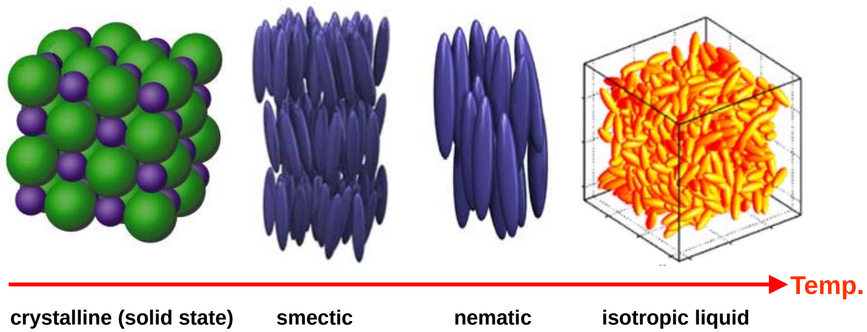


- Liquid crystals occur for certain rod-like molecules with anisotropic polarizabilities

- Liquid crystal is a state of order in between solids and liquids (mesophase)

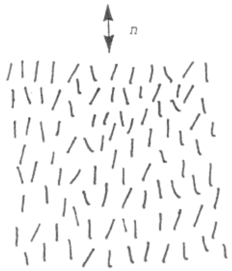
Display technology basics: What is an LCD ?
… a Liquid Crystal Display.

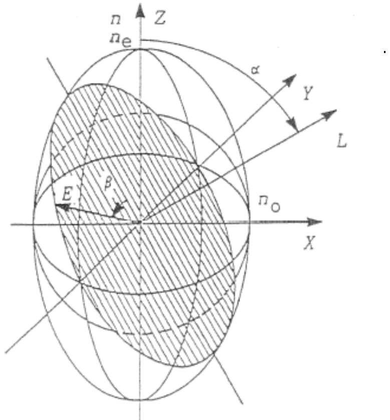
So what is a liquid crystal ?



Source: M. Becker

Liquid crystals

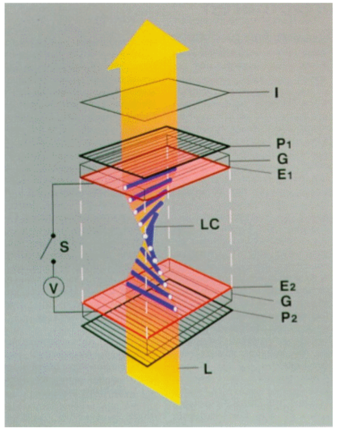


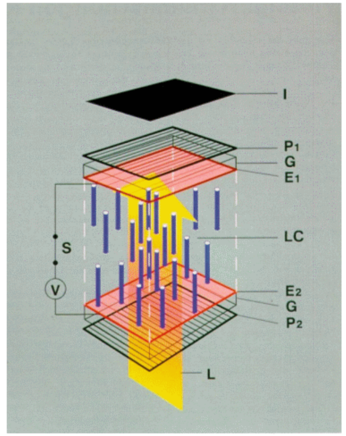


The anisotropic polarizability results in a *switchable* birefringence:

$\Delta n = n_{||} - n_{\perp} = n_e - n_o$

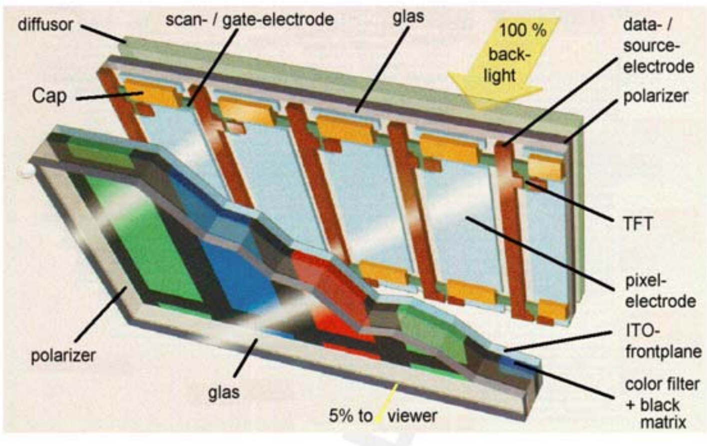
…and this can be utilized for realizing „light valves“.



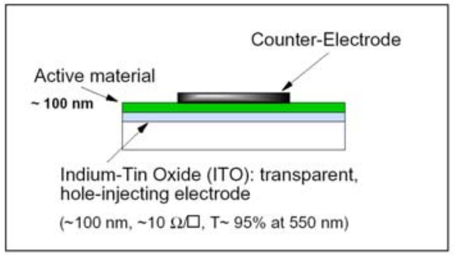


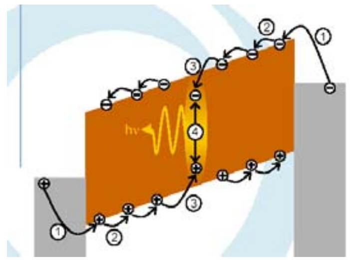
The Twisted Nematics(TN)-cell was the first LCD with widespread applications (pocket calculators, wrist-watches, other portable, battery operated devices) and it started the LCD-industry. More complicated (and better) switching schemes are used nowadays.

Active matrix multichrome LCD displays



Organic light emitting diodes (OLEDs): Highly efficient thin film electroluminescence devices





Source: T. Däubler, Schott

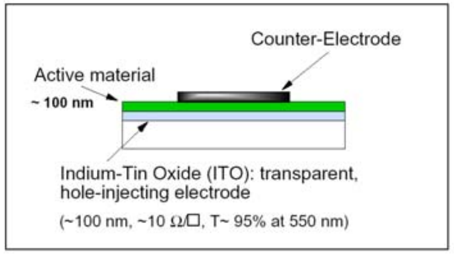
An organic light emitting diode (OLED) consists at least of three layers:

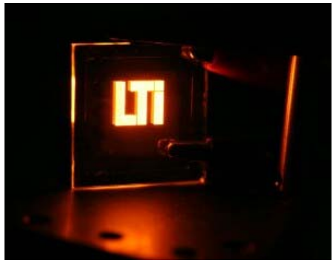
- a (transparent) anode (e.g. ITO))
- a thin film of an organic semiconductor
- a cathode (e.g. Ca/Al)

Steps during device operation:

1: Carrier injection
2. Transport
3: Formation of excitons
4: Radiative decay

Organic light emitting diodes (OLEDs): Highly efficient thin film electroluminescence devices





Source: LTI, Karlsruhe

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Active matrix OLED displays (AMOLED)

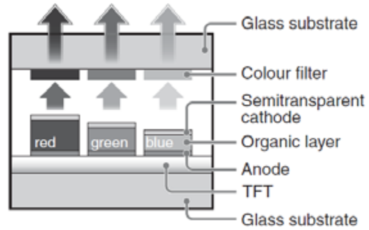

Figure 3

Source: XEL-1 Manual

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Group 1: Micro-Display Technology LCD vs. OLED

Key Questions and References

Key Questions

1. **Which different LC-switching technologies are available for microdisplays?**
2. **What are the specific challenges of an LCD microdisplay? (= RGB pixel pitch of <= 15µ)?**
3. **What are specific challenges of an OLED microdisplay?**
4. **What are the most important performance differences of LCD and OLED microdisplays? (Key advantages of each technology, major applications,…)**

References

1. **David Armitage, Ian Underwood, Shin-Tson Wu, Introduction to Microdisplays, Wiley Series in Display Technology**
2. http://www.kopin.com/what-is-cyberdisplay/
3. http://www.emagin.com/technology/index.php
4. http://www.displaysearch.com/
5. http://www.eetimes.com/
6. http://www.ednmag.com/
7. http://www.electronicnews.com/
8. http://www.electronictrendpubs.com/

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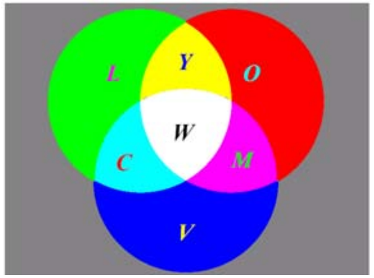
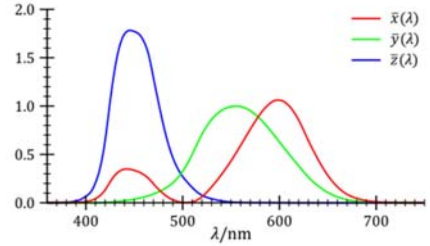
Color management basics





Additive color mixing

in an active (self emitting) display (as in the Cinemizer) colors are generated by additive color mixing.

Visual perception

The visual color perception can be described by the tri-stimulus functions.

Color space and color coordinates (CIE)

$$X = c \cdot \int S(\lambda)\, \bar{x}(\lambda)\, d\lambda$$

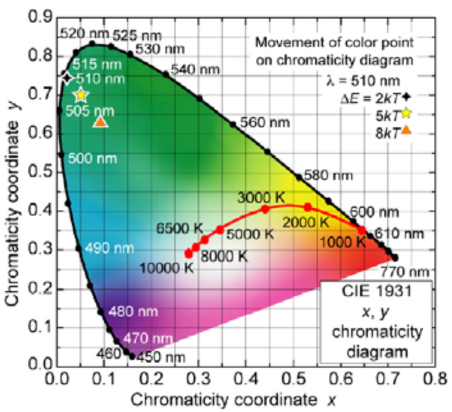
$$Y = c \cdot \int S(\lambda)\, \bar{y}(\lambda)\, d\lambda$$

$$Z = c \cdot \int S(\lambda)\, \bar{z}(\lambda)\, d\lambda$$

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z}$$

$$z = 1 - x - y$$

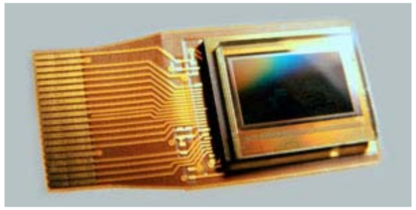
Colors are described by color coordinates, e.g., by x and y within the CIE 1931 system

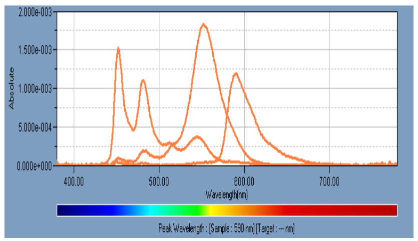


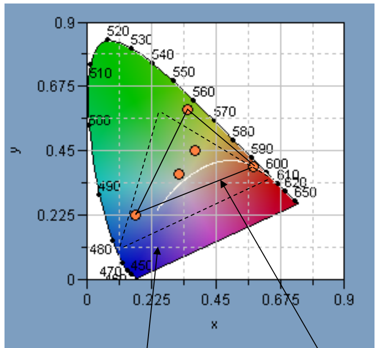
Source: E. F. Schubert

Color Vision for Visualization Systems

Example for color measured OLED-micro display

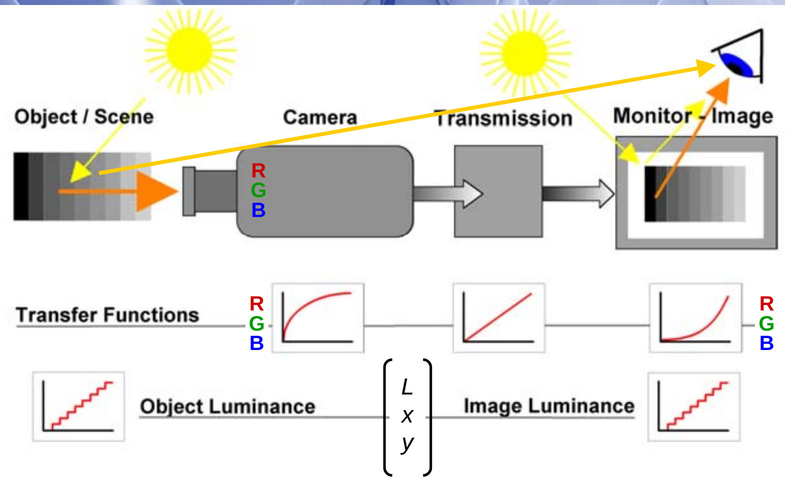






sRGB/PAL/HDTV

MicroOLED



Transmission chain: From the object to the observer's eye

Source: M. Becker

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Group 2: Color Management

Key Questions and References

Key Questions	**1. What are the key parameters and tools to do color management (color temperature, color space, …)** **2. What are major applications that require color management?** **3. How is color management implemented in hard- and software?**
References	**1. Herbert Gross, Handbook of Optical Systems, Wiley-VCH, 2005, Volume 1: Fundamentals of Technical Optics**

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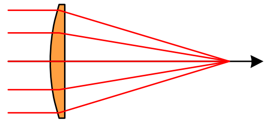
Hollywood HMDs do not always work

Example: Tomb Raider

Why is this display impossible to use?

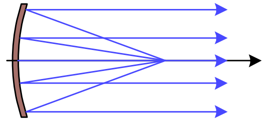
Refresher: How to deviate light

Lens: Refraction



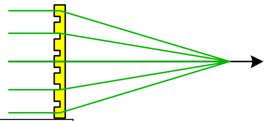
⇨ **Law of refraction**

Mirror: Reflection



⇨ **Law of reflection**

DOE: Diffraction

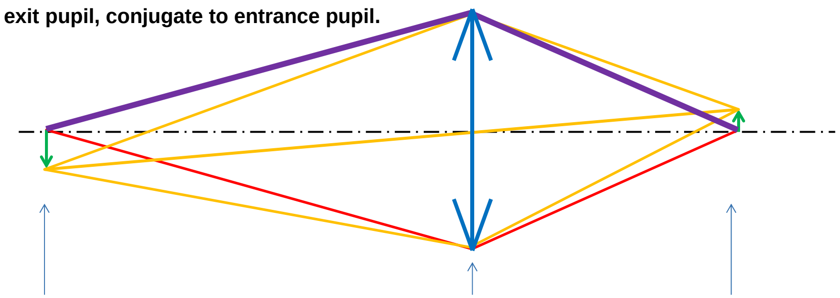


⇨ **Grating equation**

DOE = Diffraktiv Optical Element

Refresher: Pupil and field

Field = image plane, conjugate to object plane.
Pupil = exit pupil, conjugate to entrance pupil.

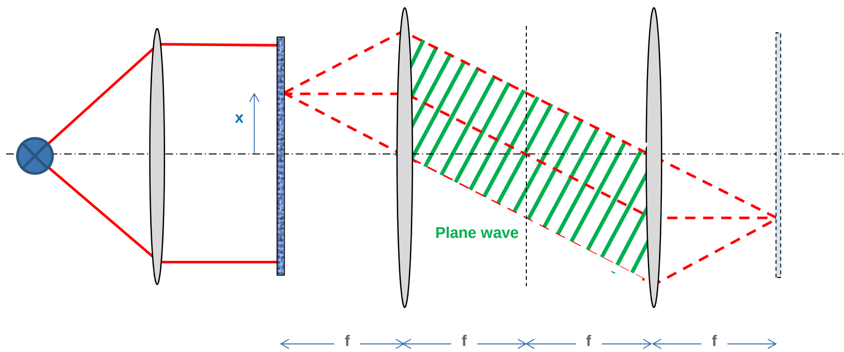


Position → Angle → Position'

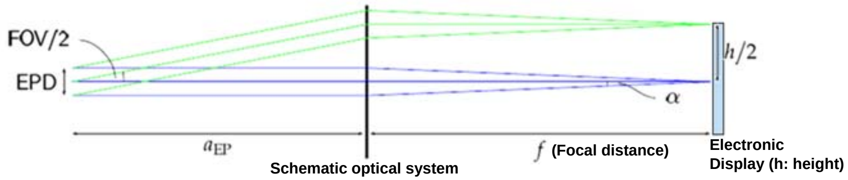
Angle → Position → Angle'

Refresher: A 4f-Setup is a 1:1 imaging system with a well defined pupil

The spherical wave of a single point is transformed into a plane wave



Three Key Performance Parameters of Head Mounted Display optics



Field of View (FoV): Determines perceived size of virtual image

Pupile Position (a_{EP}): „Eye-relief" determines how far the human eye can be positioned from the first lens

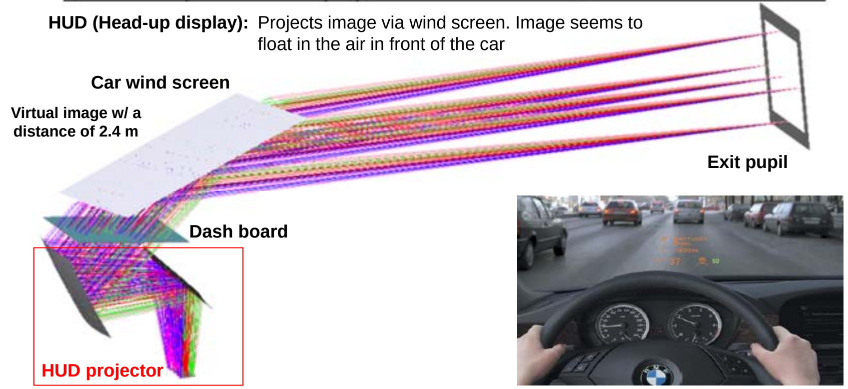
Exit pupil diameter (EPD): "Eye-box" the entrance pupil of the human eye has to be within that area to ensure that the virtual image is visible

Dilemma of all HMD optics designs: Maximize all three key parameters while keeping the total optical systems small and light weight

HMDs project a virtual image as nobody can focus on an image a few mm in front of his eye

Other example for virtual projection: Automotive HUD

HUD (Head-up display): Projects image via wind screen. Image seems to float in the air in front of the car



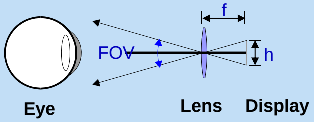
HMDs and HUDs project a "virtual" image seen far away from the eye

Most simple HMD system: A loupe

Mutual dependencies of key parameters

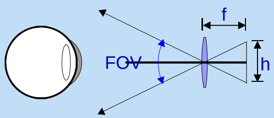
Loupe: Display in focal plane of lens
-> virtual image seems to be in infinity

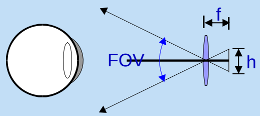
$$FOV_{opt} = 2\arctan\left(\frac{h}{2f}\right)$$



h bigger
-> **FoV** bigger

f smaller
-> **FoV** bigger





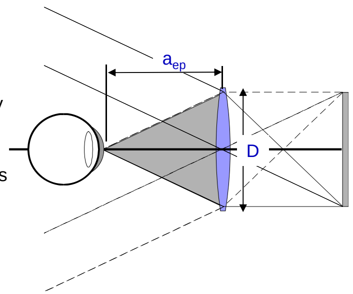
Caveat: bigger h = bigger display = higher cost !

Severe disadvantage of loupe: Eye has to be very close to loupe to see full image

The maximum visible FoV with a loupe is defined by
The rays coming from the edges of the lens

$$FOV_{lens} = 2\arctan\left(\frac{D}{2a_{ep}}\right)$$

D: Diameter of the lens
a_{ep}: Pupil position



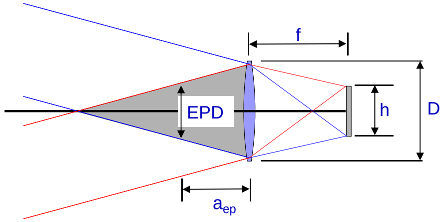
FOV_{lens} has to be bigger than FOV_{opt} to make sure that the full image can be seen

$$a_{ep} < \left(\frac{D \cdot f}{h}\right)$$

Eye box: Optical system has to allow movement of the eye, as relative positions are not fixed

EPD (exit pupil diameter):
"Eye box" or „eye motion box" =
The area in which the human eye
can move and still see the full image

$$EPD = D - \frac{a_{ep}\, h}{f}$$



For a simple loupe system, the following is true:
- EPD gets bigger when the eye moves closer to the lens
- Maximum EPD is the lens diameter

To allow comfortable viewing the EPD has to be big enough to
- Cover the whole area of the eye pupil
- Allow the eye to move around to look at the image while not leaving the eyebox
- Cover users with different relative eye positions

If exit pupil position cannot be adjusted, it has to be big to accommodate different PDs

PD (pupil distance): Distance between the middle of the pupil of each eye when looking at a far away object

Human PDs vary a lot: 50 mm - 74 mm

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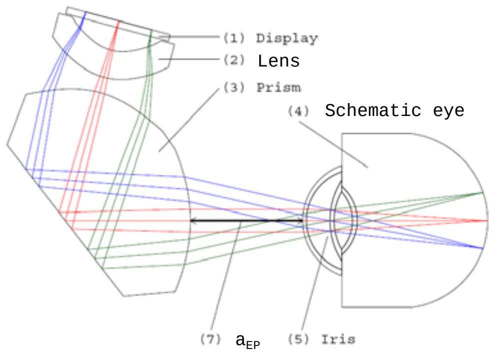
Cinemizer design with folded optics to allow for better integration into ergonomic housing



The Cinemizer design works like a folded microscopy eyepiece with the display at the position of the intermediate image plane. Focus can be adjusted by moving the display and lens group

Group 3: HMD - Optical Designs I: "Cinemizer approach"

Key Questions and References

Key Questions

1. **How does a microscopy eyepiece work?**
2. **What are main differences between a loupe and a microscopy eyepiece? (e.g. why is a multiple lens system used)**
3. **What are the main differences between a microscopy eyepiece and the cinemizer HMD optics? (e.g. with respect to the key parameters discussed before)**

References

1. http://en.wikipedia.org/wiki/Optical_microscope
2. http://en.wikipedia.org/wiki/Eyepiece
3. J. Melzer, K. Moffitt, Head-Mounted Displays, New York (1997), Mc Graw-Hill
4. Bertram Achtner, Frank-Oliver Karutz, Michael Pollmann, Markus Seeßelberg, Videobrille für das Kino unterwegs, Photonik 01/2008

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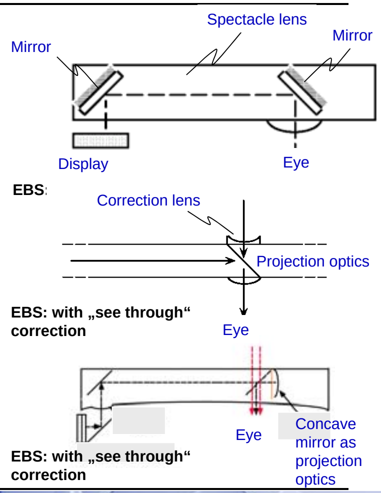
If a small FoV is enough, the optical system can be embedded in a spectacle lens

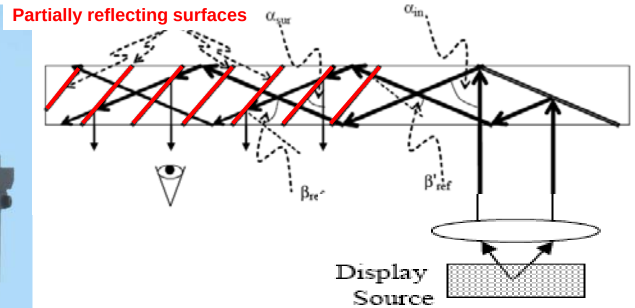
EBS (eyeglass based system): Planar approach with HMD Optics embedded in spectacle lens

- Spectacle lens thickness: 6 mm -> FOV ca. 8°
- Bigger FOV requires thicker spectacle lens (FOV 16°-20° -> 12 mm)



More complex embedded systems try to overcome these barriers

Example: LUMUS



LUMUS design uses an array of partially reflecting surfaces embedded in the spectacle lens to reflect the image into the eye

Group 4: HMD Optics Design II: “Planar approach”

Key Questions and References

Key Questions

1. **How does the LUMUS HMD design work?**
2. **What are the advantages and disadvantages of the LUMUS approach vs. a “cinemizer” HMD design?**
3. **What do you consider the main reason for this technology not being commercialized yet?**
4. **What are the challenges for light guides in curved glasses**

References

1. **Yaakov Amitai, P-27: A Two-Dimensional Aperture Expander for Ultra-Compact, SID 2005 Digest**
2. **Yaakow Amitai, Extremely Compact High-Performance HMDs Based on Substrate-Guided Optical Element, SID 2004 Digest**

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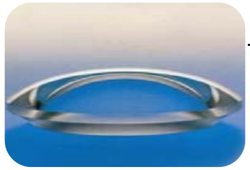
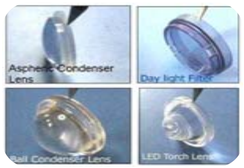
Materials for transmittive optics



Glasses

Crystals



Plastics

Liquids

Gases

Cements

Parameters of optical materials

Optical properties

- **Refractive index** $n(\lambda)$ **with spectral variation**
- **Transmission** $T(\lambda)$
- **Reflection** $R(\lambda)$
- **Absorption** $\alpha(\lambda)$
- **Uniformity of the refractive index (stria)**
- **Isotropy of the refractive index**
- **Autofluorescence**
- **Temperature coefficient of the refrative index**
- **Inclusions, bubbles, impurities**

Non-optical properties

- **Thermal expansion**
- **Mechanical properties (density, hardness)**
- **Chemical properties (sustainability against water, acids, …)**
- **Price (Money makes the world go around…)**

Dispersion & Absorption

Dispersion: Refractive index in real materials depends on wavelength $\Delta n = n(\lambda_1) - n(\lambda_2)$

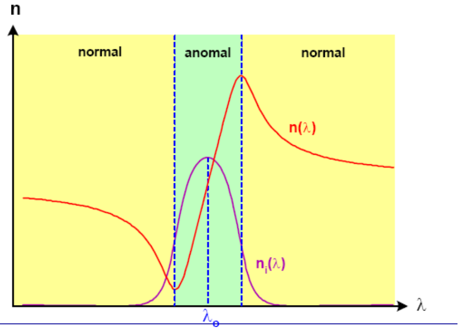
Normal dispersion: Refractive index decreases with wavelength (blue light with higher refraction than red light) $\frac{dn}{d\lambda} < 0$

Whereas the dispersion & absorption are related by the Kramers-Kronig relation

$$\varepsilon_r(\omega) = 1 + \frac{2}{\pi}\int_0^\infty \frac{\omega' \varepsilon_i(\omega')}{\omega'^2 - \omega^2} d\omega'$$

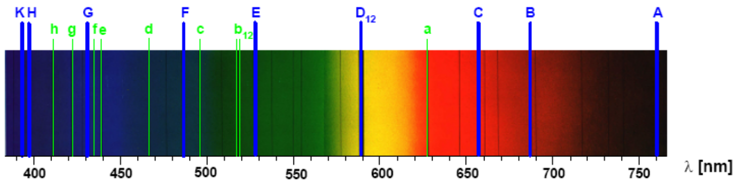
$$\varepsilon_i(\omega) = \frac{2\omega}{\pi}\int_0^\infty \frac{1 - \varepsilon_r(\omega')}{\omega'^2 - \omega^2} d\omega'$$

And the complex refractive index $\boldsymbol{n = \sqrt{\varepsilon_r + i\varepsilon_i}}$



Quantifying dispersion of optical materials: The Abbe number

Selected spectral lines in the solar spectrum are used to characterize dispersion in materials



Nomenclature of important spectral lines:

			I	(Hg)	365,0nm
F	(H)	486,1nm	g	(Hg)	435,8nm
d	(He)	587,6nm	E	(Hg)	546,1nm
C	(H)	656,3nm	D	(Na)	589,3nm

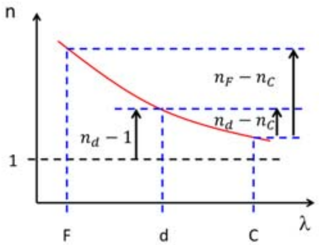
Dispersion quantities

Refractivity: $n_d - 1$

Principal dispersion: $n_F - n_C$

Partial dispersion: $n_d - n_C$

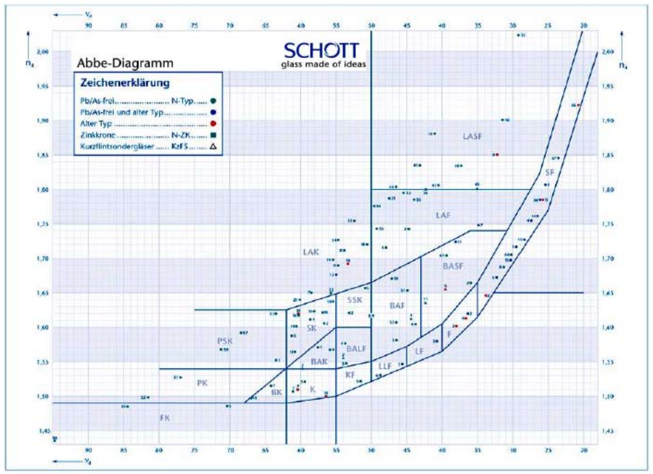
Relative partial dispersion: $P = \frac{n_d - n_C}{n_F - n_C}$



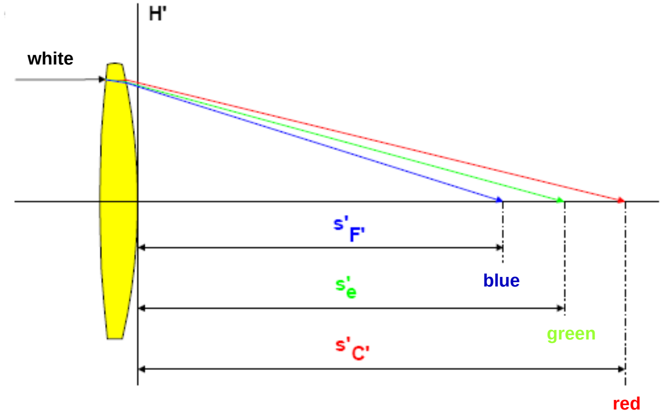
Abbe number characterizes dispersion

$$\nu = \frac{\text{Refractivity}}{\text{Principal dispersion}} = \frac{n_d - 1}{n_F - n_C}$$

Different optical materials show different behavior: The Abbe diagram



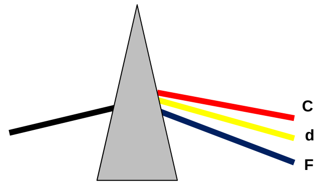
Simple lens systems made of one material have different focal planes for each color: Chromatic abberations

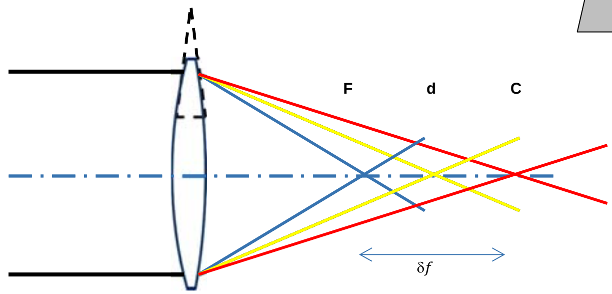


Axial chromatic aberration

Axial chromatic aberration (axial color, CHL), is the variation of the system focus with the wavelength.

It is caused by the dispersion of the marginal ray.





$$\frac{\delta f}{f} = \frac{\delta\phi}{\phi} = \frac{1}{\nu}$$

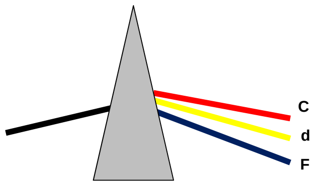
$\nu \sim 30 - 70$

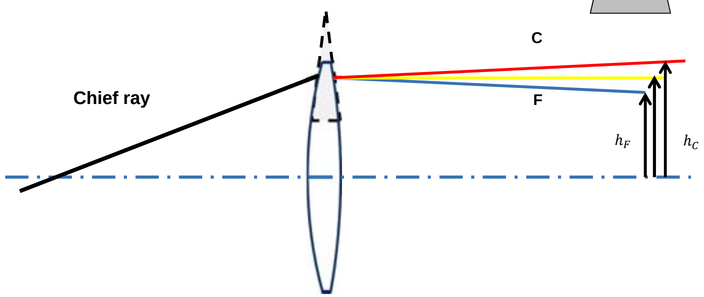
$\rightarrow \delta f / f = 1 - 3\%$

Lateral chromatic aberration

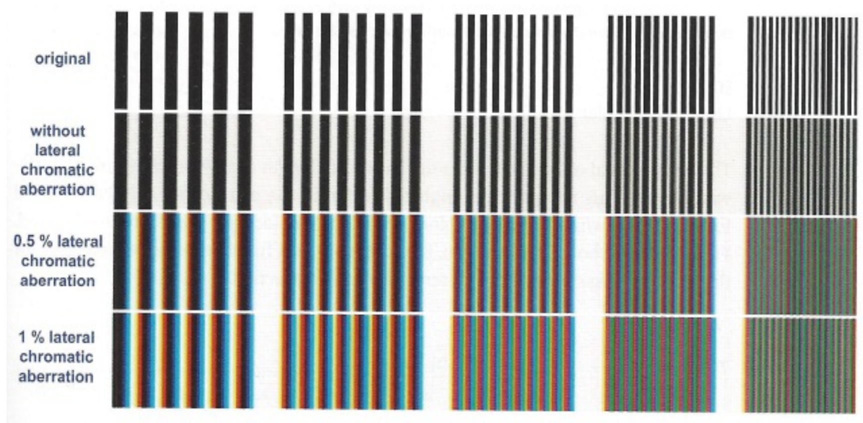
Lateral chromatic aberration (lateral color, CHV), is the variation of the image height with the wavelength.

It is caused by the dispersion of the chief ray



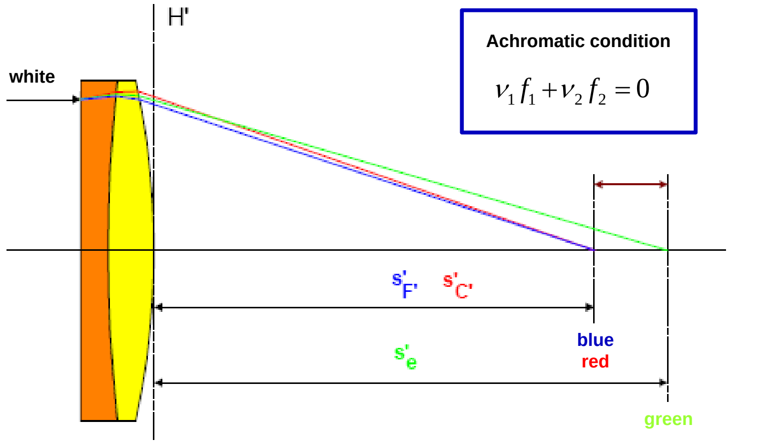


Effect of lateral chromatic abberation



Source: [4]

Achromatic system: Two lenses with different materials reduce the problem



Group 5: Low Cost Plastic Optics for Consumer Products

Key Questions and References

Key Questions	**1. Where are flint and crown glasses in the Abbe diagram?** **2. Describe and characterize a simple achromatic system made out of one flint and one crown glass?** **3. Where are plastics and glass optics material in the Abbe-Diagramm and what are the main implications concerning “plastic achromatic systems”?** **4. What are advantages and disadvantages of plastic optics vs. glass optics and to which major applications does this lead for either one?** **5. How are plastic optical elements manufactured and what are the challenges? (injection moulding and achievable accuracy vs. glass)**
References	**1. Herbert Gross, Handbook of Optical Systems, Wiley-VCH, 2005, Volume 1: Fundamentals of Technical Optics** **2. Stefan Bäumer, Handbook of Plastic Optics , Wiley-VCH, 2005**

Technology Basics to be summarized and presented by 6 Groups

Introduction to display technology

Group 1: Micro-Display Technology LCD vs. OLED

Introduction to color management

Group 2: Color Management

Introduction to HMD optics: Key parameters and their mutual dependencies

Group 3: HMD - Optical Designs I: “cinemizer approach”

Group 4: HMD Optics Design II: “Planar approach”

Group 5: Low Cost Plastic Optics for Consumer Products

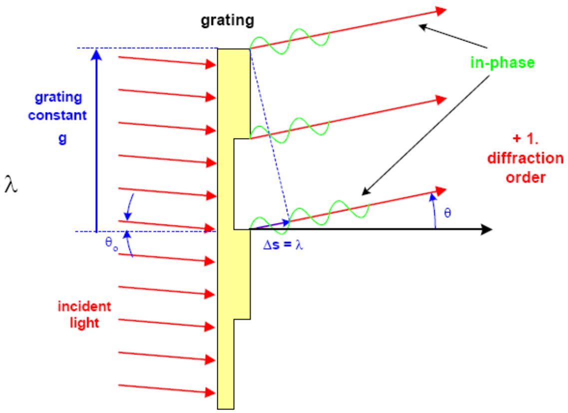
Group 6: Diffractive Optics

Refreshing your memory: Diffractive optics

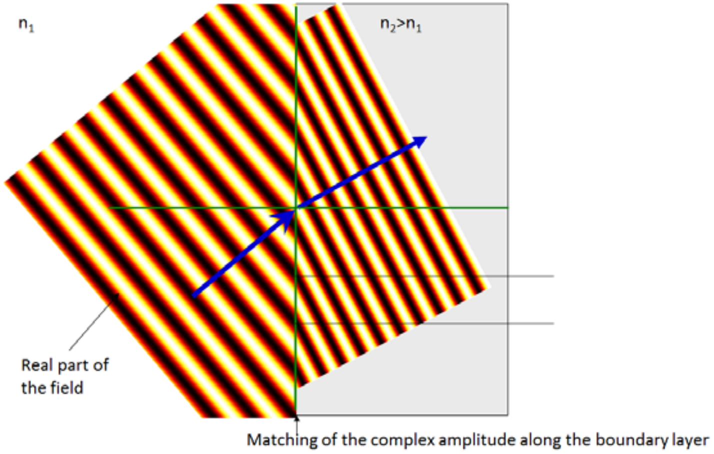
Intensity Maxima:
Constructive interference of in-phase light waves

Gratings formula:

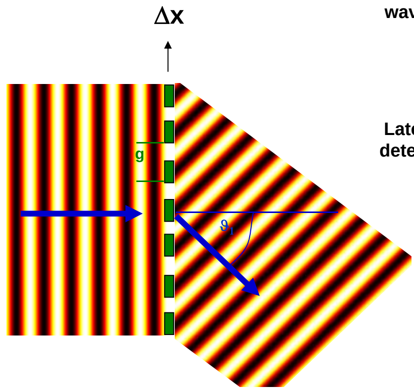
$$g \cdot (\sin\theta - \sin\theta_o) = m \cdot \lambda$$



Diffraction as wavefront matching – Snell's law



Grating equation as wavefront matching



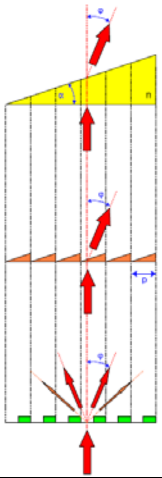
Deflection angle is determined by the wavelength & grating constant

$$\sin \vartheta_m = m \frac{\lambda}{g}$$

Lateral grating Δx is determines the phase

$$\Delta\varphi = \varphi_0 + 2\pi \frac{\Delta x}{\lambda}$$

Blazed grating ensures that light is diffracted only into one diffraction order



Refractive Optics (e.g. prism):
- No structured surface
- Light is refracted into one specific direction

Blazed Grating:
- Structured surface
- Light is diffracted into one specific direction

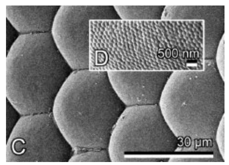
Binary ("normal") Grating:
- Structured surface
- Light is diffracted into many directions (diffraction orders)

Lens: Normal dispersion, Abbe number > 0

Blazed grating: Anornmal dispersion, Abbe number < 0

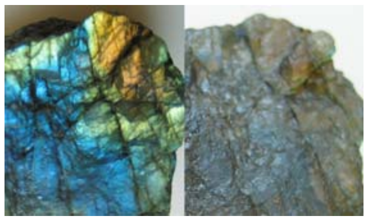
Blazed gratings can be used in plastic optics to build achromatic systems

Diffractive optics in nature



Moth eye


Opal


Labradorit crystal


Morpho

Group 6: Diffractive Optics
Key Questions and References

Key Questions

1. **Describe and characterize a simple plastic achromatic system made out of a lens and a blazed grating?**
2. **What are key challenges in manufacturing such a system?**

References

1. **H.P. Herzig, Micro-Optics: Elements, Systems and Applications, Academic Press 1997**
2. **J. Turunen and F. Wyrowski, Diffractive Optics: Industrial and Commercial Applications, Wiley 1998**
3. **T. Stone, N. George, Hybrid diffractive-refractive lenses and achromats, Appl. Optics 27, 2960-2971 (1988)**

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Praktikant / Student für eine Praktikums- / Abschlussarbeit zum Thema: "Validierung von Optikdaten im XML-Format" (m/w)

Praktikum im Bereich System Design - Analyse von optischen Systemen (m/w)

ab sofort für ca. 6 Wochen

Praktikum im Innovationsmanagement, Beginn: ab Februar 2013, Dauer: ca. 6 Monate, anschl. Abschlussarbeit möglich

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Master Theses
Potential upcoming opportunities

- **Development of a miniaturized optical 3D metrology sytem for complex shaped parts**
- **Development of an integrated optical sensor based on plasmonic filters**
- **Aktuierung von Alvarez-Humphrey Linsen**
- **Regelungsentwurf für einen erweiterten dynamischen Autofokus**
- **Object pose estimation for image-based subordinate categorization**
- **Shape adaptive patches for image reconstruction**
- **Stereo image quality assessment**