Course outline

1. Imaging optics
2. Optical sensors
   2.1 Spectroscopy
   2.2 Material characterization
   2.3 Distance measurement
   2.4 Angle measurement
   2.5 Optical mouse
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Interferometric distance measurement

- Interferometer
  - Light split into at least two beams
  - Beams propagate different optical paths
  - Superposition of beams at exit
- Interference effect occur for coherent superposition
  - Interference pattern depends on optical path difference that beams incur before superposition.
- Precision measurement possible by evaluation of optical interference pattern
- Examples for interferometers

Newton's rings

- Newton's rings due to interference of light reflected on lens and light reflected on glass plate

Source: Naumann/Schröder, Bauelemente der Optik, 1992

Source: www.physik.uni-ulm.de

Fabry-Perot
Michelson
Mach-Zehnder

Without lens error
With lens error
6.5 White light interferometer
- Interference of broadband light source (white light) used
  - White light has small coherence
  - Interference phenomena only visible if optical length of both paths in interferometer identical within coherence length (~$\lambda$)
  - Object scanned in z-direction by movement relative to reference plane
- „Depth image“ of object with small measurement uncertainty generated
  - Setup needs to be very stable

Source: www.3d-shape.com

6.6 Time of flight distance measurement
- Emit laser pulse and determine time difference until detection of reflected pulse
- Calculation of distance using propagation velocity

\[ \text{time-of-flight} \]

- Impuls aussenden  
- Reflektion  
- Echo empfangen  

- Problem: Light is fast
  - Propagation time for distance of 1 m is 3 ns
- Short laser pulses and fast electronics necessary

6.7 LIDAR (Light Detection and Ranging)
- Compare to Radar:
  - Electromagnetic wave emitted and reflected signal analyzed

Source: http://www.dlr.de/schoollab/

6.8 LIDAR applications
- Coordinate measurement using time of flight
- Dynamics of gas turbulences by time of flight measurement and Doppler shift
- Chemical analysis (Pollutant concentration in atmosphere) by time of flight measurement and spectral measurement (Raman signal)

The LIDAR-derived DEMs are sufficiently detailed to recognize individual features such as trees and structures.

DEM: Digital elevation model
### Raman Scattering

- **Raman signal provides fingerprint of molecules as vibrational states specific for chemical bonds**
  - Fingerprint region of organic molecules typically 500-2000 cm\(^{-1}\)
- In solid state physics Raman signal used to, e.g., characterize materials and measure temperature
- Difficulty is to separate weak Raman signal from background

![Raman Scattering Diagram](en.wikipedia.org)

### LIDAR-System (Example Univ. Baltimore)

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laser</strong></td>
<td>Q-switched Nd-YAG with 320mJ at 1064nm (additional wavelengths: 532nm and 355nm); 30Hz repetition rate; 8ns pulse; 1.8 mrad beam divergence; BigSky laser model CFR 400</td>
</tr>
<tr>
<td><strong>Telescope</strong></td>
<td>25.4 cm (10 in) diameter, Cassegrain f/10, 5mrad FOV (Meade LX50)</td>
</tr>
<tr>
<td><strong>Detector</strong></td>
<td>IR-enhanced Si avalanche photodiode (Analog Modules)</td>
</tr>
<tr>
<td><strong>Digitizer</strong></td>
<td>12-bit 100MHz, dual channel (Signatec PDA 12)</td>
</tr>
<tr>
<td><strong>Scanning system</strong></td>
<td>Azimuth rotary stage (180:1), stepper motors &amp; encoders, elevation right angle reducer (100:1), i.e. from 80° to -10°, AT6400 controller (CompuMotor)</td>
</tr>
<tr>
<td><strong>Maximum range resolution</strong></td>
<td>1.5m</td>
</tr>
<tr>
<td><strong>Data acquisition</strong></td>
<td>Pentium 133 MHz laptop</td>
</tr>
</tbody>
</table>

### Distance Measurement by Contrast Evaluation

- Modification of objective position until image focused
- Reading of distance on objective scale
- Called contrast measurement as image contrast maximum in focus
- Auto-focus of digital camera works using contrast evaluation
  - Processor of camera calculates spatial frequency distribution of image
  - Image closer to focus if fraction of high frequencies larger
  - Multiple images with different focusing necessary to evaluate contrast
  - Alternatively, beam splitting may be used

![Distance Measurement Diagram](en.wikipedia.org)

### Auto-focus using Astigmatic Imaging

- Illumination spot A imaged via objective and cylindrical lens astigmatically onto quadrant diode
- For correct focusing signals on x-diode and y-diode identical
- Setpoint tracing obtained from difference signal
  - Used in CD- und DVD-players

![Auto-focus Diagram](en.wikipedia.org)
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Angle measurement using collimator and telescope

- Collimator: Projector that images illuminated reticle to infinity
- Telescope with reticle used for evaluation
- Sensitive measurement of direction differences
- Setup insensitive vertical alignment (Parallel displacement)

Autocollimator

- Instrument combines collimator and telescope
  - Collimator reticle and telescope reticle both placed at focal plane of autocollimator objective

Example: Determination of track way profile

- Measurement of angle while slide moves
Alignment telescope

- Precision instruments for the alignment of objects to a reference line, which is defined by the line of sight of the system
- Alignment telescope focuses target to determine lateral displacement with regard to reference line
  - Setup insensitive against rotation

Adjustment of telescope axis

- Before use telescope axis needs to be aligned with track way
  - Adjust height to front target
  - Adjust direction to rear target
  - Repeat if necessary
- Identical procedure for adjustment of alignment laser with two iris apertures

Example: Evaluation of alignment

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6.21 Opto-mechanical mouse (since 1984)
- Direction obtained from time sequence of signals

6.22 Optical mouse (old – since 1968)
- Special pattern on mouse pad used for modulated reflection during movement

6.23 Optical mouse (new)
- Image scanned (as in digital camera) and displacement calculated

6.24 Examples for optical mouse systems
- Different systems:
  - Example of image from bottom

Source: http://www.howstuffworks.com
Source: http://www.howstuffworks.com
Source: http://www.mstarmetro.net/~rlowens/OpticalMouse/
6.25 Laser mouse (very new – since November 2004)

- Illumination with IR-laser
- Image taken with camera
- Movement of speckle-pattern evaluated

Figure 3: Interpreting differences in image fingerprints can be translated to movement of the mouse


6.26 What is speckle?

- Speckle (laser light-granulation) occurs upon reflection or transmission of coherent light on rough surfaces or distributed scatterers

6.27 Diffraction on grating

- Interference effect of large number $N$ of scattering points $k$ with fixed phase difference $\phi_k$ between 0..2\(\pi\)
- Each scattering point is origin of spherical wave. Waves superpose at observation point $r$

$$A(r) = \sum_{k=1}^{N} a_k e^{i\phi_k} \sqrt{N}$$

6.28 How does speckle form?

- Interference effect of large number $N$ of scattering points $k$ with random phase difference $\phi_k$ between 0..2\(\pi\)
- Each scattering point is origin of spherical wave. Waves superpose at observation point $r$

$$A(r) = \sum_{k=1}^{N} a_k e^{i\phi_k} \sqrt{N}$$
6.29 Speckle: influence of surface

- Speckle occurs if roughness of surface larger than wavelength of light

Observation point \( r \)

\[ \text{coherent light} \]

\( \lambda \)

6.30 Speckle: influence of scattering particles

- Speckle occurs in transmission if scattering particles are distributed in volume with distance larger than wavelength of light
- Possible difference to scattering on surface:
  - Multiple scattering (random walk) increases effective roughness to more than layer thickness

Observation point \( r \)

\[ \text{coherent light} \]

6.31 Problems caused by speckle

- Holograms
  - Besides desired object and reference wave speckle exists due to rough objects
- Laser projection displays
  - Roughness of projection screen causes speckle and blurred images
- Astronomy
  - Wave front are disturbed in atmosphere and limit resolution (“Seeing”)
- Wireless microphone
  - Lecturer with wireless microphone cannot be heard at certain position in auditorium (dead spots)
- Ultrasonic imaging
  - Granulated image due to speckle

6.32 Possibilities by using speckle

- Speckle metrology
  - Superposition of pattern 1 from measurement object and pattern 2 from reference object results in pattern 3 that depends on phase difference at given wavelength
  - Surface analysis by comparison to reference surface
Laser mouse

Figure 4: Laser uncovers surface features not detected by LED.

Glossy packaging (LED)    Glossy packaging (Laser)

Whiteboard (LED)           Whiteboard (Laser)


Laser mouse (very new – since November 2004)

- Other laser properties may be used as well
  - e.g., Philips Twin-Eye laser sensor: Input device based on laser Doppler effect

Source: http://www.business-sites.philips.com/lasersensors/about/article-15031.html

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Early data storage systems

- Data storage is used to save and distribute information independent of humans

- cuneiform writing
- cave-painting
- letterpress
- music box
Photocopyer
- 1938: Effect discovered by Carlson
- 1947: Technology licensed to Haloid
- 1949: First commercial photocopier
- 1961: Company was renamed from Haloid to Xerox

The first photocopy

Source: Xerox

Copying I

(1) CHARGE

DOCUMENT

PHOTORECEPTOR

DC VOLTAGE

(2) EXPOSE

TONER PARTICLES

PHOTORECEPTOR

(3) DEVELOP

Source: Borsenberger, "Organic Photoreceptors for Imaging Systems"

Copying II

(4) TRANSFER

Fuser Roller 150-200°C

Pressure Roller 40-80°C

(5) FIX

LAMP

(6) CLEAN

PHOTORECEPTOR

(7) ERASE

PHOTORECEPTOR

Source: Borsenberger

Image drum
- Core of copier is drum coated with photoconductor
- Photoconductor should have small dark conductivity and high photo sensitivity
- Photoconductor needs to be applied onto round or flexible substrates
- Until 1975 selenium mainly used, today organic semiconductor materials are used (see lecture "Plastic Electronics").

Photo courtesy of Xerox
Toner

- Toner consists of pigments, iron and resin
  - Pigments responsible for color, e.g., soot for black toner
  - Iron particles allow for sticking to electrically charged drum
  - Resin allows for “melting” toner onto paper in fuser

Photocopier (analog)

- Imaging of document onto drum using system of lenses and mirrors
- Exposure and development need to be in one instrument

Digital copier

- Digital copiers consist of two separate units, the scanner and the printer
- Document digitalized with scanner and saved in digitally (RAM or hard drive)
- Saved image transferred electronically to printer and usually printed with laser printer

Advantages and disadvantages of digital copying

- **Advantages**
  - Compact and cost-effective construction possible
  - Document may be copied several times without repeated exposure
  - Additional functionality such as print, fax, scan possible
  - Possibility of digital modification of copy before print

- **Disadvantages**
  - More likely noise on image
  - Grey increments worse
6.45 Exercise: Laser scanner unit

- Suggest a layout for the laser scanner unit!

6.46 Laser unit of laser printer

- Beam path not shown correctly, light reflects on edge of polygon mirror!

6.47 Laser printer

- Laser printer has printer part only
- Image on drum generated by exposure with laser (for LED-printers using row of LEDs).

6.48 Color laser printer

- Individual toner cartridge for each color (cyan, magenta, yellow and black) necessary
- Laser exposes drum or transfer band four times for each print – once for each color
**Color laser printer: Inline-technique**

- Individual drum for each color
- Sequential transfer of colors to paper
- Advantage is high print speed

![Inline-system diagram](source: www.druckerchannel.de)

**Color laser printer: Revolver-technique**

- Only one laser unit used
- Images of individual colors printed on transfer band
- When all colors are on transfer band, image transferred to paper
- Compact construction, but rather slow and loud

![Revolver-system diagram](source: www.druckerchannel.de)

**Fuser**

- At the end paper passes fuser rolls: Heat and pressure fuse toner into paper
  - One of the Teflon coated rolls is heated to about 200 degrees Celsius.
  - Other roll necessary for counter pressure
  - Heat and pressure melt toner particles and fixate them on paper
- Small bristles visible at paper ejection. These neutralize electrically charged paper to prevent sticking of pages.

![Fuser diagram](source: www.druckerchannel.de)

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Classification of data storage I

- **Mass storage:** Storage medium and access unit separate
- **"random-access"-storage:** Storage medium and access unit joined

Classification of data storage II

**Mass storage**
- One or more access units and information saved on one or more storage units
- Data access by positioning of access unit onto storage unit
- Data exchange using different physical transactions, e.g., mechanical, optical, magnetic fields, electric fields.
- Access times for HDD are a few milliseconds, for CD/DVD/MO ca. 100 milliseconds

**"random-access"-storage**
- Access using matrix of conductors. Storage medium located at cross points
- Data access by electrical addressing of rows and columns in random order
- Electronic data exchange.
- Access times of few nanoseconds.

Source: Waser, „Nanoelectronics and Information Technology“

How is data stored on CD?

- Digital data saved in continuous spiral on CD
- Data saved as bits in pits
- Height profile coated with reflective layer to increase intensity of reflected light

Sources: www.howstuffworks.com; www.physics.udel.edu/wwwusers/watson/scen103/ess-ccd.html

Fabrication of CD I

- Glass master fabricated by exposure of photo resist
- By galvanization (electrochemical process) 3-6 molds are fabricated

Sources: www.ee.washington.edu/consele/CE/kuhn/cdaudio/95x6.htm
### Fabrication of CD II

- After two more galvanic molds resulting metal stampers ("Sons") used to fabricate CDs using inexpensive die casting in polycarbonate (1.2 mm).

- At the end surface is coated with metal (Ag, Al, Au, Cu 50-100 nm), and protective layer (1-30 µm). Label is applied.

### Exercise: Layout of CD-player

- How does a CD-player work?
  - What are components 1 to 6?
  - What function do they have?

### Circuit diagram for photodiode

- Tracking
- Data signal
- Auto focus

### Layout of CD-player

- Optical beam path consists of laser diode, grating, polarizing prism, $\lambda/4$-waveplate, various lenses and photodetector.

Source: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm

Source: hyperphysics.phy-astr.gsu.edu/hbase/audio/cdplay.html

Source: Imlau

Source: hyperphysics.phy-astr.gsu.edu/hbase/audio/cdplay.html
Reading data I

- The compact disc is 2 cm in diameter and 1.2 mm in thickness. The disc spins about 2 mm above the laser lens assembly.
- Data read by laser (780 nm) through polycarbonate-substrate.
  - Laser diameter at focus is 1.7 µm on reflective coating.
  - Beam enters through substrate with diameter of 0.8 mm. Thus, dust or small scratches have no influence.

Source: hyperphysics.phy-astr.gsu.edu/hbase/audio/cdplay3.html

Reading data II

- As all areas of CD are metal coated, reflectivity does not change with position.
- Signal due to constructive or destructive interference.
  - "Pits" (actually mounds) have depth of exactly 1/4 in polycarbonate.
  - 780 nm/(4*1.55)=125.8 nm.
  - Half the beam reflected from "Land" other half from "Pit" causes destructive interference in vertical direction due to 180° phase shift.
  - If beam completely reflected from "Land", constructive interference results.

Source: www.howstuffworks.com; hyperphysics.phy-astr.gsu.edu/hbase/audio/cdplay3.html

Reminder: Polarization

- Linearly polarized light is plane wave with fixed orientation of electric field.
- Circularly polarized light may be described by two plane waves with equal amplitudes and 90° phase difference.

Source: hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html

Polarizing beam splitter

- Reflected light passes to photodetector and not back to laser diode due to polarizing beam splitter and 1/4-Wellenplatte.

Source: hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html
Focusing of laser beam I

- Objective lens focuses laser beam onto active layer.
- Due to circular aperture beam exhibits Airy-pattern.
- Beam is diffraction limited.

\[ \lambda = 780 \text{ nm} \]
\[ n = 1.5 \]
\[ NA = 0.45 \text{ (in air)} \]
\[ d = 1.3 \times 10^{-6} \text{ m} \]
\[ \delta = 7.7 \times 10^{-6} \text{ m} \]

Source: Imlau

Focusing of laser beam II

- As planarity of CD is ca. 50 µm and "Wobble" is ca. 100 µm continuous refocusing is necessary to prevent crosstalk.
- Focusing achieved with astigmatic lens (Combination of spherical objective lens and cylindrical lens in front of detector) and quadrant detector.

Source: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm

Astigmatic lens combination

- Astigmatic lens combination causes only at correct spacing round shape.
- Quadrant detector used to analyze beam shape

Source: www.physics.udel.edu/%7Ewatson/scen103/cd-astig.html

CD too close

Source: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm
6.69

CD too far

[Diagram of optical system]

Source: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm

6.70

Autofocus

- Quadrant detector allows for simultaneous reading of data and generation of autofocus signal.
- Objective lens adjusted fast and precise with moving coil.

[Diagram of autofocusing mechanism]

Source: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm

6.71

Rotation of CD

- Data on CD read with constant linear velocity of 1.3 m/s.
- Due to constant linear velocity, angular velocity needs to be reduced from 500 RPM on the inside to 200 RPM on the outside.

[Diagram of CD rotation and track]

Source: Waser: „Nanoelectronics and Information Technology”

6.72

Tracking I

- During reading of CD optical head needs to be kept on spiral track.
  - Accomplished with „Three-beam-tracking“.
- Grating generates side beams around main beam.

Sources: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm; hyperphysics.phy-astr.gsu.edu/hbase/phyopt/photop/photopic/gratinghene2.jpg
6.73 Tracking II

- Side beams fall between data tracks and are measured with two extra detectors.

Source: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm

6.74 Tracking III

- If signal intensity of side beams is equal, tracking is adjusted correctly.
- Tracking done with servo drives.

Source: www.physics.udel.edu/~watson/scen103/cd-tracking.html

6.75 How may the data density be increased?

- Data density given by:

\[
D_{2D} = \frac{\text{\#bits}}{\text{Area}}
\]

- Thus, bits should be chosen as small as possible for high data density.

- Resolution determines minimum size of bits:

\[
y_{\text{min}} = 1.22 \frac{\lambda}{2n \sin \alpha}
\]

- \(n \sin(\alpha) = \text{NA}\) is numerical aperture of objective (n=1, as objective in air).

- To achieve high data density, wavelength should be small and NA large!

Source: www.ee.washington.edu/conselec/CE/kuhn/cdaudio/95x6.htm

6.76 Comparison CD and DVD

- For DVD smaller wavelength and larger NA is used. Also number of layers is increased to increase data density.

Source: Waser: „Nanoelectronics and Information Technology“
6.77 DVD Formats

- Distance between double-layer layers: 55 +/- 15 µm

Source: Waser: "Nanoelectronics and Information Technology"

6.78 Comparison CD and DVD

<table>
<thead>
<tr>
<th></th>
<th>CD</th>
<th>DVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>120 mm</td>
<td>120 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>1.2 mm</td>
<td>2 x 0.6 mm or 4 x 0.3 mm joint layers</td>
</tr>
<tr>
<td>Track distance</td>
<td>1.8 µm</td>
<td>0.74 µm</td>
</tr>
<tr>
<td>Width of pits</td>
<td>0.83 µm</td>
<td>0.40 µm</td>
</tr>
<tr>
<td>Laser wavelength</td>
<td>780 nm</td>
<td>650/635 nm</td>
</tr>
<tr>
<td>Data layers / sides</td>
<td>1/1</td>
<td>1/1 or 4.7 GB</td>
</tr>
<tr>
<td>Capacity</td>
<td>660 MB</td>
<td>8.5 GB or 9.4 GB</td>
</tr>
<tr>
<td></td>
<td>2/2 or 17 GB</td>
<td></td>
</tr>
</tbody>
</table>

NA = 0.45 to 0.6

Source: Waser: "Nanoelectronics and Information Technology"

6.79 Comparison CD - DVD - Blu-Ray

<table>
<thead>
<tr>
<th>CD</th>
<th>DVD</th>
<th>Blu-Ray</th>
</tr>
</thead>
<tbody>
<tr>
<td>λ = 780 nm</td>
<td>λ = 650 nm</td>
<td>λ = 405 nm</td>
</tr>
<tr>
<td>NA = 0.45</td>
<td>NA = 0.6</td>
<td>NA = 0.85</td>
</tr>
<tr>
<td>0.65 GBytes</td>
<td>4.7 GBytes</td>
<td>25 GBytes</td>
</tr>
</tbody>
</table>

© Philips Research

6.80 Writable CDs and DVDs

- The following categories are distinguished:
  - Prewritten CDs and DVDs are read-only
  - WORM (write once read many): may be written once and read many times, e.g., CD-R
  - R/W (read/write): may be written and read many times

- Most important criterion for writable CDs and DVDs is that they may be read in conventional CD- and DVD-players
  - As in conventional read-only CDs and DVDs the reflection properties need to be changed.
Methods for writable CDs/DVDs I

- a) Burning of holes in thin metal layer (e.g., Tellurium due to low melting point)

- b) Blister formation upon heating

Methods for writable CDs/DVDs II

- c) Thermo-plastic methods

- d) Change of texture

Methods for writable CDs/DVDs III

- e) Chemical change of dye layer -> used in CD-R

- e) Phase change from crystalline to amorphous -> used for DVD-R/W

CD-R: Tracking and Timing

- Pre-groove allows for tracking.
- Additionally pre-groove has “Wobble” superimposed, a 22.05 kHz sinusoidal deviation from track center with 30 nm amplitude. This allows for adjustment of writing speed.
6.85 DVD-R/W

- Rewritable DVDs based on reversible phase change of medium by heating with laser beam.

![Diagram of DVD-R/W](image)

-Waser: „Nanoelectronics and Information Technology“

6.86 Phase Change Media I

- X-ray diffraction shows different structure of amorphous and crystalline layer of Ge$_2$Sb$_2$Te$_5$.

![Graph of X-ray diffraction](image)

-Waser: „Nanoelectronics and Information Technology“

6.87 Phase Change Media II

- Amorphous and crystalline layer have different optical properties.
- Data may be coded by reflectivity.

![Graph of index of refraction](image)

-Waser: „Nanoelectronics and Information Technology“

6.88 DVD-R/W: Layer sequence

- Dielectric layers on both sides of active layer ensure maximum energy absorbance and protect active layer.
- Tracking and timing again by use of pre-groove with „wobble“.

![Diagram of DVD-R/W layer sequence](image)

-Waser: „Nanoelectronics and Information Technology“

www.digitaldrives.com/Sections/TechReferences/Sources/DVD-RW%20Standard
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Magneto-Optical Discs (MOD), MiniDisc (MD)

- Data stored in small ferromagnetic domains that may be written and erased
  - Ferromagnetic domains are volume elements of homogeneous orientation and magnetization.
- Generation of domains by combination of light and magnetic field. Light heats material locally.
  - Principle of MOD investigated in 70th
  - Announced with CD in 1982
  - First commercial MOD in 1988

MOD: Reading

- Magneto-optical Kerr-effect (MOKE) causes slight rotation of polarization state of reflected compared to incident light (ca. 0.5°).
  - Sign depends on orientation of ferromagnetic domain
- Polarizer converts polarization modulation to amplitude modulation.

MOD: Writing

- For applied magnetic field larger than coercivity $H_c$ change in domain orientation achieved
- In MODs materials are used whose $H_c$ depends strongly on temperature.
  - At room temperature and heating by weak read laser beam, $H_c$ should be large to keep data state.
  - Upon heating with intensive write laser beam, $H_c$ should be small to write data with applied magnetic field.
MOD: Materials

- Only a magnetization orthogonal to layers may be read with typical reading configurations.
  - Most materials have orientation of domains parallel to layer (shape anisotropy FA)
  \[ FA \approx \frac{1}{2} \mu_0 M_s^2 \]
  - Only materials with larger orthogonal anisotropy Ku than shape anisotropy FA may be used: \( Ku > FA \).
  - This is the case e.g. for Co. Co has small magnetization though.
  - Better is combination of several materials, e.g., TbFeCo.

Layer sequence of MOD

- Al-layer reflects light. Light passes TbFeCo-layer twice.
- \( \text{Si}_3\text{N}_4 \)-layer prevents water absorption in the TbFeCo-layer and serves as antireflective layer.

Comparison MO-disc and DVD-RAM

- 3,5” MO-Disk
  - At maximum 2,3 GB,
  - 16 EUR
  - Operating system recognizes MOD as hard drive
  - Higher physical data security
    - MOD insensitive to light
    - MOD insensitive to temperature up to ca. 100 °C
- DVD-RAM
  - 4,7 GB
  - 2,40 EUR
  - Faster data transfer
  - DVD-RAM-burner cheaper
  - DVD-RAM sometimes linked as DVD-burner

Compilation of questions

- Name three methods for optical distance measurements! Explain one in detail!
- For which distances may time-of-flight measurements be used?
- What is an autocollimator?
- How does an optical mouse work?
- When does speckle occur?
- How does a photocopier work?
- How does a laser printer work?
- Sketch and explain the laser scanner unit of a laser printer!
- What are differences between mass storage and "random-access"-storage?
- Sketch a CD-player and explain the individual components!
- How is the data coded on a CD?
- How is the laser beam kept on track during CD-reading?
- How may the data density be increased?
- Name three methods for realizing writable CDs!
- How is the data stored in an MOD?
- What are the parts of an MOD-player?
- Name an advantage of an MOD compared to a DVD-RAM!

Source: [http://de.wikipedia.org](http://de.wikipedia.org)