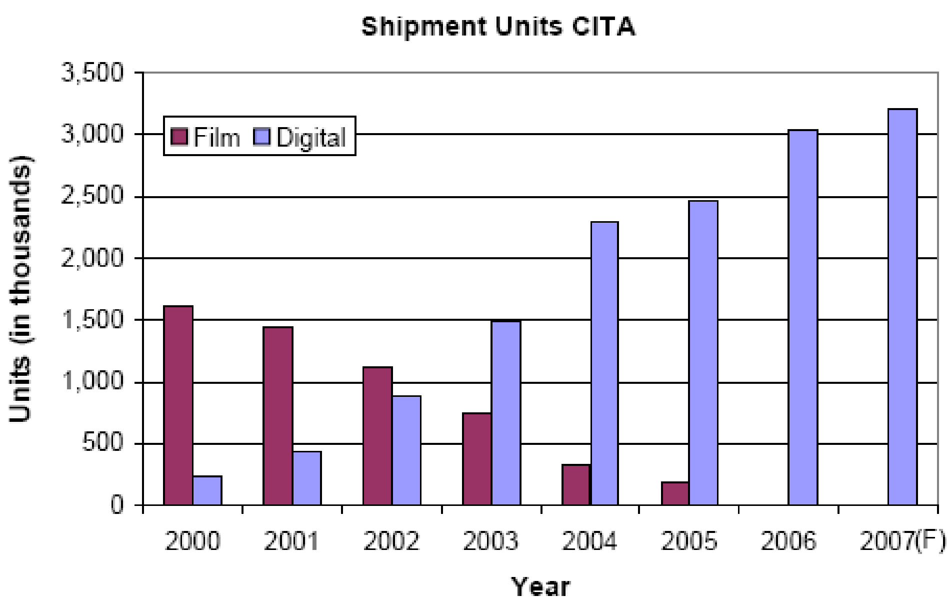
The Collapse of Film Photography

- Can Your Digital Camera reach Film Photography Performance?
- Film photography started in early 1800's – almost 200 years
- Commercial Digital Cameras started late 1995
- By 2000 digital "point & shoot" fell <$400
- Digital Single Lens Reflex Cameras
  (Nikon D1) appeared in 1999 at $10,000
- Cannon 10D first semipro DSLR <$2000
- Digital Rebel in 2003 first <$1000
- By 2006 film camera almost stopped



Why Digital Cameras Succeed

- Digital has clear advantages in many areas
- Immediate image view – can correct picture
- Film hours/days (or minutes with polaroids)
- Cost: Film >50¢ photo,
- Storage – film bulky, digital 4GB cards now $40, <0.1¢/photo
- If use DVD 4GB disk cost 25¢, holds ~4000, 0.006¢/picture
- Digital SLR's now near film in price

EOS Rebel K2 ~$400

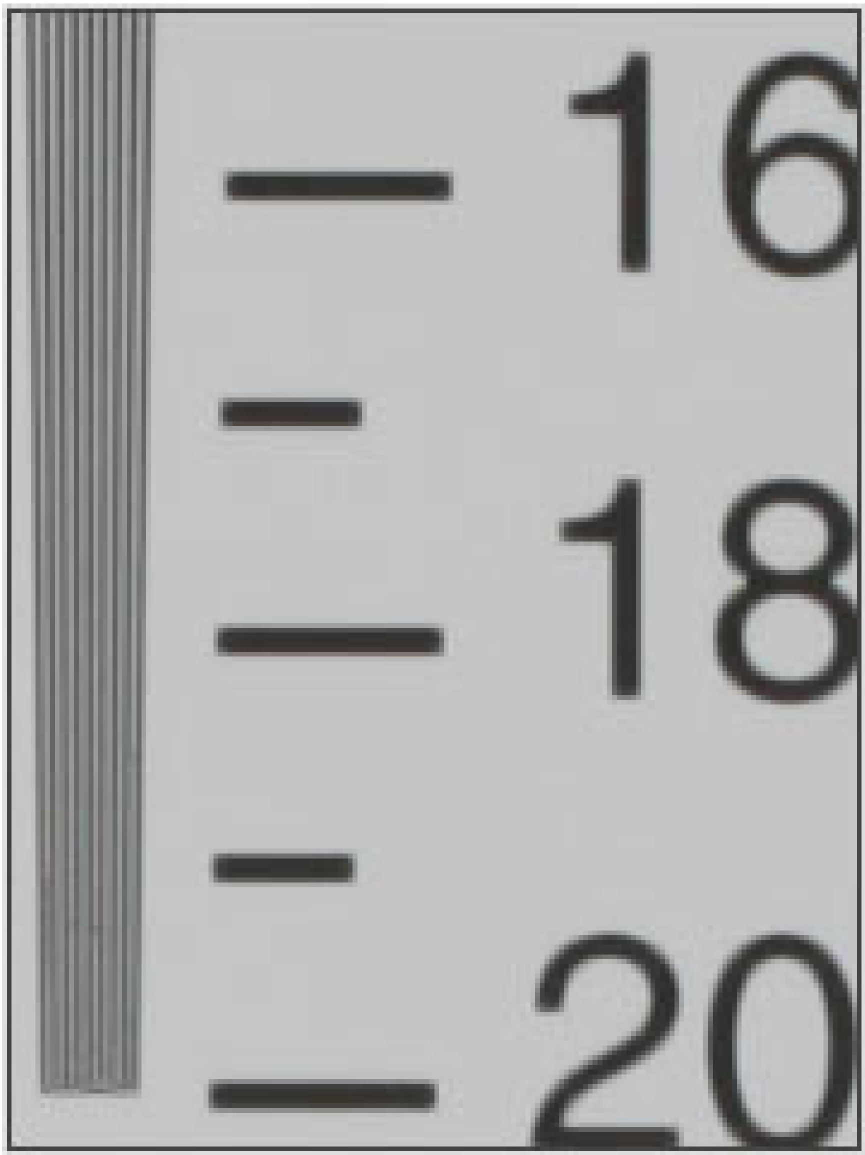
Digital Rebel XTi ~$800

Why have Pro Photographers not Fully Converted

- Journalist & sports professionals photographers have converted
- But Portrait & high end have not – Why
- Film still has advantages in several area
- Resolution
- Colour accuracy
- Dynamic Range
- Special photographic conditions eg. Cold climates
- Let us look at why & where digital is responding

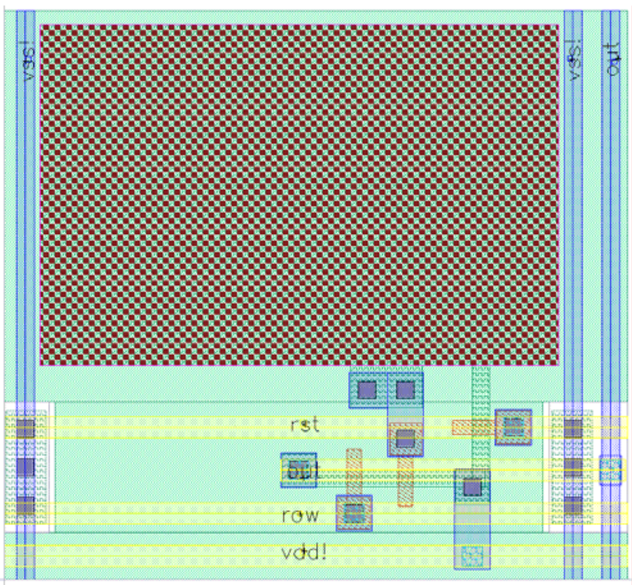
Resolution Measurements

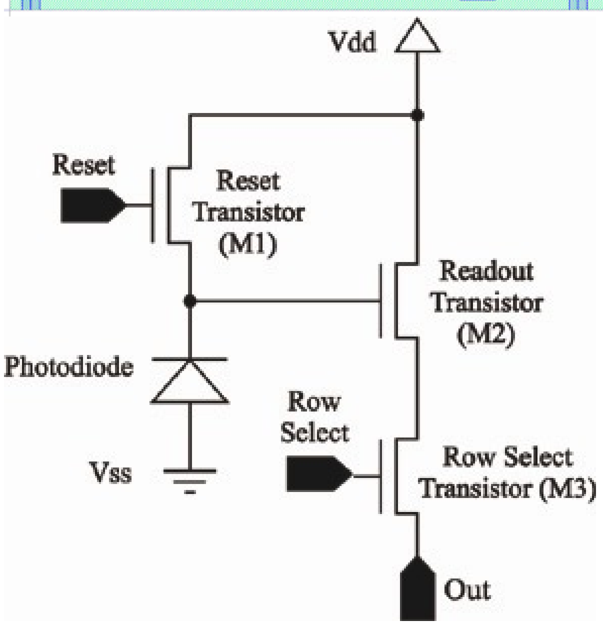
- Measure resolution in line pairs per millimeter (lp/mm)
- Basically MTF type measurement
- One line and space per line pair
- Nyquest theorem: need minimum of 4 pixels per line pair
- So size of pixel limits resolution

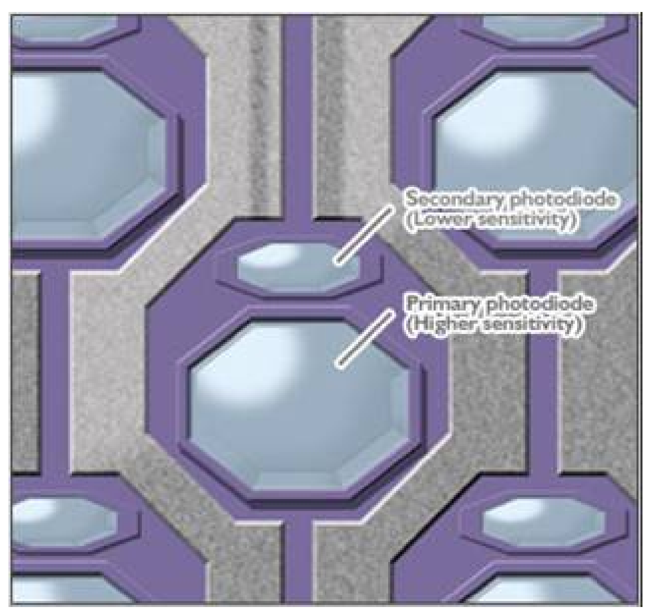


Digital Resolution

- CCD: Charge Coupled Device
- or Active Pixel Sensor (CMOS) resolution set by pixel size
- Typical size 5-10 microns
- Sensor area (fill factor) ~25%-50%
- Use microlenses to get closer
- Best Digital resolution ~35 line pairs/mm
- Smaller pixels do not generate better resolution

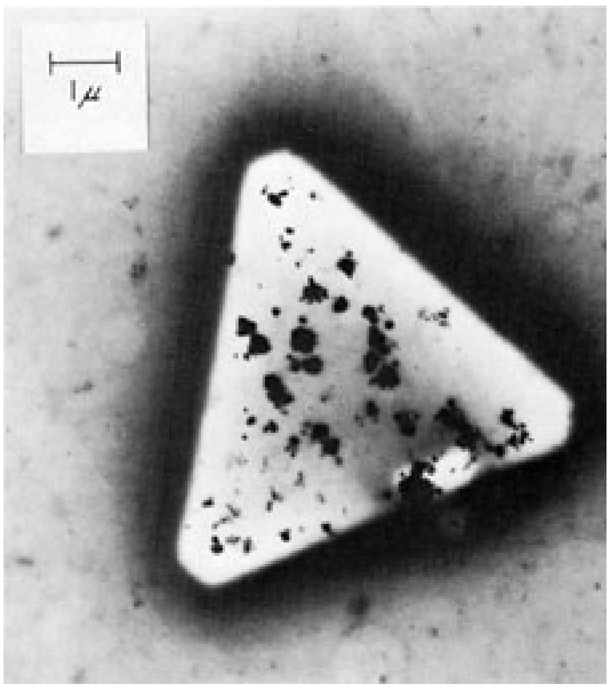


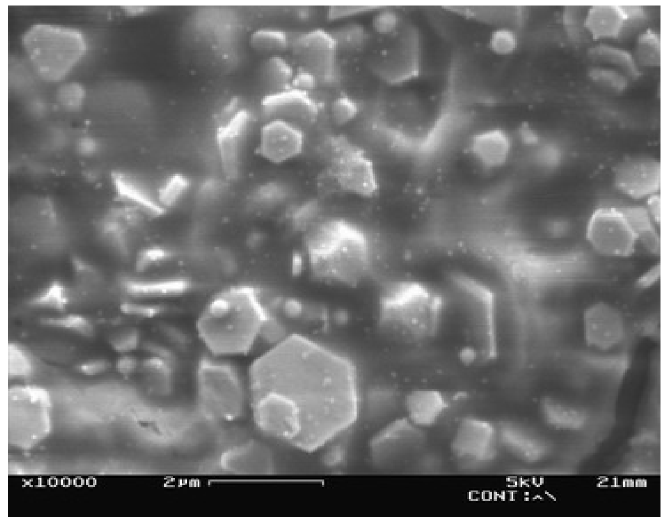


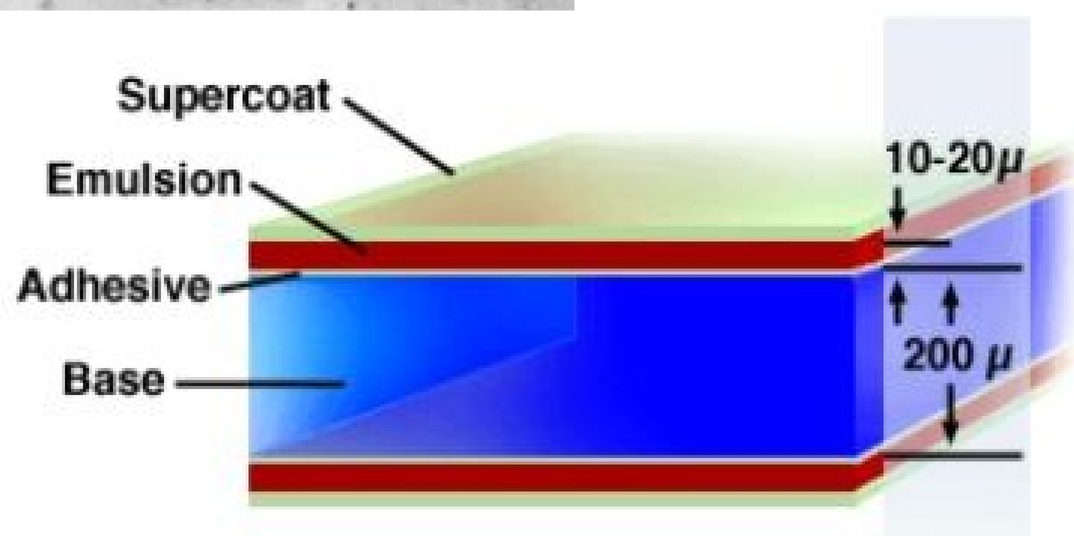


Film Resolution set by Grain size

- Film sensor is silver halide grains in emulsion layer 10-20 um
- Resolution in film set by silver halide grain size
- Typical grain is ~1-2 um
- Large grain ~20 um
- Ultra fine grain 0.015 um

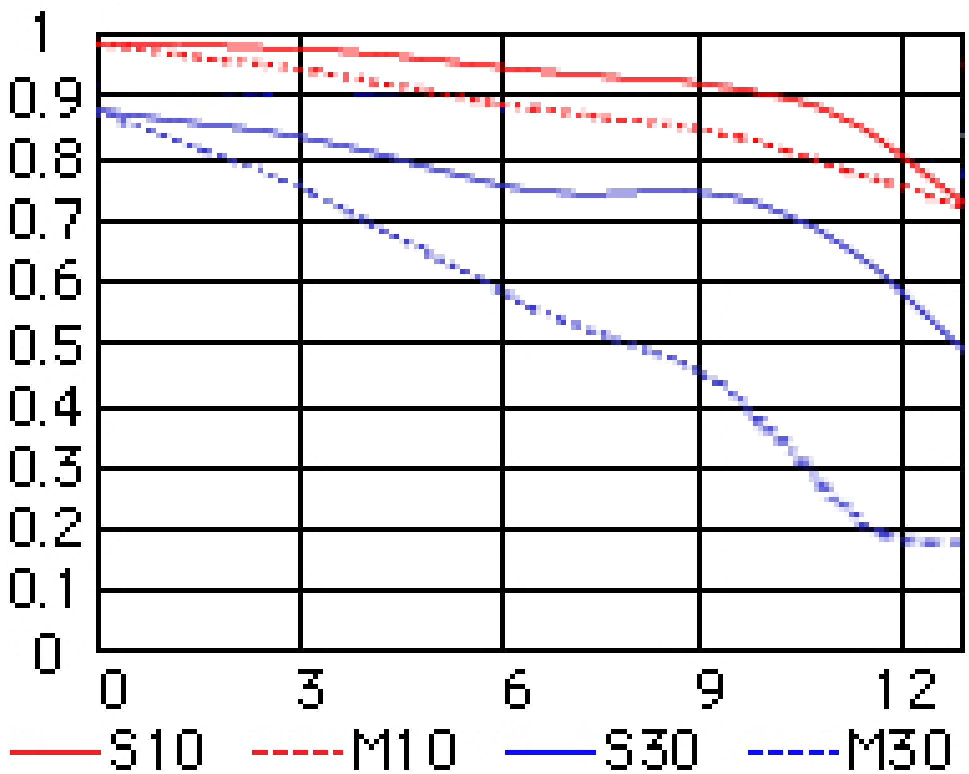






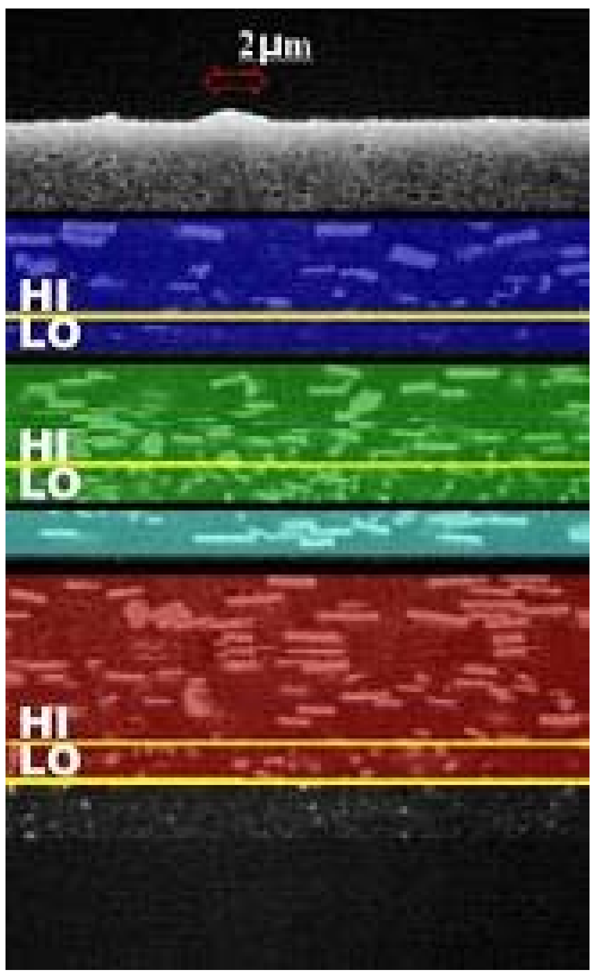
Resolution Limit by Lens

- Best resolution is usually limited by the lens
- For digital point and shoot lens and imager about same resolution
- But for DSLR lens still better
- Resolution limit of fines lenses 200 lp/mm
- Requires at lest 1.2 um pixels
- Top Digital end 20 Mpix (~4200x3000 pix)
- Film limit on 35 mm ~29,000x19,000 pixels = 552Mpix



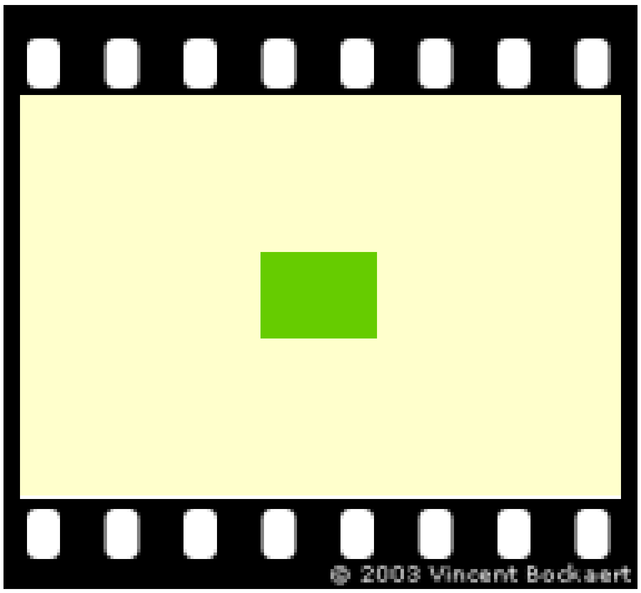
Film Resolution

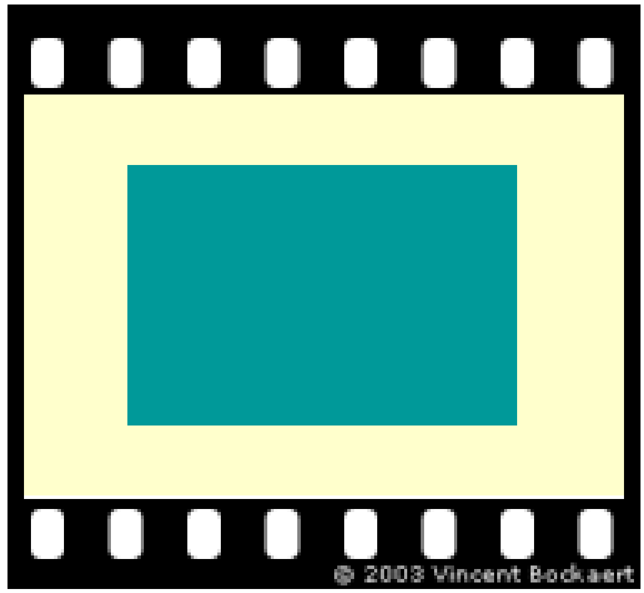
- Film has many layers of gain, and may have several sizes
- Often have course layer & fine grain layer
- Grain size also distributed in film
- Resolution also set by developer:
- fine grain developer better resolution for same film
- Typical film has 80-100 lp/mm
- Ultra fine grain films very high
- Panatomic Areographic
- Regular developer 120-200 lp/mm = 1.25 um pixels
- Fine grain developer 400-500 lp/mm=0.5 um pixels
- Best films 1000-2000 lp/mm =0.25-0.12 um pixels



Sensor Size

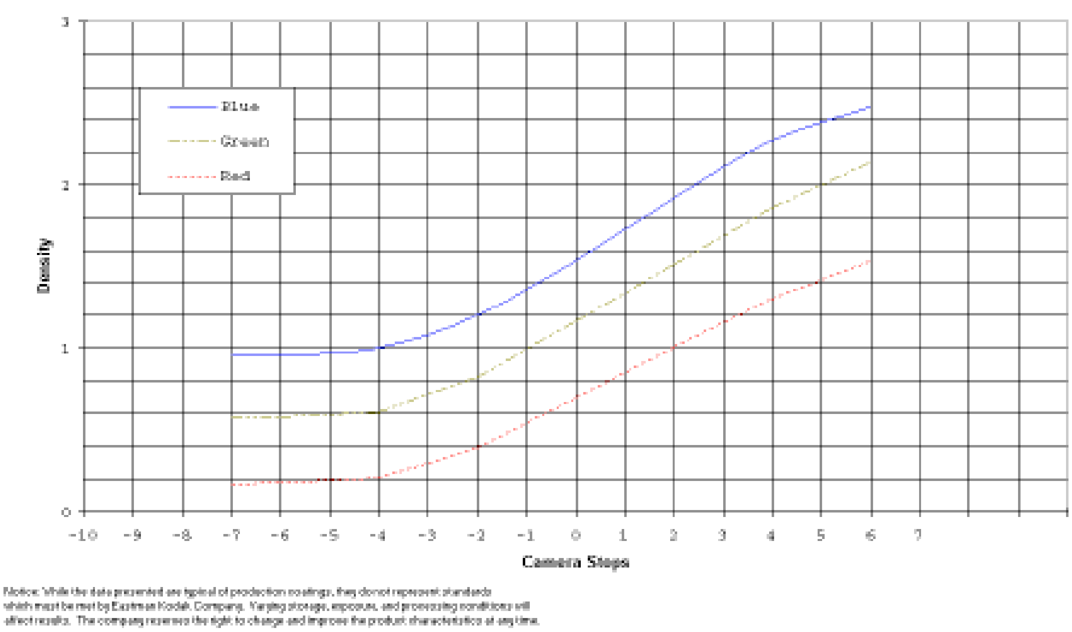
- Typical film 36x24 mm
- High end 57x57 and 100x127 mm but really no limit
- Digital point & shoot about ~3-5 mm
- Semi pro 24x15 mm
- Full pro 36x24 mm (but ~$5K cost)
- Best Digital Hasselblad 35x54 mm (but large pixels)

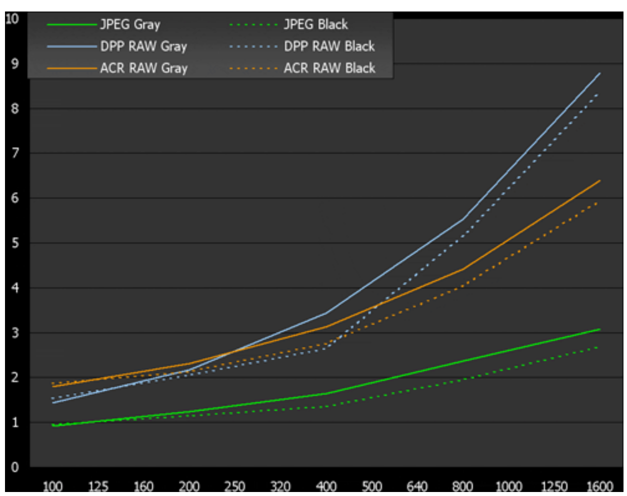




Dynamic Range

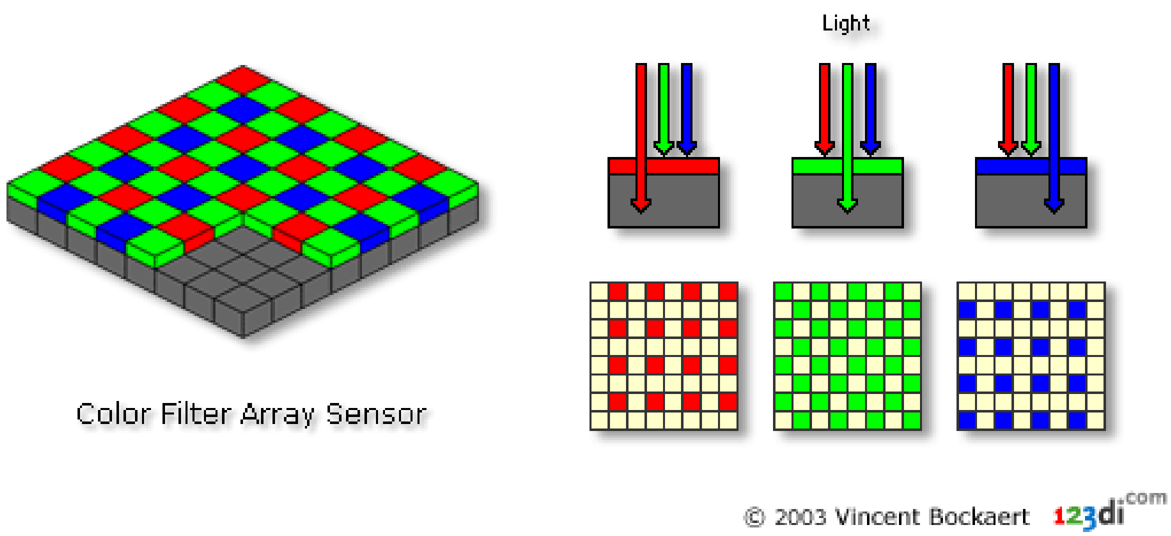
- Digital 8 bit (256 levels)
- Digital cameras do have 10-14 bit conversion
- But noise limit is about bit 8
- Film records a dynamic range of 50,000 (~16 bit)
- Top and bottom saturation
- Comes from distribution of grains
- At most sensitive end film has some large grain halides
- This extends sensitivity at low exposure end
- Similarly distribution of small grains
- Hence extension of sensitivity at high exposure end

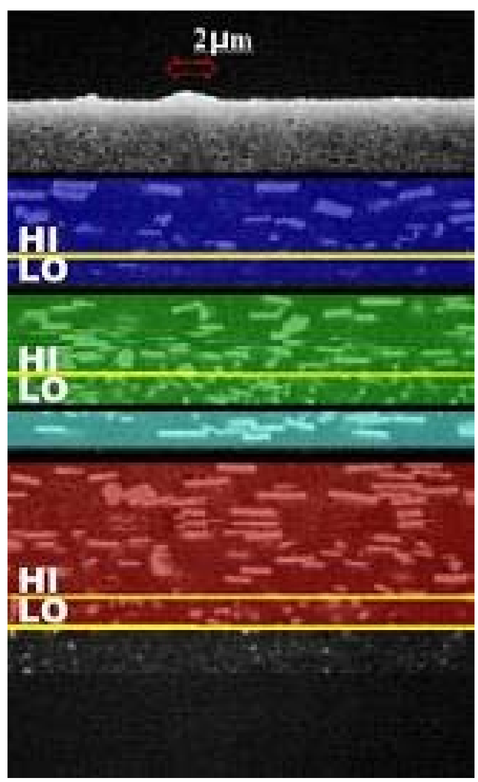




Colour Limits

- Digital uses Bayer colour filter
- Interpolates colour between pixels called demozaicing
- Produces colour error
- Film does all 3 colours at same spot
- Better colour resolution



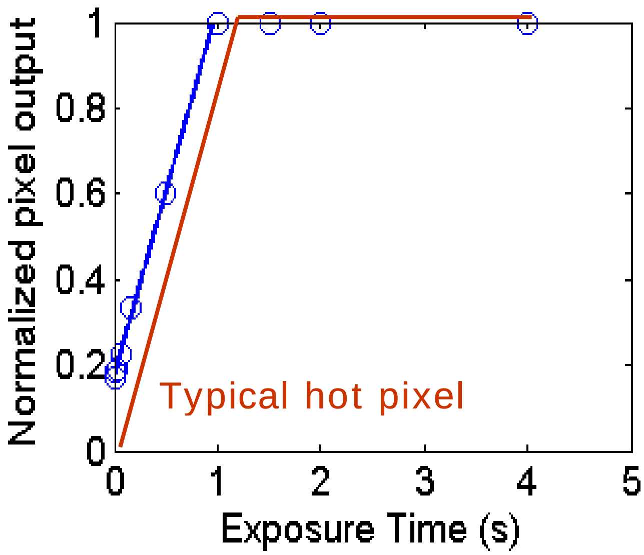


High Dynamic Range Photos

- Take several pictures:
- usually 3 spaced at -2, 0, +2 f stops
- Extends Dynamic range to about 1000
- Possible now in photoshop CS2


Defects in Digital Imagers: Hot Pixels

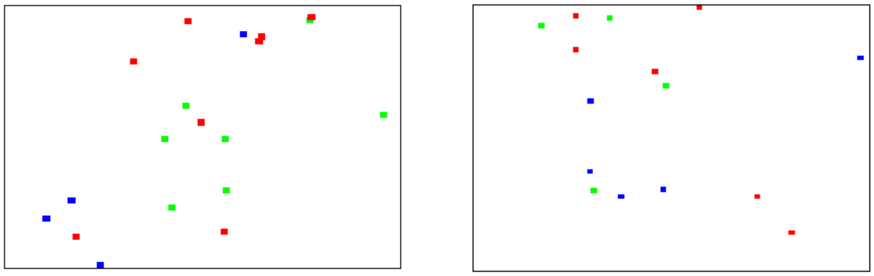
- 9 of 11 cameras developed significant faults
- Total: 101 faults
- 3 – 26 faults per camera
- All hot pixels
- No stuck pixels or abnormal sensitivity
- Contrary to user reports
- Found partially-stuck hot pixels
- Offset independent of exp. time
- May be source of user-reported stucks

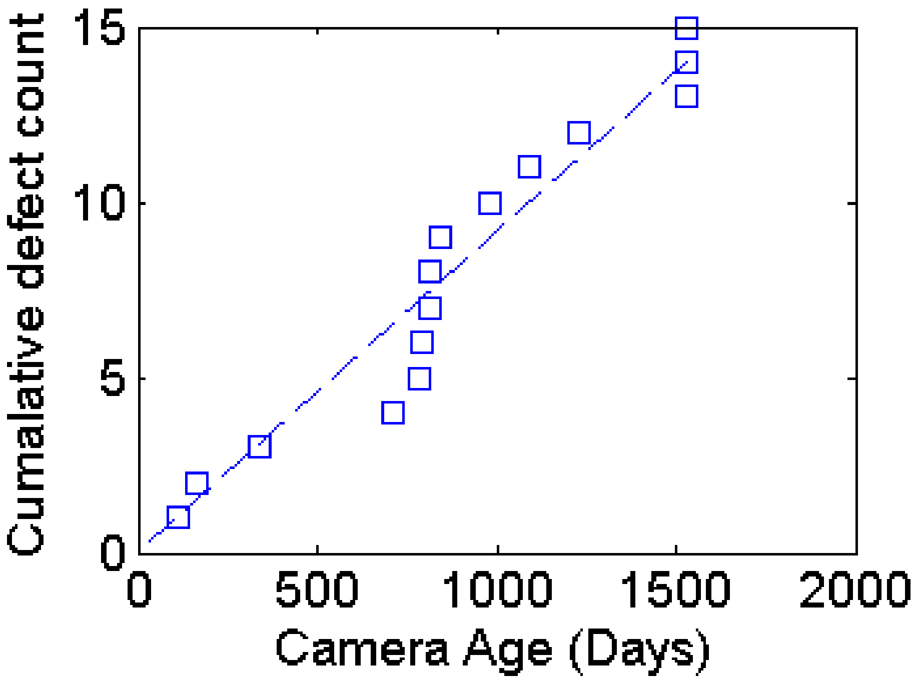


Defects and Digital Imagers

- Defects accumulate in digital camera
- Grow at about 3.5 defects per year in DSLR cameras
- Defects are randomly distributed spatially

Camera Fault Locations





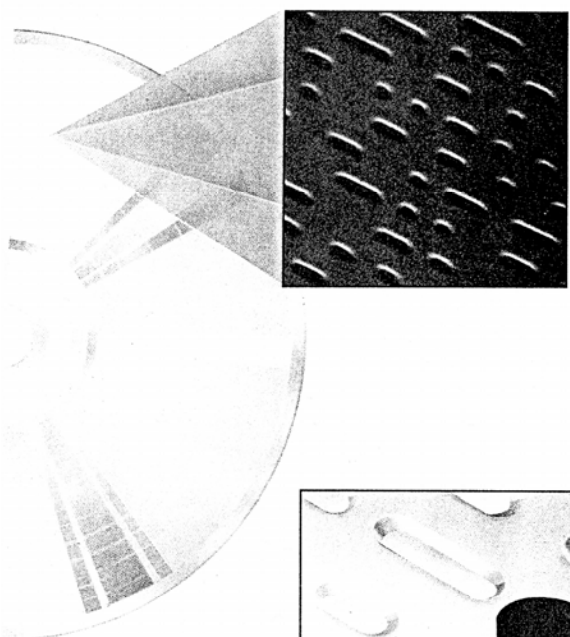
Compact Disk

- Largest user of laser systems
- Began with Video disk by Philips & MCA
- Original video sold 1980
  1 - 1.5 hour disk
- Original version failed to compete with tape video
  >1990 strong high quality video market
- 1983 Sony & Philips developed Audio CD
- Now 50,000,000 CD's sold/year in Canada but 40,000 records
- CD declining due to mp3 files

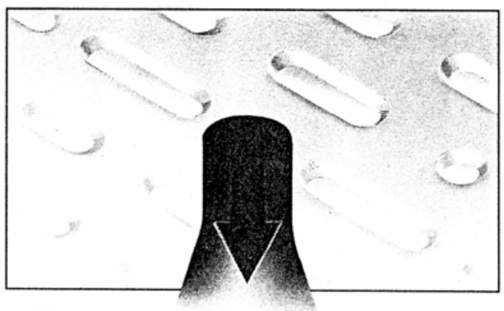
Fig. 2-1. The compact disc is only 120 mm in diameter with a large 15 mm center hole.

CD Operation

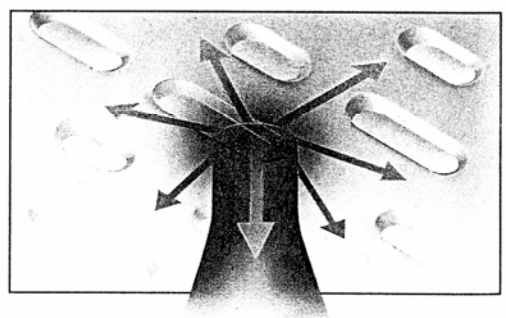
- 12 cm disk with plastics substrate, aluminum coating and plastic cover
- 0.6 micron wide pits, 1.6 micron spacing
- 4.8 Km of paying surface, 16,000 track/inch
- Designed Beethoven's 9th symphony, now 74 minutes,



Topography of a disk. The pits on a prerecorded optical disk, here enlarged by a scanning electron microscope and seen from the laser's point of view, resemble parallel lines of regularly spaced ridges. Each of these protrusions—the underside of a recorded pit—is the size of a typical bacterium, about .6 micron (.6 millionth of a meter) wide. If 3,000 pits were lined up side by side, they would be about as wide as this letter *o*.



The land's bright spot. When the focused laser beam hits a flat space between pits—a so-called land—much of its light *(red arrow)* is reflected straight back toward the detector. At the point where the laser strikes the disk, it has been focused to a spot about a micron in diameter, almost twice as wide as a pit. This diameter is only a little larger than the wavelength of the laser light—the theoretical minimum. As a result, the beam, originally cone-shaped, assumes a cylindrical shape near its point of focus.



The pit's dark spot. When the focused laser beam hits the protrusion of a pit, much of the light is scattered sideways, so that very little is reflected back to the detector. Thus, each time the beam moves from a land to a pit, the reflected light changes in intensity, generating a detector signal that can be decoded to reproduce the recorded data.

CD Operation

- Laser focused on surface
- Reflects back from the flats (land)
- Light scattered by the pit
- Actually looks for the change in reflectivity
- Easier to see a change than compare levels

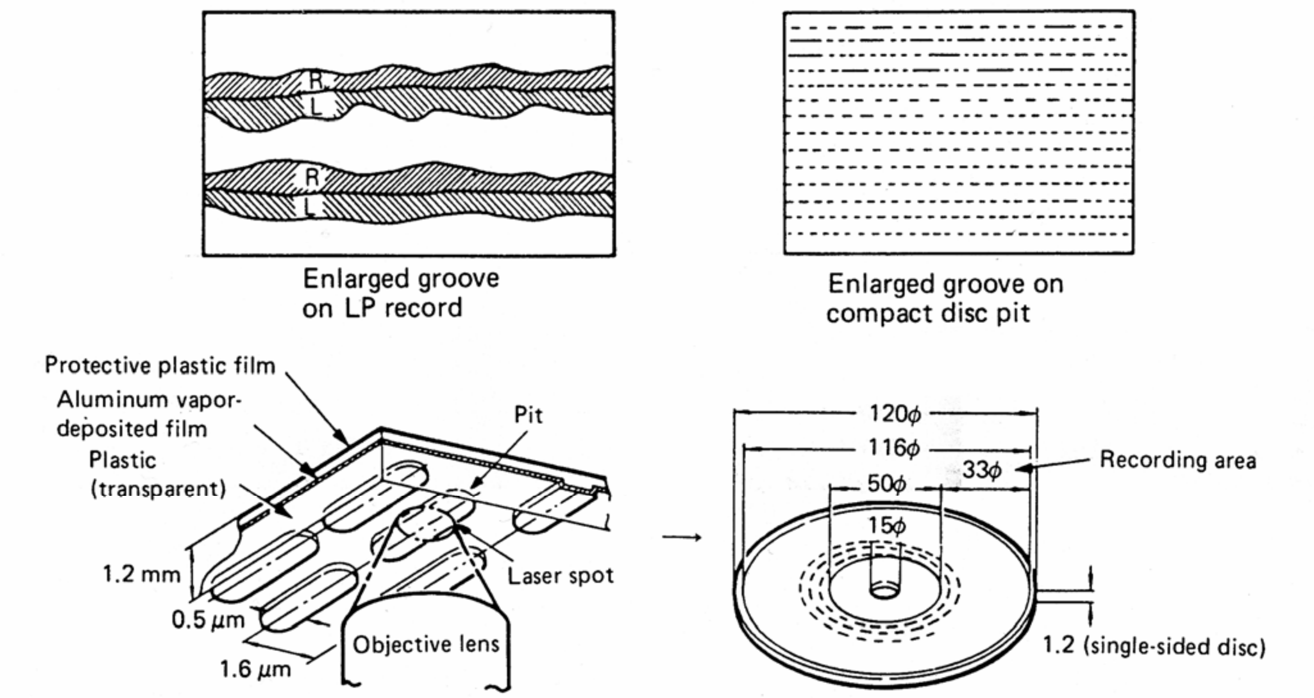
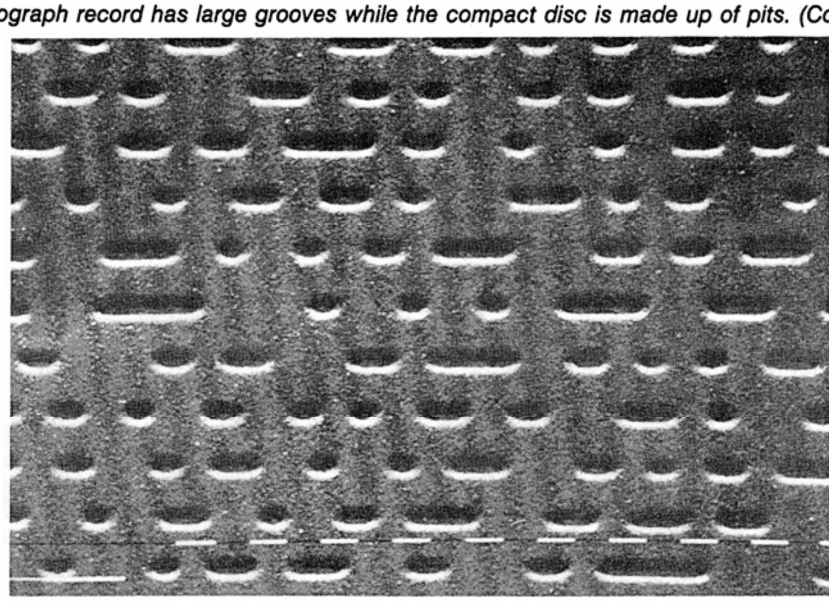


Fig. 2-2. The phonograph record has large grooves while the compact disc is made up of pits. (Courtesy of RCA Corp.)

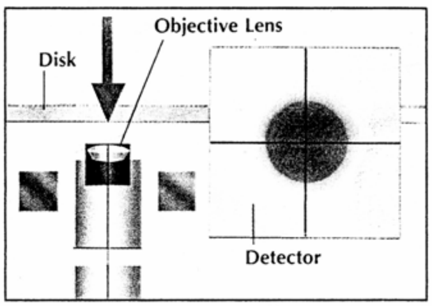


(b)

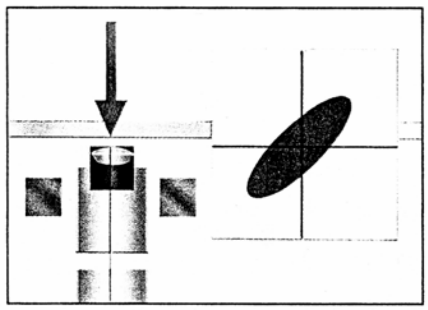
Fig. 7.34 (a) Schematic of a typical optical disk. The precise 'geometry' of a pit depends on a number of factors including the storage mode and readout technique employed. (b) Scanning electron micrograph of an optical disk (From G. Bouwhuis, A. Huijser, J. Pasman, G. Von Rosmalen, K. Schouharner Immink, *Principles of Optical Disc Systems* (1985). Courtesy Adam Hilger Ltd).

CD Operation

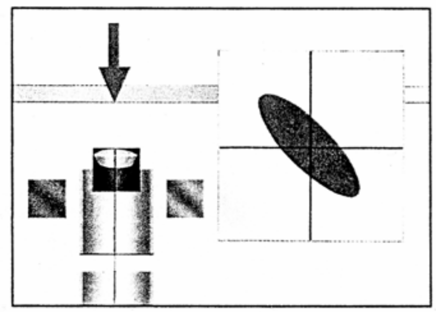
- Laser turned to parallel beam by collimating lens
  focused by objective lens
- Split beam means part goes to CD, part to detector
- Creates a focusing system using four sectors of detector
- Voice coil moves optical head, & tracking motor focuses
- Actually uses polarization of the light



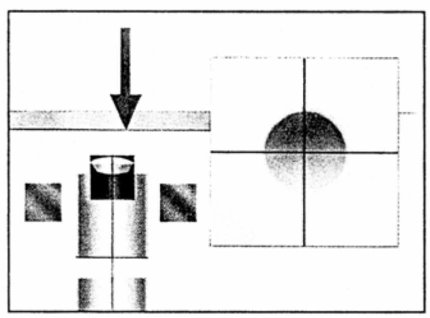
Lens in focus, on track. When the laser beam is properly focused on the center of the track *(red arrow)*, the reflected beam makes a fuzzy circle on the detector. Here, all quadrants of the detector receive the same amount of light, so no signal is sent to the voice-coil motors that guide the objective lens.



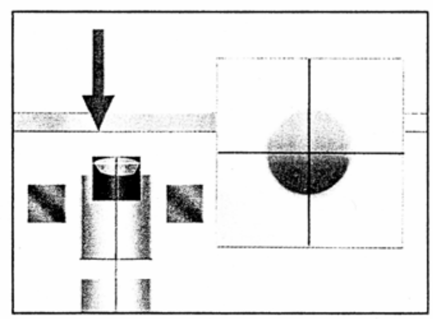
Lens too close. If the disk moves toward the lens, the light becomes a sharp, tilted oval. The northeast and southwest quadrants get more light, a signal for the focusing motor to move the lens back.



Lens too distant. If the disk moves away from the lens, the beam becomes a left-leaning oval, reversing the signal to the focusing motor and bringing the lens closer.

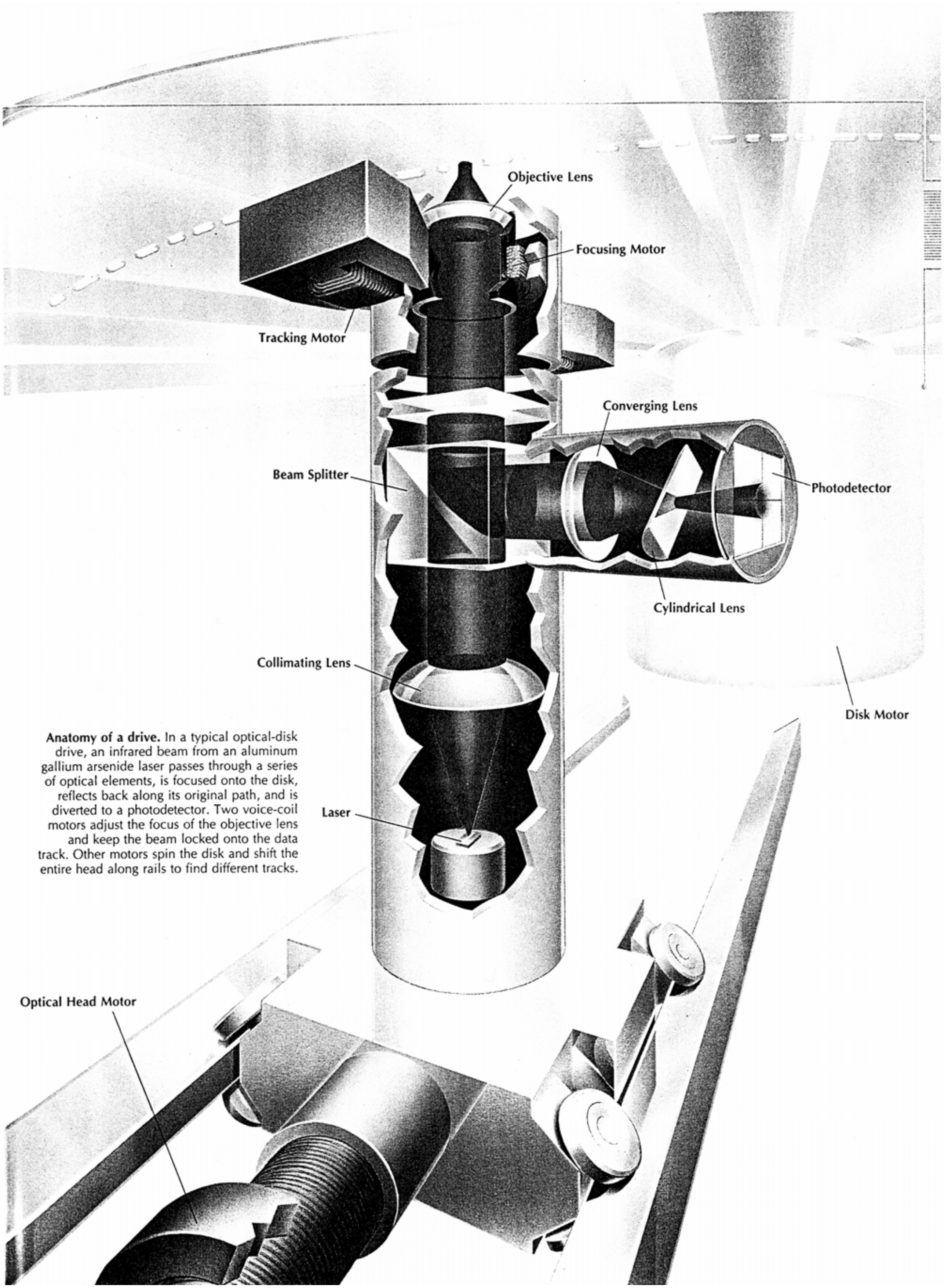


Beam inside track. If the track veers right, sending the beam inside the track, north quadrants of the detector receive more light because part of the beam falls only on lands. A correcting signal moves the lens right.



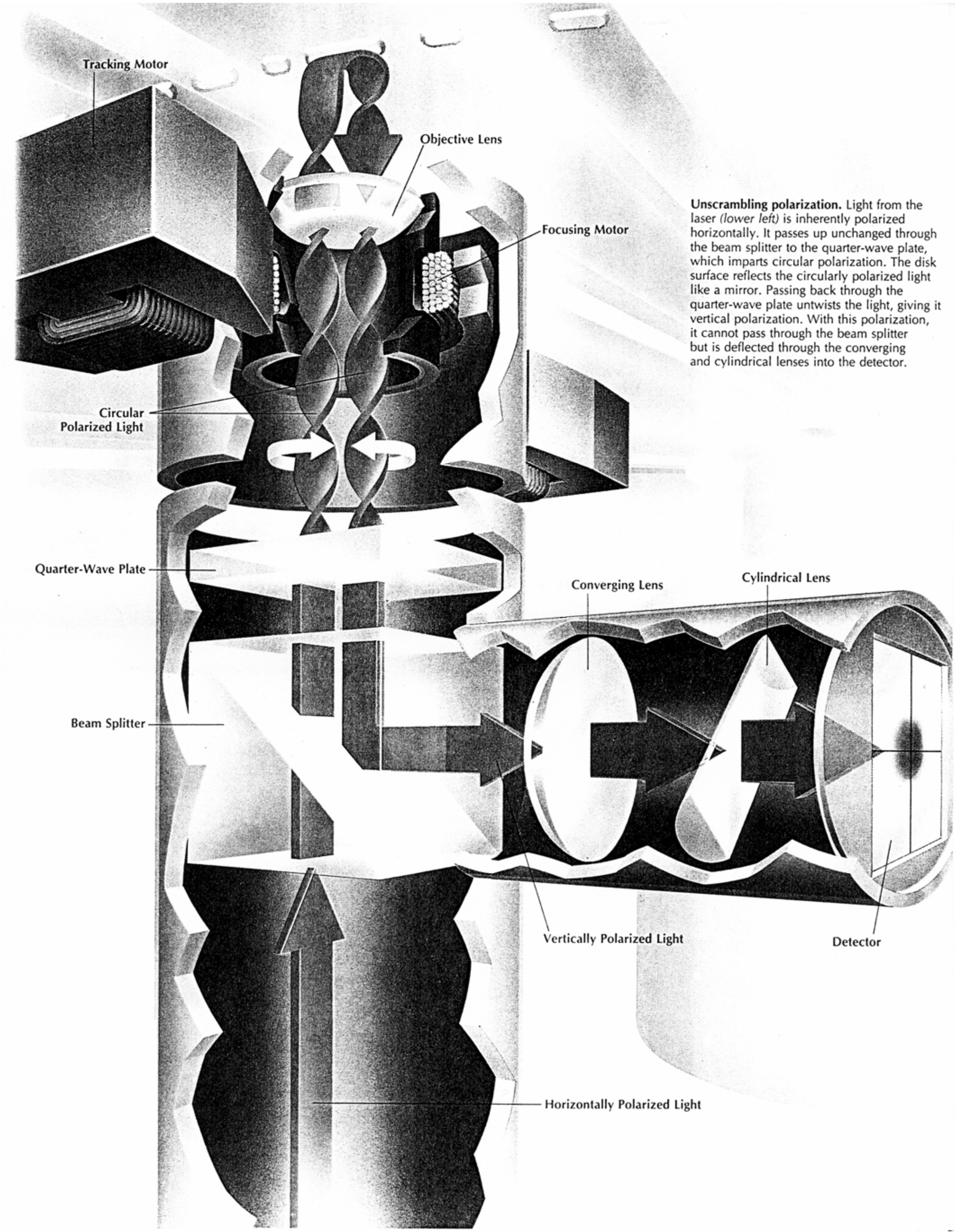
Beam outside track. Similarly, if the track veers to the left, the pattern of light on the detector is stronger to the south. A signal to the tracking motor returns the beam to the center before any data is misread.

CD Optics



Anatomy of a drive. In a typical optical-disk drive, an infrared beam from an aluminum gallium arsenide laser passes through a series of optical elements, is focused onto the disk, reflects back along its original path, and is diverted to a photodetector. Two voice-coil motors adjust the focus of the objective lens and keep the beam locked onto the data track. Other motors spin the disk and shift the entire head along rails to find different tracks.

CD Optics Polarization



Unscrambling polarization. Light from the laser *(lower left)* is inherently polarized horizontally. It passes up unchanged through the beam splitter to the quarter-wave plate, which imparts circular polarization. The disk surface reflects the circularly polarized light like a mirror. Passing back through the quarter-wave plate untwists the light, giving it vertical polarization. With this polarization, it cannot pass through the beam splitter but is deflected through the converging and cylindrical lenses into the detector.

CD Data

- Sample audo signal at 44.1 Khz
- 16 bit conversion = 90 Db range
- Master disk made by Argon laser on master plate
- Disks pressed in plastic, then aluminized
- Both sides pressed, best side used
- Error correcting codes added at ends

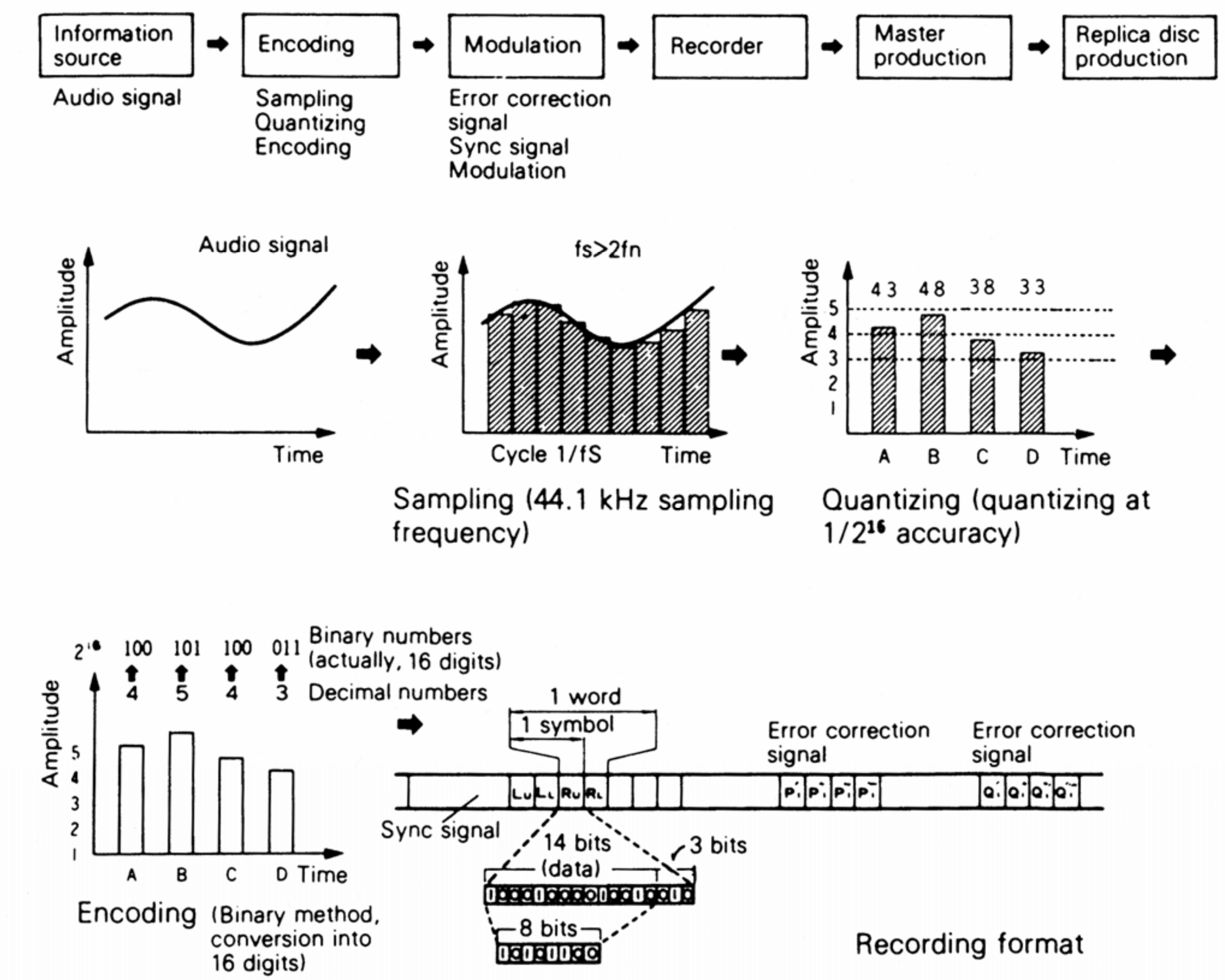
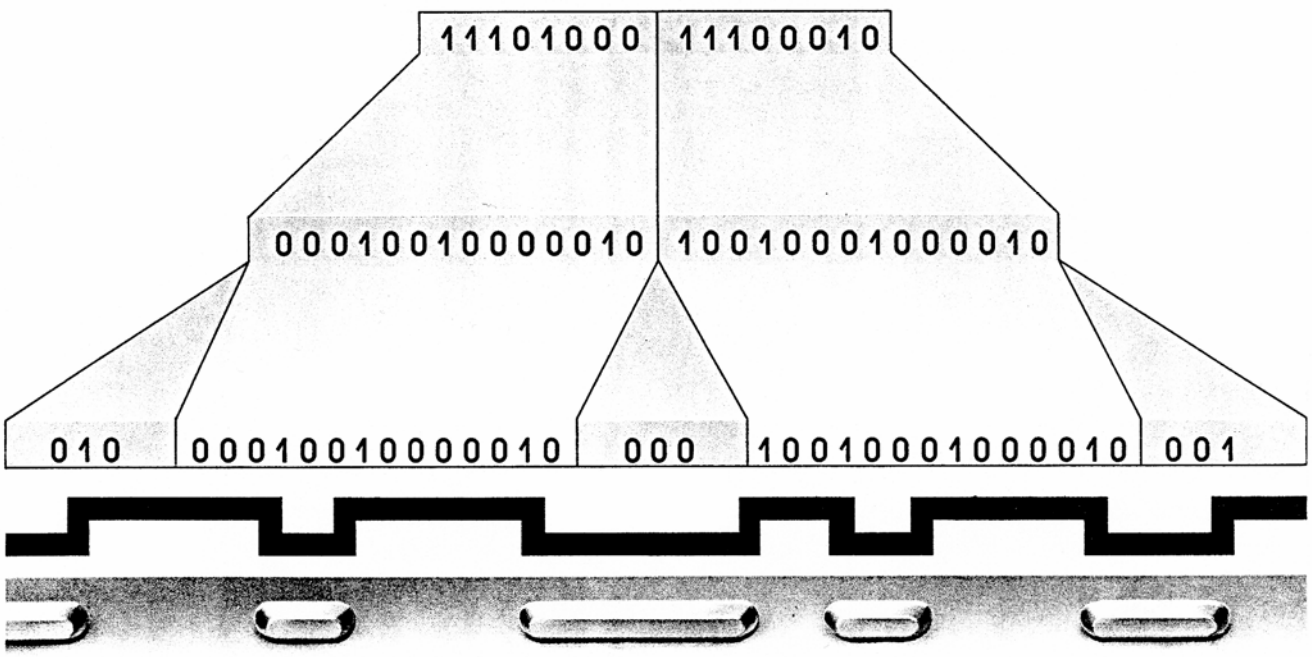


Fig. 2-3. The encoding and recording format of the compact disc. (Courtesy RCA Corp.)

CD Data

- Two 8 bits turned into 14 bit signal
- Must have more than 2
  but no more than 10 zeros in a row
- Add 3 merge bits to get that
- Transitions from pits to land or back what measured
- CD Roms use same setup, but different data combination
  better error correcting code (Reed-Solomon error correction)
- Generate 500 Mbytes data
- Fabrication costs started at $2-4 in 1983 now under $0.10

A code from CD-ROMs. In the eight-to-fourteen modulation on CD-ROM disks, two bytes of data *(top row)* are replaced by fourteen-bit symbols *(middle row)* in which ones have at least two but no more than ten zeros between them. Groups of three merge bits then link successive fourteen-bit symbols into a steady stream *(lower row)* that follows the rules about maximum and minimum zeros. Each one in this bit stream thus corresponds to a transition from land to pit, as indicated by the square-wave binary signal used to create pits and lands on the disk *(bottom)*. Playback reverses the process.



Immunity to Defects

- Error correcting codes removes some
- Focused below surface - surface defects eliminated
- Multisampling - measure several times

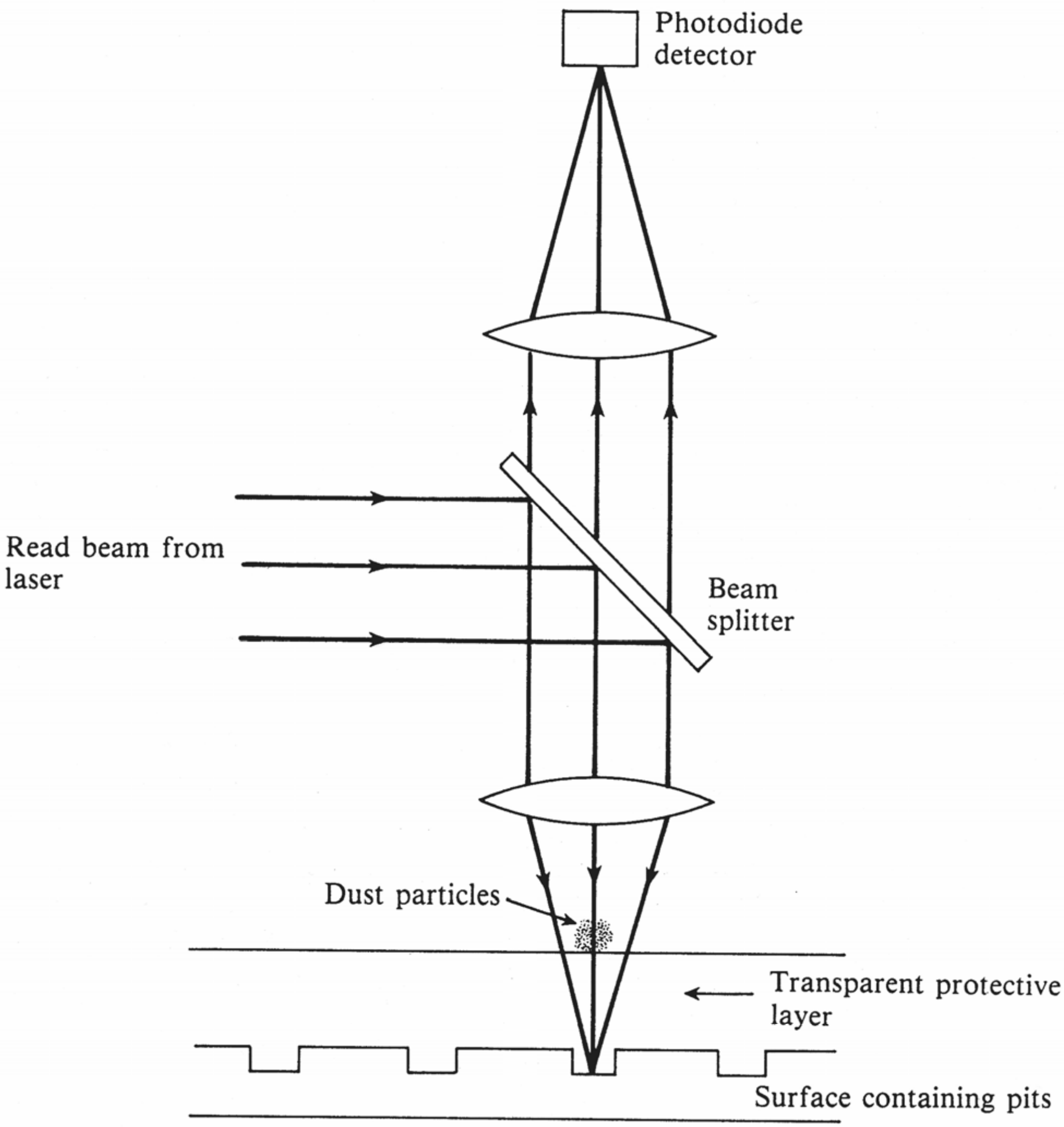
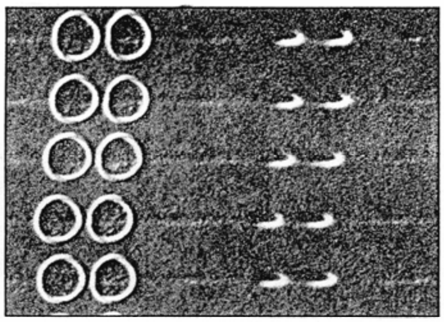


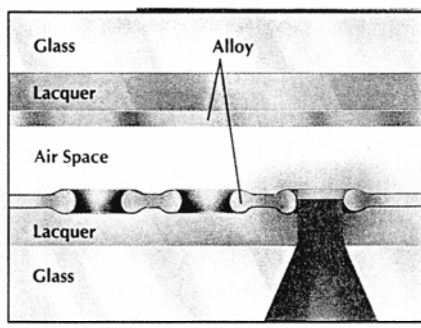
Fig. 7.35 The basis of readout from an optical disk. The read beam from a laser is focused onto the surface containing the pits. Particles of dust on the protective layer are not in focus and do not affect the readout process.

Computer CD-R & WORM Disks

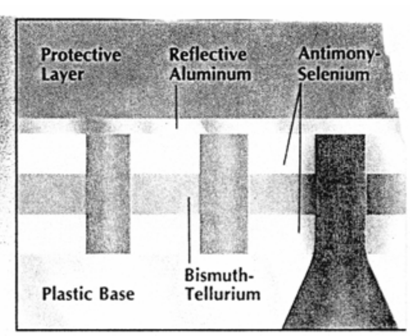
- First read/write system 12" to 14" disks •
- Write Once, Read Many (WORM)
- Operates by making physical changes in special disk
- Hole making: melts tellurium selenium alloy
  holes less reflective
- Fusion method: melts antimony-selenium into
  Bismuth-tellurium, changes to transparent hole



Recordable disk. An electron micrograph of a WORM disk reveals manufactured grooves that facilitate tracking, prerecorded pits *(above, left)* for synchronization and identification, and the holes of recorded data created by the heat of the high-power laser beam.



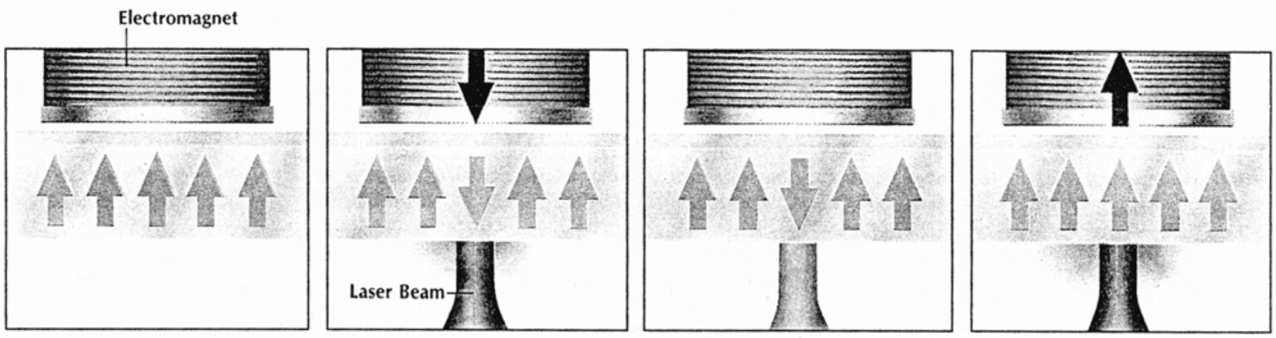
A hole-making approach. To record information on a tellurium-selenium alloy disk, a laser shines through the protective layers of glass to melt holes in the alloy; the air space accommodates the molten materials. When read, the holes are less reflective than their surroundings.



A fusion method. In another type of WORM disk, heat from a laser, shining through a plastic base, fuses two layers of antimony-selenium alloy with one of bismuth-tellurium alloy. A metallic plug fo that, during reading, is more transparent to laser l than is the surrounding unfused area.

Magneto-optical Read Write disks

- Uses a more powerful laser
- Starts with magnetic film in one direction
- Laser melts magnetic film, with magnet opposite field
- When freezes field changed
- Change magnet field and can reverse
- Read by Kerr effect: polarization angle changed
  by magnetic direction



The unrecorded disk. Before recording, particles *(orange arrows)* on a magneto-optic disk are all magnetized in the same direction *(up, here)*, at right angles to the surface of the disk.

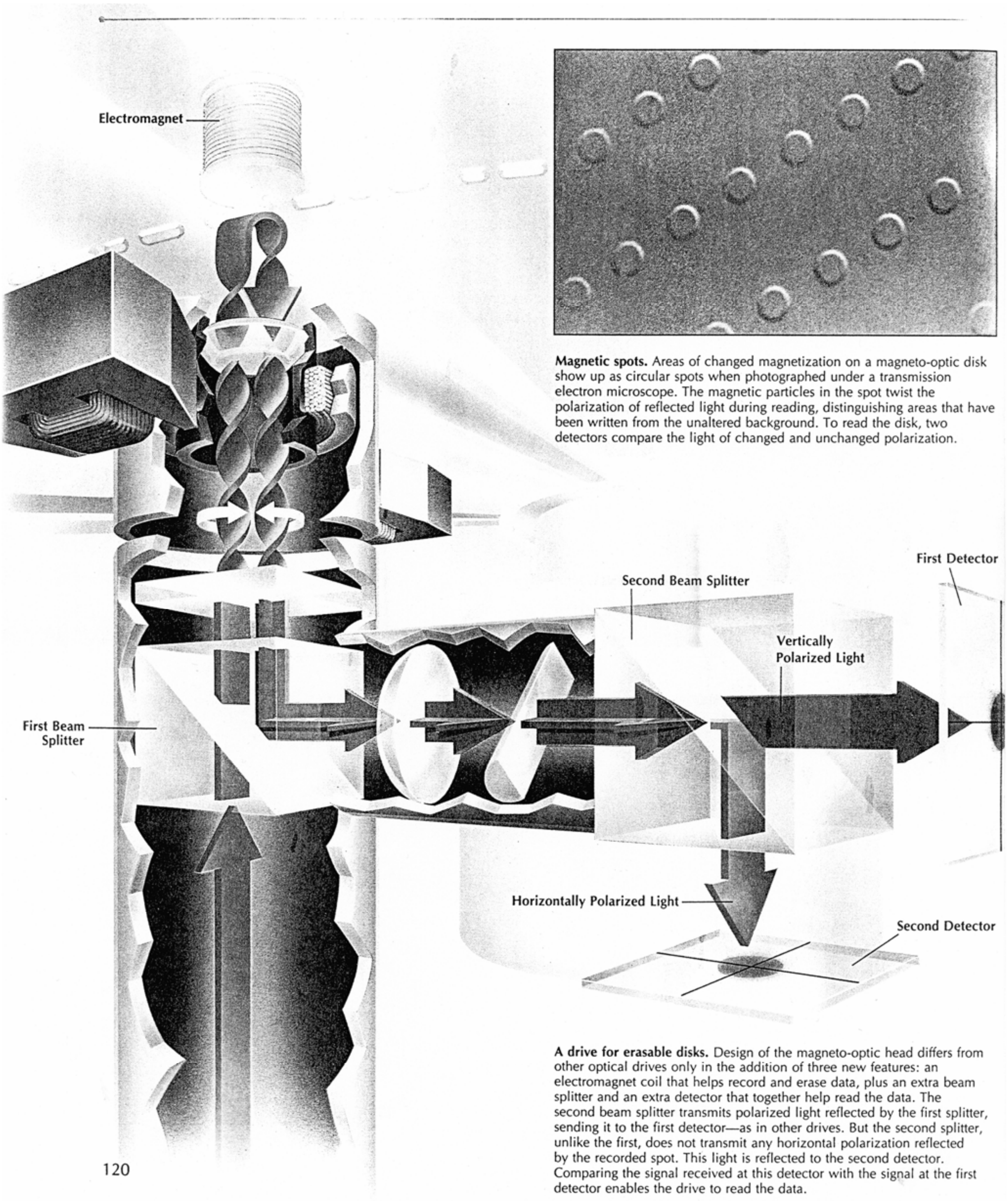
Recording. To write on the disk, a coil is switched on, with its magnetic field *(purple arrow)* oriented opposite to the direction of magnetic particles on the unrecorded disk. Where the recording beam heats the disk, the magnetization of the particles is reversed by the external magnetic field.

Reading. With the external magnet switched off, a low-power beam reflects off the spot of reversed magnetization. Its reversed magnetization twists polarization of the beam relative to polarization of reflections from unrecorded areas, generating a signal to be read by the paired detectors.

Erasing. The original magnetic direction can be restored to the recorded spot by reheating with the electromagnet turned on so that its field *(purple arrow)* now matches the upward orientation of an unrecorded area, causing the magnetization of the particles at the spot to reverse.

Magneto-Optical setup

- Must have polarized light in optical path



Magnetic spots. Areas of changed magnetization on a magneto-optic disk show up as circular spots when photographed under a transmission electron microscope. The magnetic particles in the spot twist the polarization of reflected light during reading, distinguishing areas that have been written from the unaltered background. To read the disk, two detectors compare the light of changed and unchanged polarization.

A drive for erasable disks. Design of the magneto-optic head differs from other optical drives only in the addition of three new features: an electromagnet coil that helps record and erase data, plus an extra beam splitter and an extra detector that together help read the data. The second beam splitter transmits polarized light reflected by the first splitter, sending it to the first detector—as in other drives. But the second splitter, unlike the first, does not transmit any horizontal polarization reflected by the recorded spot. This light is reflected to the second detector. Comparing the signal received at this detector with the signal at the first detector enables the drive to read the data.

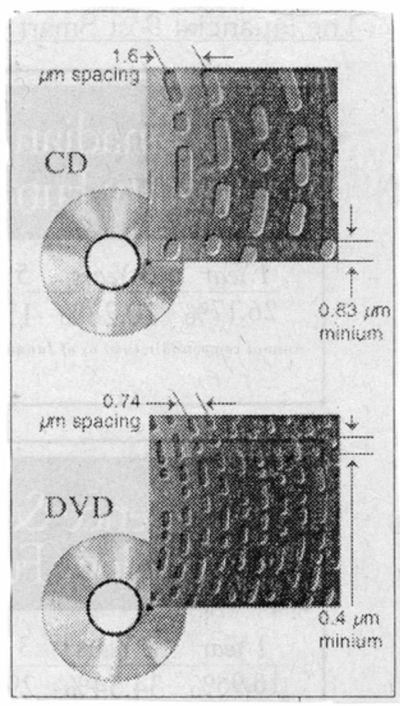
120

Digital Video Disk

- Designed for full video playback/recording
- Uses Red laser (650 nm) not IR (830 nm)
- Pit size 48%, date density 2.12x
- Total memory 4.8x to 3.28 GBytes: Transfer rate 9x CD
- DVD-R recordable, DVD-RAM printed
- Two sided, 2 levels/side top level partially reflecting
- Increase to 8.5 GB (2 sided), 17 GB (2 levels, 2 sided)
- Aimed at fully video playback of 2 hour movies
- Uses MPEG2 compression for video: movie aspect ratio
- Audio uses Dolby AC-3 for 6 track sound!
- Standard allows 50 GB with blue lasers!

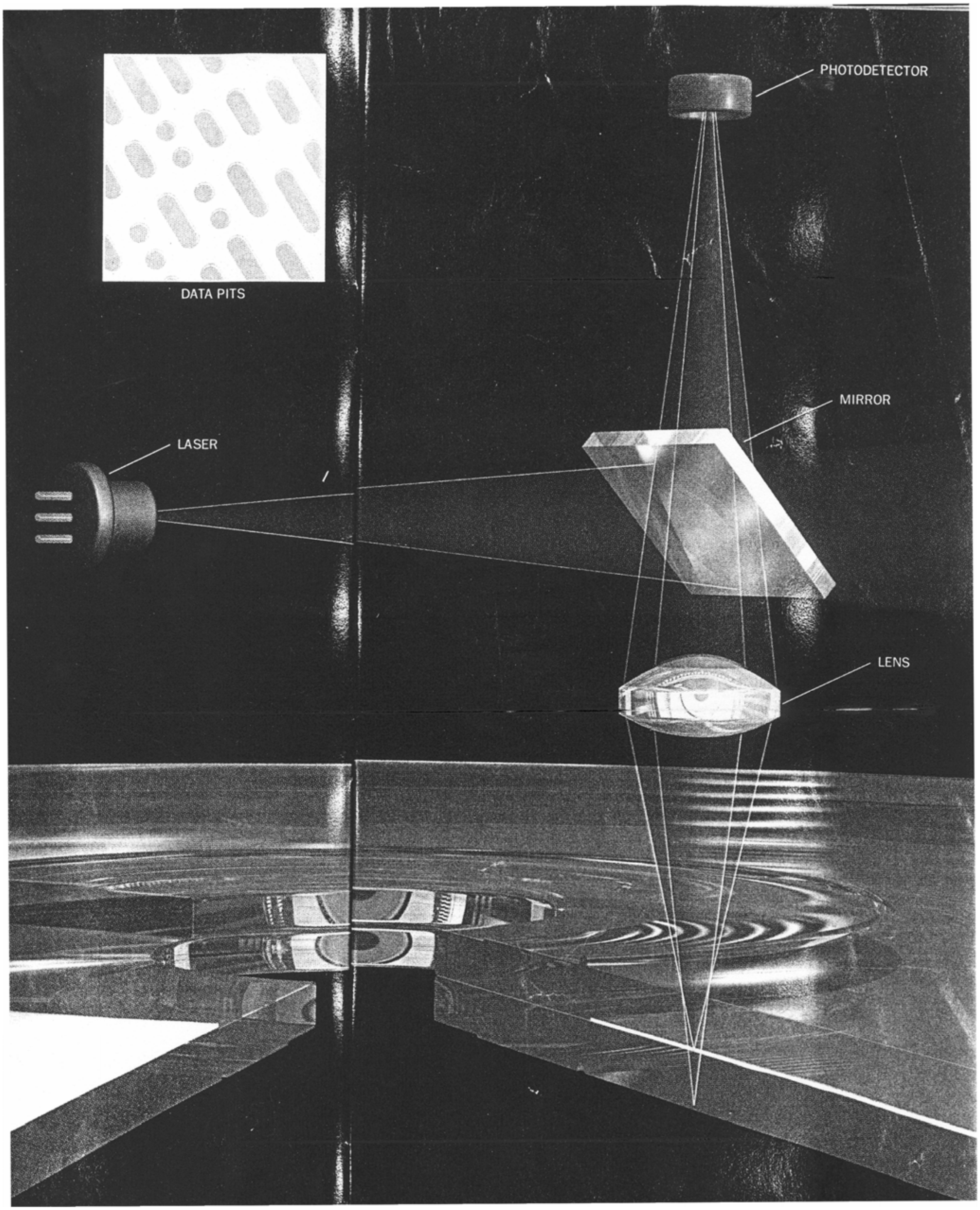
How the DVD and CD Compare

Feature	New Format	Old Format
Disc diameter	120 millimeters	120 millimeters
Disc structure	Two substrates, each 0.6 millimeter thick	One substrate, 1.2 millimeters thick
Minimum pit length	0.4 micron	0.83 micron
Laser wavelength	635 to 650 nanometers	780 nanometers
Capacity	Two layers, one on each side, 9.4 gigabytes total Two layers, both on one side, 8.5 gigabytes total Four layers, two on each side, 17 gigabytes total	One layer on one side, 0.68 gigabyte total
Numerical aperture	0.60	0.45
Track density	34,000 tracks per inch	16,000 tracks per inch
Bit density	96,000 bits per inch	43,000 bits per inch
Data rate	11 megabits per second	1.2 to 4.8 megabits per second
Data density	3.28 gigabits per square inch	0.68 gigabits per square inch



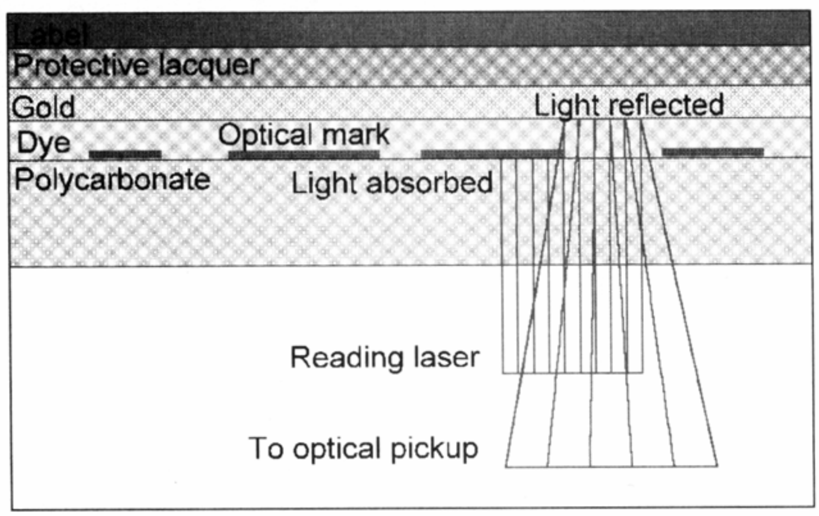
Digital Video Disk

- 2 level have two different focus points



CD-R Organic Dye Disks

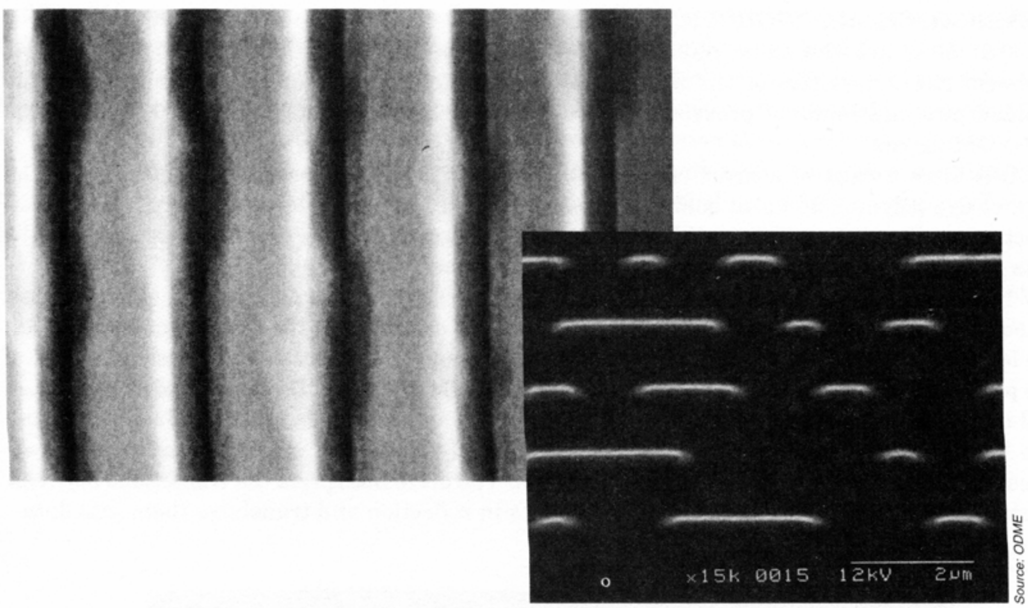
- CD-R (12 cm) uses organic die molecules
- Gold, silver or aluminum coating provides reflection
- Dye layer blue, green (better), gold (best) in unwritten state
- Laser writer 4-11 mW 790 nm (CD-R), 630-650 nm (DVD)
- Laser heats dye to 250 C (when 11 mW)
- Depending on dye either destroys dye or may disintegrate material
- Problem: ratio of dark/light spots 50%-30% regular
- Hence may not play in some CD players



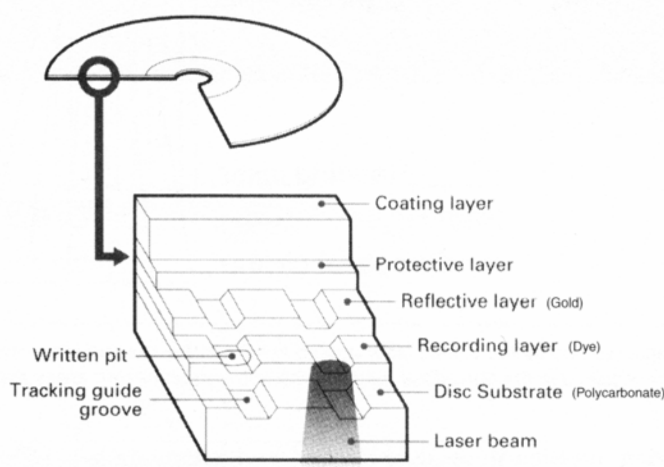
The optical marks created by the writing laser absorb light from the reading laser, while unmarked areas reflect the light back. Again, it is the transitions between marked and unmarked areas that represent binary ones.

CD-R/DVD-R/DVD+R Operation

- Different dyes use different processes: give different reflectivities
- Cheaper dyes burn to dark, have less reflection ratios
- Others melt or chemically degrade & heats recording layer
- Has less volume – cover layer melts in & creates pit
- Much harder to see the pits in CD-R under microscope
- Hence much less reflection
- Higher speed (52x) uses higher power lasers & rotation rate



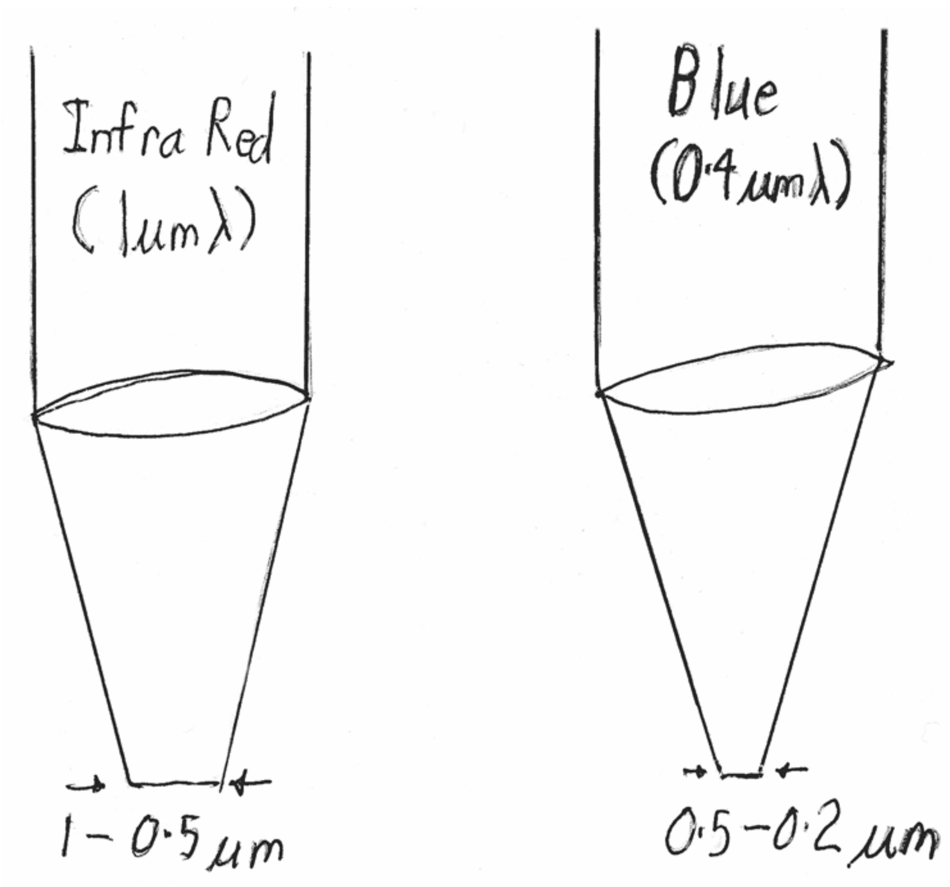
These enlarged photos of marks in CD-R dye polymer and molded pits in a pressed CD demonstrate that even if optical marks are not physically apparent, a laser can "see" the differences in reflectivity.



A CD-R disc uses a thin layer of pure gold, instead of aluminum, as a reflector, and adds a layer of organic dye polymer as a recording layer.

What Limits the Data on a CD/DVD?

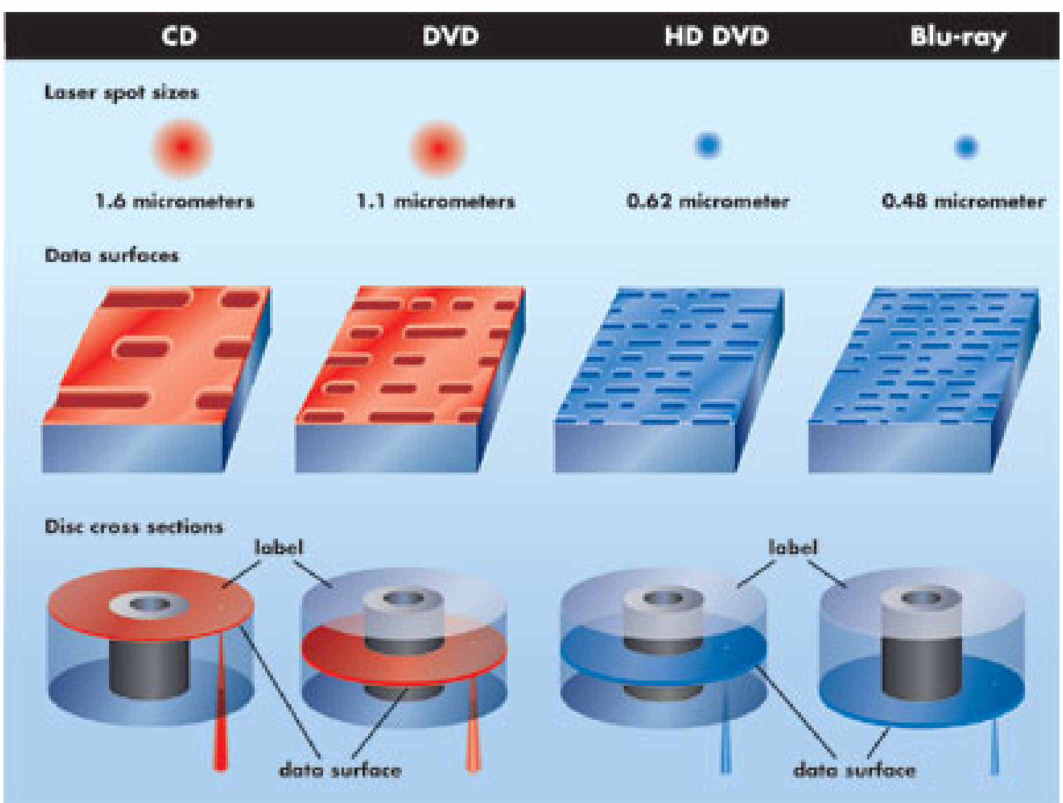
- Each pit is one “bit” (0 or 1) of data
- How fast the CD turns (1.4 m/sec for single speed)
- Rotation speed limit: about 52x (72.8 m/sec)
- Beyond that disk destroyed by rotation stress
- Infrared GaAs light 830 nm & 790 nm currently
- Final DVD target Blue lasers ~405 nm to get 0.2 μm pits
- Problem is lifetime of Blue laser approaching 1000 hrs



HD-DVD vs Blue Ray DVD Wars

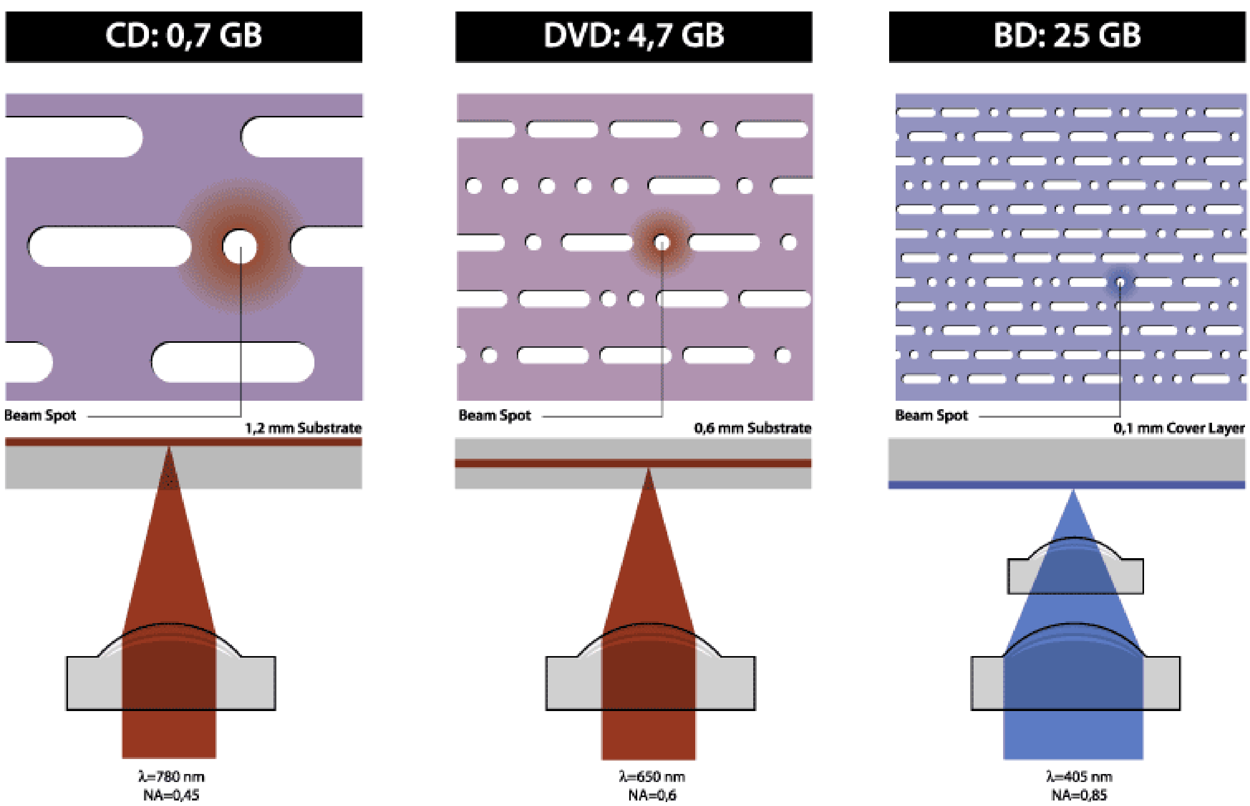
- Next generation DVD format has two competitors
- HD-DVD: Toshiba, NEC, Microsoft, entertainment industry
- Blue Ray (BD): Sony, Hatachi, Panisonic, Apple etc (PC makers)
- All use 405 nm blue (really violet) laser diodes
- Blue Ray higher capacity (25 GB) vs HD (15 GB)
- Reason: Blue ray spot smaller (0.48 μm) vs HD (0.62 μm)
- Hence shorter pits/track: Blue ray 0.16 μm, HD 0.205 μm
- Track spacing: Blue ray 0.32 μm, HD 0.40 μm
- Problem is that Blue ray is much nearer the surface (0.1 mm)

OPTICAL-DISC FORMAT SPECIFICATIONS				
Prerecorded formats	CD	DVD	HD-DVD	BLU-RAY DISC
Maximum data rate, in megabits per second (Mbps)	1.4 Mbps	11 Mbps	36 Mbps	36 Mbps
Data capacity (single-side, single-layer), in gigabytes (GB)	0.74 GB	4.7 GB	15 GB	25 GB
Laser wavelength, in nanometers (nm)	780 nm	650 nm	405 nm	405 nm
Diameter of laser spot on data layer, in micrometers (μm)	1.6 μm	1.1 μm	0.62 μm	0.48 μm
Track pitch	1.6 μm	0.74 μm	0.4 μm	0.32 μm
Minimum pit length	0.83 μm	0.40 μm	0.204 μm	0.15 μm
Overall disc thickness	1.2 mm	1.2 mm	1.2 mm	1.2 mm
Distance from disc surface to data surface	1.1 mm	0.6 mm	0.6 mm	0.1 mm



HD-DVD vs Blue Ray DVD: Why the Difference

- Problem is Blue ray uses Higher NA lens 0.85 vs HD 0.65
- Much shorter focus: Blue ray 0.1 mm vs HD 0.6 mm
- Allows for smaller spot, higher density
- But production equipment different:
- Blue ray 1.1 mm substrate (new technology)
- HD uses standard DVD 0.6 mm substrates
- HD simple modification to existing DVD lines & faster production
- Will be to market first
- Blue ray can have 8 layers, up to 200 GB, HD 4 layers, 60 GB
- Initial format 2 hours of High Definition TV, 4 hours later/layer
- Limit is really the codecs (digital decoding)
- Harder to make Blue Ray read current DVD's



CD/DVD Manufacturing: Creating Masters

Premastering • Converting the video/sound into data • Conversion to mpeg/compressed files	
Mastering • Glass master coated with photoresist • UV laser beam Recording writes data pattern • Develop resist to create pits • Sputter silver coating	
Electroplating • Electroplate nickel layer on glass master • 0.3 mm nickel forms mould for disk • Separate pressing mould from glass master • Called a stamper	

CD/DVD Disk Manufacturing

Pressing • Liquefied polycarbonate injected into mould • Cools to create base layer with pit pattern	
Metallization • Sputter deposit aluminum layer • Creates reflective layer with pits	
Varnishing • Varnish lacquer layer spun on • Forms hard layer for scratch protection • Acts as vapour barrier to water • Prevents Aluminum distruction	
Labelling • Silk screen printing the label	

- Multilayer/Double sided disks
- Repeat stamp/metallize/varnish for each level

HD-DVD Blue Ray DVD Wars

- HD backed by Toshiba/Microsoft/Hitachi
- Studios Paramount Pictures/Universal
- Blue Ray: Sony/Philips
- Studios Sony, MGM, Walt Disney,Universal, Warner Bros.
- Sony learned from Beta/VHS tape: get many on board
- HD advantage – could modify DVD production equipment
- But Blue ray costs came down to same level <$1/disk
- Hence Disk cost to consumer the same
- Also Blue ray can do next generation HD
- Make money when switch formats
- End case when major retails saw 2:1 blue to HD sales
- Walmart/Best Buy switched in Feb. 2008