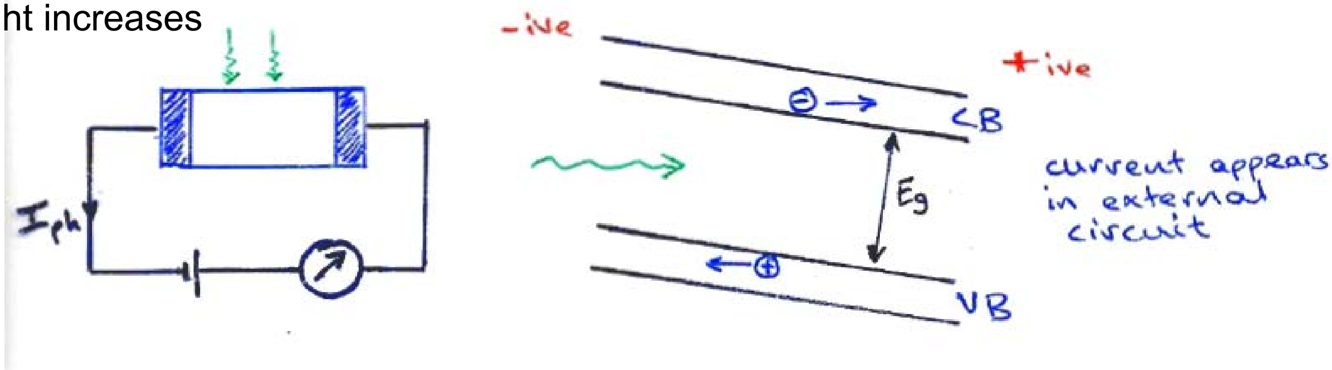
Detectors

Two types

(a) Photoconductive:. Conductivity increases as the light increases



Needs photons of energy > E_g to work. Also the conductivity of the semiconductor needs to be high in the dark (σ-> 0).

Under illumination **$\sigma = e(n_e\mu_e + n_p\mu_p)$.** But 1 photon makes 1 electron and 1 hole so **$\sigma = en(\mu_e + \mu_p)$.**

Assume light of frequency ω (energy hω) and input optical power P(J/s).

Average number of e-h pairs/sec = $$= \frac{P}{h\omega} x \eta$$

Where η is the efficiency

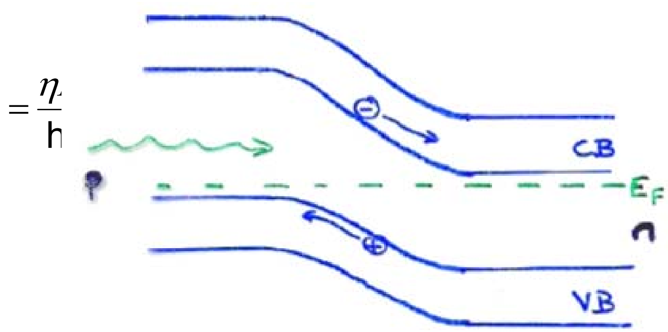
= no.pairs/ no..photons

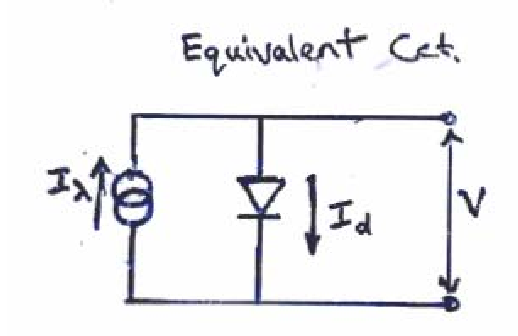
However some of these pairs will recombine before they reach the contacts.

Hence the equilibrium number of pairs $= \dfrac{\eta P \tau}{\hbar \omega}$

Since $\sigma = en(\mu_e + \mu_p)$. Conductuvtivity (s) is proportional to Input optical power (P)

(b) Photodiode





Built in field (can also be reversed baised) causes e-h pairs to separate, generating a current or voltage (open circuit).

Consider the equivalent circuit.
Remember diode equation

$$I_d = I_0 \exp(\frac{eV}{KT} - 1)$$

Semiconductor Optoelectronics

For an open circuit $I_d = I_\lambda$ (input current due to arriving photons)

I_λ = charge arriving per second $= \dfrac{\eta e P}{\hbar\omega}$

$$I_\lambda = \frac{\eta e P}{\hbar\omega} = I_0[\exp(\frac{eV}{kT}) - 1)]$$

$$V = \frac{kT}{e} In[\frac{\eta e P}{\hbar\omega I_0}]$$

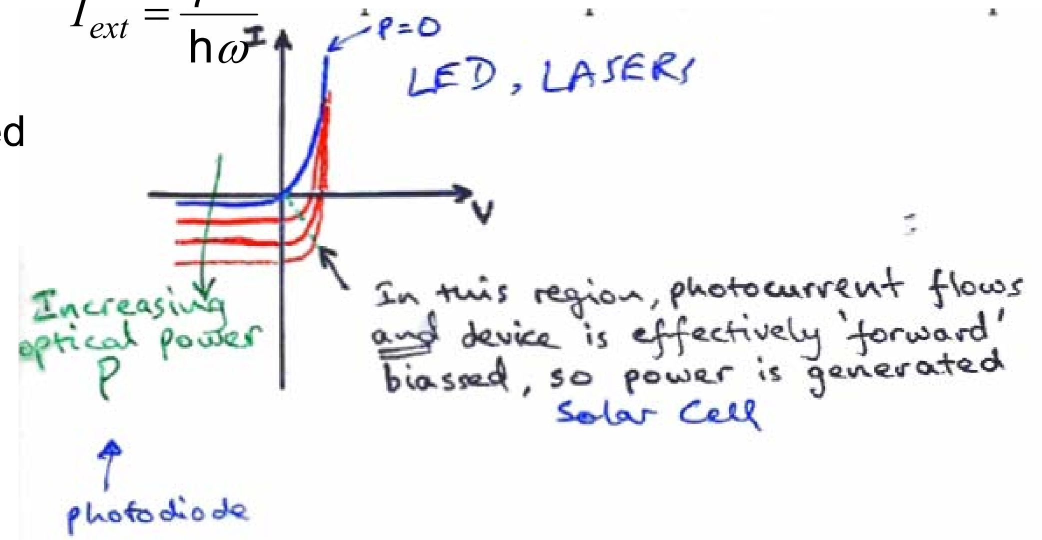
In photoconductive mode

$$I_{ext} = I_d - I_\lambda = I_0[\exp(\frac{eV}{kT}) = 1] - \frac{\eta e P}{\hbar\omega}$$

First term is insignificant if reverse biased

$$I_{ext} = \frac{\eta e P}{\hbar\omega}$$

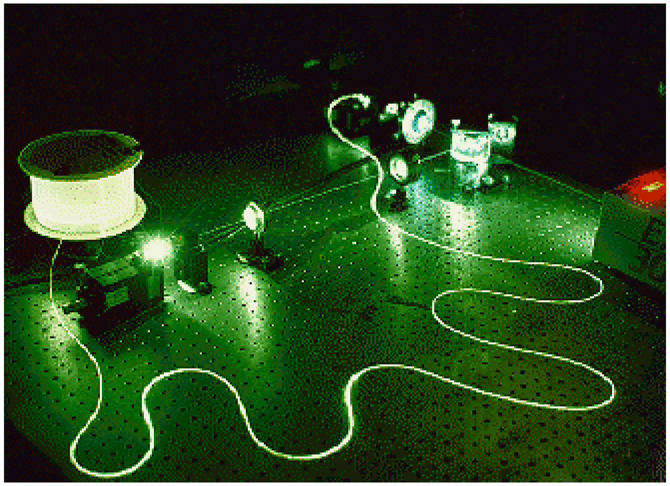
In a **Solar cell** the photodiode is optimised for maximum power output



Fibre Optic Communications

Optical communication systems in the past consisted of techniques such as fire signals, smoke signals, flash lanterns, reflected sunlight and signal flags. Such systems had limited bandwidth and were not competitive with electronic communications (like radio).

The invention of the laser provided a coherent optical source capable of transmitting information at extremely high data rates. However, limitations on transmission of light through the atmosphere (such as turbulence, haze, fog, absorption and rain) limited the usefulness of lasers for transmission of information through the atmosphere. Modern optical communication systems use semiconductor lasers that transmit light through optical fibers made of glass. Such systems have become widely used for telecommunications.



Fibre Optic Communications

Laser communication systems are used to transfer information from one point to a distant point. The information may be an audio conversation, a stream of data from one computer to another, or several simultaneous television broadcasts. The distance may range from a few feet to thousands of miles. Optical communications using lasers and fiber have the following advantages.

1. Very high concentration of optical power and very little spread of that power with distance (low beam divergence).
2. Ability to carry huge amounts of information (high information bandwidth).
3. Small antennas required (compared to radio-frequency communication systems).
4. Narrow spectral linewidth, allowing the rejection of light except at the laser wavelength.
5. Coherence, allowing use of techniques such as frequency modulation

Because of these characteristics, useful information can be impressed on a beam of light, and transmitted to a remote location, where the information can be recovered.

Fibre Optic Communications

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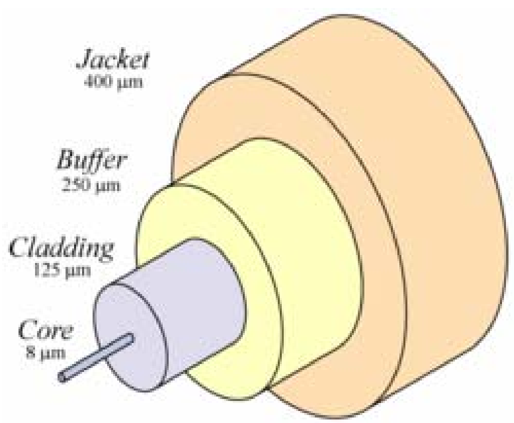
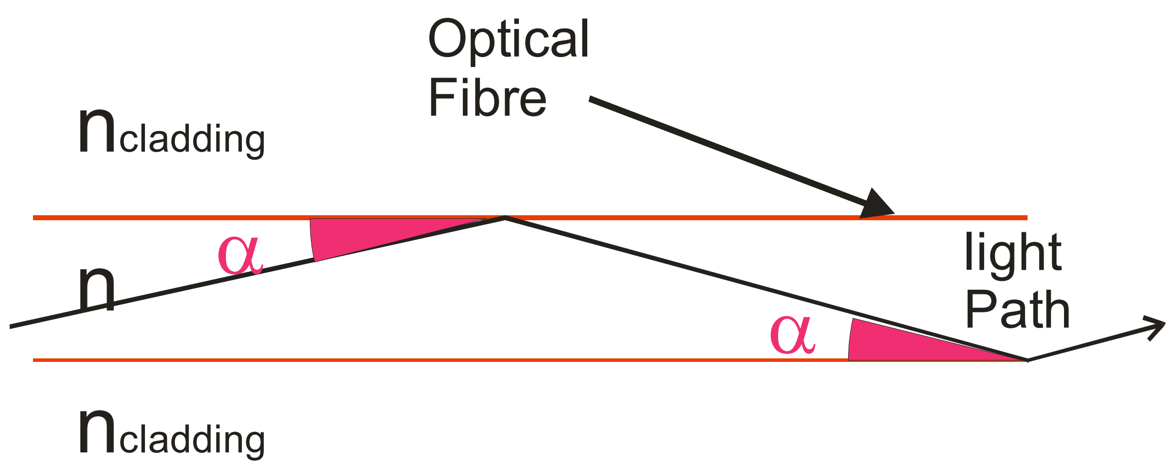
Optical fibers offer an attractive choice for a transmission medium to eliminate problems with atmospheric transmission. Thin optical fibers can be fabricated with lengths of many kilometers. A light beam coupled into one end of the fiber can propagate through the fiber without atmospheric interference, and can be detected at the other end of the fiber. The fibre has a core surrounded by a cladding with lower index of refraction. The numerical aperture (N_A) is defined as

$$NA = \sin \alpha_{max}$$

where α_{max} is the angle between the incident light and the fiber axis. The NA is a measure of how much light can be coupled into the fiber.





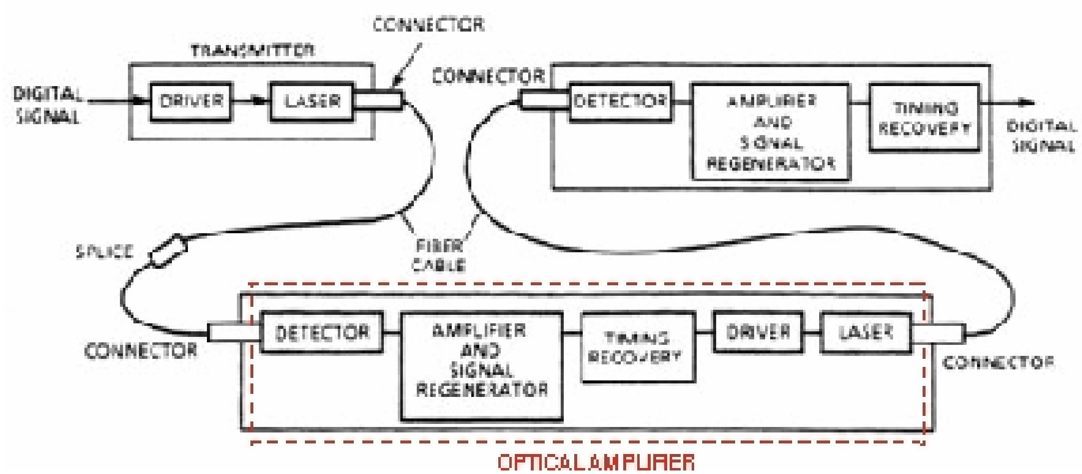
Fibre Optic Communications

For Fibre Optic communications you need an emitter and a detector (of light).

semiconductor lasers are especially well-suited for use in this type of communication system. Semiconductor lasers have suitably small size and configuration for coupling into the small-diameter core of an optical fiber. Modern operate continuously at milliwatt power levels sufficient for fiber-optic communications. They can be modulated easily, through modulation of an electric power supply, at frequencies up to the gigahertz range. This makes it possible to transmit information, by modulating the beam of light from a laser through optical fibers.

Advantages

- High bandwidth
- Low attenuation
- Light weight, small size
- No EM interference
- Immune to jamming – 'secure'
- No cross talk
- Cheaper than copper wires
- Physically strong



Signal degradation in optical fibre

There are three factors that can degrade the signal transmitted by an optical fibre: Attenuation (loss), modal dispersion and chromatic dispersion

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Fibre Optic Communications

Attenuation(loss): The signal decreases as it travels down the fibre. There are two types of losses: scattering and absorption. The loss in optical fibers is expressed commonly in terms of the number of decibels (dB) loss per kilometer of length of the fibre. Absorption is mainly due to impurities in the fibre and has a characteristic wavelength dependence

Loss in decibels is described on a logarithmic scale. If a signal P_0 is input to a fiber and a signal P is transmitted, the loss in decibels is expressed as

$$dB_{loss} = 10\, log10\, (P_0/P)$$

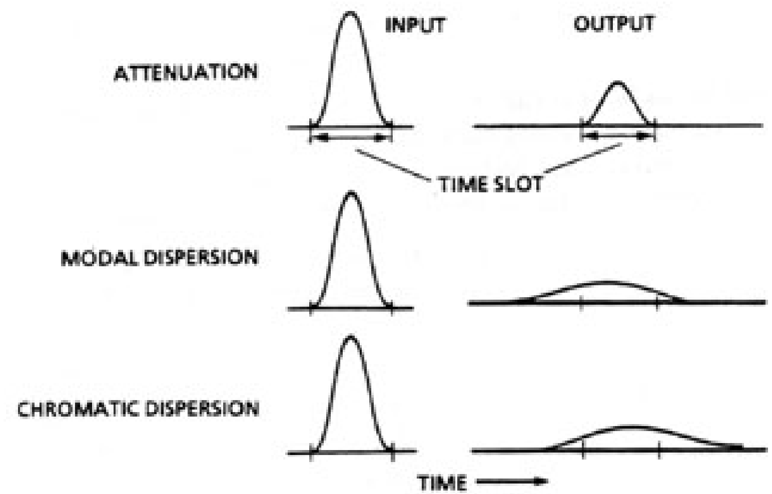
So, ten decibels corresponds to a decrease in signal level by a factor of 10 etc.

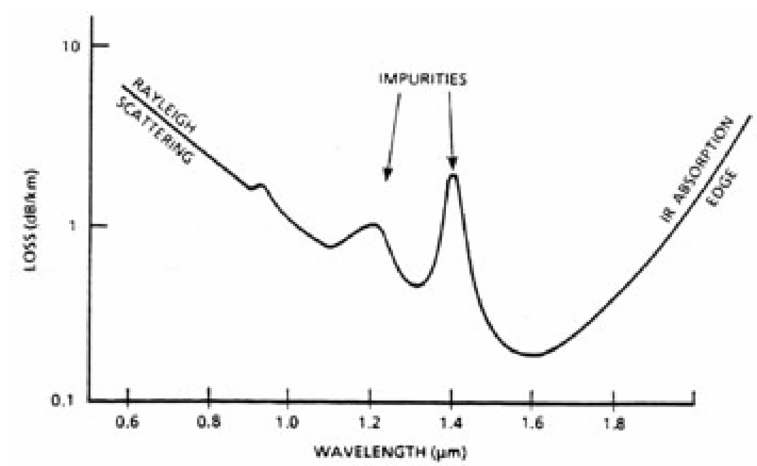
Example: A signal of 10 mW coupled into an 10-km-long fibre with a signal of 1 microwatt detected at the end of the fibre.

The loss, in *dB*, is given by: $10\, log10\, (P_0/P) = 10\, log10\, (10\, mW/10^{-3} mW)$

$P_0/P = 10\, log10\, 10^4 = 40\, dB$

So the *dB* loss of the fiber per kilometer of fibre length is: $40\, dB/10\, km = 4\, dB/km$





Fibre Optic Communications

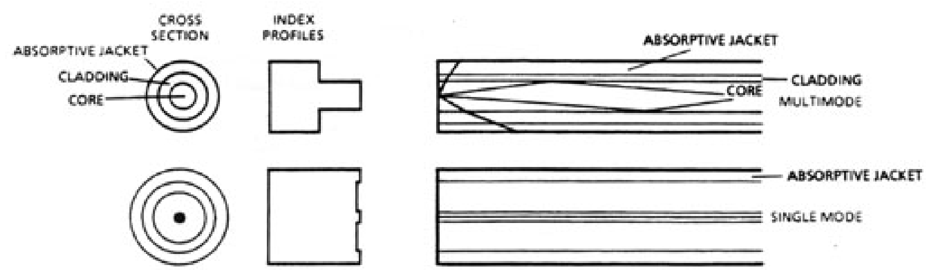
There are three main minima in the fibre loss versus wavelength characteristics, at 850, 1300 and 1550nm and named the 1st, 2nd and 3rd windows respectively.

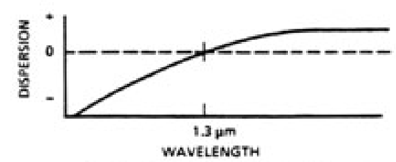
The two other mechanisms of signal degradation ***do not*** involve loss of light intensity, but do cause the optical pulse to broaden and to move out of its time slot.

The first of these, called ***modal dispersion,*** results from the fact that light can travel along different paths down the length of the fiber. This means that the initial short pulse will be broadened, and will spread out of its time slot.

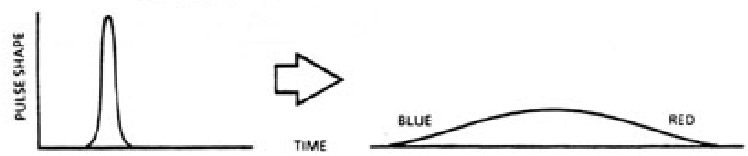
The second, called ***chromatic dispersion,*** results from the variation of index of refraction with wavelength, so that light of different wavelengths travels through the fiber at different velocities

window	Loss	Laser	detector
1st/850nm	2dB/km	AlGaAs	Si
2nd/1300nm	0.5dB.km	InGaAsP	InGaAs
3rd/1550nm	0.2dB/km	InGaAsP	InGaAsP





DISPERSION EXPRESSED IN PICOSECONDS OF PULSE DELAY PER KILOMETER OF FIBER LENGTH PER NANOMETER BANDWIDTH.

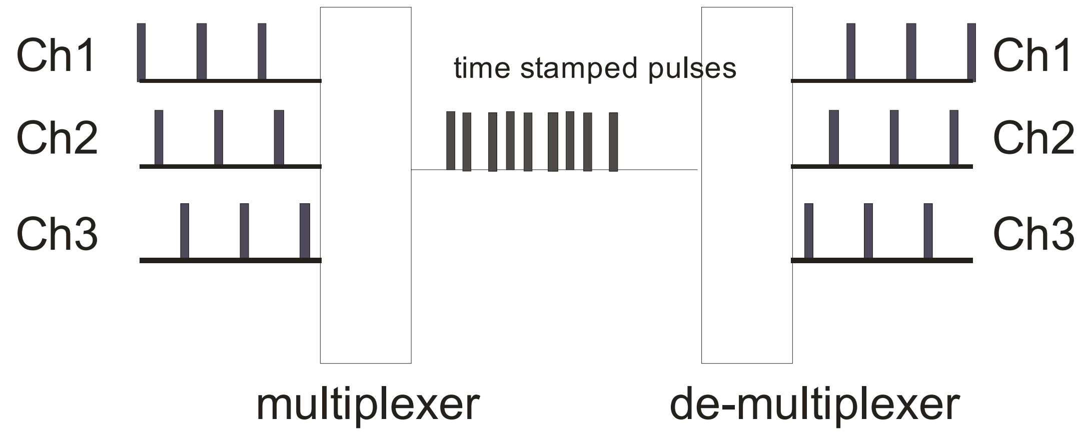


Typical Components for Fiber-optic Systems

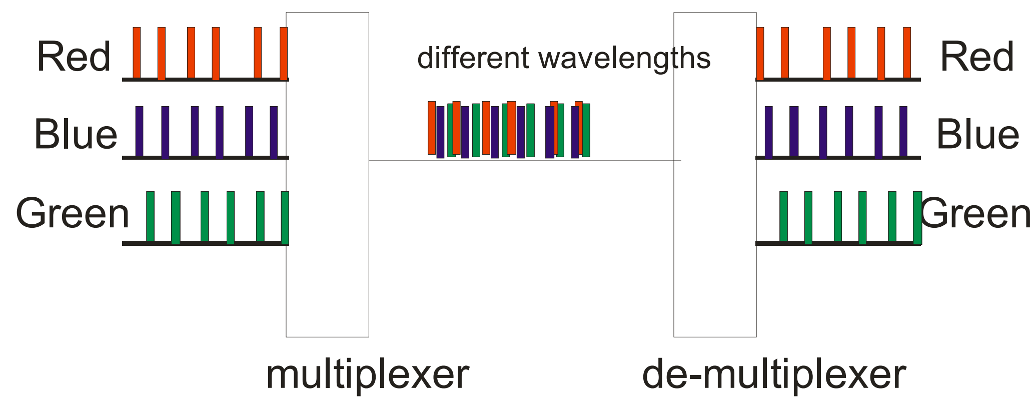
Fibers	Silica Fibre with loss <0.2 dB/km at 1550 nm . Bandwidth—distance products to 3000 MHz-km
Sources	Lasers give 2-10 mW into cable, up to 6000-MHz modulation rates, 10^6 hour life. LEDs give 0.1 mW into cable, 200-MHz modulation, greater than 10^6 hour life.
Detectors	PIN photodiodes give responsivity 0.5 A/W, noise equivalent power (NEP) 10^{-12} W/(Hz)$^{1/2}$. Avalanche Photodiodes (APDs) give responsivity 75 A/W, NEP 10^{-14} W/(Hz)$^{1/2}$.
Connectors and Splices	0.1-0.5 dB insertion loss.

Fibre Optic Communications

Time division multiplexing allows the sending of bits as successive pulses pulses from different channels. Multiplexing depends on a clock pulse



Wavelength division multiplexing allows the sending of different wavelength channels at the same time. In the example we would just combine the outputs of 3 lasers, then de-multiplex them using wavelength dependent filters



Fibre Optic Communications

The previous example showed 3 lasers, Red, blue and green being combined. This is no practical in fibre optics since we have to work within the fibre loss windows.

Typical modern systems have 128 or 140 channels working near 1550nm.

$$\lambda = \frac{c}{f}$$

$$\Delta\lambda = \frac{c}{f^2}\Delta f$$

1550nm = 1.94×10^{14}Hz, =194THz

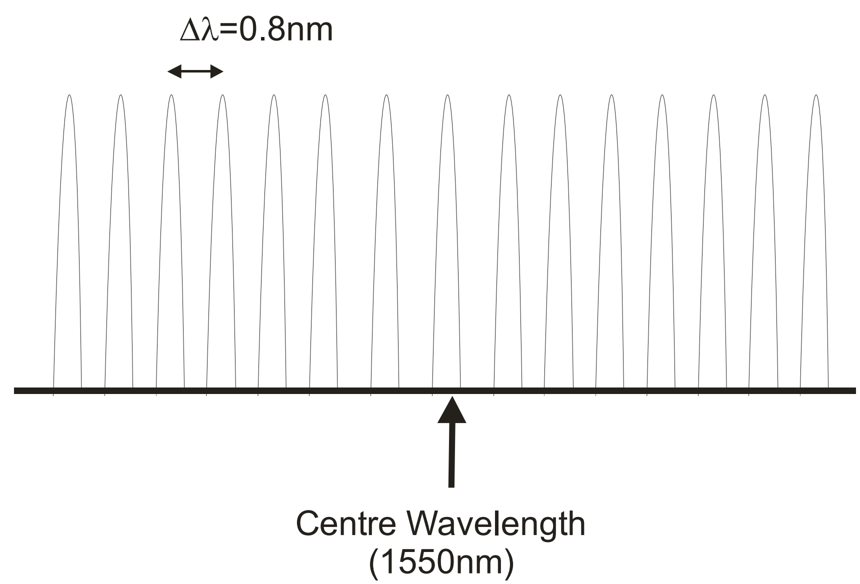
Channels are spaced 100GHz apart.

$\Delta f = 100 \times 10^9$, f=194THz $c/f^2 = 8 \times 10^{-21}$

$\Delta\lambda = 8 \times 10^{-21} \times 100 \times 10^9 = 8 \times 10^{-10}$

$\Delta\lambda$=0.8nm

This close arrangement of multiple wavelengths is called **Dense WDM (DWDM).** Need an array of lasers with slightly different emission wavelengths. For detector, use a filter or grating



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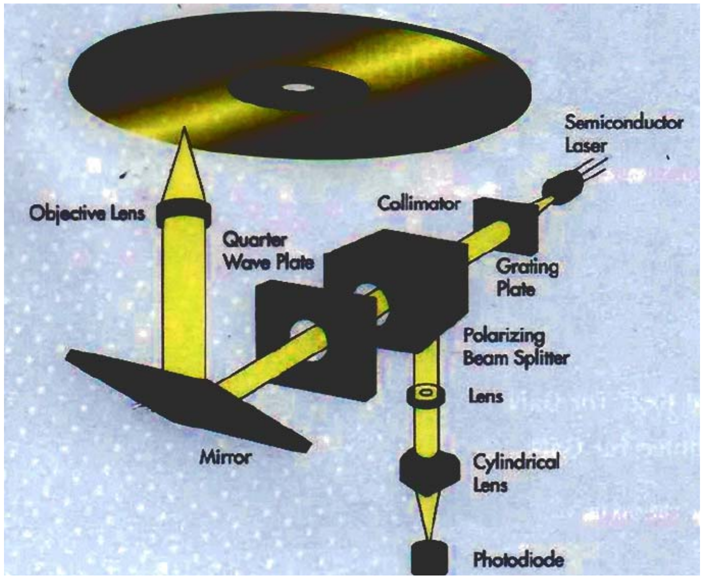
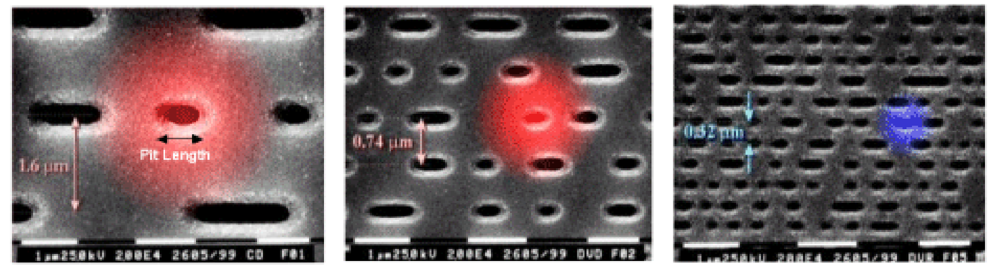
Optical Data Storage



CD 0.7 Gbyte	DVD 4.7 Gbyte	Blu-ray Disc 25 Gbyte



Track Pitch: 1,6 micron	Track Pitch: 0,74 micron	Track Pitch: 0,32 micron
Minimum Pit Length: 0,8 µm	Minimum Pit Length: 0,4 µm	Minimum Pit Length: 0,15 µm
Storage Density: 0,41 Gb/inch²	Storage Density: 2,77 Gb/inch²	Storage Density: 14,73 Gb/inch²

For light of a wavelength λ there will be a diffraction limit to the spot size given by

$$d = 1.22\lambda \frac{f}{a}$$

Where f is the focal length and a is the diameter of the beam. The spot size can be reduced by using shorter wavelength light