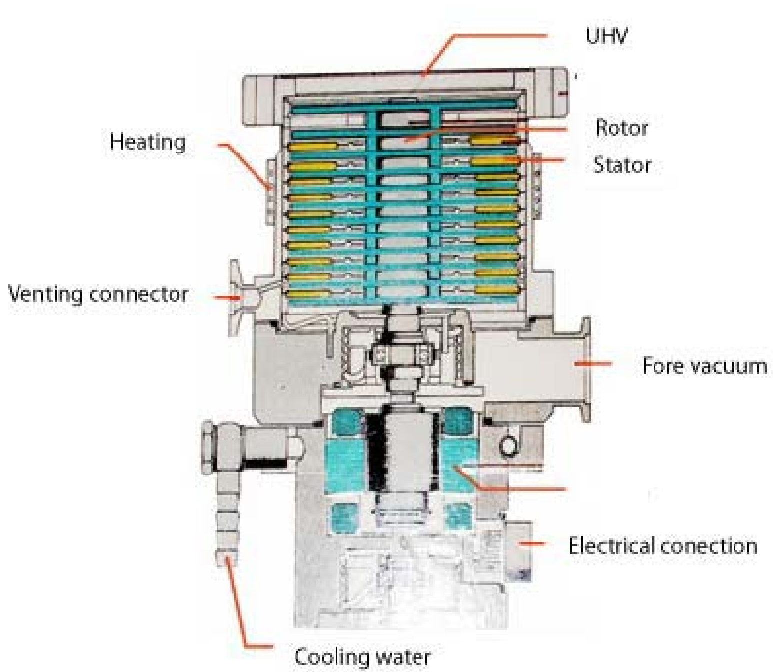
1	Turbo pump	Weger	Matthias
2	Titanium sublimation pump	Galland	Christophe Marcel Georges
3	Ion pump	Zaugg	Christian Anton
4	Vacuum gauge	Meineke	Jan Jakob
5	Vacuum windows	Weiss	Kathrina Marlen
6	Diode lasers (electronics)	Latta	Christian
7	Optical isolator	Kucsko	Georg Franz Lothar
		Thiele	Tobias Sebastian
8	Lambda plates	Kushnarenko	Alexander
		Wittwer	Valentin Johannes
9	Electro optical modulator	Monstein	Stefan Andreas
		Walt	Samuel Gebhard
10	Acousto optical modulator	Fiolka	Reto Paul
		Jha	Shankar Kumar
11	Fiber couplers	Eghlidi	Mohammad Hadi
		Pototschnig	Martin Ronald
12	Optical fibers	Hoffmann	Martin
		Lotito	Valeria
13	Fiber connectors	Oehler	Andreas Ernst Heinz
14	Beam splitters	Pinotsi	Dorothea
		Reinhard	Andreas
15	Glan-Thompson polarisation prism	Uehlinger	Thomas
16	Narrow band optical filters	Petersen	Lutz Akio
17	Photomultiplier	Schtalheim	Amos
18	APDs	Vargas Lugo Cantu	Andres

Turbomolecular pumps



- Problems pumping light elements
- vibrations

- Getter pumps or others required for optimal end pressure (BEC…)
+ Handles high gas loads
+ end pressure sufficient for many applications

Works in pressure regime of molecular (ballistic) flow, particles hit fast spinning rotors, which transfer momentum to them. Over several rotors no particles will move back.

The principle requires the rotors to spin at a speed comparable to the thermal velocity of the gas.
f_{rot} = 600 – 1500 Hz
That also means that the pump will be more efficient for heavier gases.

Do not move while operating!

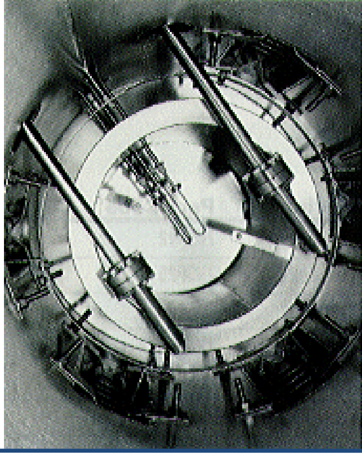
Requirements and specs:

• Fore vacuum: typically 10^{-2} mbar
• final pressure: $5*10^{-10}$ mbar by Pfeiffer, less possible
• pumps available from 10s to 1000s l/s
• pump rate proportional to rotor speed and area: $S \propto A \cdot v$
• End pressure depends on rotor speed and gas species

Titanium Sublimation Pump

Filament

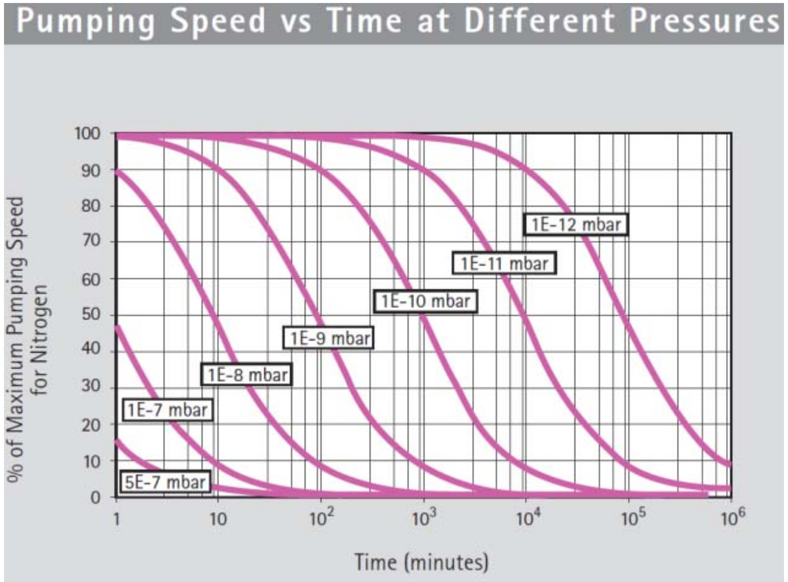
Controller



Chamber

- supplement the pumping action the UHV Ion pumps: **more effective** at pumping gettable gases.

- simple, low cost, and can give a **high pumping speed**.



Working Principle

- A **high current** (supplied by the controller) passes through a **Ti/Mo filament**

  → **Titanium is sublimated** and coats the walls of the chamber.

  → should glow white

- The clean **Titanium film** reacts with the active gas molecules to form **low vapor pressure compounds**.

- Once the film has reacted it must be **replaced by re-evaporation** from the sublimation pump.

Tip: To enhance the pumping speed, the condensing walls can be cooled to liquid nitrogen temperatures.

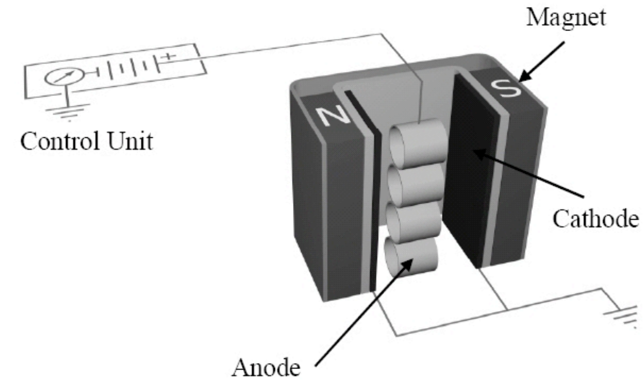
Pumping Speed in $ls^{-1}cm^{-2}$

Gas Species	H_2	N_2	O_2	CO	CO_2	H_2O	CH_4	Inerts
+ 20°C	3	4	9	9	8	3	0	0
- 196°C	10	10	11	11	9	14	0	0

Ion Getter Pump

functionality:

- high electric field (3-7 kV) accelerates electrons
- electrons ionize remaining gas in vacuum
- electric field accelerates ions towards cathode
- highly reactive gettermaterial (often Ti) bonds ions
- impact of ions releases more electrons etc.
- magnetic field to extend electron-trajectory
- no moving parts



http://www.chem.elte.hu/departments/altkem/vakuumtechnika/CERN03.pdf

requirements:

- high vacuum (~10^{-3} mbar)
- no rare gases

achievement:

- UHV down to 10^{-11} mbar
- low-maintenance
- only voltage supply

minus
- electrical feedthrough sometimes leaks => test

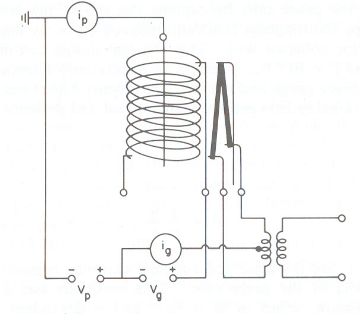
Pressure gauges

Ionization gauges

- For high and ultra-high vacuum ($10^{-3} - 10^{-12}$mbar)
- measure particle density
- depend on gas type (varying ionization)
- limited by x-rays

Different types

- Hot Chathode Gauge
- Cold Cathode Gauge



Vacuum Windows

Pressure Resistance

- modulus of rupture >> stress $S \propto \frac{r^2 \Delta p}{t^2}$
- bending → lens effect

Temperature

- deformation of glas, flanges

Sealing

- o ring (up to 10^{-12} bar)
- copper (below 10^{-12} bar)
- indium (LHe temperature)

Optical Properties

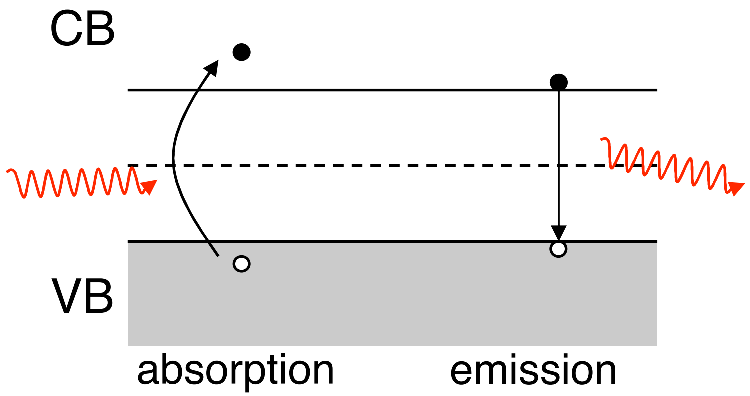
- transmission range
  fused silica (200 nm – 1.5 µm)
  BK7 (350 nm – 2 µm)
  CaF_2 (0.15 µm – 9 µm)
  Diamond (0.2 µm – 100 µm)
  ...
- coatings (anti-reflection)

Attention

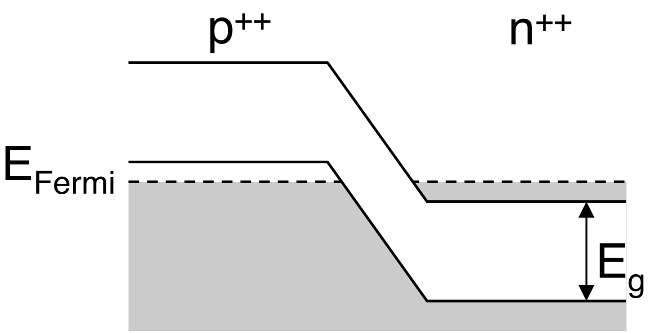
- alkalis can destroy window
- heat only with < 1°C/min
- use soft copper seals

Diode laser

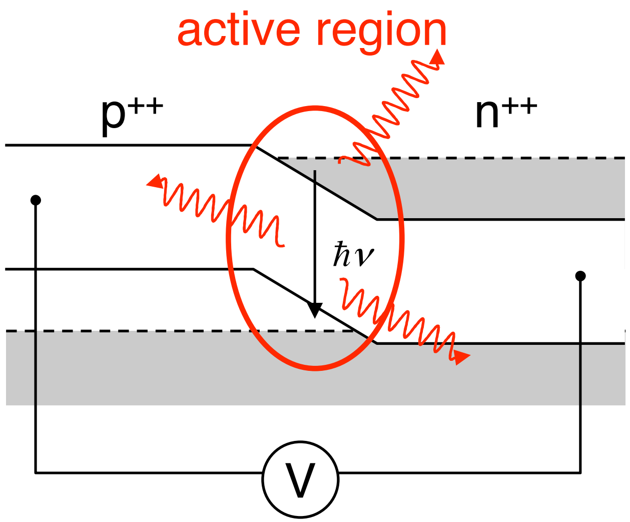
1) Direct semiconductor : **Optical transitions between the valance band and the conduction band**.
Transitions not between 2 states but between bands.



2) **pn-junction** (diode)



3) Population inversion achieved by **applying a voltage** to the diode



4) **Add cavity**:
- Facet coating
- Anti-reflection coating plus external cavity

Typical Semiconductors:
- AlGaAs 750-880 nm
- InGaAs 880-1080 nm
- InAlGaP : 1300-1550 nm
- GaN : 400 nm

$P \leq 200$ mW, protect from voltage spikes

Optical Isolator (OI)

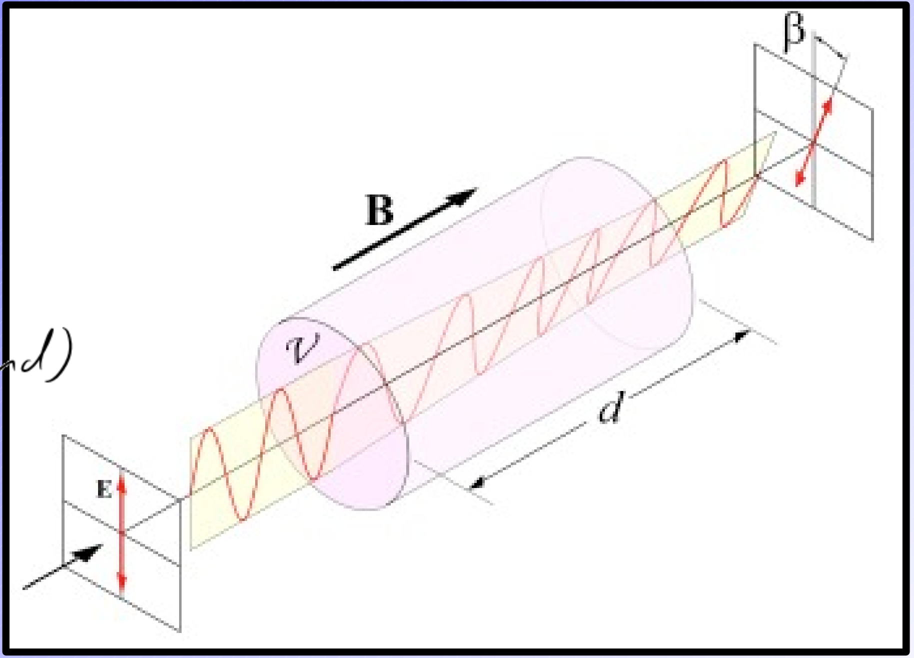
- **Application:** Feedback-elimination

- **Faraday effect:**
  - Rotation of polarization ($B \neq 0$)
  - $\beta = \nu(\lambda) B d$

- **2 types:**
  - Polarization-dependent
  - Polarization-**in**dependent

- **Installation:**
  - Maximize transmission (1 Pol.)
  - Rotate isolator (wrong way round)
  - Minimize transmission (2 Pol.)
  - Powermeter far away!

- **Important features:**
  - Aperture
  - Single/Double-dB (single 30 dB, double 60 dB)
  - Losses at polarizers
  - Wavelength
  - Damage threshold



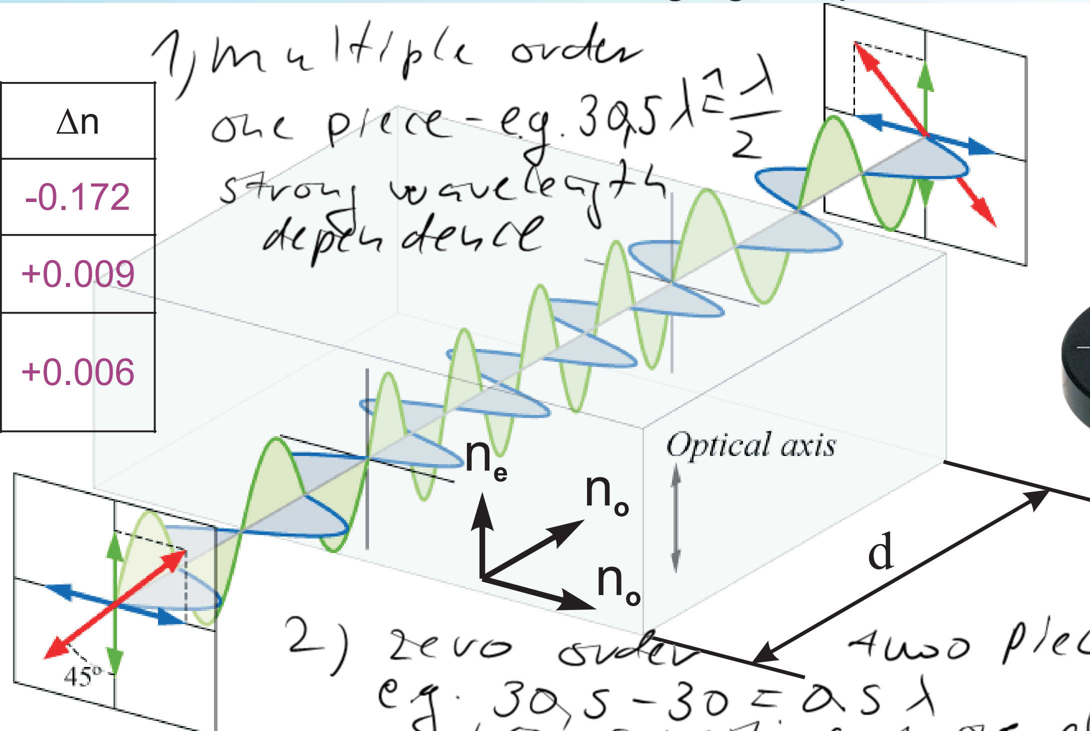
Optical Wave-Plates:

transparent plates with a defined amount of birefringence, used for changing the polarization of light

Birefringent crystals:

Uniaxial minerals	n_0	n_e	Δn
Calcite $CaCO_3$	1.658	1.486	-0.172
Quartz SiO_2	1.544	1.553	+0.009
Magnesium fluoride MgF_2	1.380	1.385	+0.006

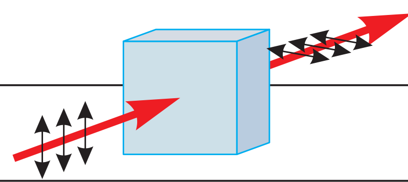
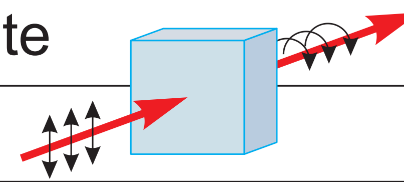
1) multiple order
one piece - e.g. 30.5 λ ≙ λ/2
strong wavelength dependence



2) zero order two pieces
e.g. 30.5 - 30 = 0.5 λ
less sensitive more expensive

Phase change:

$$\Delta\Phi = 2\pi d \Delta n/\lambda$$

Half-Wave Plate	Quarter-Wave Plate
$\Delta\Phi = \pi$ 	$\Delta\Phi = \pi/2$ 
• Rotates the polarization state of linearly polarized light • Changes the rotational direction of circularly polarized light	• Turns plane-polarized light into circularly polarized light (θ = 45°) • and vice versa :)

Electro-Optic Devices

$$\triangle E - \frac{1}{c^2}\partial_t^2 E = E(\chi^{(1)} + \chi^{(2)} E_{ext})$$

General Informations:

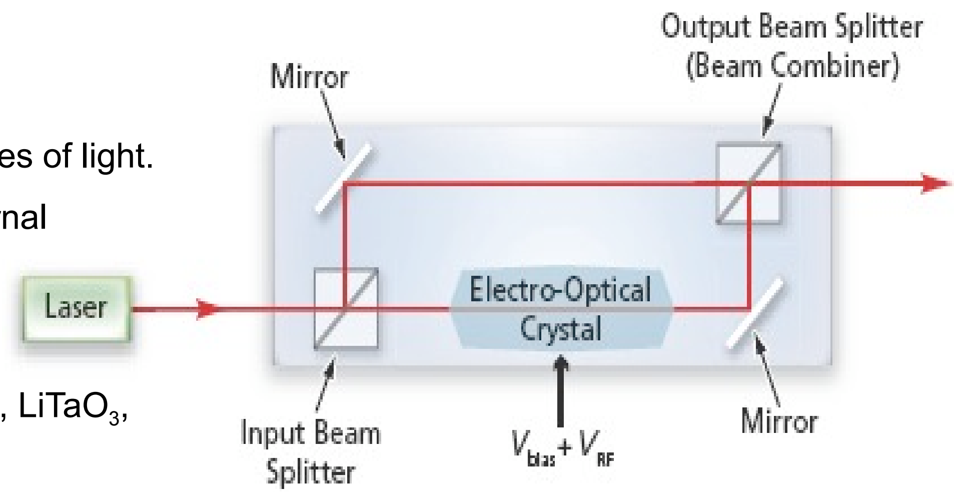
- Effect can be used to build:
  - A Lens with controllable focus length.
  - A prism which can be used as a scanning device.
  - A plate which modulates the phase.
  - An anisotropic crystal which changes the polarization properties of light.
- Electro-Optic Effect: Change of the refractive index due to an external electric field.
  - An intensity modulator.
- Change proportional to the applied electric field: **Pockels effect**
  - Used crystals for Pockels cells: $NH_4H_2PO_4$, KH_2PO_4, $LiNbO_3$, $LiTaO_3$, CdTe.
  - r (Pockels coefficient) in the range of 10^{-12} to 10^{-10} V/m

$$n(E) \approx n - \tfrac{1}{2} \mathfrak{r} n^3 E$$

- Change proportional to the square of the electric field: Kerr effect
  - Material must be centrosymmetric.

S (Kerr coefficient) in the range of 10^{-18} to 10^{-14} V^2/m^2 (for crystals)

$$n(E) \approx n - \tfrac{1}{2} \mathfrak{s} n^3 E^2$$



	EO-Amplitude Modulator
Specification	Lithium Niobate ($LiNbO_3$)
Wavelength Range	
C1	600-900 nm
C2	900-1250 nm
C3	1250-1650 nm
C4	400-600 nm
Clear Aperture	Ø2 mm
Input Connector	SMA Female
Max Optical Power Density	2 W/mm^2 @ 532 nm 4 W/mm^2 @ 1064 nm
Capacitance	14 pF
Half Wave Voltage, V_π	
Max Modulation Rate	100 MHz

Phase and Amplitude Modulators from ThorLabs

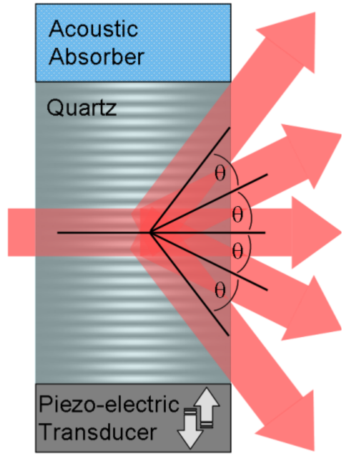
EO-PM-NR-C1

EO-AM-NR-C2
With EO-GTH5M

Acousto-optic Modulator

Reto Fiolka and Shankar Kumar Jha

- **Principle**: Acousto-optic effect - change of a material's permittivity due to a mechanical strain
    - Source of strain: acoustic waves produced by a piezo-electric transducer
    - Periodic strain produced by the acoustic wave leads to the formation of a refractive index (phase) grating (diffraction efficiency > 85%)
    - Depending on the frequency of the sound wave (f) and the interaction length (l) one can observe Raman-Nath (~10Mhz) diffraction or Bragg (~100Mhz) diffraction from the phase gratings leading to multiple or single order diffraction.
    - Most acousto-optic devices operate in the Bragg regime, the common exception being acousto-optic mode lockers and Q-switches.
    - The frequency of the light is shifted (Doppler effect) by the propagating sound wave.
    - No frequency shift for AOMs with counter propagating sound waves producing a standing wave.
- **Applications**: Q-switching, mode-locking, beam shaping, phase shifting, fast switching, beam steering, Wavelength selection, phase shifting, frequency shifting
- **Materials used**: Quartz, Lithium Niobate, Gallium Arsenide, Galium Phosphide, Germanium, Lead Molybdenate, Tellurium dioxide



$$n(z,t) = n + \Delta n \cos(2\pi f t - Kz)$$

n= is the undisturbed index of refraction,
f= frequency of acoustic wave
K = propagation constant of the acoustic wave,
Δn= amplitude variation of the refractive index

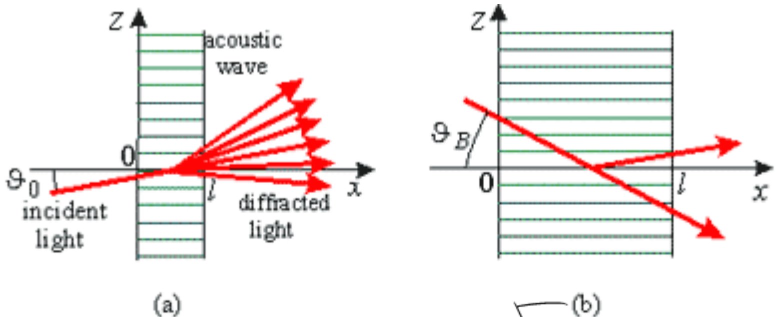
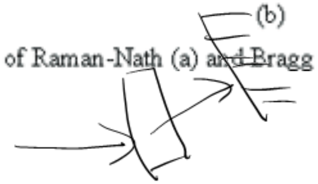


Fig.1. Diffraction of Raman-Nath (a) and Bragg (b)

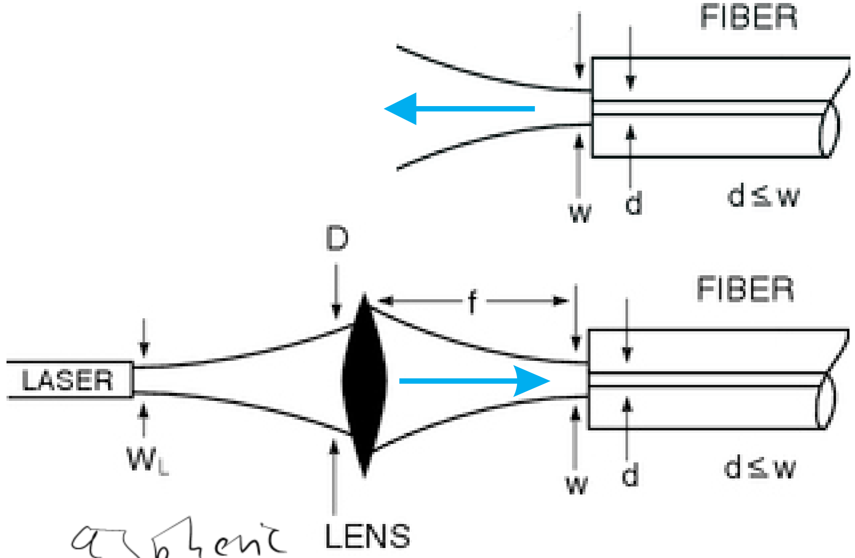
f ~ 50 - 300 MHz
P_{rf} ~ 1 W   Efficiency ≤ 80%



Double pass

Fiber Coupling

Maximum coupling efficiency: Mode matching!



aspheric

250CHF

1200CHF

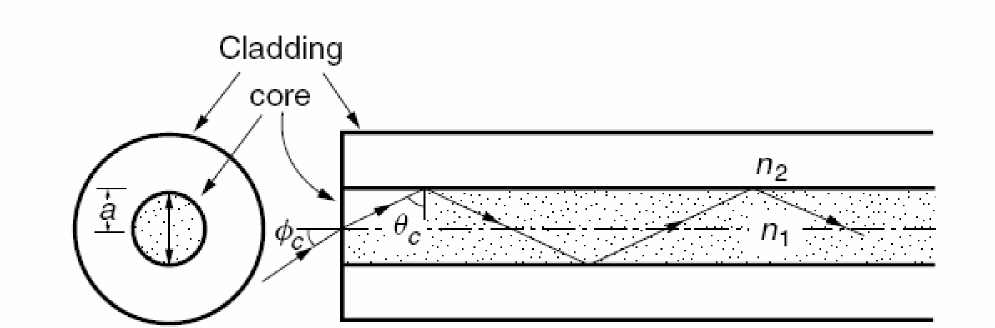
1800CHF

D: beam diameter
w: mode waist (single mode, e.g. 3.5µm @ 515nm)
d: core diameter (~20-30% smaller)

Good coupling efficiencies in the lab:
single mode: >60%, multi mode: >70%
, use reverse source as pilot beam

OPTICAL FIBERS

cylindrical dielectric waveguide made of low-loss materials such as silica glass → **Fiber-optic communication systems** → **Low transmission loss** / **Large capacity of information transmission**



however limited by

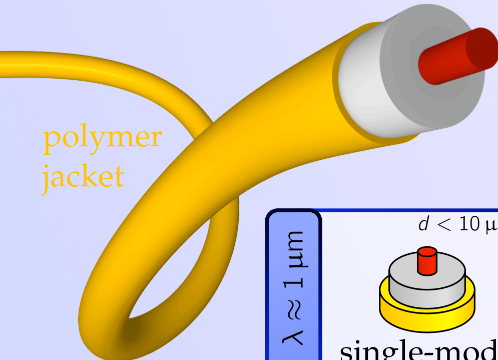
DISPERSION:

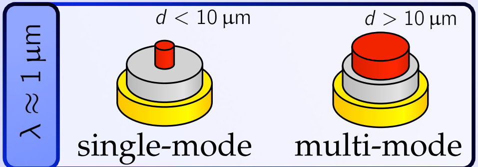
- **mode dispersion** (solution: use of graded index multimode-fibers or single mode fibers)
- **material dispersion**
- **waveguide dispersion**

} Solution: use of fibers with specific refractive index profiles (dispersion-shifted or dispersion flattened fibers) or adoption of appropriate compensation schemes

· polarisation maintaining, stress induced birefringence
· not "

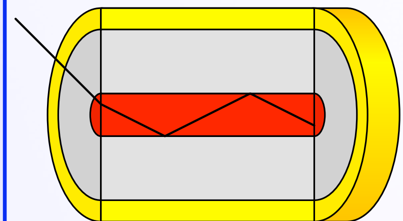
optical fibers (step-index)





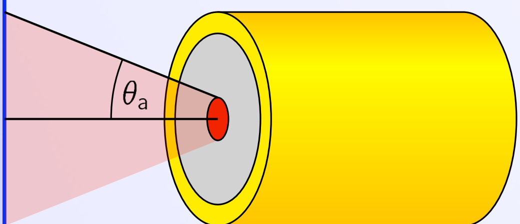
total reflection

$n_{core} > n_{cladding}$

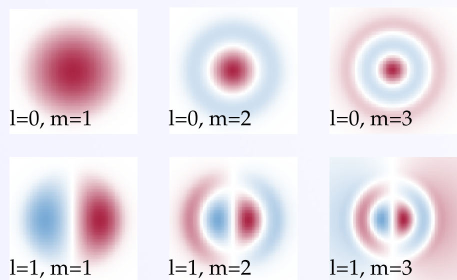


numerical aperture

$$NA = \sqrt{n_{core}^2 - n_{cladding}^2} = n_{air} \sin(\theta_a)$$

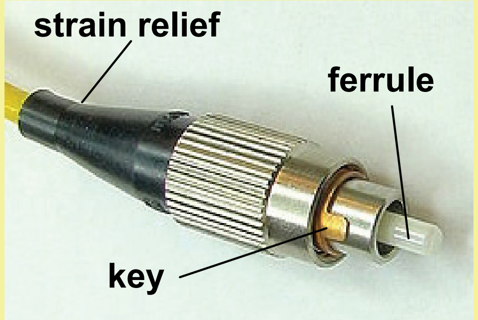


different spatial modes



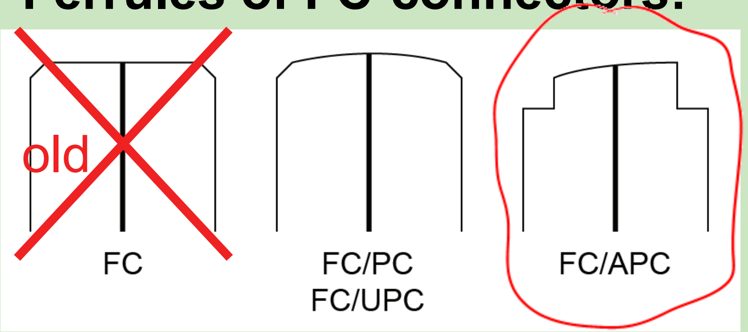
Fiber connectors (example: FC-connector)

General construction



Versions:	*MM*: Multi Mode	*SM*: Single Mode	*PM*: Polarization Maintaining
Typ. Insertion loss:	0.15 dB	0.2 dB	0.2 dB
Ferrule:	2.5 mm diameter, metal/ceramics		
Operating temp.	-40° - 70°C		
Locking-mech.	screw		

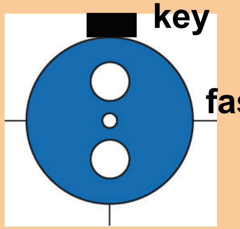
Ferrules of FC-connectors:



Versions:	*PC*: Physical Contact	*UPC*: Ultra PC	*APC*: Angular PC
Main return loss:	≥45 dB	≥50 dB	≥60 dB

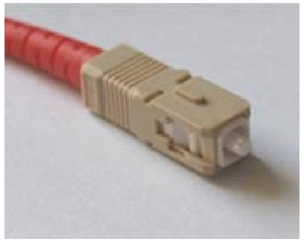
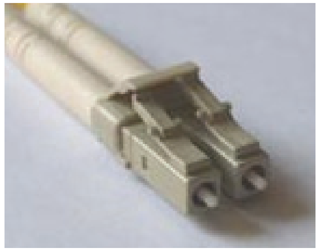
IMPORTANT: APC-connectors are usually marked by a green strain relief
PC- and UPC-connectors have black or white strain reliefs
NEVER CONNECT APC-CONNECTORS TO PC- OR UPC-ONES!
ALWAYS CLEAN FIBER-TIPS BEFORE EACH CONNECTION!

Key of FC-connectors:

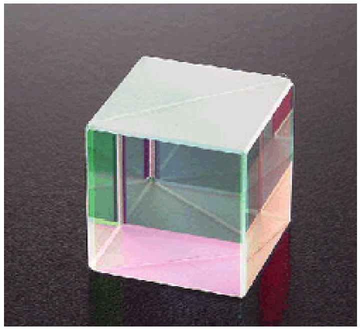


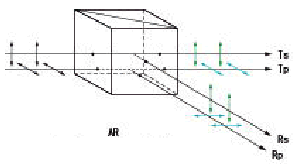
- Only Important for PM-fibers and APC-connectors
- Two different key-widths: wide: 2.13 mm → more precise angular orientation
  small: 2.02 mm
- PM-fiber: key is aligned along slow-axis

Fiber connectors

	FC/PC	ST	SC	LC	SMA
picture					
Name	Ferrule Connector	Straight Tip	Siemon Connector	Lucent Connector	Sub Miniature A
Locking mechanism	Screw-on	Bayonet	Push-pull	Push-pull	Screw-on
Ferrule	2.5 mm metal/ceramic	2.5 mm metal/ceramic	2.5 mm metal/ceramic	1.25 mm metal/ceramic	3.14 mm metal
Insertion loss MM/SM	0.15 / 0.2 dB	0.2 / 0.15 dB	0.2 / 0.2 dB	0.2 / 0.12 dB	?
Versions	MM/SM/PC/APC	MM/SM/PC/APC	MM/SM/PC/APC	MM/SM/PC/APC	MM
Rotational alignment	key	key	coded	coded	No alignment

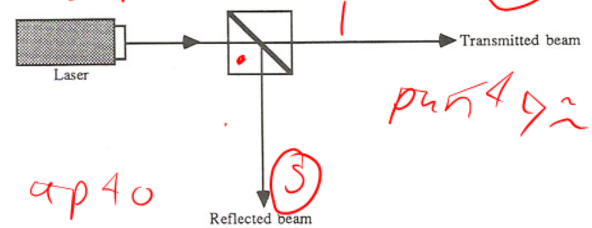
Beam Splitter

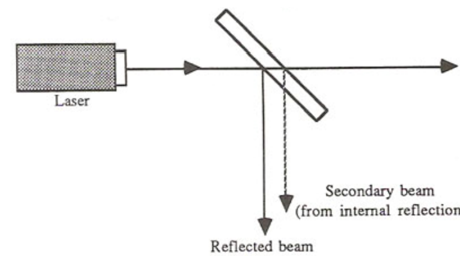




Types: - Beam splitter cubes
- Partially reflecting mirrors

Purpose: -split beams for several applications , i.e. attenuation of signal, interferometry, autocorrelation, laser systems,cameras
-combining beams
-split beams into s and p polarised light (polarising beam splitter,PBS)





only 1 side good for reflection

Principle of function: Fresnel laws of reflection on a surface

- Beam cubes: two prisms (e.g.BK7) seperated by a layer of a different refractive index (e.g. cement)
- Partially reflecting mirror: plate with a thin silver layer or dielectric mirror (alternating layers of different material)

Important features:

- Split ratio
- Angle of incidence
- Polarization dependence
- Wavelength dependence
- Antireflection coating

determined by beam splitter design and material

- Thickness and refractive index of intermediate layer (Beam cube)
- Thickness of silver layer or number of alternating layers (mirror)

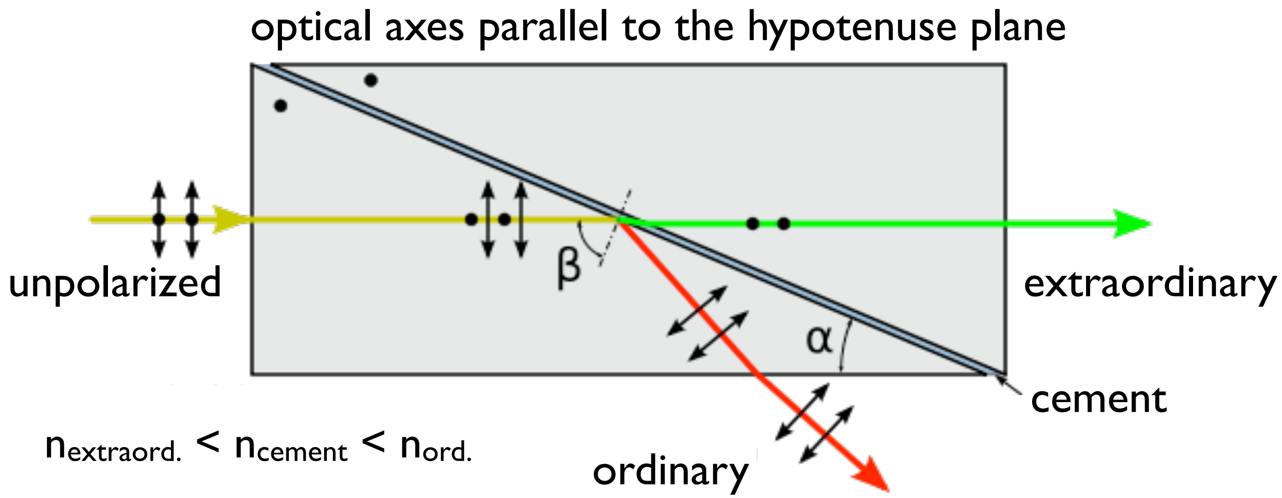
buy from Linos

good 2 kW/cm²

Thomas Uehlinger

Glan-Thompson Polarizing Prisms

- simplest form of calcite (birefringent crystal) polarizer
- versatile general purpose polarizer
- consists of two calcite prisms cemented together

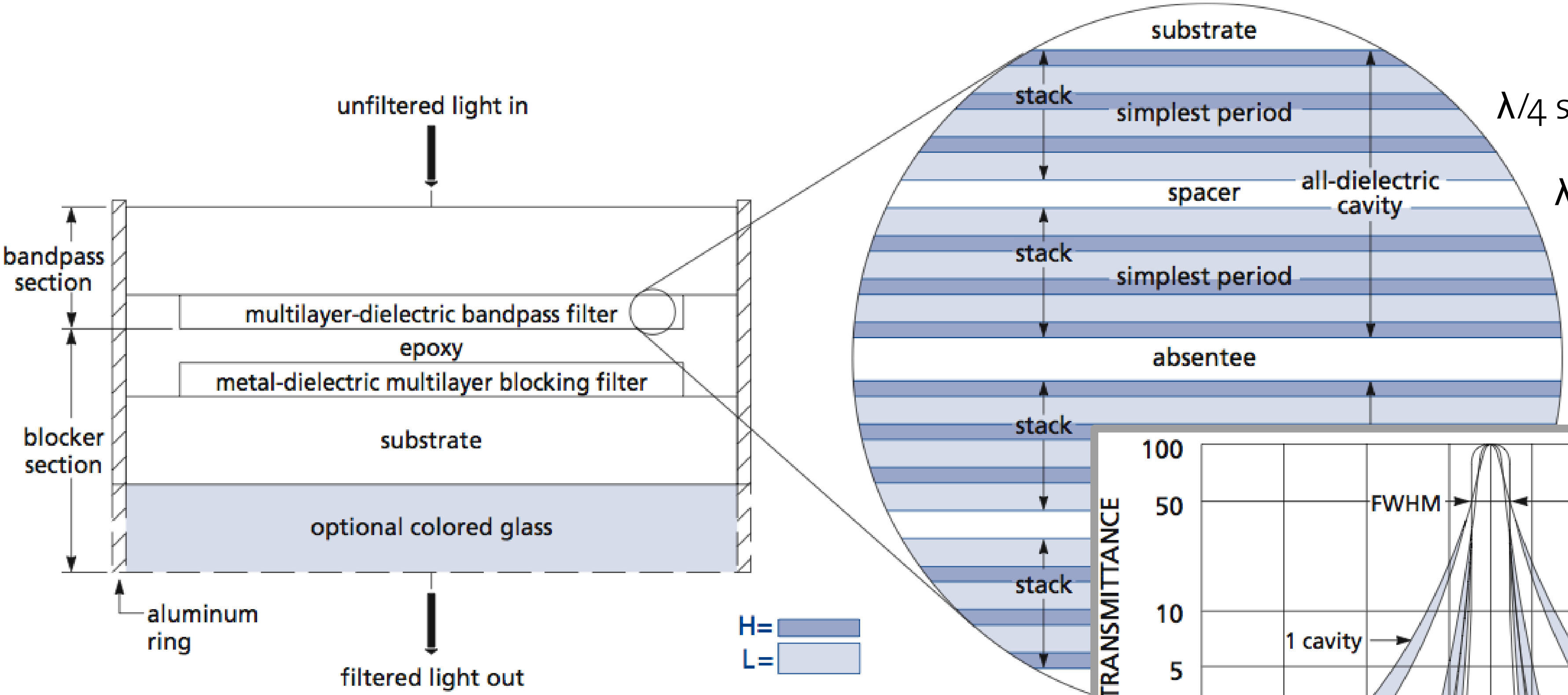


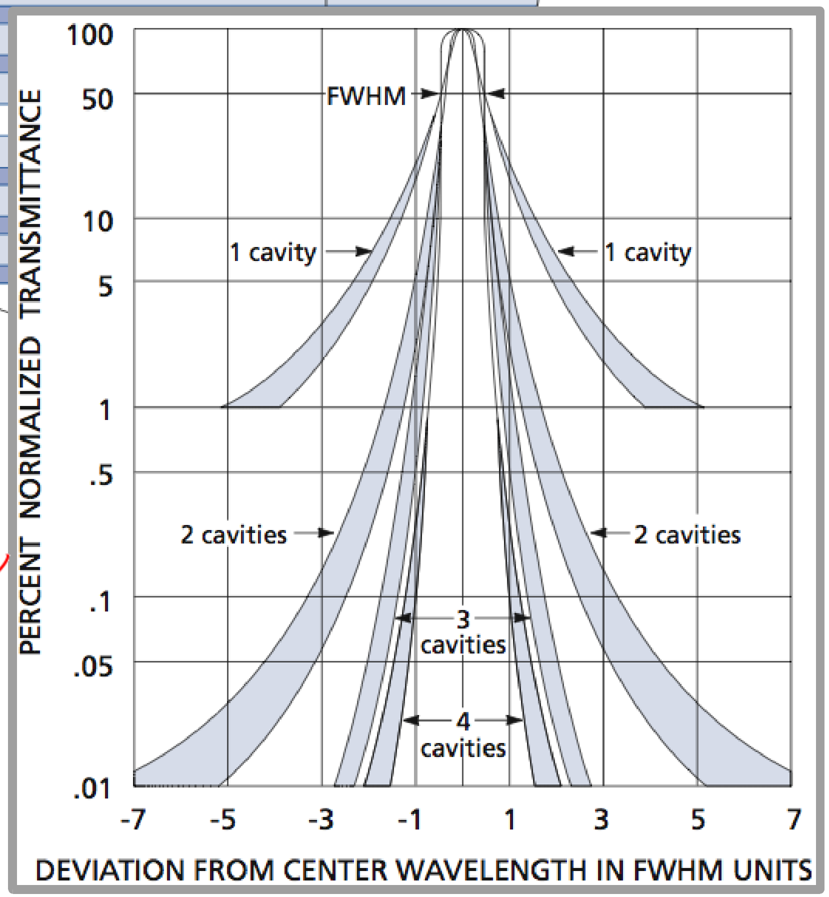
$n_{extraord.} < n_{cement} < n_{ord.}$

extinction ratio	up to about 10^{-6} for extraord. beam, ord. beam not very well polarized	cannot be used as a beam splitter
wavelength range	320 - 2300 nm	
transmittance	about 90%	
beam deviation	almost no beam deviation for extraord. beam	
maximum power level	about 1 W/cm^2 cw	only usable for low power applications because prisms are cemented together
angular field of view	about 15° (symmetrical)	

same family: Glan-Foucault prism (air-spaced → more power)
Glan-Taylor and Glan-laser (air-spaced, different orientation of optical axes → asymmetrical and smaller angular field of view, but better transmission)

Narrow optical bandpass filter

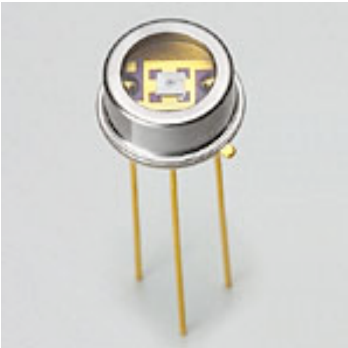




- *principle*
  - thinnest possible Fabry-Pérot cavity (FSR = c/λ)
  - additional blocking filters for longer wavelengths
- *characteristics*
  - FWHM down to ~0.5 nm

buy from Semrock

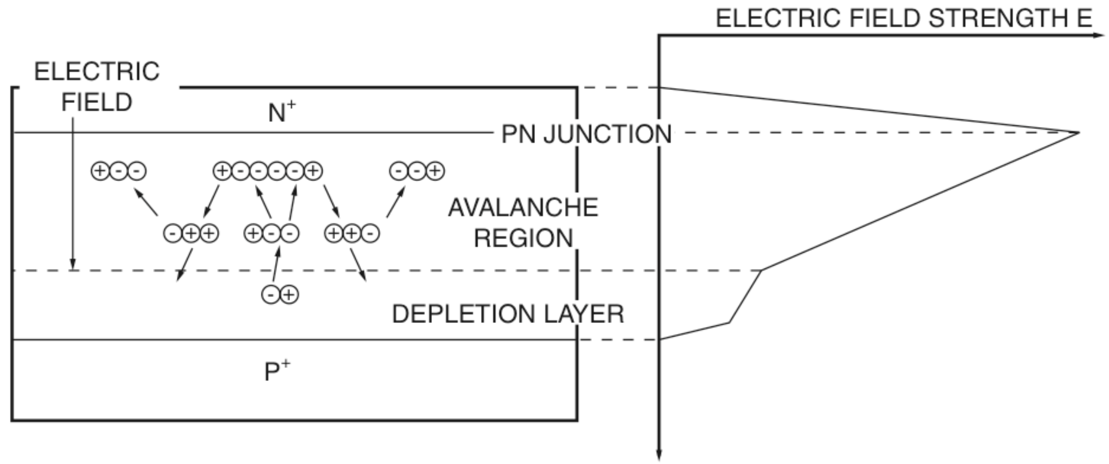
- *advantages*
  - custom pass band (center, width, steepness)
  - high damage threshold (reflective filter)
  - somewhat tunable: $\lambda_c = \lambda_0 \cos(\vartheta)$



APDs
(Avalanche Photo Diodes)

Photodiode (pn junction) devices working at reverse bias.

A photon incident creates a electron-hole pair in the depletion region



The reverse bias accelerates the created carriers enough to generate more carriers when collide with the lattice (like a chain reaction).

Used for low optical power measurements and as single photon detectors when operated at high reverse bias.

Quantum efficiency up to 80% timing accuracies below 200 ps.

limit light power, otherwise destroyed.