First ICO/ICTP/TWAS Central American Workshop in Lasers, Laser Applications and Laser Safety Regulations

Optical spectroscopy: fundamentals and applications

Module: Laser and LED applications

Lecture 2, May 9, 2012 (2:00 PM – 3:00 PM)

Carlos Rudamas, PhD
Escuela de Física, Facultad de Ciencias Naturales y Matemática
Universidad de El Salvador

e-mail: carlos.rudamas@gmail.com//carlos.rudamas@ues.edu.sv

Content

This lecture will be divided in the following parts:

1) **Fundamentals of optical spectrocopy (Lecture1 and 2)**

2) **Light sources (Lecture 2)** (e. g. frequency spectrum, linewidths, and tuning ranges)

3) **Optical components(Lecture 2)** (e.g. mirrors, prisms and gratings)

4) **Spectroscopy equipment (Lecture 3)**(e.g. spectrographs, monochromators, detectors)

5) **Applications [Lecture 3]**(physics, geophysics, biology, medicine and environmental sciences)

Widths and profiles of spectral lines

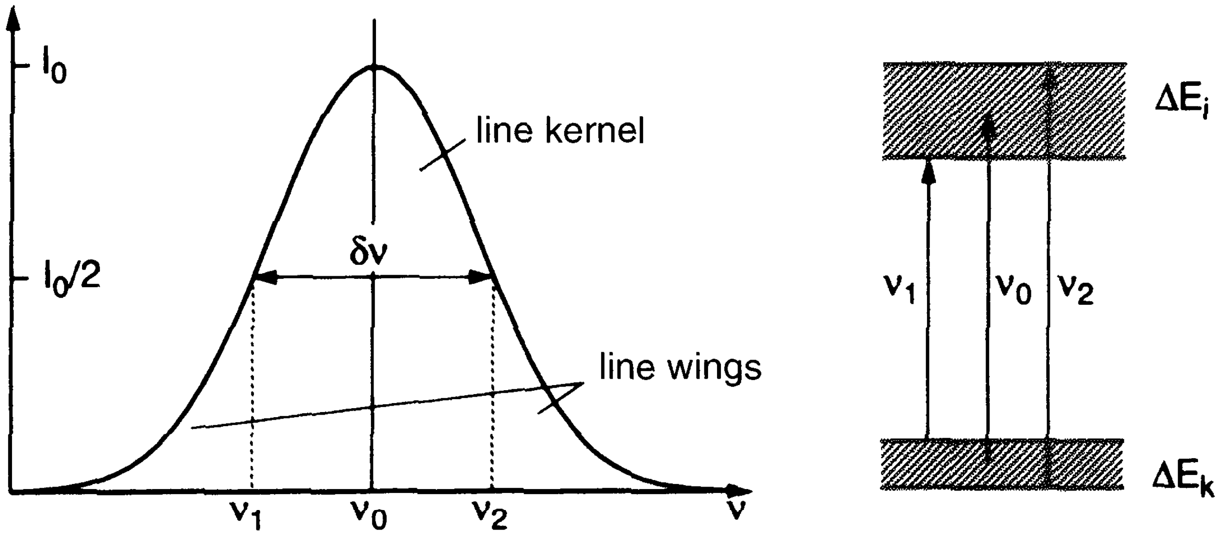
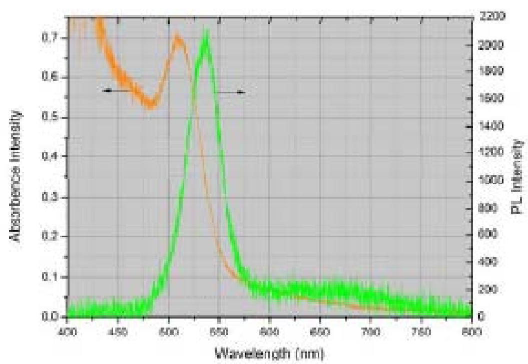


Fig. 3.1. Line profile, halfwidth, kernel, and wings of a spectral line

Demtröder 2003



M. Pacheco et al., 2011

Widths and profiles of spectral lines

Natural linewidth (Lorentzian profile)

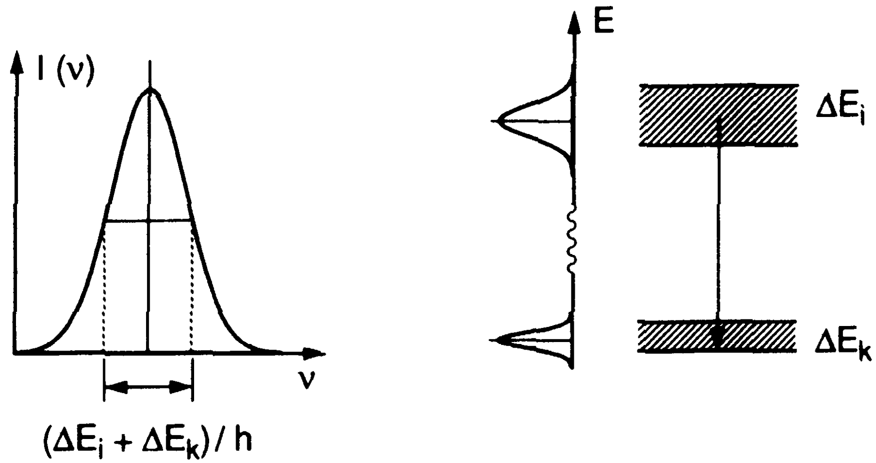
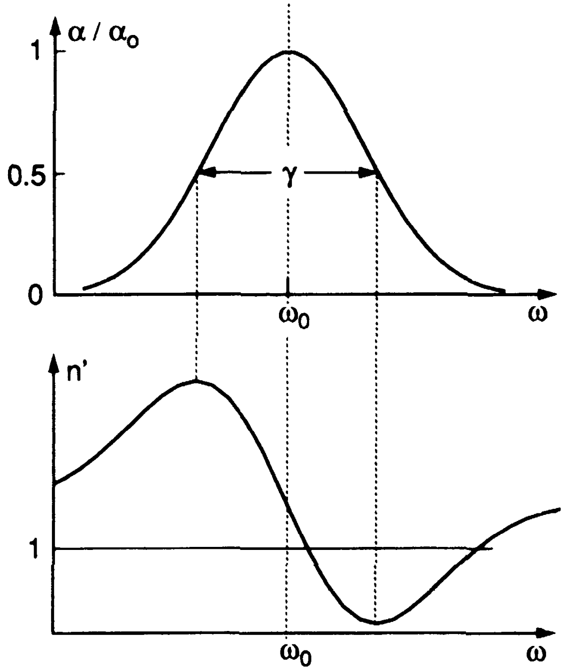


Fig. 3.3. Illustration of the uncertainty principle, which relates the natural linewidth to the energy uncertainties of the upper and lower levels

$$\delta\omega = \Delta E_i/\hbar = 1/\tau_i$$

Demtröder 2003

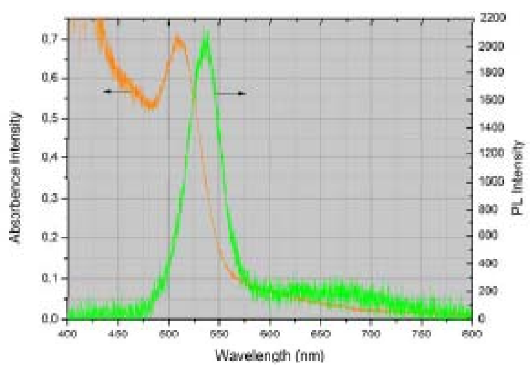
Fundamentals of optical spectroscopy

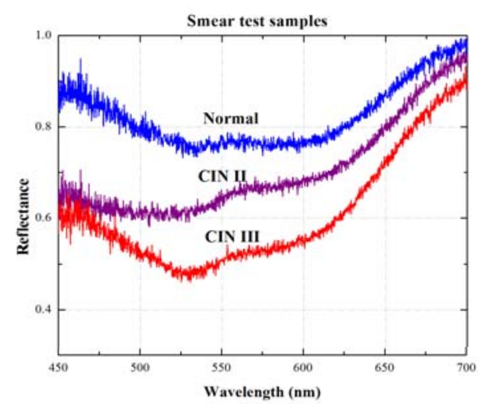


Absorption profile (from the Kramers-Kronig dispersion relations) in the neighborhood of a molecular transition:

Demtröder 2003

Fig. 3.5. Absorption coefficient $\alpha = 2k\kappa(\omega)$ and dispersion $n'(\omega)$ in the vicinity of an atomic transition with center frequency ω_0





M. Pacheco et al., 2011

Y. Fernández et al., 2012

Widths and profiles of spectral lines

Doppler linewidth

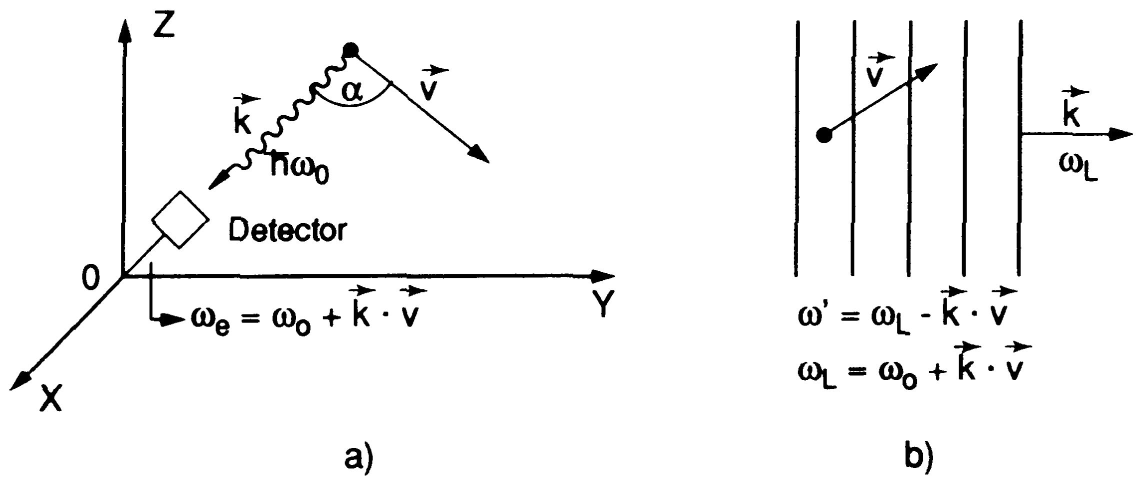


Fig. 3.6. (**a**) Doppler shift of a monochromatic emission line and (**b**) absorption line

Demtröder 2003

Typical Doppler linewidth: 10^{-3} nm (Gaussian profile)
It is two orders of magnitude higher than the natural linewidth

There exist also a collisional broadening. This is a few higher (~ factor 3) than the Doppler width

Fundamentals of optical spectroscopy

Widths and profiles of spectral lines

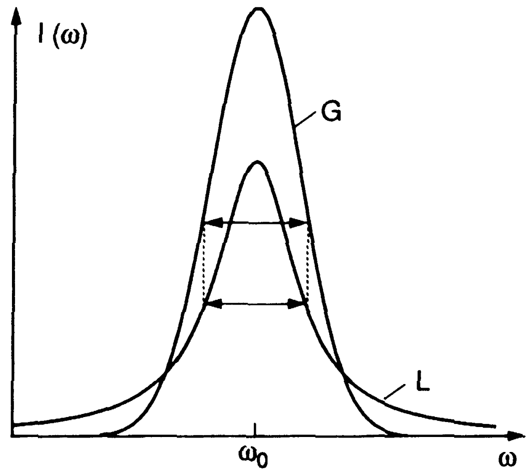


Fig. 3.7. Comparison between Lorentzian (L) and Gaussian (G) line profiles of equal halfwidths

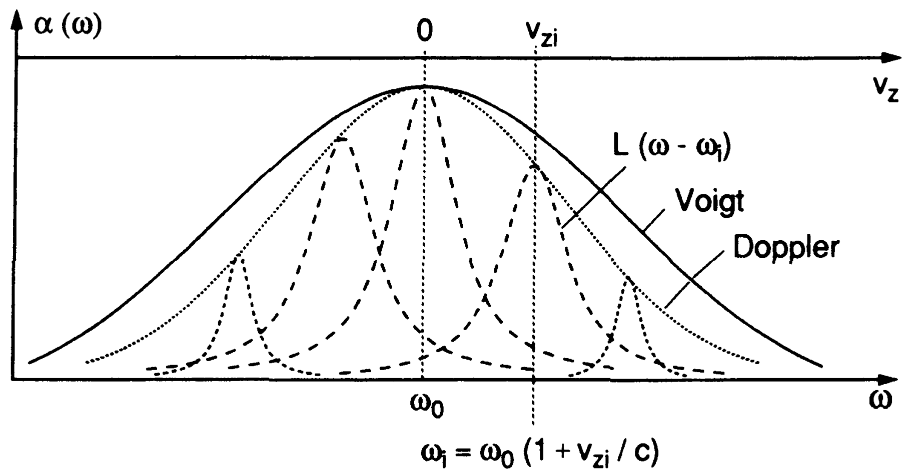


Fig. 3.9. Voigt profile as a convolution of Lorentzian line shapes $L(\omega_0 - \omega_i)$ with $\omega_i = \omega_0(1 + v_{zi}/c)$

Demtröder 2003

Widths and profiles of spectral lines

Collisional broadening

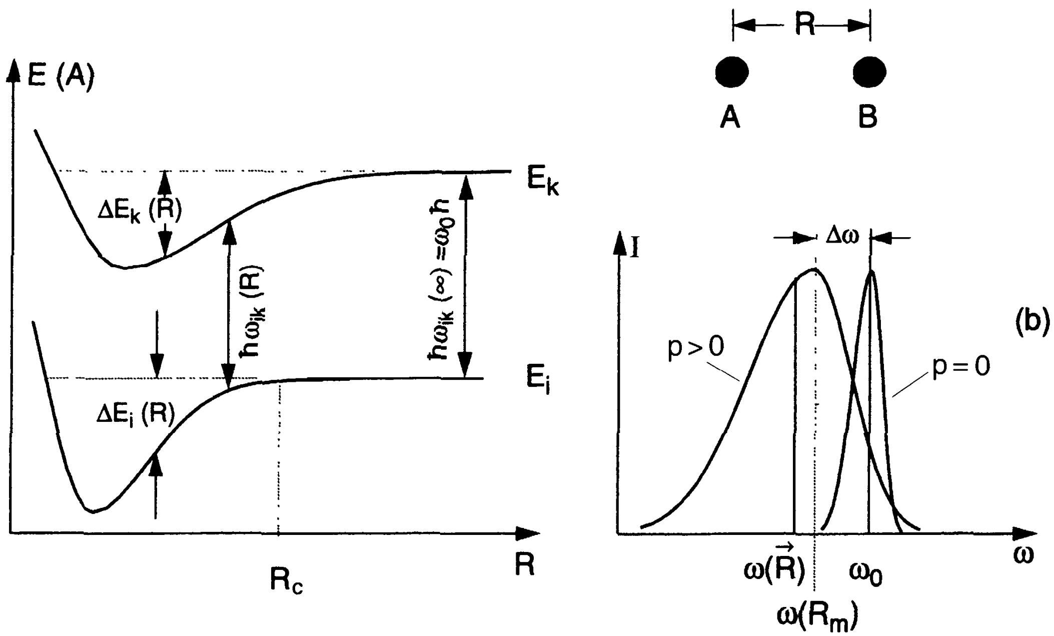


Fig. 3.10. Illustration of collisional line broadening explained with the potential curves of the collision pair AB

Demtröder 2003

There exist also a collisional broadening. This is a few higher (~ factor 3) than the Doppler width

Fundamentals of optical spectroscopy

What kind of information can we obtain from the spectral line profile:

- **Energy states (from the maxima of the bands)**
- **Allowed transitions between states (Intensity of the lines)**
- **Lifetime of excited states**
- **Velocity distribution of absorbing or emitting molecules**
- **Information about collision processes or interatomic potentials**
- **Structural properties of samples**
- **Size of nanostructures**
- **Optical quality of samples**
- **etc., etc.**

What do we need then in order to perform optical spectroscopy?:

- **Light sources** (lamps, lasers),
- **Optical components** (filters, lenses, prisms, gratings),
- **Spectroscopy equipment** (spectrographs, monochromators, detectors)
- **Samples** (Liquids, solids or gases)

Light sources

To be suitable for optical spectroscopy applications light sources must fulfill several important requirements:

- **Frequency spectrum,**
- **Linewidth,**
- **Tuning range,**
- **Minimal spectral intensity variation** ($I_o(\lambda)$=Const.),
- **Long lifetime** (for long-term applications)
- **Low cost** (for long-term applications)

Light sources

Type of lamp	Brightness	Typical input power W	Spectral range nm	Typical lifetime hours
High pressure Xe-Arc	High	75 to several 1000	<200–3000	200–2000
D-Arc	Medium	25	180–300	
Incandescent lamps	Low	10–500	300–3000	50–1000 depending on voltage
(Broadband) laser	Very high		<0.3 nm in a 200–3000 nm, interval	Dependent on type
Light emitting diodes (LED)	Low-medium	0.05–4.0	350[a] to several µm, certain wavelengths	>10000–100000

[a]Rapid technological advances towards lower wavelengths LEDs are being made.

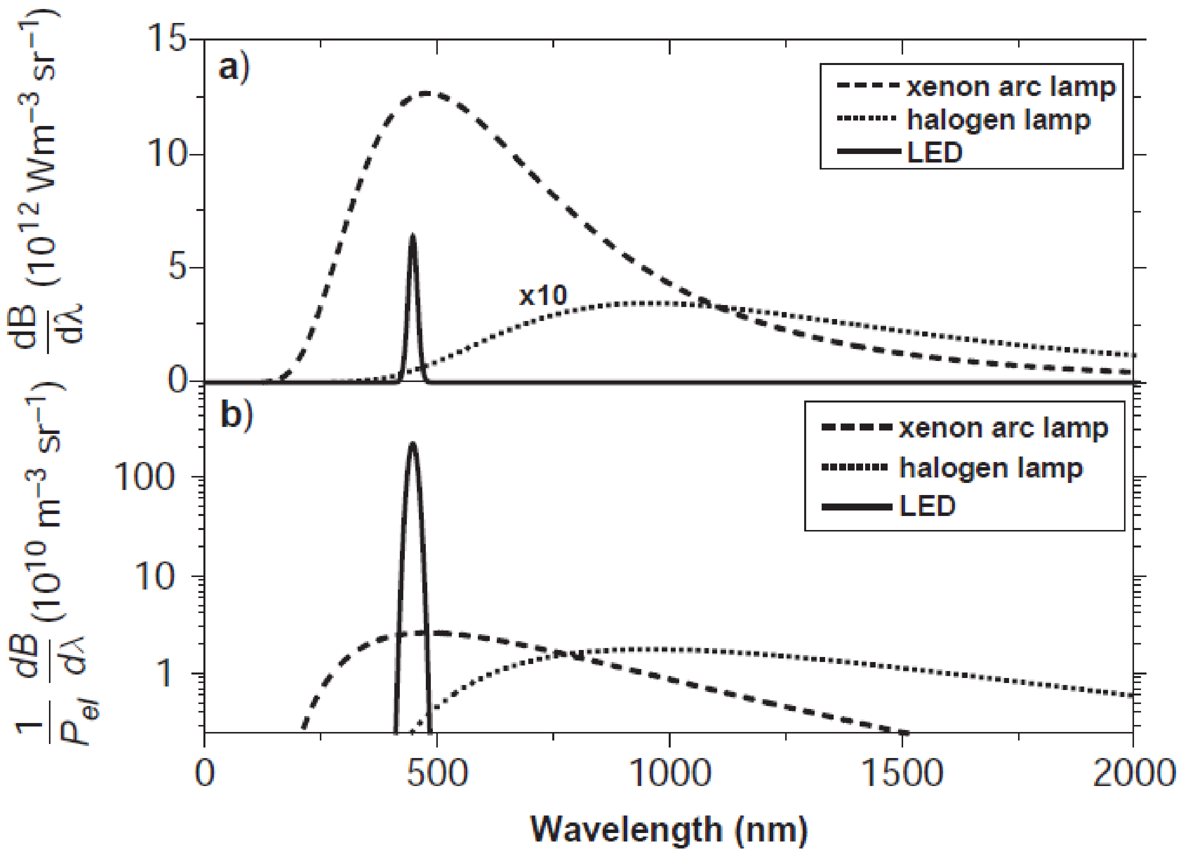
Platt and Stutz, 2008

Light sources

Incandescent lamps:

These type of lamps are very cheap and very easy to operate

Spectral intensity distribution

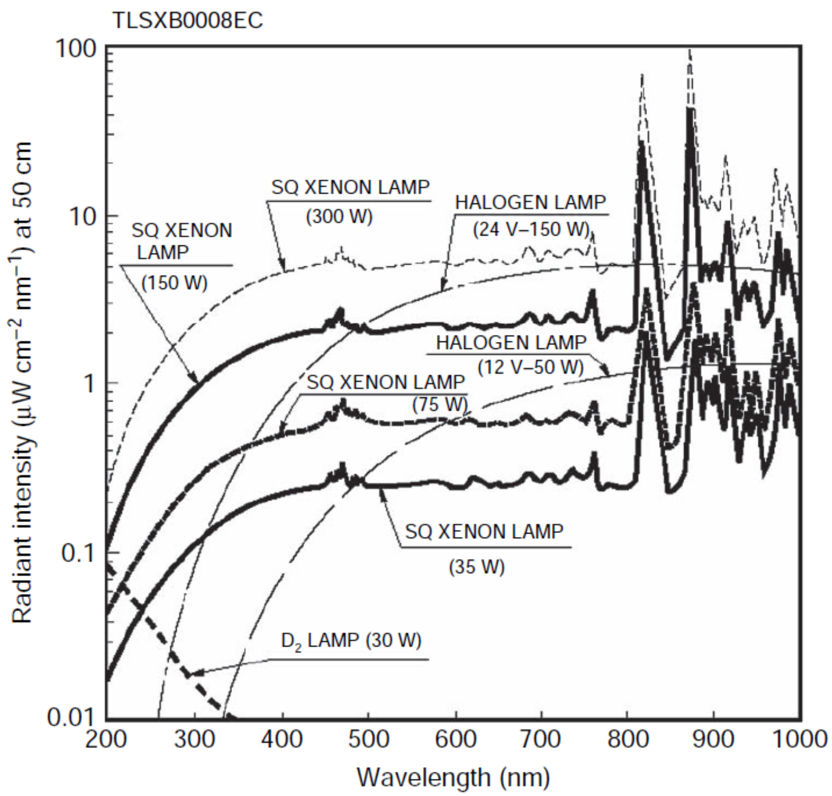


Platt and Stutz, 2008

Light sources

Arc lamps (Xenon and Deuterium):

These type of lamps (Xe) have much larger brightness than incandescent lamps. With Deuterium lamps we obtain good UV intensity.



Platt and Stutz, 2008

Light sources

LEDs: They generally emit a smoth spectrum with an emission band around [10 nm - 60 nm]. The problem could be the intensity.

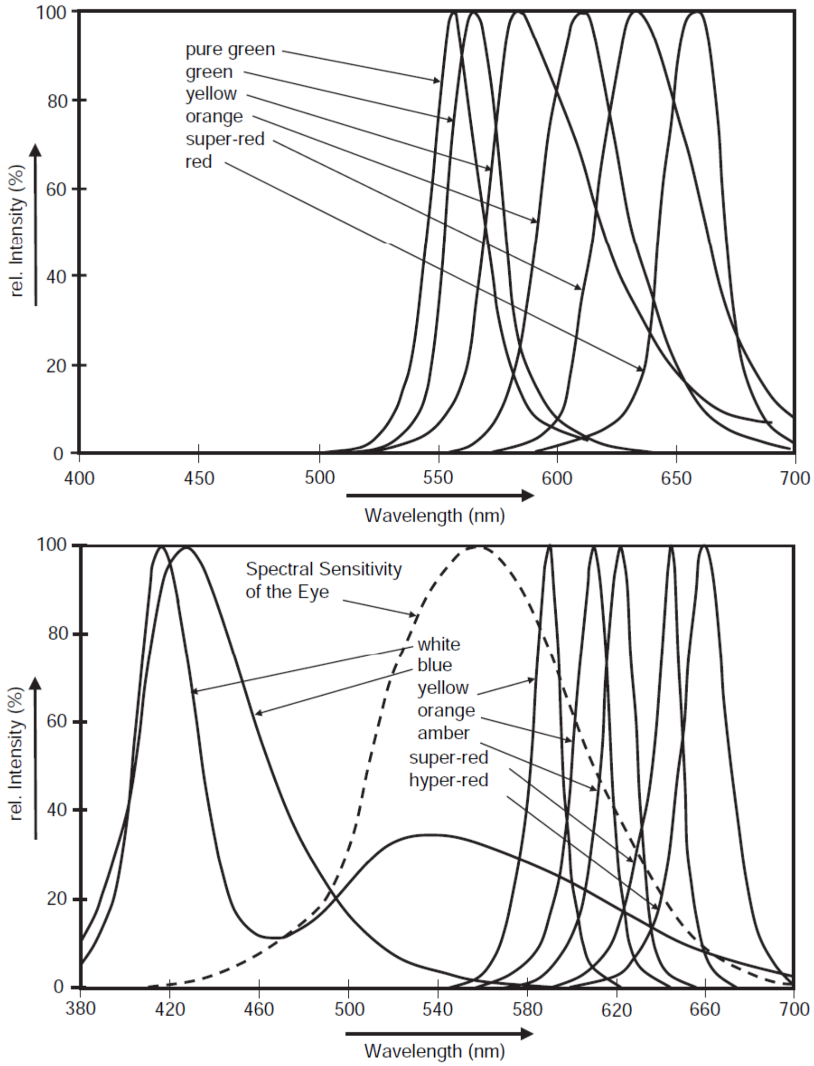


Fig. 7.9. Spectral intensity distribution of a series of LEDs. **Upper panel**: Standard LEDs. **Lower panel**: High brightness GaN LEDs. The dashed line indicates the eye sensitivity

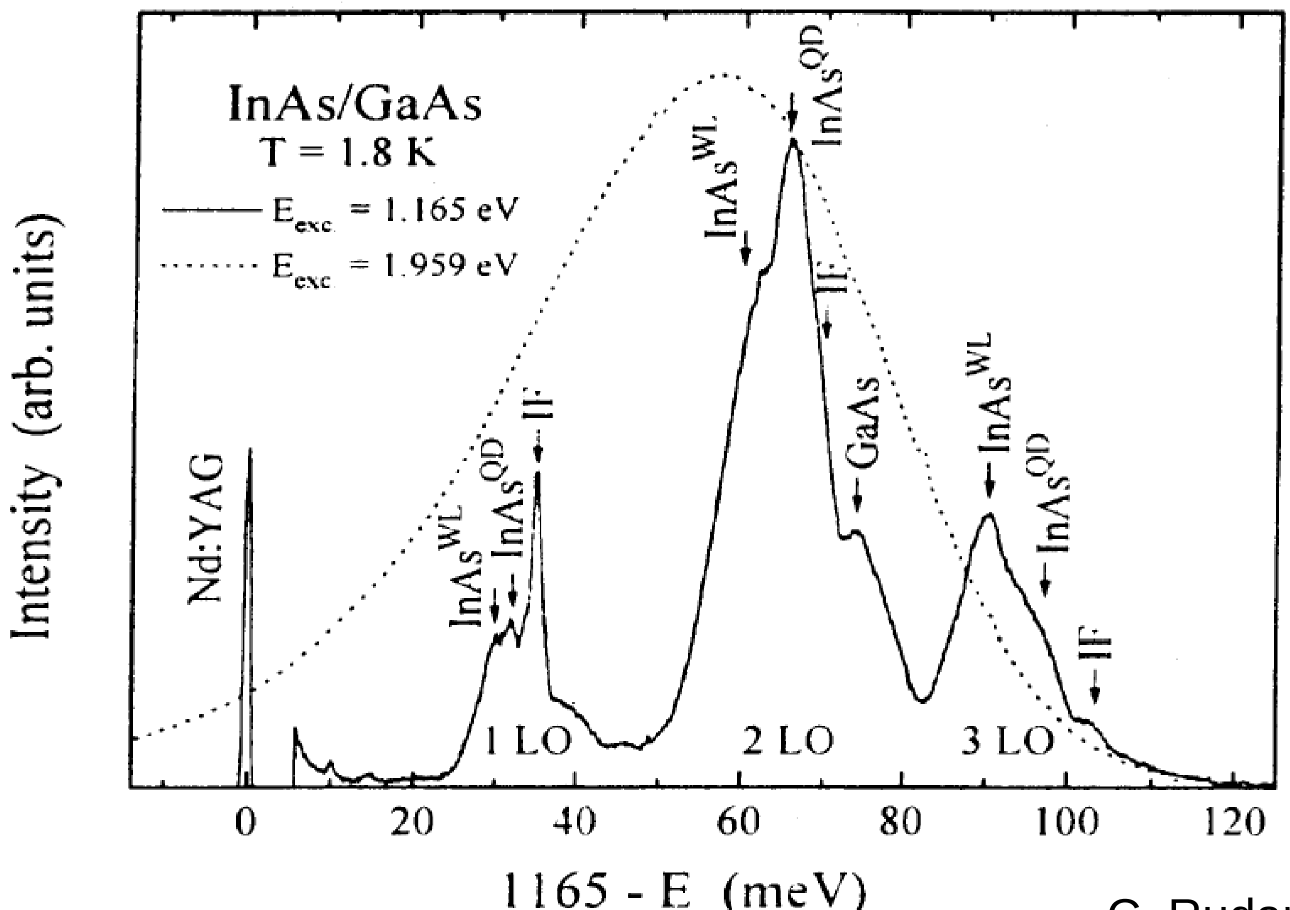
Platt and Stutz, 2008

Light sources

Lasers:

- Give a lower beam divergence and higher spectral intensity.
- The spectral line width of a CW-laser is lower.
- For pulsed lasers the linewidth could be around 60 nm
- There exist also tuneable lasers.
- There exist a possibility to generate a white light continuum with pulsed lasers.

Comparison between the linewidth of a laser and emission bands in quantum semiconductor structures:



C. Rudamas, 2002

Tuneable lasers:

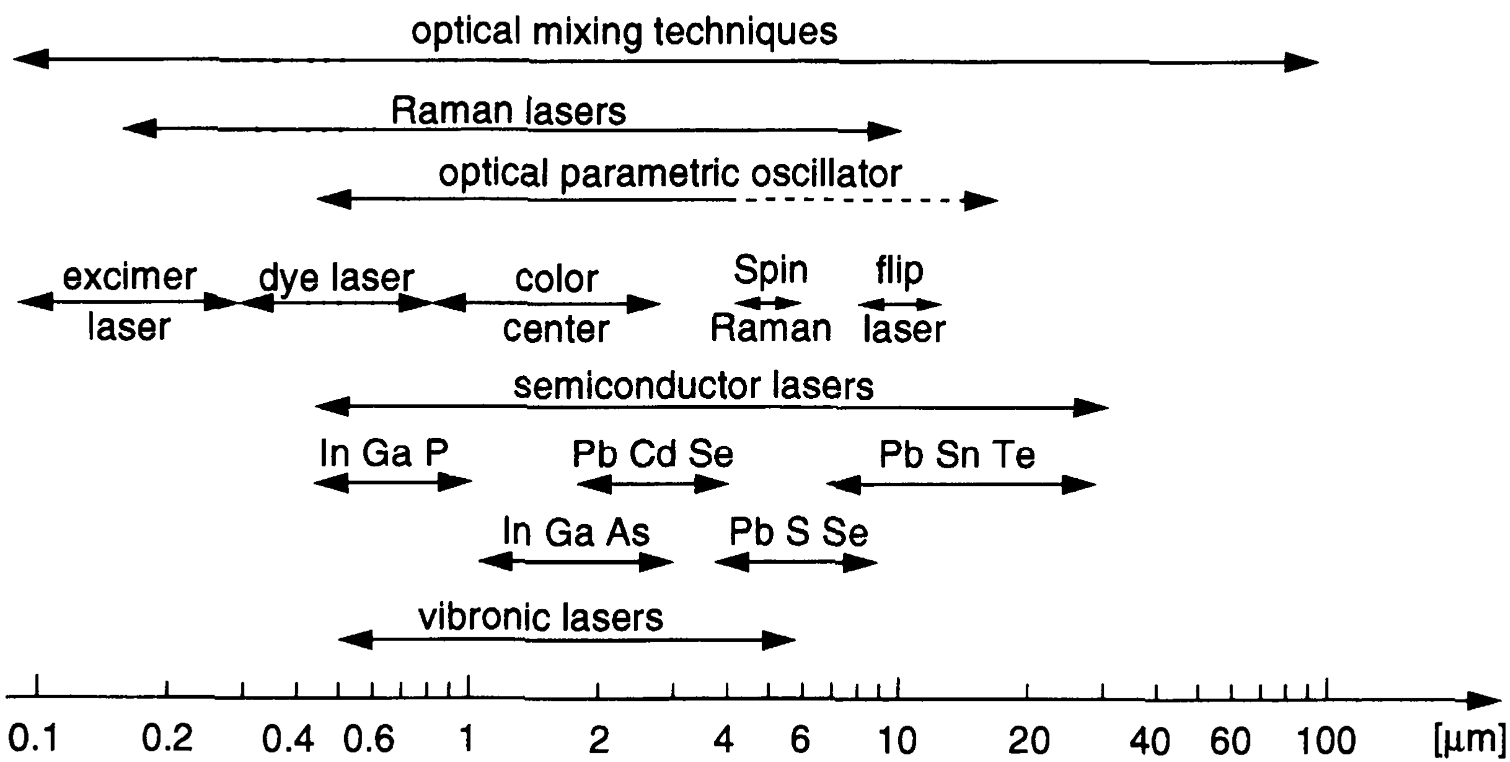


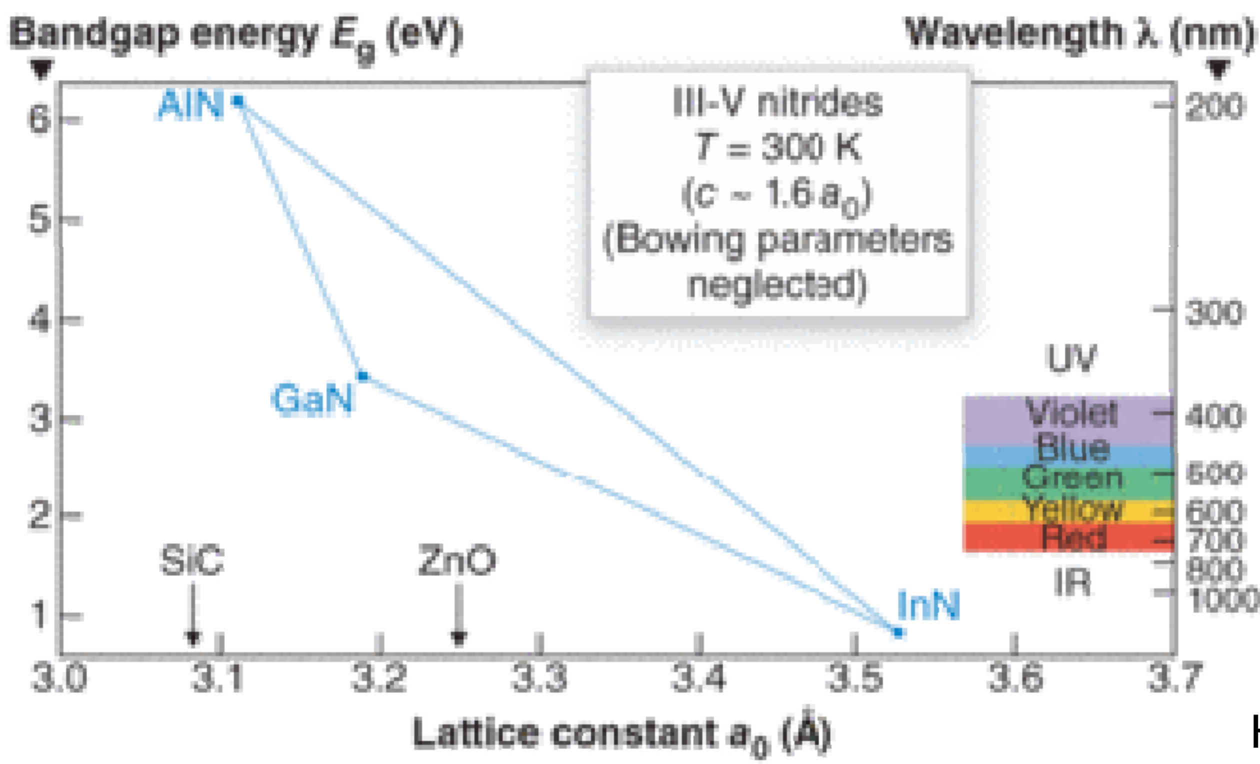
Fig. 5.62. Spectral ranges of different tunable coherent sources

Demtröder 2003

Light sources

Why we do not have UV diode lasers?

Bandgaps of binary nitride semiconductors		
Nitride Compound	**Bandgap energy (eV)**	**Bandgap wavelength (nm)**
InN	0.7	1770
GaN	3.4	362
AlN	6.2	200



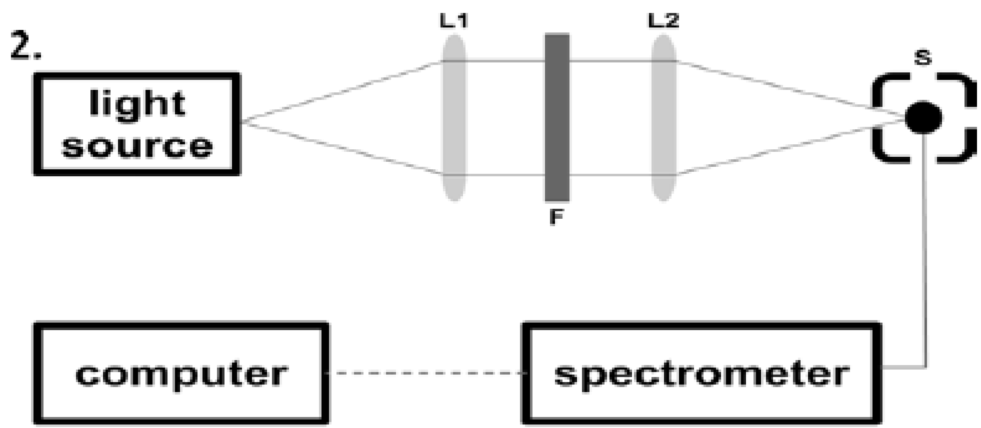
Hecht, 2008

Optical components

Fundamentals of optical components:

•**Spectroscopy need optical components to transfer the radiation energy from one component to the next in a efficient way!!!**

• **Incident radiation on a surface is absorbed, reflected, or transmitted.**

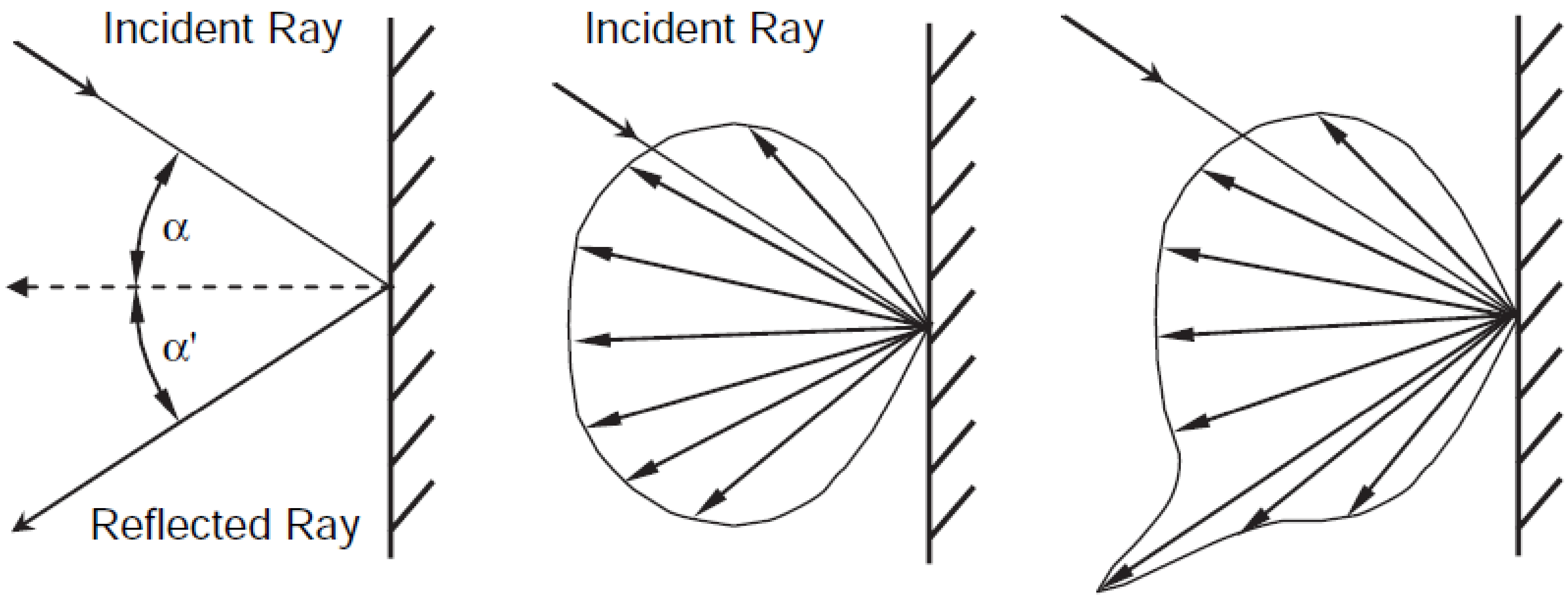


E. Adverdi et al., 2012

Optical components

Fundamentals of optical components:

The reflection from a flat surface could be specular (from a mirror like surface) or diffuse (from a matte-finish surface)

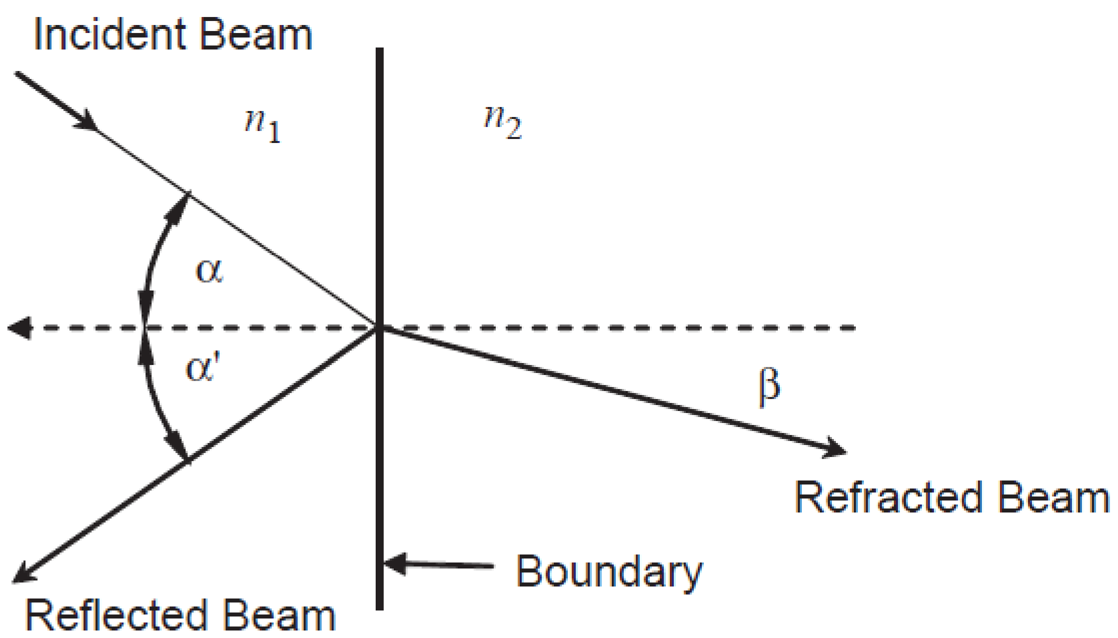


Platt and Stutz, 2008

Optical components

Fundamentals of optical components:

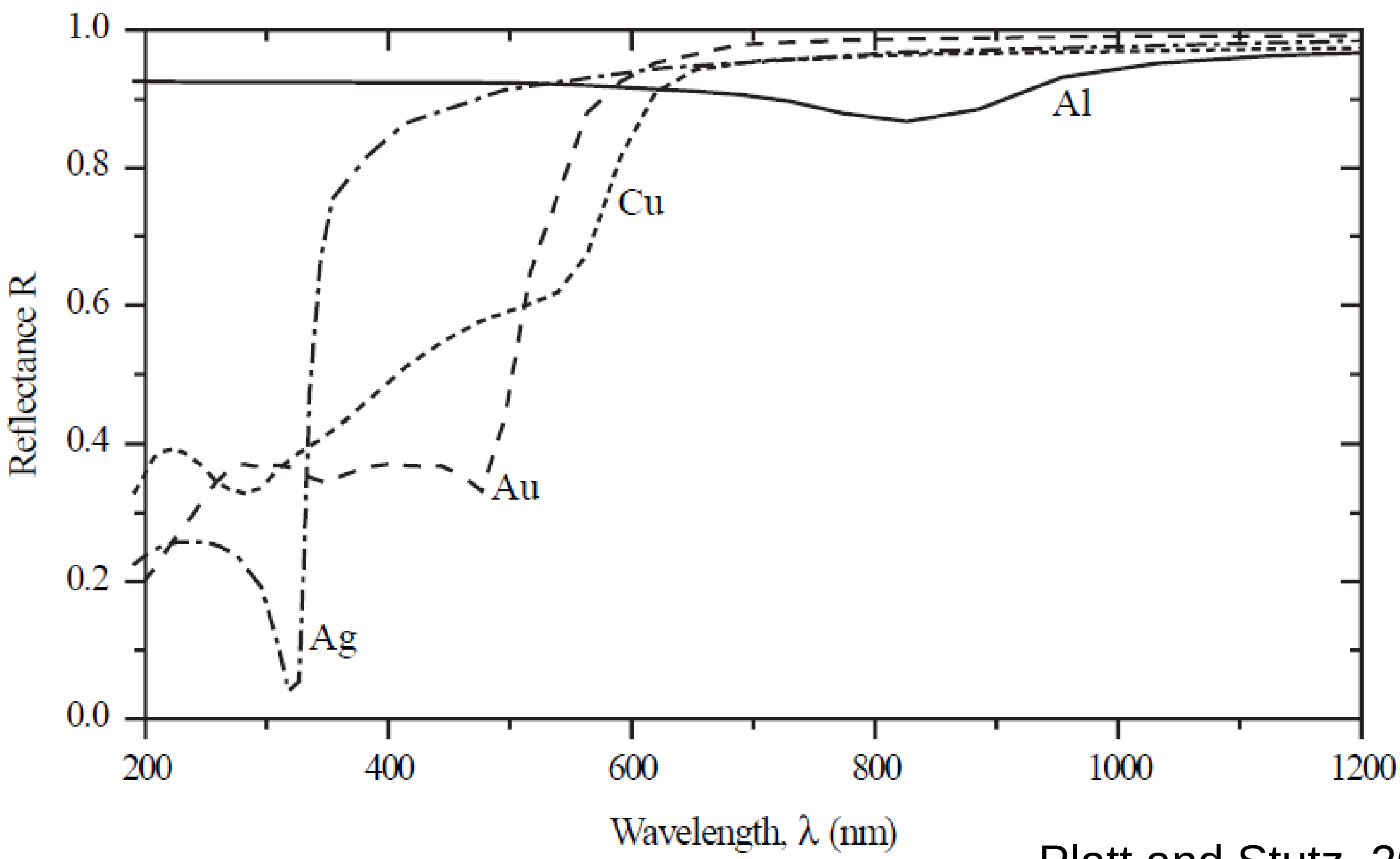
Incident radiation on transparent surfaces is partially reflected and refracted!



Platt and Stutz, 2008

Optical components

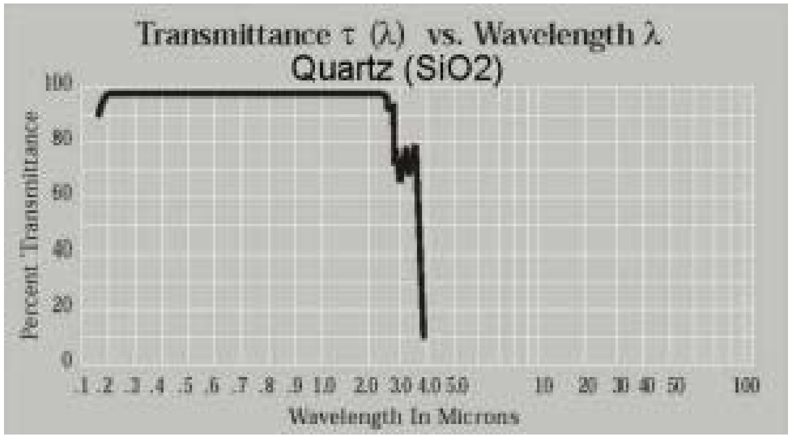
Fundamentals of optical components:

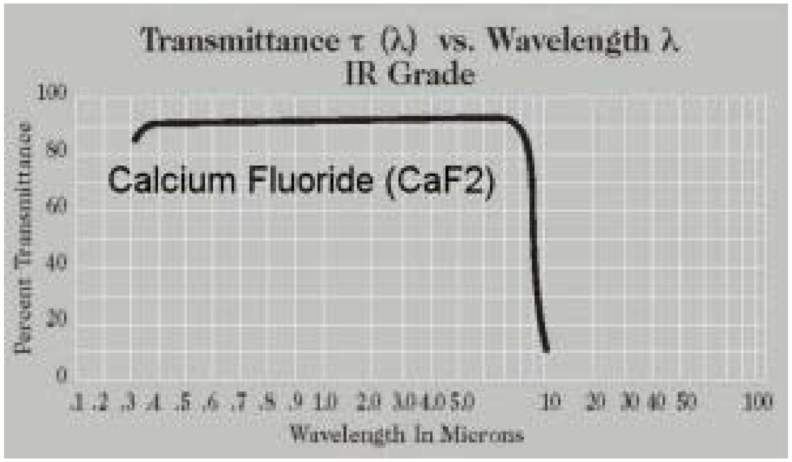


Platt and Stutz, 2008

Optical components

Fundamentals of optical components:

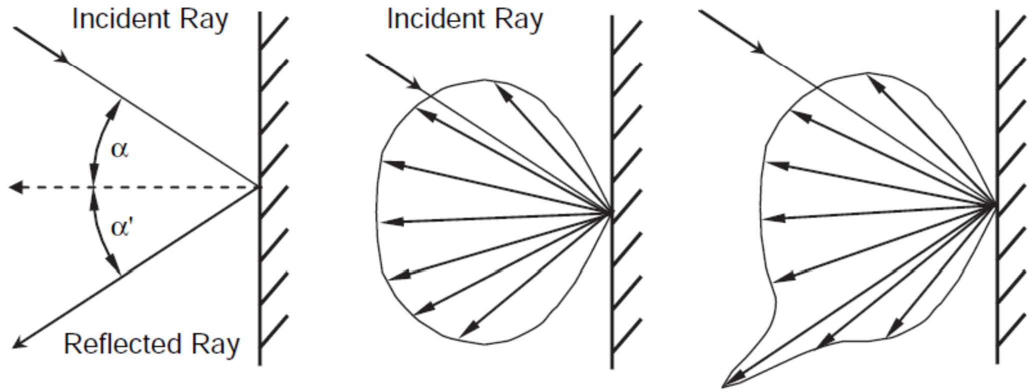




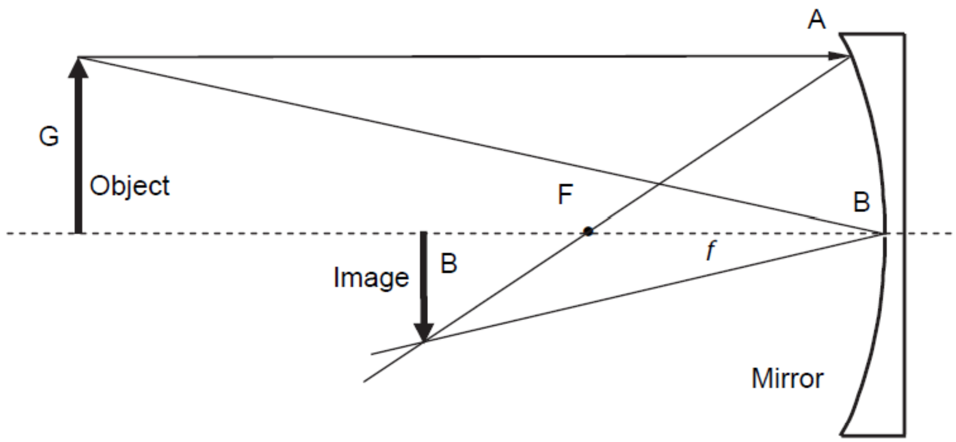
Optical components

Mirrors

Plane mirror:



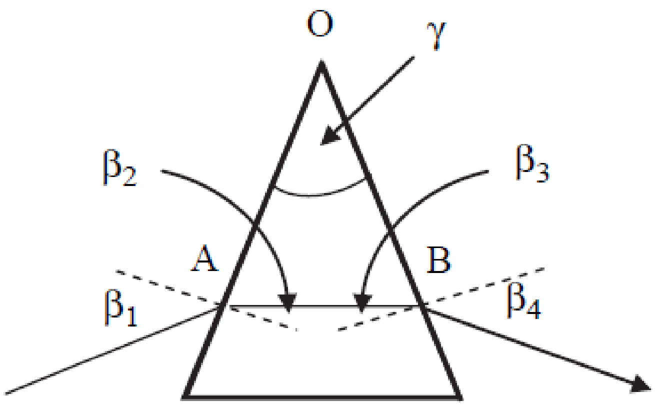
Spherical mirror:



Platt and Stutz, 2008

Optical components

Prisms and gratings



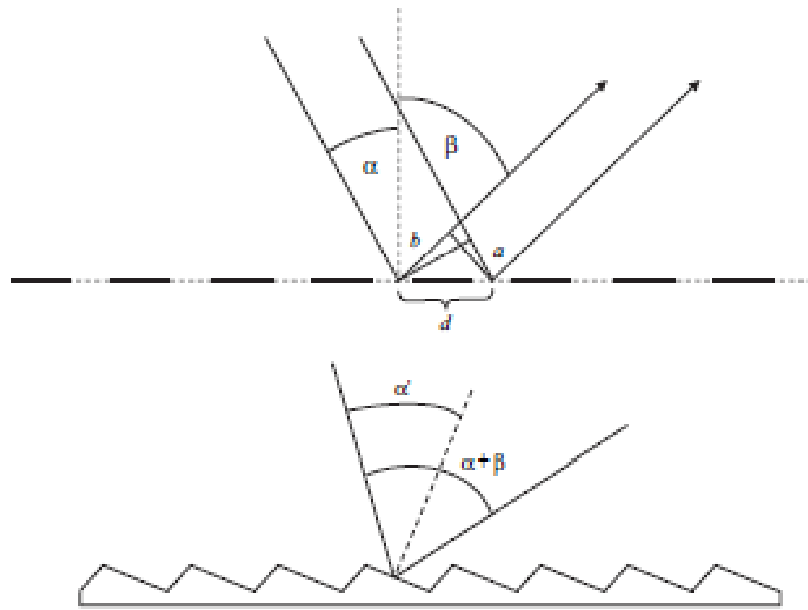
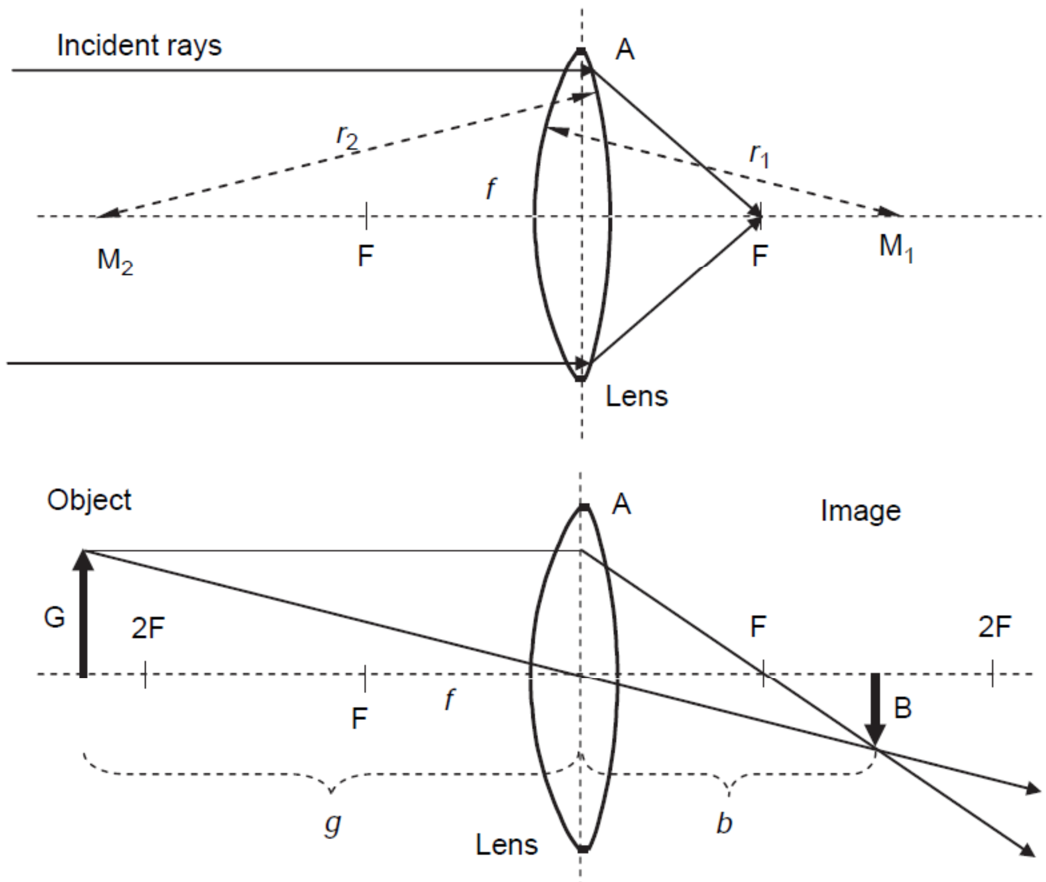


Fig. 7.28. Reflective diffraction grating. **Upper panel**: The optical path differences for the incident ray are $a = d \cdot \sin\alpha$, for the exiting ray $b = d \cdot \sin\beta$. The total path difference is $a + b$. **Lower panel**: The blaze angle of a grating is defined as the angle $\alpha + \beta$ where the refracted beam has the same direction as a specular reflected beam would have

Platt and Stutz, 2008

Lenses



Platt and Stutz, 2008

Optical components

Filters

Filters are usually required for several purposes:

- **Blocking unwanted spectral orders and lines**

- **Reducing the amount of stray light**

Filters can either be:

•**Colour glasses**

•**Thin film partially reflecting filters,**

•**Thin-film interference filters**

Optical components

Filtros de color

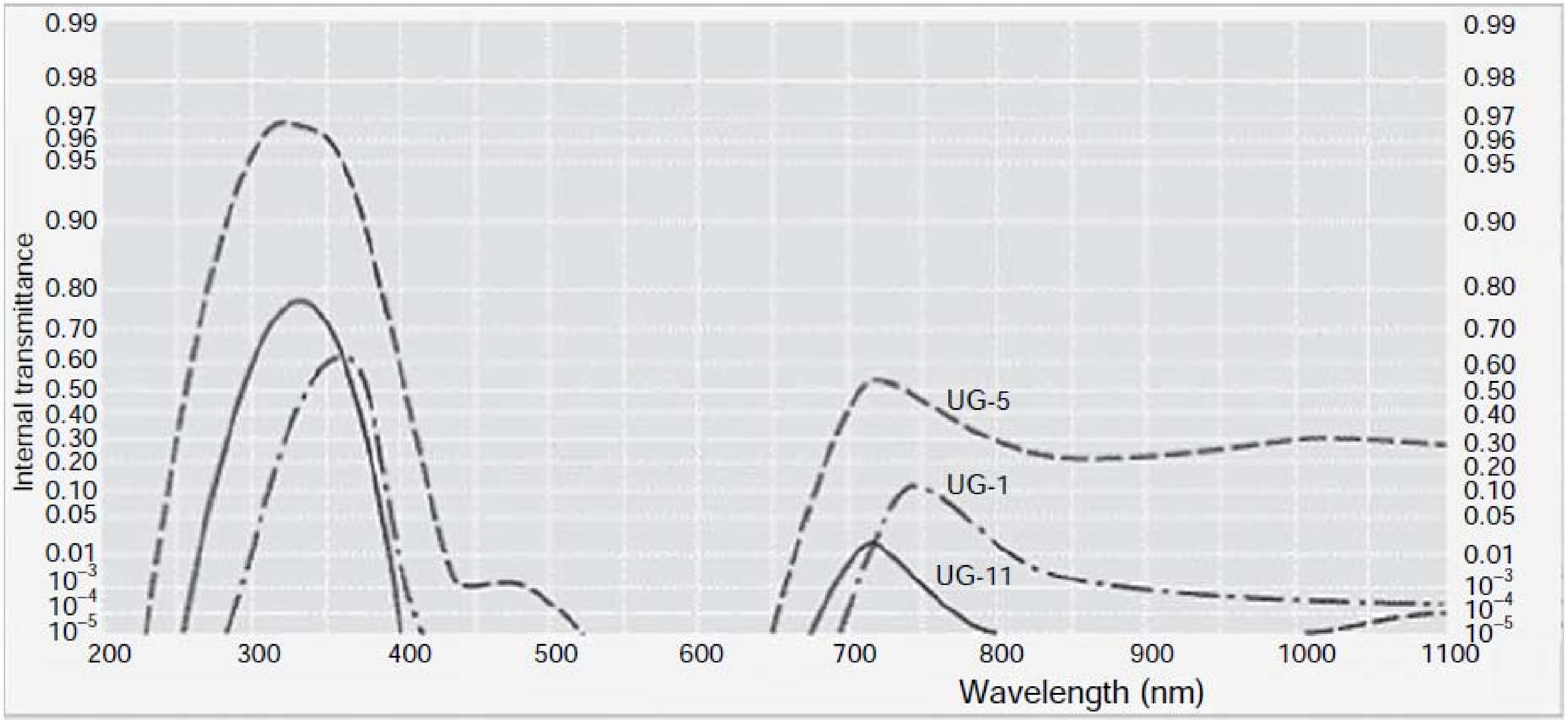
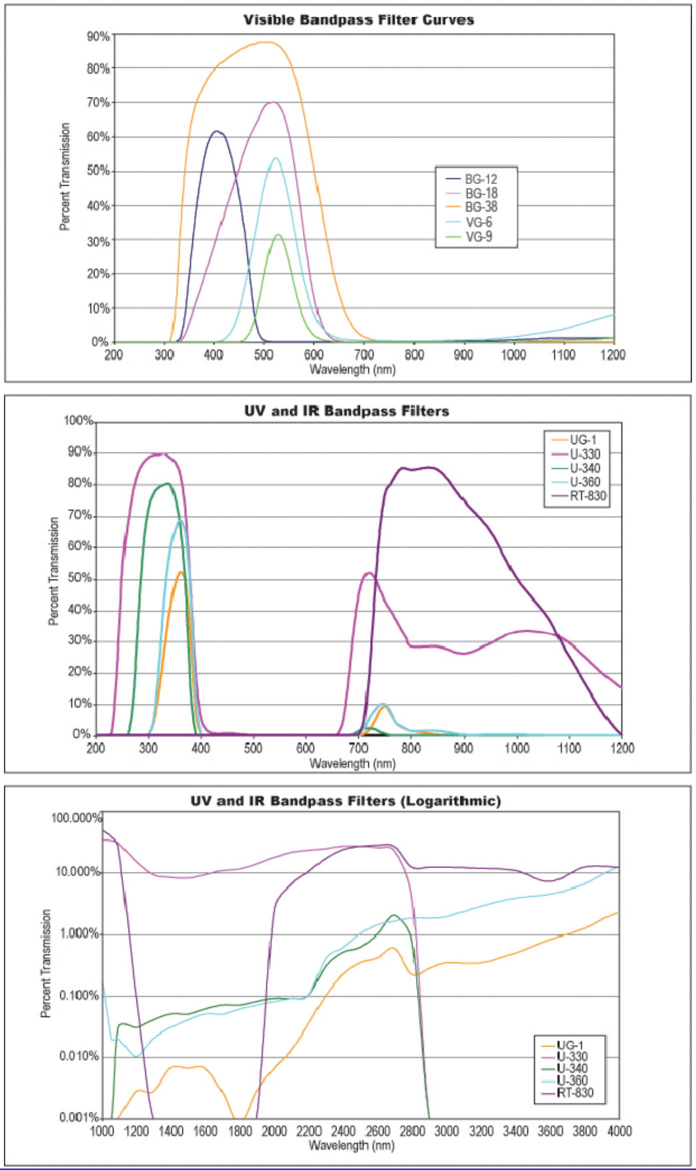


Fig. 7.25. Sample transmission curve of colour glass filters (UG-1, UG-5, UG-11 from Schott, Mainz, 2 mm thickness). These filters are used to reduce spectrometer stray light in DOAS applications. Note that the second transmission maximum in the red/near-IR region is where the sensitivity of silicon detectors usually reaches its maximum (figure courtesy of Schott)

Platt and Stutz, 2008

Optical components



Filtros de color

- UG:	Black and blue glasses, UV transmitting
- BG:	Blue, blue-green, and multi-band glasses
- VG:	Green glass
- GG:	Nearly colorless to yellow glasses, IR transmitting
- OG:	Orange glasses, IR transmitting
- RG:	Red and black glasses, IR transmitting
- NG:	Neutral density glasses with uniform attenuation in the visible range
- N-WG:	Colorless glasses with different cutoffs in the UV, transmitting in the visible range and the IR
- KG:	Virtually colorless glasses with high transmission in the visible and effective absorption in the IR (heat protection filters)

Edmund optics website

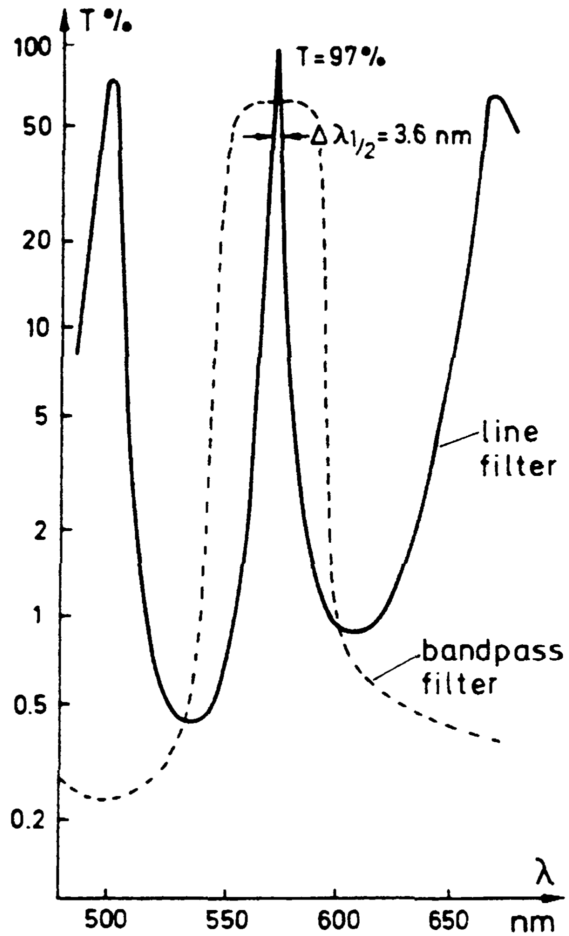
Optical components

There exist also:

- **High and low pass filters**
- **Neutral density filters**

Optical components

Interference filters



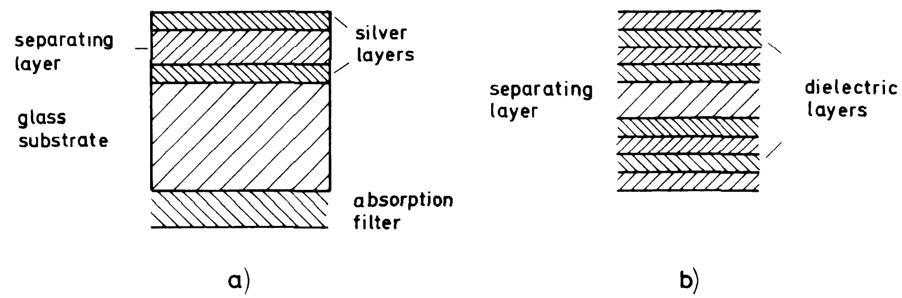


Fig. 4.56a,b. Interference filters of the Fabry–Perot type: (**a**) with two single layers of silver; (**b**) with dielectric multilayer coatings

Fig. 4.57. Spectral transmission of interference filters. *Solid curve*: line filter. *Dashed curve*: bandpass filter

Demtröder 2003

Thank you