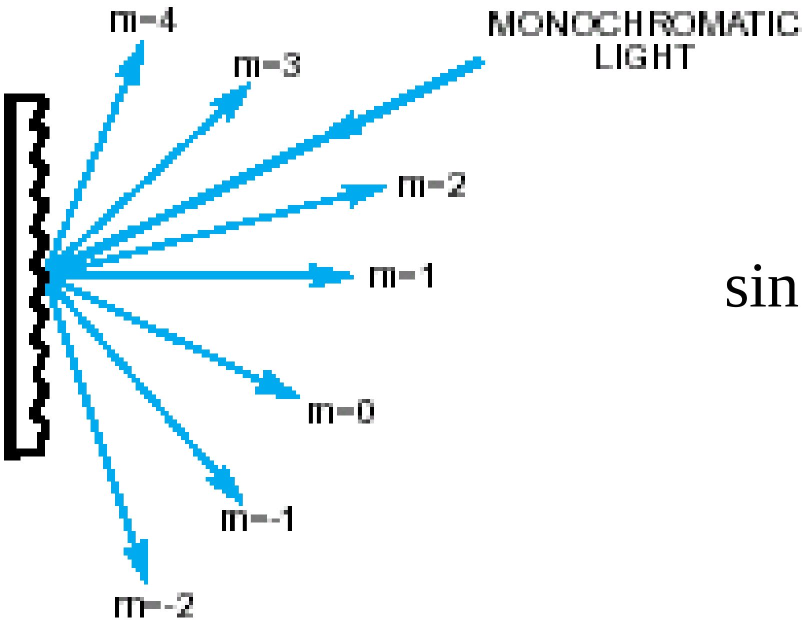
Spectroscopy

- Diffraction gratings
- Resolution
- Throughput
- Interferometers
- Filters

Terminology

- Spectrometers measure wavelengths, monochromators separate wavelengths
  - Scanning grating
  - Fixed grating with linear array
  - Fixed grating with area array
- Laser spectroscopy: tunable laser as monochromator
- Interferometers
- Filters

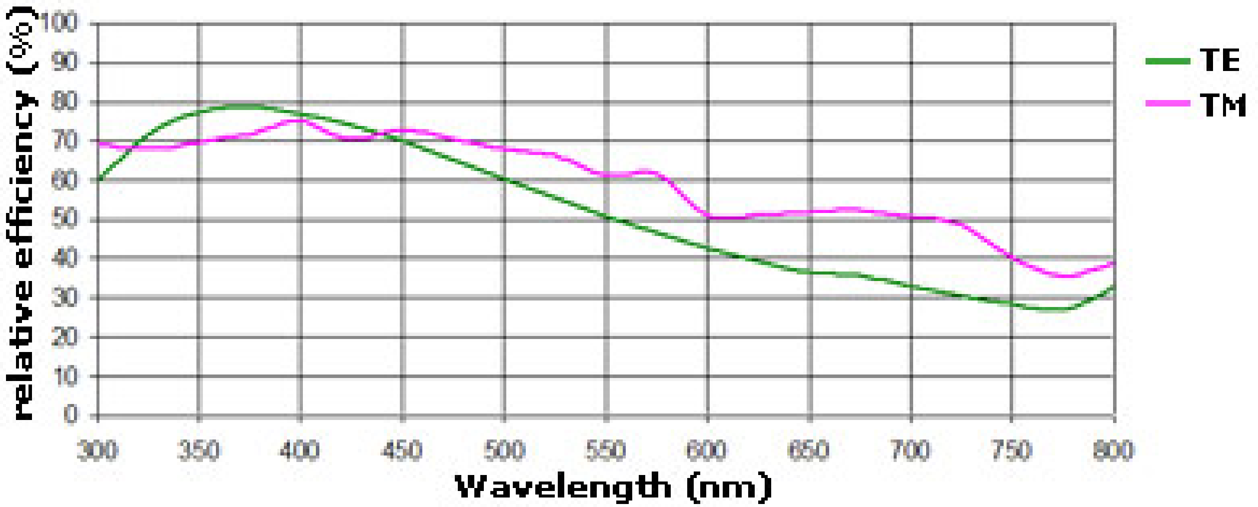
Diffraction Gratings



$$\sin\theta_i + \sin\theta_d = m\frac{\lambda}{a}$$

- Ruled gratings: up to 1200 lines/mm (a = 0.83 μm)
- Holographic gratings: 150-5670 lines/mm
- Grating width, W: 1 mm – 12 cm

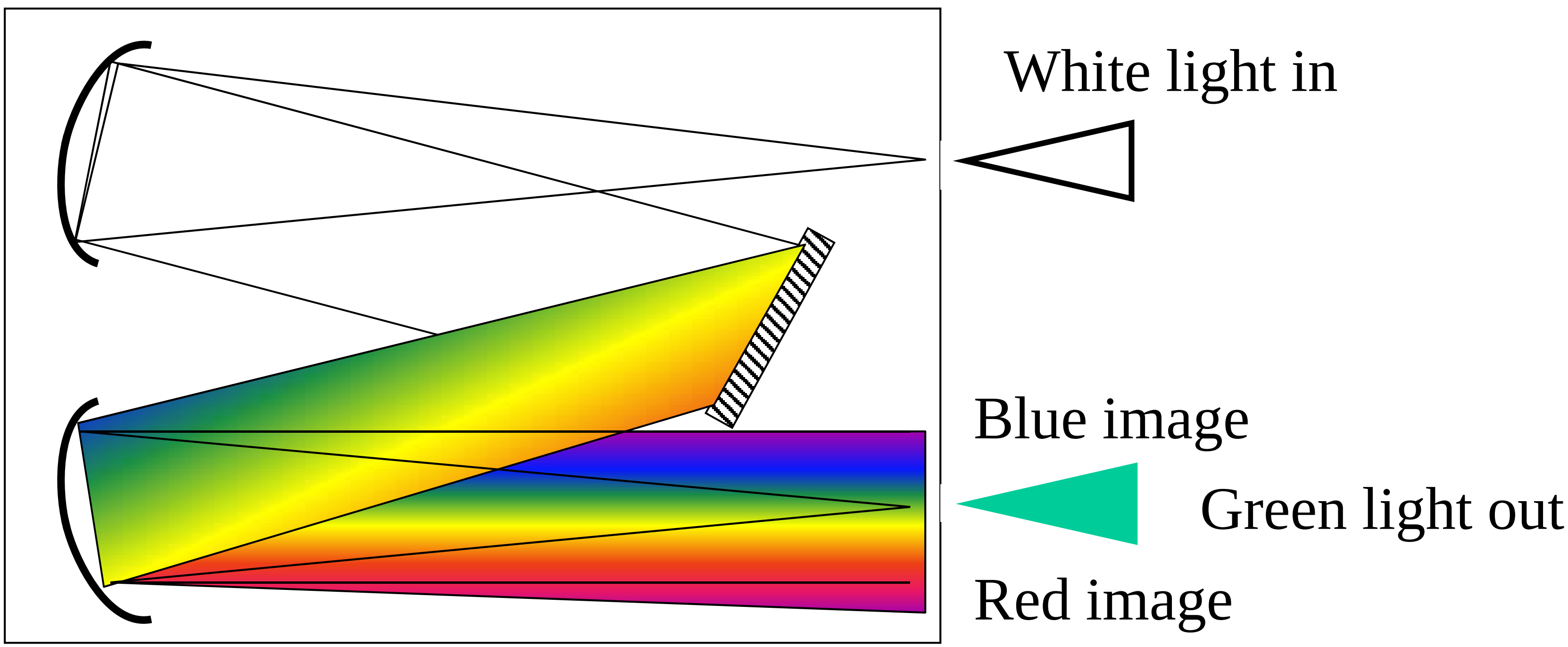
Grating Efficiency



510 12; 600 l/mm; blaze 400 nm

- Polarization dependent
- Blazed gratings shift energy into particular order
- Efficiency falls fast at $\lambda < \lambda_{blaze}$

Grating Monochromator



Mirrors determine system focal length f, and NA (f/#)

Resolution

Linear Dispersion: $$\frac{dL}{d\lambda} = \frac{fm}{a\cos\theta_d}$$

Slit-limited resolution: $$\Delta\lambda = \frac{\text{slit width}}{\text{linear dispersion}}$$

Pixel-limited resolution: $$\Delta\lambda = \frac{\text{1-3 times pixel width}}{\text{linear dispersion}}$$

Resolving Power: $$R = \frac{\lambda}{\Delta\lambda} = \frac{W\left(\sin\theta_i + \sin\theta_d\right)}{\lambda}$$

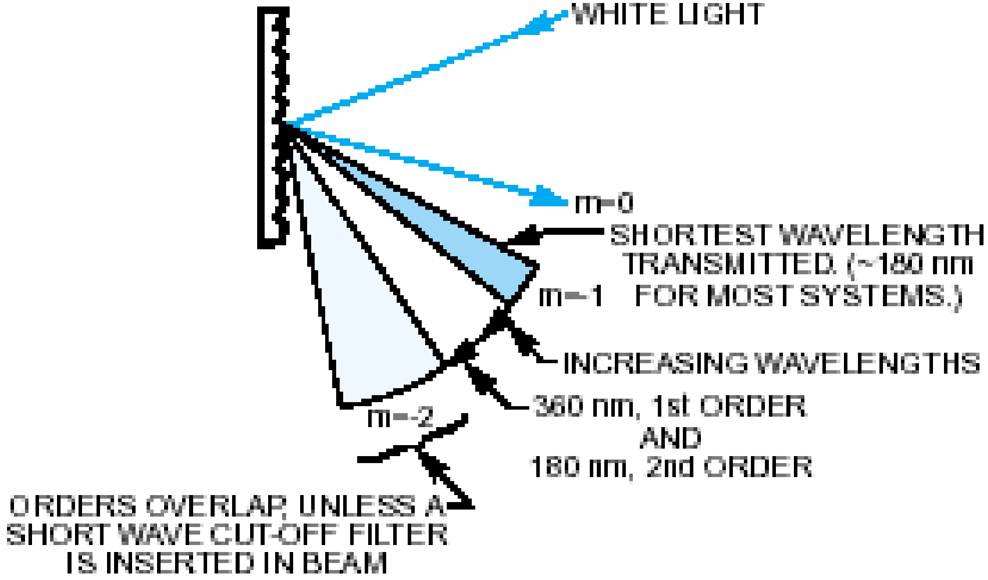
Aberration-limited resolution: coma ~ NA^3

Throughput

$$\frac{P_{out}}{P_{in}} = \text{Grating Efficiency} \cdot \text{Reflection losses} \cdot \left[\frac{NA_{mono.}}{NA_{illum.}}\right]^2$$

- A monochromator is an optical system: consider geometrical extent
- Don’t *dramatically* decrease NA_{illum} to increase throughput: resolution will suffer

Free Spectral Range

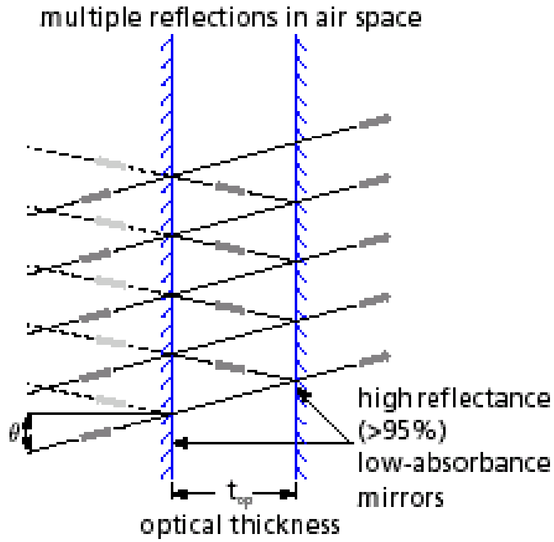


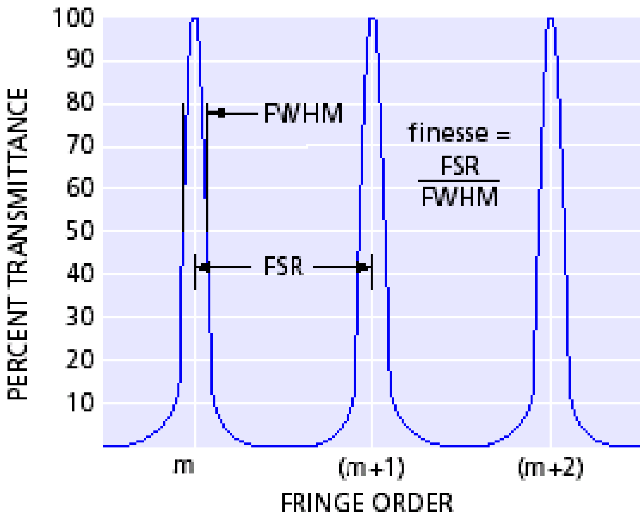
- Spectra from different diffraction orders can overlap
- Use optical filters to narrow spectral range to single order
- Order 0 has no dispersion: useful for alignment

Interferometers

- Fabry Perot
  - tunable filters
  - high resolution optical spectrum analyzers
  - interference filters
- Michelson
  - FTIR spectrometers
  - Wavemeters
- Mach-Zehnder
  - Fiber interferometers
  - Integrated optics

Fabry Perot Interferometer

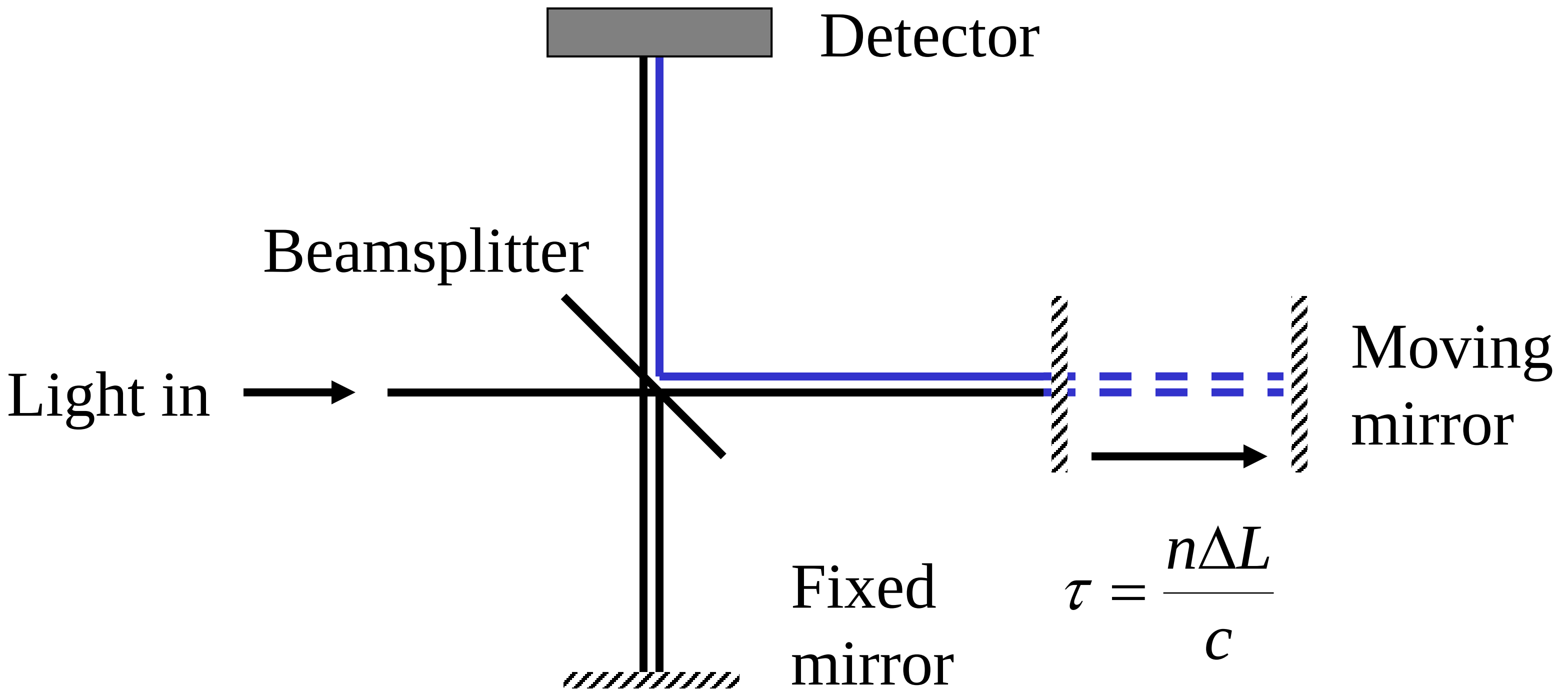




$$\Delta\lambda_{1/2} = \frac{\lambda^2}{2\pi nl}\frac{1-R}{\sqrt{R}} \qquad FSR = \frac{\lambda^2}{2nl}$$

- Vary gap width to scan resonant wavelength
- Cascade 2nd FPI or grating monochromator for higher FSR

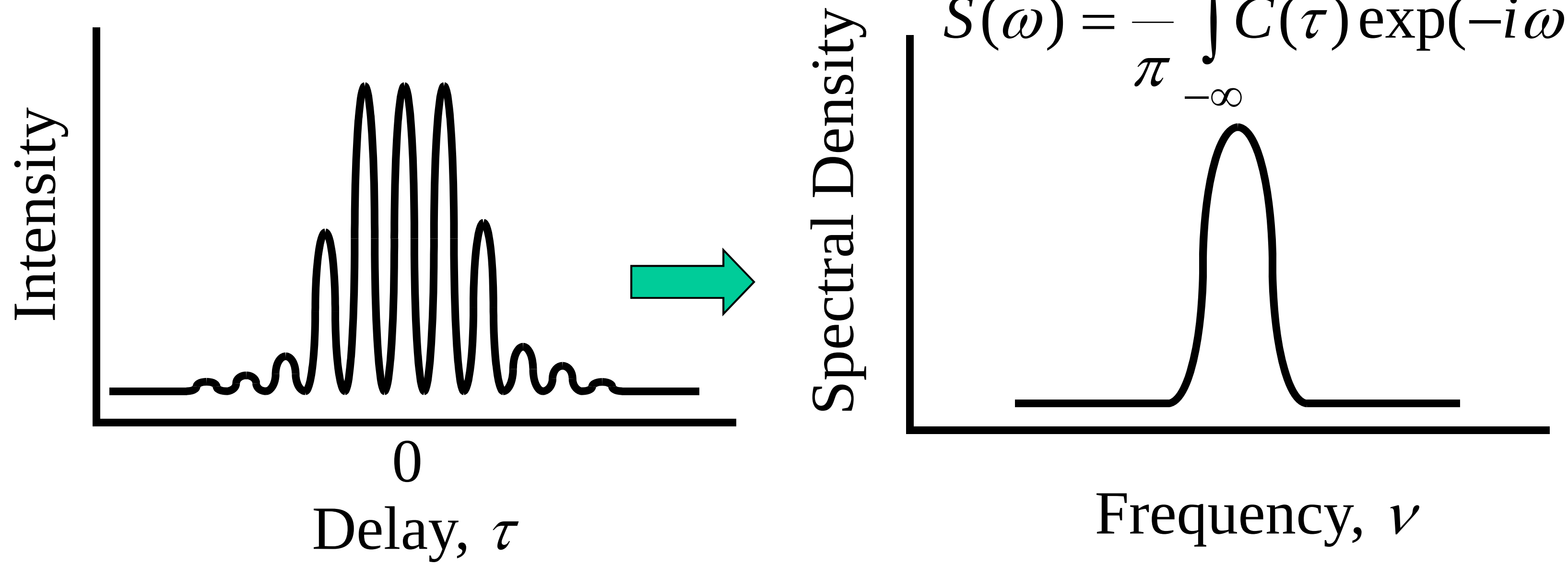
Michelson Interferometer



$$\tau = \frac{n\Delta L}{c}$$

Fourier Transform Spectroscopy

$$S(\omega) = \frac{1}{\pi} \int_{-\infty}^{\infty} C(\tau) \exp(-i\omega\tau) d\tau$$

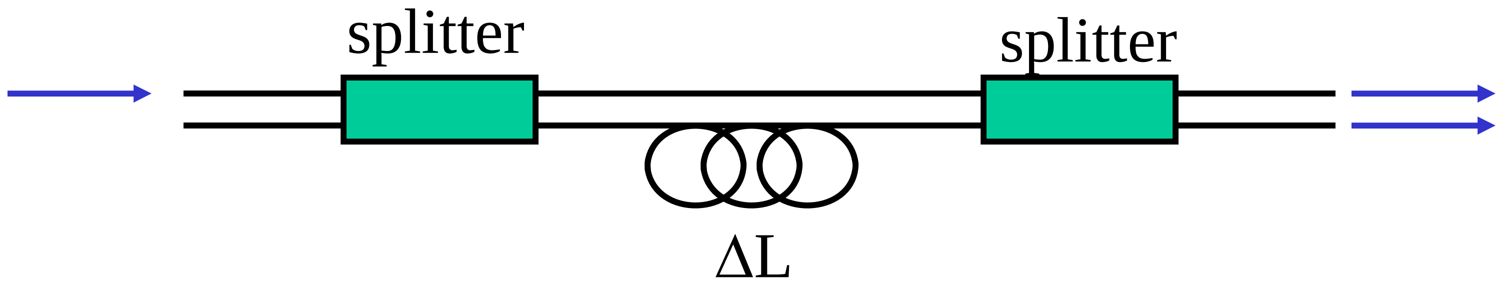


Throughput advantages:

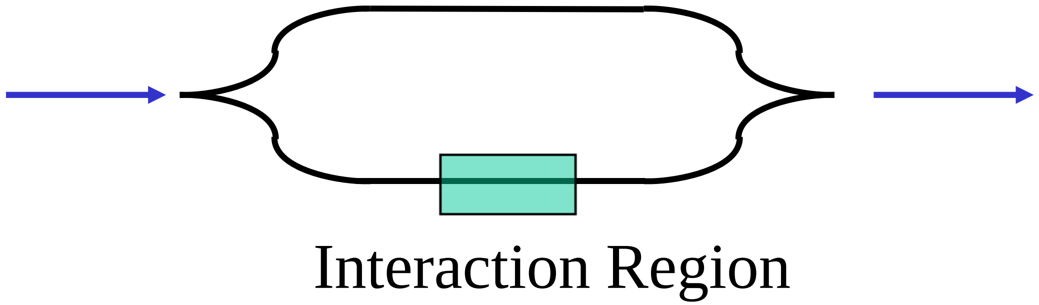
- Large collecting aperture (no slits)
- All wavelengths measured at the same time

Mach Zehnder Interferometer

Fiber Implementation: Very long ΔL possible



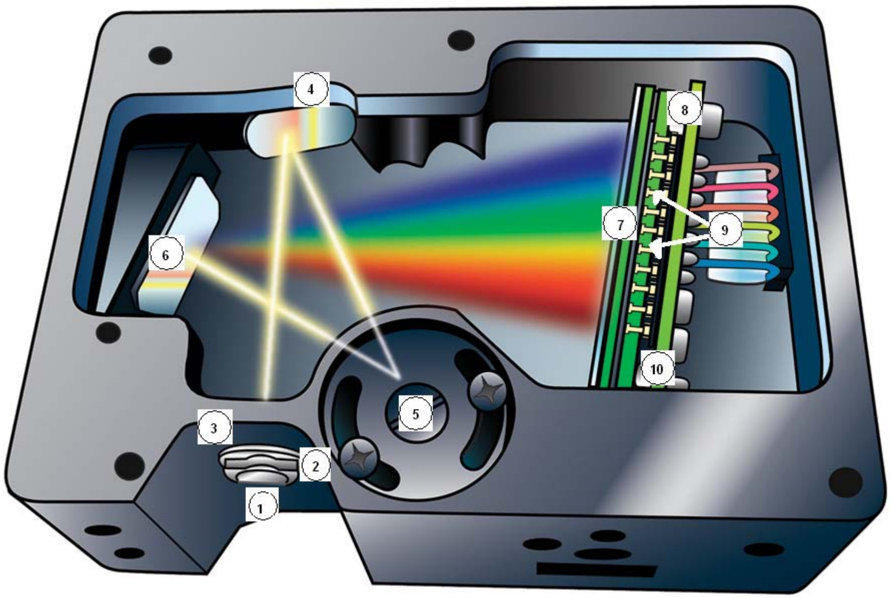
Planar waveguide implementation: Mass-producible



Optical Spectrum Analyzers

- Fixed grating spectrometers with CCDs or Diode Arrays
- Scanning grating spectrometers
- Interferometers

Miniature Computerized Spectrometers

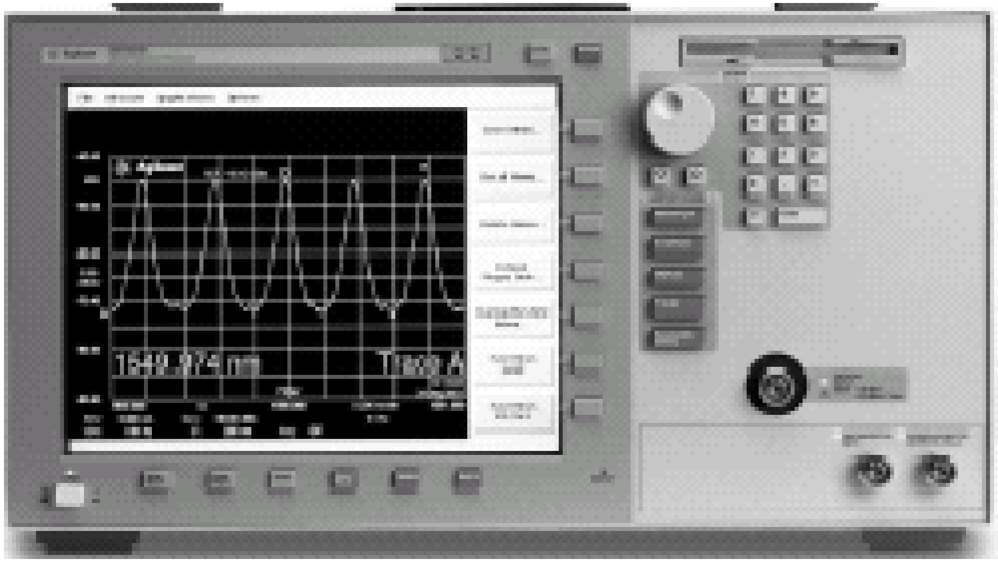


- Palm sized
- Si CCD or InGaAs array
- ~ 1 nm resolution
- USB driven
- Fiber or free space coupling
- Fast and low cost

Spectrometer and Diode Array

- Flexible configuration
- Free space or fiber coupled
- Components controlled by external computer
- Not portable

Optical Spectrum Analyzer

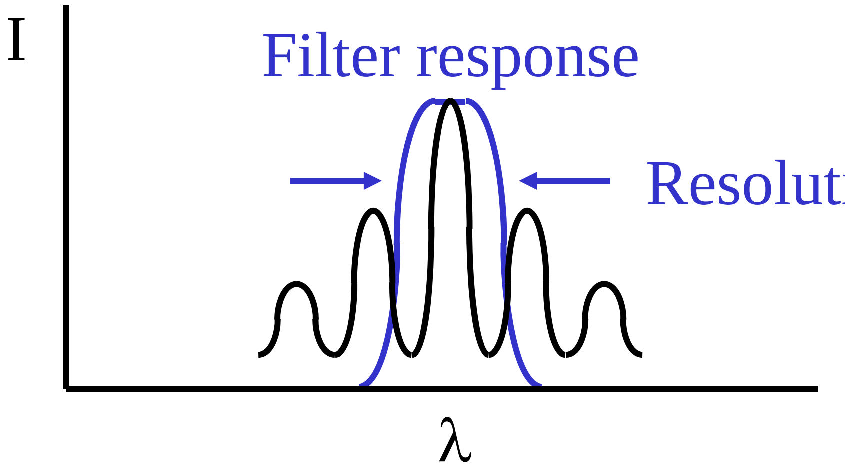


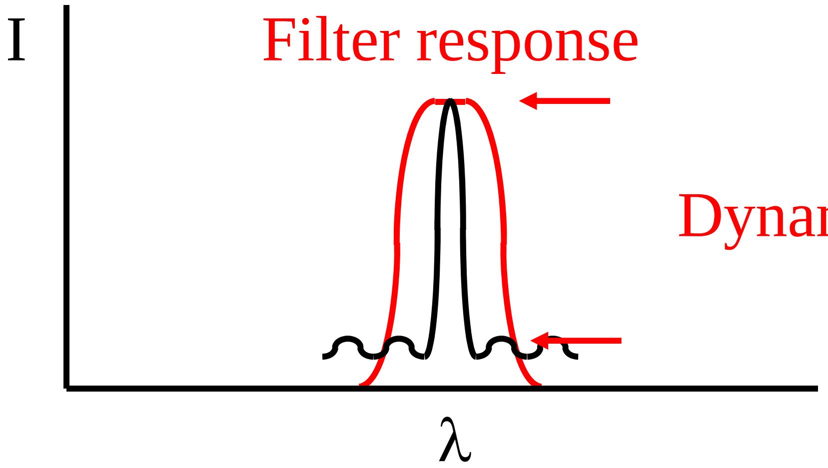
- Fiber input
- Computerized
- ~0.05 nm resolution

Wavemeter

- Interferometer based
- Fiber input
- Computerized

OSA Definitions





dB and dBm

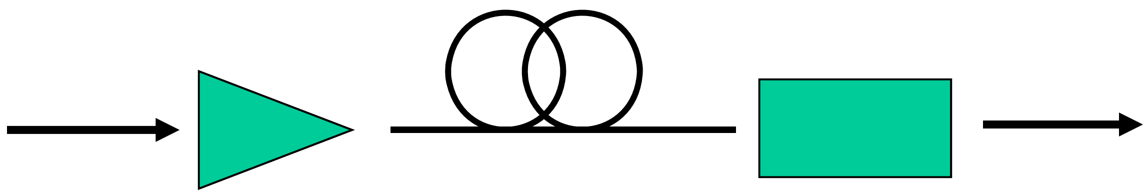
Decibels(dB) refer to a POWER ratio:

$$dB = 10LOG(P_{out}/P_{in})$$

dBm measures relative to 1 mW

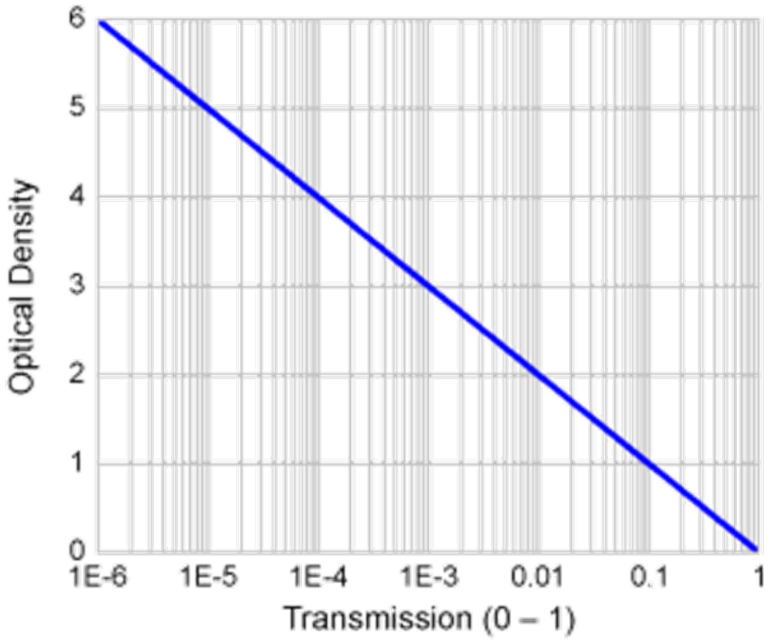
$$dBm = 10LOG(P_{out}/1\ mW)$$

Losses through system add, if measured in dB.

0 dBm  -25 dBm

+10 dB -25 dB -10 dB

Neutral Density Filters



- “Neutral” = wavelength independent
- Optical Density OD = $-\log_{10}(T)$

Interference Filters

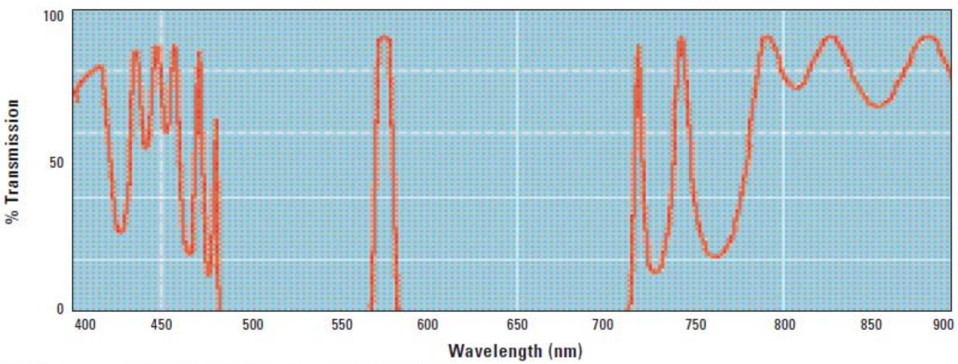


Figure 3: Bandpass Without Extended Attenuation

- Fabry Perot Cavity
- Limited blocking beyond resonance

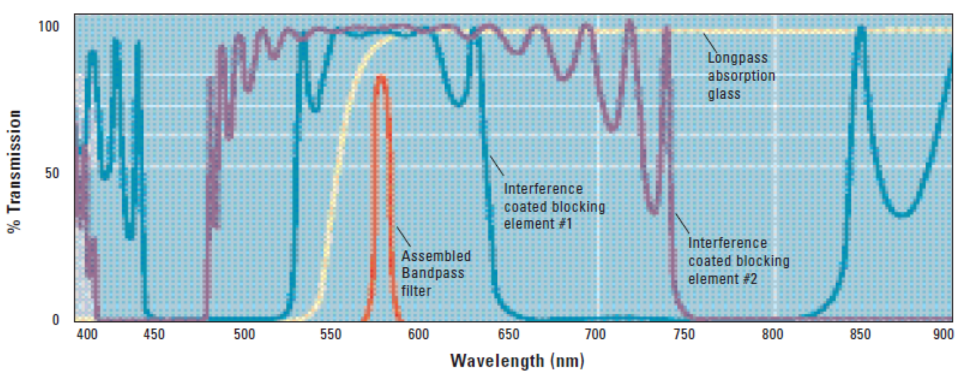


Figure 4: Bandpass With Extended Attenuation

- Extended blocking with additional layers, absorbers
- Blocking layers reduce T, and can fluoresce

Angle and Polarization Response

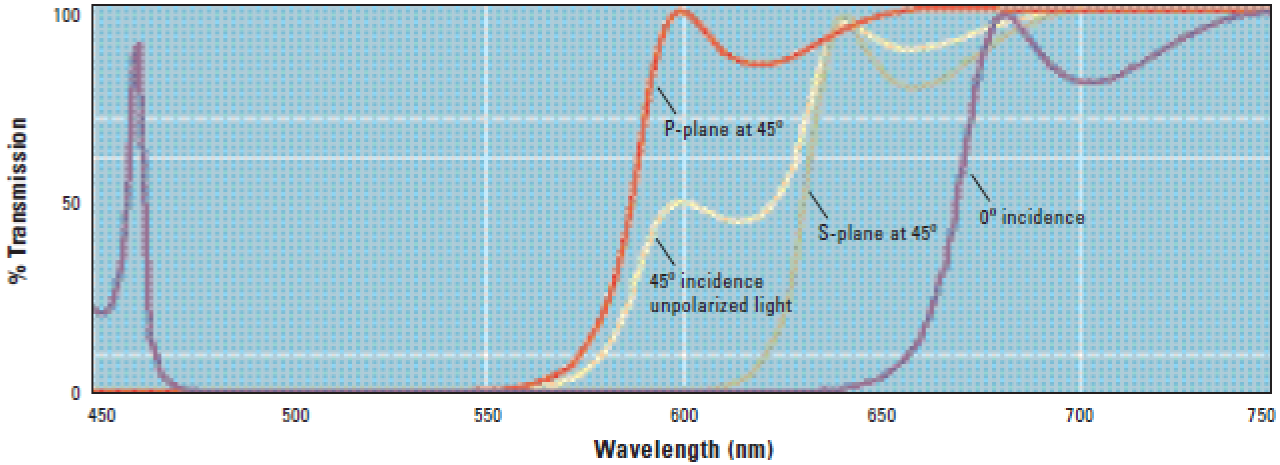


Figure 5: Angle of Incidence Polarization Effects—Longpass Filter

- Increasing angle of incidence shifts edges to shorter wavelength
- Filters are polarization dependent at non-normal incidence

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