Attenuation Methods

Marla Dowell
NIST Optoelectronics Division

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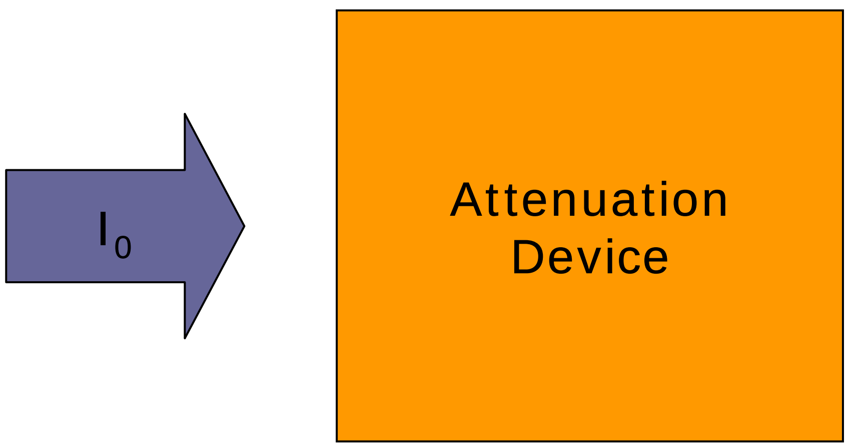
Attenuation Methods

- What is attenuation?
- Why would you want to attenuate a laser beam?
- How do you attenuate a laser beam?
- How do you measure attenuation?

What Is Attenuation?

- Attenuation is the reduction in amplitude or intensity of a signal as it travels through a medium
- The amount of attenuation in a device is a function of the material composition and fabrication method.
- Common units of attenuation are decibels (dB) or percent (%) transmitted



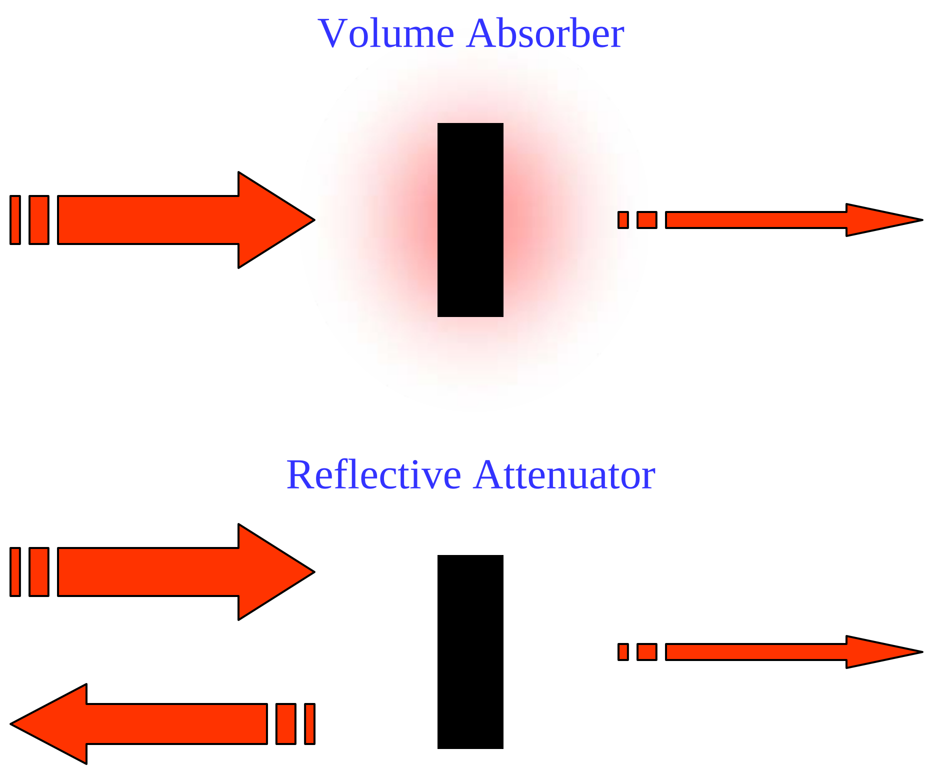
Why Attenuate A Laser Beam?

- Safety
- Avoid detector saturation
- You want to vary the laser power for your application
  - Photolithography uses photomasks to attenuate power as a function of spatial position
  - Power linearity of optical processes
- Spectral filtering

How To Attenuate A Laser Beam

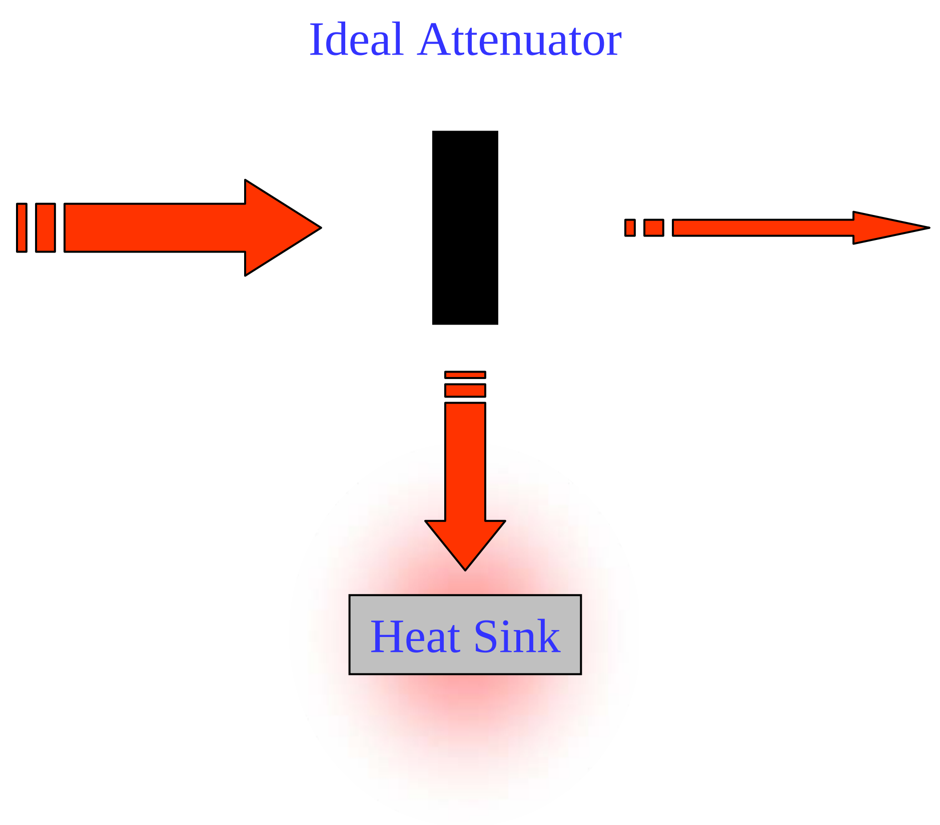
- Bulk absorbers
- Filters
- Beam splitters
- Attenuation techniques for high power lasers

Where does the power go?



Lehman, 2006

Where does the power go?



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Absorption of Light

- Beer-Lambert Law

$I = I_0 e^{-Kz}$ **or** $I = I_0 10^{-\alpha c z}$

$K = 4\pi n_i/\lambda$

n_i = *extinction coefficient*

(aka imaginary part of refractive index)

λ = *vacuum wavelength*

$\alpha = K/c$

c = *concentration of absorbing species*

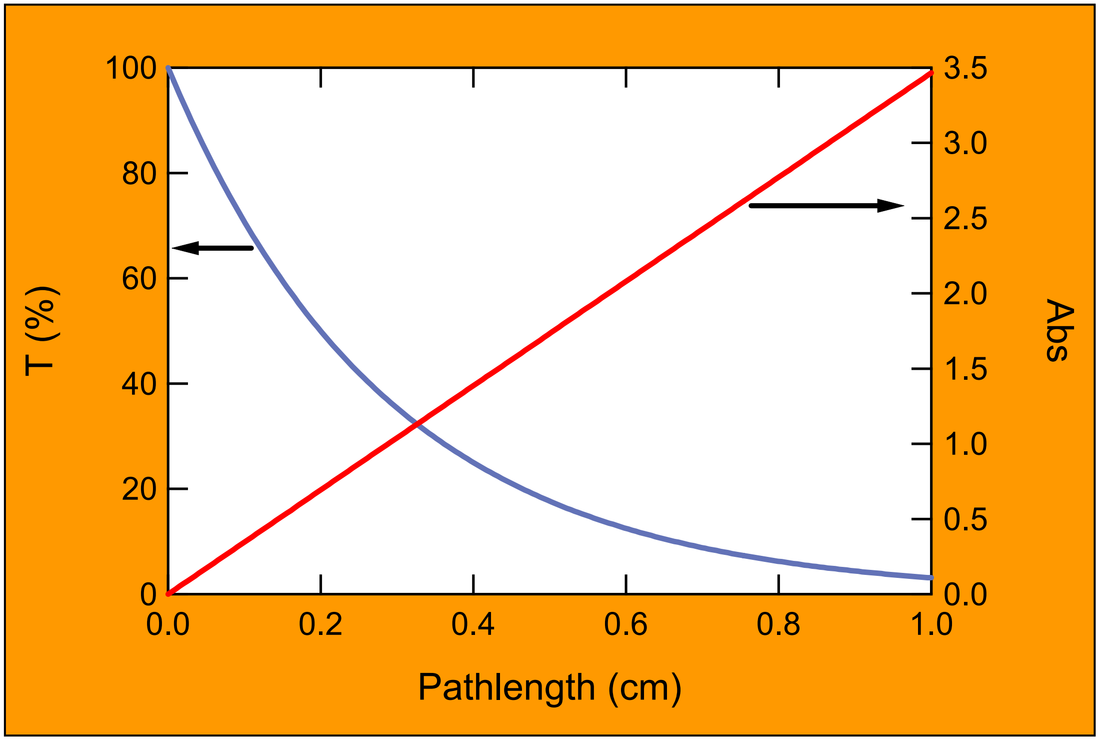
(more common form for liquids and gels)

Absorption of Light

Transmittance T (%) $= 100(I/I_0)$

Absorbance Abs $= -\ln(T/100)$ **or** $= -\log_{10}(T/100)$

$= \ln(I_0/I)$ $= \log_{10}(I_0/I)$



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Neutral Density Filters

- Reduces light of all wavelengths equally
- Works well for low power applications
- Can degrade with time
  - Bleach or darken
- Absorptive or reflective

OD	.3	.6	1	1.3
T(%)	50%	25%	10%	5%

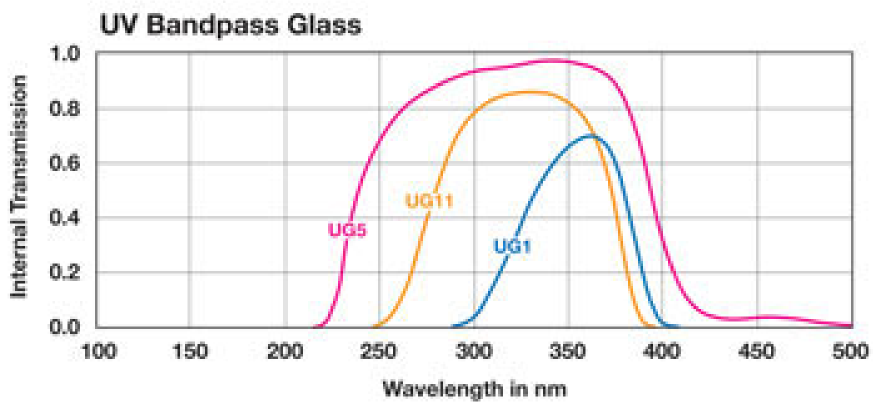
Gotchas

Know where the non-transmitted light is going

- Reflective → stray beams
- Absorbing → filter heating

Colored Glass

- Specially formulated for bulk absorption at specific wavelengths
- High damage threshold
- Can be difficult to find for some wavelengths



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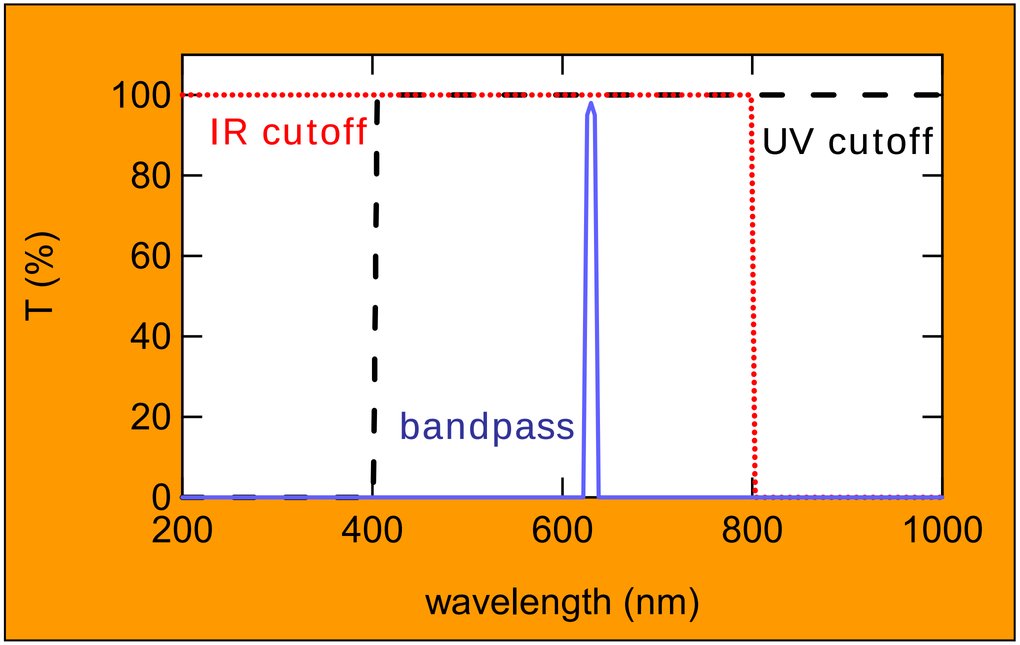
Filters

Useful for attenuating light at specific wavelengths

- Bandpass
  - For transmitting specific wavelengths and rejecting others
- Cut off (aka Edgepass, Short Pass and Long Pass)
  - For transmitting above (or below) a specific wavelength
- Can be reflective and absorptive



Types of Filters

- Dichroic
  - multilayer reflective coating on glass substrate
  - Number, thickness, and material composition of layers determines filter response

  Pros: tunable to specific wavelengths, more resistant to heating effects and photobleaching

  Cons: custom filters are expensive, more fragile than some others
- Dielectric
  - Multiple thin layers of dielectric material uses interference effects for wavelength selection

  Pros: tunable to specific wavelengths

  Cons: change in angle of incidence can change the filter response as a function of wavelength, need a protective layer on top of the coating
- Polarizer
  - Blocks or transmits light according to its polarization
  - Absorptive or reflective

  Pros: continuous variable attenuation, polarized output

  Cons: polarized output
- Absorptive
  - Usually glass, can be plastic, gel, or liquid

  Pros: cheap

  Cons: easily damaged by high power laser exposure

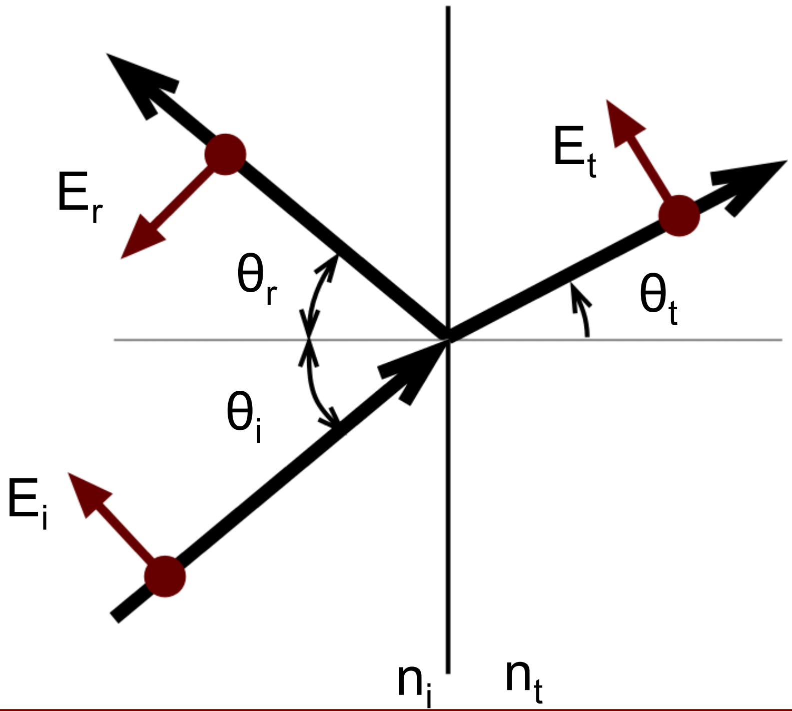
Gotcha

Check the damage thresholds and wavelength response to make sure that it is suitable for your application

Beam Splitters

- Bulk material
  - Wedged optical elements
  - Typical materials are quartz, crown glass, sapphire, etc.
  - Amount of reflected light depends on refractive index of beam splitter, incident angle of light with respect to beam splitter, and polarization of light
  - Light that is not transmitted is absorbed and reflected
- Partial reflectors
  - Typically made from stacks of dielectric coatings
  - Light that is not transmitted is reflected
  - 60/40 beam splitter reflects 60 % and transmits 40 %

Fresnel's Equations and Snell's Law



Snell's Law

$$n_i \sin\theta_i = n_t \sin\theta_t$$

Intensity reflection coefficients depend on polarization, angles, and refractive indices

$$R_p = \left[\frac{n_t\cos\theta_i - n_i\cos\theta_t}{n_t\cos\theta_i + n_i\cos\theta_t}\right]^2$$

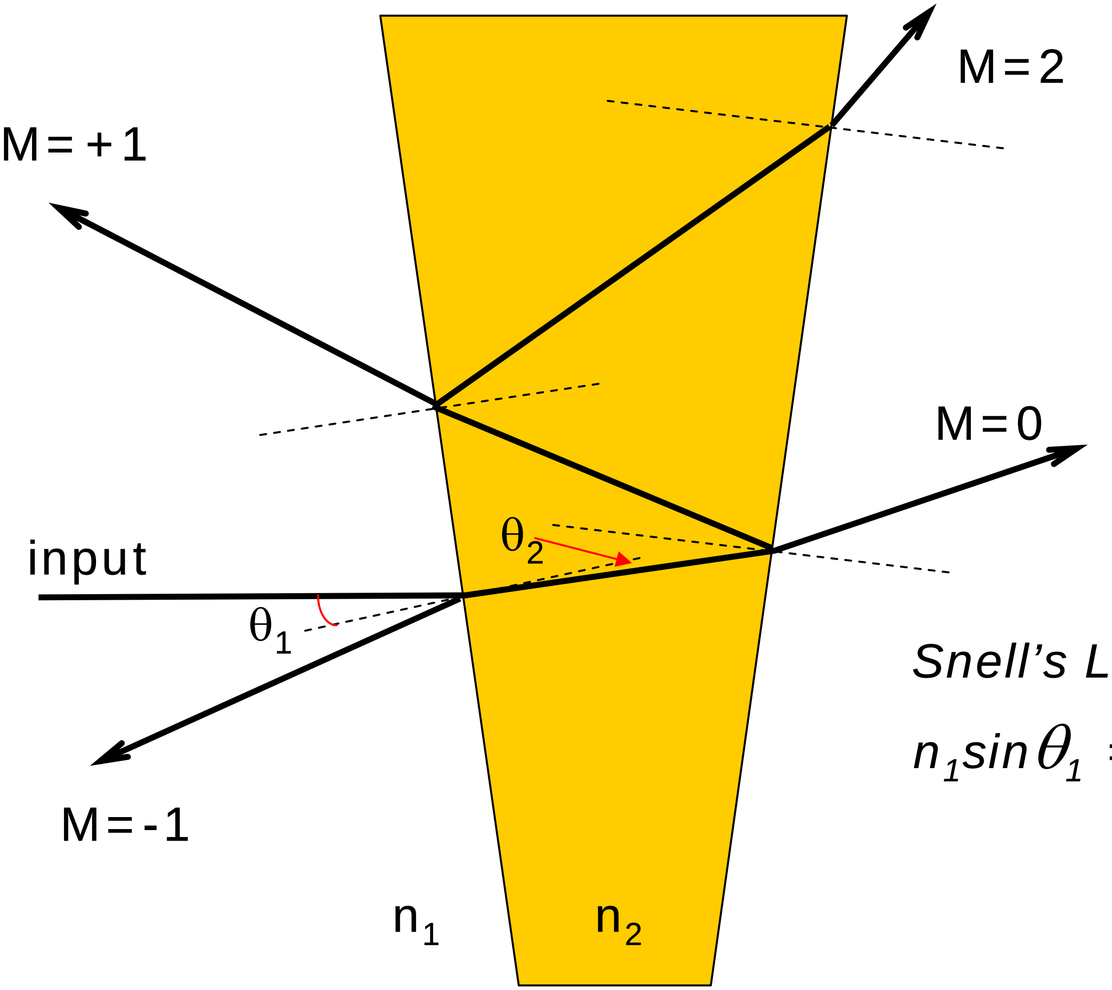
$$R_s = \left[\frac{n_i\cos\theta_i - n_t\cos\theta_t}{n_i\cos\theta_i + n_t\cos\theta_t}\right]^2$$

Define reflectance and transmittance as

$$R = \left[\frac{E_r E_r^{*}}{E_i E_{i^*}}\right] = \frac{I_r}{I_i} \qquad T = 1 - R$$

Rochford, 2006

Bulk Beam Splitters



Snell's Law

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

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Crude Estimate Of Attenuation For Wedged Beam Splitter

For normal incidence:

$$R = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2$$

For a Fused Quartz beam splitter in Air,

R = 3.48 % from first surface
R = 3.36 % from second surface
T = 93.17 % transmitted through medium
(neglecting absorption)

Attenuation for M=-1 → 3.48 %
Attenuation for M = 0 → 93.17 %

Material	Refractive Index *n*
Air	1.0002926
Crown glass	1.520
Nitrogen, gas	1.000297
Nitrogen, liquid	1.2053
Plexiglas	1.50
Quartz	1.544
Fused Quartz	1.45843
Sapphire	1.760
Water (35 °C)	1.33157

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Attenuation For High Power Lasers

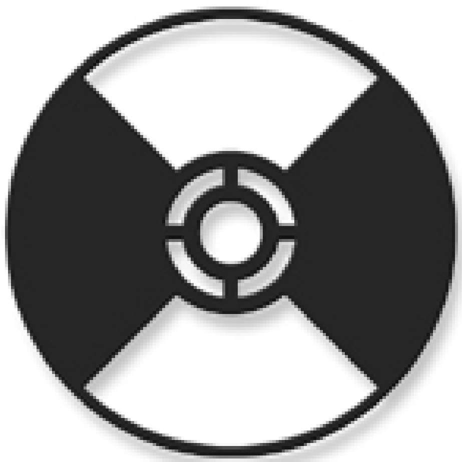
- High power for this discussion is > 1 W
- Pulse energies > 0.1 J
- Most absorptive designs will not work because too much heat is generated in the absorbing material

➔ Reflective attenuation methods

  - Single reflection
  - Multiple reflection

Single Reflection Method: Chopper Wheel

- Attenuation = $\text{Area}_{open} / (\text{Area}_{open} + \text{Area}_{blocked})$

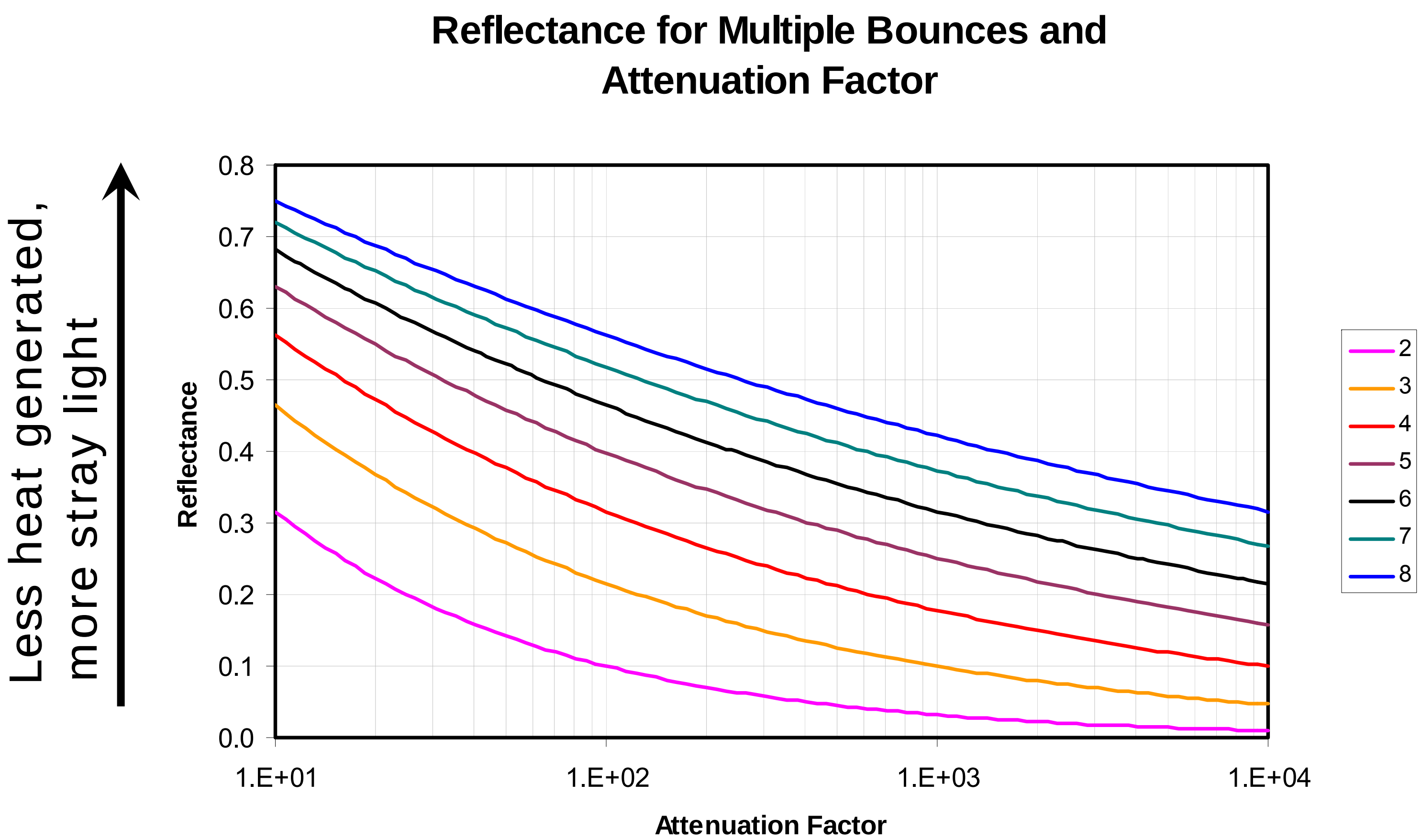


50 % Attenuation

NIST high power chopper wheels use reflective materials on chopper blades to avoid heating of the chopper wheel.

Reflected light should be directed towards beam dump for safety purposes.

Multiple Reflection Method



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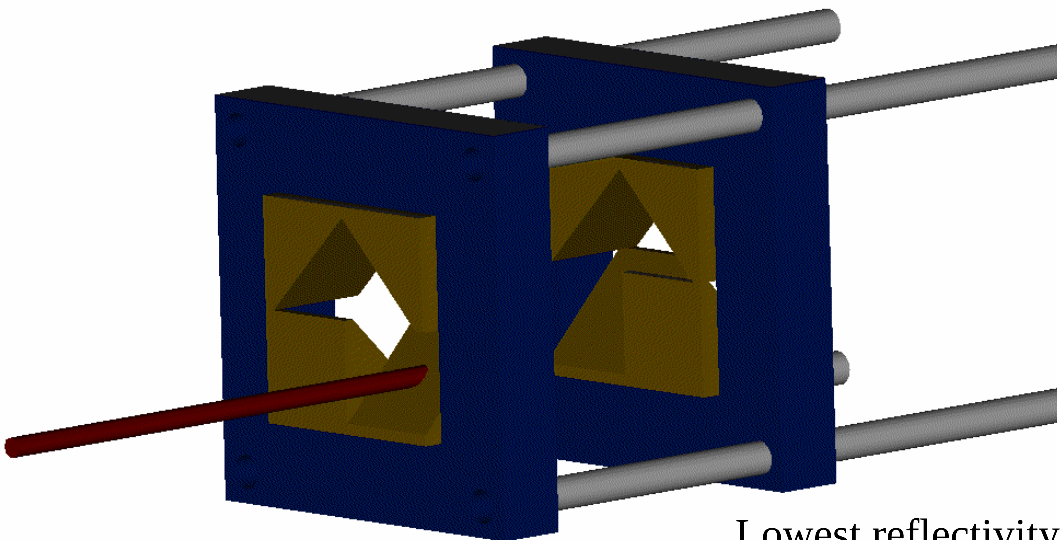
Modular Reflective Attenuator



mulitple "modular" additions to achieve desired attenuation with flexibility

Lowest reflectivity for a metal mirror (without dielectric) is ~ 75 % for Beryllium

4 reflections per module

0.75 each wedge for A = 0.75^4 = 3.16
4 modules: 3.16^4 = 100
6 modules: 3.16^6 = 997

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How to Measure Attenuation

- Crude method: $T = \dfrac{I_{out}}{I_{in}}$

This method is good enough for most purposes where the amount of transmitted light is the desired quantity.

This method is not good for determining the source of attenuation or the absorption and reflection properties of an optical component.

Summary

- Any combination of reflectors and absorbers can be used to attenuate a laser beam
- Be aware of where the attenuated light is going
  - Stray reflected beams
  - Absorption in unintended materials
- Pick an attenuation method appropriate for your application. For most applications, off the shelf components are good enough

References

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- Klein, Miles, Optics, Wiley, 1970.