Advanced Radiation Sources - PHSY761

Exercise 02

Summary

Laboratory demonstration: Nd:YAG laser

- The Nd:YAG laser system overview
- Instrumentation
- The laser kit
- Summary
- Safety / hands-on

28 September 2023

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Neodymium : Yttrium Aluminum Garnet ($Y_3Al_5O_{12}$)

- Nd 3+ ion substitute Y atoms
- 2 x s and 1 x f electrons are used for the ionic bond
- Remaining f electrons are split by Coulomb repulsion, spin-orbit coupling, crystal field splitting
- Screening by 5s and 5p electrons
- Transition f-f, "weakly" allowed. Strongest @ 1064 nm. 230 us, BW = 126 GHz (Room T)

TABLE 9.1. Electronic configurations of some rare earth and transition metals of interest as laser active impurities. For reference, the fundamental configuration of Xe is also shown

Xenon, Xe	$(Kr)4d^{10}5s^2 5p^6$
Neodymium, Nd	$(Xe)4f^4 5d^0 6s^2$
Holmium, Ho	$(Xe)4f^{11} 5d^0 6s^2$
Erbium, Er	$(Xe)4f^{12} 5d^0 6s^2$
Thulium, Tm	$(Xe)4f^{13} 5d^0 6s^2$
Ytterbium, Yb	$(Xe)4f^{14} 5d^0 6s^2$
Chromium, Cr	$(Ar)3d^5 4s^1$
Titanium, Ti	$(Ar)3d^2 4s^2$
Cobalt, Co	$(Ar)3d^7 4s^2$
Nickel, Ni	$(Ar)3d^8 4s^2$

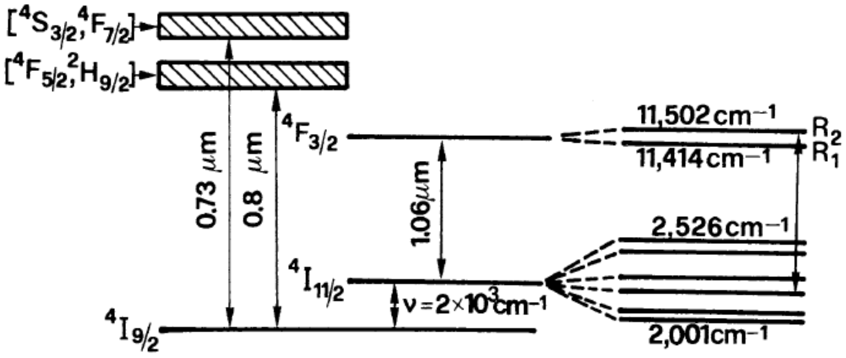
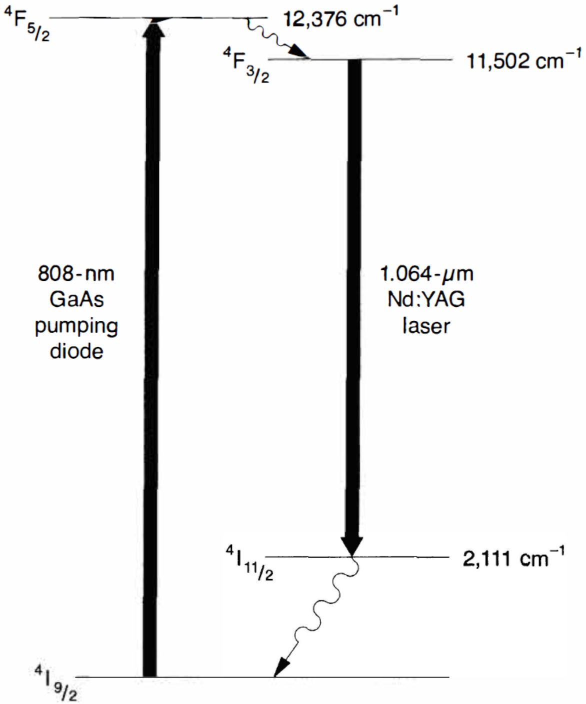
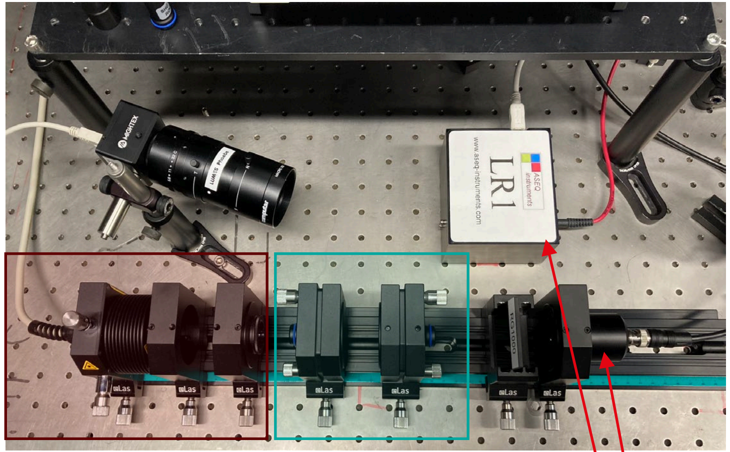


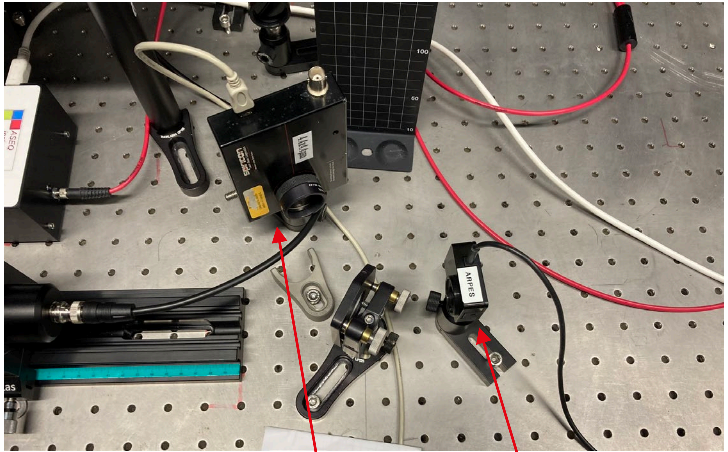
FIG. 9.2. Simplified energy levels of Nd:YAG.



	Nd:YAG $\lambda = 1.064\,\mu m$
Nd doping [at. %]	1 at. %
N_t [10^{20} ions/cm^3]	1.38
$\tau\,[\mu s]$	230
$\Delta\nu_0$ [cm^{-1}]	4.5
σ_e [10^{-19} cm^2]	2.8
Refractive index	$n = 1.82$

- 4 level behavior
- Matches well GaAs pumping laser diode:
- Compact “end-pumped” system are possible
- Efficiency in the several % range





PUMP DIODE
- T stabilized diode
- Pump focusing

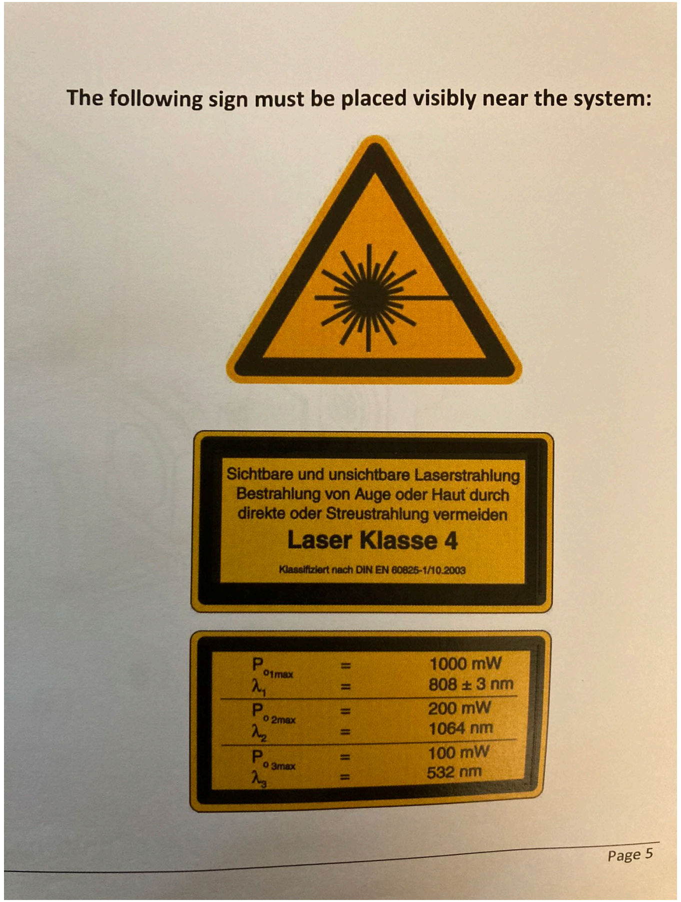
CAVITY and GAIN MEDIUM

Laser beam characterization instruments
- Photodiode
- Fiber coupled Spectrometer
- Power meter
- Beam profiler

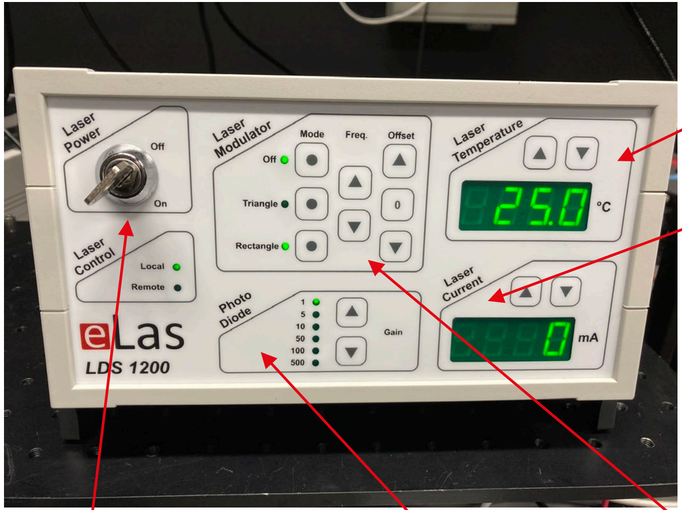
Laser safety

- Laser radiation is hazardous for the eyes.
- NIR radiation, more dangerous than VIS
  - mostly invisible – no eye reflex
- The laser is enclosed in a barrier, demonstration is shown via a scree
- Wear protection googles (provided) whenever operating the instrument, or directly looking in the laser enclosure
- Laser can only be operated under supervision
- Compare the wavelengths of your googles with the one listed:

  808 nm and 1064 nm



The pump laser diode controller



T controller

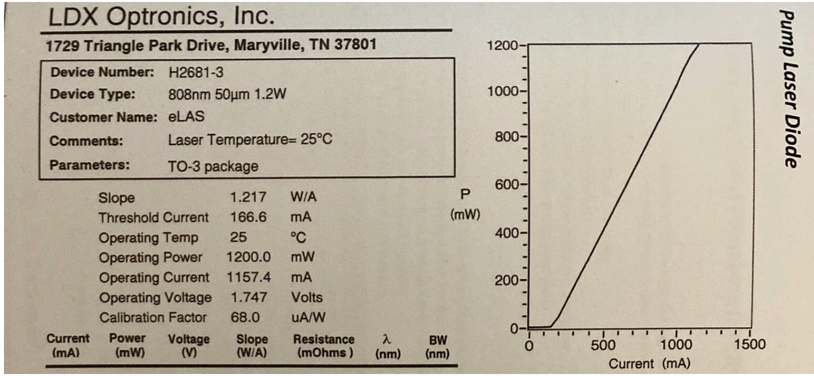
Photodiode current

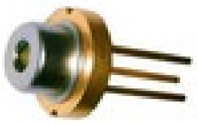
Frequency modulation

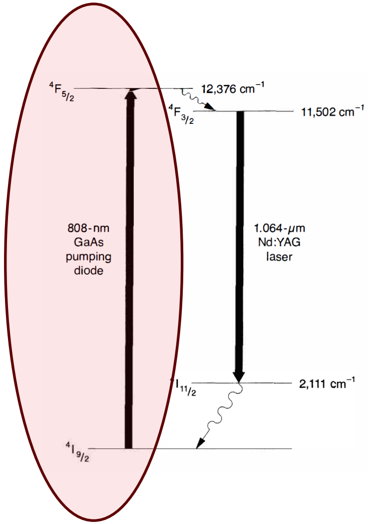
ON/OFF switch

Photodiode detector gain

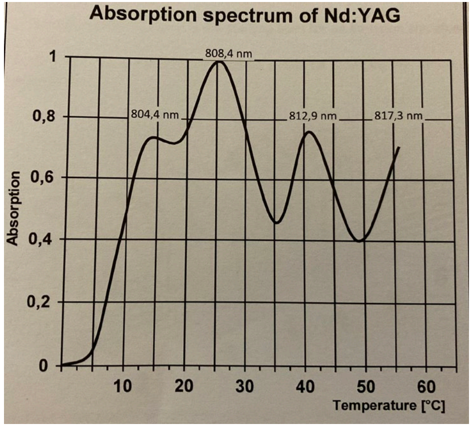
GaAs pump laser diode







- The gap of the material changes with temperature
  - Wavelength can be tuned by T control
  - Absorption band in Nd also has a fine structure
  - Operating T 25° C, 20°<T<30° exceed limits only for short time



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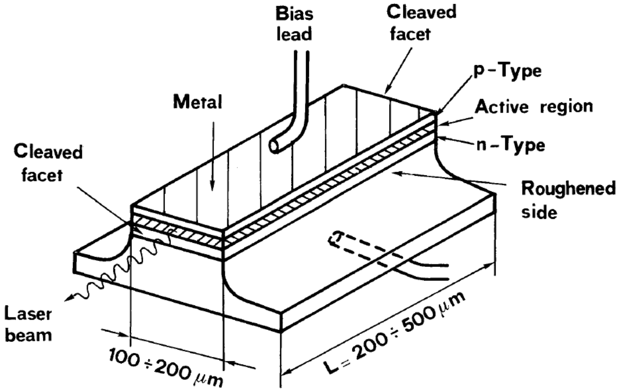
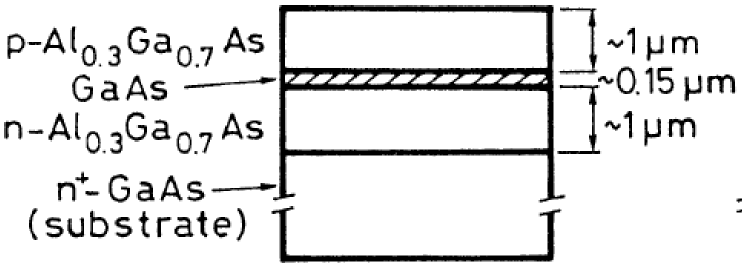
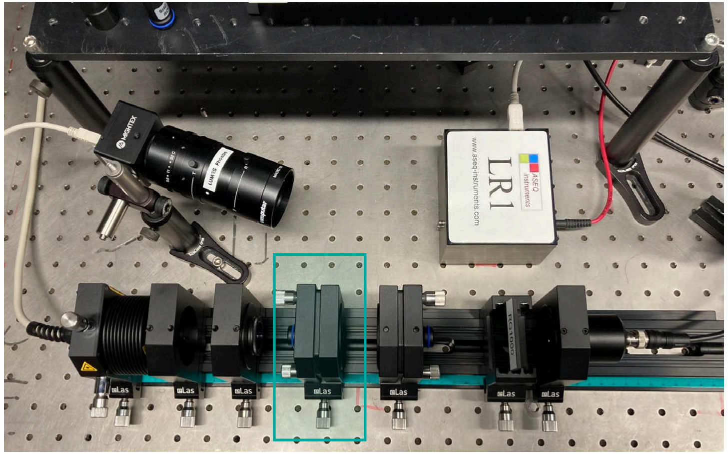
- Mode shape: elliptical – why?

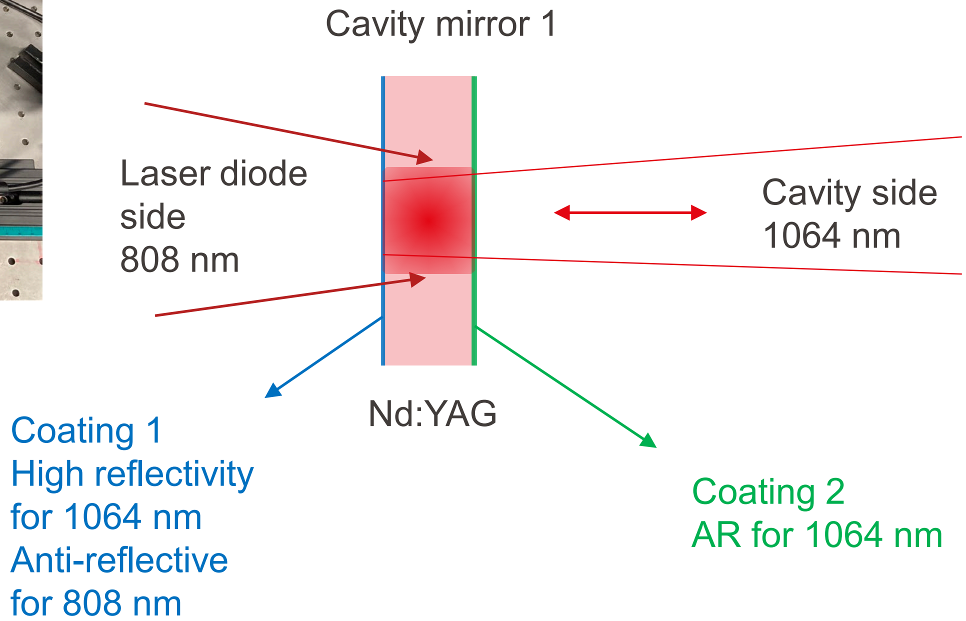




- Measurement of radiant power vs current
- Temperature dependence of wavelength
- Triangular current ramp: lasing threshold

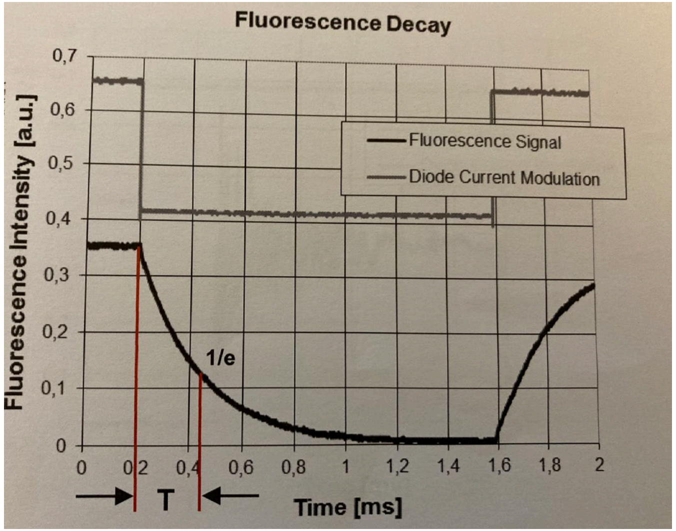
PART 2 Radiative lifetime, lasing and lasing threshold



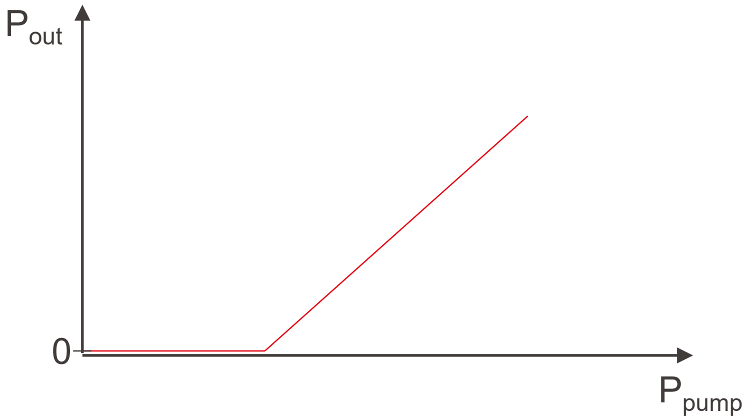


Measure the fluorescence of the material

Upper state lifetime = 230 us



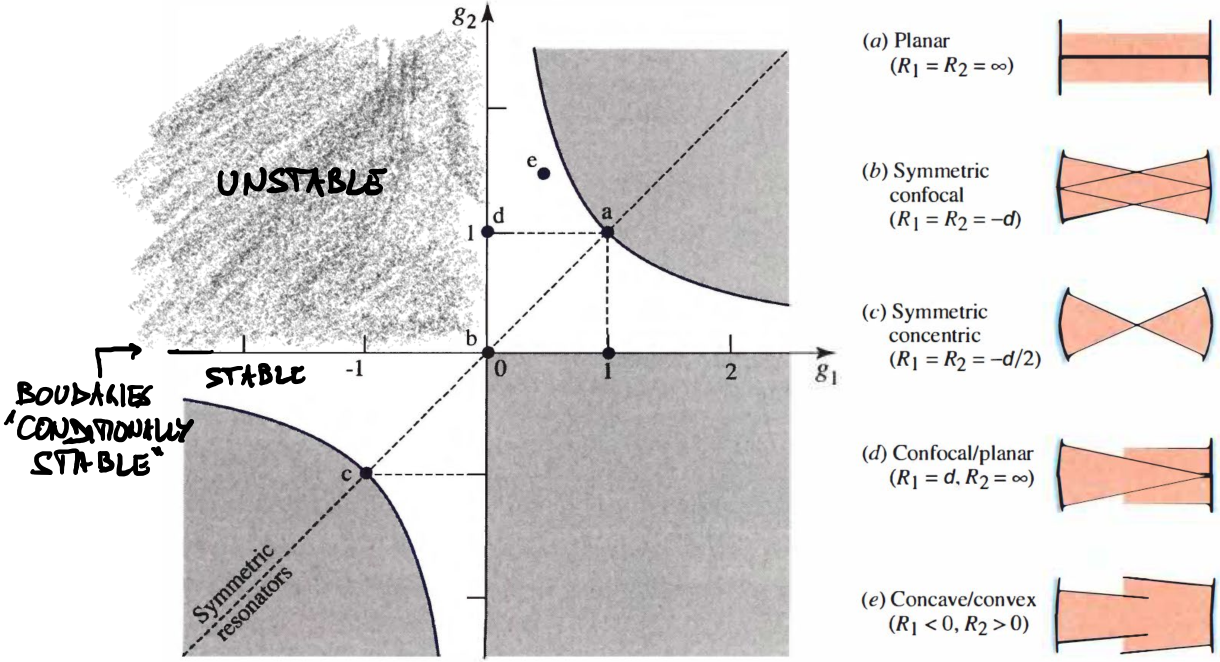
- Rectangular LD current modulation: Nd lasing threshold behaviour



Stability criterion for curved mirror resonators

$$0 \le \left(1+\frac{d}{R_1}\right)\left(1+\frac{d}{R_2}\right) \le 1$$

g_1 g_2

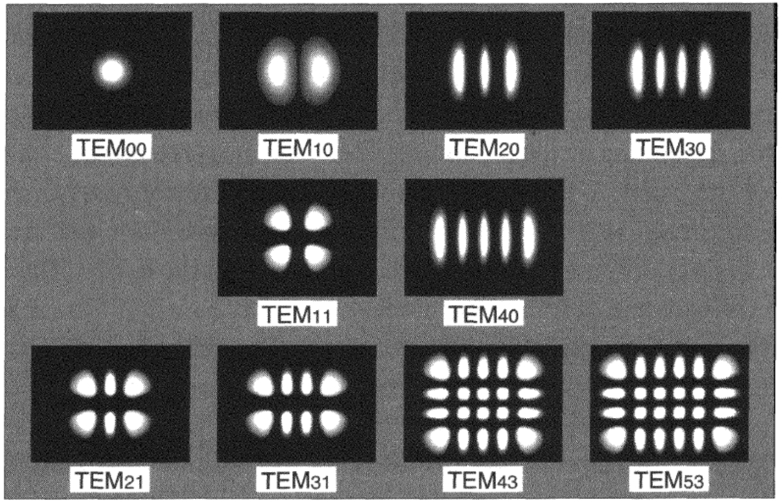


- We still don't know anything about the mode spatial shape and spectral structure!

The Transverse Electromagnetic Modes (TEM)

$$U_{pq}(x,y) = H_p\left(\frac{\sqrt{2}x}{w}\right) H_q\left(\frac{\sqrt{2}y}{w}\right) e^{-(x^2+y^2)/w^2}$$

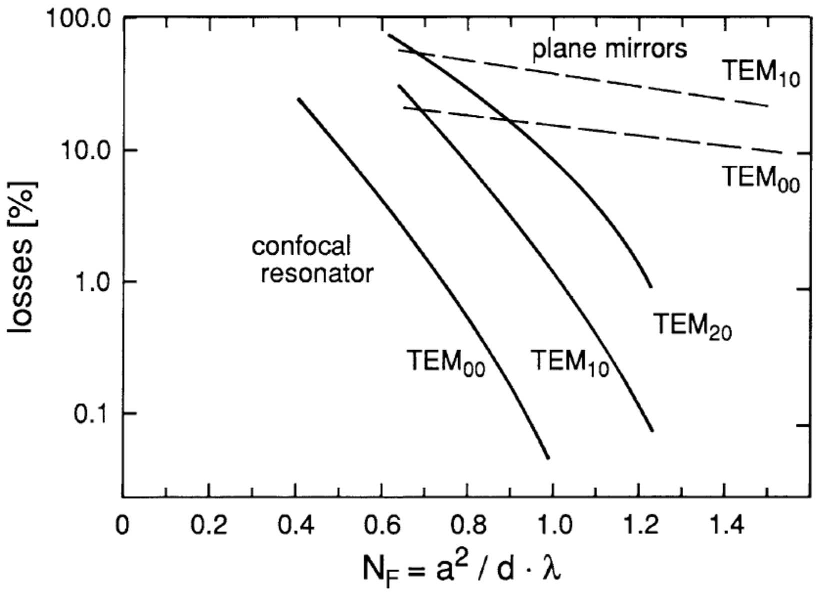
H_n HERMITE POLINOMIALS



- TEM_{lm} modes can be calculated for every longitudinal mode n,
- The mode frequency ν_{nlm}, depends more strongly on n, but also on l and m
- Also the transverse mode are important in the laser dynamics: higher order can be minimized by cavity design, but this is not optimal for every application.

Diffraction losses in resonators

- Fresnel number for a cavity of lenght d, with mirror radius a, and wavelength λ: N_F dimensionless parameter, diffraction losses are low for large $N_F = a^2/d\lambda$



- Confocal resonators presents much lower diffraction losses!