Final laser project

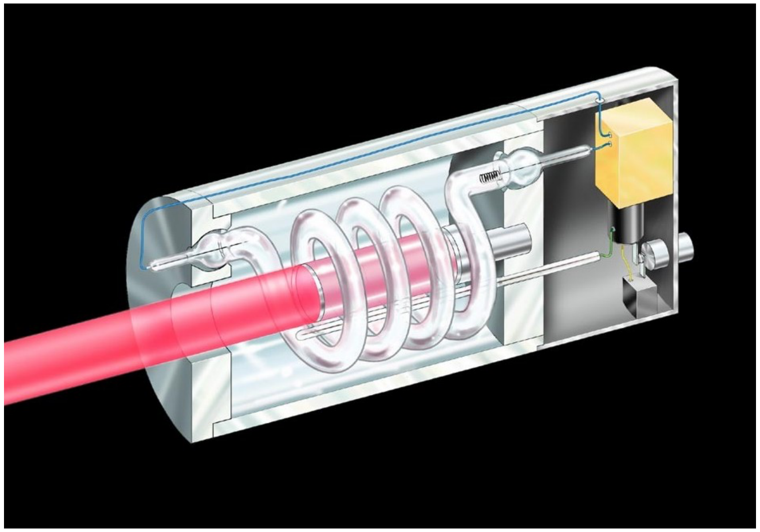
- Two approaches
  - Case-study: pick a specific laser design, model
    - Pumping, gain dynamics
    - Resonator design
    - Pulsed operation – q-switching, mode locking
    - Modeling of how a design can be scaled or adapted
  - Survey: pick a general class of lasers
    - Physics of how gain is achieved
    - Describe different architectures
    - How lasers are designed for applications
    - Many references

Project requirements

- Pick a topic
  - Ok to pick a topic that is relevant to your research
- Meet with me to make a plan
- Write a summary of project plan
  - 1 page, plus list of references to be used (Nov 18)
- Short powerpoint presentation to class - ~ 8 minutes
  - 10 Dec, during normal lab time
- Written report, including code if applicable
  - 15 Dec
- Extra credit for extra good report!

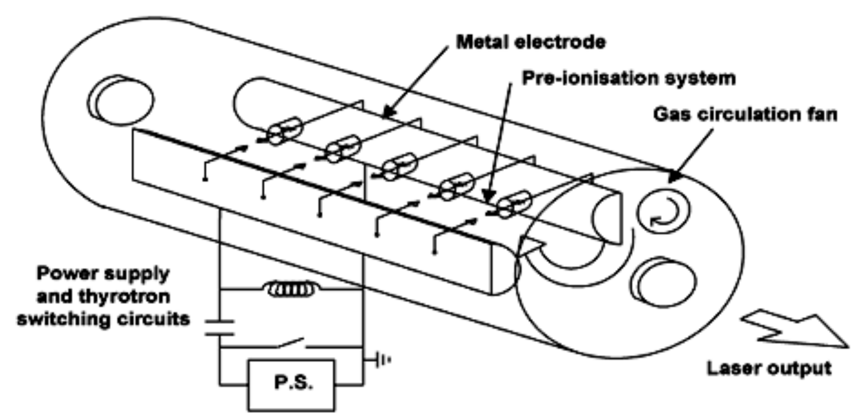
Laser classics

- Ruby laser:
  - 3-level system, first laser
- HeNe laser
  - Several lasing lines, visible and near-IR
  - Stabilized laser
- Alexandrite: tunable solid-state
  - Walling, J., Heller, D., Samelson, H., Harter, D., Pete, J., & Morris, R. (1985). Tunable alexandrite lasers: development and performance. *Quantum Electronics, IEEE Journal of*, *21*(10), 1568–1581.



Discharge lasers

- Argon-ion, Krypton-ion laser:
  - high average power CW, many lines near-UV and visible, used in most laser light shows
- Excimer laser
  - XeCl, ArF, KrF created in discharge, emit UV in dissociation
  - High pulse energy, used in surgery, materials processing
  - CARO, R., et al (1982). A Simple Tunable Krf Laser System with Narrow Bandwidth and Diffraction-Limited Divergence. *Journal of Physics D: Applied Physics*, *15*(5), 767–773.
- Nitrogen lasers
  - UV output
  - “air lasing”



Dye lasers liquid and solid state/ polymer

- Liquid-dye lasers for tunable output in spectral regions from visible to near-IR
- Chénais, S., & Forget, S. (2012). Recent advances in solid-state organic lasers. *Polymer International*, *61*(3), 390–406. http://doi.org/10.1002/pi.3173

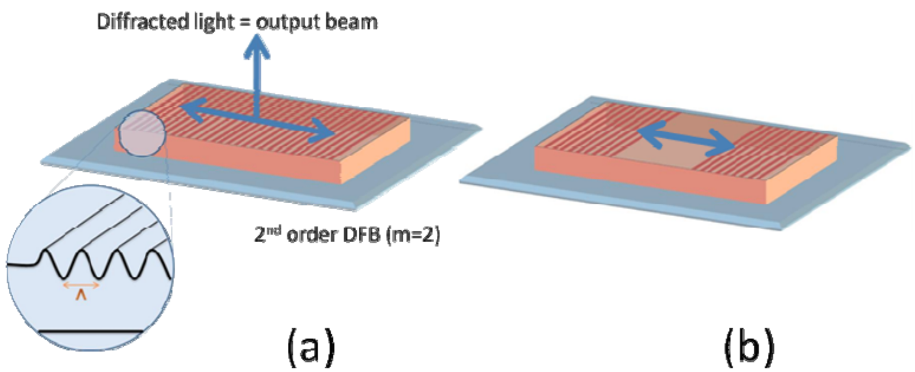
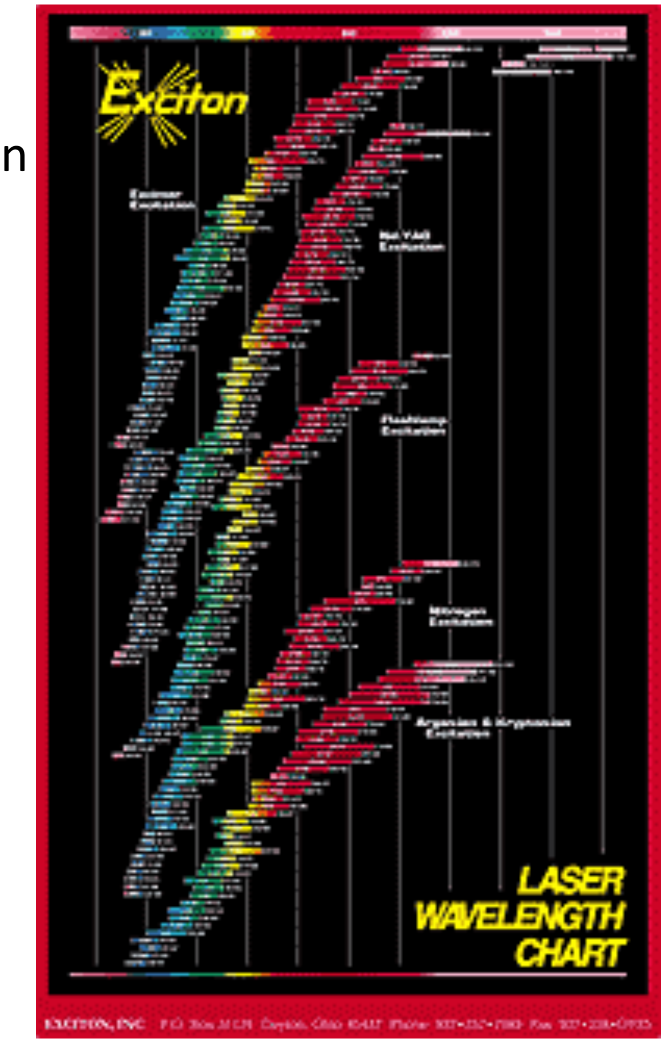


Figure 7 *(a) DFB structure directly engraved onto a polymeric film. If Λ= λ/neff (2nd order grating, m=2) then a diffracted beam (first diffraction order) is emitted in the direction perpendicular to the film plane (b) DBR structure with no corrugation between two Bragg mirrors.*

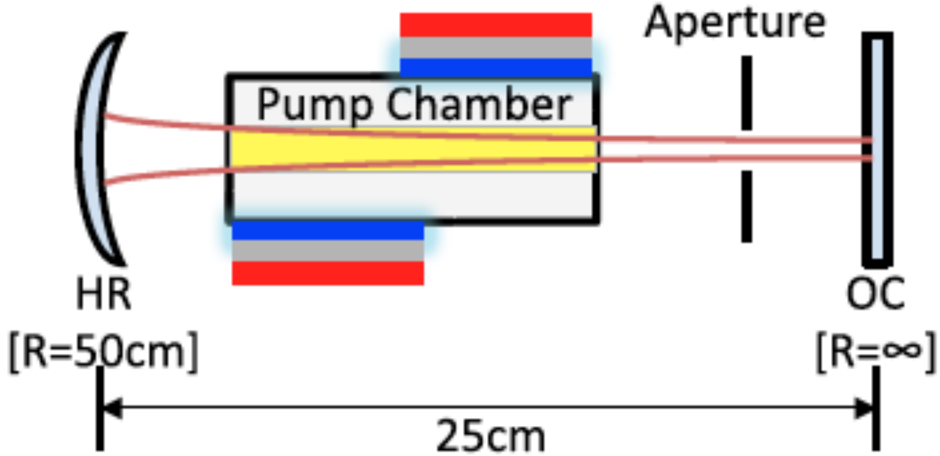


Fiber lasers

- Waveguide with doped core
- Pumping configurations: WDM coupled pump to core or to larger core (dual-core)
- Applications: communications, ultrafast, high power
- Digonnet, M. J. F., & Gaeta, C. (1985). Theoretical analysis of optical fiber laser amplifiers and oscillators. *Applied Optics*, *24*(3), 333–342.
- Sell, A., Krauss, G., Scheu, R., Huber, R., & Leitenstorfer, A. (2009). 8-fs pulses from a compact Er: fiber system: quantitative modeling and experimental implementation. *Optics Express*, *17*(2), 1070–1077.

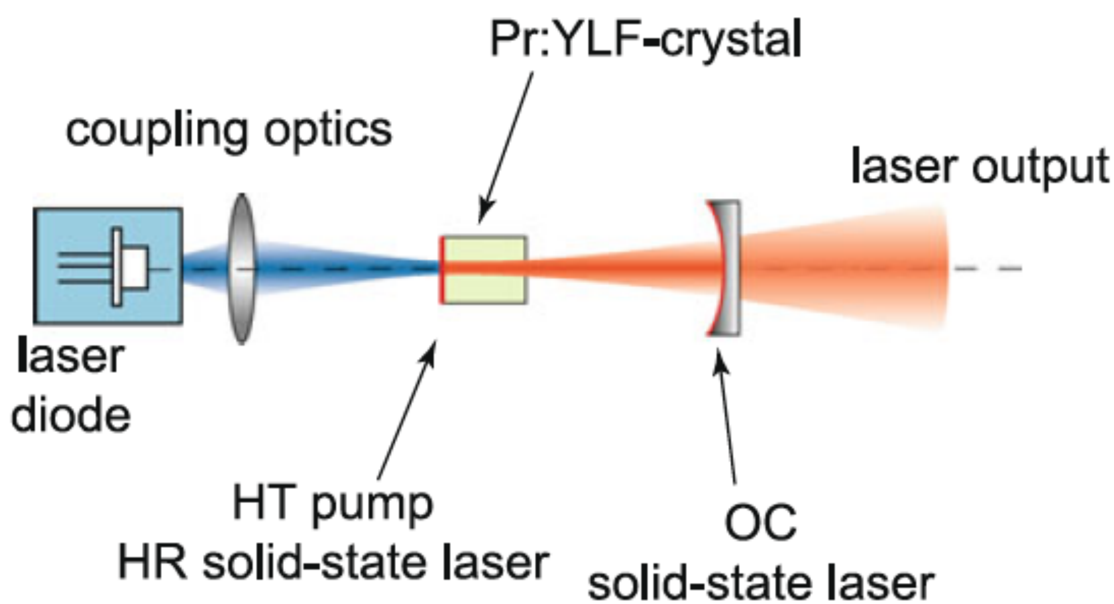
LED-pumped Ce:Nd:YAG laser

- Villars, B., Steven Hill, E., & Durfee, C. G. (2015). Design and development of a high-power LED-pumped Ce:Nd:YAG laser. *Optics Letters*, *40*, 3049. http://doi.org/10.1364/OL.40.003049



Praseodymium lasers

- Blue pump, emission in several bands in the visible
- Weichmann, U., Bellancourt, A. R., Gronenborn, S., Mackens, U., & Moench, H. (2010). Blue diode-pumped Pr:YLF laser with planar resonator optics. *Applied Physics B*, *101*(4), 747–751. http://doi.org/10.1007/s00340-010-4083-x



Slab lasers

- Side pumping, thermal lensing averages out
  - Richards, J., & McInnes, A. (1995). Versatile, efficient, diode-pumped miniature slab laser. *Optics Letters*.

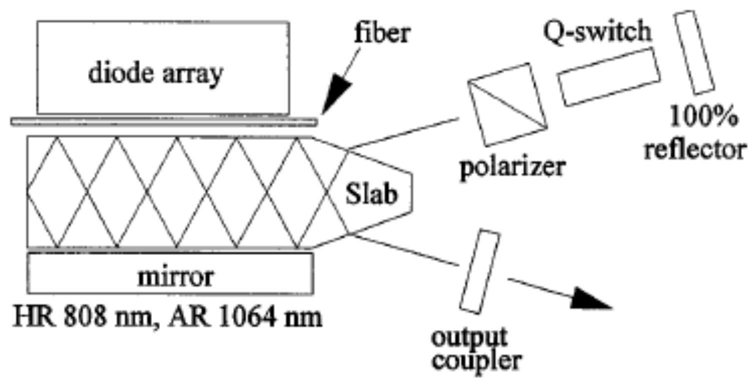


Fig. 1. Diode-pumped slab laser in Q-switched configuration.

Diode-pumped alkali vapor lasers

- Goal: efficiently convert poor laser diode beam to high quality at high power
- Krupke, W. F., Beach, R. J., Kanz, V. K., & Payne, S. A. (2003). Resonance transition 795-nm rubidium laser. *Optics Letters*, *28*(2), 2336–2338. http://doi.org/10.1364/OL.28.002336

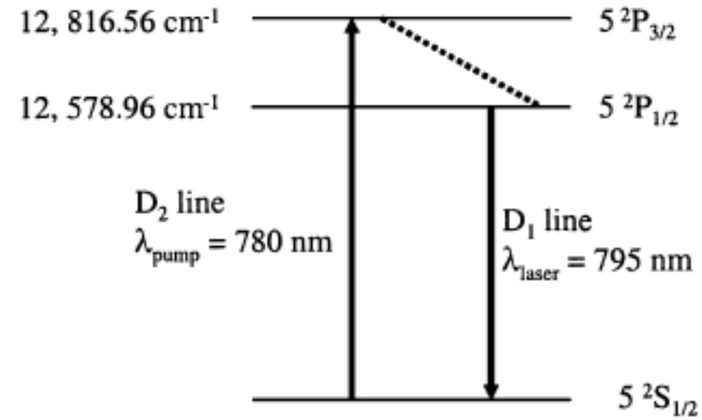


Fig. 1. Energy levels of atomic Rb. The solid lines denote the dipole-allowed D-line transitions involved in the laser, and the dotted line denotes the collisional mixing of the fine structure ${}^2P_{3/2,\,1/2}$ levels that are due to the 75 Torr of ethane in the cell.

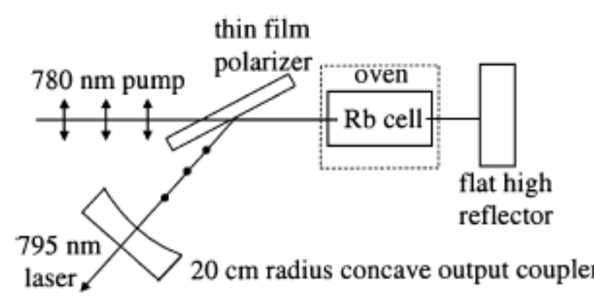


Fig. 2. Schematic diagram of the atomic Rb vapor laser used in our demonstration. The overall cavity length of the laser was 19 cm for the data presented within.

Single-atom laser

- An, K., Childs, J. J., Dasari, R. R., & Feld, M. S. (1994). Microlaser: A laser with one atom in an optical resonator. *Physical Review Letters*, *73*(2), 3375–3378. http://doi.org/10.1103/PhysRevLett.73.3375

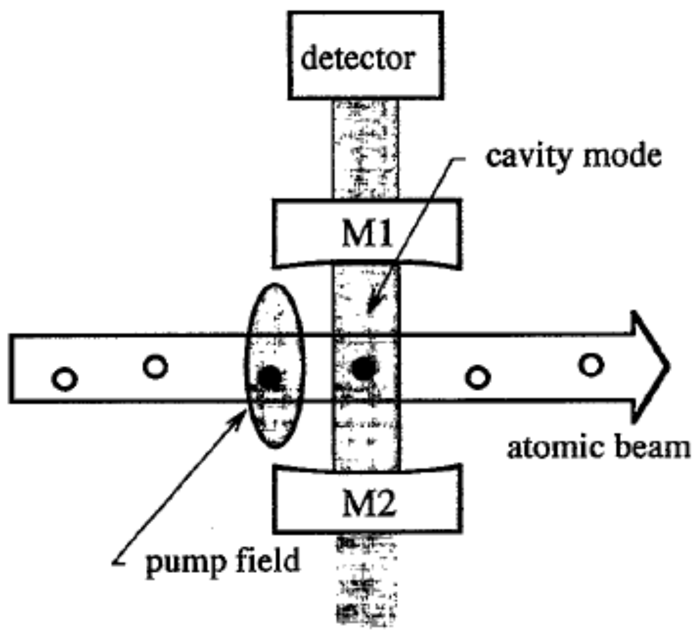
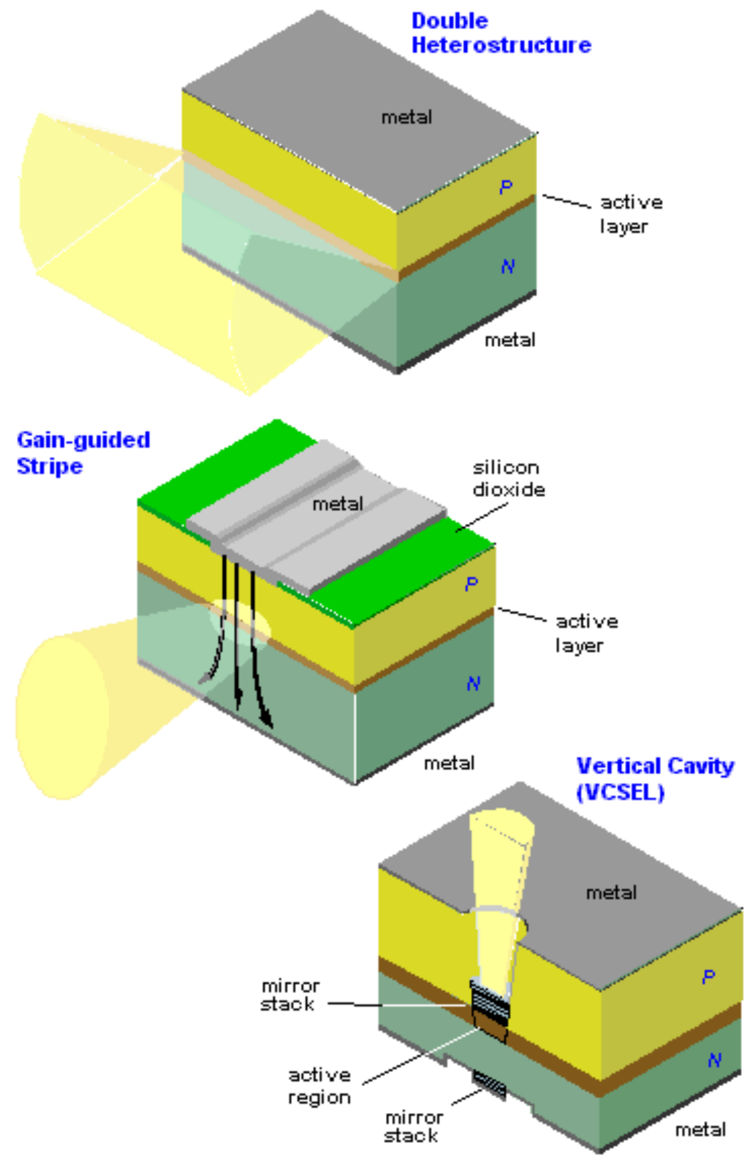


FIG. 1. Schematic of a microlaser experiment.

Semiconductor diode lasers

- Laser architectures:
  - quantum well, VECSL
- External cavity diode lasers
  - Narrow linewidth, tunable
  - Phasing multiple laser emitters, e.g. Talbot cavity
  - Used in atom cooling, remote sensing
- Power scaling:
  - Laser diode bars, fiber-coupled lasers for pumping
- Quantum cascade lasers
  - Tunable mid-IR lasers



Microchip lasers

- Small diode-pumped solid state lasers
- Active or passively q-switched
- Zayhowski, J., & Dill, C., III. (1992). Diode-pumped microchip lasers electro-optically Q switched at high pulse repetition rates. *Optics Letters*, *17*(17), 1201–1203.

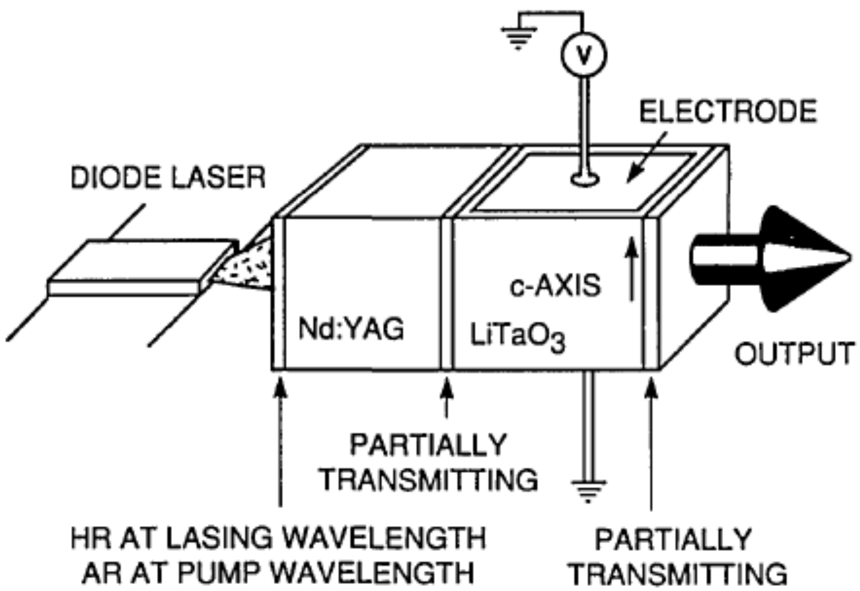
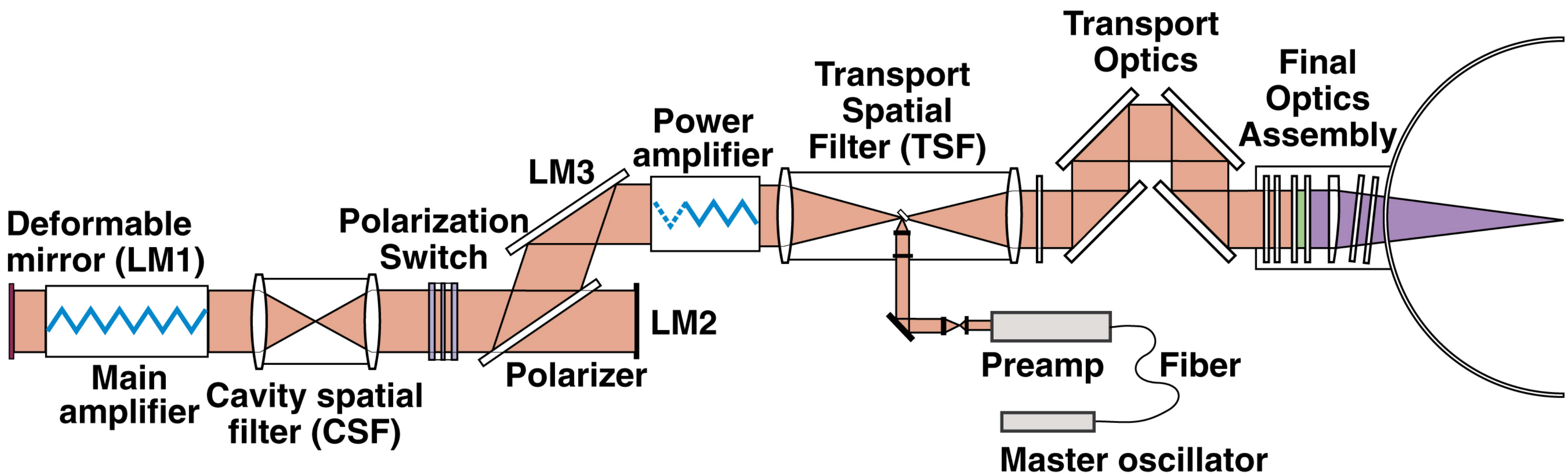


Fig. 1. Illustration of an electro-optically Q-switched microchip laser. HR, highly reflecting; AR, antireflecting.

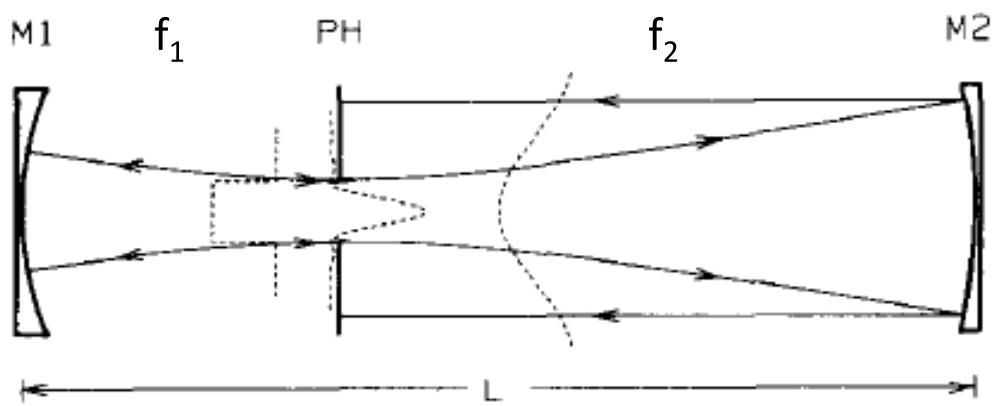
High power lasers and amplifiers



- Nd:glass
  - Highest pulse energy in an amplifier
  - Used in NIF fusion laser and petawatt pulse amplifiers
- CO_2 lasers
  - Highest CW power >10kW
  - Used for cutting and welding

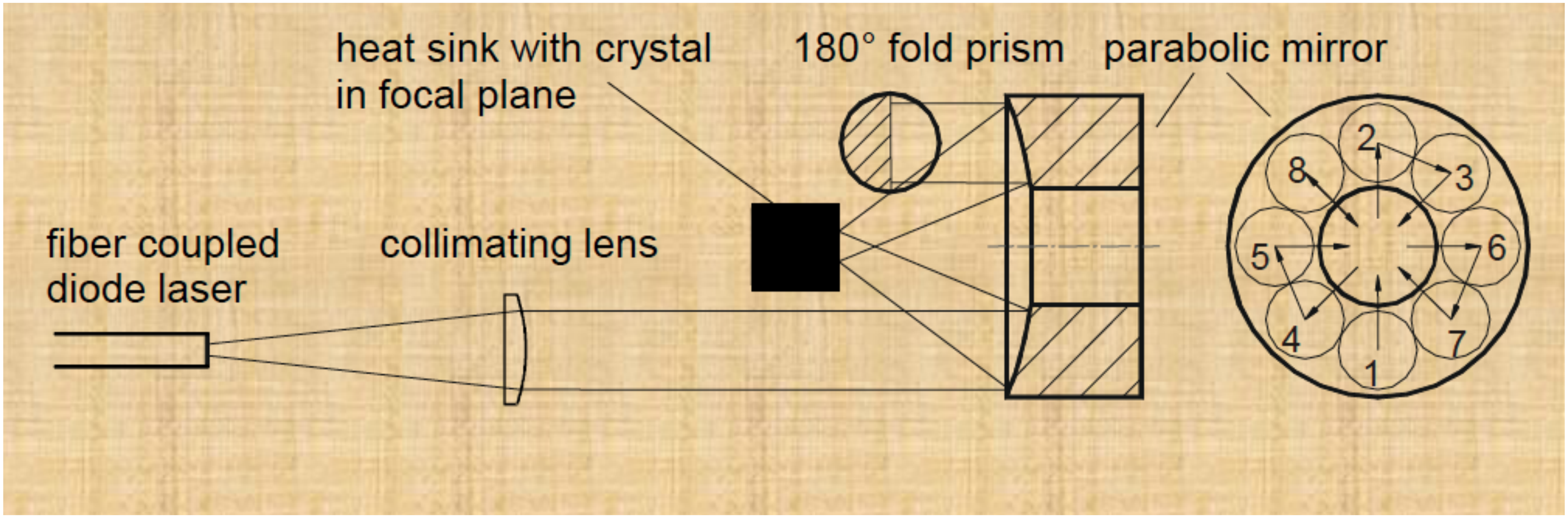
Unstable-resonator lasers/amplifiers

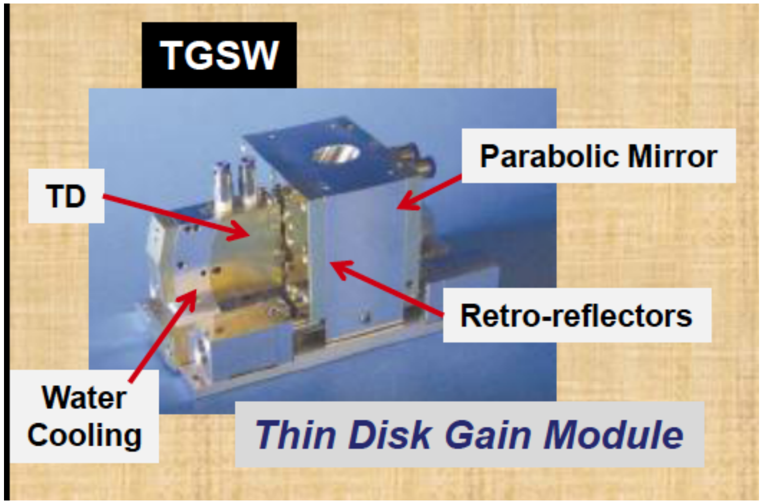
- Self-filtering unstable resonator
  - Gobbi, Opt Commun 52, 195 (1984)



- Other high-gain systems: CO_2, excimer

Thin disk lasers

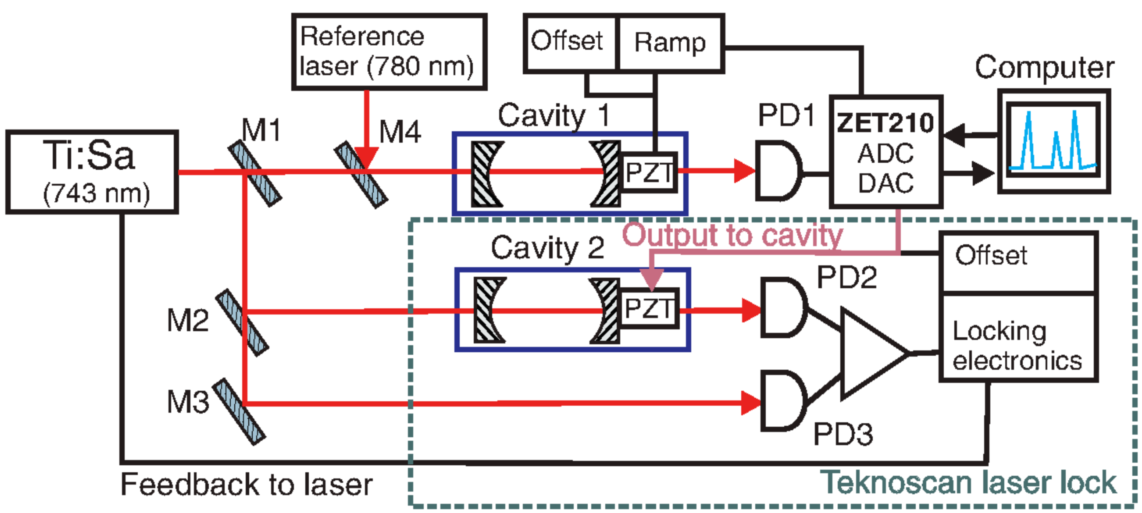




- A. Giesen and J. Speiser, "Fifteen years of work on thin-disk lasers: results and scaling laws", IEEE J. Sel. Top. Quant. Electr., 13 (3), 598 (2007)

Narrow linewidth, stabilized lasers

- External cavity feedback diode lasers
  - Arnold, A. S., Wilson, J. S., & Boshier, M. G. (1998). A simple extended-cavity diode laser. *Review of Scientific Instruments*, *69*(3), 1236. http://doi.org/10.1063/1.1148756
- Locking to atomic transition, separate passive cavity
- Applications to atom clocks, atomic physics, remote sensing



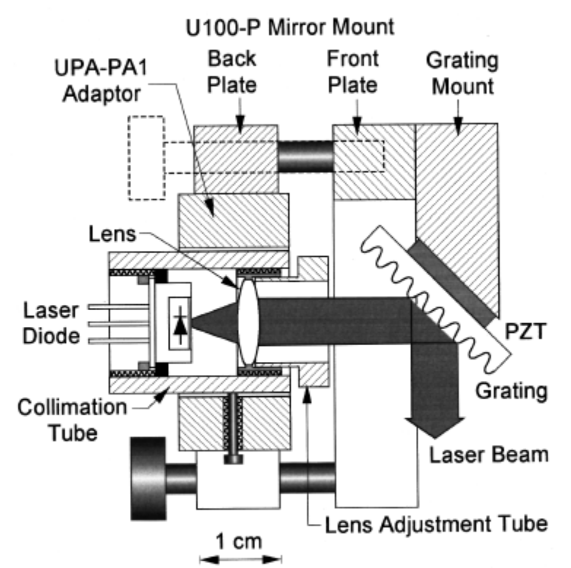


FIG. 1. Schematic diagram of the extended-cavity laser, viewed from above. The Peltier thermoelectric cooler and mounting base are not shown.

Ultrashort pulse lasers

- Ti:sapphire:
  - Kerr-lens and SESAM modelocking
  - Cerullo, G., De Silvestri, S., Magni, V., & Pallaro, L. (1994). Resonators for Kerr-lens mode-locked femtosecond Ti: sapphire lasers. *Optics Letters*, *19*(11), 807–809.
  - Durfee, C. G., Storz, T., Garlick, J., Hill, S., Squier, J. A., Kirchner, M., et al. (2012). Direct diode-pumped Kerr-lens mode-locked Ti:sapphire laser. *Optics Express*, *20*(13), 13677. http://doi.org/10.1364/OE.20.013677
- Amplifiers: high peak power (petawatt and above), high average power
- Other media: Cr:LiSAF, Cr:forsterite, …