Fiber Lasers: Fundamentals and Applications

Lecture - 3

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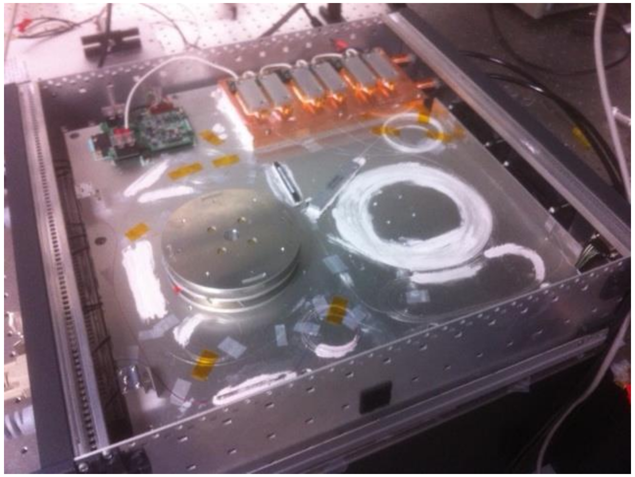
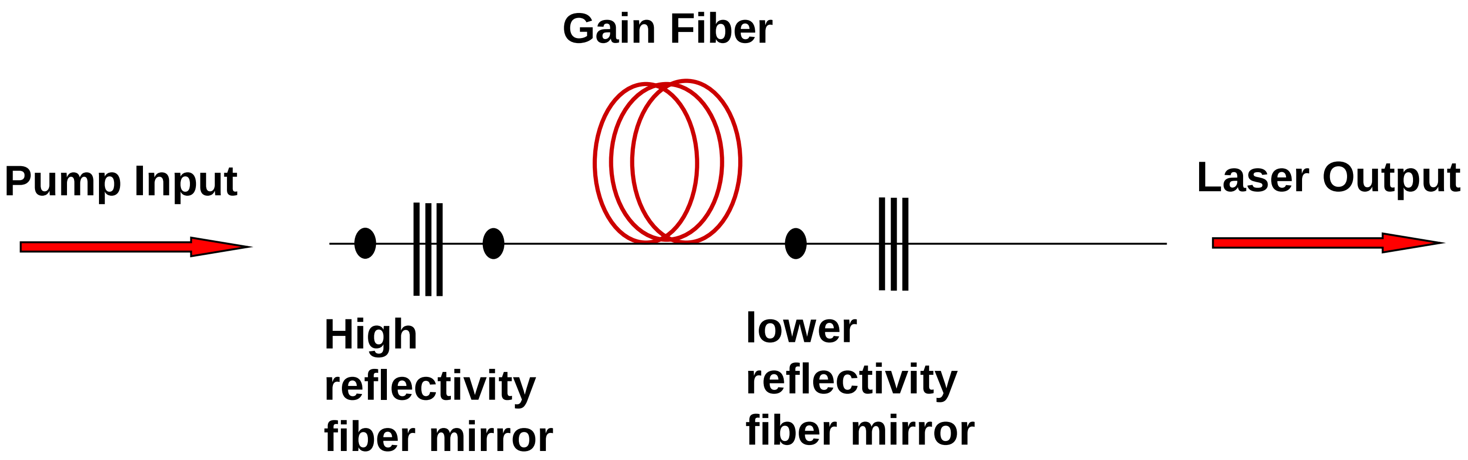


Fiber Laser Characteristics

- Resonator Types
- Laser parameters – Threshold and Efficiency

Fiber Lasers: Resonator Types

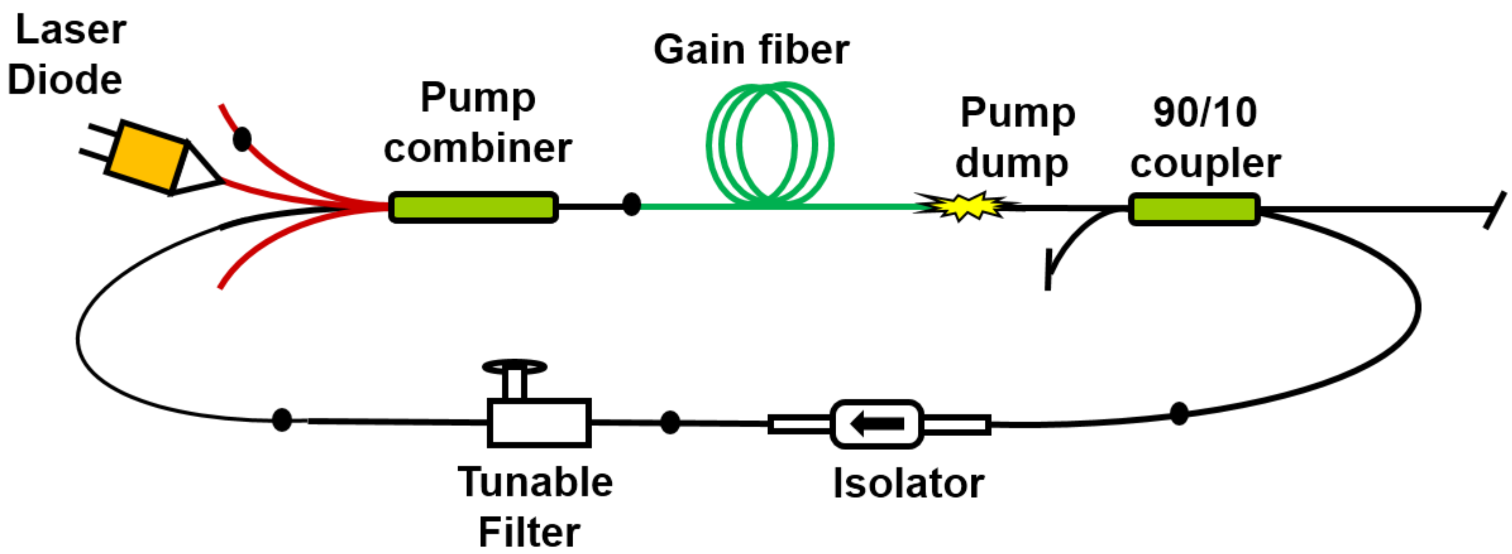
Linear cavity, Fabry Perot, DBR



In each resonator type, pumping direction can be forward, backward or bidirectional

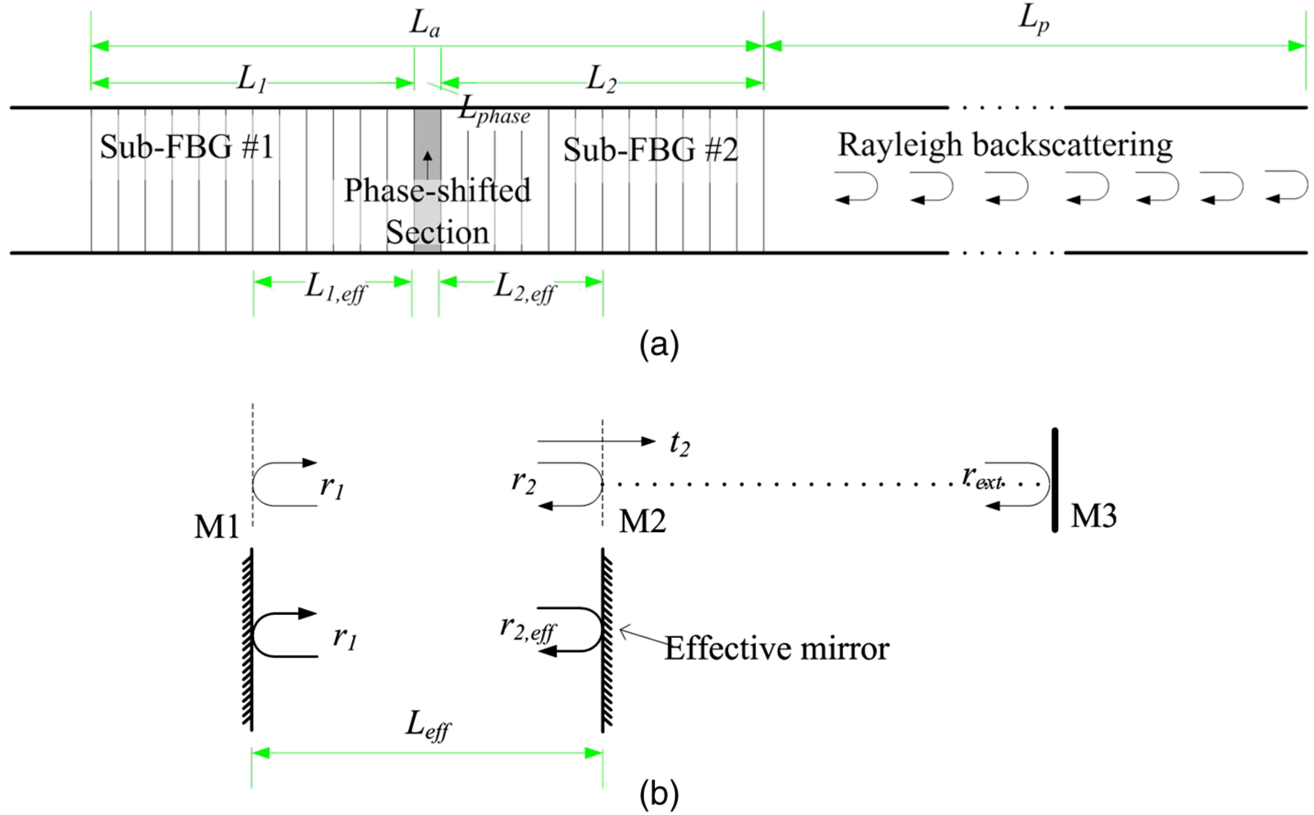
Fiber Lasers: Resonator Types

Ring Cavity



Fiber Lasers: Resonator Types

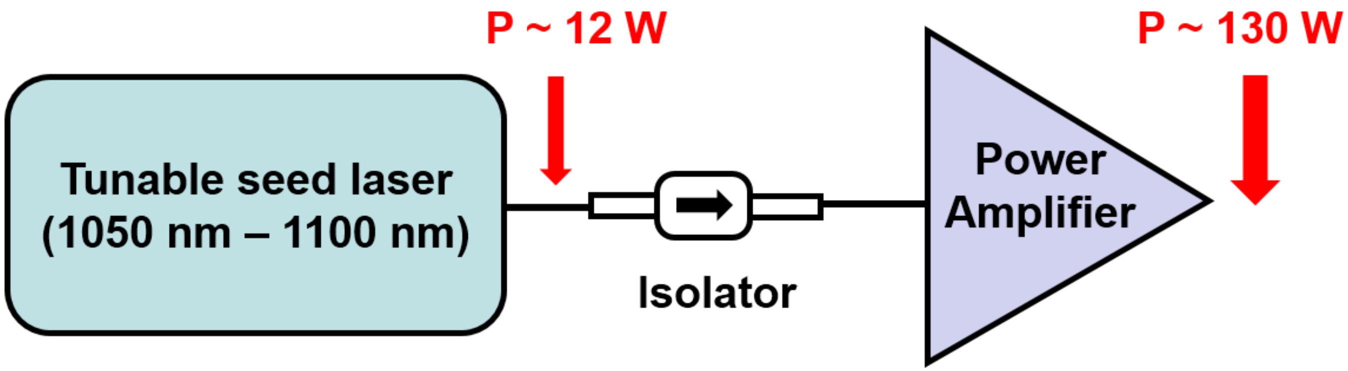
Distributed Feedback cavity



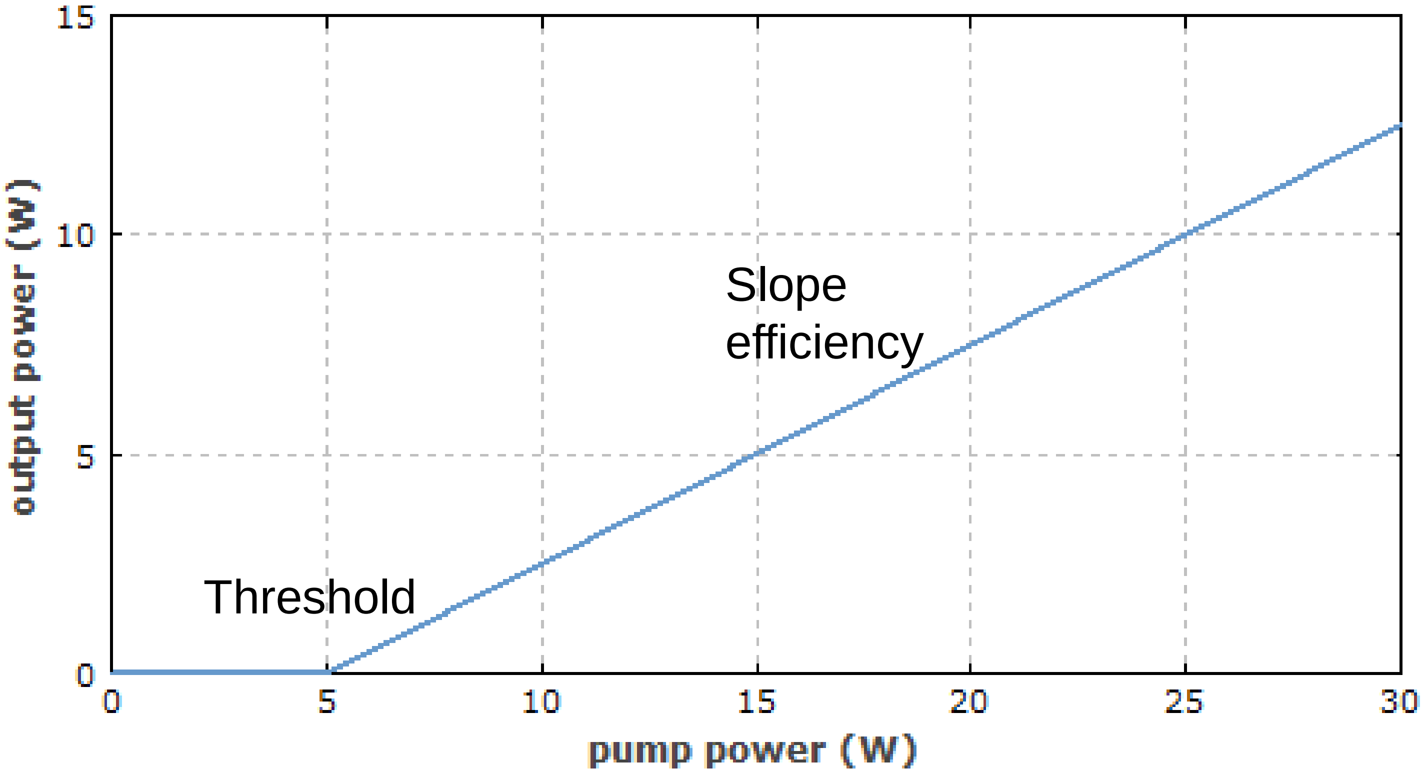
From SPIE Optical Engineering

Fiber Lasers: Resonator Types

Master Oscillator, Power Amplifier (MOPA)



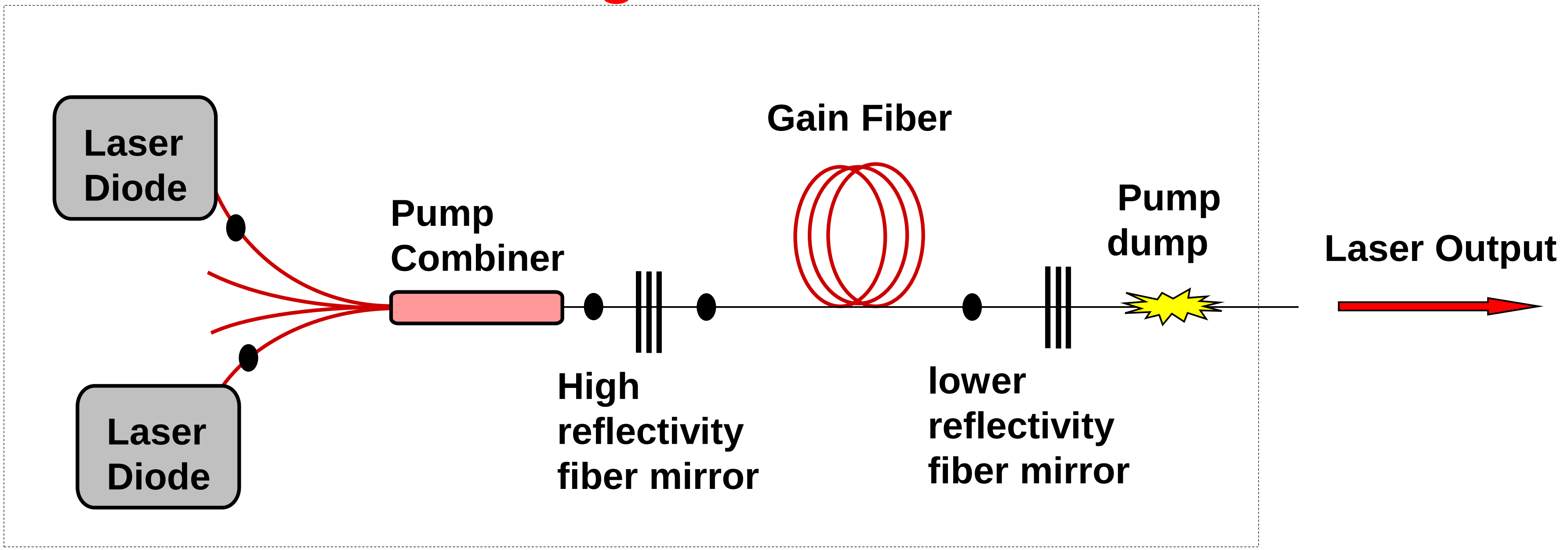
Laser Parameters: Threshold, Slope Efficiency



Frequently: Lower threshold means lower efficiency

From encyclopedia of laser physics and technology

Schematic of a High Power CW Fiber Laser



Key components

- Laser diodes
- Gain fiber (Rare earth doped)
- Fiber mirrors
- Laser diode (Pump) combiner
- Pump dump

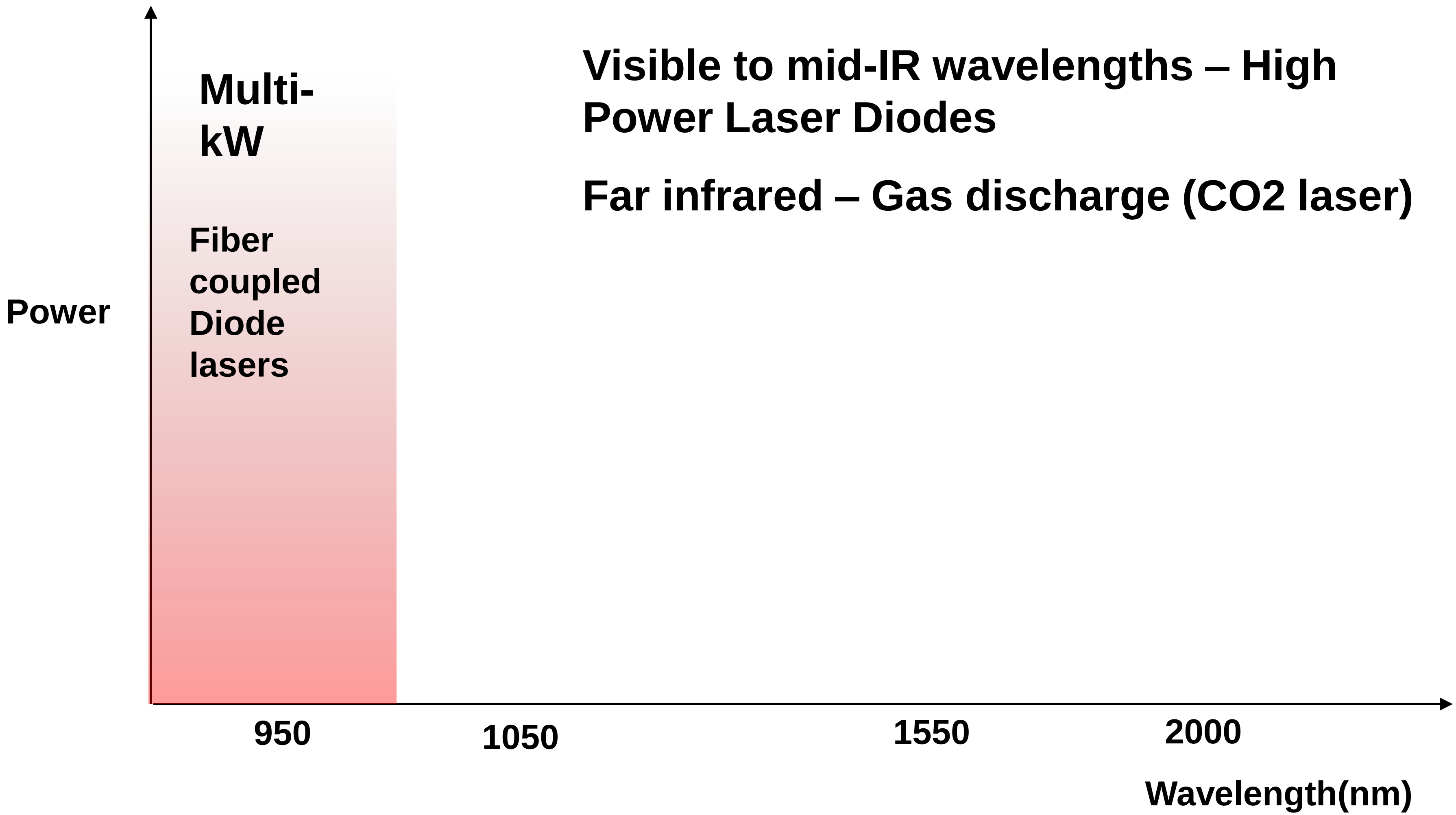
Key process steps

- Design
- Optical fiber splicing
- Fiber recoating
- Measurement and testing

Starting Point: High Power Laser Diodes

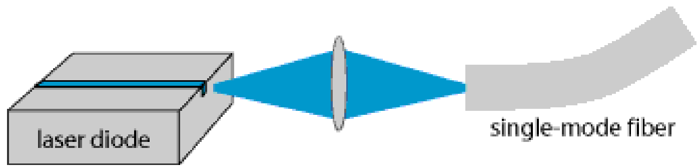
Visible to mid-IR wavelengths – High Power Laser Diodes

Far infrared – Gas discharge (CO2 laser)

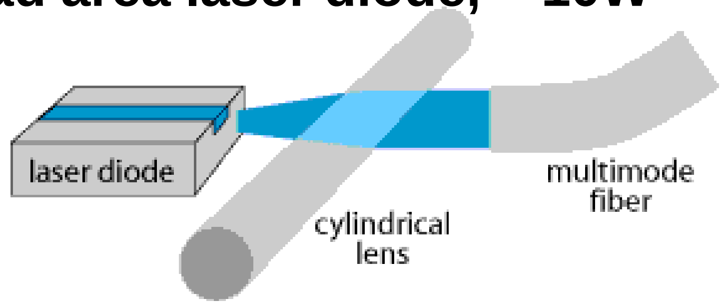


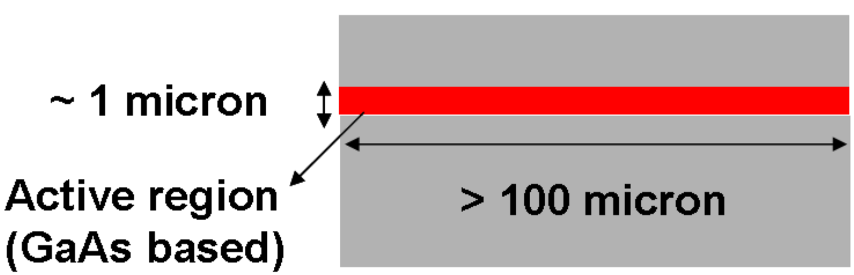
High Power Laser Diodes

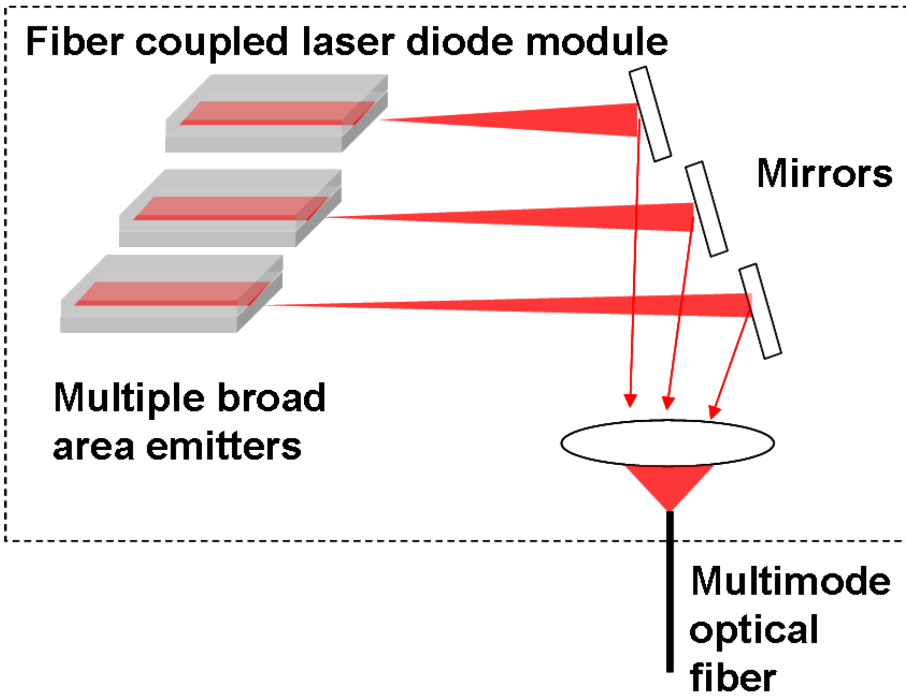
Low power laser diode, < 1W



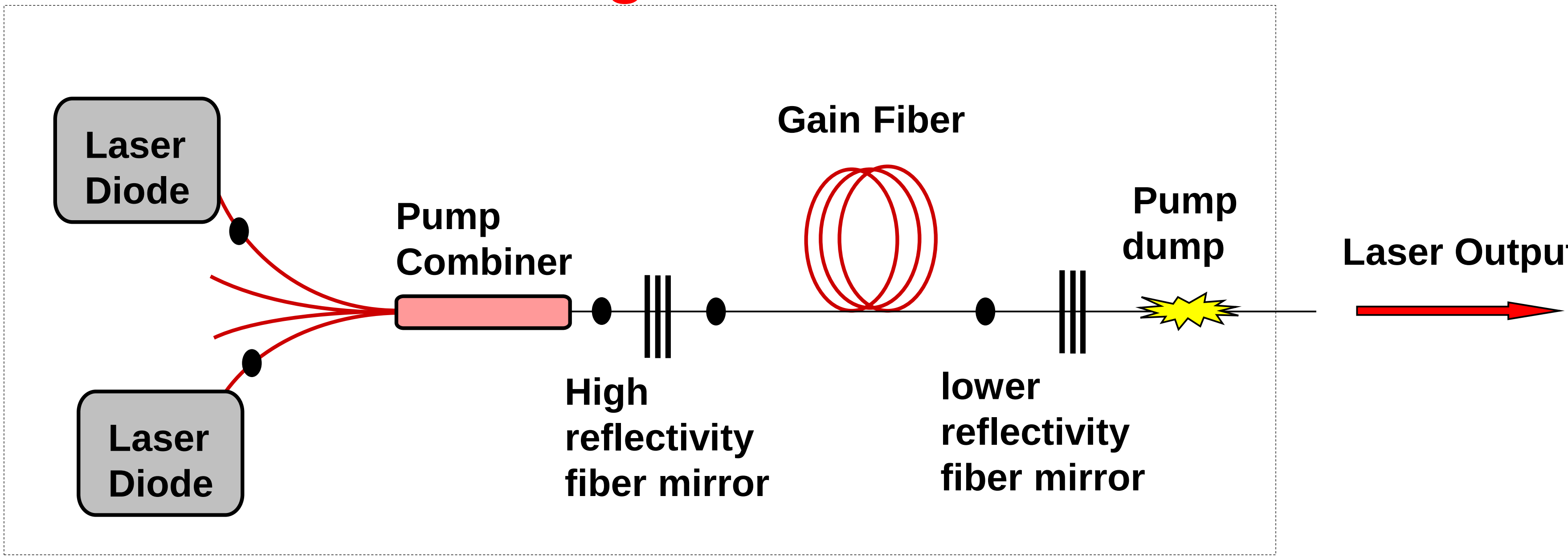
Broad area laser diode, ~ 10W







Schematic of a High Power CW Fiber Laser



Key components

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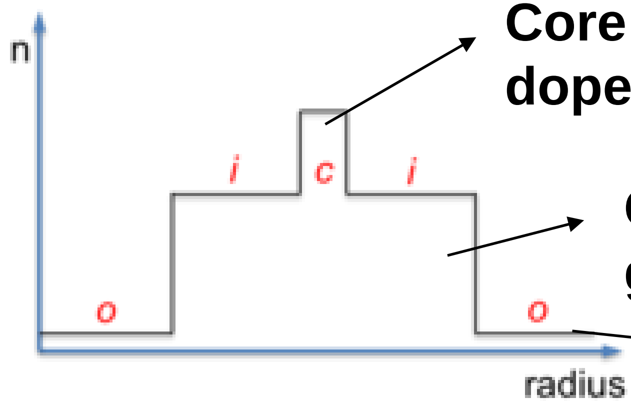
Rare-earth Doped Optical Fibers



Core – guides signal, doped with rare-earth

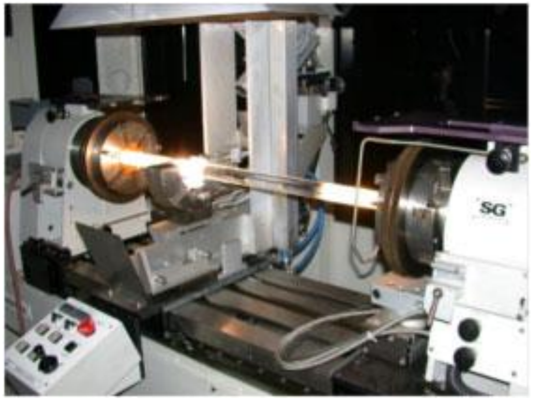
Cladding – undoped, guides pump

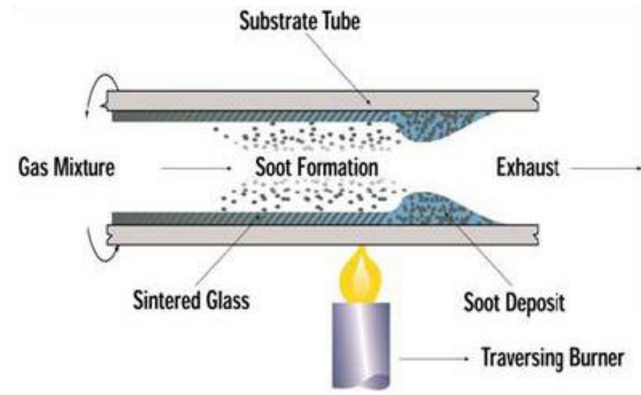
Coating (low index)

Start with high purity glass tubes

From heraeus

MCVD Process



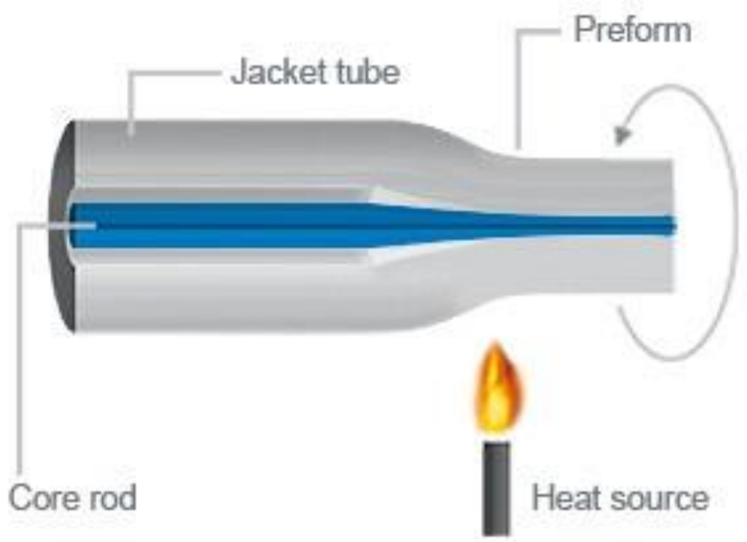


$$SiCl_4 + O_2 \Leftrightarrow SiO_2 + 2Cl_2$$

$$GeCl_4 + O_2 \Leftrightarrow GeO_2 + 2Cl_2$$

Rare-earth Doped Optical Fibers

Tube collapse

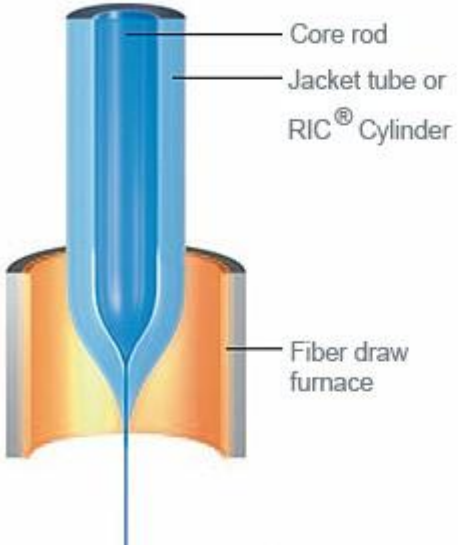


Optical Fiber Preforms

From heraeus

Rare-earth Doped Optical Fibers

Optical Fiber Draw

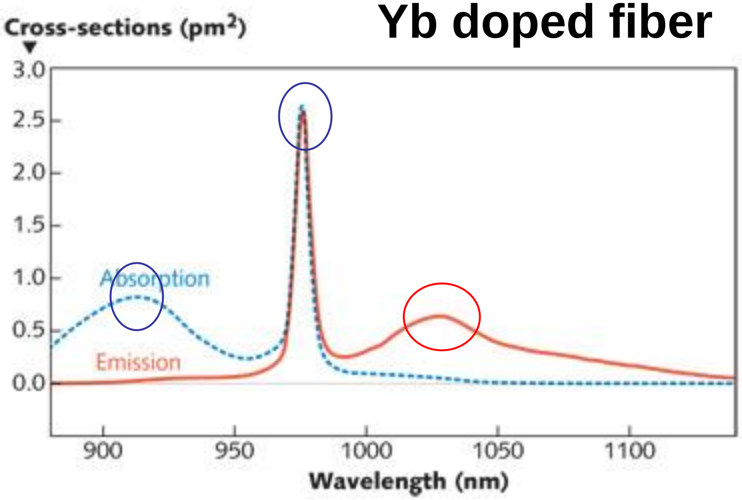


For double-clad fibers: a lower index polymer coating is applied after draw

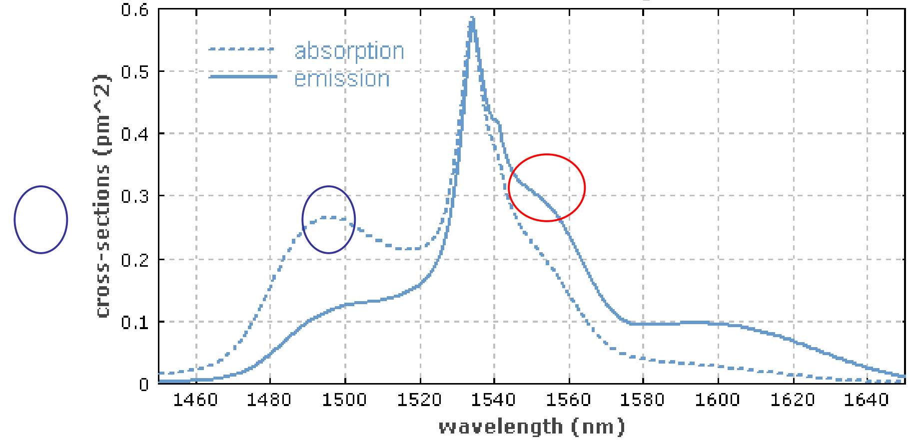
From heraeus, bell labs

Absorption in Rare earth Doped Fibers

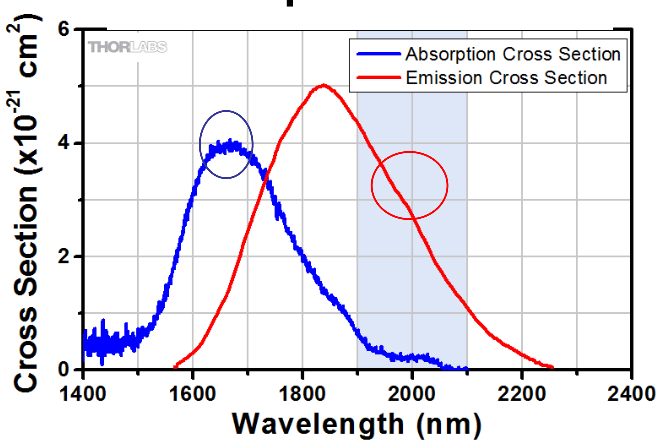
Yb doped fiber



Er doped fiber



Th doped fiber

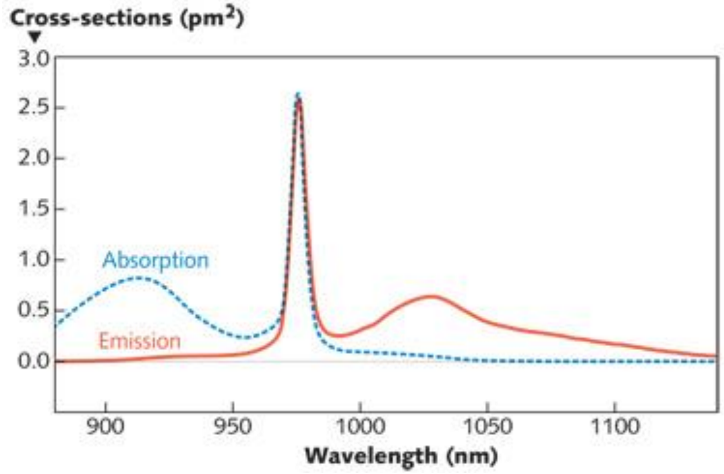


Fundamental Conversion Efficiency

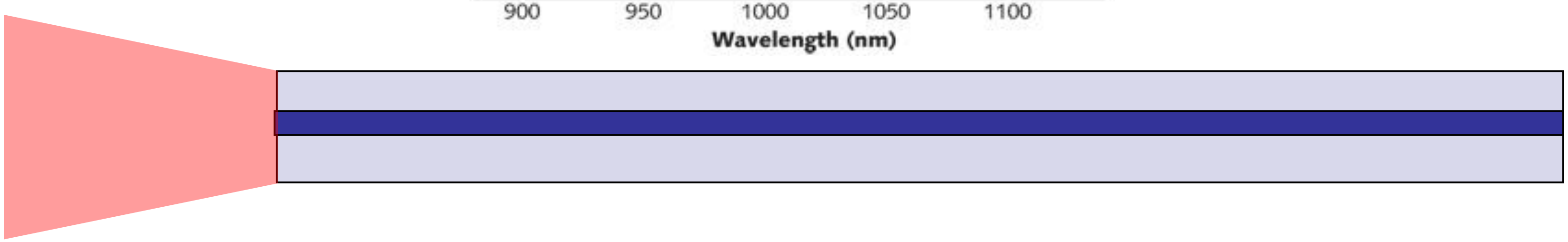
Pump wavelength/Signal Wavelength

Reduced quantum efficiency = high heat load

Absorption in Ytterbium Doped Fibers



Wavelength drift of pump diodes need to be considered



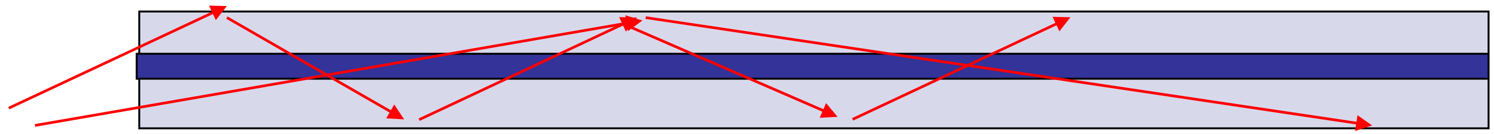
Net absorption ~ core absorption*(core area)/(cladding area) (wavelength dependent)

Some numbers – core abs (Yb doped fiber at 975nm) ~700dB/m, core, cladding dimensions – 6/125 micron

Net absorption ~ 1.6dB/m (at 975nm)

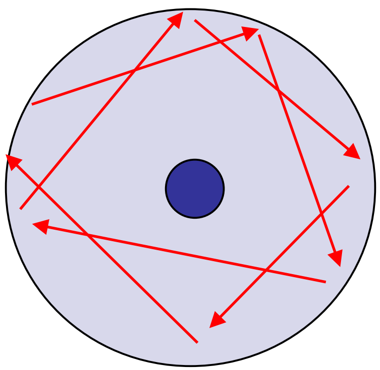
Double Clad Fibers: Cladding Effects

Early cladding pumped fiber lasers had unnaturally low efficiency !



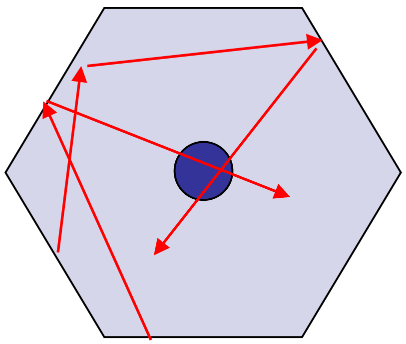
1-D case

Low core overlap

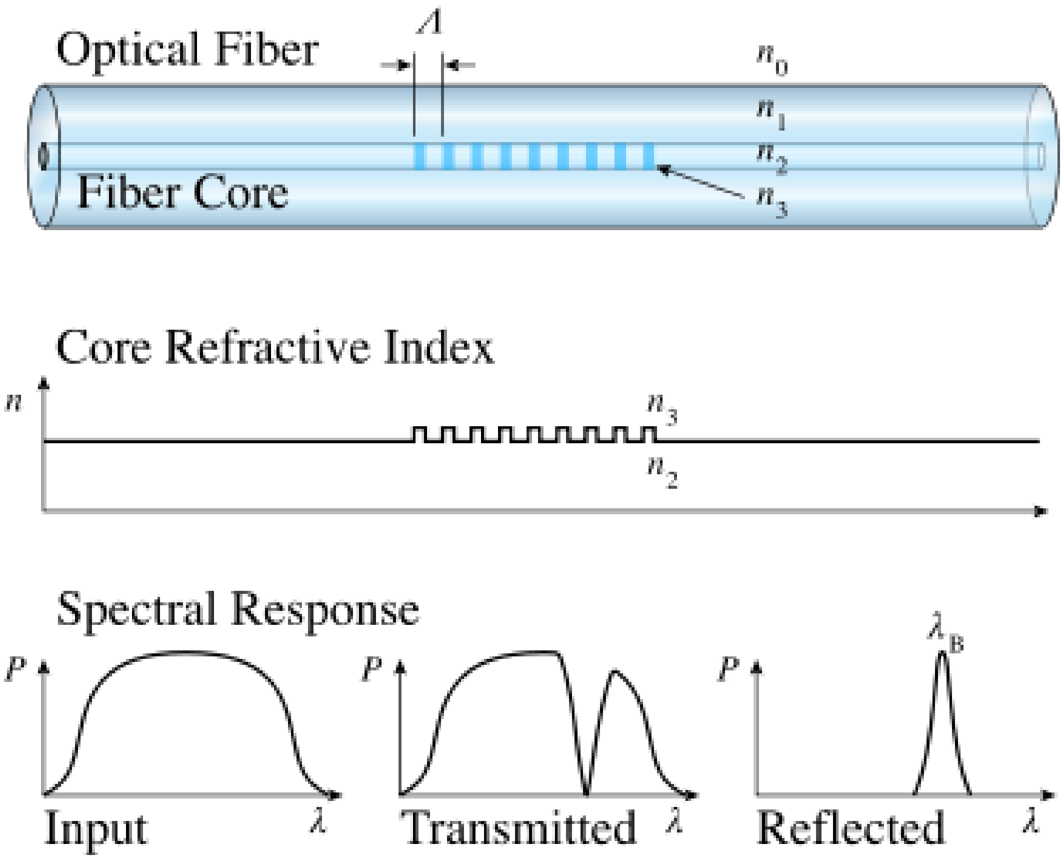


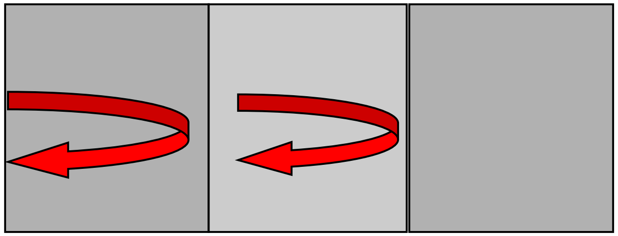
2-D (Actual) case

Shaped Cladding solves the problem



Fiber Mirrors: Fiber Bragg gratings

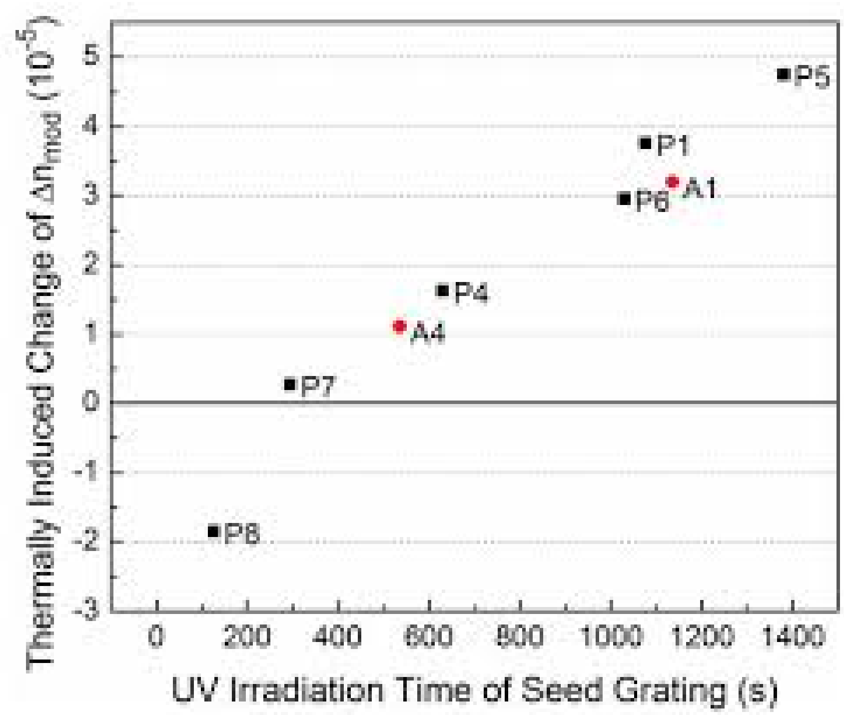




Reflected wavelength = 2*neff*period

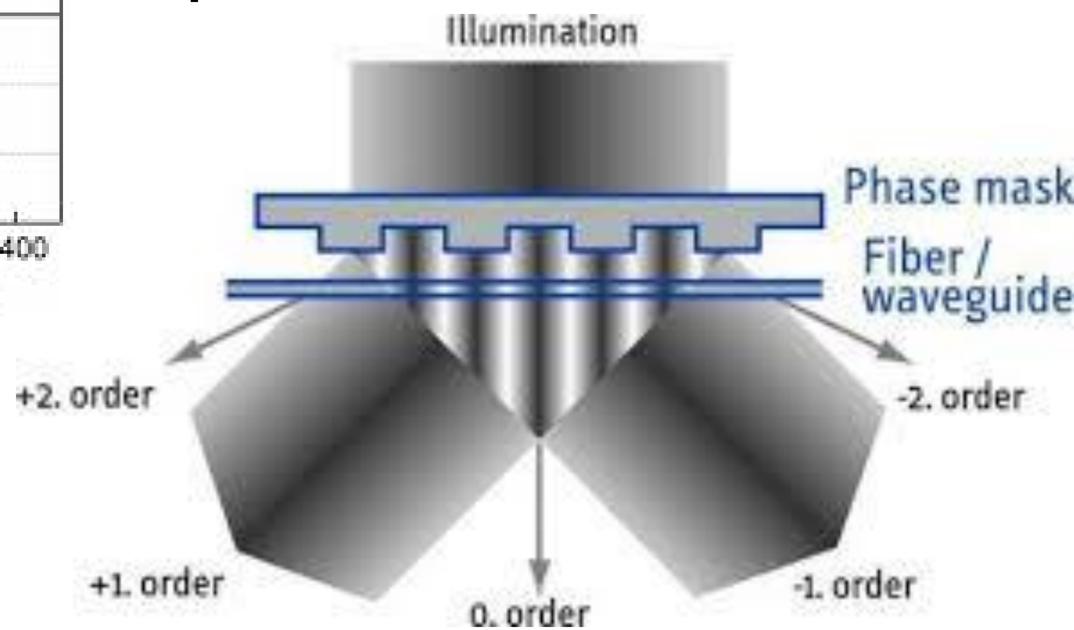
From wikipedia

Fiber Bragg gratings: Fabrication



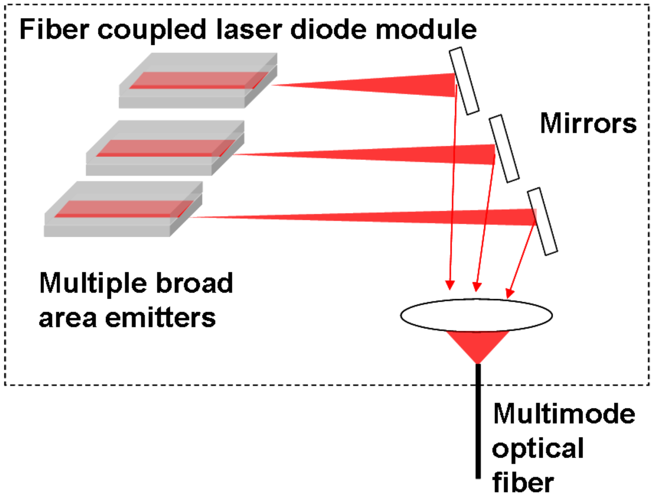
Exposure to UV (242nm) modifies the refractive index of optical fiber core

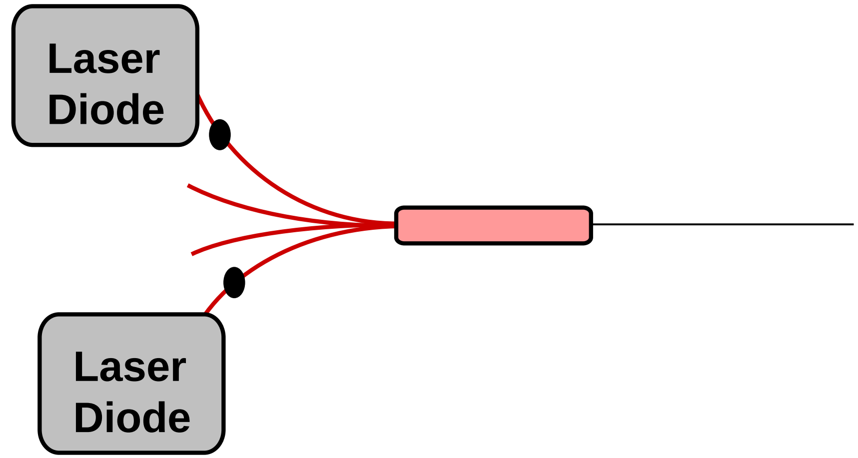
- **Interaction with Germania dopants**



From Ibsen Photonics

Pump Combiners





Pump combiners combine multiple diode modules

Brightness conservation –

Total input brightness >= Output brightness

For optical fibers – a measure of brightness = fiber diameter X NA (numerical aperture)

NA = $\sqrt{n_{core} \wedge 2 - n_{cladding} \wedge 2}$

Pump Combiners

Output properties should be the same as the gain fiber

- **Currently the choice of gain fiber properties is small – NA = 0.45 and D = 125, 200, 250 and 400 micron**

Input fibers are decided by the pump diodes

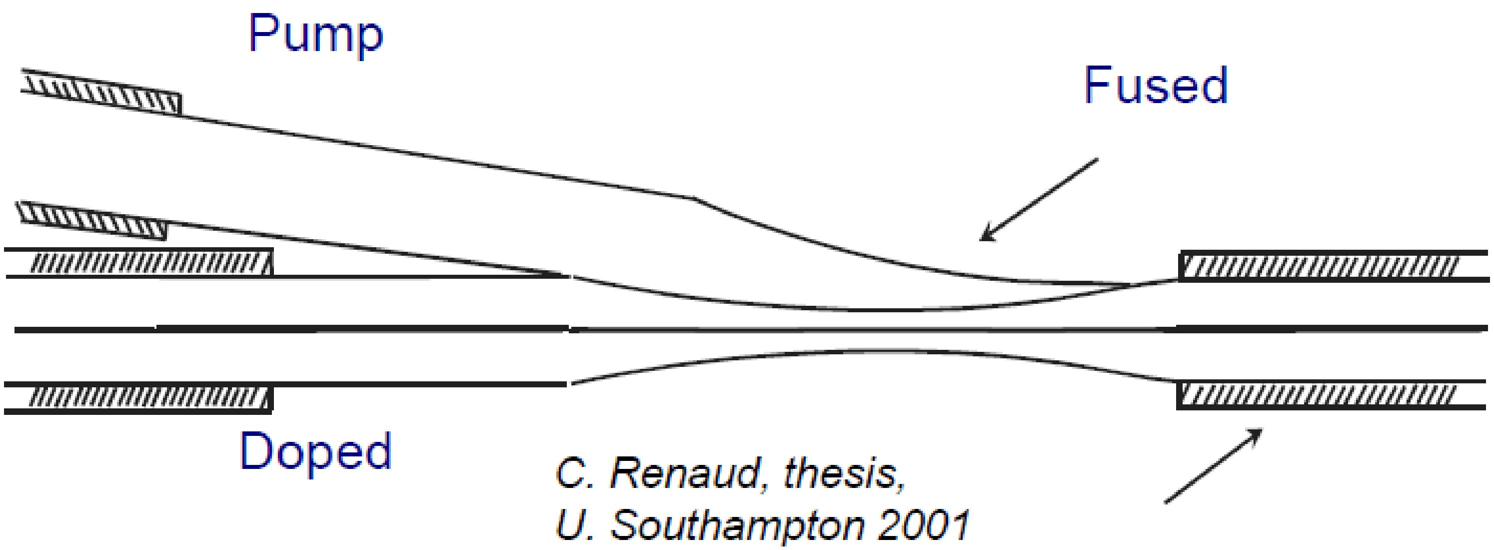
- **Current dimensions – 105micron, 200 micron, NAs of 0.15 and 0.22**
- **Output powers per module ~ 10W, 25W, 55W, 80W….**

Combiner brightness conservation equation

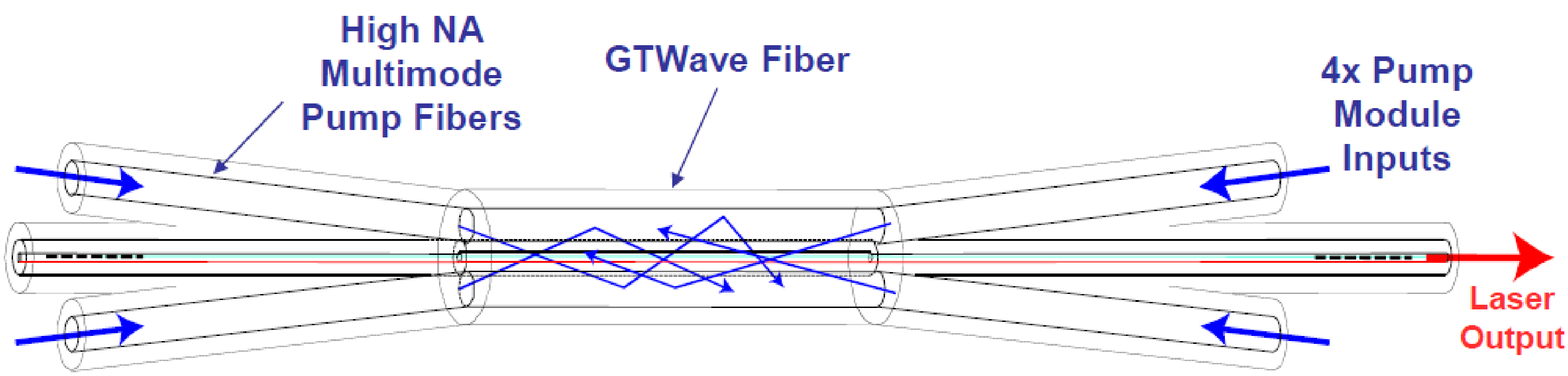
$$sqrt(n) * D_{input} * NA_{input} = D_{output} * NA_{output}$$

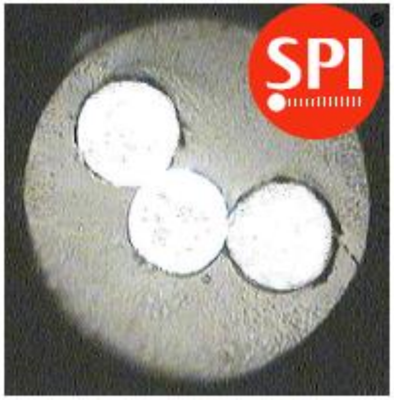
This tells us the maximum power that can be combined

Pump Combiners – Side Splicing



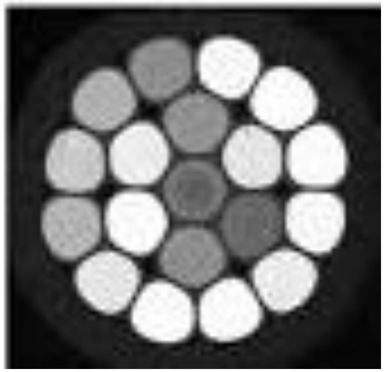
Pump Combiners – GT Wave

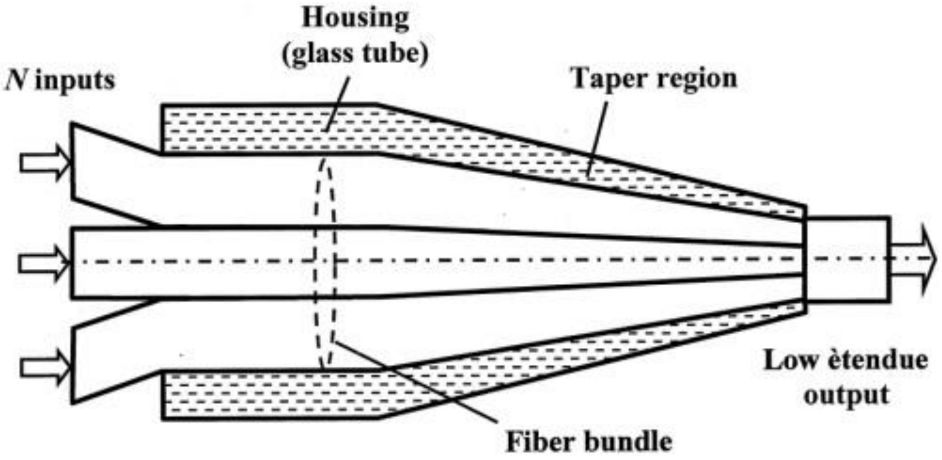




Pump Combiners – Tapered Bundles

Fused fiber bundle





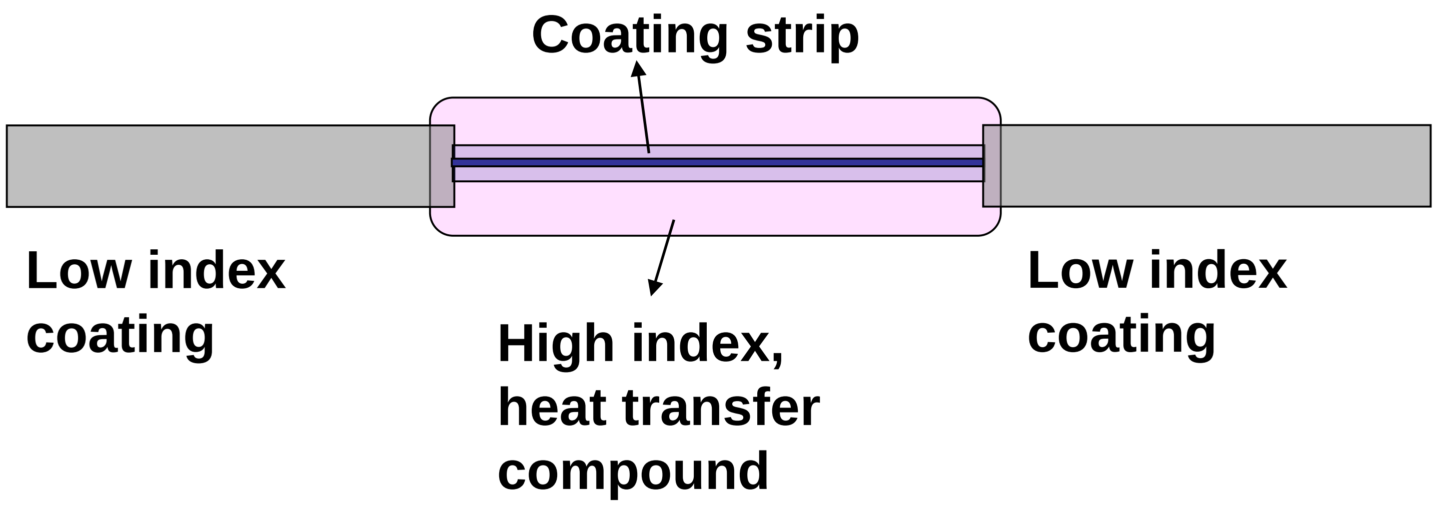
Due to hexagonal close packing advantages – standard combiners have 7, 19 ports

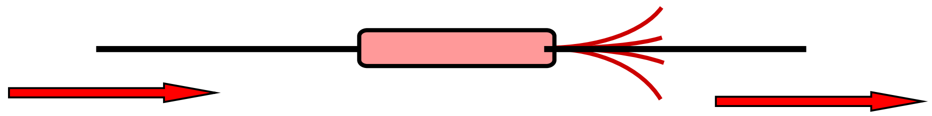
Example combiners – 7 to 1 (105, 0.15 NA to 125, 0.45NA)

19 to 1 (105, 0.15NA to 200, 0.45NA)

Need for output power decides simultaneous choice of pump diodes and combiner

Pump Dump (Cladding power stripper)





Reverse pump combiner (with terminated ports)

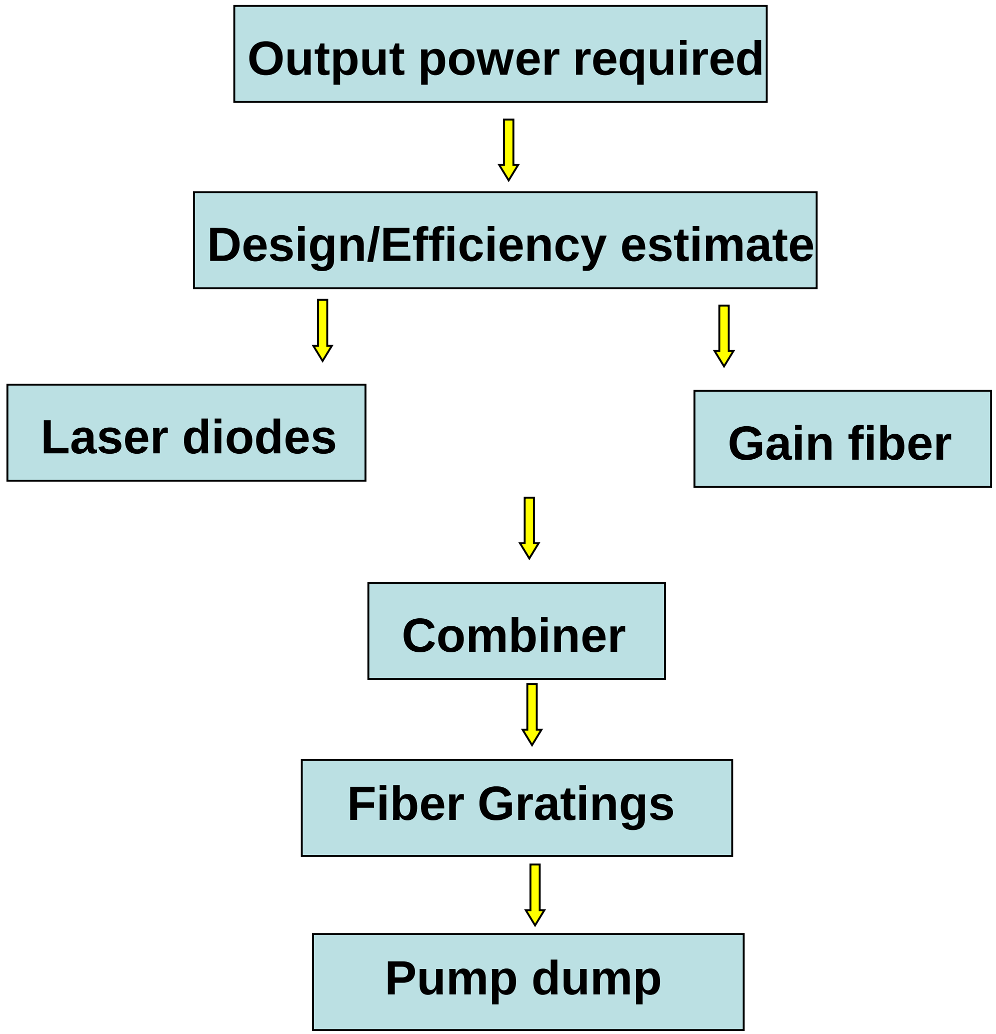
Performance Estimation

Loss contributors

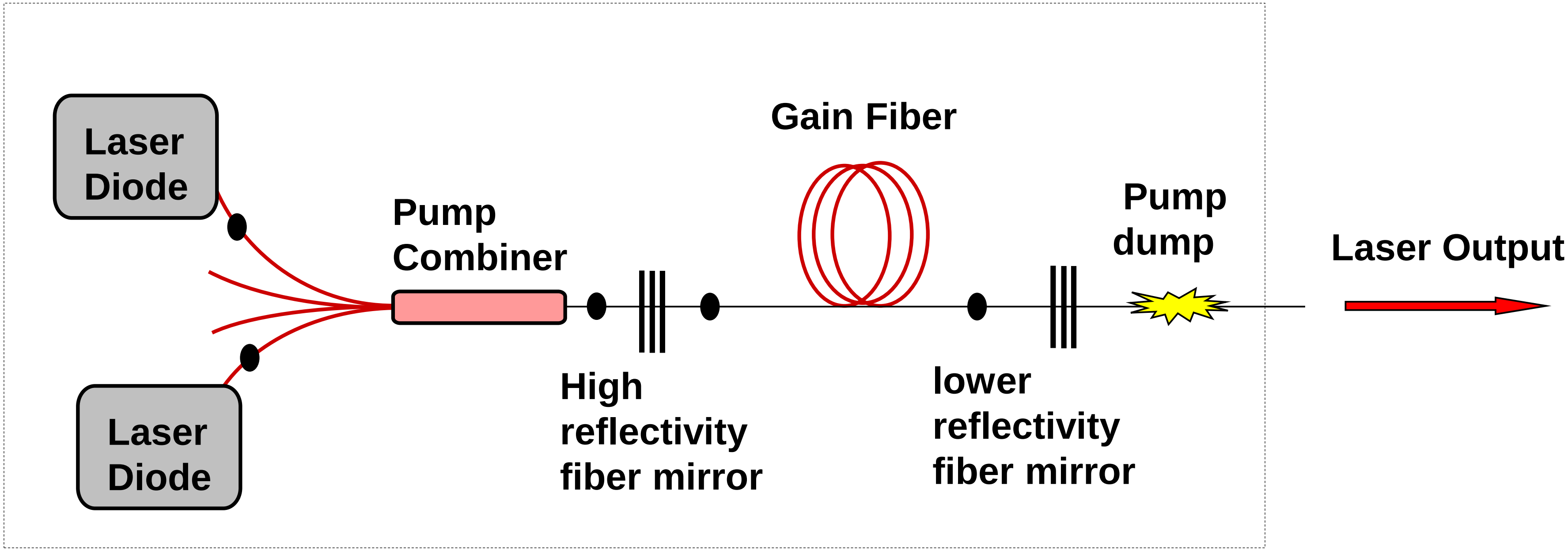
- **Pump combiner – 5% (0.95 transmission)**
- **Splice losses - 1% per splice (~5 splices, 5%) (0.95 transmission)**
- **Light leakage behind the high reflector – 3%**
- **Quantum limited efficiency (975/1064 ~ 91%)**

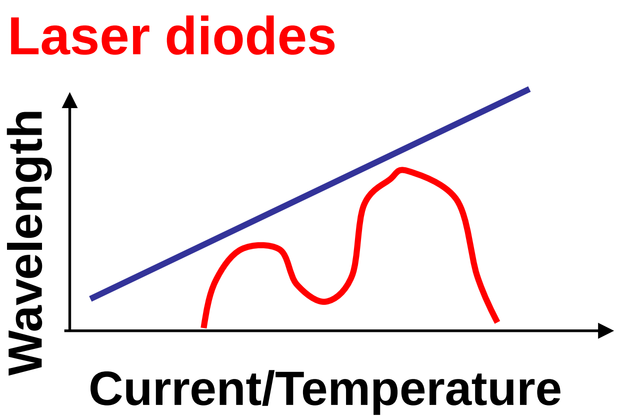
Net efficiency – 0.95*0.95*0.97*0.91 = 79% (70-80% in practice)

Flowchart - Design



Build Procedure: Design





- **Laser diodes with similar wavelength drift properties**
- **Data on diode behavior measured (needed for gain fiber, pump dump stage)**

Build Procedure: Design

Gain fiber

- **Choose enough fiber for >15dB total absorption + margin to account for laser diode drift**
- **Pump dump has a power rating it can dissipate, gain fiber should always be long enough to overcome this.**

Laser diodes and Gain fiber fix combiner

Fiber mirror

- **At the wavelength of choice in the emission window**
- **High reflectivity grating (>99%) reflection, 1-3nm bandwidth**
- **Low reflectivity grating (<10%) reflection, 0.5-1nm bandwidth**
  - **Highly asymmetric cavities**

Build Procedure: Design

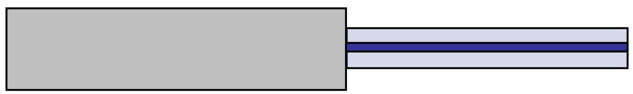
Pump dump (cladding mode stripper)

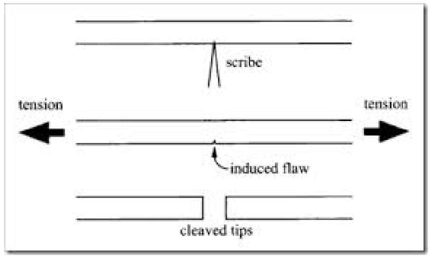
- **Maximum amount of unabsorbed pump can be estimated from**
  - Length of gain fiber
  - Wavelength drift of diodes
  - Total power

The pump dump should be testing to ensure its survivability at the maximum amount of dissipated power (for long enough durations)

Build Procedure: Optical Fiber Splicing

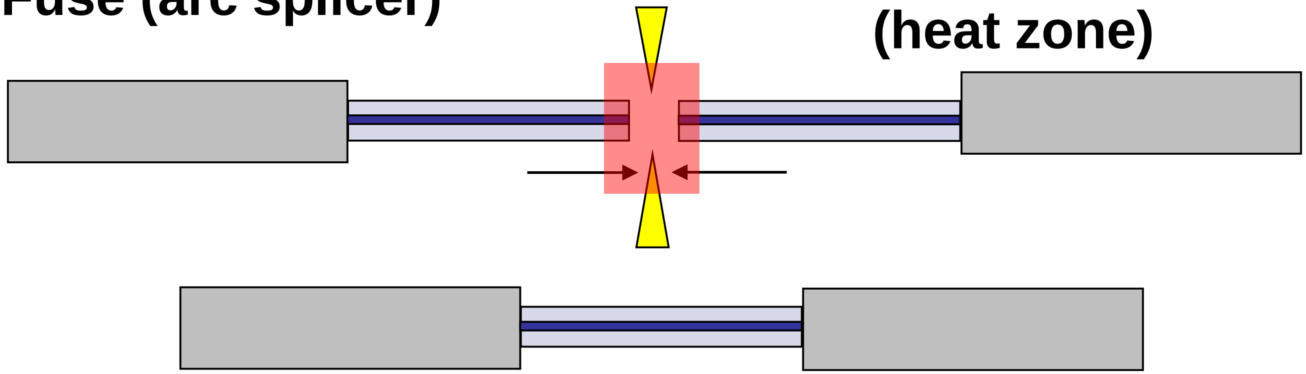
Strip and cleave (wheel cleaver)



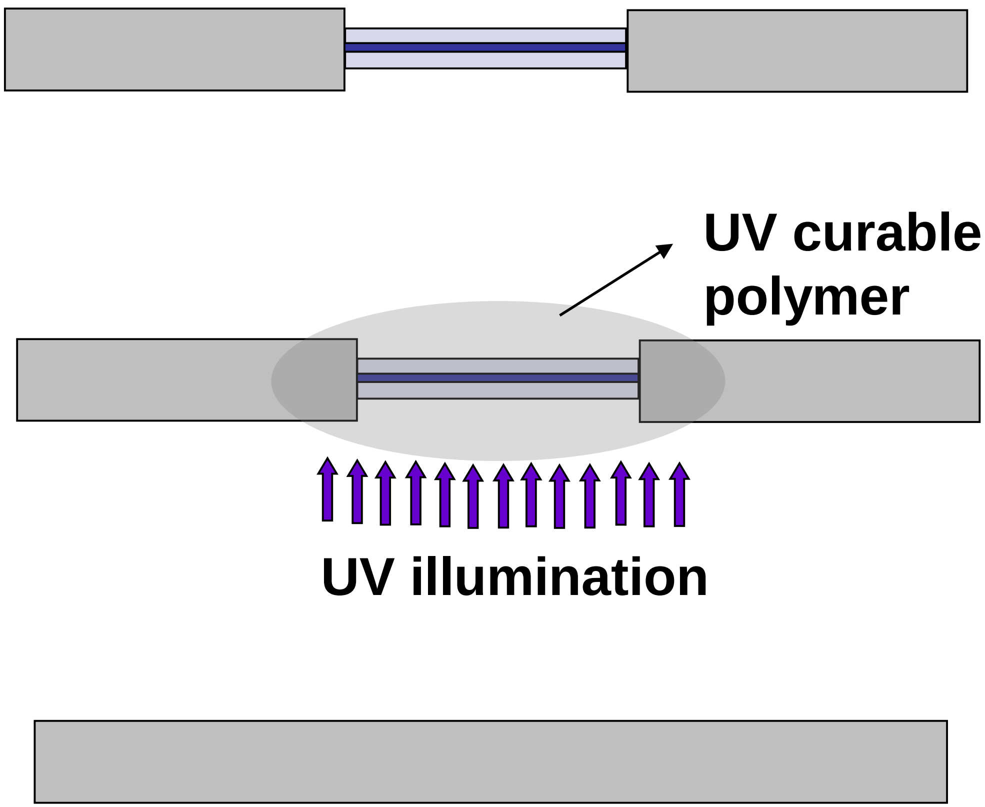


Fuse (arc splicer)

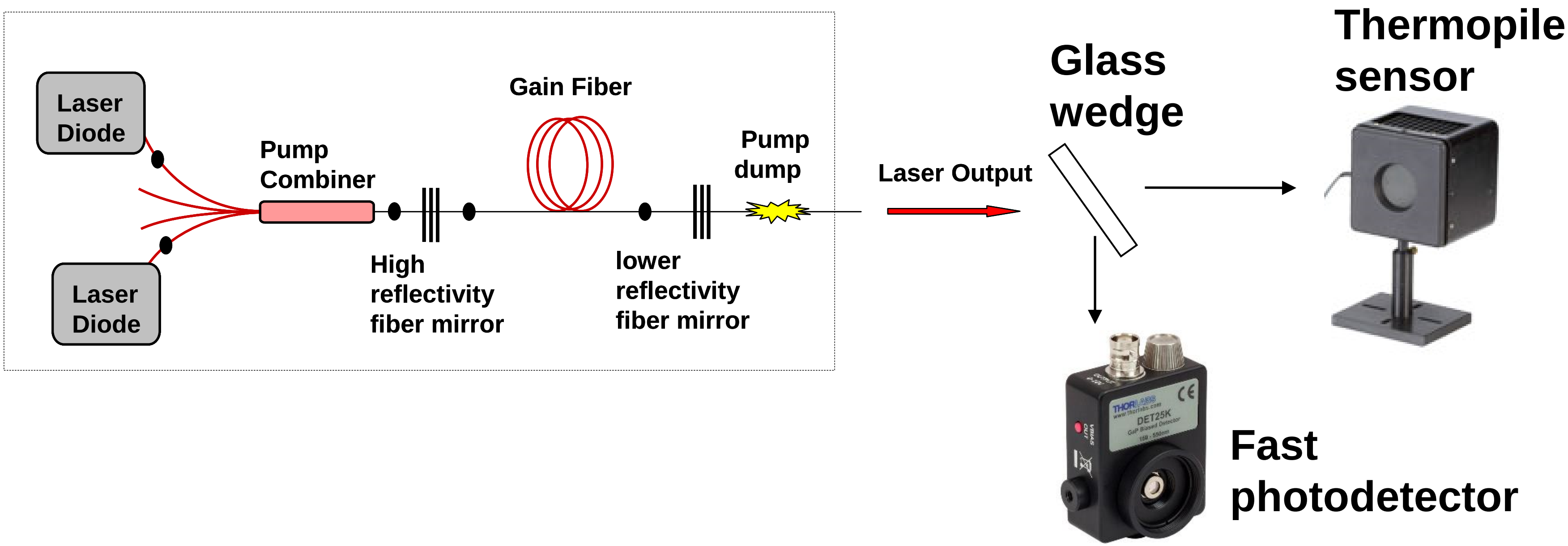
Electric arc (heat zone)



Build Procedure: Optical Fiber Recoating



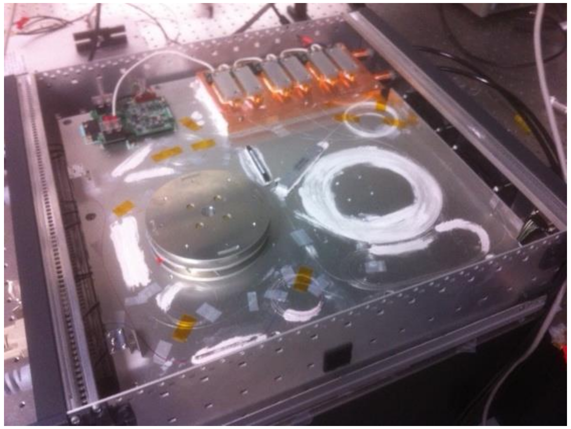
Measurement and Monitoring

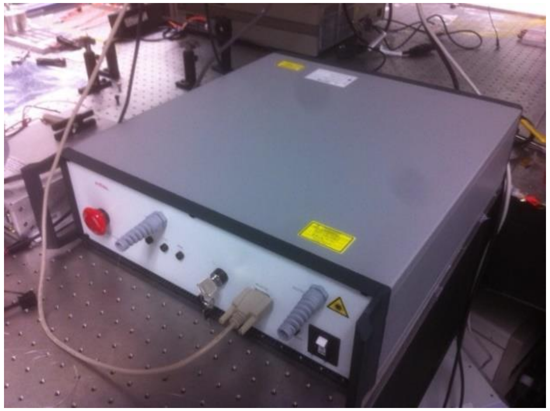


Fast temporal fluctuations –
DANGER ! (Turn laser off quickly !)

Length optimization of Gain fiber in laser

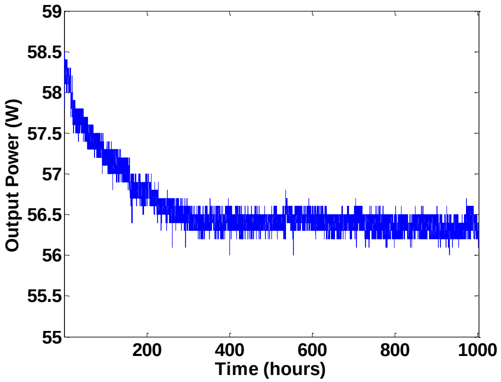
Packaged Lasers





Packaged Units with Electronics, rugged enclosure

- **Some package tests – Long burn-in (1000 hours), power cycling**



More importantly –
Need a good AC !

- **Lifetime estimations can be obtained from these tests**

Fiber Fuse