SAND2008-5771P

Fiber Laser Grand Challenge (FLGC)

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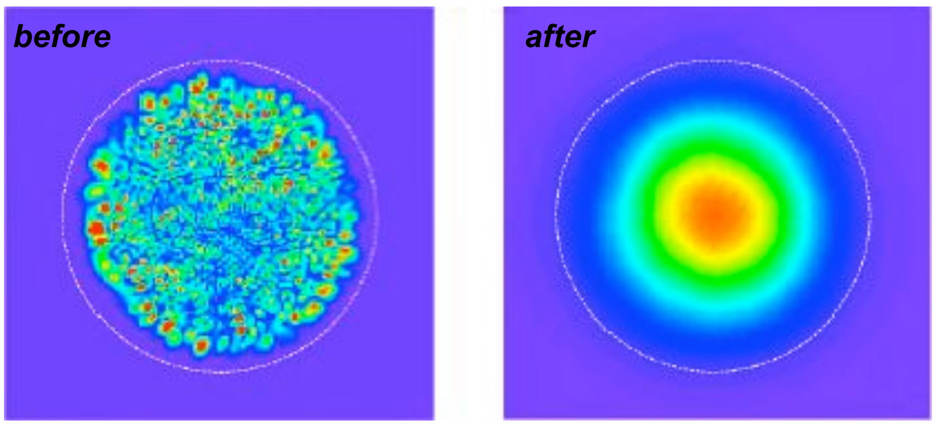


Near-field intensity distributions a for highly multimode Yb-doped double clad fiber amplifier, before and after application of mode filtering technique (U.S. Patent 6,496,301, Koplow et al.)

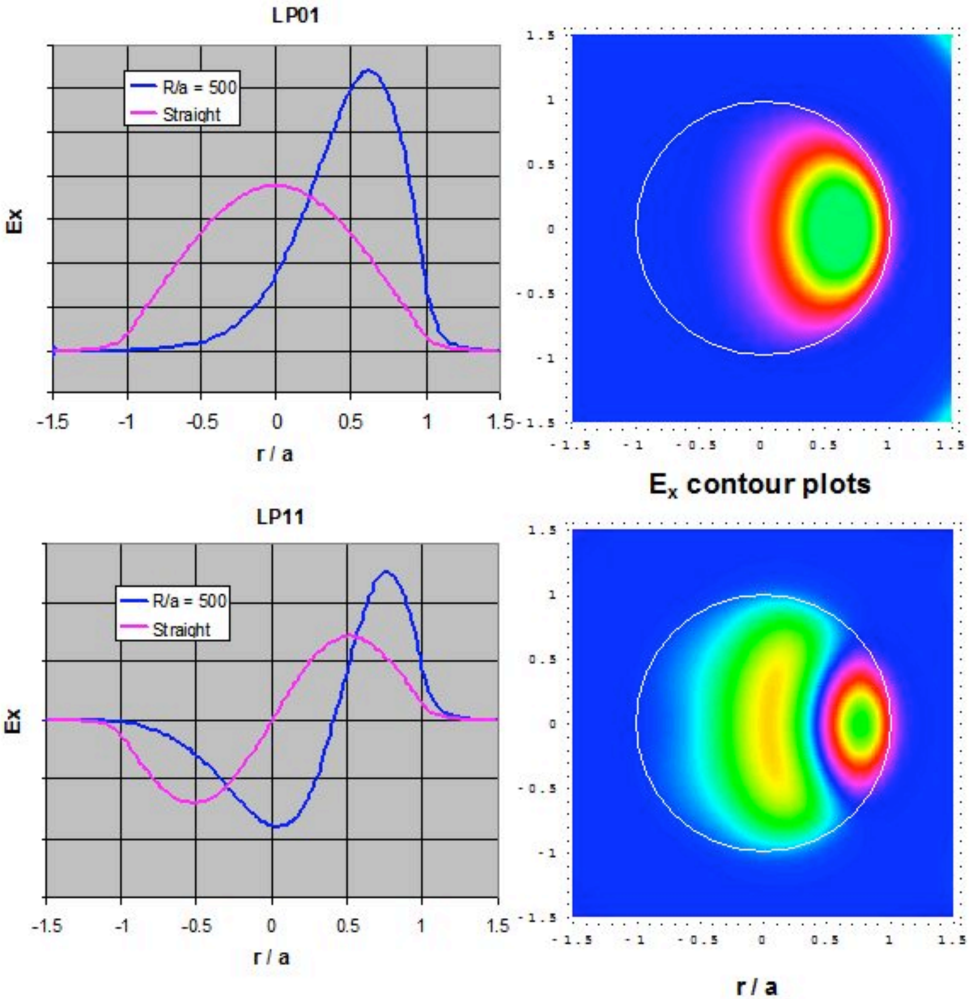
The mode filtered fiber amplifier, developed jointly by Sandia and the Naval Research Laboratory, is used extensively in commercial fiber lasers.

Primary objectives of Sandia's Fiber Laser Grand Challenge:

1) *determine ultimate limits of mode filtering technique for power scaling of pulsed fiber lasers*
2) *understand hierarchy of physical processes that impose limitations of fiber laser performance*
3) *development of globally optimized double-cladding fiber architecture*
4) *incorporation of functionality of bulk optics into all fiber device architectures*

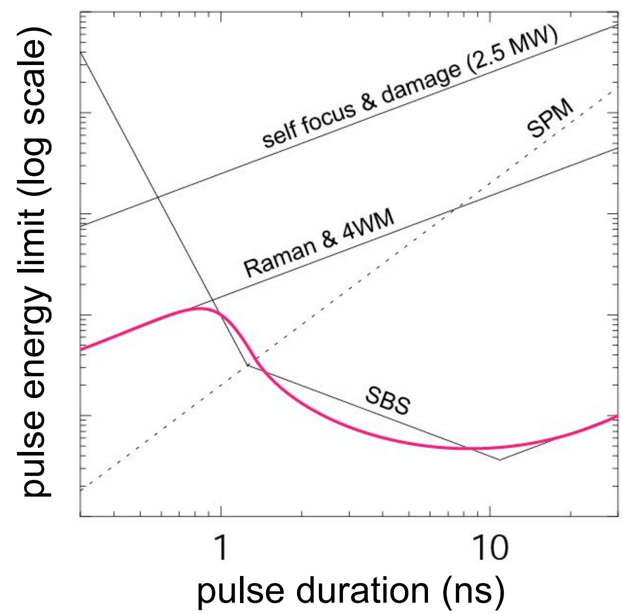
Key results from Fiber Laser Grand Challenge modeling program

LP01 and LP11 modal distributions in bent fiber waveguide



Mode distortion in bent fiber waveguide effects nonlinear effects, gain extraction efficiency, and higher-order mode discrimination. This imposes a limit on the maximum fiber core diameter to which the mode-filtering technique can be applied.

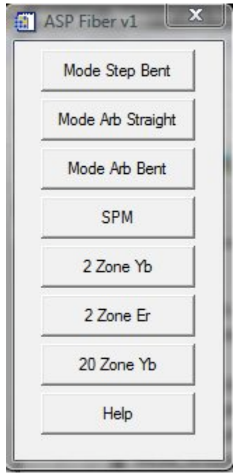
pulse energy limitations imposed by nonlinear effects for a transform-limited Gaussian pulse

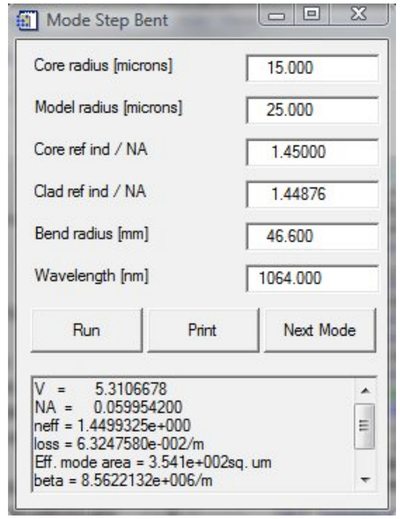


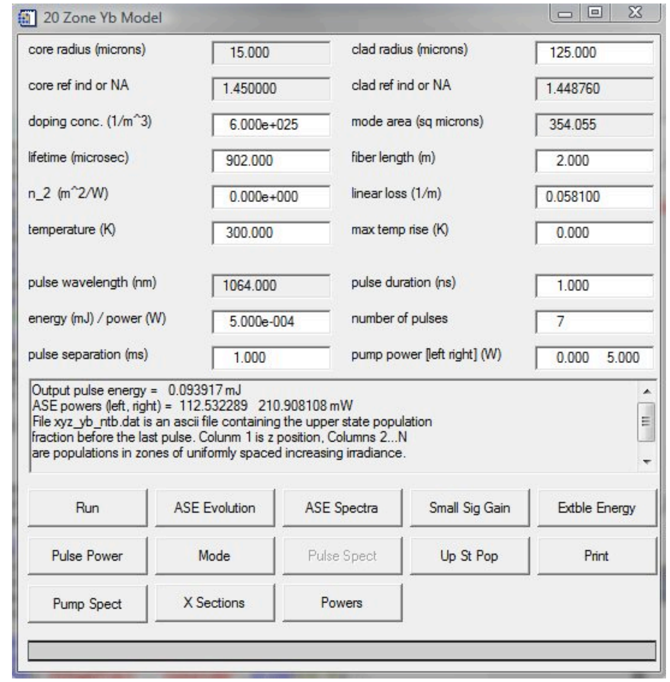
- hierarchy of five key nonlinear process
- has above pulse duration dependence
- ~800 ps optimum if transform-limited
- self focusing won't occur for τ > 500 ps
- higher pulse energy can be obtained at
- τ > 800 ps by sacrificing transform-limited
- linewidth (to suppress SBS)

Fiber laser modeling software developed under FLGC

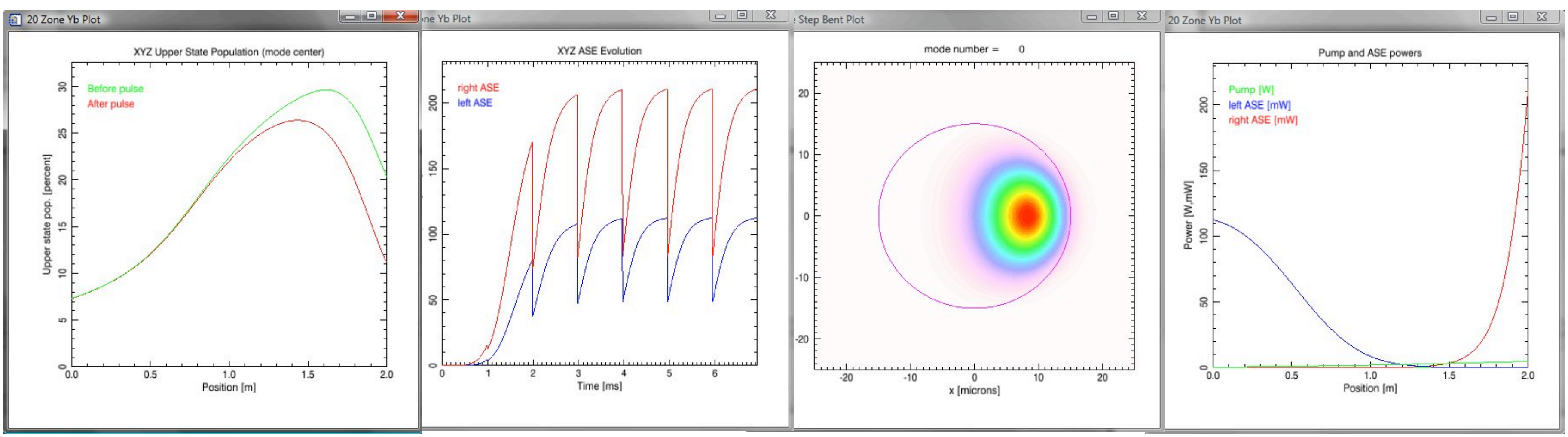
- beam propagation
- mode distortion
- stimulated scattering
- self focusing
- 4-wave mixing
- self phase modulation
- ASE
- spatial hole burning
- small signal gain
- excited state distribution



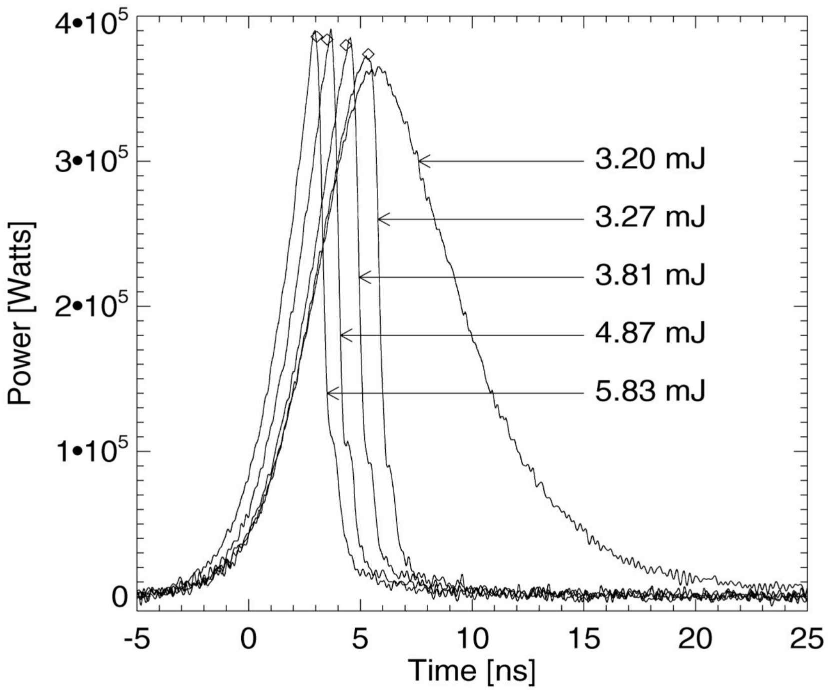




Further development of Sandia's fiber laser modeling software for general use in the fiber laser community is planned for FY09.



FLGC rewrites literature on optical damage in fused silica



Optical damage process is deterministic, not statistical

Breakdown occurs at nearly constant irradiance of 5 kW/μm^2 for ns-duration pulses (±1% variation)

Damage threshold same for different grades of silica

Damage threshold at surface can be as high as in bulk

Past measurements done with noisy non-injection seeded lasers explain a large scatter literature data

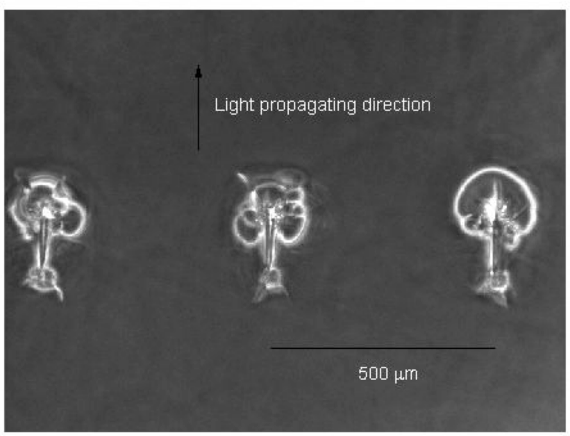
Tight focus required to eliminate SBS measurement artifact

Simple electron avalanche model is applicable

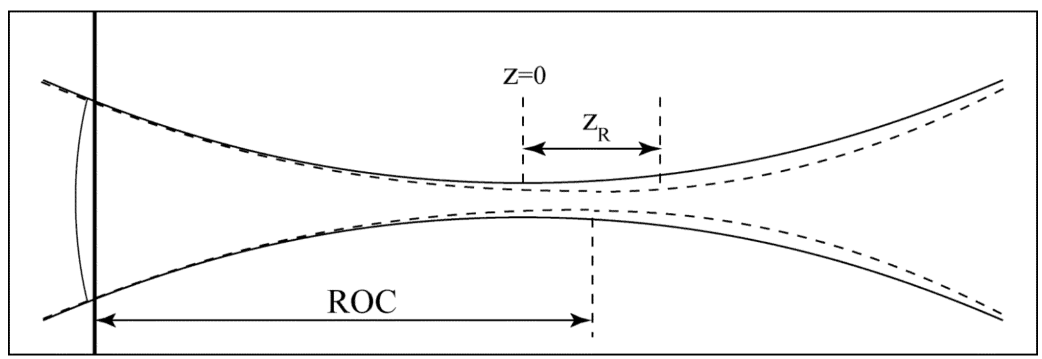
Self-focusing must be accounted for in spot size calculations

$$\frac{dn}{dt} = \beta I^k + \alpha n I - \frac{n}{\tau_r}$$

n: density of free electrons
β: photo-ionization coefficient
k: number of photons required to ionize
α: electron avalanche coefficient
τ: electron-hole recombination time

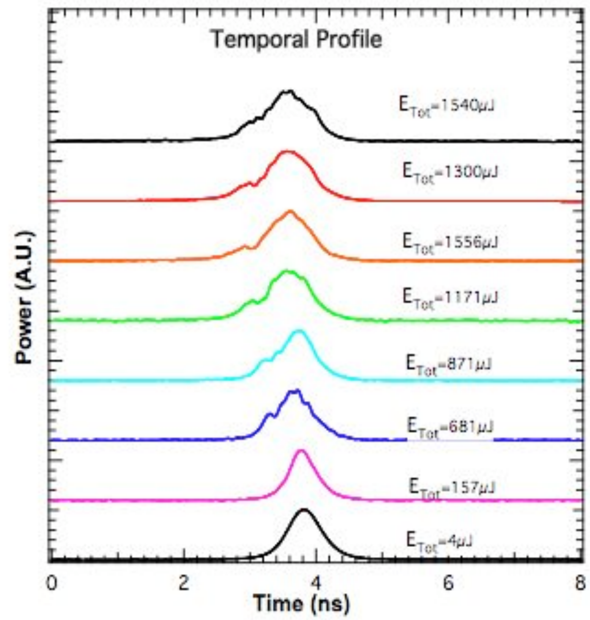


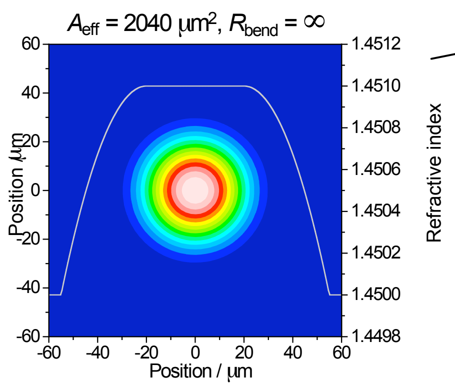
optical damage morphology



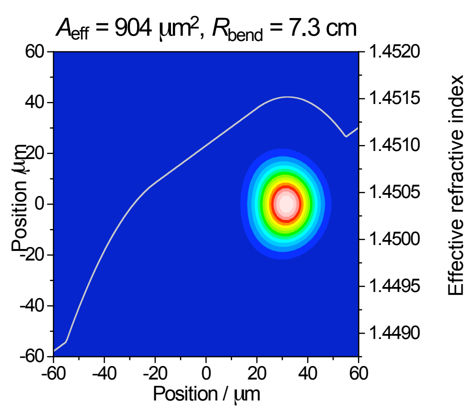
Key results, power scaling experiments:

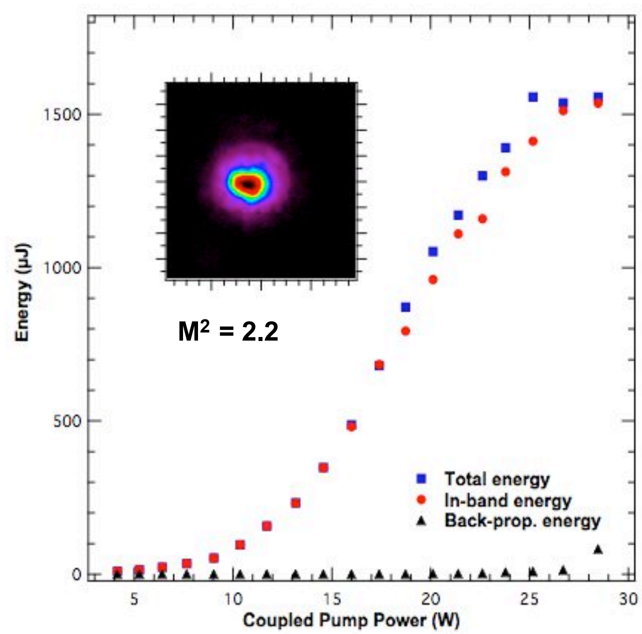
- practical limit of ~2 mJ and ~2 MW
- fiber manufacturing process control a problem
- seed laser: Yb-YAG preferable to Nd:YAG
- globally optimized fiber: hybrid index design
- results reproduced by FLGC fiber laser model

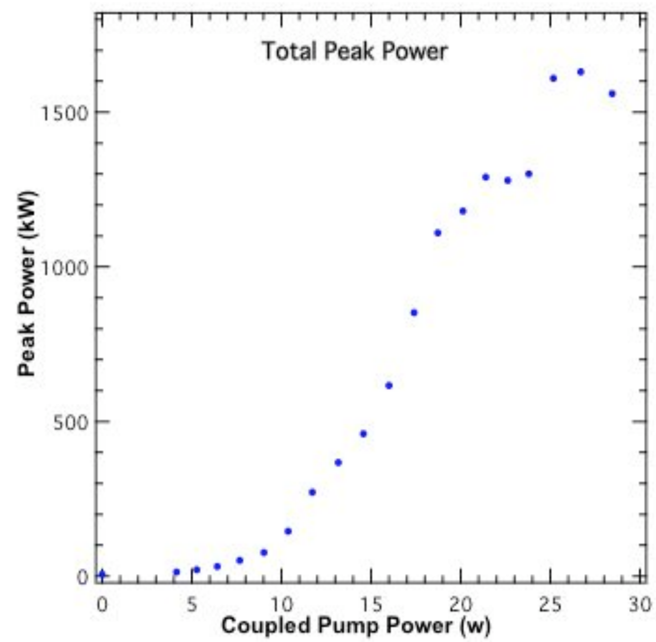




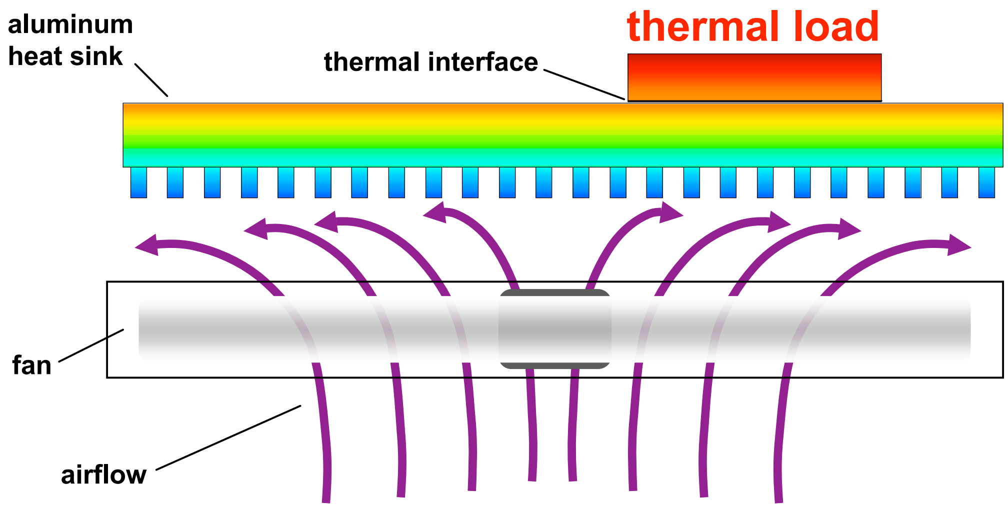
FGLC Hybrid Index Fiber:
R_{core} = 55 μm, R_0 = 20 μm

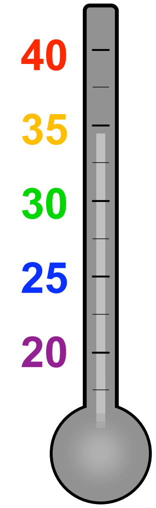


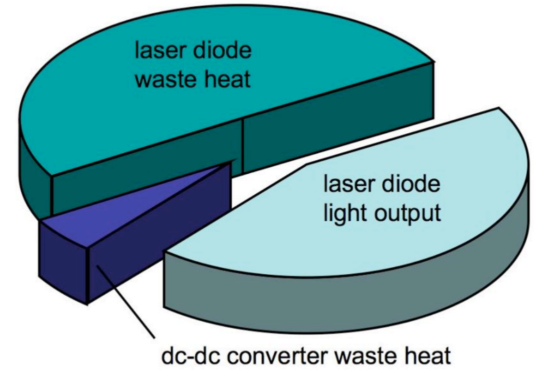




The FLGC allowed a thorough re-examination of the air cooling problem.

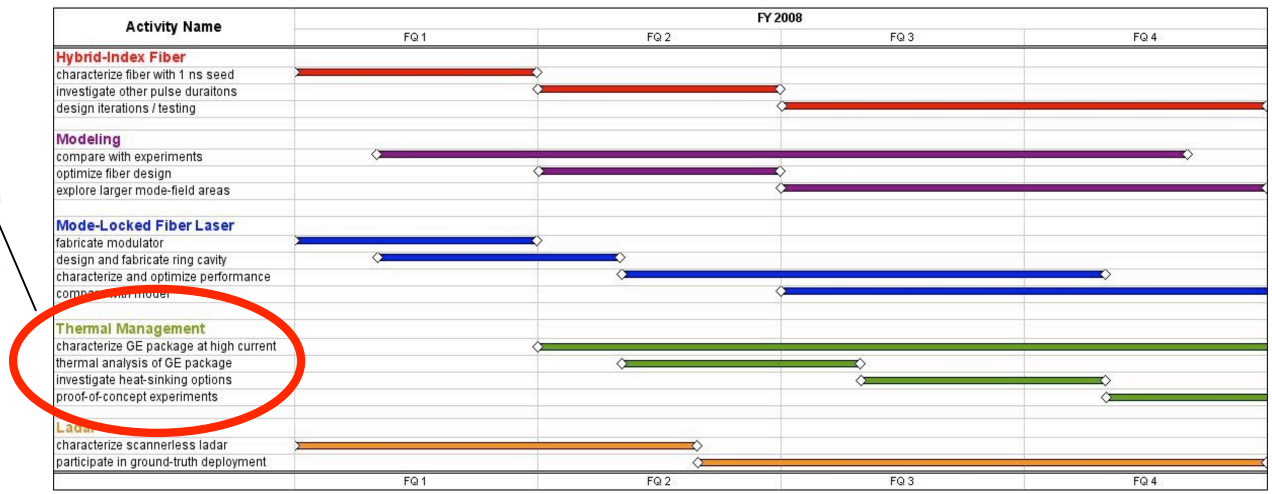






The wall plug efficiency of a typical 975 nm pump laser is 45%. The remaining 55% of electrical power is converted to waste heat.

The EAB advocated a 4th year of support for the FLGC, and encouraged us to investigate further the challenge of the fiber laser air cooling problem.

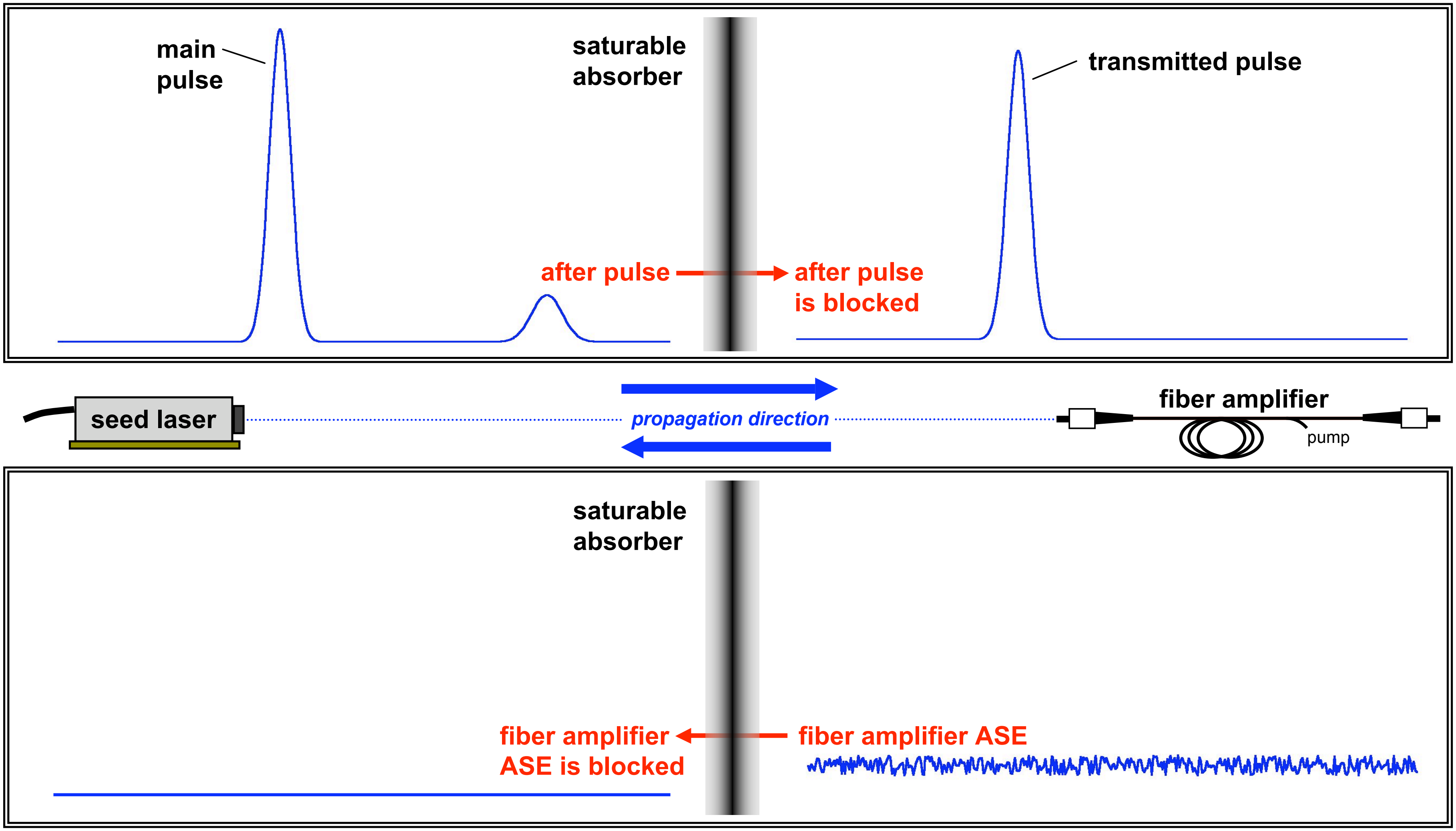


Result: development of fundamentally new approach to air cooling

Patent application filed August 4, 2008:

Koplow, J. P., HEAT EXCHANGER DEVICE AND METHOD FOR HEAT REMOVAL OR TRANSFER

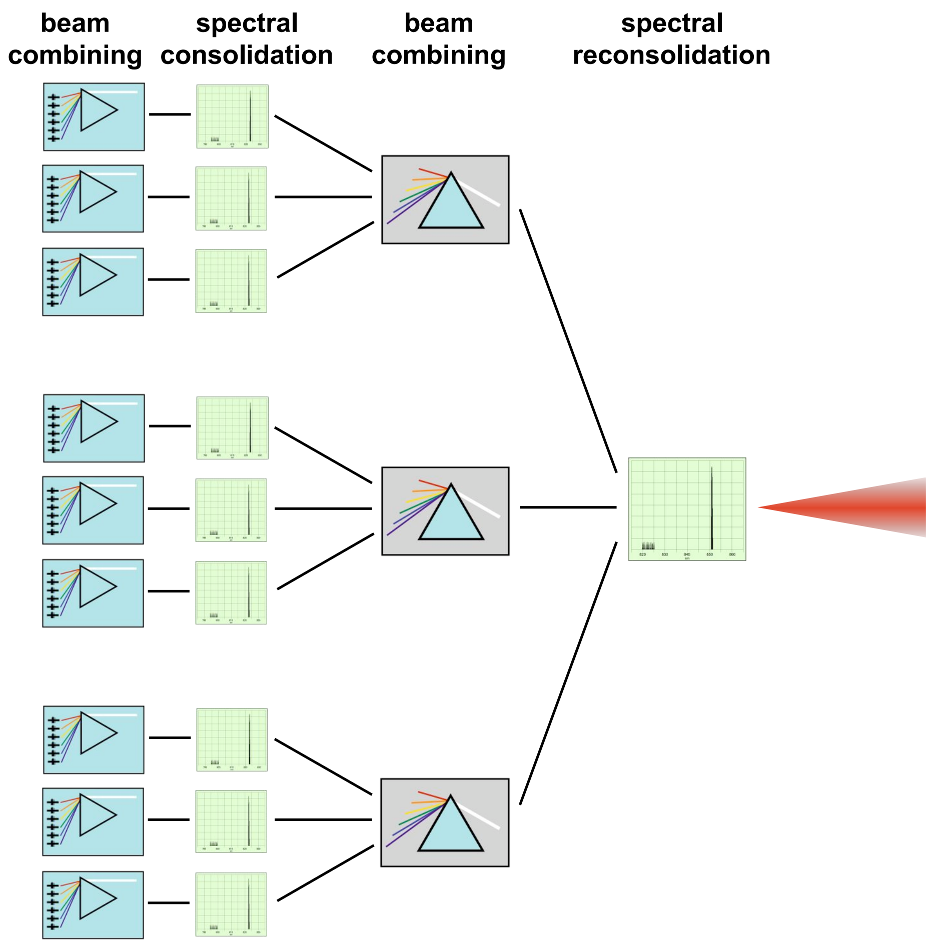
Development of all-fiber saturable absorber device



- **Nonlinear amplitude transfer function filters out ASE and other low-level signals**
- **Intrinsically a bi-directional device (unlike a Faraday isolator)**
- **Device will drastically simplify pulsed fiber laser architecture**
- **Device allows high-gain fiber amplifiers to be cascaded without gain compression**

Patent application in preparation: **Koplow, J. P., ALL-FIBER SATURABLE ABSORBER**

Development of exponentially scalable beam combining technique



low power stage(s):
long fiber lengths,
Ge-doped high-n_2 fiber

medium power stage(s):
medium fiber lengths,
conventional SMF fiber

high power stage(s):
short fiber lengths,
F-SiO_2 low-n_2 fibers

Advantages:

- Higher efficiency (high efficiency diodes as the starting power source, Raman conversion has high quantum efficiency, no temperature-dependent 3-level gain medium).
- Far less demand on thermal management (very small quantum defect [~3%], uniformly distributed heat load, small diameter fibers).
- Simple passive architecture (no phase control or pump wavelength stabilization required).
- Relaxed demand on fiber fabrication (no specialty or double-clad fibers required, no photo-darkening of rare-earth doped core, no LMA bend-sensitive fibers required).
- All components are nominally identical. Very amenable to low-cost mass production.

Underlying technology:

- Spectral combining has been demonstrated.
- Fiber Bragg grating technology is very mature.
- Fiber Raman lasers with quantum efficiencies as high as 98.4% have been demonstrated.
- Proof-of-concept demonstration of spectral consolidation has not been undertaken yet.

Patent application filed July 26, 2008: **Koplow, J. P., LASER APPARATUS CONGIFURED TO OUTPUT SPECTRALLY CONSOLIDATED LASER BEAM, LASER SYSTEM, AND RELATED METHODS**