Modeling High Power Fiber Lasers and Amplifiers

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Motivation—Fiber lasers and amplifiers pumped by diode lasers can efficiently generate high quality beams with a continuous power of kilowatts or a pulse energy of millijoules. Fiber lasers are often more compact, more rugged, more efficient, and generate better beams than lasers based on a bulk gain medium. These attributes make fiber lasers promising coherent sources for a wide range of applications such as remote sensing of chemical and biological agents or for nonproliferation monitoring, for laser welding, for pumping nonlinear optical converters to shift the wave length to the mid infra red for countermeasure applications, and for direct optical initiation of explosives. However, many of these applications require that the laser operate near the upper limits of power or pulse energy, and achieving this requires careful balancing of a large number of design factors. Our research is centered on pulsed fiber lasers that produce nanosecond or picosecond pulses, a time range where the power is limited by self focusing and the fluence is limited by optical damage of the fiber core. Large cores have higher damage threshold energies but produce poorer quality beams. Long fibers have higher pulse energies and gains but encourage the parasitic processes of stimulated Raman scattering and amplified stimulated emission. Carefully balancing these factors is necessary in optimizing the fiber laser for each application, and this can be done efficiently only if we develop the appropriate fiber laser models.

Accomplishment—We are developing a suite of numerical models that individually address the most important power or energy limiting processes in fiber lasers. Our models include semi analytical (SA) and fully numerical finite difference time domain (FDTD) models that calculate transverse mode profiles and their radiative loss for both straight and bent fibers. Other completed modules numerically propagate beams with arbitrary transverse profiles to study the influence of the intensity-dependent refractive index (n_2) which is responsible for the self focusing that limits power transmission through a fiber and is also responsible for self phase modulation which alters the spectrum of a pulse as it propagates through the fiber. We are also developing a graphical user interface and integrating the models under it so they will be relatively easy to maintain and use.

Significance—The transverse mode computations are critical because bending the fibers is necessary to make the devices compact, and it is also used to discriminate against the high order transverse modes to maximize beam quality. The degree of discrimination depends on the tightness of the bend, the refractive index profile of the core and cladding, and the profile of the Yb^{+3} gain ions in the core. Our models include all of the important factors that determine the beam quality. The critical power for self focusing for pure silica is approximately 4 MW. It is probably impossible to exceed this significantly by optimizing the fiber design, but we will test this using our models. Doping the core with Yb^{+3} changes n_2 by unknown amounts and probably reduces the critical power. Quantitative comparisons with laboratory measurements are part of the modeling project, and we anticipate that these comparisons between model and measurement will lead to higher fiber energy and power limits.

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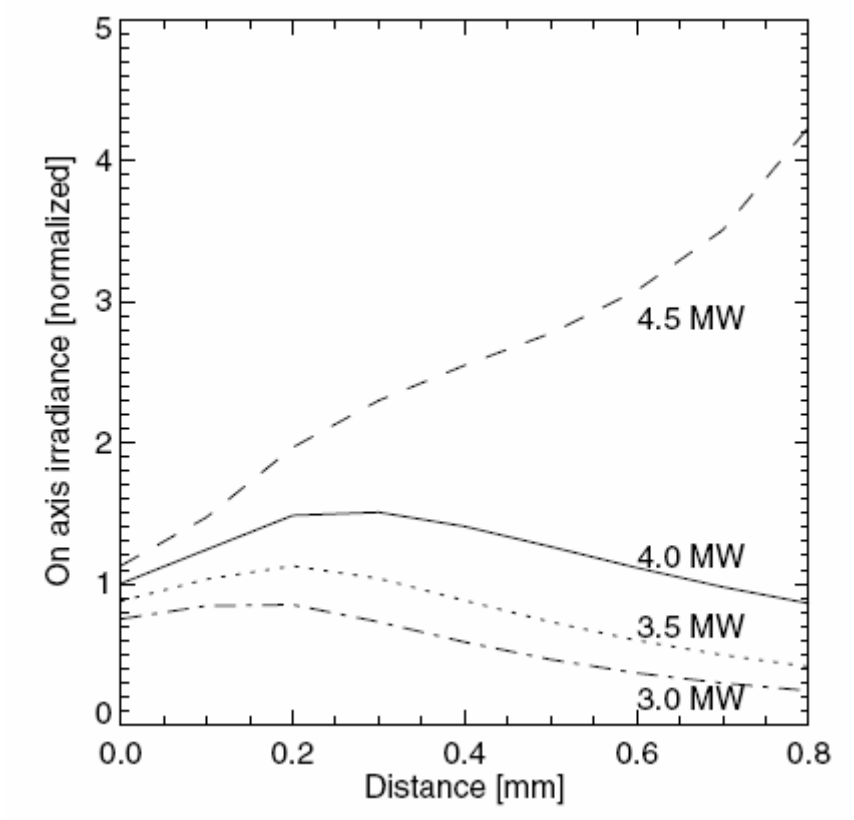

Figure 1. On-axis irradiance versus propagation distance for different powers launched into a fiber with n_2=2.7x10^{-20} W/m^2. The self focusing power for this value of n_2 is 4.3 MW.

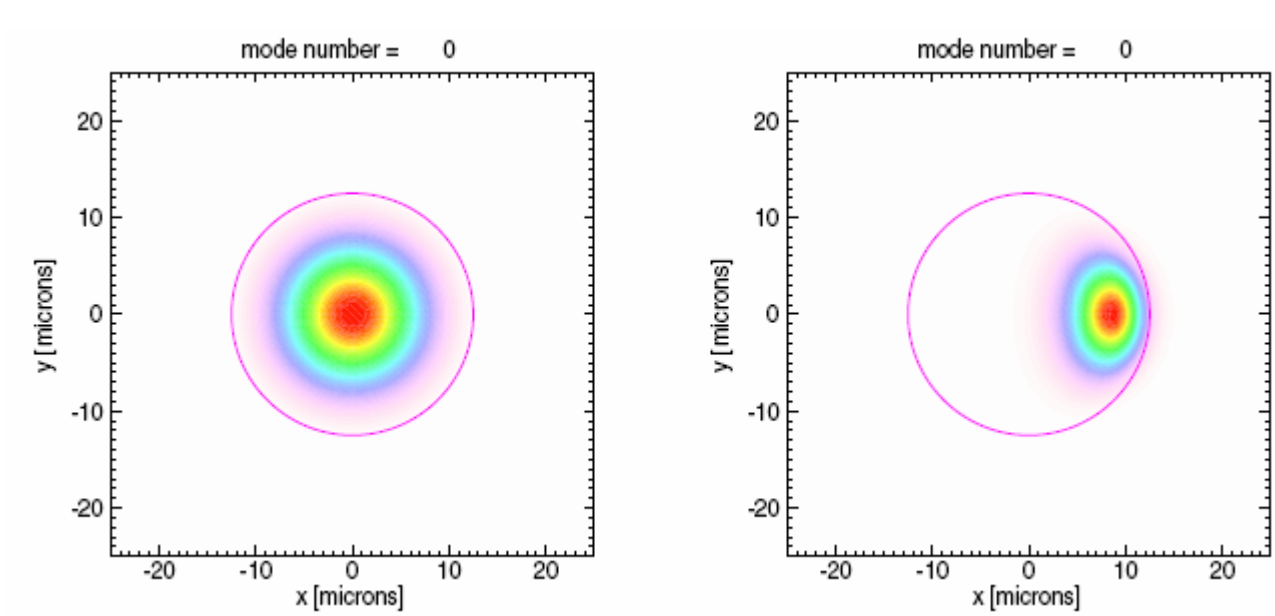

Figure 2. Transverse mode profiles for a straight fiber (left) and for same fiber when it is tightly bent (right).