Robustly Single-mode Polarization Maintaining Er/Yb co-doped LMA Fiber for High Power Applications

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Abstract: We demonstrate a large core diameter PM Er/Yb fiber incorporating a unique raised inner-cladding which facilitates the use of conventional LMA mode selection techniques to achieve robustly single-mode operation, making it ideally suited to high power applications.

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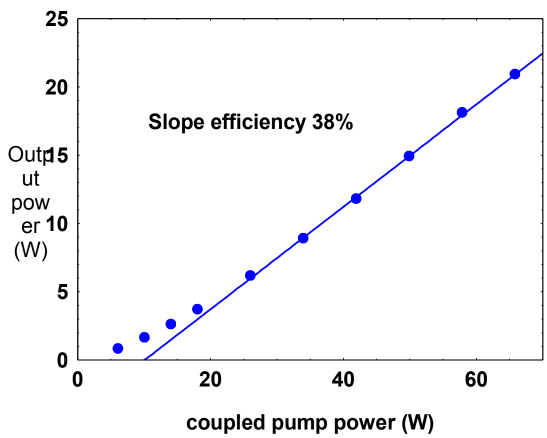
1. Introduction.

The development of large-mode area (LMA) fibers has lead to demonstrations of kiloWatt level CW outputs and megaWatt level peak powers in sub-nanosecond pulsed amplifiers. Such output powers have been achieved with near diffraction-limited output beam quality, because the low NA core supports only a few modes and the higher order modes can be easily discriminated against by preferential seeding [1], and/or bending [2]. However, due to the inherent difficulties associated with manufacturing fibers containing the relatively high lanthanide ion dopant concentrations required for high optical-efficiency whilst maintaining a low core NA, the development of LMA fibers has largely been restricted to ytterbium fibers for use at around 1.0µm. In spite of the numerous advantages, a significant drawback of the ytterbium based system is the relatively high sensitivity of the human eye to wavelengths in the 1.0µm region. Consequently for certain applications, such as ranging, pollution monitoring, clear-air turbulence analysis and free-space communications, operating in the "eye-safe" 1.5-2.0µm range is preferred.

Notwithstanding the lack of LMA fibers, a number of significant steps toward the extraction of high output powers from multimode Er/Yb fibers have been reported. Koroshetz *et. al.* [3], demonstrated a 40W, 10Gb/s amplifier; Shen *et. al.* [4] reported 188W of CW output with an M^2 of 1.9 using fibre with a 30µm 0.22NA core; and Yusim *et. al.* [5] employed a 20µm core fiber, which supports 30 modes, to achieve 100W output with a near diffraction-limited beam by employing single-mode fiber based components in the cavity and making highly precise splices between the single-mode fibers and the multi-mode active fiber. Although a high-power near diffraction-limited output was achieved, such methods are cumbersome and further emphasize the need for LMA fibers. We recently reported the development of such an LMA fiber [6] and present here an advancement in this technology that allows the fabrication of highly efficient, polarization maintaining (PM) LMA fibers. A PM-LMA Er/Yb co-doped fiber suitable for nanosecond pulsed amplification applications as well as high power CW amplification has been designed and fabricated. This fiber possesses a relatively large 25µm core and 300µm cladding diameter but incorporates a unique raised inner cladding (pedestal) which reduces the V-value at 1550nm to less than 5, thereby facilitating the use of seeding and/or coiling technology to achieve single-mode operation with relative ease. Manufacturing challenges for these novel fibers are discussed and amplification performance data including up to 40% power efficiency is presented.

2. Experiment and results.

The challenges associated with fabricating LMA Er/Yb and Tm-doped fibers have previously been discussed in detail by Tankala *et. al.* [6]. In the case of a PM-LMA fiber the manufacturing is further complicated by the spatial requirements of the stress inducing elements [7] and this is further exacerbated here by the presence of the pedestal. Care is also required so as to avoid shattering the highly stressed core during the machining steps. Notwithstanding these complications, by careful positioning and compositional optimization of the stress elements we found that it is possible to achieve a birefringence of around 2.0-2.5 x 10^{-4}. We chose a core to pedestal NA of around 0.09 and a pedestal diameter of around 40micron, because at such a diameter the pedestal behaves as a "true" cladding to the core rather than an extended core feature [6]. The fiber was drawn in a double clad (DCF) geometry with a 0.46NA provided by a fluoroacrylate polymer, the peak core absorption of the erbium (circa 1550nm) was 25dB/m and the 915nm cladding absorption was measured to be around 0.8dB/m. The fiber was tested in both CW and nanosecond high pulse energy amplifiers. Depending upon the amplifier configuration and length of fiber used, slope efficiencies of between 30-40% were typical; see Figure 1. Using an EM4 high-power DFB laser to produce 2ns seed pulses with 550pJ pulse energy (at a pulse repetition rate of 10Kpps), amplification of around 50dB (to ~70uJ) was achieved using the PM-LMA-EYDF in the third stage of a three stage amplifier; for an average power of 0.7W. A 30% optical to optical efficiency was also achieved when amplifying 500ns seed pulses (at 50Kpps) to achieve 160µJ/pulse (around 300W peak power), before the onset of SBS.



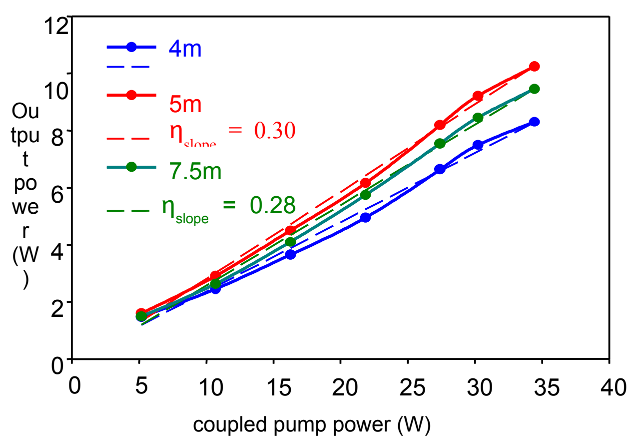


Figure 1: Slope efficiency of a 10m long PM-LMA-EYDF-25/300 CW fiber amplifier pumped at 975nm and seeded with 100mW at 1559nm (left) and Slope efficiency of a 500ns seeded amplifier as a function of coupled pump power for 4m, 5m and 7.5m fiber (right).

We also used standard mode matching techniques, in a seeded amplifier configuration, to compare this LMA fiber with that of a more typical 0.17NA 18µm core fiber and found that despite the larger core single-mode output was more readily achieved from the LMA fiber. We measured the output signal beam afterpropagating through 10m of Er/Yb amplifier and found that the achievable mode quality was close to diffraction-limited with a measured M^2 of 1.1.

In conclusion, we have found that by incorporating a pedestal feature between the core and cladding of a conventional PM Er/Yb DCF it is possible to create an LMA-like structure and thereby increase the non-linear threshold and achieve the pulse energies, peak powers, efficiency and beam quality suitable for many "eye-safe" coherent monitoring systems.

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