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High-power fiber lasers: progress and opportunities

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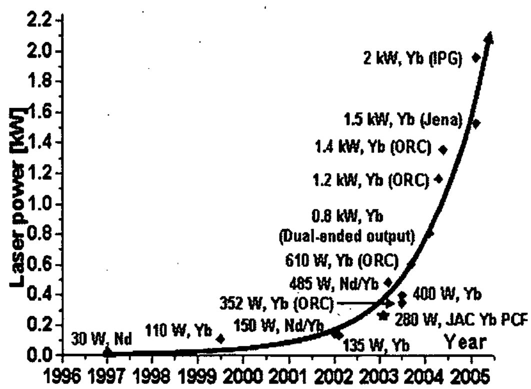
Cladding-pumped fiber lasers and amplifiers offer a number of unique properties. These enabled the very rapid power-scaling seen in the last few years. However, there are many additional advantages, that enable the power to be combined with exceptional control of the output characteristics. Such sources promise to make a drastic difference in a range of new applications. The figure shows the progress in reported output powers from single mode or nearly diffraction-limited fiber lasers at wavelengths around 1.1 μm, which now exceeds 1 kW (see, e.g., [1]). Advances in high-power multimode diode and fiber technology, combined with the inherent power-scalability of cladding-pumped fibers, lie behind this rapid progress. Compared to the telecom technology and especially erbium-doped fiber amplifiers that these high-power fiber lasers have evolved from, the most important differences in the fiber design are the use of double-clad fibers, the much larger core and inner cladding sizes that allow for the launch of high-power, large, pump beams and increases the damage threshold, as well as the use of ytterbium-doping. The high efficiency of low-loss Yb-doped fiber lasers (YDFLs) – over 80% is possible with high-quality, high-purity fabrication – means that even a 1 kW fiber laser generates no more than ~200 W of heat. This exceptionally low heat load simplifies heat-sinking. The overall efficiency is further enhanced by improvements in diode efficiency, which is currently at ~70%.



Other RE-dopants, such as erbium and thulium, are used for high-power fiber lasers at other wavelengths, 1.5 – 1.6 μm and 1.8 – 2.1 μm, respectively. They are less efficient than Yb, but still most attractive relative to alternative lasers in these wavelength ranges. The development of these and other types of sources follow similar rapid rates of progress as the high-power Yb-doped fiber sources do, but with some delay in time.

A further key attraction of rare-earth doped fibers is the high gain they can reach. Combined with their other properties, it allows fiber amplifiers to be used in master oscillator – power amplifier (MOPA) configurations in which a low-power seed is amplified to a high power level. In contrast to other high-power sources, advanced low-power, fiberized, components can be used to precisely and interactively control the characteristics of the seed, and thus the high-power output. This makes fiber MOPAs very attractive for high-power single-frequency or femtosecond and picosecond sources with precise specifications. In continuous-wave operation, we have recently demonstrated a 264 W (later increased to 400 W) single-frequency, single-mode, linearly polarized 1060 nm MOPA that employed a large-core polarization-maintaining birefringent ytterbium doped fiber [2]. Similarly, we reached over 150 W of single frequency cw output power with a Yb-sensitized Er-doped fiber MOPA at 1563 nm, with tunability from 1546 to 1566 nm [3]. In the pulsed regime, we have demonstrated a 1550 nm 4.5 ps 10 GHz source with 60 W of average power [4] and a 20 ps, 1 GHz source with 320 W of average output power at 1060 nm [5].

The high power and high control open up for new applications of fiber lasers. The high efficiency allows devices to be cascaded, and fibers make excellent pump sources, e.g., for bulk lasers [6]. Beam combination techniques, either coherent or incoherent, is an attractive alternative to reach even higher power levels. On a commercial standpoint, standardization of high-power fibers would enable the development of standard high-power components similarly to what was achieved in telecom, for the realization of monolithic high-power fiber sources.

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[3] Y. Jeong et al, "Tunable single- frequency ytterbium-sensitized erbium-doped fiber MOPA source with 150 W (51.8 dBm) of output power at 1563 nm," OFC 2005, PDP1.
[4] B. C. Thomsen et al., "60 W 10 GHz 4.5 ps pulse source at 1.5 microns," CLEO/IQEC 2004, CMAA (2004).
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