Laser power scaling and beam quality improvement with a tapered rod amplifier

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In order to achieve an improved beam quality at high laser power we investigated the effect of tapering a large mode area all-solid fiber in a master oscillator power amplifier configuration. With a non-tapered fiber, the highest peak power we achieved is 540kW and the beam quality (M^2) was roughly 10. The local adiabatic tapered fiber for seed coupling can improve the beam quality to a value of about 4 which is an improvement by a factor of about 2.5.

1 Introduction

At present, high-power fiber lasers combining nanosecond pulses with a multi-kilohertz repetition rates are crucial elements for many industrial applications. The combination of high peak power and near diffraction-limited beam quality is essential for such pulsed fiber laser systems, which may be limited by parasitic nonlinear effects of standard fiber amplifiers due to the small active fiber core [1]. Therefore increasing the fiber effective mode area is a promising solution to suppress nonlinear optical effects and to scale up the peak power provided that the high beam quality can be maintained.

Up to now, many solutions have been reported to maintain single mode operation with the use of large mode area (LMA) fibers [2~4]. Solid core photonic crystal fibers (PCF) and large pitch fibers (LPF) are successful examples which have scaled the peak power up to the self-focusing limit (4 Megawatt) [3, 4]. But these fibers are expensive and hard to process due to their air filled holey structure. Consequently, all-solid LMA fibers are economical and practical alternatives. Several methods have been proposed with all-solid LMA fibers as amplifier [5]. For the last few years, a new technology named Reactive Powder Sinter Technology (REPUSIL) [6] was developed to fabricate fiber preforms which allow a precise refractive index control and homogeneous dopant distributions for very large core preforms and fibers.

In this paper, we present a rod type fiber which was fabricated by this REPUSIL technology. A non-tapered fiber piece and a tapered fiber piece were tested and compared in a master oscillator power amplifier (MOPA) system. With the non-tapered fiber piece, we achieved amplified pulses with 540kW peak power and 1.4mJ pulse energy. In order to improve the beam quality, another piece of fiber was tapered down for the seed launch to suppress the coupling to higher order modes (HOM). The result shows that the beam quality (M^2) was improved from 10 to 4 when compared to the result of the non-tapered fiber.

2 Experimental details

For the preform preparation of the rod type fiber, the Yb^{3+}-doped active core rod and the passive inner cladding rods were prepared by the REPUSIL technology. The components were stacked in a hexagonal pattern in a fluorine doped silica tube and drawn to the desired fiber size. The rod type fiber had 56µm core, 460µm inner cladding and 1000µm outer cladding diameters showing a very homogenous step index profile with a core NA of 0.14 and a pump cladding NA of 0.22.

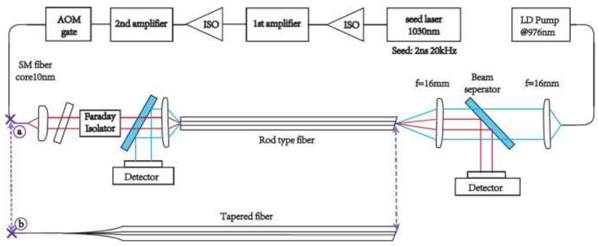

Fig.1 *Experimental setup: (a) Free-space coupling with non-tapered rod type fiber. (b) Splice onto the MOPA system with local adiabatic taper.*

A three-stage fiber MOPA laser system was employed as depicted in figure 1. The two pre-amplifier stages were based on all-fiber structures and operated with standard PM single-mode fibers. The signal laser beam after the second amplifier stage provides 140mW average output power and roughly 3kW peak power with a 2ns pulse width and 20kHz repetition rate. A diffraction-limited Gaussian beam with M^2~1.06 for the seed beam was measured. The third stage of the MOPA system is the main stage to test the LMA fiber with a pump wavelength of 976nm launched in the counter-propagating direction. Two different methods for seed coupling were used: (1) for a non-tapered rod fiber, free-space coupling has been applied as shown in figure 1(a); (2) for a tapered rod fiber, we directly spliced the taper onto the MOPA system to optimize the seed coupling efficiency.

3 Result and discussion

In order to characterize the rod-type fiber amplifier efficiency and the pump absorption, the non-tapered fiber with 60cm length was tested first. The measured slope efficiency was 66% with respect to the absorbed pump light and 50% with respect to the launched pump power. The highest output power reached 24W using 67W pump power. The highest peak power was measured to be 540 kW with 1.4mJ pulse energy. The beam quality was determined to be between 6 and 12.

Then we replaced the non-tapered fiber rod by a tapered fiber for beam quality improvement. The measured slope efficiency was in this case 36.7% with respect to the launched pump power. The highest output power reached 10.4 W with 43W pump power. The highest peak power was measured to be 200kW with 0.5mJ pulse energy. The beam quality was determined to be between 2.5 and 4. In order to compare the results of the non-tapered fiber and the tapered fiber, we plot the beam quality value against pump power in figure 2. The beam quality was significantly improved by the use of a local adiabatic taper at the same pump power level. If we compare the beam quality with the same pump power of 43W, the M^2 value for tapered fiber was 4 while the M^2 value for non-tapered fiber was roughly around 10. The fiber end facet of the tapered fiber was damaged at high peak power levels due to the smaller laser beam spot size and the higher power density at the output fiber facet. This problem could be reduced by the additional use of fiber endcaps.

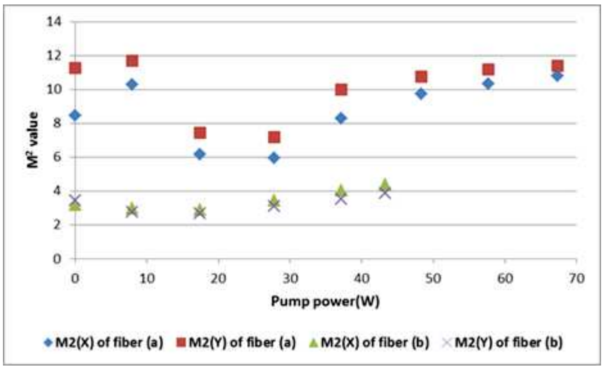

Fig.2 *The measured beam quality (M2) for both fibers (a) Non-tapered fiber. (b) Tapered fiber*

The output spectrum (not shown) of both fibers was quite similar with some power appearing in the first-order Stokes peak due to stimulated Raman scattering (SRS) in the second amplifier. The relative amplitude of the Stokes peak was actually lower after the main amplifier when compared to the seed input, confirming that the main amplifier is not yet at the SRS limit.

4 Conclusions

We demonstrated the use of a double clad rod-type fiber with a tapered seed coupling for significant improvement of the beam quality for fiber laser systems at high power levels. A beam quality improvement by about a factor of 2.5 has been achieved at comparable power levels. For the non-tapered fiber, the highest achieved peak power is 540kW with 1.4mJ pulse energy. The observed damage at the output facet of the tapered fiber at 200kW peak power should be avoidable by the additional use of fiber endcaps. Future work will concentrate on further peak power scaling as well was further improvement of the beam quality by suppressing diffusion effects during the tapering process.

References

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