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Abstract: A Master Oscillator Power Amplifier configuration using a Nd:YAG single-crystal fiber to amplify a passively Q-switched microlaser is presented. We achieved the amplification of 80 μJ, sub-nanosecond pulses to the multi-millijoule regime.
OCIS codes: (*140.3580) Lasers, solid-state; (140.3480) Lasers, diode-pumped; (140.3530) Lasers, neodymium; (140.3380) Laser materials; (060.2290) Fiber materials; (140.3280) Laser amplifiers; (140.3540) Lasers, Q-switched.*

1. Introduction

The MOPA (Master Oscillator Power Amplifier) configuration is very useful to extend laser performance of passively Q-switched sub-nanosecond Nd:doped microlaser addressing applications like material processing or instrumentation which require high energy (several millijoules), sub-nanosecond pulses at the kHz regime. Different configurations and gain media have already been used in the past few years. Multipass amplifiers with Nd:YAG or Nd:YVO_4 bulk crystals can reach high energy (>100 mJ) for pulse duration of few tens of ns at low repetition rate (<200 Hz) [1] or energy below the millijoule level for sub-nanosecond pulses at the kHz regime [2]. Yb fiber amplifiers [3,4] provide high efficiency and high beam quality but are limited to the MW peak-power due to non-linear effects. Recently the millijoule level with sub-nanosecond pulses at 10 kHz was demonstrated, but with a more complex system using two transverse pumped Nd:YVO_4 amplifiers operating at grazing incidence [5].

Bridging the gap between bulk crystals and glass fibers, single-crystal fibers are interesting new laser media [6,7]. Indeed, crystal fibers are long and thin rod where the pump is guided (like in fibers) and where the signal in unguided (like in bulk materials) propagating with beam size much larger than in typical glass fibers. Hence the crystal fibers can benefit from the good thermal management coming from fibers and may sustain high peak power pulses and have high emission and absorption cross-section as the bulk crystals. Because the pump is confined in the single-crystal fiber, the gain can be high (following the trend observed in glass fibers). Therefore, it could be very interesting to use this particular gain medium as an amplifier in a MOPA design. Nd doped single-crystal fibers have already been used to amplify high repetition rate microchip laser [9] and an average power of 7 W at 29 kHz was obtained with a moderate peak-power of 45 kW. In this work we study the potential of single-crystal fibers to amplify pulses above the MW level.

2. Experiment

The experimental setup (Fig. 1) consisted in a simple pass amplifier using a Nd:YAG crystal fiber, a high power fiber coupled laser diode for the pump and a Nd:YAG passively Q-switched oscillator emitting at the wavelength of 1064 nm for the seed.

The pump laser diode emitted 60 W at 808 nm (100 μm diameter fiber with numerical aperture of 0.22). Its output is imaged into the crystal through a dichroic mirror by a 1:4 telescopes consisting of two AR coated lenses and with the focal lengths of 50 mm and 200 mm respectively. In order to maximize the output power, the focus point is put slightly inside the single-crystal fiber, close to the pumped face. It corresponds to a 400 μm diameter beam. Then the pump beam is guided by total internal reflections inside the crystal fiber. The Nd:YAG crystal fiber – 50 mm long and a diameter of 1 mm – was 0.2% at. doped and mounted in a water-cooled copper block. A pump absorption of more than 94% is reached. As seed source, we used a passively Q-switched Nd:YAG microlaser providing linearly polarized and diffraction limited 400 ps pulses at the frequency of 1 kHz with an energy of 80 μJ and an average power of 80 mW. The signal was sent inside the single-crystal fiber in a counter propagating way with respect to the pump. A half-wave plate and a thin film polarizer allowed an adjustment of the input power inside the crystal fiber. Then the signal was slightly focused so that it was in free space propagation. Because of the transmission of each optical component, the maximum input power inside the crystal fiber was about 60 mW.

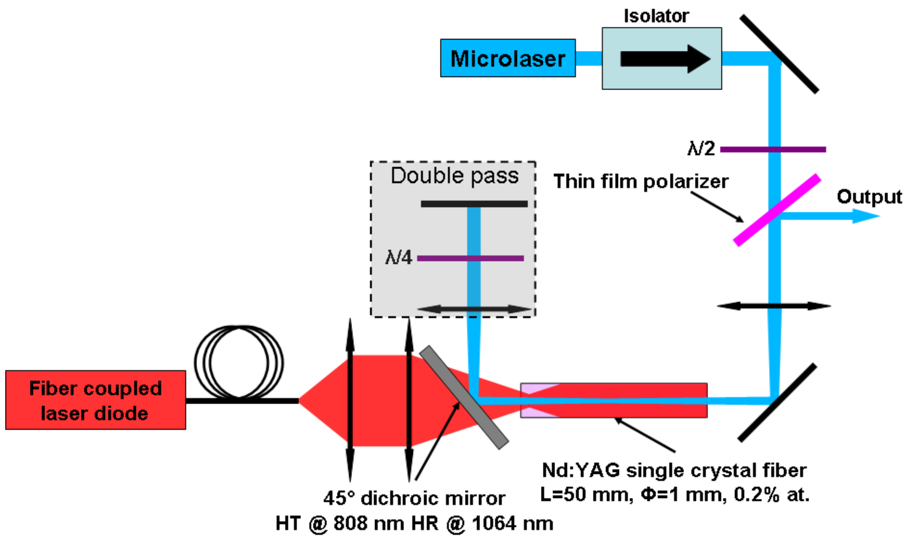

Fig. 1. Experimental setup for single or double pass configuration.

3. Results

With this configuration, the influence of the position and the size of the waist of both seed beam and pump beam were carefully studied in order to reach the highest efficiency. Fig. 2 shows the output single pulse energy as a function of the pump power. Pulses with an energy of 1.56 mJ are obtained under 60W of pump power corresponding to a peak-power of 3.9 MW assuming a pulse duration of 400 ps after amplification. This represents a gain of 26. The M^2 at the output of the microlaser is 1.1. The M^2 of the beam injected in the crystal fiber is 1.3 due to non-optimized optics for the beam propagation. After amplification, the M^2 becomes approximately 1.45. This shows that the crystal fiber amplifier induces only limited distortion on the input laser beam.

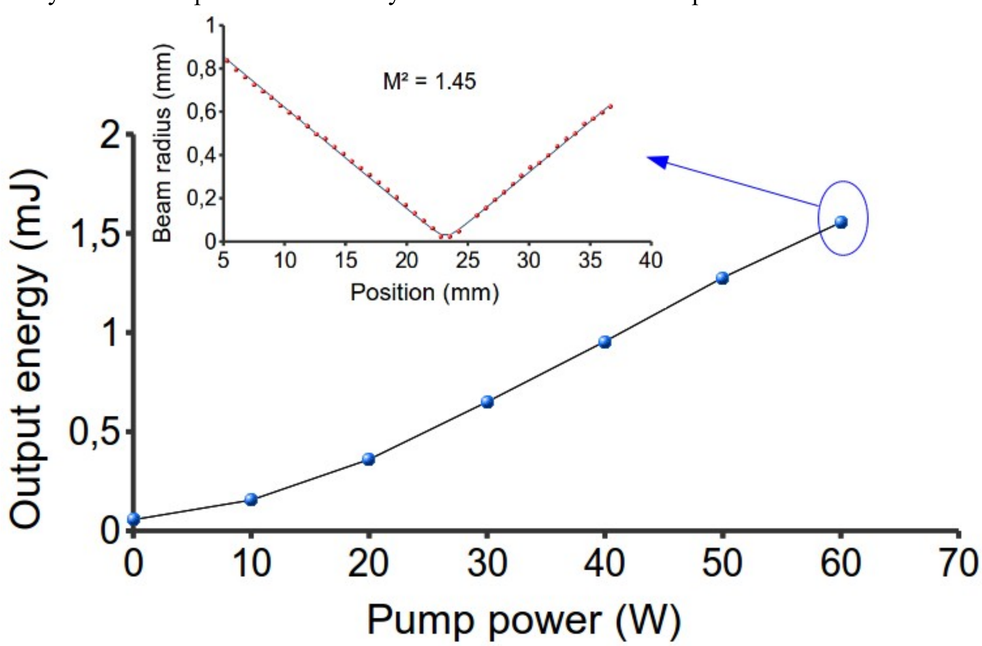

Fig. 2. Output single pulse energy versus the pump power at 1 kHz in single pass configuration. Inset: Beam radius of the signal versus the position for an output single pulse energy of 1.56 mJ and spatial profile of the signal beam.

The output energy presented no obvious sign of saturation versus the pump power. This means that higher energy could be extracted with more pump power. This clearly shows the advantage of crystal fiber limiting the parasitic effects (such as upconversion) and the thermal effects by a low doping concentration in Nd.

Preliminary experiments were done in order to extract more energy from the gain medium by using a double pass configuration. The double pass is achieved by switching the polarization of the signal. At the output of the single-crystal fiber, the signal is sent through a quarter-wave plate and reflected back by a flat mirror. First results show a gain of 1.6 between the first and the second pass (see Fig. 3). This leads to an output single pulse energy of 2.52 mJ at maximum pump power, corresponding to a peak-power of 6.3 MW assuming a pulse duration of 400 ps after amplification.

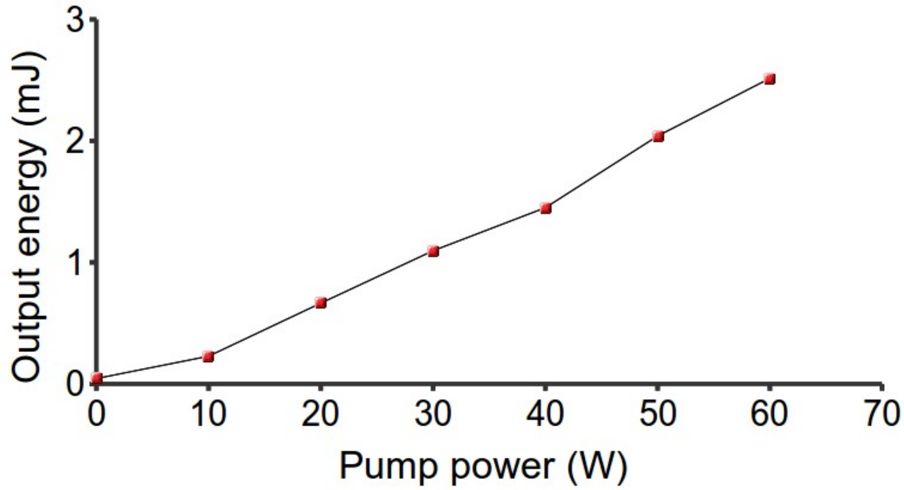

Fig. 3. Output single pulse energy versus the pump power at 1 kHz in double pass configuration.

4. Conclusion

We have demonstrated that Nd:YAG single-crystal fiber is a laser medium with high gain able to produce mJ, MW pulses in a very simple design. To our best knowledge, this is the first time that such performances are obtained in a simple one pass configuration (1.56 mJ, 3.9 MW). It overcomes the performances of fiber amplifiers by the peak power and the previous Nd doped bulk amplifiers by its simplicity.

The first results obtained in double pass are very encouraging for the development of a multi-millijoule Nd:YAG single-crystal fiber amplifier.

5. Acknowledgement

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6. References

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