Generation of 85 fs laser pulses from a diode-pumped Kerr-lens mode-locking Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic laser

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2014 Laser Phys. Lett. 11 115302

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 159.226.35.202
This content was downloaded on 29/09/2014 at 03:21

Please note that terms and conditions apply.
1. Introduction

In recent years, the interest in compact, efficient and robust femtosecond lasers has been motivated by the fact that they have increasing scientific and industrial applications, such as in optical frequency combs, femtosecond optical coherent tomography, cutting thin silicon substrates, and processing for fine structures. Until now, the Ti:sapphire laser is the most developed laser system in the ultrafast laser regime. However, the Ti:sapphire laser system requires a complicated and expensive green laser as a pump, which limits its wide application either in scientific research or in industry. On the other hand, with the rapid development of semiconductor InGaAs laser diodes, they have been widely used as direct pump sources in various all-solid-state lasers benefiting from their high power, high brightness, compact size, long life and much lower cost. In the ultrafast laser regime, the Yb3+-based laser has attracted much attention. First of all, the absorption bands of the Yb3+-doped laser materials match well with the emission bands of the high power laser diode in a near infrared wavelength. Secondly, Yb3+-doped laser materials also possess numerous excellent characteristics, such as no excited state absorption, no cross relaxation, a broad absorption and emission bandwidth, a small quantum defect and low thermal loading. In recent years, various kinds of Yb3+-doped lasers realized mode-locking operations either with the help of saturable absorbers such as semiconductor saturable absorber mirrors (SESAM) [1–4], single wall carbon nanotubes (SWCNT) [5–8], grapheme [9, 10], graphene oxide [11], or by means of Kerr-lens mode-locking (KLM) [12]. KLM is a promising technique in diode-pumped solid state Yb3+ lasers for generating sub-100 fs pulses. Up to now, there have been several reported experiments on KLM operation of diode-pumped Yb3+ lasers at the sub-100 fs level, such as Yb:YVO4 [13], Yb:YAG [14], Yb:YGG [15], Yb:CaF2 [16], and Yb:KGW [17], Yb:Sc2O3 [18], Yb:Lu2O3 combined with nondoped Y2O3 [19], Yb:Lu2O3 [20] and so on.

Yb3+-doped sesquioxide Re2O3 (Re=Y, Sc, and Lu) crystal-line materials are very attractive materials for high power laser
and ultrashort laser operation due to their excellent thermal conductivities and broad fluorescence spectra. Among them, Y$_2$O$_3$ has outstanding optical and thermal properties with a low phonon energy and high thermal conductivity compared to YAG [21]. However, a high-quality large-size Y$_2$O$_3$ single crystal is difficult to obtain using common growth methods because the melting temperature for a Y$_2$O$_3$ single crystal is as high as 2430 °C, and the structural phase transition temperature is at about 2280 °C. The transparent Y$_2$O$_3$ ceramic could be fabricated at a relatively low sintering temperature of 1700 °C [22], which is about 700 °C lower than the melting point of the Y$_2$O$_3$ single crystal. When La$_2$O$_3$ was added as a sintering aid in Y$_2$O$_3$ to form a Yb:(Y$_{1-x}$La$_x$)$_2$O$_3$ ceramic, the sintering temperature of the Yb:(Y$_{1-x}$La$_x$)$_2$O$_3$ ceramic was decreased to 1450–1650 °C [23], thereby shortening the fabrication time and reducing the cost of the production. The first mode-locking experiment with a Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic was demonstrated by W. Li et al resulting in 174 ps pulses at a central wavelength of 1032.5 nm with an average output power of 162 mW [24]. Femtosecond passive mode-locking was first demonstrated by Z. L. Wang et al 730 fs pulses at a central wavelength 1033 nm were generated, and the average output power of the femtosecond laser was 92 mW [25]. Recently, 357 fs pulses with an average power of 670 mW were obtained with a Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic by using a SESAM [26]. All the experiments reported above rely on SESAMs for initiating mode-locking and the pulse duration is far beyond 100 fs. Sub-100 fs pulses from a Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic laser have not been reported so far.

In this letter, we report on a diode-pumped KLM femtosecond Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic laser. Pulses as short as 85 fs at a repetition rate of 118 MHz were obtained. The full width at half maximum (FWHM) bandwidth of the laser spectrum was 17 nm at a central wavelength of 1074.5 nm. The maximum average output power was 80 mW under 4 W of pumping power. To the best of our knowledge, this is the first demonstration of a KLM Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic laser with a sub-100 fs pulse duration.

### 2. Experimental setup

In our experiment, the high quality Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic is the same as described in [26]. The overall experimental setup is described in figure 1. The Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic was wrapped with an indium film and placed on a water-cooled copper mount at 14 °C. A 7 W high-brightness fibre-coupled diode laser emitting at 976 nm (Jenoptik, JOLD-7.5-BAFC-105) was used to end pump the laser ceramic. The diverging pump laser from the fibre (NA = 0.22, 50 µm core diameter) was focused into the ceramic by a coupling system with a magnification of 0.8, thereby resulting in a diameter in the ceramic of about 40 µm. The laser cavity was designed as an astigmatically compensated X-type cavity. The Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic was positioned at Brewster’s angle between two curved folding mirrors (M1 and M2) with a radius of curvature (ROC) of 75 mm. The output coupler had a transmission rate of 0.8% (1020 nm–1100 nm). Two SF6 prisms with a tip-to-tip distance of 261 mm were used to introduce a negative group delay dispersion of about −1500 fs$^2$ for the chirp compensation of the Yb:(Y$_{0.9}$La$_{0.1}$)$_2$O$_3$ ceramic. The total cavity length was 1.27 m, corresponding to a repetition frequency of 118 MHz. Based on the above design and the ABCD matrix calculation, the laser beam waist diameters in the laser ceramic were 40 µm × 39 µm.

### 3. Experimental results and discussion

At first, we optimized the CW performance of the laser cavity. The maximum average output power was 250 mW under a pump power of 4 W. In order to realize KLM operation in the diode pumped Yb ceramic laser, two measures were taken. Firstly, we carefully designed the mode match between the
The corresponding spectra of the Kerr-lens mode-locked pulses under three different transmissions (T = 0.8%, 1.5% and 2.0%, respectively). The bandwidth (FWHM) of the corresponding spectra were about 17 nm, 13.4 nm and 8 nm, respectively, at central wavelengths of 1074.5 nm, 1072.8 nm and 1072.5 nm, respectively. The above experimental results indicate that the mode-locked pulse duration reduces with a smaller transmission of the OC at the expense of a smaller output power. The time-bandwidth products were 0.375, 0.363, and 0.367, respectively, closing to the Fourier transform limit of the sech²-pulse.

4. Conclusion

In conclusion, we have presented the first experimental demonstration of a diode-laser pumped KLM Yb:(Y₀.9La₀.1)₂O₃ ceramic laser. Pulses as short as 85 fs at a central wavelength of 1074.5 nm and an average output power of 80 mW were obtained at a repetition rate of 115 MHz. These are also the shortest pulses generated from the Yb:(Y₀.9La₀.1)₂O₃ ceramic laser up to now. In addition, we compared the performance of the KLM operation under three different transmissions at different pump powers. With a 2% OC, 189 fs pulses with an average power of 260 mW were obtained. The experiment shows that the Yb:(Y₀.9La₀.1)₂O₃ ceramic is an excellent laser material for the generation of sub-100 fs pulses. We believe that sub-50 fs pulses should be possible by using a smaller transmission output coupler as well as careful chirp compensation with chirped mirrors.

Acknowledgements

We gratefully acknowledge the helpful discussions with Prof Xiaodong Zeng, Prof Zhiguo Zhang and Wenlong Tian. This work is partially supported by the National Major Scientific Instruments Development Project of China (Grant No. 2012YQ120047), the National Natural Science Foundation of China (Grant No. 61205130) and the Fundamental Research Funds for the Central Universities (No. JB140502).

References


