Yb-Doped Single-Mode Fiber CPA Laser System

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INTRODUCTION

High peak power laser systems of up to petawatt [1] are based on chirped pulse amplification (CPA) technique [2]. In the CPA laser system, ultrashort pulses from an oscillator are first stretched below the nonlinear pulse distortion threshold to reduce the peak power and the amplified pulses are recompressed at the output by a compressor. Stable ultrashort pulse oscillator is necessary for CPA laser system. CPA laser systems based on fiber amplifiers and fiber-optic components are attractive for industrial applications. Fiber lasers are compact and easy to manage and offer better stability.

Ultrashort pulse generation in the mode-locking technique needs compensation of group velocity dispersion (GVD) in the laser cavity as well as an effective saturable absorber to start and stabilize the pulse train. The GVD of silica glass fiber is positive at around 1.0 μm, while it is negative at around 1.5 μm. To compensate the GVD in the cavity, a grating pair or prism pair can be used. For pulse stretching in the CPA laser system, bulk grating pairs or a conventional fiber is usually used. Pulse stretching with bulk gratings needs large air space, while a conventional fiber normally needs 1,000 m fiber to stretch a pulse from 100 fs to 500 ps. A chirped Fiber Bragg Grating (FBG) [3] also used as pulse stretcher. 10 cm-long chirped FBG is enough to stretch 100 fs pulse to 500 ps. A chirped FBG is compact, low loss, low nonlinearity, and operates as a chirped mirror. The optical period of the grating changes along the fiber length. In the chirped FBG, the position of low and high frequency ingredient of a pulse varies with Bragg wavelength.

Here we demonstrate a self-starting mode-locked YDF laser that delivers femtosecond pulse train using single-mode fibers. The oscillation wavelength of mode-locked laser was tuned by inserting a slit in the cavity. Femtosecond pulse from a mode-locked oscillator was stretched by a chirped FBG. And then the stretched pulse was amplified by two single-mode YDF pre-amplifiers for the fiber CPA laser system. The CPA laser system was constructed of only single-mode fibers. The major advantage of single-mode fibers is that a high-quality single-mode beam was produced without any special precaution for higher order mode suppression, which may not be stable for long-time.

EXPERIMENTS

The pulse fiber laser oscillator is an Nonlinear Polarization Rotation (NPR) mode-locked laser as shown in Fig.1. NPR was employed as a saturable absorber to start and stabilize the mode-locked pulse operation. The rotation of the elliptical polarization resulting from the optical Kerr nonlinearity is proportional to the light intensity, the area of the elliptical polarization, and the fiber length [4]. Polarization controller is used to control the NPR, as the losses are minimum at the center and maximum at the wings of the pulse. The polarization controller was composed of quarter-wave plate (QWP), half-wave plate (HWP) and polarization beam splitter. The single-mode YDF was forward pumped in-core with 977 nm fiber-pigtailed laser diode (LD) of approximately 500 mW through 977/1020-nm wavelength-division multiplexing (WDM) coupler because forward pumping system is superior to backward pumping system in reducing noise figure of YDF [5]. A pair of grating was used in the double-pass configuration. The mirror of dispersive delay line is slightly tilted to separate the outgoing beam from the incoming beam. The intracavity grating pair provides negative dispersion $B_2$ of -0.21 ps².

Mode-locked operation was observed by adjusting three wave-plates. After adjusting polarization inside the cavity, mode-locked operation was self-started by increasing LD current. The net cavity GVD was optimized for short pulse duration by adjusting the grating separation using micrometer. We tried to tune the center wavelength of mode-locked laser by inserting a slit in front of a mirror between the dispersive delay lines because the reflectivity of chirped FBG has been fixed at 1048 nm ~ 1058 nm. The center wavelength of mode-locked oscillation could be tuned from 1015 to 1060 nm (45 nm) by inserting and moving a slit. Pulse repetition rate obtained was 26.3 MHz corresponding to about 7.9 m of total optical length of laser cavity. Figure 2 shows the temporal waveform and the spectrum. This figure show the reconstructed waveforms from the spectrogram observed.

Fig.1 Schematic setup of the mode-locked Yb fiber laser oscillator.
using the second harmonic generation frequency resolved optical gating (SHG FROG) method. The solid and dotted curves show the intensity and chirp, respectively. Inset shows the spectrum. The center wavelength of the mode-locked pulses was 1053 nm, and the pulse width was 62.5 fs. The optical spectrum was observed by optical spectrum analyzer. The spectral bandwidth was 55 nm at full width half maximum (FWHM). The time-bandwidth product was 0.93, indicating that the pulses were chirped slightly. This is because higher order dispersion remains. The net GVD indicating that the pulses were chirped slightly. This is (FWHM). The time-bandwidth product was 0.93, indicating that the pulses were chirped slightly. This is because higher order dispersion remains. The net GVD of laser cavity is assumed 0.0015 ± 0.0123 ps² from 1000 nm to 1100 nm. The output average power was 130 mW, the pulse energy was 4.9 nJ and its peak power was 79 kW. The stability of mode-locked laser oscillator was below 0.2 % at 12 hours continuous operation. It is difficult to generate shorter pulse in this fiber ring oscillator because higher order dispersion remains inside the laser cavity. Exact compensation of higher order dispersion inside the laser cavity by using prism pairs makes it possible to generate much shorter pulse, though the constitution became complicated.

A chirped FBG was used as a pulse stretcher. In chirped FBG, the optical period of the grating changes along the fiber length. Low and high frequency ingredient of a pulse are reflected at different locations within the chirped FBG because of variations in the Bragg wavelength. When a pulse is incident on a chirped FBG, different spectral components of the pulse are reflected at different parts of the grating. The 10 cm long chirped FBG of peak reflectivity 85 % at 1048 nm ~ 1058 nm and target dispersion 71.5 ps/nm was fabricated by phase mask technique [6]. The chirped FBG was spliced with optical circulators. The pulses from mode-locked oscillator were stretched to 0.7 ns with bandwidth of 10 nm.

We installed pre-amplifier after chirped FBG stretcher. The stretched pulses were then amplified in two stages of YDF preamplifier. Each 3-m long YDF which is same as oscillator (Yb ion concentration of 10,000 ppm by weight) was backward pumped in-core by LD because backward pumping system is superior to forward pumping system in power conversion efficiency. The second pre amplifier consists of a 3 m-long YDF

was backward pumped by beam-combined LDs at approximately 500 mW through a 980/1060-nm WDM coupler. The slope efficiency of the second pre-amplifier was 60 %, the output power was 356 mW, the pulse energy was 13.5 nJ and its peak power was 19.3 W.

CONCLUSION

We have demonstrated self-starting mode-locked YDF laser which generates femtosecond laser and all single-mode fiber CPA laser system. The oscillation wavelength of mode-locked laser can be tuned widely from 1015 to 1060 nm (45 nm) by inserting a slit in the cavity. The mode-locked fiber oscillator gave the pulse energy of 4.9 nJ, pulse duration of 62.5 fs with the repetition rate of 26.3 MHz. The spectral width measured was 55 nm at FWHM. The time-bandwidth product was 0.93. The femtosecond pulse was stretched to 0.7 ns in chirped FBG and then amplified in two YDF preamplifiers of the fiber CPA laser system. The slope efficiency of the second pre-amplifier is 60 %, the output power was 356 mW, the pulse energy was 13.5 nJ and its peak power was 19.3 W. The mode-locked YDF oscillator described here is compact, stable and free from misalignment. The tunability of this type of fiber laser will be useful as an oscillator for the amplifier using various materials such as Nd:YAG, Nd:silica, Nd:phosphate glass and Yb:YAG. The single-mode fiber CPA laser system is also compact, stable and high quality.

REFERENCES