Front-end system used in PM-Yb fiber laser for high-peak power laser system

YOSHIDA Hidetsugu, TSUBAKIMOTO Koji, FUJITA Hisanori, NAKATSUKA Masahiro, MIYANAGA Noriaki, and IZAWA Yasukazu
Institute of Laser Engineering, Osaka University, Suita, Osaka, Japan
hideyo@ile.osaka-u.ac.jp

Abstract. We have demonstrated the generation of optional pulse shape by Yb doped fiber laser system for EUV lithography laser and IFE front-end system. Yb fiber laser system operated the polarization-maintained pulses for single-transverse and -longitudinal mode using fiber Bragg grating (FBG). The several output waveforms obtained including rectangular pulses from 1 ns to 12.5 ns with a 500-ps rise time, and Gaussian pulses from 1 ns to 25 ns. The increase in output power has been achieved to 30W (300µJ, 100kHz) with a 30-µm core Yb double-clad LMA fiber.

1. Introduction

The output power of cw Yb-doped fibers (YDF) dramatically increases to achieve diffraction limited beam during the last two years. Yb doped silica fiber has several advantages, such as broadly gain bandwidth, high output power efficiency and large saturation fluence. Recently, the most high power works, such as few hundred watts, are focused on the Yb-doped fiber operation around 1 µm region because the output efficiency could be achieved extremely higher than 60-80 %[1, 2]

We have demonstrated the generation of optional pulse shape by single-mode YDF laser system. Yb fiber laser system operated the polarization-maintained pulsed for single-transverse and -longitudinal mode using fiber Bragg grating (FBG). The laser oscillator can be tuned at four wavelengths of 1030, 1053, 1064 and 1080 nm.

2. Arbitrary pulse-shape generation using a polarization-maintained mode Yb fiber laser system

The schematic layout of YDF laser system is shown in Fig. 1. The YDF pulse laser system consists of a master oscillator, a LiNbO$_3$ (LN) modulator for temporal pulse shape, and three YDF amplifier stages. The master oscillator is a combination of a YDF oscillator using FBG’s and a 30-cm YDF amplifier. We have succeeded in imprinting all FBG cavity oscillators of different reflectivity. A part of oscillator is made by writing over 50-mm linear Bragg gratings in YDF using a 248-nm light source. The refractive index modulation of fiber grating was about 1 x 10$^{-5}$. The active cavity made by FBG’s is a 40 mm long, and length of a rear high-reflection mirror and output coupler made by FBG are 20 mm and 10 mm, respectively. The active length of the side hole polarization maintaining YDF
also uses a 20-% reflective FBG. The reflectivity of rear and output end of the FBG are 99% and 85%, respectively. The FWHM reflection bandwidth for 99.5-% FBG is about 0.15 nm, and the Bragg wavelength is 1064.1 nm at room temperature.

The YDF is pumped by a 977 nm laser diode through the fiber coupler. The YDF has Yb$^{3+}$ concentration of 10000 wtppm, N.A. of 0.21, and a cutoff wavelength of 800 nm. The core and clad diameters are 6.5 µm and 125 µm, respectively. When the YDF is pumped with a 200-mW laser diode, the oscillator produces about 40 mW CW in a single longitudinal mode. The oscillation threshold was about 39 mW of pumping power, and the slope efficiency was about 20%. The master oscillator is fixed at 1064.1-nm wavelength, and is precisely tuned within 0.1 pm of the desired value by temperature-controlling within 0.01 degrees.

The Bragg wavelength changes by strain and the thermo-optic effects. The FBG define the cavity end, active region and the output coupler, which are narrow band reflectors that allow only one cavity mode to lase. The laser bandwidth was measured with a 20-km long self-heterodyne delay line. In laser operation the linewidth of the YDF oscillator was about 100 kHz, whereas the linewidth of the phase-shifted YDF was 150 MHz. The oscillation linewidth was independent of the output power.

An electronic-pulse-shape generator supplies an arbitrary-voltage pulse to an integrated optic LN amplifier modulator which modulates the laser pulse. The electronic waveform generator works by adding rectangular pulse voltages from 1 ns to 12.5 ns with rise time of 500 ps, and Gaussian pulse voltages from 8 ns to 25 ns. Figure 2(a) shows several rectangular pulses and (b) Gaussian pulses when second amplifier is pumped with a 325-mW LD. The LN modulator has bandwidth of 12.5-GHz bandwidth, and the temporal resolution of pulse shape is limited to about 80 psec.

The amplified pulse energy as a function of a pulse repetition rate is shown in Fig.3. The output energy of about 620 nJ with 12.5-ns Gaussian pulse was obtained when the pumping power was 975 mW at repetition rate below 10 kHz. At a repetition rate of 50 kHz, the output energy increases to about 770 nJ at 975-mW pumping power because no SBS (stimulated Brillouin scattering) generated. At lower repetition rate below 10 kHz, the output energy decreased to about 20% because the shade of band-pass filter due to SBS generation with high stored energy. After passing through three amplifiers and undergoing several optical component losses, the 20-ns pulse has a peak power of about 20W at 650-mW pumping power.

---

Fig. 1 Optical layout of YDF laser front-end system
Fig. 2 (a) several rectangular pulses from 1 ns to 12.5 ns in rise time by 500 ps, and (b) Gaussian pulses from 8 ns to 25 ns.

Fig. 3 The amplified pulse energies as a function of a pulse repetition rate for YDF fiber system.
3. Power amplifier system used in LMA Yb fiber.

Two optical isolators were inserted to prevent the back-reflection into nano-second Yb fiber laser oscillator, which could disturb the laser operation. Large-mode area (LMA) Yb double-clad fiber was pumped with a fiber coupled laser diode (LD) of 980 nm. The maximum pump power was ~90 W. A 3-m long polarization-maintained LMA fiber with core diameter 30 µm (NA: 0.07), and clad diameter 400 µm (NA: 0.46) was used. Figure 4 shows the output power of LMA main amplifier. The output power has been achieved to 30W (300 µJ, 100kHz) at a wavelength of 1053 nm. The beam quality was observed with near- and far-field patterns of the amplified laser pulse. The focal spot size was about 1.3 times the diffraction-limited value with a bending radius of 75 mm.

4. Conclusion.

We have demonstrated the generation of optional pulse shape by Yb doped fiber laser system for EUV lithography laser and IFE front-end system. Yb fiber laser system operated the polarization-maintained pulses for single-transverse and -longitudinal mode using fiber Bragg grating (FBG). The laser oscillator can be tuned at four wavelengths of 1030, 1053, 1064 and 1080 nm. The several output waveforms obtained including rectangular pulses from 1 ns to 12.5 ns with a 500-ps rise time, and Gaussian pulses from 1 ns to 25 ns. The increase in output power has been achieved to 30W (300µJ, 100kHz) with a 30-µm core Yb double-clad LMA fiber.

For applications, this system can be used as the fiber source for interferometer, nonlinear frequency converter and seed light source for IFE (Inertial Fusion Energy) laser system.

A part of this work was performed under the auspices of the Ministry of Education, Culture, Science, and Technology, Japan (MEXT) under the contact subject “Leading Project for EUV lithography source development”.

References

[1] Y. Jeong, J. K. Sahn, D. N. Payne and J. Nilsson, Opt. Express.12, 6088 (2004). Another reference
[2] A. Tunnermann, Workshop on Fiber laser 2006, (2006).