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DEVELOPMENT OF A PULSE RADIOLYSIS SYSTEM BY ULTRA-FAST SUPER CONTINUUM PROBE LIGHT AT WASEDA UNIVERSITY*

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Abstract

We have been studying the pulse radiolysis using photo-cathode rf gun at Waseda Univ. Pulse radiolysis is one of the powerful methods to trace early chemical reactions by ionizing radiation. In pulse radiolysis, the probe light absorption, which produced by active species formed by electron beam of rf gun, is measured at each wavelength and made possible to trace reactions. Therefore, we have used the super continuum (SC) light for the probe light. The SC light has a broad spectrum and is generated by nonlinear optical effect caused by injecting picosecond laser to photonic crystal fiber (PCF). However, the resulting SC light was unstable because its peak intensity was not enough. We need to use a femtosecond pulsed laser which is expected to be stronger peak intensity than a picosecond laser. We have developed a mode-locked Yb-doped fiber laser based on Non-Linear Polarization Rotation as a femtosecond pulsed laser and the chirped pulse amplification system which will be able to amplify the femtosecond pulse. In this conference, we will report the performance of the SC light using this fiber laser system, recent results of pulse radiolysis experiments and the future plans.

INTRODUCTION

The photo-cathode rf gun has been developed at Waseda University, and pulse radiolysis has been studied as application of electron beam obtained by photo -cathode rf gun. In pulse radiolysis, the probe light absorption, which produced by active species formed by electron beam of rf gun, is measured at each wavelength and made possible to trace reactions. When we measure the lifetime of the target transient active species, temporal resolution of pulse radiolysis is determined mainly by the pulse width of electron beam and probe light. Probe light is required to be pulsed light with high intensity, good stability and broad spectrum. On these backgrounds, we have started to study SC light based on PCF for the probe light.

SUPER CONTINUUM (SC) LIGHT WITH PHOTONIC CRYSTAL FIBRT (PCF)

The SC light with PCF is a new technique of pulsed white light generation. Figure 1 (left) shows the cross-sectional micrograph of PCF. PCF is the optical fiber which is made of silica glass and clad has many micro air holes. The refractive index difference between core and clad become higher by these holes. It can realize the small core area of PCF and contributes to enhance the nonlinear optical effect. The SC light has a broad spectrum and is generated by nonlinear optical effect caused by the high peak intensity of pulsed laser in PCF. The spectrum of SC light previously generated by picosecond pulsed laser (4ps) is shown in Fig. 1 (right). It is clear that the SC light has enough spectral bandwidth, however, the resulting SC light was unstable because the peak intensity was not enough. Thus we started to use a femtosecond pulsed laser which is expected to be stronger peak intensity than a picosecond laser. We have developed a mode-locked Yb-doped fiber laser based on Non-Linear Polarization Rotation as a femtosecond pulsed laser. [1]

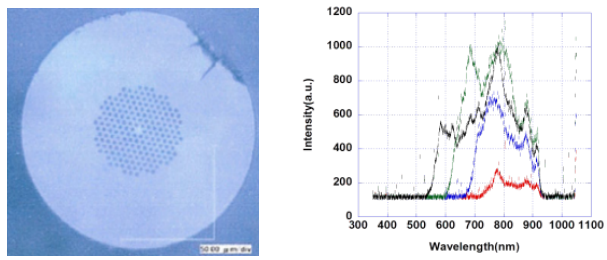

Figure 1: Cross-sectional micrograph of PCF (left) and the spectrum of SC (right).

Yb-DOPED FIBER

We have developed a fiber laser oscillator for injecting to PCF based on Yb-doped fiber as gain medium. Yb is one of the rare-earth elements and Yb-doped fiber is a fiber which is doped $Yb^{3+}$to the core. The energy level of Yb^{3+} has a simple structure compared with Er^{3+}, Nd^{3+}, and it is possible to ignore the excited state absorption, therefore excitation efficiency of Yb^{3+} is higher than the others. Yb-doped fibers make exceptional sources in the 1.0 – 1.1 μm wavelength range because of an excellent power conversion efficiency of over 80% and a broad tunability over several tens of nanometers. [2]

NONLINEAR POLARIZATION ROTATION (NPR)

Using Nonlinear Polarization Rotation as mode-locking method, we generate a pulsed laser. The NPR is one of the passive mode-locking methods. Figure 2 shows a mechanism of NPR mode-locking. In the fiber, a nonlinear optical effect tends to occur because a laser peak power becomes higher to the long interaction length and small core diameter of the fiber. In the passive mode-locked fiber laser, NPR with polarizer is commonly employed as a saturable absorber. When injecting linear polarized light to the fiber, phase difference is generated by difference of polarization intensity and a linear

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polarized light varies to elliptically-polarized light. Only high intensity part of elliptically-polarized light passes through wave plate and PBS (Polarizing Beam Splitter), and a pulse is generated. [3]

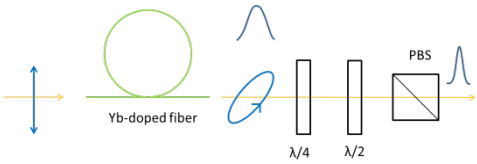

Figure 2: mechanism of NPR mode-locking.

CHIRPED PULSE AMPLIFICATION (CPA) SYSTEM

Chirped-pulse amplification (CPA) has become a common technique for producing the energetic optical pulses of less than picosecond duration. Amplifying energetic optical pulses by fiber amplifier, the spectrum of pulse would be changed by nonlinear optical effect in fiber. Therefore, we need to amplify pulse after stretching femtosecond pulses as shown in Figure 3.

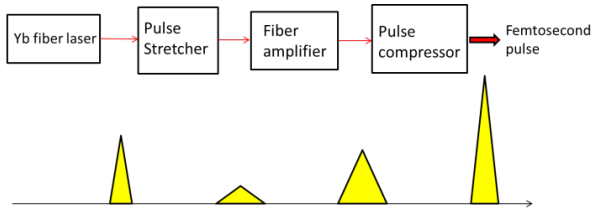

Figure 3: CPA system.

EXPERIMENTAL SETUP

We have developed a mode-locked Yb-doped fiber laser based on NPR. Figure 4 shows a mode-locked Yb-doped fiber laser setup. The Yb-doped fiber is pumped by a 980 nm laser diode. In order to achieve the NPR in fiber we used the transmission grating pair for dispersion correction.

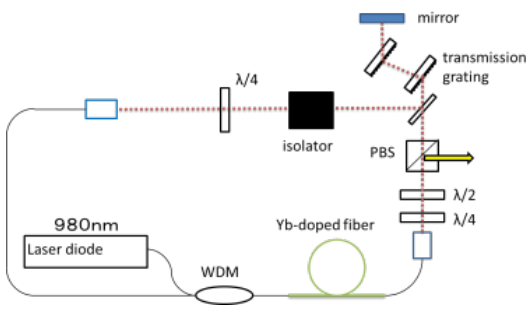

Figure 4: a mode-locked Yb-doped fiber laser setup.

We need to introduce CPA system because the peak intensity of Yb fiber laser is lower than that of picosecond laser that we used previous studies. Figure 5 shows the layout of CPA system setup. In pulse stretcher and compressor, the femtosecond pulse of Yb fiber laser is stretched or compressed by diffraction angle of transmission grating at each wavelength.

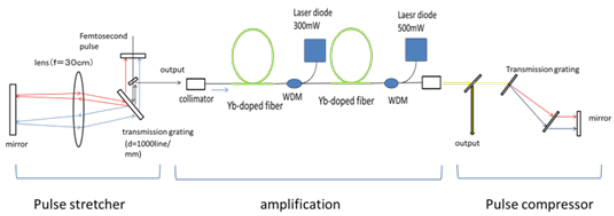

Figure 5: CPA system setup.

RESULT AND DISCUSSION

Yb Fiber Laser

Figure 6 shows mode-locked pulses from Yb-doped fiber laser observed by using photo-detector and the oscilloscope. Pulse repetition rate obtained was 36 MHz, average power was 32.4 mW, pulse duration measured by the autocorrelator was 146 fs (rms) and resulting peak intensity was 6.12 kW at the oscillator. Table 1 shows the parameter of Yb fiber laser and picosecond laser. Peak intensity of picosecond laser is about 10 times higher than that of Yb fiber laser.

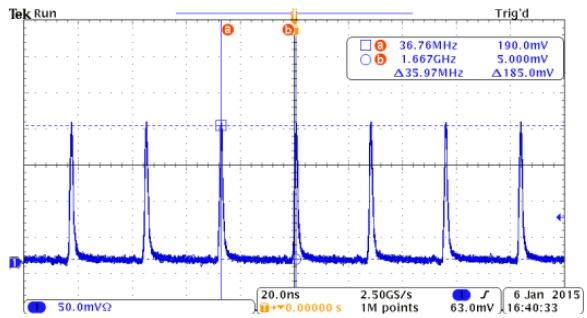

Figure 6: mode-locked pulses of Yb-doped fiber laser observed by using the oscilloscope.

Table 1: The Parameters of Yb Fiber Laser and Picosecond Laser

	Yb fiber laser	Picosecond laser
Pulse duration(rms)	146fs	4ps
Average power	32.4mW	29W
Repetition frequency	36MHz	119MHz
Peak intensity	6.12kW	60kW

CPA System

Figure 7 (top) shows the stretched pulse duration by autocorrelator. We succeeded to stretch pulse duration from 146 fs to 18.9 ps and average power was changed from 32.4 mW to 24.0 mW by loss of the stretcher. Figure 7 (bottom) shows the relation of pump and output power of the fiber amplifier. We obtained the high output power (204 mW) with 450 mW pump power and the change of spectrum by nonlinear optical effect was not observed in fiber amplifier. Eventually, the duration of the pulse through the fiber amplifier was compressed from 18.9 ps to 127 fs by pulse compressor and average power was changed from 204 mW to 183 mW by loss of the pulse compressor.

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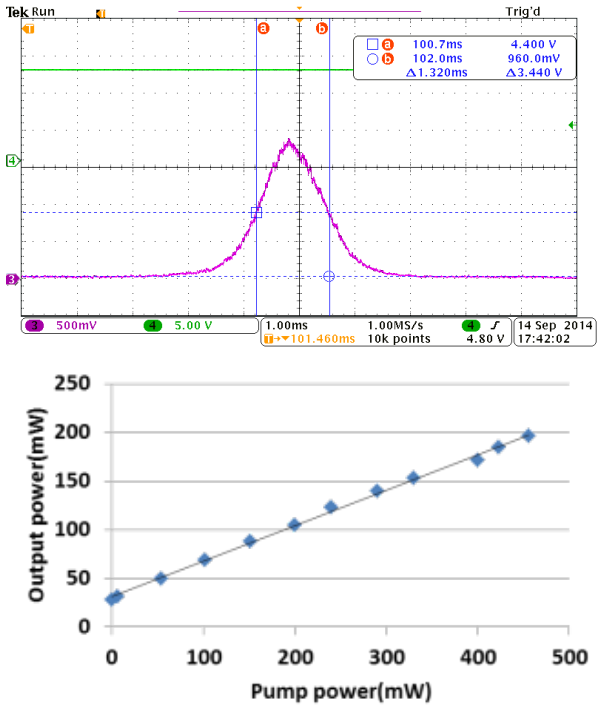

Figure 7: The stretched pulse observed by using the oscilloscope (top) and the relation of pump and output power (bottom).

SC Light

Figure 8 shows the spectrum of Yb fiber laser and SC light which is generated by injecting Yb fiber laser with CPA system to PCF. The spectrum of SC light is broadened from 850 nm to 1100 nm by nonlinear optical effect in PCF. However, comparing Figure 1 (right) and Figure 8, the spectrum of SC light based on picosecond pulse is broader than that of SC light based on Yb fiber laser (femtosecond pulse). That is caused by the difference of peak intensity between Yb fiber laser and picosecond pulse. According to Table 2, peak intensity of picosecond laser is about 1.5 times higher than that of Yb fiber laser. Therefore, we need to improve CPA system, for example using a laser diode with higher pump power for fiber amplifier.

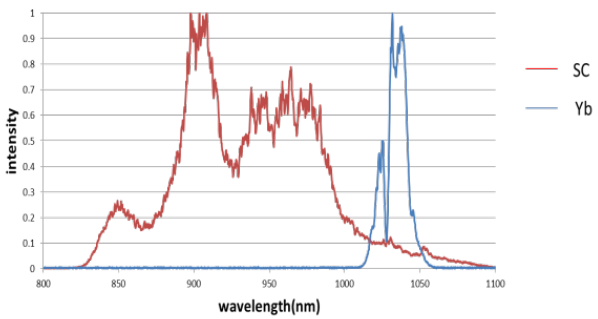

Figure 8: The spectrum of Yb fiber laser and SC light.

Table 2: The Parameters of Yb Fiber Laser with CPA and Picosecond Laser

	Yb fiber laser(CPA)	Picosecond laser
Pulse duration(rms)	127fs	4ps
Average power	183mW	29W
Repetition frequency	36MHz	119MHz
Peak intensity	40.4kW	60kW

CONCLUSION

We have developed a mode-locked Yb-doped fiber laser based on Non-Linear Polarization Rotation as a femtosecond pulsed laser and CPA system. We obtained pulse repetition rate of 36 MHz, average power of 183 mW, pulse duration of 127 fs (rms) and peak intensity of 40.4 kW. In the recent study, peak intensity of picosecond laser is about 1.5 times higher than that of Yb fiber laser. Therefore, the resulting SC light by PCF had narrower bandwidth than that of picosecond laser. In near future, we need to improve CPA system to achieve the higher peak intensity. We will improve a laser diode with higher pump power in fiber amplifier system.

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