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SUPERCONTINUUM GENERATION FOR THE IMPROVEMENT OF PULSE RADIOLYSIS SYSTEM

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Abstract

Pulse radiolysis is one of the absorption measurement methods for investigating the fundamental, ultrafast process of radiation chemical reactions. Analytical light is transmitted simultaneously with electron beam irradiation, and its absorption by reactive species is detected. Since the target reactions arise in pico second time scale or even shorter, analytical light is required to have such duration. Besides, so as not to be buried in noise of the radiation source, the optical power of the analytical light must be high enough. Furthermore, it is desirable that the analytical light covers visible region because important absorptions caused by irradiation products such as hydrated electron, hydroxyl radical, or so exist in the region. We considered that the supercontinuum light generated from an ultrashort pulse laser is suitable as an analytical light because it has all these characteristics. In this study, we generate the second harmonic (775 nm) of an erbium fiber laser (1550 nm) as a seed laser for supercontinuum generation. In this conference, we report the current situation of our laser system and prospects.

INTRODUCTION

Pulse Radiolysis

When materials are irradiated by radiation, energy-unstable and highly reactive intermediate species are generated, and the overall reaction proceed through them. It is very important to study such intermediates for understanding radiation chemical reactions. Pulse radiolysis is one of the transient absorption measurement methods for investigating the behavior of intermediates. In pulse radiolysis, analytical light is transmitted simultaneously and its absorption by reactive species with very short lifetime is measured. Figure 1 shows the schematic of pulse radiolysis.

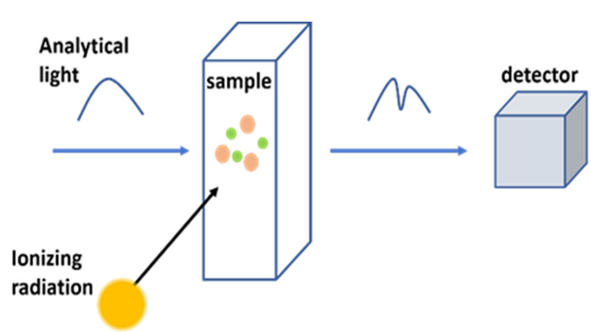

Figure 1: Schematic of pulse radiolysis.

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Since the reactions by the intermediate species arise in pico second time scale or even shorter, analytical light needs to have such duration. Besides, the optical power must be high enough so as not to be buried in noise of the radiation source. Furthermore, absorption band of important reactive species exist in the visible region, so it is desirable for analytical light to cover the region. We considered that the supercontinuum light (SC light) generated from the second harmonic of Er fiber laser is suitable as the analytical light. In this study, we develop the laser system for the SC generation.

Supercontinuum Light

SC light is generated from ultrashort pulse laser. The spectrum of the seed laser is broadened in nonlinear medium by nonlinear optical effect such as self-phase modulation. In this study we use the photonic crystal fiber (PCF) as the nonlinear medium. Unlike ordinary fibers, PCF has air holes regularly arranged in the cladding. Thanks to this structure, high light confinement efficiency can be achieved, and any wavelength can be set to zero dispersion. Parameters of our PCF are shown in Table 1.

Table 1: Characteristics of Our PCF

Parameters	Value
Core Diameter	1.71 [μm]
Cladding Diameter	135 [μm]
Zero Dispersion Wavelength	772 [nm]
Length	3 [m]

Improvement of Pulse Radiolysis System

There are two advantages in using SC light generated by Er fiber laser as the analytical light of pulse radiolysis. One is that the SC light can be applied for both nano and pico second time resolution measurements. Since SC light is based on pulse laser, nano seconds time resolution can be achieved by absorption measurement according to the pulse repetition time. Besides, pico seconds time resolution can be obtained by stroboscopic method. In stroboscopic method, a delay stage is provided on the optical path to add a delay to the analytical light. By increasing the delay time at equal intervals, measurement can be performed according to the delay time interval, and this becomes a time resolution of about picoseconds. Another improvement is the compactness of the system contributed to fiber laser. Although the oscillation wavelength of Ti:

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sapphire laser is close to the zero-dispersion wavelength of our PCF, the system could be larger and expensive. On the other hand, the system will be very compact in the case of SC generation based on the second harmonic of Er fiber laser.

LASER SYSTEM

Overview

The overview of our laser system is shown in Fig. 2.

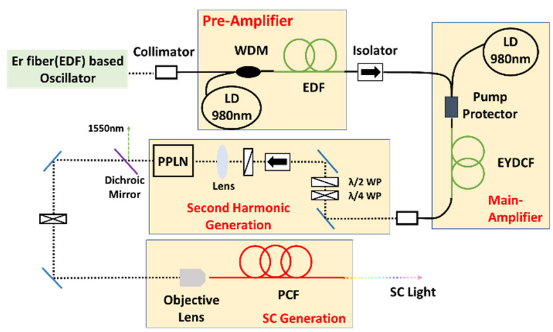

Figure 2: Overview of our laser system.

A 1550 nm pulsed laser is oscillated using an erbium fiber as a gain medium, and the output is amplified by the two-stage amplifier. Then the second harmonic is generated by periodically poled lithium niobate (PPLN) crystal. After that the second harmonic is guided to the PCF to generate SC light. However, we haven't obtained SC yet because of low conversion efficiency to the second harmonic. In this paper, we will describe the current situation.

Oscillator

In the oscillator, mode-locked pulse laser is generated by nonlinear polarization rotation. Performance of the oscillator is shown in Table 2.

Table 2: Performance of the Oscillator

Parameters	**Value**
Repetition Frequency	52.8 [MHz]
Average Power	33.7 [mW]
Spectrum Width (FWHM)	46.6 [nm]

Amplifier

The pre-amplifier compensates for the loss of collimator incidence. The main amplifier amplifies the optical power to 625 mW. In the main amplifier, Er-Yb co-doped double cladding fiber is used as the gain medium in order to introduce high power pump light. Though the spectrum broadens in the gain fiber due to self-phase modulation, the average power is amplified about 19 times. Table 3 shows the characteristics of the amplified pulse at the output of the amplifier. Figure 3 shows the autocorrelation trace and Fig. 4 is the spectrum after the amplifier.

Table 3: Performance of the Amplifier

Parameters	**Value**
Average Power	625 [mW]
Pulse Duration	1.54 [ps]
Peak Power	7.69 [kW]
Spectrum Width (FWHM)	357 [nm]

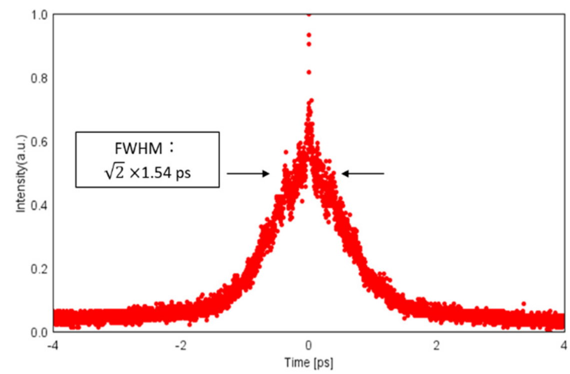

Figure 3: Autocorrelation trace after the amplifier.

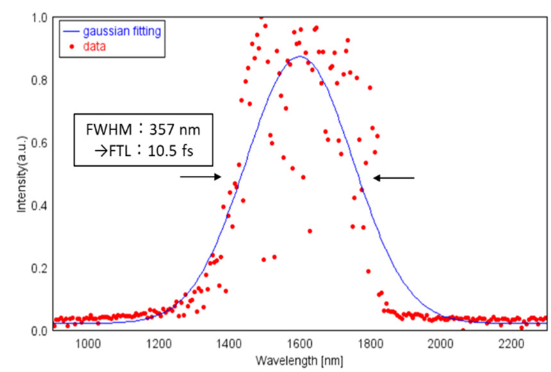

Figure 4: Spectrum after the amplifier.

Second Harmonic Generation

We generate the second harmonic by PPLN crystal. In PPLN crystal, the phase mismatching between the fundamental wave and the second harmonic is compensated by periodic polarization reversal. This is called quasi-phase matching (QPM), and the QPM condition is described as follows.

$$d = \frac{\lambda_{SH}}{2(n_{SH} - n_F)}\,. \quad (1)$$

In Eq. (1), d is the periodic polarization reversal period. λ_{SH} is the second harmonic wavelength. n_{SH} is the refractive index of the second harmonic. n_F is the refractive index of the fundamental wave. As shown in Eq. (1), the wavelength of second harmonic is up to d. There are 10 different ds in our crystal, and so we can selectively change the conversion wavelength according to the position to pass the laser through the crystal. In addition, since the refractive index changes in temperature, the central wavelength can also be changed by adjusting the crystal

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temperature. The spectrum of the second harmonic generated when passing through each *d* at room temperature is shown in Fig. 5. Although we have succeeded in generating the second harmonic, the conversion efficiency is very low regardless of the central wavelength. Table 4 shows the typical parameters of the second harmonic at room temperature.

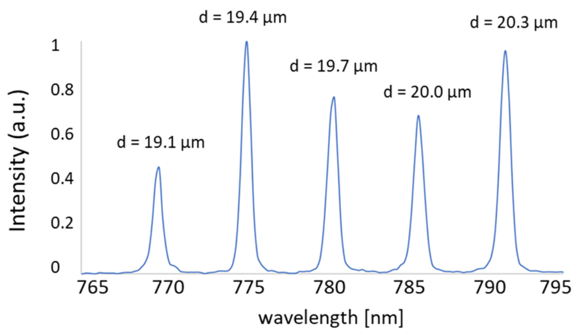

Figure 5: Spectrum of the second harmonic.

Table 4: Parameters of the Second Harmonic

Parameters	Value
Maximum Average Power	3.19 [mW]
Maximum Conversion Efficiency	0.51 [%]
Central Wavelength	775 [nm]

We consider this low conversion efficiency is due to insufficient fundamental laser optical power and pulse duration [1]. Thus, we must compress the pulse for higher peak power and shorter pulse duration.

CONCLUSION

In this study, we develop a laser system using Er fiber laser for the generation of SC light for the improvement of pulse radiolysis system. The second harmonic of Er fiber laser is used as a seed for PCF, but the SC has not been obtained because of low conversion efficiency to the second harmonic. In order to generate sufficient second harmonic, we will compress the pulse duration of Er laser by diffraction grating pairs. We then incident the second harmonic on the PCF to generate SC light. We plan to evaluate the performance as an analytical light source for pulse radiolysis.

REFERENCES

[1] K. Moutzouris, *et al.*, "Multimilliwatt ultrashort pulses continuously tunable in the visible from a compact fiber source", *Optics Letters*, vol. 31, no. 8, pp. 1148-1150, Apr. 2006. doi:10.1364/ol.31.001148