DEVELOPMENT OF AN YB-DOPED FIBER LASER SYSTEM FOR AN ERL PHOTOCATHODE GUN

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Abstract

We are developing an Yb fiber laser system that drives an ERL photocathode gun. An Yb fiber laser is expected to have both high stability and high output power required for the drive laser. We have developed 10W preamplifier using an Yb doped photonic crystal fiber and demonstrated second harmonic generation by the conversion efficiency of 49%. In addition, we have been developing an Yb fiber laser oscillator with a high repetition rate up to 1.3 GHz that is the RF frequency of a superconducting accelerating cavity. We report our recent progress in this development.

INTRODUCTION

An electron source significantly contributes to the performance of an Energy Recovery Linac (ERL) because an electron beam goes around it only one or a few times not to reach the equilibrium between the radiation damping and quantum excitation. A 500kV DC electron gun with a negative electron affinity (NEA) GaAs photocathode is being developed as an ERL gun [1,2]. In order to produce ultra-low emittance and high-charge beam by the photocathode gun, a drive laser system requires leading-edge technology, as shown in table.1.

Table.1.Parameters of the Gun and the Drive Laser [2]

Gun	Beam current	10-100mA
	Repetition frequency	1.3GHz
	Pulse length	10-20ps
	Emittance	0.1 - 1.0mm mrad
	Quantum efficiency	1%
Laser	Repetition frequency	1.3GHz
	Average power	15W
	Pulse width	1ps (Shaping 10-20ps)
	Wavelength	800nm (variable)

Fig.1 shows the schematic of the drive laser system [2]. The drive laser system is MOPA (Master Oscillator and Power Amplifier) type with an Yb fiber laser oscillator and two Yb fiber laser amplifiers. The Yb fiber laser is expected to have high stability and high output power. On the other hand, the Yb fiber laser cannot directly drive the NEA-GaAs photocathode because the wavelength of Yb fiber laser (1030nm) is much longer than that of the band gap of NEA-GaAs (867nm). Therefore, the wavelength conversion from 1030nm to 800nm is done by second harmonic generation and optical parametric amplification.

In this paper, we report development of the Yb fiber laser amplifier and the demonstration experiment of second harmonic generation as part of drive laser system development. Additionally we report progress of development of the Yb fiber laser oscillator toward the 1.3GHz drive laser system

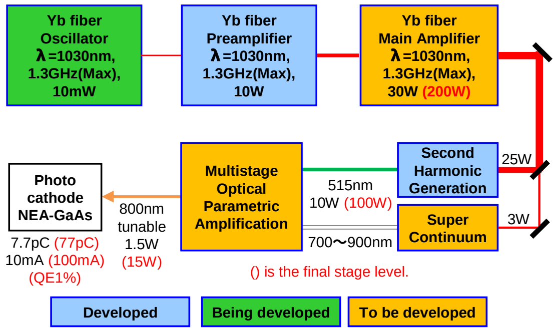

Fig.1. Schematic of drive laser system

LASER AMPLIFIER

Fig.2 shows the system schematic of the Yb fiber laser amplifier. An Yb doped photonic crystal fiber is used to amplify the seed pulse. The photonic crystal fiber has a large core doped with Yb ions and a clad having periodically allocated air holes. In order to suppress nonlinear optical effect that distorts the amplified pulse, the core diameter need be large to decrease the power density of the amplified pulse. However, if the core diameter is overlarge, multi-mode travelling happens in the core and it distorts the pulse shape. For the case of the photonic crystal fiber, the refractive index of the clad is slightly less than that of the core because of the periodical air holes. So, only single mode can travel in the large core.

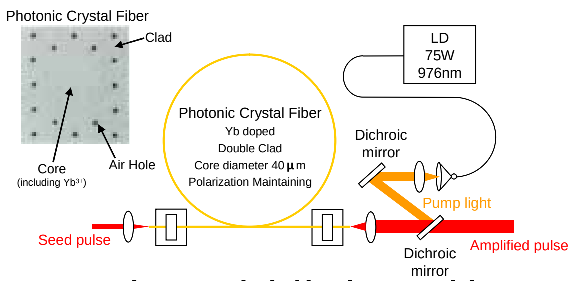

Fig.2. Schematic of Yb fiber laser amplifier

We evaluated the amplifier slope efficiency, the optical spectrum and the pulse duration using the 85MHz pulse as a seed. Fig.3 shows the amplifier slope efficiency. The slope efficiency is 36%. The 85MHz pulse can be amplified to 150nJ/pluse (=13W/85MHz), which is the same pulse energy as when a 1.3GHz seed pulse is amplified to 200W.

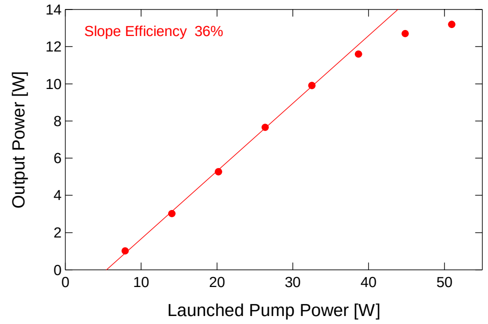

Fig.3. Amplifier slope efficiency

Fig.4 shows spectra of a seed pulse and amplified pulses. A dot line shows the seed pulse and solid lines amplified pulses. FWHMs of amplified spectra are about 10nm, and significant bandwidth broadening does not appear. Fig.5 shows the autocorrelation traces of a seed pulse and amplified pulses. The autocorrelation trace is the convolution of two pulses into which a pulse is divided. FWHMs of the autocorrelation traces are about 1.4ps and almost unchanged. Therefore, we can confirm that nonlinear optical effect that causes the pulse distortion is suppressed in the Yb doped photonic crystal fiber laser amplifier.

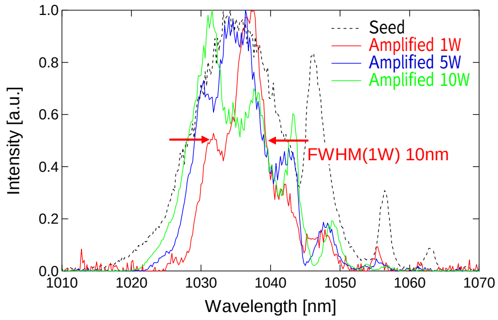

Fig.4. Optical Spectrum

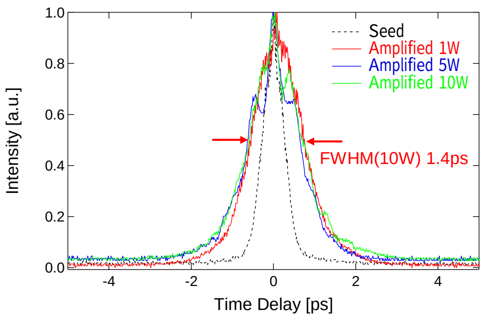

Fig.5. Autocorrelation trace

SECOND HARMONIC GENERATION

Since the Yb fiber laser amplifier with the 85MHz seed pulse realized the same pulse energy as required for the ERL photocathode gun, we demonstrated second harmonic generation using the amplifier output. Fig.6 shows a setup of second harmonic generation. The 85MHz seed pulse is amplified to 10W, and the amplified pulse is input into LBO crystal (LiB_3O_5) [3]. We use a type-I 5-mm-long LBO crystal. The pulse passing through the LBO crystal involves the fundamental (1035nm) and the second harmonic (518nm). So we lead only the second harmonic to the power meter with two mirrors that reflect only 518nm light.

Fig.7 shows the second harmonic power and the conversion efficiency as the function of the fundamental power. When the 9.8W fundamental power is input into the LBO crystal, the second harmonic power of 4.8W is achieved. So the conversion efficiency is 49%. Fig.8 shows the optical spectrum of the 4W second harmonic, and its band width (FWHM) is 1nm.

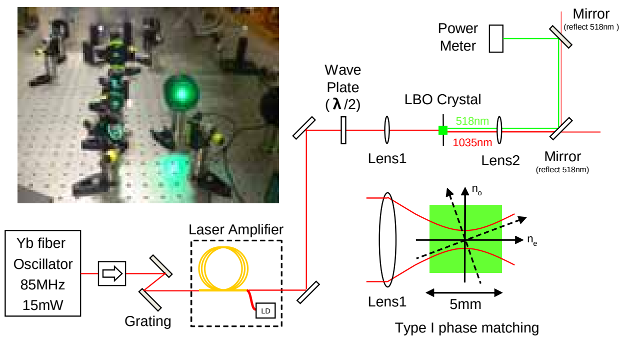

Fig.6. Setup of second harmonic generation

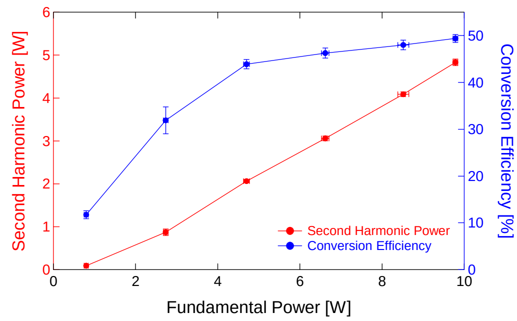

Fig.7. Conversion efficiency of second harmonic

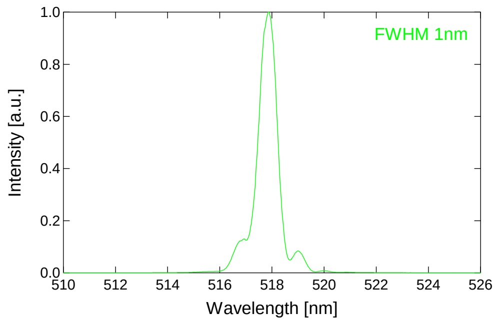

Fig.8. Optical spectrum of second harmonic

TOWARD THE 1.3GHZ OSCILLATOR

The repetition frequency of the generally used Yb fiber laser is up to 100MHz. It is not enough for ERLs that have 1.3GHz RF frequency. In order to realize the 1.3GHz repetition frequency in the Yb fiber laser, we have been developing several different type laser oscillators [4,5]. One of them is an active harmonic mode-locking laser oscillator [6].

Fig.9 shows the schematic of the active harmonic mode-locking laser oscillator. This oscillator type is the all-normal dispersion. The electro-optic (EO) modulator is built in the ring cavity. The EO modulator can modulate the amplitude of CW light at the frequency of the applied electric field by the Pockels effect that the refractive index varies in proportional to the applied electric field. If the frequency of the applied electric field is equal to an integral multiple of the fundamental frequency of the ring cavity set to 1.3 GHz, the amplitude of CW light is modulated at 1.3 GHz and the mode-locked pulse is oscillated at 1.3GHz.

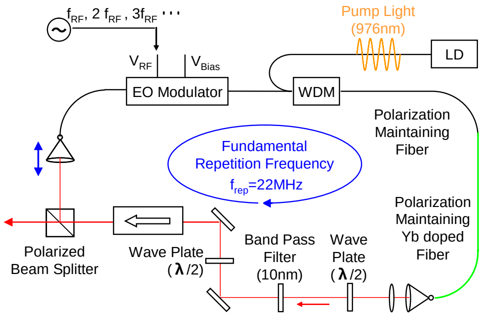

Fig.9. Active harmonic mode-locking laser oscillator

Fig.10 shows the optical spectrum of the 421MHz pulse. FWHM of the spectrum is about 0.2nm (0.06THz). Fig.11 shows the autocorrelation trace of the 421MHz pulse. If the pulse shape is Gaussian, the pulse width (FWHM of the pulse) is equal to the FWHM of the autocorrelation trace divided by $\sqrt{2}$. So the pulse width is 21ps (=30ps/$\sqrt{2}$). Since the TB product is significantly large, the 421MHz pulse does not reach the Fourier transform limit. Therefore, the pulse width is expected to be even shorter by the pulse compression.

Fig.12 shows the RF spectrum of the 421MHz pulse. The sidebands appear every 22MHz around 421 MHz main peak. This is the supermode noise that results from combinations of the longitudinal mode (22MHz) of the ring cavity. The supermode noise causes the intensity fluctuation, and prevents the high repetition. Several suppression methods for the supermode noise are reported. One of them is the method that only one supermode is allowed to travel in the ring cavity using the Fabry-Perot etalon that filters other supermodes. [7]

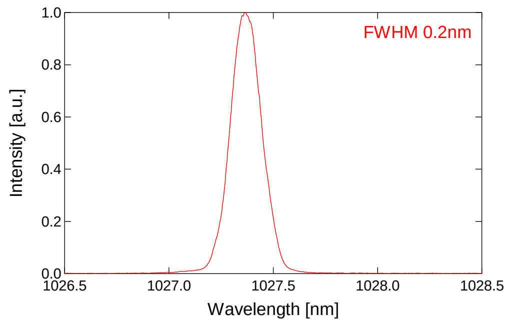

Fig.10. Optical spectrum of 421MHz pulse

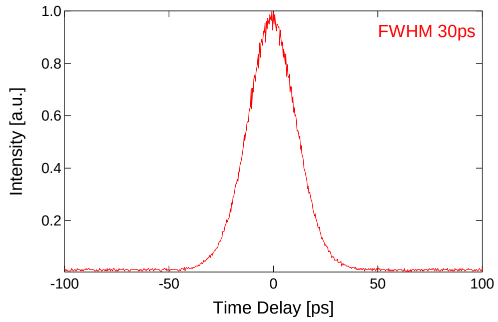

Fig.11. Autocorrelation trace of 421MHz pulse

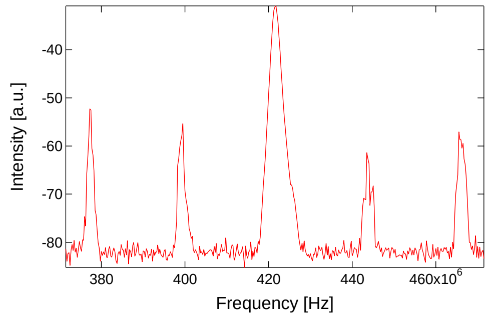

Fig.12. RF spectrum of 421MHz pulse

SUMMARY

We developed a 10W level laser amplifier by use of an Yb doped photonic crystal fiber as the preamplifier of the drive laser system for the ERL photocathode gun. The drive laser system could provide 150nJ energy per pulse at 85MHz. Pulse distortion by the nonlinear optical effect is small.

Since the Yb fiber laser amplifier with the 85MHz seed pulse realized the same pulse energy as needed for the ERL photocathode gun, we demonstrated the second harmonic generation. When we input the 9.8W fundamental pulse into a 5-mm-long type-I LBO crystal, we could obtain 4.8W second harmonic pulse. The conversion efficiency was 49%.

In order to realize a 1.3GHz drive laser system, we have been developing the active harmonic mode-locking Yb fiber laser oscillator. At present, we could generate 421 MHz pulse (bandwidth: 0.2nm, pulse width:21ps). In order to increase the repetition rate to 1.3GHz, we need to suppress the supermode noise.

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