RECENT PROGRESS OF AN Yb-DOPED FIBER LASER SYSTEM FOR AN ERL-BASED LIGHT SOURCE

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Abstract

We have been developing an Yb fiber laser system for an ERL photocathode gun. The Yb fiber laser system is expected to have both high stability and high output power required for the drive laser. We have improved the output power of the Yb fiber laser system up to 31 W at 85 MHz by installing a preamplifier and keeping the wavelength of pump light and the temperature of a photonic crystal fiber. We also have demonstrated wavelength conversion from 1 μm to 800 nm with a conversion efficiency of 9.5% by generating a supercontinuum light, which is planned to be amplified by optical parametric amplification (OPA) in future. In addition, we are developing a Nd:YVO_4-based mode-locked oscillator that can operate at the same frequency as 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.

Figure 1 shows the schematic of the drive laser system. 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. In addition, the optical parametric amplification (OPA) is done to convert the wavelength of the Yb fiber laser (1030nm) to the wavelength equal to the band gap of the photocathode NEA-GaAs (700-800nm). Firstly, two lights are diverged from the light amplified by the Yb fiber laser amplifier. One is converted to a second harmonic (SH, 515nm) by a nonlinear optical crystal and the other to a supercontinuum light (SC, 800±50nm) by a high nonlinear photonic crystal fiber (PCF). Finally, OPA is done using SH as the pumping light and SC as the seed light.

In this paper, we report the development of the Yb fiber laser amplifier and the demonstration experiment of wavelength conversion from 1 μm to 800 nm by the supercontinuum generation. Additionally we report the development of a Nd:YVO_4-based mode-locked oscillator that can operate at the same frequency as the RF frequency of a superconducting accelerating cavity.

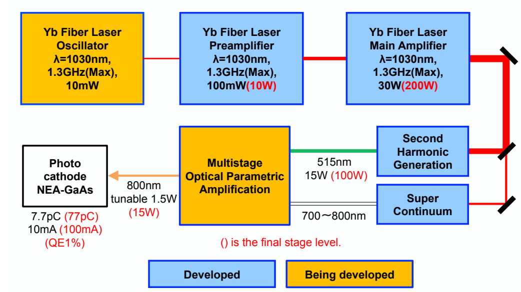

Figure 1: Schematic of drive laser system.

LASER AMPLIFIER

We previously developed an Yb doped phonic crystal fiber laser amplifier and amplified an 85MHz seed pulse up to 10W [3]. This time, we have improved the output power of the amplifier system up to 31 W at 85 MHz.

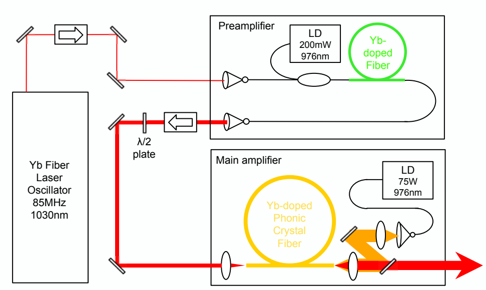

Figure 2: Schematic of Yb fiber laser amplifier system.

Figure 2 shows the schematic of the Yb fiber laser amplifier system. An 85MHz seed pulse is made by an Yb fiber oscillator and amplified to 60mW by a preamplifier. The preamplifier is composed by the Yb doped fiber (core diameter:5 μm, length:5m). The preamplifier can amplify 10mW pulse up to 100mW without nonlinear optical effect. The 85MHz seed pulse from the preamplifier is then amplified by a main amplifier. The main amplifier is composed of an Yb doped photonic crystal fiber (PCF, core diameter: 40μm, length:1.2m). Because the PCF has a large core doped with Yb ions and a clad having periodically allocated air holes, it can significantly amplify the seed pulse without nonlinear optical effect. If a pump power becomes much higher, various troubles happen. First of all, the PCF is at risk of burning by much

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higher pump power. So we installed a cooling fun near the PCF tail edge into which pump light is input. Additionally, the amplified efficiency decreases due to the shift of the center wavelength of the laser diode (LD) output by its heating. As a result we kept the center wavelength of the LD output at 976nm by controlling the LD temperature.

We performed evaluation of the amplified pulse. Fig. 3 shows the amplifier slope efficiency. The slope efficiency is about 40%. The 85MHz pulse can be amplified to 31W and have almost the same pulse energy as required at 1.3-GHz repetition rate for the ERL. Fig. 4 shows spectra of the seed pulse and amplified pulses. A dot line shows the seed pulse and solid lines the amplified pulses. FWHMs of the amplified pulse spectra are about 10nm, and significant bandwidth broadening does not appear. Fig. 5 shows the autocorrelation traces of the 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 10ps and almost unchanged. Therefore, we can confirm that nonlinear optical effect that causes the pulse distortion is suppressed in the main amplifier.

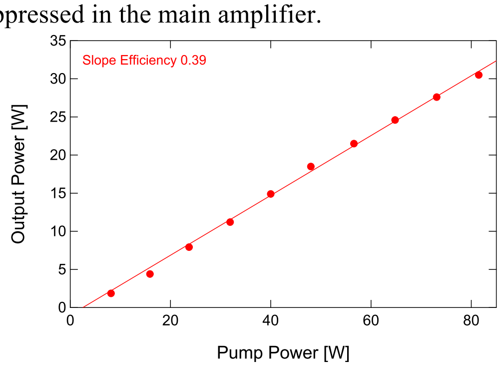

Figure 3: Amplifier slope efficiency.

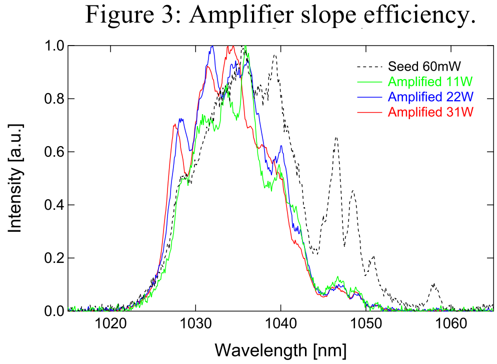

Figure 4: Optical Spectrum.

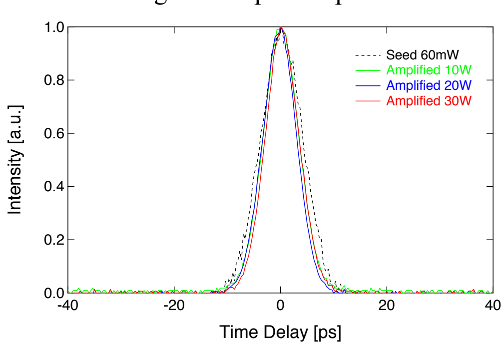

Figure 5: Autocorrelation trace.

SUPERCONTINUUM GENERATION

In order to use as a seed light of the optical prametoric amplification (OPA), we generated the supercontinuum (SC) by the high nonlinear PCF (NKT Photonics, NL-1050-ZERO-2). Fig. 6 shows the schematic of the experiment setup. The 85MHz amplified pulse (2W) was input into the high nonlinear PCF. Because the high nonlinear PCF has low dispersion around the wavelength 1μm, the input pulse whose wavelength is 1030nm can propagate with its peak intensity kept and the broadband SC can be generated efficiently. In order to extract frequency component around 800nm from the SC, the broadband SC is reflected by two mirrors that have the center wavelength of 800nm and the bandwidth of 80nm.

Figure 7 shows the spectrum of the SC. The center wavelength is 800nm and the bandwidth is 85nm. The average power is 190mW and the conversion efficiency is 9.5% (0.19W/2W). At the present stage, the wavelength of the SC can satisfy the specification required by the ERL.

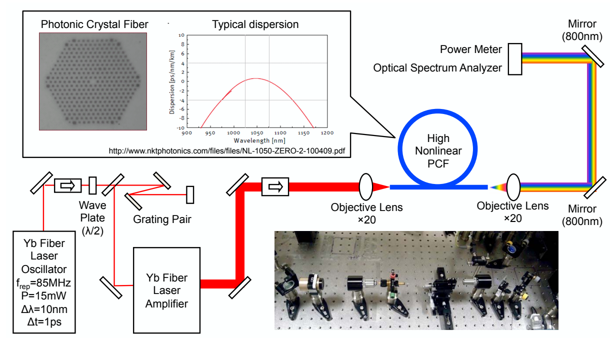

Figure 6: Setup of supercontinuum generation.

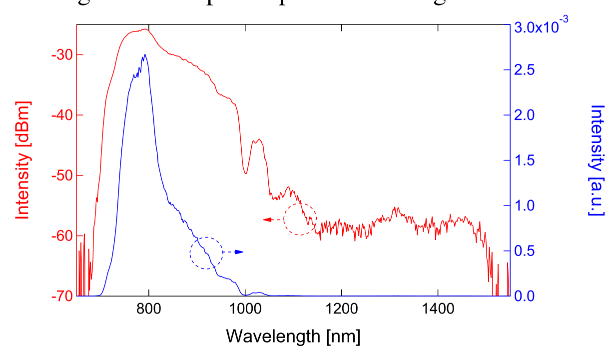

Figure 7: Spectrum of suercontinuum light.

TOWARD THE 1.3GHz LASER SYSTEM

We have developed the Nd:YVO_4 laser oscillator for the 1.3GHz laser system. Fig. 8 shows the schematic of the Nd:YVO_4 laser oscillator. The fiber coupled laser diode (center wavelength: 808nm) is used as the pumping light source. The core diameter of the fiber is 105 μm. Because the center wavelength of the LD depends on temperature, we have developed the temperature controller that holds the LD temperature and keeps the center wavelength at 808nm. The lens (f=25mm) is used to focus pumping light. Nd:YVO_4 crystal has 0.5% doped

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density and 8mm crystal length. The dichroic mirror (DM) is coated with the anti-reflective 808nm and high-reflective 1064nm. The output coupler (OC) is the concave mirror that has 99% reflection ratio and 1% transition ratio and 50mm curvature radius. The semiconductor saturable mirror (SESAM) is used for mode locking. The spontaneous light output from Nd:YVO_4 crystal pumped by the LD is locked in the cavity by DM and SESAM. This locked light turns around in the cavity and the induced emission happens. This induced emission light is amplified in the cavity and mode locking happens. One percent of this mode locked pulse light is extracted by the OC.

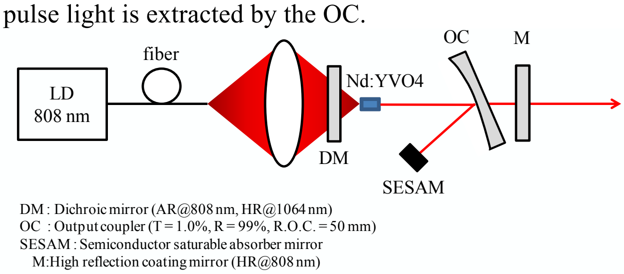

Figure 8: Schematic of Nd:YVO_4 oscillator.

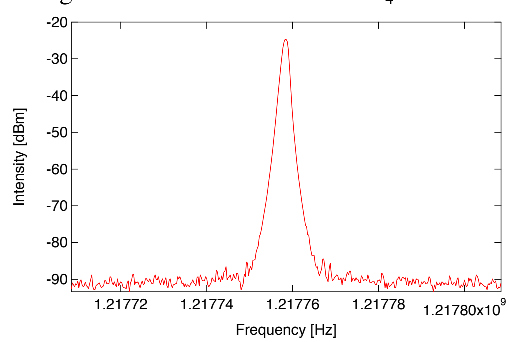

Figure 9: RF spectrum of Nd:YVO_4 oscillator pulse.

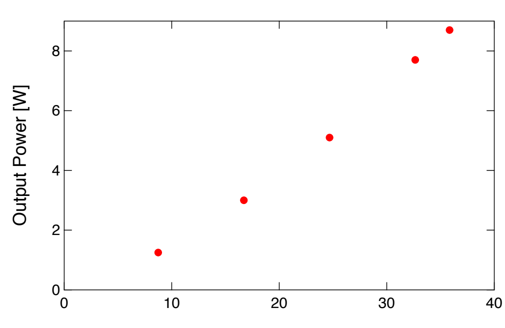

Figure 10: Input and output characteristics of the 1.2GHz laser system.

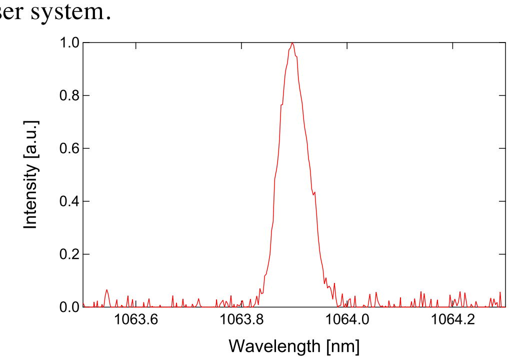

Figure 11: Optical spectrum of 1.2GHz pulse.

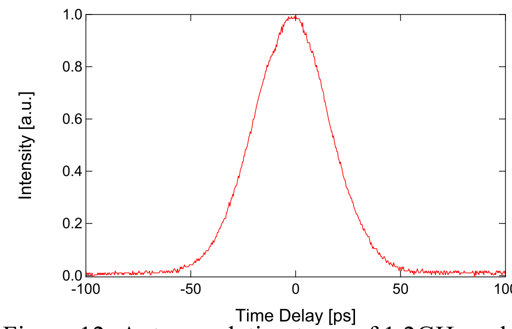

Figure 12: Autocorrelation trace of 1.2GHz pulse.

Figure 9 shows the RF spectrum of the seed pulse from the Nd:YVO_4 oscillator. We can find the peak at about 1.2GHz due to the mode locked pulse.

We amplified the mode locked pulse by the photonic crystal fiber laser amplifier. Fig. 10 shows the input and output characteristics of the 1.2GHz laser system. The 1.2GHz laser system can amplify 1.2GHz mode locked pulse to 8W by 33W pumping light.

Figure 11, 12 show the optical spectrum and the autocorrelation trace of the amplified pulse. In the optical spectrum, the center wavelength is 1063.9nm and the bandwidth is 0.067nm, which is almost the same as the resolution of the optical spectrum analyzer (0.05nm). The FWHM of the autocorrelation trace is 42ps, from which the pulse width is estimated at 27ps by fitting $sech^2$ type pulse.

SUMMARY

We have been developing an Yb fiber laser system for an ERL photocathode gun.

We improved the Yb doped photonic crystal fiber laser amplifier by installing the Yb fiber preamplifier and keeping the temperature of the LD and the PCF. The improved amplifier can amplify the 85MHz seed light up to 30W that is the first goal in compact ERL laser system.

We demonstrated the supercontinuum generation for OPA. We could convert wavelength from 1 μm to 800 nm with a conversion efficiency of 9.5%.

We are developing a Nd:YVO_4-based mode-locked oscillator that can operate at the same frequency as the RF frequency of a superconducting accelerating cavity. The band width is 0.067nm and the pulse width is 27ps. Additionally, we could amplify pulse light of Nd:YVO_4 oscillator up to 8W by the photonic crystal fiber laser amplifier.

REFERENCES

[1] R. Hajima et al. (ed.), KEK Report 2007-7/JAEA-Research 2008-032 (2008) (in Japanese).
[2] R. Nagai et al., Rev. Sci. Instr. 81, (2010) 33304.
[3] I. Ito et al., Proceedings of IPAC10, 2141-2143 (2010).

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