FIBER LASER DEVELOPMENT FOR DIELECTRIC LASER-DRIVEN ACCELERATOR AND ELECTRON BEAM SOURCE*

H. Okamoto†, M. Uesaka, K. Koyama, S. Otsuki, University of Tokyo, Bunkyo-ku, Japan
M. Yoshida[1], High Energy Accelerator Research Organization, Tsukuba, Japan
T. Shibuya, D. Satoh, Tokyo Institute of Technology, Meguro-ku, Japan

Abstract

Our laboratory is working on developing Dielectric Laser Accelerators (DLAs) in order to construct table-top micro electron beam source for radiation biology researches in the future. If this device were realized, we could irradiate 1μm order electron beam whose energy is 1MeV onto cell nucleus (~1μm). For driving laser for DLAs, we choose Yb laser (λ:1030nm), and finally got 11.6W output with stable oscillator and PCF amplifier.

INTRODUCTION

X-ray treatment is now useful for curing cancers, but the mechanism of DNA damage has not been solved systematically, and still in the process of research. Experiments for these research are done in the huge facility, and the machine time is restricted to night, and the energy range is limited. To solve those problems, we are now aiming to develop a table-top system that can irradiate micro-order electron beam into cell nucleus and monitor in real time, which we think can contribute to development of radiation biology. For this purpose, small-sized accelerator and electron source are necessary, but accelerator these days using microwave such as X-band Linac is still large, so we are going to use Dielectric Laser-driven Accelerator (DLA). DLA has mainly two features; it uses the frequency range of light so that acceleration gradient can be much higher (~GV/m,), and the structure is made of dielectric material so that the laser damage threshold is higher than metal material (SiO_2: ~1GV/m for 1ps Ti:Sa laser). Ultra-short high intensity laser pulse is incident to the side wall, and after the phase is modulated by the difference in refraction index of structure and vacuum, accelerating field is formed on the beam path so that particle is continuously accelerated (Fig. 1). To drive this accelerator electron bunch and acceleration field must be on rightly the same timing, so we must synchronize the electron source and laser, or use those comes from the same master oscillator.

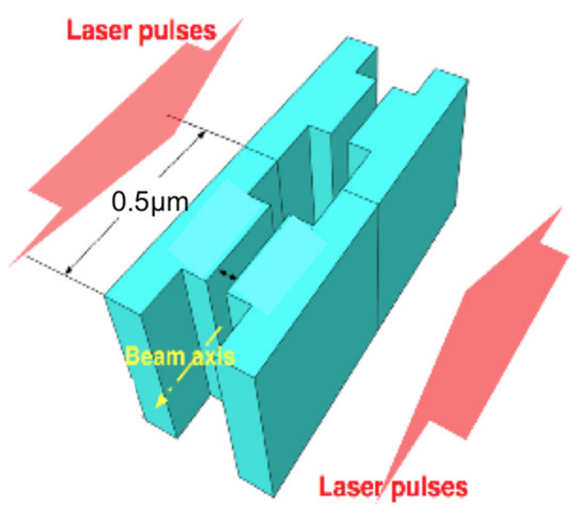

Figure 1: Schema of DLA [1].

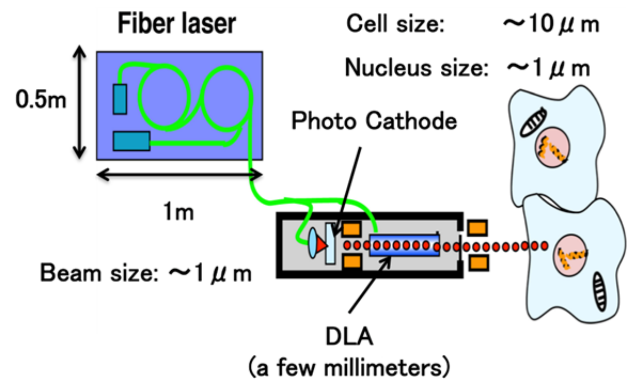

Figure 2: Outline of irradiation system.

Therefore, we are going to construct the laser system for experiments of DLA in infrared region and driving laser for photocathode in ultraviolet region, and aim to realize the table-top micro beam source (Fig. 2).

Table 1: Required Specification for 1MeV DLA[1] and Laser Target

	For 1MeV DLA	Fiber laser target
Central λ	1μm	1030nm
Pulse energy	1mJ	2μJ
Peak power	20MW	10MW
Pulse width	50ps	200fs
Reputation rate	50kHz	10MHz
Average power	50W	20W

YB FIBER LASER

Characteristics of Yb Fiber Laser

There is a previous research in Uesaka laboratory about laser development for radiation biology shown above[2]. This research is aiming to develop and improve it.

The capacity of laser required for micro-order electron beam source using DLA can be pointed out as

- small-sized
- easy maintenance

* Work supported by JSPS KAKENHI (B) (Grant-in-Aid for Scientific Research) Grant Number 15H03595.
† hayato.okamoto@nuclear.jp

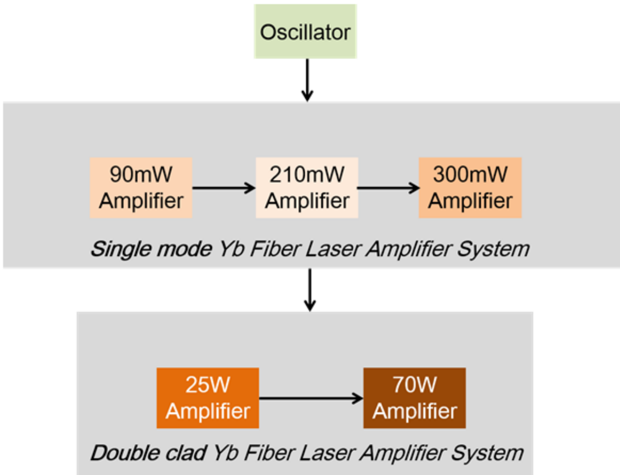

Figure 3: Outline of Yb fiber laser system.

- stable.

In fiber laser, light is incident into the core of grass fiber doped with rare earth elements such as Yb and Er, and then amplified by stimulated emission. Fiber can be formed into a circle so that space can be saved, and also since the ratio (volume) / (surface area) is larger than other laser media, residual heat removal can be done by just an air and no large cooling system is required, which can realize the miniaturization of the laser system. Fiber laser, in which each fiber is fixed by fusion, can withstand some vibrations, so that it can be more stable than solid-state laser and need not so much maintenances. However, since the core diameter is a few micro meter and it is necessary to focus the beam, it becomes difficult to be amplified by fiber when laser power is high because the breakdown threshold. Also, at the end face it is difficult to adjust the angle and position of incident laser and fiber, and if light is not incident sufficiently into the fiber the end face will be damaged, so we must handle carefully. Therefore, we will construct the ultra-short pulse oscillator and low-power amplifiers by fiber laser up to several μJ, and amplifiers of higher power by solid-state medium.

As mentioned above, Erbium (Er) and Ytterbium (Yb) can be pointed out as doping rare earth. The central oscillating wavelength of Er-doped fiber is 1530nm, and that

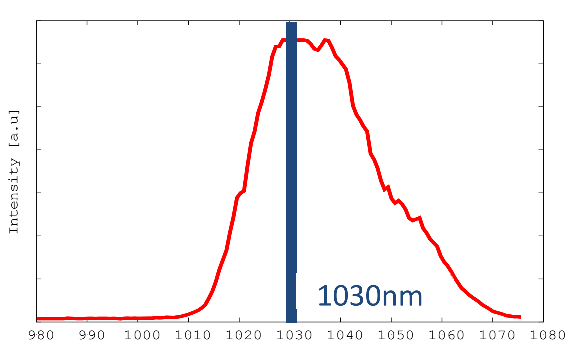

Figure 4: Spectrum of pulse from oscillator.

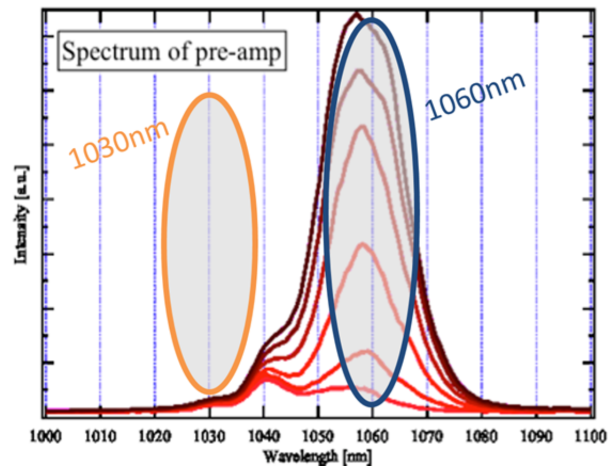

Figure 5: Amplification in 1060nms with Yb-doped single mode double clad fiber [3].

of Yb-doped fiber is 1030nm. As for Er-doped fiber we need not to compensate dispersion because the fiber gives negative dispersion at 1530nm, however, the bandwidth is rather narrow so that it is necessary to convert into super-continium light to generate ultra-short pulse. On the other hand, Yb-doped fiber can generate fs pulses only by compensating dispersion.

In addition, Yb has some characteristics such as

- high quantum efficiency (91%)
- enable to be pumped by laser diode (LD)
- good thermal conductivity (11W/mK).

Since Yb has high quantum efficiency, less pump power is converted into heat, and the quality of laser profile changes little. Therefore, we concluded Yb to be best fit to our estimated system, and we selected Yb:Silica for fiber laser medium and Yb:YAG for solid-state laser.

Development of Yb Fiber Laser

Yb fiber oscillator Figure 3 is the whole image of the laser system. First we construct the oscillator to generate ultra-short pulses using Nonlinear Polarization Rotation (NPR) mode locking. Spectrum changes with the length of Yb doped fiber, because the longer the length is the more 1030nm region will be absorbed.

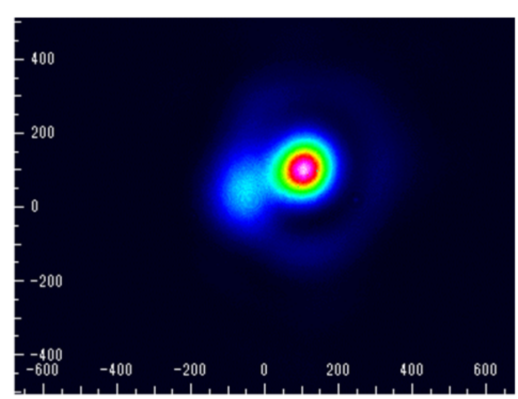

Figure 6: Spatial beam profile of pulse from PCF amplifier.

ISBN 978-3-95450-147-2

We adjusted the Yb-doped fiber to be 20cm so that there is less absorption in 1030nms because the gain wavelength of Yb:YAG is at that region. We compensate the dispersion by grating pairs with the distance of 1cm, and finally succeeded in generating ultra-short pulses with central wavelength of 1030nm, the pulse width of 30nm, the pulse energy of 0.48nJ, and the reputation rate of 84MHz for more than a month. The spectrum of earned pulse is shown in Fig. 4.

Yb fiber amplifier We constructed three amplifiers in this system. When amplifying ultra-short pulses, Chirped Pulse Amplification (CPA) is usually used because of the problem of peak power of the pulses. To stretch the pulse, we combined single mode fiber of several meters with Yb-doped single fiber, and then amplified. Thus, it is assumed that pulse is stretched to several ps. Then we constructed two amplifier, 25W and 60W. We firstly used single mode double clad polarization maintaining fiber for amplifiers, but there were some problem of difference in amplifying gain region. The fiber we firstly used does not amplify 1030nms (Fig. 5), so that pulse were not amplified but the ASE were strongly added to the pulse train. Thus, we changed the fiber to Photonic Crystal Fiber (PCF) of 1m length, and reconstructed the amplifier. PCF has the specification that there is no reabsorption of seed pulse. Since there was no proper fiber cutter for PCF, we grinded the fiber's end face using glass paper fixed on rotating base gradually (3μm→1μm→0.3μm). Finally we got 11.6W output with 84MHz, and with the clean spatial profile (fig. 6).

The reason why pulse was not amplified satisfactorily is thought to be that the end face of PCF was not cleanly grinded, and the discordance of NA of lens and fiber so that the pump power was not incident into fiber sufficiently. We will grind the end face and going to improve the amplification rate.

Table 2: Result of Laser System and Target

	Result	Target
Central λ	1030nm	1030nm
Pulse energy	0.14μJ	2μJ
Reputation rate	84MHz	10MHz
Average power	11.6W	20W

SUMMARY

We are now constructing the fiber laser system for DLA experiment for table-top micro electron beam source (fig. 7). At the current level we succeeded in stably (for more than a month) oscillating ultra-short pulses, and amplifying to more than 10W continuously. We will next improve the amplifier to perform high amplification, and next we will synchronize the oscillator with 84MHz function generator. To realize this, piezo component is introduced in the oscillator and adjust the cavity length receiving feedback of difference in reputation rate. Then, we will reduce the reputation rate to 10MHz in the future, so that pulse energy will be higher. We will start to create the grating structure of SiO_2 with 125keV electron beam source by lithography in June and try to irradiate it with our laser system to measure the damage threshold in infrared region.

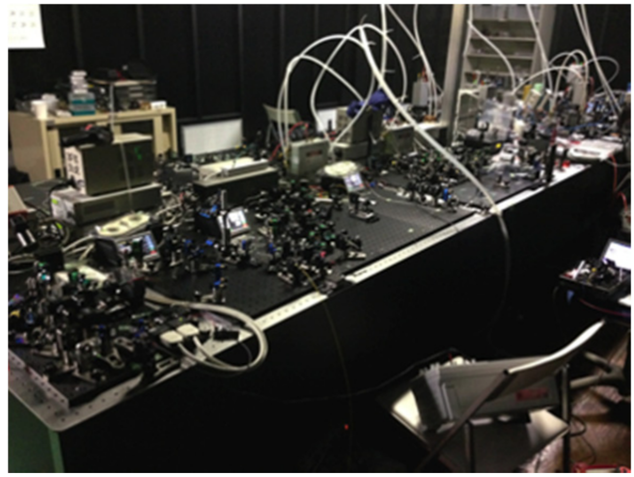

Figure 7: Picture of Yb fiber laser system.

REFERENCES

[1] K. Koyama, et al., *Journal of Physics B: At. Mol. Opt. Phys.*, 47, Nov. 2014, 234005.

[2] Y. Matsumura, et al., Proceedings of the 10th Annual Meeting of Particle Accelerator Society of Japan, Nagoya, Japan, Aug. 2013, pp. 777-780.

[3] X. Zhou, et al., Proceedings of the 9th Annual Meeting of Particle Accelerator Society of Japan, Osaka, Japan, Aug. 2012, pp. 317-321.