FREE ELECTRON LASER PULSE CONTROL BY ACOUST OPTIC MODULATORS

Taizou Kanai*, Sachiko Yoshihashi-Suzuki, Kunio Awazu, Osaka University

Abstract

Free Electron Laser (FEL) in Osaka University can be continuously varied in the range of 5.0-20.0 μm when using 30 MeV electron beam. The FEL has a double pulse structure. The structure consists of a train of macropulses of pulse width 15 μs, and each macropulse contains a train of 330 micropulses of the pulse width 5 ps. The tunability and short pulse afford new medical applications such as investigation of protein dynamics and the ablation of soft tissues. Precise control of micropulse train is essential for medical applications using FEL because macropulse with long pulse duration leads to undesirable thermal effects. FEL pulse control system using an Acousto Optic Modulators (AOM) was developed in order to investigate non-thermal effect between the FEL and living tissues. This system provides efficiency (~ 70 %) and a fast switching speed (> 200 ns). Thus, this is expected as a novel tool.

INTRODUCTION

The free electron laser (FEL) at Osaka University is a pulsed, tunable infrared source. It is designed to work in the region from 5 to 20 μm at an average power of up to 50 mW. The FEL applications research is broadly interdisciplinary, including measurements of investigation of protein dynamics, the ablation of soft tissues and narrow band-gap materials [1-4].

An electron beam of 30 MeV energy is the laser gain medium for the FEL. It is accelerated with a linear, pulsed RF accelerator. This leads to the pulsed beam current and complex temporal intensity profile of the emitted IR light as shown in Fig.1. The accelerated electron pulses have up to 20 μs duration and each of them generates one optical "macropulse" have duration of 15 μs. The mode locked pulse or "micropulse" have duration of approximately 5 ps with 44.8 ns spacing between pulses.

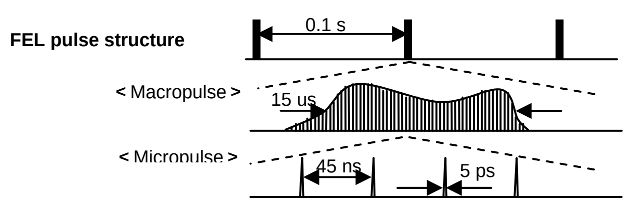

Figure 1: Pulse structure of FEL. One macropulse is made of 330 micropulses.

For many FEL application 15 μs duration of the macropulse leads to undesirable thermal effects or obscures signals from fast optical process. The FEL user community has identified the need for selecting a number of micropulse. The switching device to achieve this should have the following properties;

(1) Operating wavelength 5 to 12 μm.
(2) Pulse duration; variable, picoseconds (single micropulse) to full macropulse length with fast rise and fall times.
(3) Easy adjustment of pulse duration.
(4) Portability between different experiment stations.

An Acousto Optic Modulators (AOM) is chosen as the best solution for the needs of the Osaka university FEL system. Section 2 describes the principle of AOM and pulse control system. Section 3 describes performance evaluations of pulse control system. Section 4 reports the result of pulse control

MATERIALS AND METHODS

The principle of an Acousto Optic Modulator

An AOM is a device which allows to control the power, frequency or spatial direction of a laser beam with an electrical drive signal. It is based on the acousto-optic effect, i.e., the modification of the refractive index by the oscillating mechanical pressure of a sound wave. The geometry of Input and Output laser beams relative to the acoustic column is shown in Fig.2.

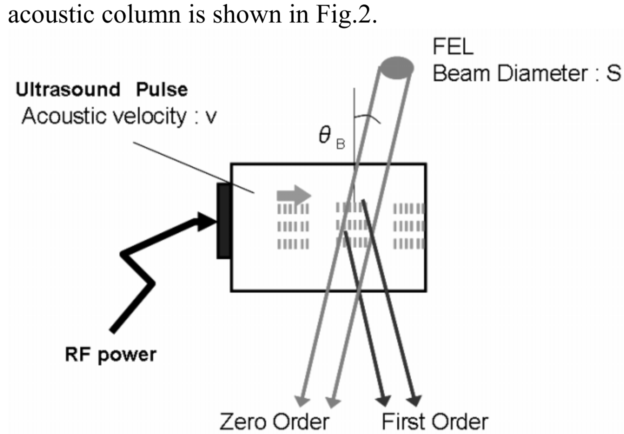

Figure 2: Principle of AOM. AOM switch out 1st order FEL when ultrasound pulse cover incident FEL.

The key element of an AOM is a transparent crystal (or a piece of glass) through which the light propagates. A piezoelectric transducer attached to the crystal is used to excite a high-frequency sound wave. Light can then be diffracted at the periodic refractive index grating generated by the sound wave. The scattered beam has a slightly modified optical frequency (increased or decreased by the frequency of the sound wave) and a

*Corresponding author. Institute of Free Electron Laser, Graduate School of Engineering, Osaka University, 2-9-5 Tsuda-Yamate, Hirakata, Osaka 573-0128, Japan. Tel.: +81-72-897-6410; fax: +81-72-897-6419.E-mail address: kanai@fel.eng.osaka-u.ac.jp (K. Taizou).

slightly different direction. The frequency and direction of the scattered beam can be controlled via the frequency of the sound wave, while the acoustic power allows to control the optical powers. For sufficiently high acoustic power, and the input laser beam is aligned for the true Bragg input angle, more than 70 % of the optical power can be diffracted as first order beam.

While a supersonic wave intercepts incident beam, AOM generates first order beam. Therefore rise time of first order beam depend on diameter of incident beam, speed of a supersonic wave. The rise time of the first order beam is given by equation (1). It is time before the primary light output reaches 90 % from 10 % [5].

$$TR = S/(v*1.56) \quad (1)$$

Where:

TR = Rise time of first order beam.
S = Diameter of incident beam.
V = Speed of supersonic wave.
1.56 = correction factor

Pulse control system design

The schematic diagram of a FEL pulse control system is shown in Fig.3. The FEL beam (50 mm Φ) was reduced in size to 1.0 mm Φ in diameter by two pieces of ZnSe plano-convex lenses of a long focus (focal length=381.0 mm) and a short focus (focal length=65.0 mm). Table 1 shows specifications of the AOM (IntraAction Corp, AGM-402A1) used for this system. The supersonic wave that is launched into the AOM is generated by an AOM driver (IntraAction Corp, GE-4020). The supersonic wave can be controlled by a pulse oscillator (Pulse Generator; Stanford Research Systems, DG535).

PERFORMANCE EVALUATIONS

The laser damage threshold for Ge was determined empirically with the FEL. Surface damage occurred at 20 mW average power, below 1.5 mm Φ beam diameter, 6.3 µm wavelength. The absorption of Ge does not change significantly between 6 and 12 µm. We input the FEL beam of diameter of 1.5 mm Φ onto the AOM and controlled it by adding a supersonic wave pulse to AOM.

Efficiency of pulse control system

An AOM can control average power of first order beam 0-MAX by control RF output power 0-20 W.

Measurement of first order FEL

First order beam is detected by infrared detector (MCT; VIGO Systems, R005). MCT signal is recorded by an oscilloscope (LeCroy, WaveMaster 8000).

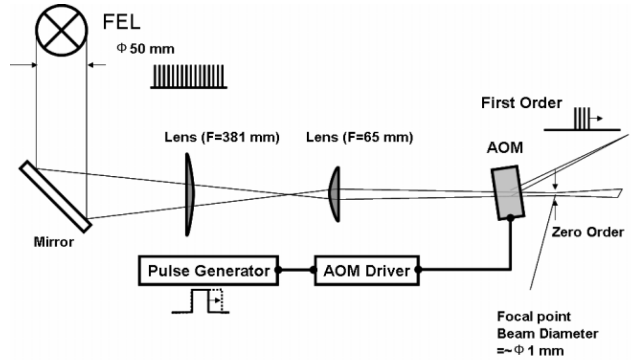

Figure 3: Experiment setup for pulse control. The FEL beam was reduced in size to 1.0 mm in diameter by using ZnSe lenses and FEL pulse was controlled by pulse generator.

Table 1: Specifications of Ge-AOM

Optical Wavelength	@10.6 µm
Acousto-optic Material	Single Crystal Germanium
Acoustic Velocity	5.5 mm/µsec
RF Center Frequency *	40 MHz
Optical Insertion Loss	<7 %
Optical Power Capability	25 Watts
Laser Polarization	Parallel to Base
Rise Time (diameter)	116 nsec (1 mm)
Bragg Angle	38.5 mrad
Beam Separation	77 mrad
Diffraction Efficiency	<70 %

*Other frequency available

RESULTS

Efficiency of pulse control system

Result of first order radiation power versus RF output power control is shown in Fig. 4. This pulse control system can control FEL first order power 0-18 mW (incident FEL power is 20 mW).

The photograph which confirms the state of switching with a thermosensitive film is shown in Fig. 5.

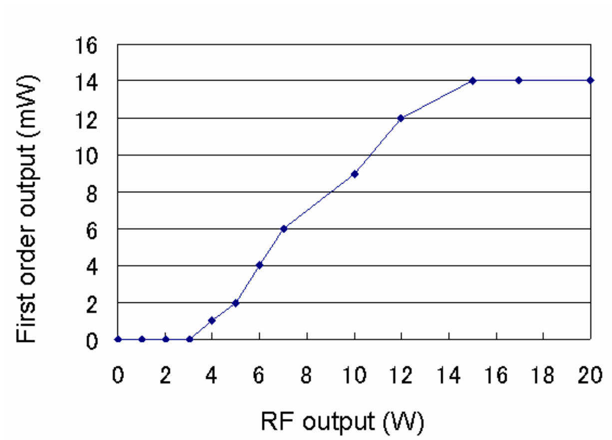

Figure 4: Result of first order power control by RF output control. An AOM can control average power of first order beam 0-MAX by control RF output power 0-20 W.

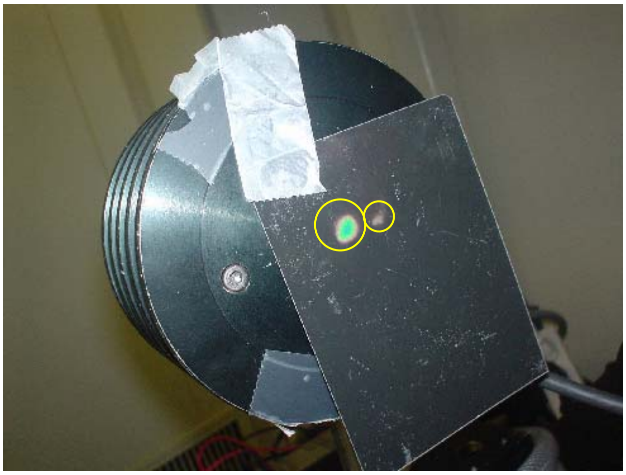

Figure 5: The photograph which confirms a state of a switch with a thermosensitive film. First order FEL (Left). Zero order FEL (Right).

Measurement of first order diffraction of FEL beam

MCT signal of FEL first order beam is shown in Fig. 6. This pulse control system can control FEL pulse width with efficiency of 70 % in a range of 4~5 micropulses (>200 ns) to full macropulse (15 µs) (incident FEL diameter > 1.5 mm Φ), however when this pulse control system is going to achieve pulse control at earlier speed (single ~ 3 micropulse<200 ns) (incident FEL diameter < 1.0 mm Φ), power density of FEL exceeds the damage threshold of AOM and efficiency of pulse control falls (<30 %) (Fig.7).

DISSCUSSION

Cutting out one micropulse is impossible by this device, however with a time scale of 200 ns ~ 15 µs, it is a very successful pulse control technique.

Using this system, pulse width has been the third parameter of the FEL system in addition to conventional two irradiation parameters of wavelength and power density. This system enabled setting of more highly precise FEL-biomolecular interaction. Improvement of pulse control system (high speed, high power density) can realize more selective excitation of biomolecules of pico, nano time scale. In addition, we can move the stage of activity of pico second time resolution vibration minute light method to the field of study of chemistry / biology from the field of physicochemical study by using FEL as excitation light.

To achieve high-speed switch, improvement is necessary. A plan of FEL pulse control system with two AOM is shown in Fig.8. This system realizes a high-speed switch, by cross the gate pulse, without damage of AOM.

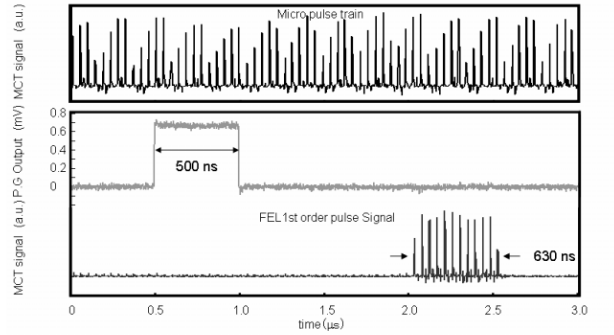

Figure 6: Result of FEL pulse control. AOM can control FEL pulse width 200 ns-15 µs with >70 % efficiency.

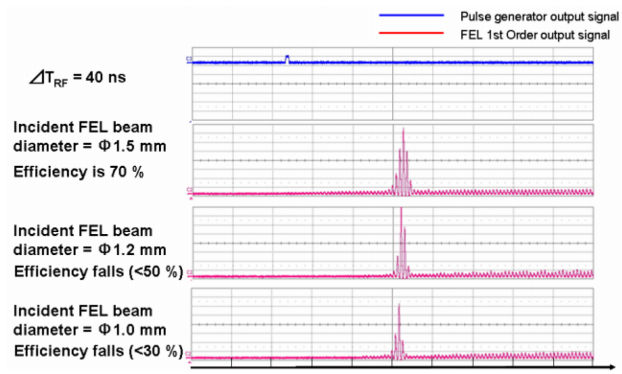

Figure 7: Result of FEL pulse control. When FEL pulse control system is going to achieve pulse control at faster speed, power density of FEL exceeds the damage threshold of AOM and efficiency of pulse control falls.

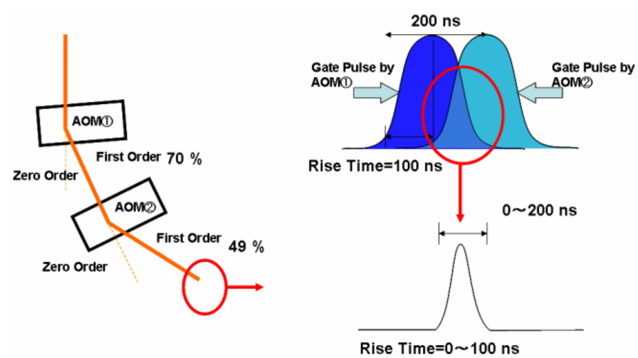

Figure 8: A plan of FEL pulse control system with two AOM.

CONCLUSIONS

FEL pulse control system using an AOM was developed in order to investigate non-thermal effects between the FEL radiation and living tissue. With a time scale of 200 ns ~ 15 µs, this system provides the efficiency of ~70 % and a fast switching speed (>200 ns). Pulse control system gives 3 parameters for use: pulse width, wavelength, and power density for biomedical research.

REFERENCES

[1] GS. Edwards, D. Evertson, W. Gabella, TL. King, J. Kozub, M. Memdenhall, J. Shen, RH. Traeger: IEEE J. Sel. Top. Quantum Elec. Vol.2 (1998), pp.810
[2] K. Awazu, A. Nagai, K. Aizawa, The Reveiew of Laser Engineering. Vol.26, No.5 (1998), pp.369
[3] K. Awazu, The Reveiew of Laser Engineering.Vol.28, No.5 (2000), pp.291
[4] Klaus Becker, J. Bruce Johnson, Gleen Edwards, Rev. Sci. Instrum. Vol.26, No.5 (1998), pp.1496
[5] Mike Hillier: Acousto Optic Tuneable Filters Basic Theory And Design Considerations, Isomet corporation (1998)