ALL-SOLID-STATE PICOSECOND LASER SYSTEM FOR PHOTOCATHODE RF GUN *

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Abstract

A compact diode-pumped picosecond laser was developed for the illumination of the photocathode of RF guns. Nd:YLF and Nd:YAG were selected as the active medium and the laser stability was the main interest during the development. Achieved performances were 0.5ps timing jitter in the oscillator, 1-% UV pulse energy fluctuation and 5μrad beam pointing stability.

1 INTRODUCTION

A reliable and compact picosecond UV light source is the key requirement for the stable operation of RF guns. The improvement of the beam quality may benefit the ultra-short pulse X-ray generation by Thomason scattering [1]. As the high brightness electron source and the high peak power laser develop, the laser Thomson X-ray source becomes more realistic [2]. We have been developing a photocathode RF gun [3] and an all-solid-state picosecond compact laser for the photocathode [4]. The laser stability, e.g., energy stability, timing stability and the pointing stability, was requested stringently during the course of the research. A compact and stable laser system was developed by a joint project with Sumitomo Heavy Industries, Ltd and Time-Bandwidth Products Ltd.

In this paper, the research and the system performance are reported on the Nd:YLF all solid state picosecond laser. Additionally to the laser system, a pulse compression and an oblique incidence optical system are also reported.

2 LASER SYSTEM

The laser system, which was shown in Fig.1, was composed of a passive mode-locked oscillator with a timing stabilizer, a regenerative amplifier and a frequency conversion part. Some photo-diodes were equipped for diagnostics and monitors. Optical elements were fixed on a breadboard of Invar plate with 1000x600mm dimension, to avoid thermal misalignment. A controller box, which was composed of power supplies for diode-lasers, high voltage circuits for Pockels Cells, timing stabilizer circuits and so on were installed near the laser box.

2.1 Oscillator

The seeding laser was a passive mode-locked laser with a semiconductor saturable absorber mirror (SESAM). Repetition rate of the mode-locked pulse was determined by the length of the cavity. 79.34MHz-repetition rate was equal to 1/36 of 2856MHz S-band radio frequency, which was used for the photocathode RF gun. The cavity length was controlled to be synchronised with 79.34MHz repetition frequency. The timing stabilizer measured the phase and the frequency offset between the laser pulses, which was detected by a photo-diode, and the reference RF signal, and adjusted the cavity length to maintain the constant phase relation between two signals. The system adjusted the cavity length with a piezoelectric transducer for a small cavity length change, and with a motor moving stage to cover 0.1 MHz wide range change.

2. 2 Regenerative Amplifier

A Pockels Cell captured a single seed laser pulse to increase the pulse energy from sub-nano-Joule to mJ range, and released the amplified single pulse from the regenerative amplifier cavity. The temperature change of the Pockels Cell crystal was the main source of the amplitude fluctuation. Water cooling of the Pockels Cell was introduced to achieve the pulse energy stability.

2. 3 Harmonics Generator

This component converted the fundamental output to the 4-th harmonics, which was necessary for the illumination of the photocathode, with KTP and BBO crystals. The temperature of crystals was also controlled to stabilize the frequency conversion efficiency. The net conversion efficiency was close to 10% from the fundamental to the 4-th harmonics. The UV energy was obtained up to 200μJ depending on the choice of the operational condition. The UV output energy was controlled with a rotational half wave plate and a thin film polarizer by a remote controller to change the emission electron charge from the RF gun.

3 LASER PERFORMANCE

3.1 Energy and Pulse length

The UV pulse energy, which was quadrupled from the fundamental of 1053nm wavelength, was measured to be around 200μJ. The energy on the cathode surface was requested to be around 50μJ to obtain 1nC bunch charge in the condition of the quantum efficiency of $1x10^{-4}$. There could be energy delivery loss in the laser injection optical system where laser beam was shaped by an iris and reflected by a grating, but the UV pulse energy seemed enough for the requirement after accounting the delivery loss. The pulse duration of the fundamental part was measured as 12 ps by a single scan auto-correlator. The UV pulse duration was estimated as around 6ps.

3.2 Stability

UV energy stability was measured for 10,000 shots and over hours. Energy was detected by a photo-diode for 10,000 shots and by a power meter for over hours, respectively. The histogram of energy deviation from the mean value was shown in Fig.2. Energy fluctuation was estimated to be 0.55 %rms. Long term UV pulse energy stability over hours was also measured. As a result, UV averaging energy was stable within +/- 2%, except 2-5 minutes of warming time from the switch-on.

The timing jitter of the laser oscillator was estimated from the output of the phase detector in the feedback loop [5]. A phase detector measured the phase difference between the fast photodiode signals of laser pulse and the reference RF signal, and generated an "error signal". This phase difference was related to the timing jitter between the laser phase and the reference RF phase. The timing jitter of the oscillator was estimated as 0.39ps rms.

The pointing stability of UV output pulse was measured by a CCD camera. UV beam profiles were measured on a diffuser plate at 1.5m away from the laser output port. Beam profile was shown in Fig.3. Pointing stability of the beam centroid was estimated to be 5 μrad rms.

The specification and the laser performance are listed on Table 1.

4 OPTICAL SYSTEM

4.1 Pulse compression

The duration of the fundamental pulse was about 12ps. We have developed a pulse compression device to obtain shorter pulse duration from the laser system. The pulse compression system was composed of a single-mode optical fiber of 450m length and a pair of gratings with 1800G/mm groove density. As the first step, the output from the fiber was compressed directly with the gratings without an amplifier to evaluate the optical fiber characteristics. A Nd:YLF oscillator with longer pulse length of 24ps was used for this experiment. The relation between the input energy to the fiber and the pulse duration was measured. The pulse length measured by a scanning auto-correlator is shown in Fig.4.

4.2 Delivery system of oblique injection

In many cases, the laser beam was injected onto the cathode surface at an oblique angle with p-polarization, because the quantum efficiency was known to be enhanced by a factor of three in comparison with one at normal incidence. There are two problems in this configuration, namely the prolonged beam shape and the arrival time difference between the beam edges on the cathode surface. We designed a correction beam delivery system. Laser beam was cut to be flat top shape with an iris. Image at the iris was translated to the cathode surface by an image relay method. In this optical system, the transverse beam shape was made to be ellipse with four littrow prisms and the longitudinal beam shape was made to be tilt with a grating. In this way, beam shape was circle with near flat top and beam pulse duration was kept to be the same as one of laser output at the cathode surface. The beam profile measurement by a CCD camera was carried out, and the image relay system was confirmed to work as was designed We have a plan to check the longitudinal beam shape with a streak camera.

5 CONCLUSION

The all-solid-state picosecond UV source has been developed based on the laser diode pumping, the passive mode-locked oscillator with SESAM and the feedback timing stabilizer. Invar breadboard and water cooling of thermal components prevented thermal misalignment of optical components. The laser performance was quite stable for the reliable photocathode RF gun operation.

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6 REFERENCES

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Table.1 Laser Performance

Wavelength(UV)	263nm
Oscillator Frequency	79.34MHz
Oscillator Frequency Adjustable Range	0.01MHz
Energy(UV)	0.2mJ
Repetition rate	1-100Hz
Pulse width (fundamental)	12ps
Timing jitter for oscillator	0.39ps rms.
Beam profile	TEM_{00}
Pointing stability	5μrad
Energy stability(UV, hours)	<2%
Energy Stability(UV,10000shots)	0.55%rms

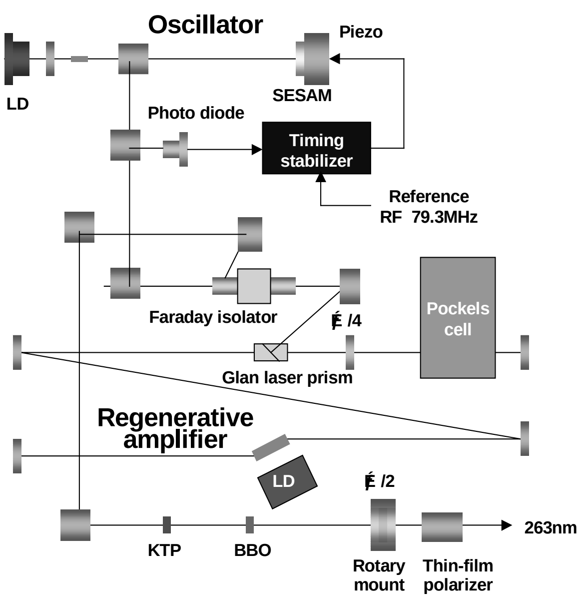

Fig.1 Layout of the Picosecond Nd:YLF laser system

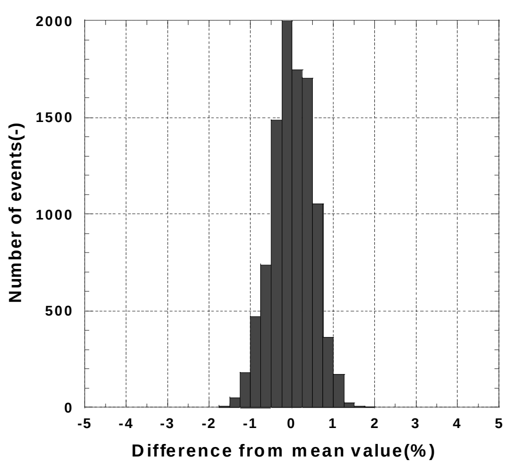

Fig.2 Histogram of UV energy fluctuation for 10000 shots (σ=0.55%)

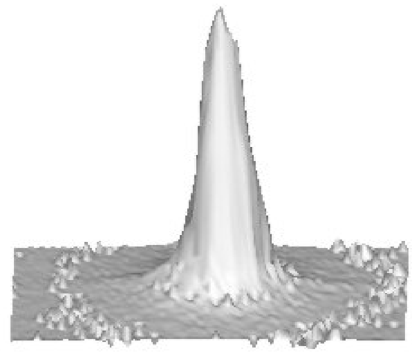

Fig 3 Beam profile of UV pulse

Beam diameter is about 3.5mm at FWHM

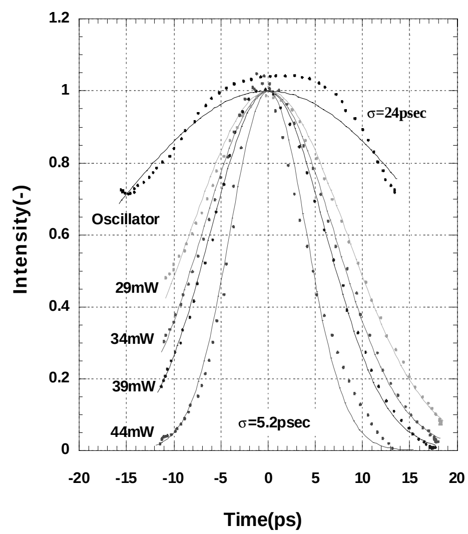

Fig.4 The relation between the input energy to the fiber and the pulse length

The output from the fiber was compressed directly with gratings without amplifier. These data were measured by a scanning auto-correlation.