SuperKEKB 入射器における RF 電子銃用レーザーの高性能化

IMPROVEMENT OF THE LASER SYSTEM FOR RF-GUN AT SUPERKEKB INJECTOR

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Abstract

For SuperKEKB project, the electron beams with a charge of 5 nC and a normalized emittance of 10 μm are expected to be generated in photonchathode RF gun at injector linac. Compared to the previous laser system, current ytterbium laser system is operating in high repetition rate of 25 Hz but suffering thermal effect. In order to minimize the thermal effect, ytterbium cascade laser design is proposed. The proposal is different from the standard ytterbium laser, 1035 nm laser is selected as pump source. As to the output or amplified laser at 1050 nm, the quantum defect can be reduced to just 1.5% with minimized thermal effect. Meanwhile, higher gain and less reabsorption can be obtained. At present, Yb:KGW and Yb:BOYS crystal are chosen as the gain materials. For out next step experiment, the laser properties of the crystals at 1050 nm are tested and studied.

1. INTRODUCTION

Higher luminosity is required in the SuperKEKB, the photocathode RF gun with strong electric focusing filed for high-current, low-emittance should be adopted in the injector linac [1]. For generating electron beams with a charge of 5 nC and a normalized emittance of 10 μm in the photocathode RF gun, according to the simulation of emittance due to the space charge effect, the ultraviolet (UV) laser source with a pulse width of several tens of picoseconds (ps) is required. Furthermore, for reducing the energy spread, the laser pulse should be reshaped to rectangle from Gaussian shape [2].

As shown in Table 1, to satisfy the above conditions for the SuperKEKB, a laser source should with central wavelength of 260 nm, pulse width of 30 ps, pulse energy of 1 mJ is required. In addition, for the stable operation of the SuperKEKB, the stability of the laser system is also important. In order to synchronize with the SuperKEKB, the repetition rate of the laser must be set at 51.9 MHz.

Table 1: Required Laser Source

Pulse Property	Required Date
Repetition rate of Oscillator	51.9 MHz
Central wavelength	~260 nm
Pulse Width (FWHM)	~30 ps, reshape
Pulse Energy	>mJ
Spectral Width	>6 nm
Others	Stale, compact, removable

With the aim of achieving the demands on the laser source, a hybrid laser system which include an ytterbium (Yb) ions doped fiber oscillator, Yb-doped fiber amplifier and thin disk Yb:YAG amplifiers. In 2 Hz repetition rate setup, more than 1 mJ UV pulse was obtained. As a result, the electron beams with a charge of 5.6 nC was generated [3]. When the laser system was upgrade to 25 Hz, 20 mJ fundamental laser pulse energy and 400 J UV pulse were obtained and 0.8 nC electron beam was gotten. Because of the thermal effect, the laser quality degradation induced the reduction of electron charge.

In order to minimize the thermal effect in high repetition rate operation, Yb cascade laser design was proposed. Before developing the Yb cascade laser and amplifier, it is necessary and important to test the laser properties of Yb doped crystals. In this paper, we introduce the Yb cascade laser design basing on our current laser system and report the test results of Yb doped laser crystals. Excellent thermal management and potential application would be expected.

2. CURRENT LASER SYSTEM

Basing on the above requirements for SuperKEKB project, suitable laser crystal should be selected. Yb ions doped laser crystal possesses wider bandwidth compared to Neodymium-doped crystal laser, so it is relatively simple to adjust the laser pulse shape to rectangular. Secondly, Yb-doped laser crystal has comparative long fluorescent life time of almost 1 ms, this is very suitable for archiving high laser output power. Thirdly, Yb doped laser crystal has small energy level difference at room temperature. Current commercial 970 nm laser diode can be used as excellent pumping laser source for Yb-doped laser, and 1030 nm output laser can be generated. It makes

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the quantum efficiency become high comparing with the other rare earth doped laser at 1 micron wavelength. Finally, Yb-doped glass fiber laser offers quite stable laser oscillator with high repetition, high output power and high energy extraction efficiency and so on. In particular, Yb doped fiber laser provides broader bandwidth; it is good for adjusting the seed laser wavelength in the solid stale amplifier stages. Therefore, on the basis of the above characteristics of Yb-doped laser, it is the most suitable candidate for the photocathode RF gun in SuperKEKB injector.

From the end of last century, the fiber laser and thin disk laser have attracted a great of attention to utilize for further progress. The fiber laser offers high repetition rate, excellent amplification efficiency, simple configuration and low cost. Especially, the stability of the fiber laser is evidently higher than solid state laser because of the optimized thermal removal. In addition, the thin disk laser, which possesses very favorable thermal management, makes the high energy pulse amplifier become possible and available. It also ensures the high output power from thin disk laser by using of the current commercial high power laser diode as pump laser source because of the thermal lens effect.

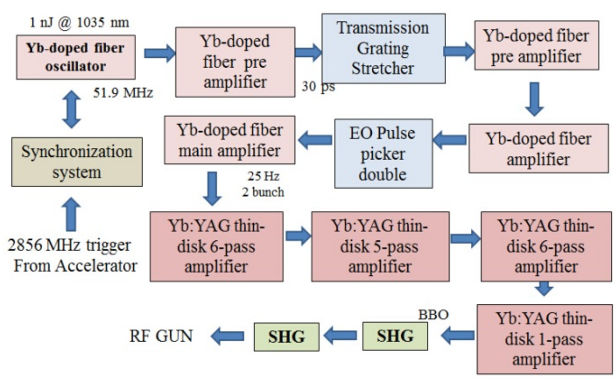

Figure 1: Layout of current laser system.

The current laser system of RF gun is designed as a hybrid system, which include Yb-doped fiber oscillator, Yb-doped fiber amplifiers and Yb:YAG amplifiers. The schematic diagram of the laser system is shown in Figure 1. The current laser system operated in repetition rate of 25 Hz, 0.8 nC electron charge was generated. Compared with the former laser system of 5 Hz repetition rate, the beam charge is lower. In order to overcome the thermal effect, we plan to apply Yb cascade laser design and test the availability of it in advance.

3. YTTERBIUM CASCADE LASER

3.1 Principle of Yb cascade laser

Standard Yb doped crystal laser and amplifier are pumped by 941 nm or 970 nm laser, because of the main absorption peaks for Yb materials. Comparing with the standard configuration, the Yb cascade laser design we proposed is selected 1035 nm laser as pump source, the wavelength of output laser or amplifier laser is 1050 nm. The layout of Yb cascade laser is shown in Figure 2.

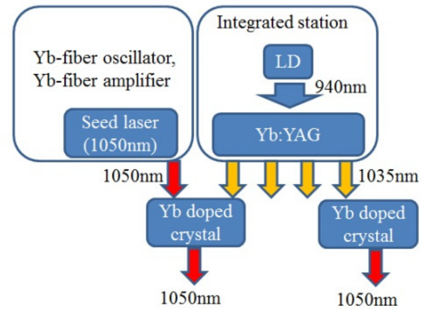

Figure 2: Layout of Yb cascade laser design.

By utilizing the Yb cascade laser design, quantum defect reduce to 1.5%. In contrast, the quantum defects are 10.1% and 6.7% for 941 nm and 970 nm pump lasers respectively. This low quantum defect can realize low thermal lens effect. Meanwhile, higher gain can be gotten benefits from the selection of 1035 nm pump source because it can get rid of reabsorption effect in Yb doped laser crystals. In addition, it is easier to manage the 1035 nm pump laser configuration and get higher excitation density. Because 1035 nm pump laser we achieved with excellent beam quality.

At present, we have gotten excellent and stable 1035 nm Q-switch laser, this is a good pump source candidate for Yb cascade laser. Besides, basing on our current laser system, 1050 nm seed laser can be outputted from Yb-fiber laser stage. Both of them ensure Yb cascade laser can be developed in the following days in our lab.

3.2 1035 nm pump laser source

For obtaining excellent and stable 1035 nm pump laser for Yb cascade laser, we built a Yb:YAG thin disk Q-switch laser. As shown in Figure 3, the Yb:YAG thin disk with 0.5 mm thickness is attached to a copper heat sink. 4 kW quasi-CW laser diode stack of 940 nm is the pump source, and the pumping laser beam is focused on both horizontal and vertical directions. In the laser cavity, one cubic polarizer and a one quarter wave plate are adopted to control the output polarized laser. The Pockels cell is used as the Q-switcher.

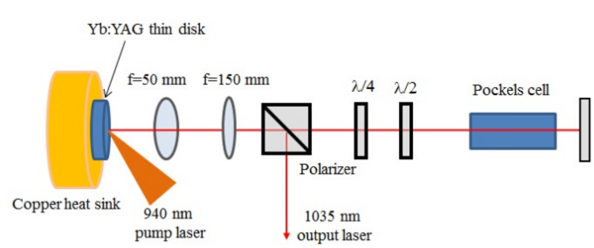

Figure 3: Experimental setup of the Yb:YAG thin disk Q-switch laser.

When the Q-switcher is turned on, we can get a stable pulses output laser. Figure 4 shows scalability of the output pulse energy. The maximum laser output energy was nearly 110 mJ. The inset of Figure 4 shows the output laser spectrum at central wavelength of 1035 nm, and FWHM is nearly 8 nm. By an oscilloscope, the laser pulse width is measured to be nearly 200 ns.

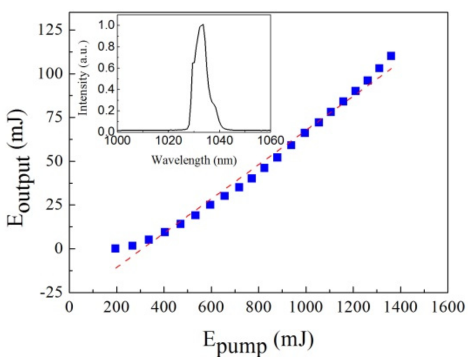

Figure 4: Output pulse energy of Yb:YAG Q-switch laser versus the pump energy. Inset: the spectrum of output laser.

By utilizing the Q-switch laser, we can test the optical properties of the Yb-doped laser crystals, such as the absorption coefficient at 1035 nm and the emission characters at longer wavelength.

3.3 Laser properties of Yb:BOYS and Yb:KGW

For realizing Yb cascade laser, Yb^{3+}:$KGd(WO_4)_2$ (Yb:KGW) and Yb^{3+}:$Sr_3Y(BO_3)_3$ (Yb:BOYS) are selected as the candidates, the laser properties of them are illustrated in Table 2 [4]. From the table we can see the Yb:KGW crystal with high stimulated emission cross section, high absorption efficiency and low laser threshold. Yb:BOYS crystal possesses boarder tuning range and longer lasing wavelength. Figure 5 shows the picture of the processed crystal samples used in our experiment.

Table 2: Laser Properties of Yb:KGW and Yb:BOYS

Properties	Yb:KGW	Yb:BOYS
Absorption wavelength (nm)	981	975
Peak absorption cross section (10^{-21} cm^2)	120 ($E \parallel a$)	σ 7.3 π 9.4
Fluorescent lifetime (ms)	0.75	1.1
Room temperature laser wavelength (nm)	1026	1066
Emission cross section at laser wavelength (10^{-21} cm^2)	28	2
Emission bandwidth (nm)	20	60
Tuning range (nm)	1020-1070	1017-1086
Mean refractive index	2.03	1.75

It is very important and valuable for the later cascade experiment to test the small signal gain coefficients of Yb:KWG and Yb:BOYS at 1050 nm which are pumped by 1035 nm laser, The future experimental setup is shown in Figure 6. The 1050 nm seed laser is a commercial fiber coupled output tunable wavelength LD laser.

Figure 5: Yb:KGW and Yb:BOYS crystal samples.

When the 1050 seed laser is impinged the Yb doped crystal which is pumped by 1035 nm laser, the output power of amplified 1050 nm laser can be gotten by

$$P_{output} = P_{in} \exp(gL), \qquad (1)$$

where g is the gain coefficient and L is the length of crystal. We adjusted the 1035 nm and 1050 nm lasers to overlap and pass through the Yb doped crystal along the length direction. Then they were separated each other by a polarizer. In order to eliminate the fluorescence emission, long propagation distance was necessary before the amplified seed laser was measured by a photodiode. Comparing with the Q-switch laser pulse duration, the upper laser level lifetime of Yb ions is much longer, so we can measure the 1050 nm laser power variation by an oscilloscope during this steady-state duration.

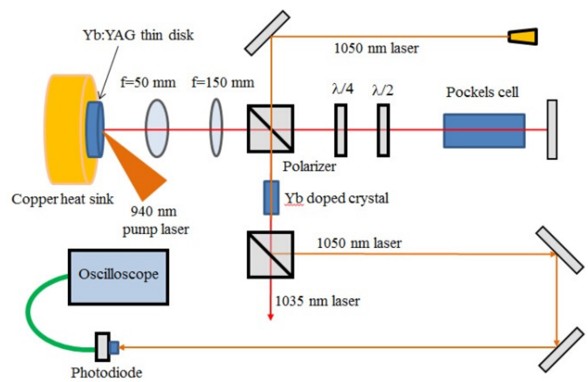

Figure 6: Experimental setup for testing the small signal gain coefficient Yb:KWG and Yb:BOYS at 1050 nm.

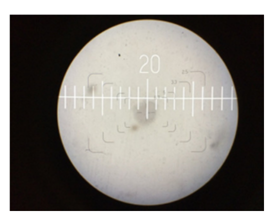

Figure 7: The pump laser spot burning hole on a film paper under microscope.

For calculating the estimated small signal gain coefficients of Yb:KGW and Yb:BOYS, we used a film paper to get the burning hole of the pump laser for obtaining the beam diameter, the measured pump laser spot size is shown in Figure 7. Then according to formula (1) and crystal parameters, the estimated small signal gain coefficients of Yb:KGW and Yb:BOYS are 0.116 cm^{-1} and 0.105 cm^{-1} respectively. We are going to test the accurate small signal gain coefficients in the next step experiment by the experimental layout which is shown in Figure 6.

4. CONCLUSION

For obtaining high current, low emittance beams in the SuperKEKB project, the current hybrid laser system operated in repetition rate of 25 Hz and 0.8 nC electron charge was generated.

To overcome the thermal lens effect, Yb cascade laser configuration is proposed. This design can minimize the thermal effect in high repetition rate laser system and get higher gain.

Yb:KGW and Yb:BOYS crystals were selected as the proper candidates for cascade laser design. The estimated small signal gain coefficients at longer wavelength were calculated. We will measure the accurate values in our next step experiment.

REFERENCES

[1] M.Yoshida, et al., "Longitudinal manipulation to obtain and keep the low emittance and high charge electron beam for SuperKEKB injector", Proceedings of IPAC 2013, Shanghai, China, May 13-17, 2013.

[2] T. Natsui, et al., "Quasi traveling wave side couple RF gun for SuperKEKB", Proceedings of IPAC 2013, Shanghai, China, May 13-17, 2013.

[3] X. Zhou, et al., "Ytterbium fiber and disk laser of RF gun for SuperKEKB", Proceedings of IPAC 2014, Dresden, Germany, Jun 15-20, 2014.

[4] S. Chenais, et al., "Spectroscopy and efficient laser action from diode pumping of a new broadly tunable crystal Yb^{3+}-$Sr_3Y(BO_3)_3$," J. Opt. Soc. Am. B 19, (2002) 1083.