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

SuperKEKB project is aimed at the generation of electron beams with a charge of 5 nC and a normalized emittance of 10 μm at injector linac. According to these demands, an Ytterbium (Yb) laser system is selected for RF-gun. For realizing the laser system operating under 25 Hz with double pulses or 50 Hz under single pulse operation, Yb-doped fiber and Yb:YAG thin-disk hybrid laser system with a central wavelength of 259 nm and a pulse width of 20 ps is developed. 3.0 nC bunch charge has been gotten by use of current laser system. In order to achieve more stable and efficient electron beam, improvements has been being done. In this letter, some improvements are introduced for optimizing the laser system.

1. INTRODUCTION

Higher luminosity and lower emittance electron beam is required in SuperKEKB. The photocathode RF gun with strong electric focusing filed for high-current, low-emittance should be adopted in the injector linac. 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 [1]. Furthermore, for reducing the energy spread, the laser pulse should be reshaped to rectangle from Gaussian shape [2].

For achieving the demands on the laser source, a hybrid laser system which consists of an Yb ions doped fiber oscillator, Yb-doped fiber amplifiers and thin disk Yb:YAG amplifiers. For 2 Hz repetition rate test, more than 1 mJ UV pulse energy was obtained. As a result, the electron beams with a charge of 5.6 nC were generated. When the laser system was upgrade to 25 Hz, 20 mJ fundamental laser pulse energy and 700 μJ UV pulse energy were obtained and 3.0 nC electron beams were gotten [1, 3].

For the repetition rate of electron beam, the 25 Hz with double bunches and 50 Hz are requested. In order to realize excellent thermal management under high repetition rate operation, the laser system has been being improved.

2. CURRENT LASER SYSTEM

In the ref [4], 0.8 nC electron beams were obtained by using of Yb laser system. By reforming the laser system configuration, 3.0 nC electron beam was archived under 25 Hz operation.

Fig. 1 shows the layout of Yb laser system. The seed laser pulse was generated by an Yb-doped fiber ring oscillator. The generated 0.2 nJ seed laser pulse with repetition rate of 51.9 MHz, which is synchronized with 2856 MHz trigger from accelerator. An electro-optical fiber pulse picker is adopted for decreasing the repetition rate of seed laser to 10.38 MHz. Then laser is amplified by Yb fiber pre-amplifier and chirped to about 30 ps by a transmission grating stretcher. Subsequently, two stages of Yb doped large-mode-area polarizing double-clad photonic crystal fiber are selected as the first and main amplifier to get strong enough pulse energy [5]. After pre-amplification of Yb-doped fiber and transmission grating stretcher, double pulse with 25 Hz repetition rate is generated. Because thin disk laser possesses very favorable thermal management, this configuration is used to obtain the mJ-class pulse energy. It is worthy of being mentioned that a novel and compact Yb:YAG regenerative amplifier is adopted which is easier to maintain and get higher amplification. After that, four stages multi-pass amplifiers are employed. UV pulse laser at 259 nm for photocathode is generated by using two frequency-doubling stages and then injected into RF gun.

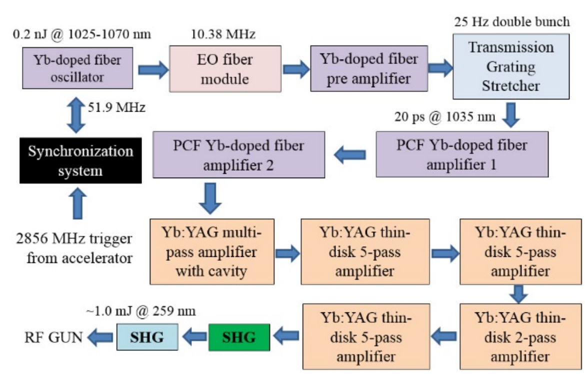

Figure 1: Layout of current laser system for RF-gun.

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3. IMPROVEMENTS OF THE CURRENT LASER SYSTEM

3.1 Au-Sn soldering Yb:YAG/Cu composite for thin disk amplifiers

The difficulty in controlling thermomechanical distortions has been one of the most important factors for preserving high beam quality and developing high average power solid-state lasers. By comparing with the 0.8 nC electron beams result we reported in the ref [4], 3.0 nC electron beams were gotten by using of Yb:YAG thin disk and copper plate composite. Waste heat generated in laser active disk can be removed to the copper plate effectively. Due to effective thermal removal in regenerative amplifier and multi-pass amplifiers, the amplified laser pulse became more stable and efficient.

Gold-tin (AuSn) was selected as soldering material for bonding Yb:YAG thin disk and copper plate. It possesses several advantages. Firstly, it has high thermal conductivity and low thermal expansion coefficient, as listed in Table 1. The thermal conductivity is high for AuSn comparing to that of indium-tin (InSn), this is very helpful for waste heat removal. Secondly, the deformation of AuSn is weak on heating because its thermal expansion coefficient is comparably small. Meanwhile, it is evident from Table 1 that the thermal expansion coefficients of AuSn and copper are almost the same. Therefore, when laser is operating, the AuSn soldering layer and copper plate can expand synchronously to avoid fracture of the bonding layer as much as possible. Finally, AuSn possesses high resistant to corrosion and high creep resistance.

Table 1: Comparison Between AuSn, InSn, Cu and Yb:YAG

Material (ingredients of constituents)	Melting point (ºC)	Thermal conductivity (W/m/K)	Thermal expansion coefficient (10^{-6}/K)
AuSn (80:20)	280	58	16
InSn (50:50)	118	34	20
Copper	-	396	16.4
Yb:YAG	-	11	6.7

The Yb:YAG thin disks used in our laser system have 0.5 inch diameter and 0.5 mm thickness. Yb-ions dopant is 10 a.t. %. Anti-reflection (AR) coating is covered on the top surface for 940 nm pump laser and 1030 nm seed laser. On the bottom surface, high reflection (HR) film is coated at 1030 nm. Outside the HR film, gold (Au) coating is covered for metalizing the Yb:YAG thin disk. As to the copper plate, it has the same diameter as the Yb:YAG thin disk and thickness of 2.0 mm. On the top surface, AnSn coating is covered as soldering material.

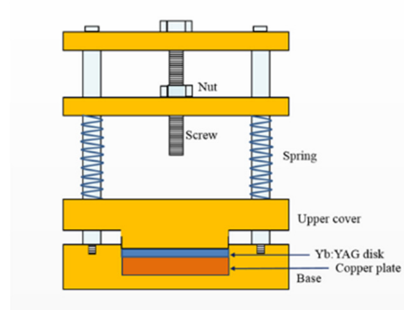

Figure 2: Configuration of fixtures for Au-Sn soldering of Yb:YAG/Cu composite.

The Au-Sn soldering fixtures are shown in Fig. 2. Three pieces of spring with force constant of 0.05 Kg/mm are used to provide pressure onto the Yb:YAG thin disk and copper plate composite. The deformation length of one spring was 10 mm, so the total pressure was 1.21 kg/cm^2. Then the whole fixtures were placed into a vacuum chamber for soldering process at 310 ºC about 10 minutes. The accomplished Yb:YAG/Cu composite is shown in Fig. 3. From side view of the composite under a microscope, we can see that thickness of the Au-Sn soldering layer is about 16 μm compare to the 0.5 mm thick Yb:YAG thin disk.

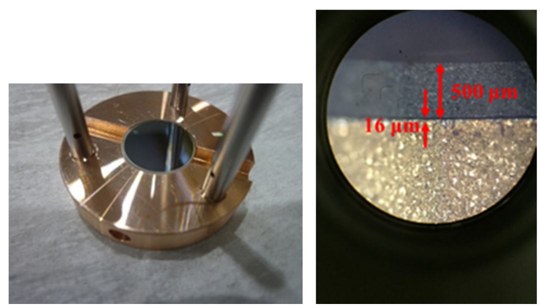

Figure 3: Accomplished Yb:YAG/Cu composite and side view under microscope.

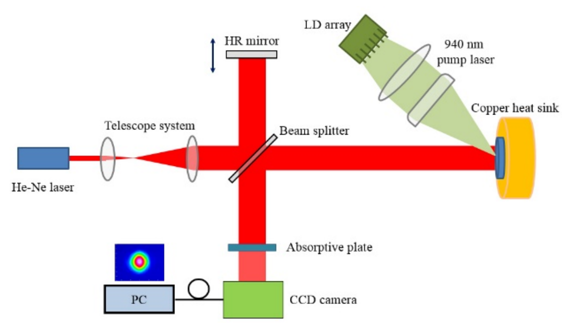

Figure 4: Optical measurement experimental setup.

For testing the thermal effect, an optical experimental setup was built, as seen in Fig. 4. A TEM_{00} mode operating He-Ne laser was enlarged and divided into two equal beams. One was impinged onto the Yb:YAG amplifier which is pumped by 5 Hz 600 μs LD laser, the other was reflected by HR mirror. Finally, two beams were collinear and overlapped, wave front interference could be monitored by CCD camera and PC.

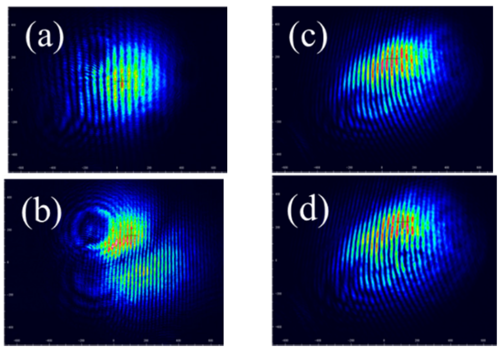

Figure 5: Optical measurement results for thermal effect. (a) and (b) are measured by use of old design; (c) and (d) are for Yb:YAG/Cu composite.

Thermal effect measurement was operated under 1 J pulse energy of LD pump. As seen in Fig. 5, (a) and (b) are wave fronts for old design without pump and with 1 J pump accordingly. As to old design, the Yb:YAG thin disk was adhered to heat sink directly. From (a) and (b) we can see the wave front distorted under pump because thermal lens effect occurred seriously. On the opposite, measurement for Yb:YAG/Cu composite showed excellent thermal management. It is evident that both the wave front without pump in Fig. 5(c) and the wave front under 1 J pump in Fig. 5(d) are almost unchanged, although some stress was introduced by soldering. Yb:YAG/Cu composite have been used in every stages of our laser system. The waste heat could be removed efficiently, it is necessary to reduce the thermal lens effect, make laser system stable and increase the electron charge from RF-gun, as shown in Fig. 6. It is also potential for high repetition rate operation in the following days.

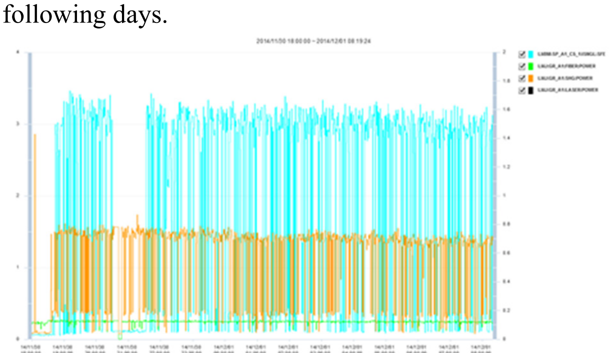

Figure 6: Electron bunch charge history.

3.2 Precise measurement of thin disk deformation

For obtaining excellent and stable output laser for RF-gun, the real time measurement of thin disk deformation is very important. A compact experimental setup was designed for measuring the thermal deformation in our laser system, as shown in Figure 7.

A pigtail output coupling fiber laser at 976 nm is adopted as measuring laser. After beam expanding, it impinged on the Yb:YAG/Cu composite which is pumped by 4 kW LD stack. Reflected measuring laser is measured and analyzed by wave front camera. By comparing the unpumped wavefront and pumped one, we can monitor the thin disk deformation caused by thermal effect. The measured results are shown in Figure 8.

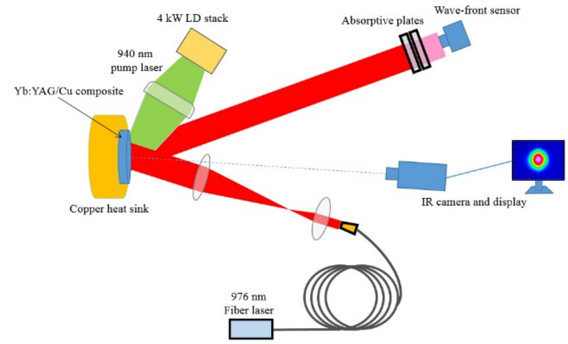

Figure 7: Measuring experimental setup of this disk deformation.

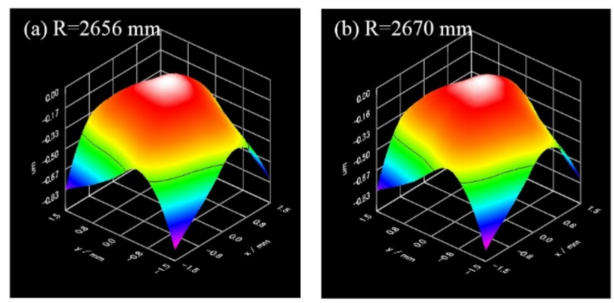

Figure 8: Wavefronts from Yb:YAG/Cu composite. (a) unpumped; (b) pumped.

By analyzing the curvature radius of wavefront from Yb:YAG/Cu composite, the instantaneous deformation of thin disk can be checked. This is very important and necessary for controlling the thermal effect occurred in the laser amplifiers and checking the quality of Yb:YAG/Cu composite. It is also a good tool for tracing the unstable part in all stages of amplifiers.

3.3 Cryogenic experiment

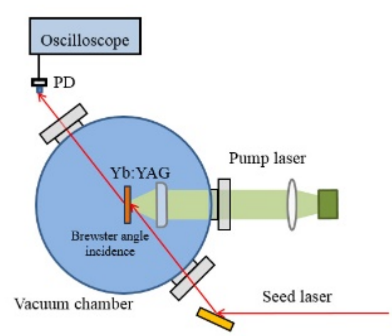

Figure 9: Gain test experimental layout.

In the aim of realizing more stable laser system and effective thermal management, cryogenic experiment is a good candidate. We also tested gain of the Yb:YAG disk under different temperature and different wavelength of seed laser. The experimental layout and setup are shown in Fig. 9. A 2 mm thick and 10 mm long square Yb:YAG disk was placed into a vacuum chamber, which is pumped by 5 Hz 600 µs laser at 940 nm. A cryocooler head was also inside the chamber. Seed laser was tunable and impinged into Yb:YAG disk at Brewster angle. The gain was tested by photodiode (PD) and oscilloscope.

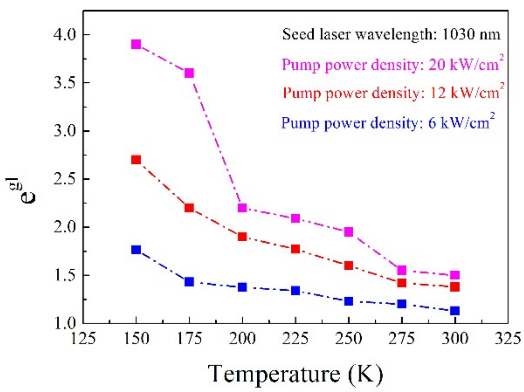

Figure 10: Gain test under different pump power density for 1030 nm seed laser at different temperature.

The amplification ratios under different pump power density for 1030 nm laser are shown in Fig. 10. The gain becomes higher with the decreases of temperature. High gain can be obtained by use of cryogenic laser operation compared to current room temperature experiment. High gain also can be realized under high pump power density due to low thermal effect under cryogenic environment. In addition, the amplification ratios for different wavelength seed laser were tested at 150 K, as shown in Fig. 11. For our Yb:YAG laser system, the highest gain can be gotten for seed laser at 1030 nm.

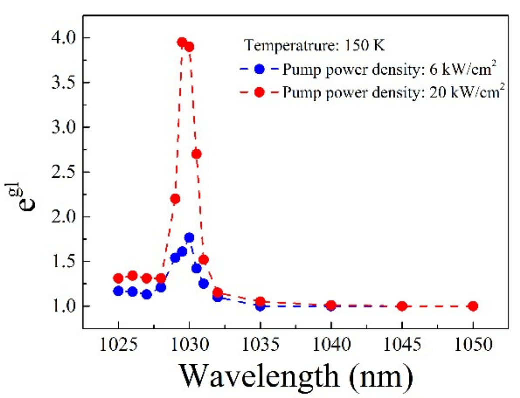

Figure 11: Gain test for different seed laser wavelength at 150 K under different pump power density.

4. CONCLUSION

Improvement of the laser system have been being done. For getting better thermal management in laser system under high repetition rate operation, Yb:YAG/Cu composite configuration and cryogenic experiment have been investigated. In addition, instantaneous measuring setup was built for realizing more stable and efficient laser output energy. It will be adopted in every stages of thin disk amplifier in the future.

Yb:YAG thin disk was soldered to a copper plate by AuSn soldering material, effective thermal removal was achieved under 25 Hz laser operation. As a result, 3.0 nC bunch charge was generated successfully.

As to the final aim of 50 Hz laser operation in the following days, cryogenic test was done. It is a good available candidate to overcome serious thermal effect in high repetition rate laser system.

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