ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWA071

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

R. Zhang*, M. Yoshida, T. Natsui, X. Zhou, Y. Ogawa, KEK, Tsukuba, Japan

Abstract

According to the requirements of SuperKEKB project, the electron beams with a charge of 5 nC and a normalized emittance of 10 μm are expected to be generated at injector linac. In order to meet these demands, an Ytterbium laser system has been being built. For realizing the laser system operating under 25 Hz with double bunch or 50 Hz, improvements of laser system are being done. We obtained 3.0 nC bunch charge by use of Yb:YAG/Cu soldering composite to overcome thermal effect. This demonstration indicates that effective and excellent thermal management can be realized for high repetition laser operation. Cryogenic experiment is also introduced.

INTRODUCTION

Higher luminosity 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].

With the aim of achieving the demands on the laser source, a hybrid laser system which includes an ytterbium (Yb) ions doped fiber oscillator, Yb-doped fiber amplifier 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.

IMPROVEMENTS OF THE 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.

Figure 1 shows the layout of Yb laser system. The seed laser pulse was generated by an Yb-doped fiber ring oscillator. 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]. Because thin disk laser possesses very favourable thermal management, this configuration is used to obtain the mJ-class pulse energy. A regenerative Yb:YAG thin disk regenerative amplifier and 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.

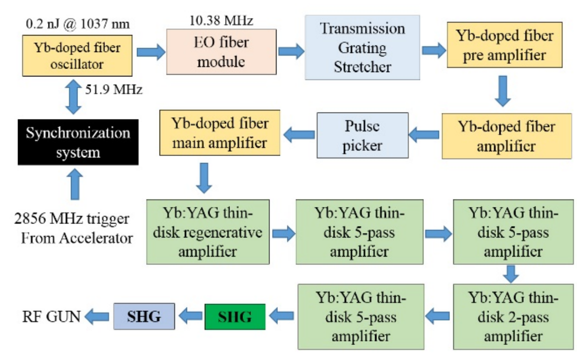

Figure 1: Layout of laser system.

Au-Sn soldering Yb:YAG/Cu Composite for Amplifier

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

*rui.zhang@kek.jp

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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	**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.

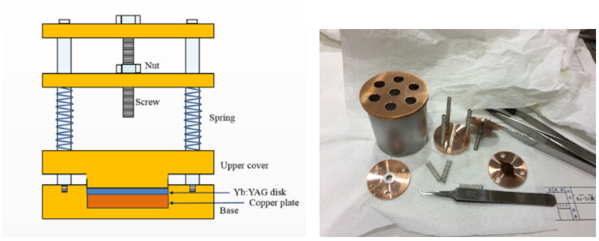

Figure 2: Configuration and components of fixtures for Au-Sn soldering.

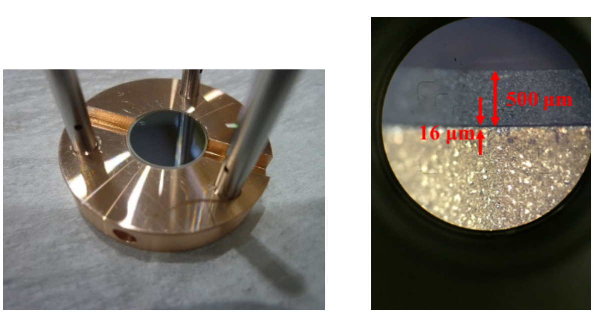

Figure 3: Accomplished Yb:YAG/Cu composite and side view under microscope.

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.

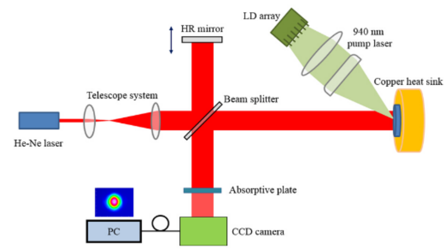

Figure 4: Optical measurement experimental setup.

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.

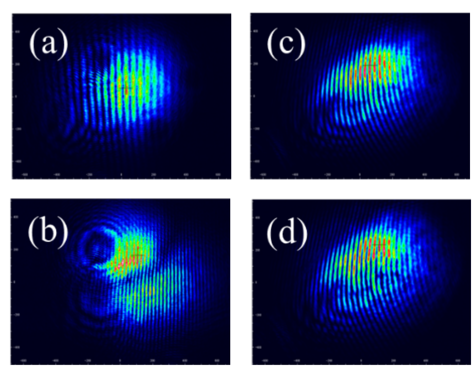

Figure 5: Optical measurement results for thermal effect. (a) and (b) are measured by use of old design; (c) and (d) are for Yb:YAG/Cu composite.

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.

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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.

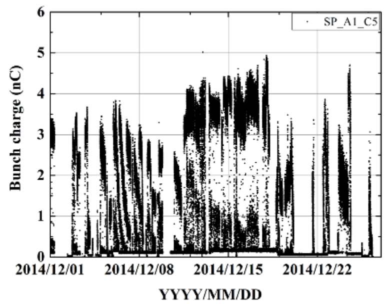

Figure 6: Bunch charge history.

Cryogenic Experiment

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. 7. 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.

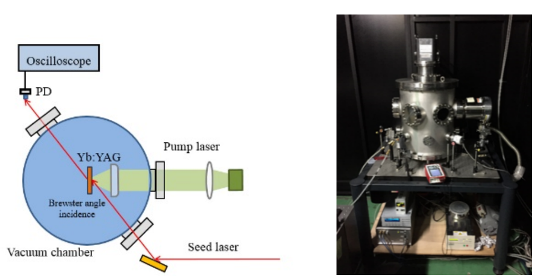

Figure 7: Gain test experimental layout and setup.

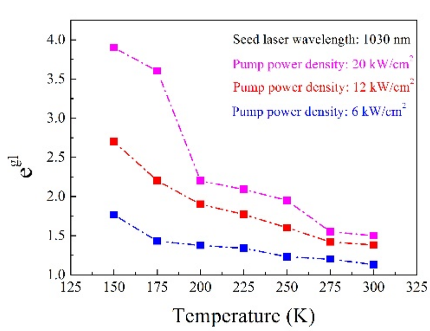

Figure 8: Gain test under different pump power density for 1030 nm seed laser at different temperature.

The amplification ratios under different pump power density for 1030 nm laser are shown in Fig. 8. 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. 9. For our Yb:YAG laser system, the highest gain can be gotten for seed laser at 1030 nm.

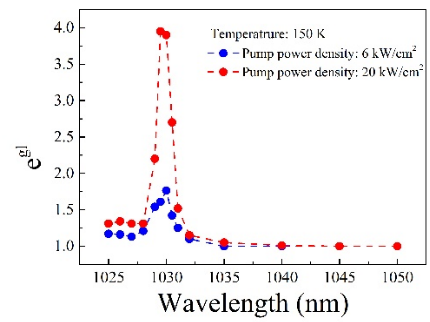

Figure 9: Gain test for different seed laser wavelength at 150 K under different pump power density.

CONCLUSION

Improvement of the laser system have been being done. In order to meet the demands of SuperKEKB, laser system should be operated at high repetition rate. For realizing excellent thermal management in laser system under 25 Hz and 50 Hz repetition rate operation, Yb:YAG/Cu composite configuration and cryogenic experiment have been investigated and demonstrated.

Yb:YAG thin disk was soldered to a copper plate by AuSn soldering material, effect 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 method to overcome serious thermal effect under high repetition rate laser system.

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