NEW ACHIEVEMENTS OF THE LASER SYSTEM FOR RF-GUN AT SuperKEKB INJECTOR

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Abstract

SuperKEKB Phase I commissioning has finished. By use of Ytterbium hybrid laser system, 1.5 nC electron charge is generated and injected into High Energy Ring successfully for 10 days operation. According to the operation results, some improvements are done for next phase commissioning. New Yb:YAG/CuW laser head is designed for stable laser operation and efficient heat management. Moreover, indium solder material is chosen for getting excellent quality of soldering composite. Low temperature laser is also explored for obtain higher amplification factor and reduce unwanted nonlinear effect to increase the electron generating efficiency of RF gun.

INTRODUCTION

In order to achieve SuperKEKB project demands on electron beam with high charge and low emittance, RF gun and Ytterbium (Yb) doped laser system are adopted [1]. Since the RF gun processes strong focusing electric field and high accelerating efficiency, it is possible to generate high quality electron beam for accelerator. High energy laser pulse can be gotten by use of Yb hybrid laser system which consists of Yb fiber laser part and Yb:YAG thin disk laser part [2]. For Iridium Cerium photocathode with high quantum efficiency inside the RF gun, proper Ultra-violet (UV) laser can be generated by utilizing two stages of second harmonic generation [3]. According to this basic line, an Yb hybrid laser system has been exploited and applied for SuperKEKB phase I commissioning. About 1.5 nC electron charge is generated and injected into SuperKEKB High Energy Ring (HER) successfully in 2016 summer. Meanwhile, 10 days stable injection with 1 nC is also accomplished smoothly for the first time.

SuperKEKB Phase II will start from the end of this fiscal year. With the aim of achieving the demand on electron charge of 2 nC, an additional Neodymium laser system is prepared and tested [4]. Therefore, before SuperKEKB Phase III operation, the Yb laser system should be improved according to the operation experiences of Phase I and demands of Phase III. For 25 Hz double pulses or 50 Hz laser operation, more efficient thermal management should be considered. In addition, laser operation stability is very important to generate stable and low emittance electron charge for accelerator ring. More stable laser amplifier configuration and additional laser box should be used. At the same time, it is also necessary to avoid nonlinear effect in Yb:YAG thin disk amplifier stages. High charge is required in Phase III, high pulse energy laser at high repetition rate is necessary. Hence, cryogenic laser operation with high amplification efficiency has been being done.

In this proceeding, some new improvements are introduced to enhance performance of the Yb hybrid laser system for SuperKEKB Phase III.

IMPROVEMENTS OF THE LASER SYSTEM

Figure 1 shows the layout of the Yb hybrid laser system used in SuperKEKB Phase I. The seed laser pulse is generated by an Yb-doped fiber mode lock oscillator which is synchronized with main trigger of accelerator. Then it is amplified by an Yb doped fiber pre amplifier. A transmission grating stretcher is used to stretch the seed laser pulse from several hundreds of femtosecond into 20 picosecond. An electro-optical (EO) 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 two stages of Yb doped large-mode-area polarizing double-clad photonic crystal fiber amplifier (PCF). Another EO pulse picker is applied to change the repetition rate from 10 MHz into 25 Hz. Because thin disk laser possesses very favourable thermal management, this configuration is used to obtain the mJ-class pulse energy. One stage of Yb:YAG thin disk multi-pass amplifier with cavity and four stages multi-pass amplifiers are employed. UV laser of about 1 mJ at 259 nm for photocathode is generated by using two frequency-doubling stages and then injected into RF gun.

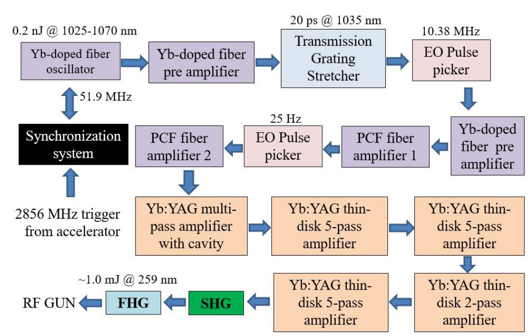

Figure 1: Layout of Yb hybrid laser system used in SuperKEKB Phase I commissioning.

According to the operation results of Phase I commissioning, there are two main problems in current laser system. One is the thermal effect, the other one is nonlinear effect. Therefore, new soldering method and low temperature laser operation are investigated to solve these problems for getting more stable and robust laser system for Phase III. Novel homemade Yb:YAG/CuW thin disk laser head can realize more efficient thermal management and stable laser system. Nonlinear effect can be reduced by using of low temperature cooling method

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with high gain to reduce the stage and pass number of multi-pass amplifiers. Details are introduce in the following two parts.

Indium Soldering Yb:YAG/CuW Composite for Amplifiers

A composite of Yb:YAG thin disk and copper plate which is made by gold-tin (AuSn) soldering is reported in the ref [2]. Compare with previous combination method by silver adhesive, it improves the laser repetition rate from 2 Hz into 5 Hz or 25 Hz in the thin disk laser amplifier stages, and 3 nC electron beam is generated successfully. However, Yb:YAG/Cu soldered composite must be combined onto a heatsink by silver adhesive, this is not a real adhesive free method. Waste heat can't be removed efficiently due to the adhesive layer. Adhesive free combination method should be explored. On the other hand, some Yb:YAG thin disks cracked or dropped during experiment. One reason is the inefficient heat removal in the Yb:YAG/CuW composite. The other reason is thermal expansion coefficient mismatch of Yb:YAG and copper. It is evident from Table 1 that the thermal expansion coefficient of copper is much bigger than that of Yb:YAG. By contrast, the thermal expansion coefficient of copper tungsten (CuW) is very close to that of Yb:YAG, so Yb:YAG/CuW composite can expand synchronously to avoid fracture of the Yb:YAG thin disk under laser operation. Furthermore, in order to reduce residual stress introduced by soldering, indium (In) solder material is chosen because it processes lower melting temperature and higher thermal conductivity compared with AuSn solder.

Table 1: Comparison between AuSn, InSn, In, Cu, CuW and Yb:YAG

Material	Melting temperature (°C)	Thermal conductivity (W/m/K)	Thermal expansion coefficient (10^{-6}/K)
$Au_{80}Sn_{20}$	280	58	16
$In_{50}Sn_{50}$	118	34	20
In	156	82	32
Copper	-	396	16.4
$Cu_{15}W_{85}$	-	200	7.0
Yb:YAG	-	11	6.7

The homemade Yb:YAG/CuW composite is shown in Figure 2. The Yb:YAG disk is directly soldered on the CuW heat sink by indium solder. Soldering process is achieved in a vacuum chamber because indium is easy to be acidified. The soldering process is very simple to achieve and doesn't take time.

The quality of Yb:YAG/CuW composite is checked by using of a TEM_{00} mode operating He-Ne laser. Reflected beam can be monitored by a CCD camera for studying the residual stress and waste hear removal efficiency of the composite. The left figure of Figure 3 shows the reflected beam without pump. Comparing with TEM_{00} mode beam, occurred deformation means residual stress is introduced by soldering process. But compare with the test results mentioned in ref [2], the residual stress of current design is much weaker than the case of Yb:YAG thin disk and copper plate composite. Meanwhile, the middle and right figures are the beam profiles under 1 J and 3 J pump separately. The reflected beam profiles deformed a little compared with the left one. It demonstrates that thermal effect is not serious under pump by soldering the disk on CuW heat sink directly. This homemade laser head will be adopted for the amplifier stage.

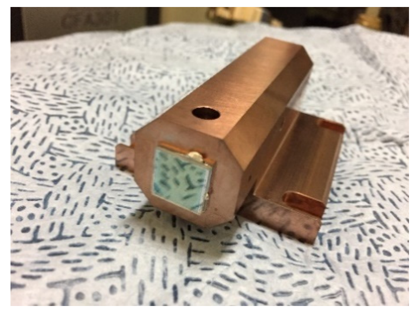

Figure 2: Homemade Yb:YAG/CuW indium soldered composite.

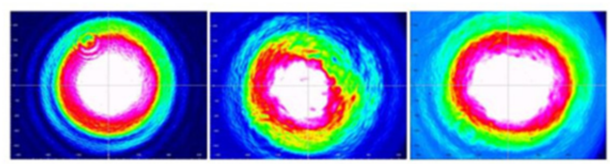

Figure 3: Optical measurement results for residual stress and thermal effect of Yb:YAG/CuW composite. From left to right: no pump, 1 J and 3 J pump.

Low Temperature Laser Experiment

In the aim of realizing more stable laser system and effective thermal management, low temperature laser experiment is a good candidate. By using of Peltier cooling plate, low temperature can be purchased easily. A compact vacuum chamber is designed for Peltier cooling laser experiment, and the homemade Yb:YAG/CuW laser head is placed into this chamber, as shown in Figure 4. About -30 °C is achieved by use of one Peltier cooling plate.

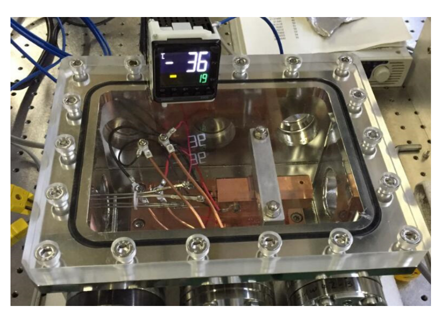

Figure 4: Peltier cooling laser chamber.

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About -50 °C can be gotten by employing two Peltier cooling plates, but the temperature stability under high power pump laser is bad, so just one Peltier plate is adopted for stable operation. Although lower temperature below -30 °C is difficult to achieve, the Peltier cooling setup is very stable for laser operation compared with cryogenic cooling setup. It is easy to control the temperature and vacuum condition. For cooling the heating surface of Peltier plate, 10 °C water cooling is applied. Amplification factor is tested at different temperature, as shown in Figure 5. A wavelength tunable laser impinged into Yb:YAG disk from the side face (12.7mm x 1mm) which is coated by AR film for seed laser, and the pump laser arrangement is face pump (12.7 mm x 12.7 mm). 3 kW pump laser is applied on the surface of Yb:YAG disk with an area of 12.7 x 4 mm^2. It is evident from Figure 5 the amplification factor at -32 °C is almost 5 times higher than that at ambient temperature.

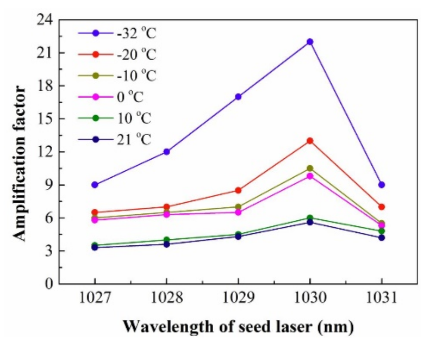

Figure 5: Amplification factor versus seed laser wavelength at different temperature.

By using of the compact vacuum chamber, a multi-pass amplifier is built as final amplifier for current laser system. The final two stages of multi-pass amplifiers in Figure 1 are replaced. The setup is shown in Figure 6. A dichroic mirror is used to realize face pump and seed laser face injection arrangement, which is placed before a window of the vacuum chamber. 3.3 kW pump laser is focused on the surface of Yb:YAG disk with an area of 8 mm x 6 mm at repetition rate of 25 Hz. Input seed laser pulse energy is about 1.5 mJ with beam radius about 3 mm. The thickness of Yb:YAG disk is 1 mm and Ytterbium dopant is 10%.

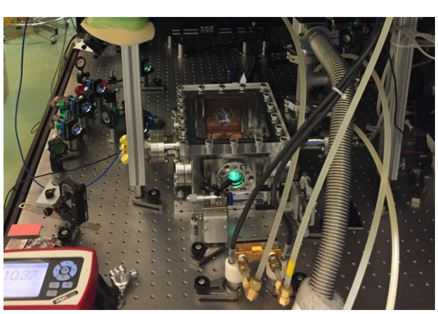

Figure 6: Experiment setup of Peltier cooling 3 pass multi-pass amplifier stage.

3 passes amplifier is built due to the limit of space and dichromic mirror size. Laser pulse energy for every pass is shown in Figure 7. After 3 pass amplification, 11.7 mJ is achieved for SHG stage. This pulse energy is almost same as the energy of laser system which is used in SuperKEKB Phase I, but pass number of multi-pass amplifier is much less. Obviously, the amplification efficiency is higher at low temperature operation, so less amplifier stage can be used to reduce size of laser system and improve the stability. In addition, it is very helpful to decrease the unwanted nonlinear effect inside the Yb:YAG crystal by using of bigger pump size and seed laser profile. The temperature fluctuation is about 4 °C during amplification. There is no cracking and dropping occurrence in experiment, it indicates that heat removal is effective and the homemade laser head is more robust than previous design.

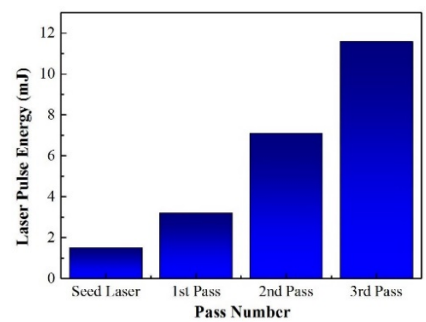

Figure 7: Laser pulse energy for all pass of the Peltier cooling multi-pass amplifier under 3.3 kW pump laser.

CONCLUSION

Some new improvements of the Yb hybrid laser system have been being done basing on the operation results of SuperKEKB Phase I commissioning. New Yb:YAG disk laser head is developed. CuW is chosen as heatsink material for avoiding the mismatch of thermal expansion coefficient. Meanwhile, indium solder is selected to get robust soldering Yb:YAG/CuW composites.

Furthermore, low temperature laser vacuum chamber is designed to for getting high laser pulse energy which is available to our homemade new Yb:YAG disk laser head. Utilizing Peltier cooling plate, -30 °C is achieved for laser operation. Amplification factor is tested at different temperature. A 3 pass multi-pass amplifier is built to replace the last two stages multi-pass amplifiers in current laser system, 11.6 mJ is achieved for RF gun which is the same output energy as that of Phase I laser system.

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