

# YTTERBIUM LASER DEVELOPMENT OF DAW RF GUN FOR SUPERKEKB

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## Abstract

For obtaining higher luminosity in the SuperKEKB, the photocathode RF electron gun with strong electric focusing field for high-current, low-emittance beams will be employed in the injector linac. In the photocathode RF gun, the laser source with a center wavelength of 260 nm and a pulse width of 30 ps is required. Furthermore, for reducing the energy spread, the laser pulse width should be reshaped from Gaussian to rectangle structure. Therefore, Ytterbium (Yb)-doped laser system that provides broader bandwidth, higher amplifies efficiency and higher output power is employed. High pulse energy and good stability would be expected.

## INTRODUCTION

SuperKEKB is a planned upgrade to the KEKB accelerator with higher luminosity [1]. Corresponding to the reduction of dynamic aperture and beam life, the photocathode DAW-type RF gun for high-current, low-emittance beams will be employed in the injector linac. In order to generate electron beams with a charge of 5 nC and a normalized emittance of 10  $\mu\text{m}$  in the photocathode RF gun, the bunch width should reach several tens of ps.

Recently, Ir<sub>5</sub>Ce was evaluated as cathode material of RF Gun because of its high efficient emission (Max QE:  $\sim 10^{-4}$ ) and long lifetime [2]. By simulation with the QE of  $5 \times 10^{-5}$ , the injection laser pulse energy should be higher than 1 mJ.

According to the simulation of emittances due to the space-charge effect, the laser source of center wavelength of 260 nm and pulse width of  $\sim 30$  ps (FWHM) are required. For the synchronization with the SuperKEKB, the repetition rate of the laser is set at 51.9 MHz.

In the ref [3], when the charge distribution is uniform in a cylinder, the energy spread of the bunch is lower than the result of Gaussian charge distribution. For the laser source, the pulse width should be reshaped to rectangle structure. Therefore, the wide spectral width pulses are expected.

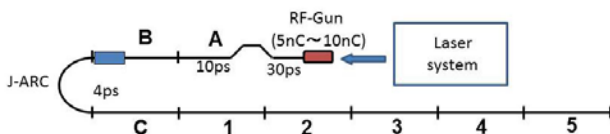


Figure 1: Schematic of SuperKEKB injector linac

The photocathode DAW-type RF-Gun with Nd:YAG laser system was already tested at the 3-2 unit [4] and the side coupled quasi-travelling wave type RF-Gun is installed at the

A-1 unit this year. In this paper, we report an ultra-short pulse laser system for RF-Gun at the A-1 unit based on the Yb-doped (Fig.1). High pulse energy and good stability would be expected.

## LASER SYSTEM

For high peak power and ultra-short UV pulse generation, the most common approach is to employ the nonlinear processes of solid-state Ti:Sapphire lasers. A Ti:sapphire laser is usually pumped with another laser with 532 nm, for which frequency-doubled Nd:YAG lasers are used. However, the low energy-extraction efficiency and heavy maintenance limit the application. In contrast, Nd:YAG lasers are optically pumped using a laser diodes, that offers high efficiency for reduction of the laser price and maintenance costs. But, the pulse shaping of Nd:YAG is difficult to be adjusted because of the narrow spectrum gain.

By contrast, the fiber laser especially Yb fiber laser has attracted attention as one of the promising practical alternatives to usual solid-state lasers, offering high repetition rate, low-cost and so on. Especially, the stability of the fiber laser is evidently higher than the other solid lasers with simple cooling conditions because of high energy-extraction efficiency of fiber. In particular, Yb-doped glass fibers provide broader bandwidth; higher amplification and higher output power than other fiber amplifiers.

The thin-disk laser is a special kind of diode-pumped high-power solid-state laser. The main difference is the geometry of the gain medium is a thin disk, where the thickness is considerably smaller than the laser beam diameter. The heat generated is extracted dominantly through one end face. Substantial pulse energies are then possible even without using chirped-pulse amplification (CPA). Within the next few years, both fiber lasers and thin-disk lasers are expected to show significant further progress.

Table 1: Characteristic of Lasers

	Ti	Nd	Yb
Type	Solid	Solid	Fiber&Solid
Energy-extraction Efficiency	0.5%	3%	3%
Gain Spectrum	Broadband	Narrowband	Broadband
Cost	High	Low	Low
Maintenance	Often	Less	Less

A schematic diagram of the laser setup is shown in Fig.2. The laser system starts with a large mode-area Yb-

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doped fiber-based amplifier system, which consists of a passively mode-locked femtosecond Yb-fiber oscillator, a transmission grating pair stretcher and two Yb-doped single-mode fiber amplifier stages. Then the repetition rate of the pulse is reduced to 2 Hz by an EO modulator pulse selector. To obtain the mJ-class pulse energy, the Yb:YAG solid-state thin-disk amplifiers are employed, include a regenerative amplifier and a two steps amplifier. Deep UV pulses for the photocathode are generated by using two frequency-doubling stages. High pulse energy and good stability were obtained. Finally, the pulses are injected into RF gun. In future, the laser pulse shape will be transformed from Gaussian shape to rectangle shape by a spatial shaping adjustment.

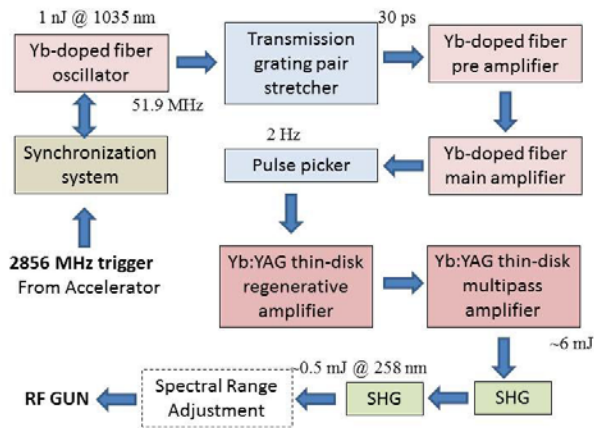


Figure 2: Layout of Laser system.

### Yb Fiber Oscillator with synchronization

A unidirectional ring cavity is employed in the passive mode-locked oscillator (Fig. 3) [5]. Highly doped Yb fiber with a length of 30 cm was pumped by a fiber-coupled pump diode delivering 250 mW at 976 nm. A piezoelectric transducer (PZT) attached to the end mirror after the grating pair is used to control the cavity length to lock the repetition rate with the SuperKEKB. All the optics is laid on the breadboard (30cm×60cm), which is easy to transport.

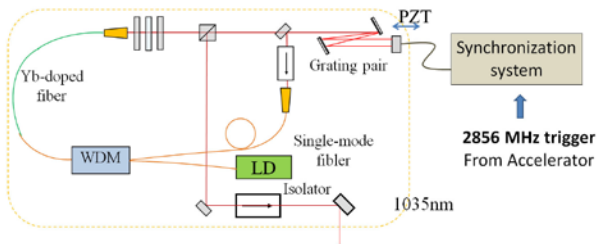


Figure 3: Layout of Oscillator.

The spectral bandwidth is ~14 nm, centered at 1035 nm. And the pulse duration after the oscillator is ~200 fs roughly with the average output power of 40 mW. Since the unabsorbed pump power was negligibly small, the calculated pulse energy is 0.8 nJ with good pulse quality.

When the pump power is above 150 mW, the mode-locking is initiated immediately by shaking the grating. An enclosure is set up to protect the oscillator that is sensitive to temperature, acoustic and wind vibration. And the mode-locked operation was stable for all days.

The seed pulses are then pass through an isolator, which provides the protection for the oscillator. Then, a wave plate and a polarizer were employed to separate a part of seed pulse to the synchronization system. The frequency source is supplied by KEKB with the repetition rate of 2856 MHz. The total fiber length is about 3.4 m, and the repetition rate is 51.9 MHz (10.38\*5 MHz). Our designs produce extremely low jitter of ~ps, with very wide operating ranges.

### Stretcher and Yb Fiber Amplifier

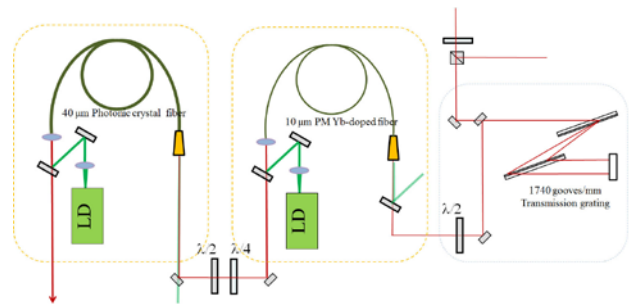


Figure 4: Layout of pre-amplifier.

Last time, a 10 m long Yb-doped fiber was employed for amplification and stretching the pulse width. The 0.5 W output power and ~20 ps pulse width was obtained [5]. Because of the absorption of the long Yb-doped fiber, the center wavelength of the pulse was shift to 1060 nm. But for Yb:YAG Thin-disk amplifier, the main gain spectrum is around 1037nm. Therefore, the length of Yb-doped fiber was reduced to avoid spectrum shift, and a transmission grating pair is added before the amplifier to stretch the pulse width.

As in the Fig.4, the pair of transmission gratings with a groove density of 1740 grooves/mm is used to stretch the seed pulse to several tens ps with an efficiency of 80%.

To precompensate for the power loss in lock system and stretcher, the pulse train is then injected into a 2 m long 10 μm core-diameter polarization-maintaining double-clad Yb-doped fiber with a cladding diameter of 125 μm and numerical aperture (NA) of 0.46. The Yb-doped fiber is cladding pumped by a fiber-coupled laser diode emitting at 976 nm. At 2.8 W of pump power, amplified pulses of 80 mW are achieved.

For higher pulse energy, the output of pre amplifier is seeded into the 2nd fiber amplifier comprised of a large-mode-area polarizing double-clad photonic crystal fiber 1.2 m in length with a core diameter of 40 μm and pump clad diameter of 200 μm. As in the Fig. 4, the structure is similar to the pre amplifier. For stability, the amplifier is backwardly pumped with light at a wavelength of 940 nm. In this stage, the output power of 1.1 W.

### Thin-disk Yb:YAG Amplifier

After reduction of the pulse repetition rate to 2 Hz with an EO modulator pulse selector, such low-repetition-rate high-peak-power pulses could not be amplified by fiber. To obtain the mJ-class pulse energy, a regenerative and a multi-pass Yb:YAG solid-state amplifier is employed.

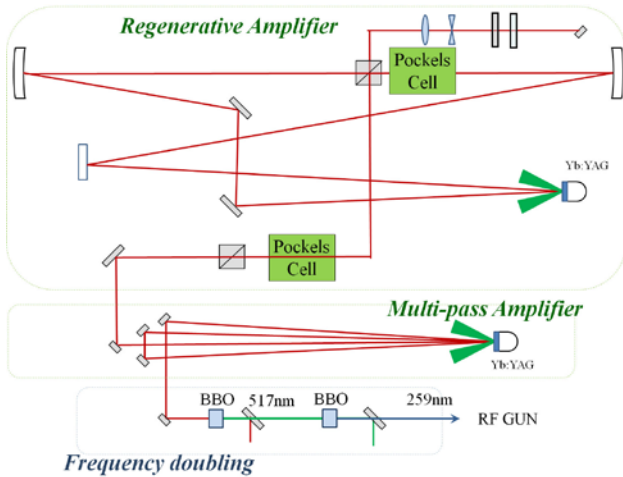


Figure 5: Thin-disk Yb:YAG.

Yb:YAG crystal, a promising laser-active materials, has a much larger absorption bandwidth to mitigate thermal management requirements for diode lasers, a longer upper-state lifetime and lower thermal loading per unit pump power, which have demonstrated significant potential for application in compact, efficient, diode-pumped laser systems.

For such high energy amplification, thin-disk laser is the best way to heat removal. The cooled end face has a dielectric coating which reflects both the laser radiation and the diode pump radiation. The gain crystal also acts as an end mirror within the laser resonator.

Although the thin-disk laser heads is not fit for high energy capacity lasers due to small thickness, it can be used for regenerative amplifiers. The relatively small gain of the thin disk can be compensated with a larger number of resonator round trips. In this step, a 2.4 kW (1.4 J) laser diode, is employed as the pump source, inject with oblique incidence into the Yb:YAG thin-disk crystal by a plano-convex cylindrical lens.

For higher amplification, the final amplifier was constructed as a purely 2-pass multipass amplifier (without a resonator and optical switch). The pump source is increased to 10 kW, with 4 laser diode setting around the Yb:YAG crystal, and 10 mJ output pulse energy is obtained. The damage surface and unregularly beam profile limit the overall gain (1%) and requires a carefully optimized setup in order to preserve a high beam quality.

Deep UV pulses for the photocathode are generated by using two frequency-doubling stages. The nonlinear SHG crystal of beta barium borate (BBO) is chosen because of its higher UV transparency. UV pulses at a center wavelength of 259 nm are generated in the same single-

pass configuration. The conversion efficiency of 6% with the pulse energy more than 0.6 mJ is obtained.

### Laser injection at RF Gun

Then the laser beam injects into the Ir<sub>5</sub>Ce cathode in RF gun with the angle of 60 degree. As a result of RF gun beam measurement, 0.7 nC beam generation from the gun was achieved. This beam can be transported to the end of J-linac. The RF-Gun cavity, cathode and experimental results will be shown in the ref [6].

### Next Upgrade of the laser system

In the amplifier stages, the pulse was stretched from several hundreds of fs to several tens of ps. For chirped pulse, the pulse shaping in the time domain can be controlled by adjusting the spectral shape of the pulse. It is also an important reason that the Yb laser was used, because the wider spectral width pulses could be generated compared with the others. A spectral range adjustment system will be constructed before the RF gun to reshaping the pulse shape.

To increase the stability and power of the laser source, the output of fiber and thin-disk amplifier should be increased. Improve the center wavelength from 940 to 976 nm and amplifier structure of the pump source will help to increase the amplification energy-extraction efficiency. Furthermore, the jitter of the synchronized system should be reduced to hundred fs level.

## CONCLUSION

For RF electron gun in the SuperKEKB, the laser source with a center wavelength of 259 nm and a pulse width of 30 ps is developed. The laser system starts with a large mode-area Yb-doped fiber-based oscillator, which generates 51.9 MHz seed pulses with center wavelength of 1035 nm and synchronized with KEKB trigger. The fs pulse is stretched until several tens ps, and amplified by Yb-doped fiber amplifier. Then pulses are reduced to 2 Hz of repetition rate by EO pulse picker. To obtain the mJ-class pulse energy, a Yb:YAG regenerative and 2-pass solid-state amplifier is employed. Deep UV pulses for the photocathode are generated by using two frequency-doubling stages. Beam generation of 0.7 nC is achieved by the laser source.

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