YTTERBIUM FIBER LASER SYSTEM OF DAW RF GUN FOR SUPERKEKB

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Abstract

For obtaining higher luminosity in the SuperKEKB, the photocathode RF gun with strong electric focusing field [1] for high-current, low-emittance beams will be employed in the injector linac. The electron beams with a charge of 5 nC and a normalized emittance of 10 μm are expected to be generated in the photocathode RF gun by using the laser source with a center wavelength of 260 nm and a pulse width of 30 ps. Introducing the Ytterbium (YB) fiber laser system, we are developing a stable laser amplifier system, which could allow steady beam injection into the SuperKEKB rings.

INTRODUCTION

SuperKEKB is a planned upgrade to the KEKB accelerator with higher luminosity. 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 μm in the photocathode RF gun, the bunch width should reach several tens of picosecond (ps).

Recently, Ir_5Ce and LaB_6 were evaluated as cathode material of RF Gun. Ir_5Ce is chosen because of its high efficient emission (Max QE: ~10^{-4}) and long lifetime. By simulation with the QE of 5×10^{-5}, the injection laser pulse energy should be higher than 1 mJ.

For a Gaussian distribution, the emittances due to the space-charge effect is given by Kim's approach [2]

$$\varepsilon_{x,z}^{SC} = \frac{\pi}{4}\frac{1}{\alpha\kappa}\frac{1}{\sin\varphi_0}\frac{I}{I_A}\frac{\sigma_z}{3\sigma_x+5\sigma_z} \qquad (1)$$

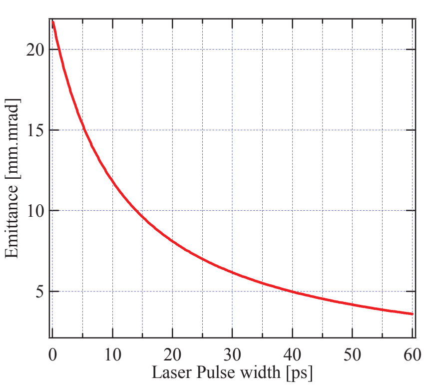

Figure 1: Emittance Simulation by laser pulse width.

According to the eq. (1), the simulation is shown in Fig. 1. Corresponding to the property of 5nC, 10mm mrad by the RF guns, the laser source of center wavelength of 260 nm and pulse width of ~30 ps (FWHM) are required.

In the ref [2], Kim also mentioned, when the charge distribution is uniform in a cylinder, the emittance 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.

Table 1: Required laser source.

Pulse Property	Require Date
Repetition Rate of Oscillator	51.9 (10.38×5) MHz
Center Wavelength	~260 nm
Pulse Width (FWHM)	~30 ps, reshape
Pulse Energy	>mJ
Spectral Width	~6 nm
Others	Stable, Compact, Removable

As the Tab. 1, for the synchronization with the SuperKEKB, the repetition rate of the laser is set at 51.9 MHz. To satisfy the above condition, a laser source with center wavelength of 260 nm, pulse width of several tens of ps, pulse energy of mJ is required. Furthermore, for the stable operation of the superKEKB, the stability of the laser source is important. Additionally, for lower emittance and lower energy spread, the pulse shaping adjustment (wide spectral width with the pulses) is required.

LASER SYSTEM

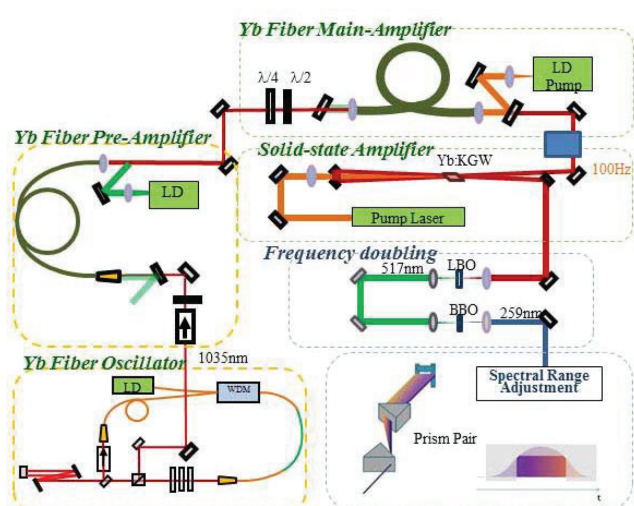

Figure 2: Schematic diagram of Laser system.

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For ultra-short UV pulse generation, the most common approach is to employ the nonlinear processes of solid-state lasers [3]. In 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 amplify efficiency and higher output power than other fiber amplifiers.

A schematic diagram of the laser setup is shown in Fig.2. The laser system starts with a large mode-area Yb-doped fiber-based amplifier system, which consists of a passively mode-locked femtosecond Yb-fiber oscillator and two Yb-doped single-mode fiber amplifier stages. To obtain the mJ-class pulse energy, a multi-pass solid-state amplifier is employed. Deep UV pulses for the photocathode are generated by using two frequency-doubling stages. High pulse energy and good stability would be expected. Finally, the pulses will be transformed from Gaussian shape to rectangle shape by a spatial shaping adjustment.

Now, the fiber oscillator and pre amplifier is done. We are still working on the development of the main amplifier.

Yb Fiber Oscillator

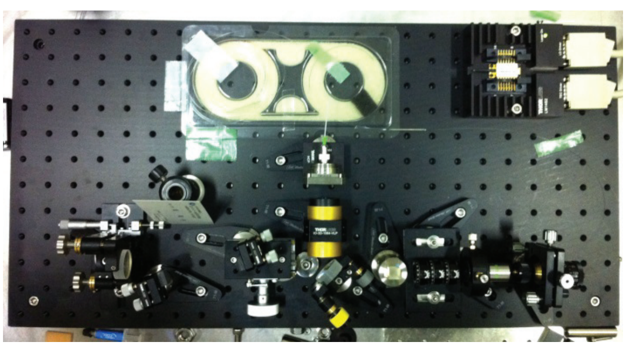

Figure 3: Layout of Oscillator.

A unidirectional ring cavity is employed in the passive mode-locked oscillator (Fig. 3) [4]. Highly doped Yb fiber with a length of 30 cm was pumped by a fiber-coupled pump diode delivering 250 mW at 976 nm. The pump light was coupled into the ring cavity via a wavelength-division multiplexer (WDM). The polarization state of the mode-locked pulses was adjusted with three wave plates before the output coupler. A 600-groove/mm grating pair separated to 65 mm, provides negative group delay dispersion (GDD) of $-1\times10^5 fs^2$, which compensates the positive GDD of fiber and optics in the cavity. A piezoelectric transducer (PZT) attached to the end mirror after the grating pair is used to control the cavity length to lock the repletion rate with the SuperKEKB. An isolator forced unidirectional ring operation. The total fiber length is about 3.4 m, and the repetition rate is 51.9 MHz. All the optics is lay on the breadboard (30cm×60cm), which is easy to transport and domination.

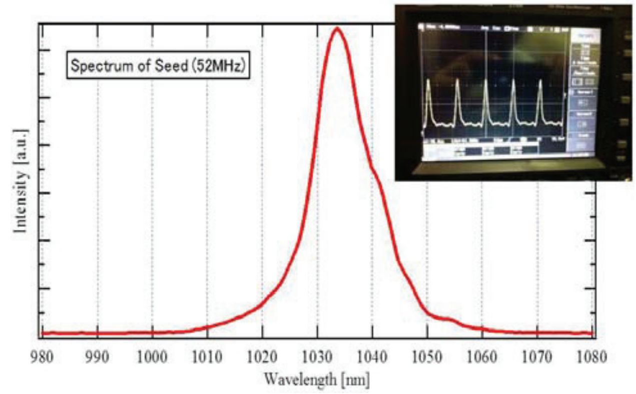

Figure 4: Measured spectra. Inset; pulse train.

The Fig. 4 shows the spectra of the output. The spectral bandwidth is ~14nm, centered at 1034 nm. And the pulse duration after the oscillator is ~200 fs roughly. The average output power was 42 mW at 51.9 MHz, as shown in Fig.4. 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. The mode-locked operation was stable for all days.

Yb Fiber Pre Amplifier

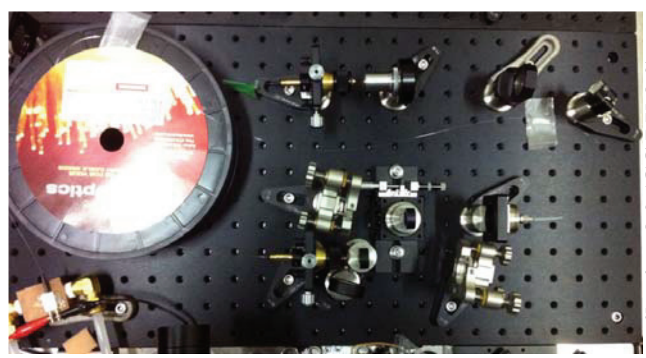

Figure 5: Layout of pre-amplifier.

The seed pulses are then pass through an isolator, which provides the protection for the oscillator. The pulse train is then injected into a 10 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. The fiber amplifier structure is designed according to the [5]. (Fig. 5)

In this stage, the long Yb-doped fiber was employed for stretch the pulse width. The calculated GDD of the total fiber is about $2.3\times10^5 fs^2$, which stretch the pulse to ~20 ps. After the laser source development, the fiber length can be adjusted to optimize the final pulse width.

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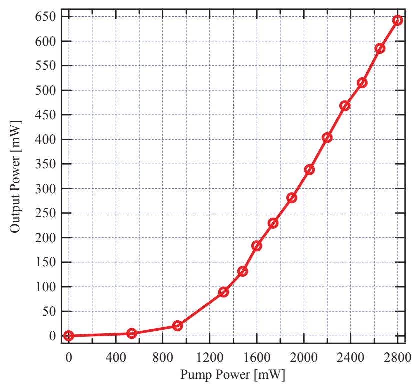

Figure 6: Output power of pre-amplifier.

The output characteristics of the fiber are shown in Fig. 6. At 2.8 W of pump power, amplified pulses of 640 mW are achieved, with the energy-extraction efficiency higher than 20%. Since the fiber is long enough, the saturation point is far from the experiment situation. We will increase the pump power to 10 W, and the output power of 2 W is expected.

Yb Main Amplifier

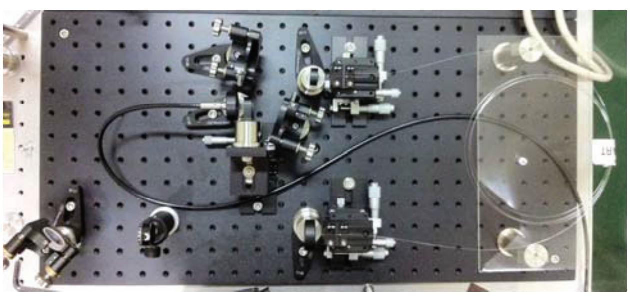

Figure 7: Layout of fiber main amplifier.

For higher pulse energy, one more Yb-doped fiber amplifier stage is employed. The structure is similar to the pre amplifier. As the Fig. 7, a 2 m long 25 μm core-diameter polarization-maintaining double-clad Yb-doped fiber was employed with the pump power of 70 W.

The development is working on. In this stage, the output power of 20 W (pulse energy of 0.4 μJ) is expected.

Solid-States Amplifier

After reduction of the pulse repetition rate to 50 Hz with an acousto-optic modulator (AOM)-based pulse selector, such low-repetition-rate high-peak-power pulses could not be amplifier by fiber. To obtain the mJ-class pulse energy, a multi-pass solid-state amplifier will be employed.

The multi-pass amplifier stage with the Yb:KGW crystal will be employed. Yb:KGW crystal can be used as ultrashort pulses amplifiers with the high absorption coefficient, high stimulated emission cross section, high slope efficiency and low laser threshold. With the pump source of 200 W, the 13 mJ pulse energy is expected. The gain of the main amplifier should be more than 3×10^4.

Frequency-Doubling Stage

Deep UV pulses for the photocathode are generated by using two frequency-doubling stages. For the first frequency-doubling stage, ~30 ps pulses at a center wavelength of 517 nm will be generated in the single-pass configuration. For second-harmonic generation (SHG), lithium triborate (LBO) crystal is chosen because of its low walk-off effect and its large nonlinear coefficient. The conversion efficiency of 40% is expected.

For the second frequency-doubling stage, 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 will be generated in the same single-pass configuration. The conversion efficiency of 20% with the pulse energy more than 1 mJ is expected. In the both stages, a dichroic mirror will be employed to separate the ω and 2 ω beams.

Spectral Range Adjustment

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 adjusted the spectral shaping of the pulse. It is also an important reason that the Yb laser was used, because the wider spectral width pulses could be generated compare with the others.

A method of selectively attenuating various frequency components utilizes a prism pair. A spatial masking is introduced into the spatially dispersed between the prism pair and the end mirror to create a variable spectral attenuation that has higher loss at those frequencies at the center and edge of the pulses. Then the rectangle pulse shape can be obtained.

CONCULUTION

For obtaining higher luminosity 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 amplifier system, which consists of a passively mode-locked femtosecond Yb-fiber oscillator. To obtain the mJ-class pulse energy, a multi-pass solid-state amplifier is employed. Deep UV pulses for the photocathode are generated by using two frequency-doubling stages. High pulse energy and good stability would be expected.

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