NEODYMIUM AND YTTERBIUM HYBRID SOLID LASER OF RF GUN FOR SUPERKEKB

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Abstract

By development of the Yb-doped laser system, more than 1.0 nC electron with double-bunch has been obtained in 25 Hz. The Yb-doped laser system is already for commissioning for the linac. Next, a new laser system is development to improve the stability and reliability.

INTRODUCTION

The electrum beam of the repetition rate of 50 Hz double-bunch is requested for injector linac of SuperKEKB. By development of the Yb-doped laser system, more than 5.0 nC and 3.0 nC electron beam with single-bunch has been generated in the 5 Hz and 25 Hz respectively [1, 2]. Also more than 1.0 nC electron with double-bunch has been obtained in 25 Hz [2]. The Yb-doped laser system is already for commissioning for the linac.

When the pump source repetition rate increases from 25 Hz, the heat in the Yb:YAG crystal cannot be dissipated effectively, which cause the thermal increase. Although the crystal thickness and soldering components was improved, the thermal conductivity is insufficient with 50 Hz pump condition. The thermal lens effect is changed lead to the serious decline of the amplify efficiency and beam quality. Therefore, for 50 Hz repetition rate, several ten mJ pulse amplification, a new laser system is development.

The most improvement is two kinds of a synthetic crystalline material that used as a laser crystals for solid-state lasers based on neodymium-doped YAG (Nd:YAG) and Ytterbium-doped YAG (Yb:YAG).

Compared with the commonly used Nd:YAG crystal, Yb:YAG crystal has a much larger absorption bandwidth to reduce thermal management requirements for diode lasers, a longer upper-state lifetime, three to four times lower thermal loading per unit pump power. Yb-doped crystal is more suitable for diode-pumping for high power diode-pumped lasers. On the other hand, Nd:YAG rods with high optical homogeneity, high damage threshold, consistent performance and high processing accuracy. Although the pulse shaping of Nd:YAG is difficult to be adjusted because of the narrow spectrum gain, the structure of the Nd:YAG is simple, that means reliable convenience and less maintenance. Therefore, both the Yb:YAG and Nd:YAG are appropriate candidate for 50 Hz double bunch amplification.

The Emission wavelength of Yb:YAG and Nd:YAG are around 1030 nm and 1064 nm with the bandwidth of ~2.0 ns and ~0.2 ns, which contained in the spectrum of Yb-doped fiber oscillator. Therefore, the Yb-doped oscillator and Yb-doped fiber amplifier also can be used with both Yb:YAG and Nd:YAG amplification. The two parts of the signal pulse was separated after fiber part and amplification respectively.

LASER SYSTEM

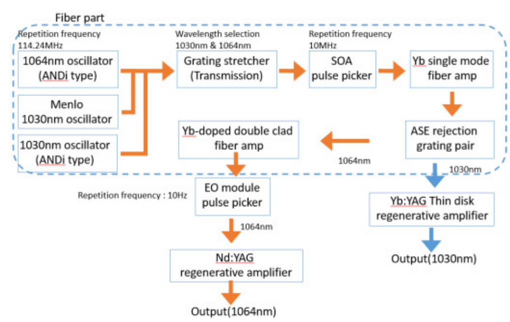

Figure 1: Layout of Laser system.

As the Fig. 1, the laser system starts with a 114 MHz Yb-doped fiber oscillator with the all normal dispersion (ANDi) structure. A transmission grating pair stretcher was employed to expend pulse to ~30 ps and separate the pulse to two parts with the center wavelength of 1030 nm and 1064 nm. Then the two kinds of pulses can be amplified by Yb:YAG and Nd:YAG crystals respectively. The weak pulses reduced repetition rate by a semiconductor optical amplifier (SOA) pulse picker and were amplified by the Yb-doped single mode fiber amplifier. Then the 1064 signal was amplified by Yb-doped double clad fiber amplifier. To obtain the mJ-class pulse energy, a Yb:YAG thin-disk regenerative solid-state amplifier and a Nd:YAG rod regenerative solid-state amplifier were employed. The fiber part structure is finished, and several ten nJ pulse energy low repetition rate pulses were generated after the Yb-doped fiber amplification stage.

ANDi Structure Yb-doped Fiber Oscillator

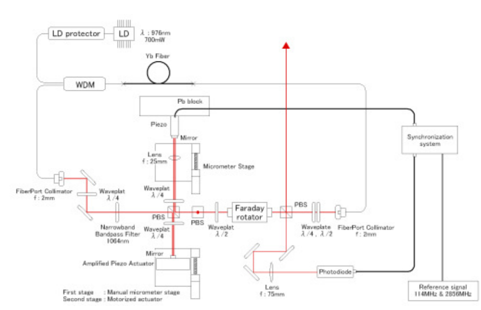

Figure 2: ANDi type Oscillator.

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The Yb-doped fiber oscillator was stable with good pulse quality and stability. But the noise signal was generated easily for unwanted modifications in signal processing. Then the oscillator was restructured. The need to compensate group-delay dispersion (GDD) is ubiquitous in femtosecond pulse oscillator. Also, a pair of diffraction gratings have been used to compensate the GDD in our old oscillator structure. The oscillator cavity have segments of normal and anomalous GDD. Pulse formation and pulse evolution become more complex as the cavity GDD approaches zero.

An Yb-doped fiber oscillator with a cavity consisting only of elements with normal GDD was described. By increasing the nonlinear phase shift accumulated by the pulse and inserting a spectral filter in the cavity, self-amplitude modulation via spectral filtering is enhanced. The pulse duration and chirp decrease in the spectral filter. The resulting spectral broadening is balanced by gain narrowing. By cutting off the wings of the spectrum, gain dispersion shapes the temporal profile of the chirped pulse. Although, the gain spectrum is limited, the stable pulse trains can even be produced without dispersion compensation.

As the Fig. 2, a spectral bandpass filter is inset into the cavity. The beam reflects or transmits the polarizer beam splitter (PBS) controlled by wave plates. Two piezoelectric transducer (PZT) is used to control the cavity length locking the repletion rate with the accelerator trigger by a synchronization system. The repetition rate of oscillators are 114.24 MHz (10.38*11 MHz) with the pulse energy of 0.2 nJ.

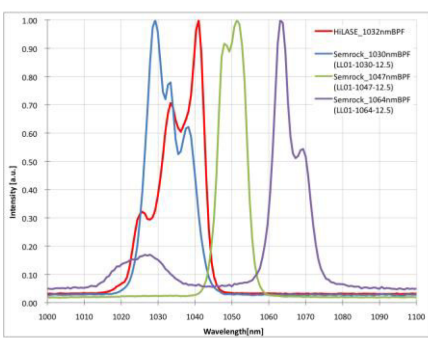

Figure 3: The spectrum of the oscillators.

The spectral filter of variable center wavelength was incorporated in the cavity. The spectrum of the output signal pulses is show in Fig. 3. Then two ANDi type oscillators was employed to generate the seed pulses with the center wavelength of 1030 and 1064 nm respectively. And a commercial fiber oscillator that produce from Menlosystems was also import. The spectral range is cover from 1025 to 1050 nm.

The three oscillators are set with different polarizations that combine by two PBS. The polarization of the each oscillators were controlled by wave plates.

Grating Stretcher

The grating-pair is the cleanest method to stretch a pulse by introducing dispersion. The dispersion is controlled by the effective distance between the second grating and the image of the first grating. For matching the gain area of Yb:YAG (2 nm bandwidth at 1030nm center wavelength) and Nd:YAG (0.2 nm bandwidth at 1064nm center wavelength) crystal, two spatial slit were performed for spectral shaping between the grating pair and reflector, where the spectrum is spatially separated with a parallel beam(as Fig. 4). The pair of transmission gratings with a groove density of 1740 grooves/mm is used to stretch the pulse to several tens ps.

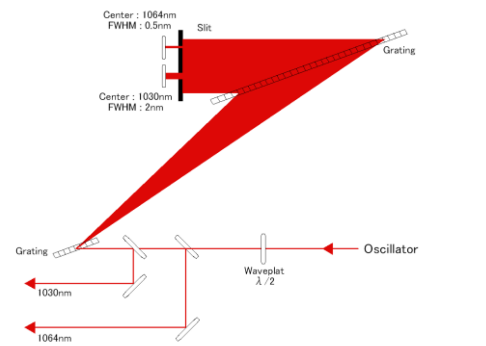

Figure 4: Grating stretcher

For 1030 and 1064 nm pulses, the spectrum width is different, which result the distance of two gratings is not match. Since the 1030 nm and 1064 nm seed pulses with the different diffraction angle at the first grating, the two seed pulses can be separated and stretched with two second gratings respectively.

SOA Pulse Picker and Yb Single Mode Fiber Amp

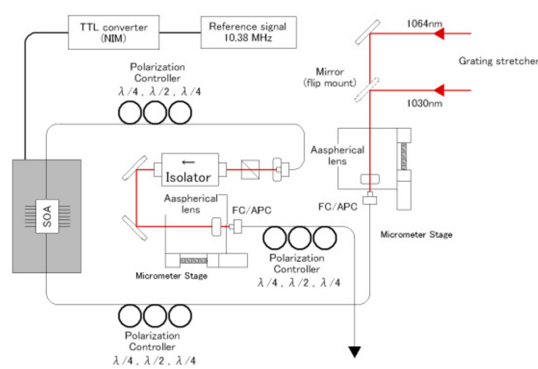

Figure 5: SOA pulse picker

SOA is amplifiers which use a semiconductor to provide the gain medium, is very promising in all-optical signal processing because they are compact, easy to manufacture and power efficient. The structure is similar to laser diodes but with anti-reflection design elements. The salient feature of the SOA pulse picker is that the selected pulses were amplified to compensate for the loss arising from the fiber coupling.

As the Fig. 5, the SOA inside after the stretcher, was used as the pulse picker and was pulse biased to reduce the repetition rate from 114 MHz down to 10.38 MHz. The pulse picker was driven by a ~5 ns 100 mV electrical pulse

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at 10.38MHz amplified through a high power RF amplifier. By SOA stage, the average power of the 1030 nm and 1064 nm signals were increased from 330 µW to 400 µW and from 250 µW to 710 µW respectively.

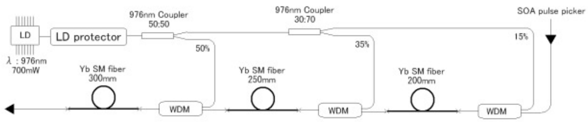

Figure 6:Yb single mode fiber amplifier

In the low power amplification, single-mode Yb-doped fiber with the core diameter 4 µm was coupled with the 976 nm laser diode (LD) pump by a wavelength-division multiplexing (WDM) coupler same as the oscillator, which compact the construction. Because the amplified spontaneous emission (ASE) easy to be generated. The ASE noise will be amplified with the weak seed pulse during each amplifier. For increase the seed pulse amplify effectively, one LD was separated to 3 parts by fiber coupler with the pump power of 15%, 35%, 50%, respectively. Seed pulse was amplified step by step (As Fig. 6). All the 3 amplifiers were coupled each other with no free space.

Grating Pair for ASE Remove at 1064 nm

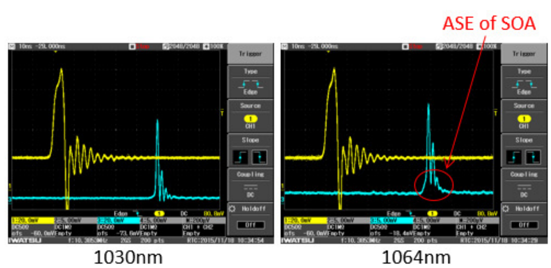

Figure 7: The pulse shape after the SOA

After the grating stretcher and the SOA pulse picker, the optical pulse with time duration of ~30ps is separate two parts with center wavelength of 1030 and 1064 nm. As the Fig. 7, the ASE noise added to the signal during the SOA amplification by 1064 nm. Fortunately, the wavelength of the noise signal is around 1030 nm. Therefore an additional transmission grating was used to separate the noise. The noise signal was cute by a slit after grating pair (Fig. 8).

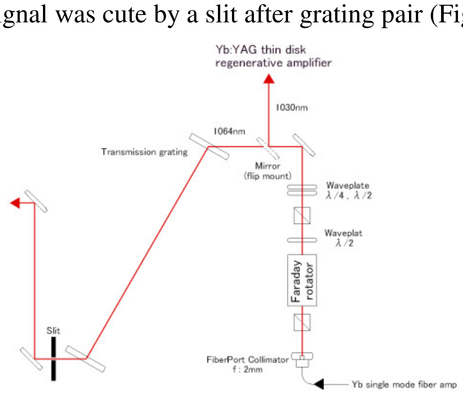

Figure 8: Grating pair for ASE remove

Yb-doped Double Clad Fiber Amplifier (1064 nm)

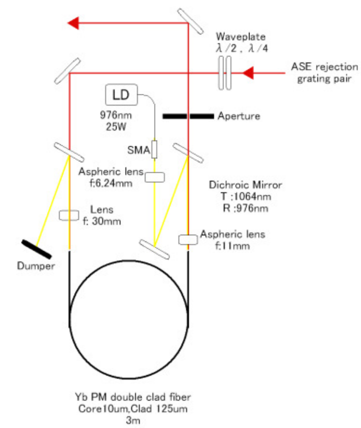

Figure 9: Double clad fiber amplifier by 1064 nm

To compensate the energy lose in the grating pair, the output of grating pair is seeded into the fiber amplifier by an Yb-doped polarization-maintain (PM) double clad fiber of 3.0 m. The core diameter and inner clad diameter of fiber are 10 µm and 125 µm, cladding backwardly pumped by a 4 W fiber-coupled laser diode emitting at 976 nm. The output power of 1064 nm signal was up to 1.0 W (Figure 9).

A pulse picker with an EO modulator was employed to reduce the pulse repetition rate.

IN THE FURTURE

For low-energy sub-µJ pulse amplification, regenerative amplifier system is a good selection. In regenerative amplifiers with low input seed energy, a large number of round trips are required to reach energy saturation. Especially, for 1030 nm Yb:YAG thin-disk amplification, because of low gain per reflection at the thin disk, the regenerative amplifier is the most suitable amplifier concepts.

Next, 1030 nm and 1064 nm parts inject into Yb:YAG thin-disk regenerative amplifier and a Nd:YAG rod regenerative amplifier respectively.

CONCULUTION

For SuperKEKB project, to obtain the 50 Hz, mJ-class pulse energy, a hybrid solid laser is developed. After an ANDi type Yb-doped fiber oscillator and fiber amplifier, the signal pulses were separated to two parts with the center wavelength of 1030nm and 1064nm. An Yb:YAG thin-disk regenerative solid-state amplifier and a Nd:YAG rod regenerative solid-state amplifier were employed. Now, the fiber part structure is finished.

REFERENCES

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