DRIVE LASER SYSTEM FOR THE DC-SRF PHOTOINJECTOR AT PEKING UNIVERSITY

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Abstract

The DC-SRF photoinjector, developed at Peking University, uses Cs_2Te as the photocathode and accordingly 266 nm laser is used as the drive laser. A drive laser system，which includes a 1064 nm laser oscillator, a four-stage amplifier, and second and fourth harmonic generators, has been designed and applied successfully. To avoid the high average current electron beam from hitting the vacuum tube and causing safety problems, a laser pulse selector with an EO modulator has been designed and included into the laser drive system to reduce the repetition rate of electron pulses during the DC-SRF photoinjector commissioning. It can adjust the repetition rate of laser pulses from 81.25 kHz to 81.25 MHz. In this paper, we introduce the drive laser system and describe the laser pulse selector in detail.

INTRODUCTION

Photoinjectors, which can produce electron bunches with high brightness, is widely applied to many accelerators as the electron source [1]. Recently, an upgraded 3.5-cell DC-SRF photoinjector, with the combination of a DC pierce gun and a superconducting radio frequency (SRF) cavity, has been developed at Peking University [2]. The DC-SRF photoinjector can deliver MHz repetition rate, picosecond electron bunches with the energy around 3 MeV, bunch charge between 6 – 50 pC, and emittance below 2 mm-mrad. This photoinjector has been in operation since 2014 and used to generate THz undulator radiation [3]. The average electron beam current has reached 1 mA and can be kept at about 0.5 mA for routine operation [4].

In the DC-SRF photoinjector, 266 nm UV laser pulse is used to illuminate the Cs_2Te cathode to produce electron bunches. To meet the requirements of the DC-SRF photoinjector, a drive laser system, which consists of 1064-nm laser oscillator, four-stage amplifier, second and fourth harmonic generators, RF synchronizer, and transport optics, was designed and built [5]. Some important characteristics of electron beam, such as the repetition rate and pulse charge, are directly determined by the drive laser pulses. The repetition rate of the laser oscillator is 81.25 MHz, which is one 16th of the radio frequency of the DC-SRF photoinjector. To avoid the high average current electron beam from hitting the vacuum tube and causing safety problems, the repetition rate of electron bunches should be decreased to a much lower level during beam commissioning. Consequently, the repetition rate of drive laser pulses should be reduced to hundreds kHz or even lower, which can’t be realized by only using a mechanical shutter. Therefore, we have designed and built a laser pulse selector based on electro-optic (EO) modulator. In this paper, we introduce the drive laser system first and then describe the laser pulse selector in detail.

DRIVE LASER SYSTEM FOR THE DC-SRF PHOTOINJECTOR

The primary parameters of this drive laser system are determined considering the requirements of the DC-SRF photoinjector. In general, the maximum quantum efficiency (Q.E) of Cs_2Te is around 10%. With the UV transport loss and practical Q.E decay in operation, a UV laser with the average power of at least 0.5 W is needed to generate electron beam with the average current above 1 mA.

Since many commercially available picosecond laser oscillators operate in the infrared (IR) wavelength region, the 1064 nm laser oscillator used for the 1.5-cell DC-SRF photoinjector before [6,7] is still adopted for the new drive laser system. A schematic layout of this new drive laser system is shown in Fig.1, which mainly consists of the 1064 nm laser oscillator, four-stage amplifier, second and fourth harmonic generator system, RF synchronizer, and UV laser transport optics.

The 1064 nm laser from the oscillator has a repetition rate of 81.25 MHz and a nearly Gaussian temporal profile with a FWHM of 10 ps. The RF synchronizer is used to synchronize the electron bunches to the RF field in the 3.5-cell SRF cavity of the DC-SRF photoinjector with a time jitter of less than 0.5 ps. An isolator module, composed by a Faraday rotator and two PBS cubes, is applied to prevent the laser from reflecting back into the oscillator and causing disturbances.

The amplifier is configured as four single-pass, single-end-pumped stages to obtain high power and high quality laser output. The average power of 1064 nm laser from the oscillator, about 8 W, can be amplified to 45 W with an instability of less than 1% by this four-stage amplifier.

After amplification, the harmonic generators convert the 1064nm laser into 266 nm laser. LBO and BBO crystals are chosen for second and fourth harmonic generation, respectively, since they are non-critically phase-matched and have high damage threshold and high conversion efficiency. The power of 532 nm green laser generated in LBO is 15W. To reduce the walk-off effect in BBO, walk-off compensation optics is used for fourth harmonic generation, where two BBO crystals having the same cut and length are arranged with the crystal optic axes in alternating directions. 266 nm laser with an average power of close to 1 W is generated in the fourth harmonic

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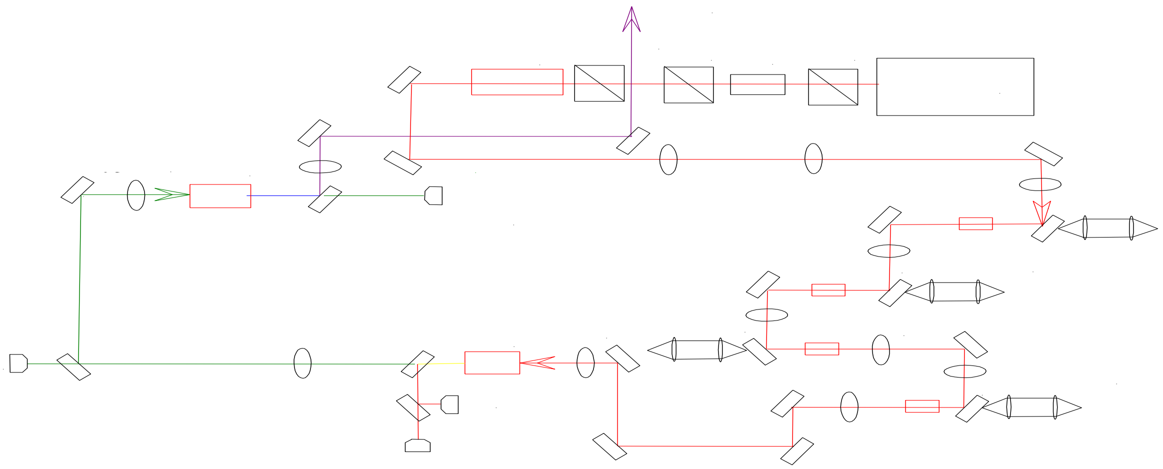

Figure 1: Schematic layout of the drive laser system for the DC-SRF photoinjector.

generator with a long-term instability of less than 5%. By using walk-off compensation optics, the 266 nm UV laser beam profile has been improved significantly compared to that of using a single BBO.

The 266 nm laser is finally transported by a distance of about 10 meters to the photocathode of the DC-SRF photoinjector. The pointing instability of 266nm laser beam, measured using a beam profiler, was less than 10 μrad(rms) in both horizontal and vertical directions.

LASER PULSE SELECTOR

The main components of the laser pulse selector are an EO modulator, a power amplifier and a synchronous divider. In our driver laser optics, the EO modulator is installed between the 1064nm laser oscillator and the four-stage amplifier considering the moderate laser power after the laser oscillator and the extra bonus introduced by the harmonic generators to improve the extinction ratio of the drive laser.

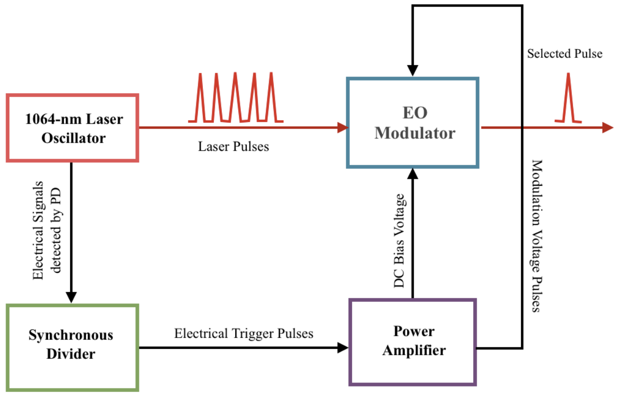

Figure 2: Schematic diagram of the laser pulse selector.

The Model 360-80 LTA modulator of Conoptics is adopted for our laser pulse selector, which is controlled by the Model 305 synchronous divider and Model 25D power amplifier from Conoptics. The EO modulator consists of an EO crystal and an output polarizer [8,9]. Electrical signal generated by a high-speed photo-detector sampling the laser pulses in the laser oscillator is used as the input signal for the synchronous divider (see Fig.2). The synchronous divider outputs electrical trigger pulse locked in time with the oscillator laser pulse. The trigger rate is 1/N of the repetition rate of the oscillator laser pulse, where N can be adjusted from 1 ~ 10^6. After being amplified by a power amplifier, the output electrical trigger is applied to the EO modulator as modulation voltage pulse to select the laser pulse passing through EO modulator. A DC bias voltage provided by the power amplifier is also exerted to the EO modulator to properly position the quiescent operating point on the transfer function of EO modulator. The EO modulator has an extinction ratio of about 100:1. Its transmittance for the 1064 nm laser is about 85%. The insertion loss is mainly due to absorption, crystal cut and antireflection coatings.

The repetition rate of laser pulses can be changed from 81.25 KHz to 81.25 MHz, satisfying the commissioning and operation requirements of the DC-SRF photoinjector. Figure 3 and 4 show the 1064 nm laser signals with the repetition rate of 81.25 MHz (CW laser) and 16.25 MHz, respectively. The amplitude signal of the abandoned laser pulses is overwhelmed by background noise (see Fig.4).

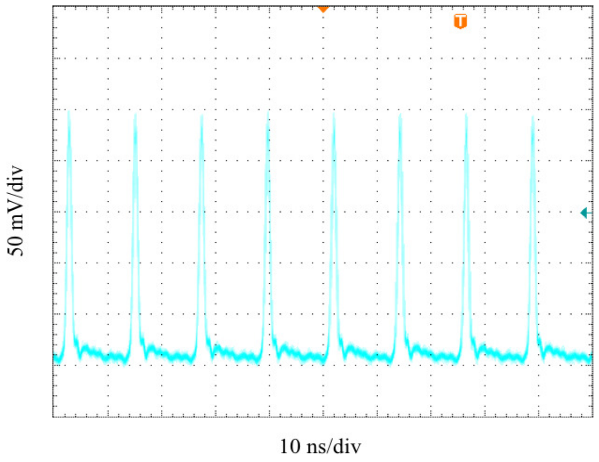

Figure 3: Signals of 1064 nm laser pulses with the repetition rate of 81.25 MHz.

In the above configuration, pulse energy of the 532 nm laser after the second harmonic generator and the 266 nm laser after the fourth harmonic generator does not keep the same while adjusting the laser pulse repetition rate using the laser pulse selector. Figure 5 shows that the 532 nm laser pulse energy increases significantly when the repetition rate of laser pulse is decreased from 81.25 MHz to 1 MHz. The pulse energy at 1 MHz is nearly 3.5 times of that at 81.25 MHz. As the laser repetition rate gets lower than 1 MHz, there is only little change with the laser pulse energy when the repetition rate varies. Further investigation shows that, as the repetition rate varies, the 1064 nm laser power before the four-stage amplifier changes linearly, while both the pulse energy of 1064 nm laser at the exit of the four stage amplifier and the 266 nm laser have the similar changing trend as that of the 532 nm laser.

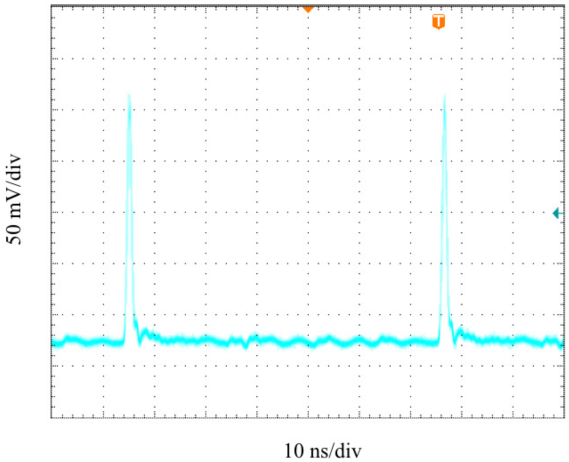

Figure 4: Signals of 1064 nm laser pulses with the repetition rate of 16.25 MHz.

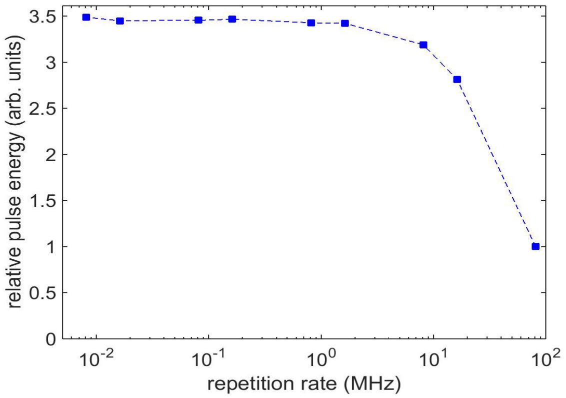

Figure 5: Relative pulse energy of 532 nm laser as a function of repetition rate of laser pulse.

The above phenomenon is related to the change of the number of excited electrons in the amplifying crystals. As the repetition rate of the incident laser decreases, there will be more electrons accumulated at the excited state in the four-stage amplifying crystals for stimulated emission. Therefore，the 1064 nm laser gains more energy during amplification, and consequently, the pulse energy of the 532 nm and 266 nm laser become larger. For the DC-SRF photoinjector commissioning, it is expected that the charge of electron bunches would be kept unchanged while reducing the its repetition rate. As a result, the pulse energy of 266 nm laser should keep unchanged as its repetition rate varies. This can be realized with combined adjusting of the repetition rate and the pump laser power in the four-stage amplifier.

The amplification efficiency increase of the four-stage amplifier at lower laser repetition rate is also very useful in those cases when the electron beam with lower repetition rate and higher bunch charge is desired. With the DC-SRF photoinjector, for example, by using the laser pulse selector, we can produce 100 kHz to MHz repetition rate electron bunches with the charge at hundred pC level.

CONCLUSION

A 266 nm drive laser system，with the average power close to 1 W and long-term instability better than 5%，has been built for the DC-SRF photoinjector at Peking University. It has good performance during the recent operation of the DC-SRF photoinjector. A laser pulse selector has also been included in the drive laser system for adjusting the repetition rate of electron pulse from 81.25 kHz to 81.25 MHz. It can also help to produce electron bunches with higher bunch charge at lower repetition rate.

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