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A phase stabilized and pulse shaped Ti:Sapphire oscillator-amplifier laser system for the LCLS rf photo-injector.

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Abstract

We have designed a laser system for the Linac Coherent Light Source rf photoinjector consisting of a Ti:Sapphire oscillator and 2 amplifiers using Chirped Pulse Amplification. The output after tripling will be 0.5 mJ tunable UV pulses at 120 Hz, with wavelength around 260 nm, pulsewidth of 10 ps FWHM and 200 fs rise and fall times. Amplitude stability is expected to be 1% rms in the UV and timing jitter better than 500 fs rms.

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We have designed a laser system for the Linac Coherent Light Source rf photoinjector consisting of a Ti:Sapphire oscillator and 2 amplifiers using Chirped Pulse Amplification. The output after tripling will be 0.5 mJ tunable UV pulses at 120 Hz, with wavelength around 260 nm, pulsewidth of 10 ps FWHM and 200 fs rise and fall times. Amplitude stability is expected to be 1% rms in the UV and timing jitter better than 500 fs rms.

1. Introduction

We report on the design of a laser system at the Stanford Linear Accelerator Center (SLAC) for the Linac Coherent Light Source (LCLS) rf photoinjector. The LCLS is a future free electron laser (FEL) in the 1-Angstrom wavelength regime, in which a 15 GeV electron beam is compressed by two magnetic chicanes to a length of 50 μm and exits the rf photoinjector with a nominal 1 nC of charge and a very low normalized emittance of 1π mm-mrad rms[1]. The repetition rate of the beam will be 120 Hz, initially with a single bunch initially but the laser system is designed for possible future multiple-bunch operation.

The rf photocathode electron gun employs a copper photocathode in the current design; consequently the laser wavelength must be near 260 nm to exceed the work function of copper. Also, to minimize the contribution of the thermionic electron emission from the cathode surface while at the same time optimizing the quantum efficiency (QE), the laser wavelength should be tunable around 260 nm.

The process of electron beam compression at the magnetic chicanes is very sensitive to electron-beam intensity jitter, and pulsewidth and timing stability. In order to avoid non-linear effects the laser amplitude stability must be 1% in the UV. Also, simulations of beam transport in the Linac indicate that a timing jitter in the electron beam of 1 (2) ps rms will lead to a 20% (40%) emittance growth. We thus aim for timing stability better than 500 fs rms. Both the amplitude and timing stability requirements are state of the art for similar laser systems and are addressed in the current design. A schematic of the laser is shown in Fig.1.

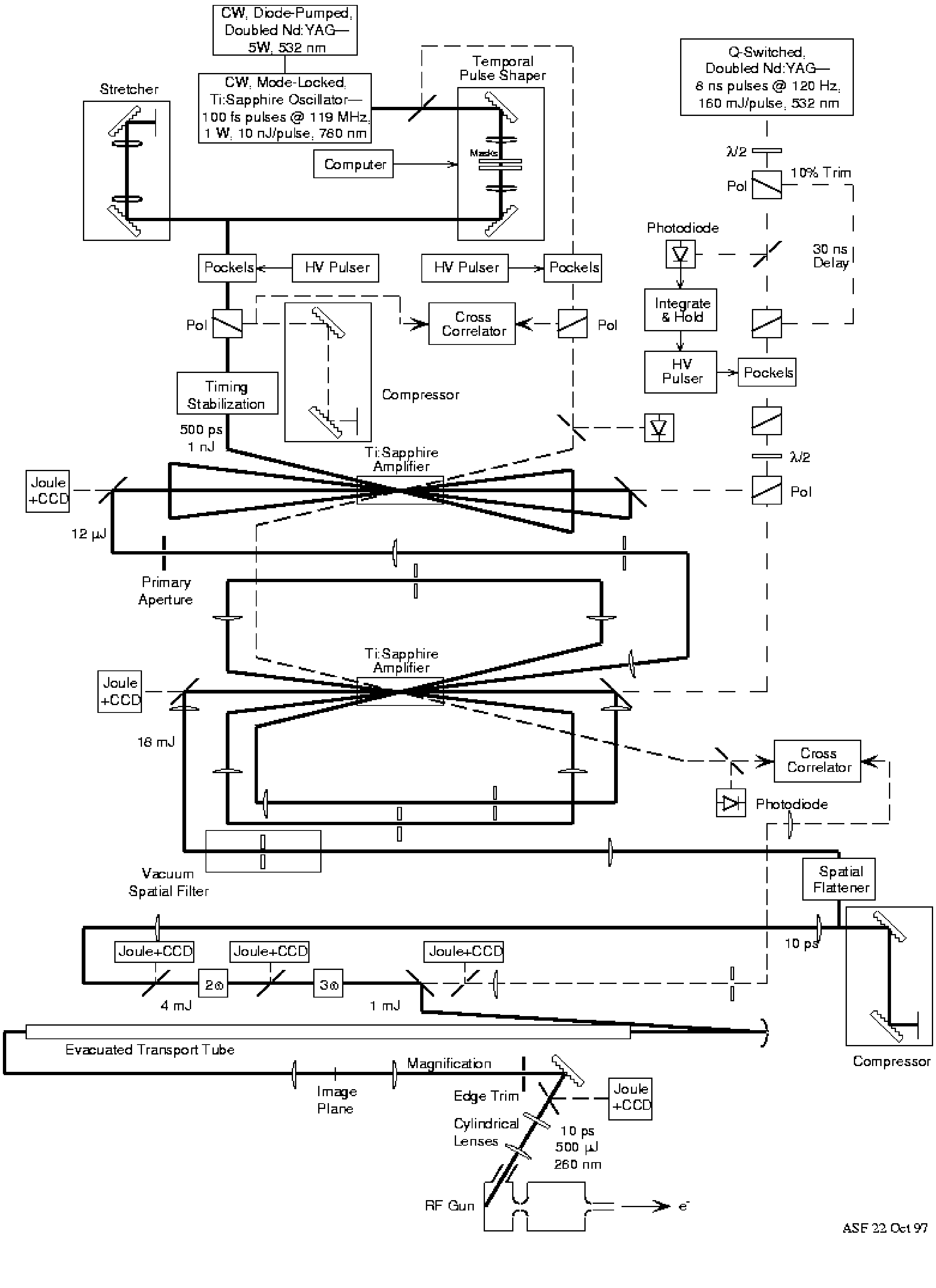

Figure 1. LCLS source laser system.

2. Laser oscillator and amplifier chain

The laser system consists of a Ti:Sapphire oscillator, pumped by a CW diode-pumped doubled Nd:YAG laser, and two 4-pass Ti:Sapphire amplifiers, pumped by a flashlamp-pumped amplitude-stabilized Q-switched doubled Nd:YAG. The system makes use of chirped pulse amplification (CPA) and is designed for a repetition rate of 120 Hz. The laser produces 0.5 mJ pulses, tunable around 260 nm after frequency tripling. The pulse duration is 10 ps FWHM with 200 fs rise and fall times. The pulse will be shaped in time to optimize the emittance of the electron beam in the injector or downstream in the accelerator[2, 3.] The technique uses commercial computer-controlled Liquid Crystal Display (LCD) amplitude and phase masks in the Fourier plane of a double-grating system to control the pulse's Fourier transform. Spatial pulse shaping to produce a flat transverse profile on the cathode involves both apertures using Fourier relay imaging and a 2-D amplitude LCD mask that could be computer controlled. The latter can also shape the pulse at the 10% level in order to account for photocathode non-uniformity. The ~780 nm pulses will frequency tripled to ~260 nm in a pair of BBO crystals using a Type II – Type II tripling scheme. Frequency conversion efficiencies in excess of 50% have been achieved with such a scheme at the 1μm input wavelength with KDP crystals[4].

The energy budget of the laser system, beginning with the 18 mJ after the second amplifier, is as follows: transmission through the spatial flattener ~50%, through the compressor ~50%, through the frequency tripling stage ~25%, and through the optical transport to the gun~50%. Consequently the required 500μJ is delivered to the cathode.

Since the laser pulse hits the photocathode at grazing incidence, cylindrical lenses are needed to circularize the spot. Also, the slew in arrival time across the laser pulse will be corrected by a grating. To control the distribution of space charge in the gun for optimal emittance, the laser will maintain a 1% variation in the diameter of the laser spot on the cathode, with a centroid location variation also below 1%. These will be achieved by trimming the edge of the spatially flattened pulse with a circular aperture at the final relay plane before the gun. This aperture is then imaged to the cathode.

3. Timing stability

Current state-of-the-art timing jitter between a relativistic electron beam and an ultrafast laser in similar photoinjectors and in high-energy physics experiments is of the order of 2 ps rms. The LCLS laser will be phase stabilized to the accelerator's rf with an rms timing jitter of 0.5 ps using the timing system of Fig. 2.

First, we measure the laser oscillator's output phase with respect to the accelerator's rf phase. The phase error signal is used to drive a piezoelectric stage on which the end mirror of the laser oscillator is mounted. The oscillator incorporates a passive modelocker (Kerr lens or Fabry-Perot saturable absorber), while the lock to the external rf reference is done by tuning the length of the oscillator cavity. The bandwidth of the method is in the kilohertz range.

Additional timing stabilization is then applied external to the laser oscillator. A prism is mounted on a stage incorporating a combination of a piezo and a fast motor, which acts as a delay for the laser oscillator pulses in order to correct the long term timing drifts. As shown in the figure this delay system uses the same phase error signal as the piezo stage internal to the oscillator, but it could also use the measured phase error signal of either the electrons or the laser with respect to the rf. The piezo and motor will be computer controlled and would account for all the slow drifts in the laser optical path length or timing drifts in the rf system.

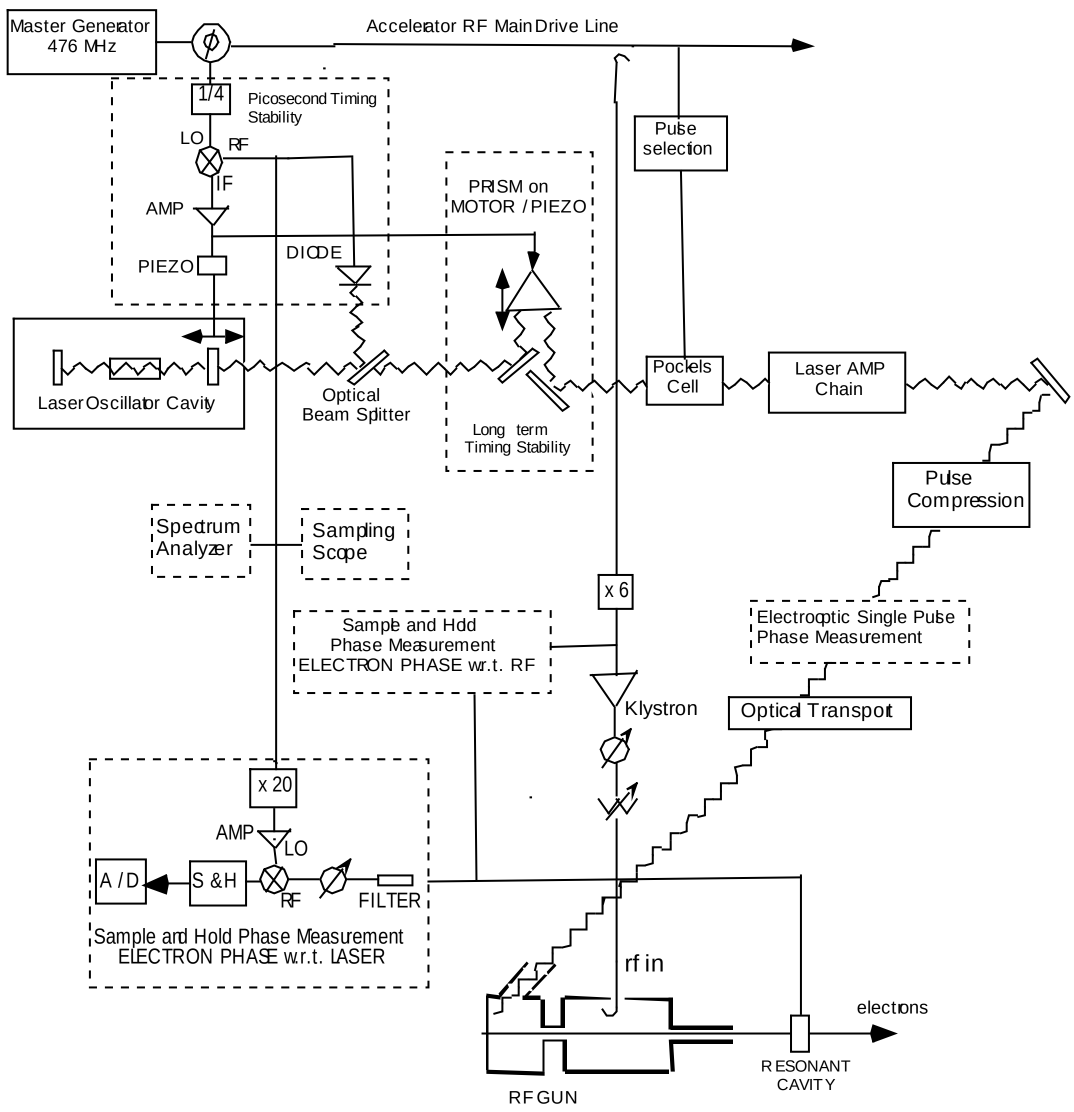

Figure 2. Timing system.

4. Amplitude stability

The laser is designed for an amplitude stability of 1% rms in the UV, a requirement set by the stability of the FEL output. Harmonic generation compounds the difficulty since 1% stability in 3^{rd} harmonic requires a 0.3% in the fundamental, i.e., at 780 nm. We plan to stabilize the Ti:Sapphire oscillator by pumping with a diode-pumped doubled YAG. Also, Fourier relay imaging of the laser beam through the amplifier chain is intended to control the pointing stability and spatial mode of the laser beam and consequently the gain of the laser pulse. The amplifier pump must be kept as stable as possible, and in the current design this is achieved by a combination of feedback loops. First we plan to make use of the relatively long upper-state lifetime of the Ti:Sapphire (3.2 μs) to keep the total pump energy constant on a pulse-by-pulse basis. To accomplish this, 10% of the pump energy will be delayed by a 30 ns optical path (necessary to adjust the HV of the Pockels cell) and used to trim the pumping of the Ti:Sapphire for a given pulse by up to $\pm 5\%$. To correct for long term drift in the UV pulse energy as monitored at the gun, a software feedback loop will adjust the set point in the primary feedback loop that stabilizes the pump energy. Finally, the second amplifier will be operated into saturation in order to achieve the amplitude stability required. We are also investigating an alternative design for a single mode, longer pulse (~1μs) system to pump the amplifiers. Longer pulsewidth allows us to stop pumping after precisely the desired pump energy is provided to the Ti:Sapphire amplifiers, so that we can achieve 0.3% intensity jitter.

5. Diagnostics

We have included in the laser design various diagnostics as seen in Fig.1. Laser pulse energy monitoring is done with joulemeters and calibrated photodiodes throughout the system. Also a diagnostic pulse from the oscillator measures the gain of the amplifiers. The temporal pulse width and shape is diagnosed in both the IR and the UV. In the UV we will use a single shot polarization-gating cross-correlator with a Kerr medium [5]. Timing stability is done both at the output of the laser oscillator and downstream, producing measurements of the rf vs. laser, rf vs. electrons and laser vs. electrons. Monitoring of the pointing and the spatial shape is done using a CCD camera, which images the profile of the laser spot on the photocathode.

6. References

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