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Yb DOPED HIGH-ENERGY UV ULTRAFAST LASER FOR AREAL FACILITY

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Abstract

For electron generation from photocathode the new laser system was developed for the AREAL linear accelerator laboratory. Besides generating electrons using the laser, we plan to provide a laser beam for other experimental stations running in parallel. The performance and capabilities of the laser system including operating frequency, electron generation in multi-bunch regime and other advantages are presented. The outlooks and steps for further upgrade are discussed.

INTRODUCTION

Advanced Research Electron Accelerator Laboratory (AREAL) is a 20 MeV laser driven RF linear accelerator [1] for the generation and acceleration of ultrashort electron bunches with small transverse emittances. The design specification of the facility implies the usage of the metal type photocathode and ultrafast UV laser.

The Yb doped high energy UV ultrafast laser for AREAL facility has been developed by the Amplitude Systèmes (France) [4]. The laser system is capable to provide about 200 µJ energy at 258 nm wavelength with pulse duration 0.5-9 psec.

The construction of the AREAL [2] is divided into two phases. In the first phase the RF gun with photocathode provides low emittance electron beam in single bunch mode with a charge of >120 pC and energy <5 MeV. In this phase the electron diffraction experiments will be conducted using ultrashort electron bunches.

The operating frequency of the electron gun is defined by the RF station pulse repetition rate, which is functioning in range of 1-50 Hz with 1 Hz steps. The laser system can operate up to 100 Hz, opening experimental possibilities for using laser beam in parasite mode. A compact layout of the laser system at the optical table allows adding more optical elements for splitting, configuring and redirecting the laser beam and conducting online measurements.

LASER SYSTEM

The laser system consists of t-Pulse Oscillator, s-Pulse HP^2 Amplifier, pulse splitter (multi-bunch) module, fourth harmonic generator (FHG) module, control electronics and Synchrolock module for laser to Master Oscillator (MO) synchronization. The Synchrolock module was developed according to MO specifications. The layout of the laser system is schematically illustrated in Fig. 1.

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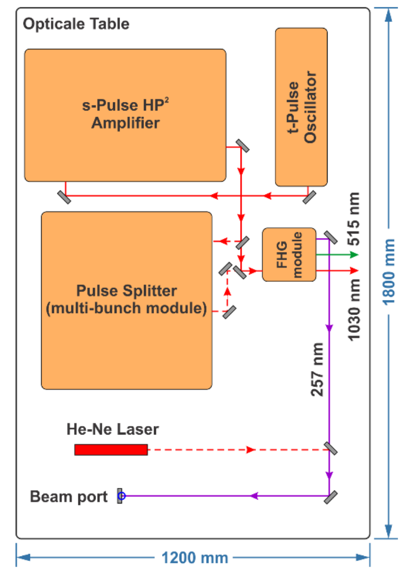

Figure 1: Schematic layout of the laser system on the optical table. The beam after amplifier can be easily switched between single bunch and multi-bunch regime. The He-Ne red laser beam serves as a guide to easily align and check the optical path of the UV beam.

Oscillator

The t-Pulse is a diode pumped femtosecond laser oscillator with Ytterbium doped gain material. Compared to Titanium:Sapphire lasers it doesn't need the pump laser. The oscillator pulse repetition rate is a sub-harmonic of MO main frequency and has an ability to be synchronized with Synchrolock module. Only 25% of oscillator power is necessary to seed the amplifier. The remaining power will be used for satellite experiments. The main parameters of oscillator laser beam are presented in Table 1.

Table 1: t-Pulse Oscillator Specifications

Parameter	Measurement
Central wavelength	1030 nm
Pulse repetition rate	49.9654 MHz
Energy per pulse	20 nJ
Pulse width FWHM	237 fs
Beam quality M^2	< 1.1
Beam divergence	1.3 mrad

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Figure 2 presents the measured laser beam transverse profile of t-Pulse oscillator.

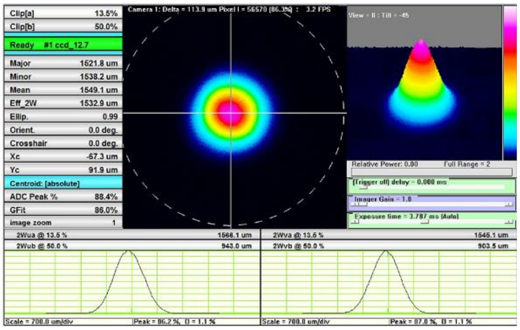

Figure 2: Transverse beam profile of t-Pulse oscillator.

Amplifier

s-Pulse HP^2 is a femtosecond regenerative amplifier with CW diode pumping. The gain material is Yb:KGW. The pulse repetition rate and pulse duration are tuneable in a wide range. The repetition rate has two synchronization mode: internal and external. The main parameters of the beam are presented in Table 2. Figure 3 presents UV beam transverse profile obtained at the AREAL site.

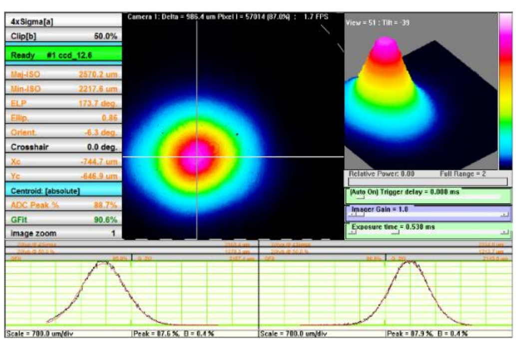

Figure 3: Measured transverse profile of UV beam with 260 µJ energy and 8.5ps pulse duration.

Table 2: s-Pulse HP^2 Regenerative Amplifier Specifications

Parameter	**Measurement**
Central wavelength	1030 nm
Pulse repetition rate	1 Hz – 1 kHz
Energy per pulse	2 mJ
Pulse width FWHM	450 fs – 9 ps
Beam quality M^2	< 1.3

Pulse Splitter

The Pulse Splitter module is a complicated optical system which splits each pulse of the amplifier into the train of 16 pulses. The repetition rate within pulse train is equal to repetition rate of the oscillator. The energy is distributed equally in the pulse train and could reach up to 10 µJ per pulse at UV for 500 fs pulse duration.

The installation of the Pulse Splitter is planned in near future. This module will be used for AREAL multi-bunch operation.

Harmonic Generator

The FHG module is a two sets of BBO crystals with dielectric mirrors as a chromatic filters. The optimal conversion efficiency from IR to UV for sub-picosecond pulse duration is 10% (200 µJ at 258nm), but can be optimized at the expense of the beam spot diameter and reach up to 35-40%.

Synchronization

Synchronisation of the laser system is one of the complicated parts of the linear accelerators. The Synchrolock module provides close loop to keep the oscillator’s pulse repetition rate synchronized to MO. The measured accuracy of the synchronized oscillator pulse repetition rate frequency is 1 Hz. The regenerative amplifier takes trigger from oscillator, which keep the whole chain of laser system to be synchronized to MO. Another key point of the synchronization is phase control to correlate electron bunch, generated by laser pulse with accelerating RF field, which was solved due to external trigger mode of amplifier.

The stable synchronisation of oscillator is possible after three hours of cold start. The longest measured synchronisation was three days.

Infrastructure

The laser system is placed in the laser room, which is right above the accelerator tunnel. The room was designed in accordance with specific conditions for high - energy ultrafast lasers. The key demands for such kinds of laboratories are clean air and stable temperature. These two key points are provided by thermally stabilized laminar air flow from air filters placed directly on the top of the optical table. The measured long term temperature stability in laminar flow is ±0.05 °C. The temperature in the laser laboratory is 24 °C.

The laser laboratory has transitional room equipped with necessary tools to keep cleanness and safety in laser laboratory.

Layout

The laser system has small footprint (about 1x1 m) which is very cost effective for local temperature stabilization and provides easy access to different parts of optical layout for alignment and diagnostics. The system is placed on an optical table with passive vibration isolation. The table has beam port which provides direct connection with electron gun optical system through another laser port between the floors. Laser beam alignment system of the electron gun is directly connected to the gun body. This kind of layout is difficult to align, but should help to avoid laser beam pointing instability on

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photocathode. The schematic simplified layout of laser beam path from laser to photocathode is presented in Fig. 4.

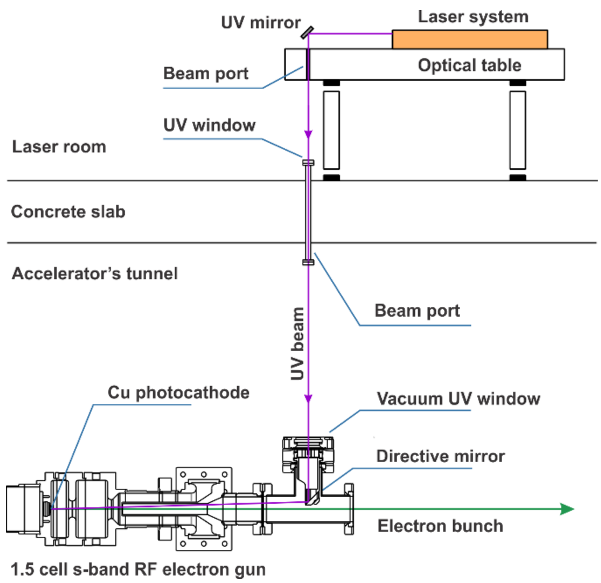
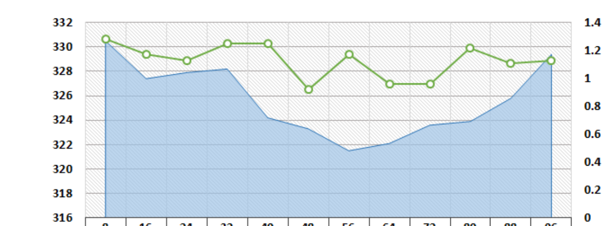


Figure 4: The simplified layout of the entire laser system. The optical layout of the electron gun has alignment system and planned to be equipped with so called virtual photocathode.

Energy Stability

The energy stability of the UV pulses was measured for different pulse durations and repetition rates. The energy stability depends on temperature stability of the laser system, repetition rate and pulse duration. In Fig. 5 is presented pulse energy long term stability measurement results.



	8	16	24	32	40	48	56	64	72	80	88	96
Avr. [uJ]	330.5	327.4	327.9	328.2	324.2	323.3	321.5	322.1	323.6	323.9	325.8	329.4
RMS [%]	1.28	1.17	1.13	1.25	1.25	0.92	1.17	0.96	0.96	1.22	1.11	1.13

Figure 5: The UV pulse energy stability measurement over 4 days at 2 Hz rep. rate with synchronization for 500 fs pulse duration. The data is averaged for each 8 hours.

PHOTOCATHODE

For AREAL linear accelerator we used in-house built photocathodes from oxygen free copper C110, which was processed by mechanical and chemical polishing. In Fig. 6 presented photocathodes and the surface image one of them under metallographic microscope.

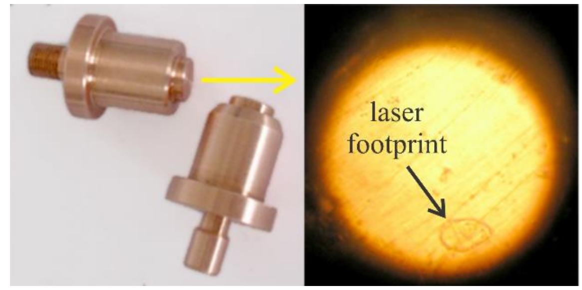


Figure 6: The photo of the AREAL copper photocathode (left side) and the working surface under metallographic microscope (right side).

The photocathode was illuminated by UV laser beam of 258 nm wavelength. According to last measurements we got up to 200 pC electron bunch charge [3].

For future we planned quantum efficiency (QE) measurements (QE map capturing) of our photocathodes, damage threshold determination and study of different polishing techniques in order to get higher number of electrons.

SUMMARY

The main parameters of laser system are measured during the phase-1 of AREAL commissioning. The synchronisation of laser with RF is achieved. The photocathode is fabricated and tested. Electron beam is generated and accelerated up to 5 MeV with small emittance. The accelerator is tested for 1-10 Hz repetition rate, and registered 200 pC/bunch charge with good transverse Gaussian profile.

For near future installation of the Pulse Splitter module is planned which will provide multi-bunch operation for AREAL phase-2. Planned upgrade of optical layout with virtual photocathode will allow us to capture QE map of photocathode and development of new photocathodes. More detailed measurements of laser beam parameters, such as pointing stability, timing jitter are scheduled. The detailed study of laser to RF synchronisation accuracy is in progress.

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