ULTRAFAST BEAM RESEARCH AT THE PEGASUS LABORATORY

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Abstract

The PEGASUS laboratory at the UCLA Physics Department has been recently commissioned as a new advanced photoinjector facility for ultrafast beam research. With a newly installed state-of-the-art Ti:Sa laser driver capable of delivering sub 100 fs UV pulses onto the cathode, the laboratory capabilities have been greatly expanded. The beam charge is low (10 pC) to avoid excessive pulse lengthening. Nevertheless various applications could greatly benefit by this novel regime of operation of an rf photoinjector. We discuss the measurements performed to characterize the system with particular attention to the ones that are peculiar of a low charge sub-ps beam.

INTRODUCTION

The Pegasus laboratory at UCLA pursues a new approach to photoinjector beam physics aimed to fully exploit the recent progress in ultra-short laser physics and techniques which has made commercially available laser systems capable of delivering sub-50 fs pulses. By illuminating the cathode with these ultrashort flashes of light it is possible to generate electron pulses with sub-ps pulse length which have many scientific and industrial applications. Such beams can in fact be used directly for pulsed radiolysis and time resolved electron diffraction to investigate matter at the fastest time scale. They can also be used to generate radiation (from IR to X-ray) with equivalently short time structure or, exploiting the coherent enhancement factor in various radiative processes (e.g. transition or undulator radiation) as high power THz sources. For high energy physics, sources capable of delivering ultrashort beams are required building blocks in future high gradient high frequency advanced accelerators. Laser and plasma structures in fact operate at THz frequencies and beyond so that it becomes necessary to utilize electron beams with characteristic time lengths short compared to the accelerating wave periods.

In this communication we report the results of the commissioning of the photoinjector system showing in detail the measurements which are characteristics of the very short laser pulse illuminating the cathode. A Mg cathode produced by depositing an Mg film on Cu by Pulsed Laser Deposition (PLD) technique was characterized and the results are reported elsewhere in these proceedings [1]. Finally we discuss the experiments that are planned for the near future and the longitudinal diagnostics proposed to be implemented.

PHOTOINJECTOR COMMISSIONING

The PEGASUS (PhotoElectron Generated Amplified Spontaneous Undulator Radiation Source) at UCLA is a compact laboratory constructed explicitly for photoinjectors, high brightness electron beam and radiation (FEL, inverse Compton scattering) production. The facility contains a radiation-shielding bunker with automated door and personnel protection system, control room, RF modulator and klystron (SLAC XK-5, 2856 MHz), and a laser room. At present, the bunker contains the 1.6 cell photoinjector/solenoid and a test beamline with vacuum systems, quadrupole optics, steering magnets, insertable beam profile monitors, and Faraday cup beam charge collector. A technical drawing of the beamline is reported in Fig.1.

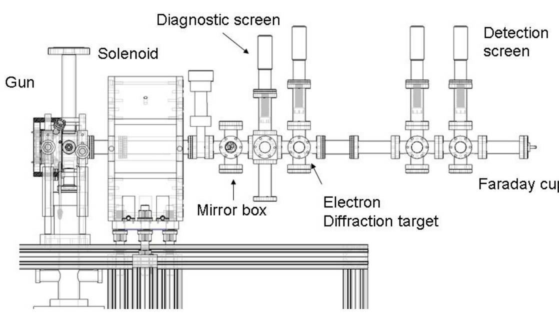

Figure 1: Pegasus beamline layout.

Driver Laser

The photocathode drive laser is a state-of-the-art all diode pumped Titanium:Sapphire based system from Coherent. A 79.33 MHz optical train from the master oscillator synchronized with the RF with an active phase locking loop at a level better than 250 fs seeds a 1 KHz regenerative amplifier. After the final compressor infrared (800 nm) pulses with energy greater than 3 mJ and length less than 35 fs are obtained. The pulse-to-pulse energy fluctuations for the system are less than 1% rms, and the mode quality is particularly good ($M^2 < 1.35$). After a two stage nonlinear harmonic conversion, 266 nm pulses of energy up to 300 μJ can be obtained. The large bandwidth of the Ti:Sa laser medium allows superior flexibility in adjusting the laser pulse length (easily changeable between 50 fs and 5 ps) and time profile as required by different kind of experiments.

A measurement of the laser temporal profile is obtained by a cross correlation technique varying the time delay on the 800 nm arm after the first harmonic generation crystal

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before recombination with the 400 nm light into the tripling crystal. Cross-correlations obtained using two different crystals are reported in Fig.2. The blue curve shows the results for the standard 300 µm long BBO crystal. For the red curve the crystal is 30 µm long. In this configuration the maximum energy in the UV is limited to 20 µJ, but the advantage is that more than 1 mJ of unconverted 800 nm laser pulse is available for other experiments.

Table 1: Drive laser and Photoinjector parameters.

Laser pulse length	30 fs (rms)
Laser energy	0.5 - 300 µJ
Laser spot size	0.1 – 1 mm
E-beam energy	3-5 MeV
E- beam charge	1 – 500 pC

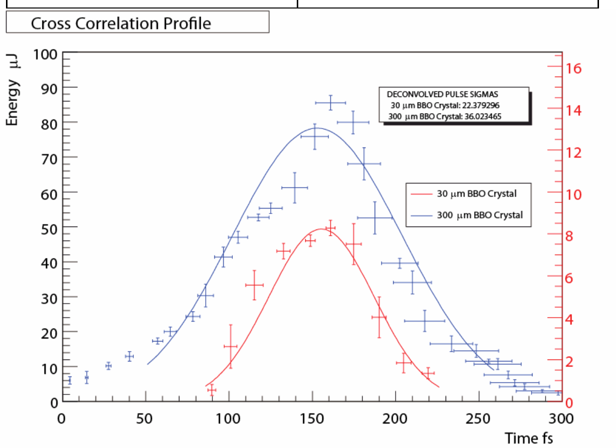

Figure 2: UV cross correlation.

RF gun and solenoid

The photoinjector at PEGASUS uses a version of the UCLA/SLAC/BNL 1.6 cell gun which has recently been retuned, extracting the tuners from the cavity in order to avoid arcing, allowing operation at a high power level (10 MW)[2]. Such levels give peak accelerating fields of 120 MV/m at the cathode. The emittance compensation solenoid, recently obtained from BNL is of the LCLS-design with a octagonal yoke with symmetric apertures to avoid skew quadrupole components [3].

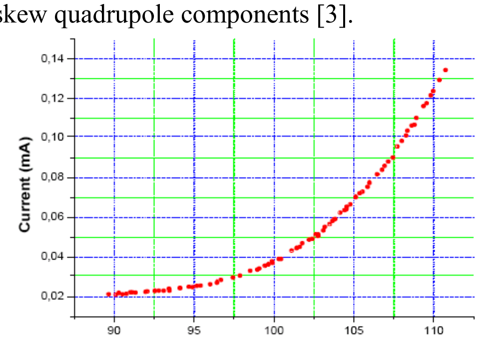

Figure 3: Dark current as a function of gun peak field.

Because the beam charge is intentionally maintained low (< 10 pC) in order to avoid excessive pulse lengthening and generate ultrashort electron beams, it becomes very important to limit the amount of the dark current out of the gun. A measurement of the dark current as a function of the peak accelerating field was performed by reading the signal off a faraday cup at the end of the beam line with no laser on the cathode. The dark current pulse shape resembles as expected the behavior of the field in the gun cavity with a rising time which is given by the gun filling time (~0.8 µs) and a length (in our case 1.5 µs) which can be controlled by varying the rf pulse length. In situations where it is desirable to eliminate the dark current noise one can choose to operate with an even shorter rf pulse and a peak accelerating field below 60 MV/m.

Using the same Faraday cup, illuminating the cathode with the driver laser ultrashort pulses we obtained the measurements of the charge versus injection phase reported in Fig. 4.

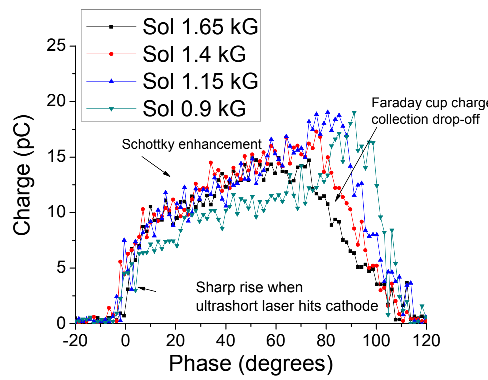

Figure 4: Charge vs phase.

These curves reveal much about the photoinjector. The very fast rise time is further evidence that the cathode is being illuminated by an ultrashort laser pulse. The width of the window in the time of arrival of the laser onto the cathode when a beam is generated by the gun is less than 90 degrees due to the relatively low accelerating gradient. This is confirmed by the dependence on the solenoid field strength of the total width of the curve is due to the energy dependent focusing and charge collection. Due to the low accelerating gradient, the gun output energy is strongly dependent on the launching phase and so for a given magnetic field amplitude only particles of a given energy are well focused and collected by the faraday cup.

MG CATHODE QUANTUM EFFICIENCY

The quantum efficiency of the cathode is measured by correlating the faraday cup charge read out with the input laser energy sampled with a 1 % beam splitter before the laser enters the vacuum chamber. The peak QE is 4.8E-5, but it is immediate to notice that the emission curve has a nonlinear behavior, evidence of oxidation of the Mg cathode surface. A laser cleaning process is expected to improve significantly the cathode electron yield.

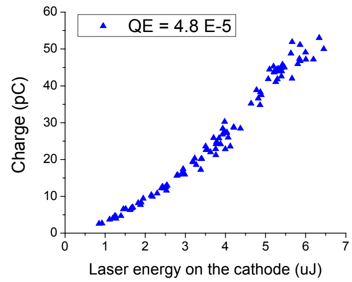

Figure 5: QE measurement.

Thermal emittance measurement

The thermal emittance of the Mg cathode has been measured as a function of the laser spot size. Following the technique reported in [4] we reduced the charge to < 1 pC and for each laser spot rms radius we measured the rms electron beam spot size on the first screen as a function of the solenoid magnetic field amplitude. A thick lens fit yields the emittance values. The results are shown in Fig.6. A linear fit gives the thermal emittance of the Mg cathode

$$\varepsilon_n\left[mm-mrad\right]=0.25+1.01\cdot\sigma_{laser}\left[mm\right] \qquad (1)$$

in good agreement with what already reported in the literature.

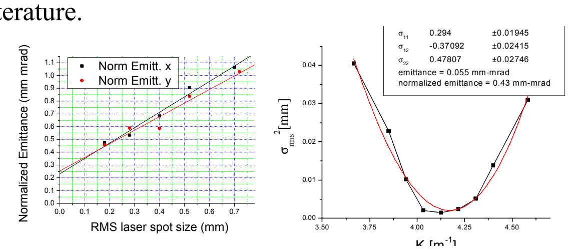

Figure 6: Thermal emittance measurement.

In the future we plan to complete these measurements by tuning the laser oscillator to a different central frequency and investigate the behavior of quantum efficiency and thermal emittance for different photon energies.

INITIAL EXPERIMENTS

One of the first experiments that will be carried out at the Pegasus laboratory is ultrafast electron diffraction. Using the electrons from a photoinjector to probe fast processes in materials has tremendous potential. The number of electrons that can be packed in in a single 100 fs long pulse makes this technique many orders of magnitude superior with respect of conventional state-of-the-art technique which uses sub relativistic electron energies. The possibility to resolve in a single shot fast processes in material science, chemistry and biology [5] is very fascinating. A preliminary image of the Pegasus beam diffracting off a polycrystalline thin Ti film is shown here. The visible ring structures correspond to the Bragg angles and carry information on the interatomic spacing. Conversely, knowing the structural information on the sample inserted in the path, one can extract information about the beam as for example its energy (from the radius of the diffraction rings) and its emittance (from their spread).

With the same experimental layout at the Pegasus lab simply increasing the laser energy on the cathode and hence the electron beam charge we plan to explore the blow-out regime of operation of photoinjectors where the beam inflates under its own space charge forces in a uniformly charge ellipsoid [6].

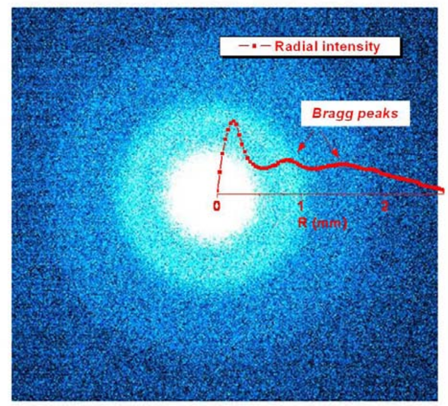

Figure 7: Diffracted beam.

FUTURE DIRECTIONS

An important ingredient in the laboratory plans is to develop advanced longitudinal diagnostics that would help in optimize the electron beam bunch length and quality. An rf deflector is planned to be installed to do time resolved measurements with 100 fs time resolution and allow visualization of the longitudinal phase space. An optical correlation using polarization gating of the Cherenkov radiation by the ultrafast unconverted infrared pulse is also being implemented.

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