APEX PRESENT EXPERIMENTAL RESULTS*

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Abstract

The APEX electron source at LBNL combines high-repetition-rate and high beam brightness typical of photo-guns, delivering low emittance electron pulses at MHz frequency. Proving the high beam quality of the beam is an essential step for the success of the experiment. It would enable high repetition rate operations for brightness-hungry applications such as X-Ray FELs, and MHz ultrafast electron diffraction. A full 6D characterization of the beam phase space at the gun beam energy (750 keV) is foreseen in the first phase of the project. Diagnostics for low and high current measurements have been installed and tested, measuring the performances of different cathode materials in a RF environment with mA average current. A double-slit system allows the characterization of beam emittance at high charge and full current (mA). An rf deflecting cavity is being installed, and a high precision spectrometer allow the characterization of the longitudinal phase space. Here we present the latest results at low and high repetition rate, discussing the tools and techniques used.

INTRODUCTION

The APEX electron gun delivers picosecond electron pulses at MHz repetition rate with a nominal kinetic energy of 750 keV (measured up to 820 keV). The Gun has been commissioned and characterized, and the performances are reported elsewhere [1], such as the project status and future activities [2]. The nominal accelerating field at the cathode is 19.5 MV/m, and the cavity was designed for maintaining a very low vacuum pressure during operations (10^{-10} mbar), an essential condition when using high quantum efficiency cathodes. Both absolute and partial pressure are important for high current operations, as the cathode degradation can be induced both by contamination (especially from water and CO_2) and ion back-bombardment (proportional to extracted current and total pressure). A high accelerating field at the cathode is needed to produce high-brightness high-current beams for driving FELs. The choice of a VHF frequency allows for CW operations without the need of special cooling techniques. Slots can be opened on the sidewalls of the cavity without distorting the field, increasing vacuum conductance toward the surrounding anti-chamber, where 20 NEG pumps are installed. The has been tested and the targeted vacuum level needed by semiconductor cathodes has been achieved [1].

The photoinjector laser [2] is based on a Ytterbium doped fiber oscillator at 37.14 MHz. The oscillator pulses seed a chain of ytterbium-doped fiber amplifiers. The repetition rate is reduced down to 1 MHz during amplification, and at the end of the chain we get about 0.7 W of average IR power, with single pulse length of 700 fs FWHM. The IR beam is then double in frequency, obtaining about 0.3 W of green pulses, and double again, producing 50 mW of UV light. Both UV and green are transported to the APEX gun, to be used with different cathode materials. A Pockels cell system allows to remotely control the laser repetition rate at the cathode, and a pulse shaping system based on pulse stacking via birefringent crystals creates flat top longitudinal profile up to 60 ps long.

Figure 1 shows the present APEX beamline. The 1.3 GHz deflecting cavity has been built and is currently being prepared for installation [2]. A double-slit system for high charge emittance measurement is being commissioned and will be used for transverse phase space mapping. The spectrometer at the end allows for energy measurements with 10^{-5} accuracy.

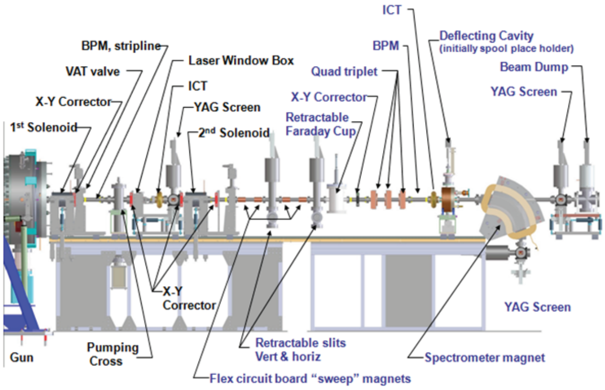

Figure 1: Present APEX layout.

PRESENT RESULTS

Great care has to be taken when designing high repetition rate sources in the characterization and minimization of dark current. High fields in the gun can indeed generate, accelerate and transport unwanted electrons emitted from the cavity wall by field emission from protrusion and/or particulates. When coupled with CW operations, such phenomena creates large amounts of undesired off-axis and off-energy electrons hitting the chamber along the beamline and leading to instrument damage and malfunction. Dark current is therefore a major concern, and must be controlled, and here we report on its characterization in the APEX photogun.

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Cathode performances degrade with time and operations, the quantum efficiency (QE) lowers, and higher laser power is requested for the same electron beam current. Such degradation can be due either to surface contamination and/or back-bombardment. In the following we report initial measurements of QE degradation during high current runs. A full set of measurement will eventually help us understanding the main mechanism degradation.

Lastly, high repetition rate single pass injectors promise an increased beam stability, allowing measurement and suppression of system noise up to half the repetition rate. We have started the characterization of the system and the development of electronics for the measurement of amplitude and phase noise, and will report on the status of this work, the details being discussed elsewhere [3] .

Dark Current Characterization

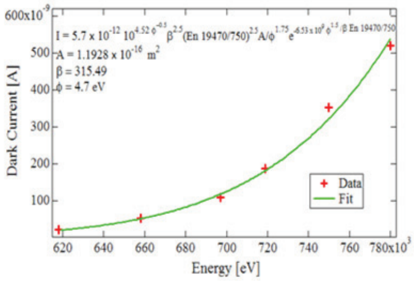

Figure 2: current as function of electron beam energy (proportional to accelerating field in the gun). At the nominal energy the dark current value is 350 nA.

Field emitted current has been measured at APEX in different configurations. While initial measurements carried out with a Faraday cup right in front of the gun exit [1] had given a total emitted current of 8 μA at the nominal accelerating field, measurements at the new faraday cup position along the beamline (about 2.5 meters from the cathode plane) depend on the magnet settings. A maximum transported current of 2.5 μA has been found for the magnet configuration imaging the cathode plane at the faraday cup (similar solenoid configuration that leads to the situation of Fig. 4). Such settings are substantially off the nominal settings for injection in the following linac foreseen in the phase II of the project [2], therefore much of the dark current will not be transported downstream. Figure 2 shows the measurement of dark current as function of output beam energy (proportional to the accelerating field in the gun), using the nominal solenoid fields for optimum transport and injection in the linac. Solenoid values have been scaled with the beam momentum. The dark current measured for nominal beam energy of 750 keV is 350 nA.

In the attempt of better understanding the sources of dark current in the gun, the two solenoidal lenses have been used for imaging the cathode plane on the different screens along the beamline. Figure 3 shows an example of imaging on the viewscreen in the first chamber hosting the slit for emittance measurements. The photoemitted electron beam determines the center of the Cs_2Te deposition area. Most of the source points are arranged in a circle with a radius that has been simulated to be the exact image of the gun aperture rim for cathode placing (inset of Fig. 3).

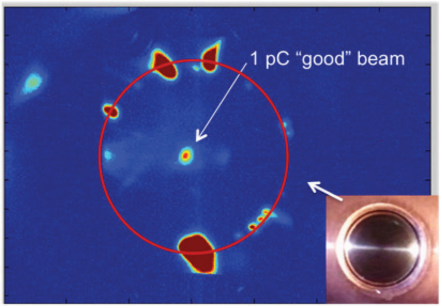

Figure 3: Cathode imaging on the viewscreen at the position of the first emitance-meter slit. The inset shows a picture of the cathode region in the gun. Most of the DC comes from the edges of the round aperture in the gun.

Given the spatial separation between photoemitted beam and dark current sources, collimators can be used in precise position along the beamline to further decrease the dark current transported along the line. Also, different sources can be isolated by collimation and characterized. Fowler-Nordheim (FN) plots of single emitters have been carried out and fitted with the FN formula, leading to of ($\beta/\Phi^{1.5}$) value similar to those found in Fig. 2. One emitter has been selected and transported to the downstream spectrometer for energy profile measurement. Figure 4 reports the energy distribution. By using the FN formula, the time profile and energy profile of the dark current can be retrieved. The black dots in Fig.4 represent the measured energy profile, while the red curve shows the profile calculated by using values for β and Φ found from the measurements in Fig. 2.

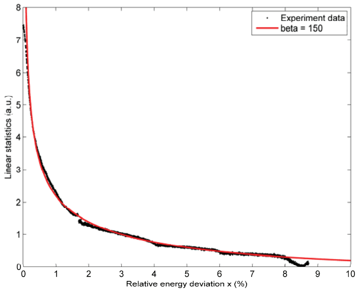

Figure 4: Single emitter energy profile (black dots), and fitting with the FN formula, using values found from measurement in Fig. 2.

Beam Measurements

Thermal emittance on a new Cs_2Te cathode have been carried out and the results for the horizontal emittance are shown in Fig. 5. The slope of the linear fit suggests a thermal emittance of 0.72 µm/mm, but the measurements reveal a large non-zero offset of about 57 nm. The cause of such large offset is presently being studied.

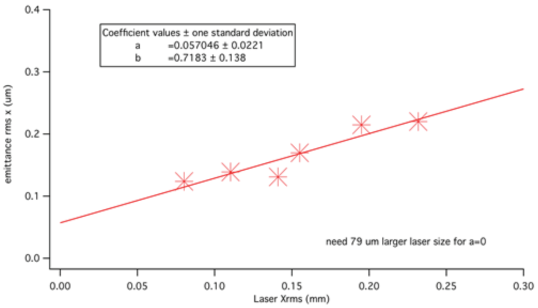

Figure 5: Horizontal thermal emittance mesurements as function of laser spot size at the cathode.

High current measurements have been carried out to study the behaviour of the cathode performances under high current extraction. In the top plot Figure 6 we report the first run at 0.3 mA current (300 pC, 1MHz).

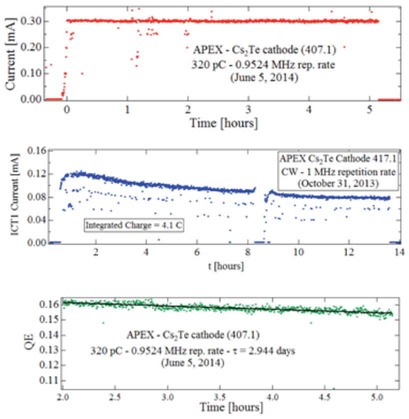

Figure 6: High current runs at APEX (top and center plots), and drop of QE during the 0.3 mA run.

The current was kept constant for 5 hours, by changing the laser average power to follow the drop in quantum efficiency (bottom plot). By fitting such drop with an exponential, a cathode lifetime (1/e) of about 3 days was found. The central plot shows another run at 100 pC. This time the laser power was kept stable, and the current dropped by approx 50% in 12 hours, giving the same value of lifetime.

Jitter Studies

An FPG-based amplitude and phase feedback is currently being tested at APEX, comparing the signal from the rf-gun probe, a reference oscillator. Although the final settings of the feedback loop are still being optimized, preliminary in-loop measurements already showed about one order of magnitude improvement in amplitude and phase stability, lowering down relative fluctuations from 10^{-3} to 10^{-4}.

Figure 7: Preliminary results of gun amplitude feedback. The blue curve shows the stabilized field amplitude (in-loop measurement). The green curve is the input signal, and shows the work being done by the feedback system.

Figure 6 shows the difference between the amplitude of the field in the cavity (green) and at the cavity entrance, showing the work being done by the feedback. With the feedback off, the green line would be constant and the fluctuations would appear in the gun field amplitude.

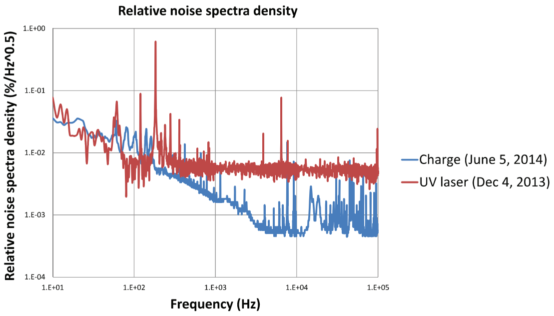

Figure 8: Frequency spectrum of the UV laser pulse energy and electron beam charge fluctuations.

We are presently developing tools for electron beam jitter measurements. An analog electronic chassis has been developed for time, charge and pointing fluctuation measurements. The board accepts as input-50dBm signals from BPMs, photodiodes, faraday cups, and provides a DC signal that can be used as an input to an FFT analyzer. In Figure 7 we report an example of the initial tests, correlating the charge fluctuations to the UV laser pulse energy fluctuations. The plan is to characterize the each subsystem, understanding the range of frequencies dominating the noise figure, and develop *ad-hoc* feedbacks for each of them.

REFERENCES

[1] F. Sannibale, et al., PRST-AB 15, 103501 (2012).
[2] F. Sannibale et. al., MOPRI054, IPAC'14, Dresden, June 2014.
[3] H. Qian, *et al.*, THPRI066, IPAC'14, Dresden, June 2014.