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STATUS OF THE APEX PROJECT AT LBNL*

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Abstract

The Advanced Photo-injector EXperiment (APEX) at the Lawrence Berkeley National Laboratory (LBNL), consists in the development of an injector designed to demonstrate the capability of the VHF gun, a normal conducting 186 MHz RF gun operating in CW mode, to deliver the brightness required by X-ray FEL applications at MHz repetition rate. APEX is organized in 3 main phases where different aspects of the required performance are gradually demonstrated. The status and future plans for the project are presented.

INTRODUCTION

Next revolutionary light source facilities, such as the LCLS-II at SLAC [1], are based on a continuous wave (CW) superconducting linear accelerator with beam supplied by a high-brightness, high-repetition-rate photocathode electron gun. A X-ray facility to meet future needs of the photon science community could be configured as multiple FEL lines to which the accelerated electron beam from a CW superconducting linac is distributed, each FEL operating at high repetition rate and with even pulse spacing. Single-pass linacs, ERLs, or recirculating linacs may be configured to accommodate FELs. One of the highest-priority requirements for understanding machine performance and reduce risk and costs at this design stage are developments in the injector systems required to deliver beam to the linear accelerator. The Advanced Photo-injector EXperiment (APEX) is the LBNL response to such a need and has been designed to demonstrate the brightness performance of an injector based on the new concept VHF RF photocathode gun developed at LBNL [2,3].

This paper describes the APEX project, its present status and results, and the plan for future activities.

THE APEX PROJECT

The APEX project builds from the existing VHF CW gun to develop a compact electron source to conservatively demonstrate the performance required by high rep. rate X-ray FEL applications [4] listed in Table 1.

APEX is organized in three stages: Phase 0, Phase I, and Phase II. In Phase 0, the VHF gun, a vacuum loadlock system for cathode replacement, and a diagnostic beamline allow for cathode characterization and measurement of their performance under real conditions, with the goal of selecting the best choice for a high repetition rate X-ray FEL application. The left part of Figure 1 shows the layout of Phase 0.

In Phase I, an electron beam diagnostic suite is added to the Phase 0 layout, to allow a full 6D characterization of the beam phase space at the gun energy. The diagnostics suite includes a two-slit emittance measurement system (to measure the emittance in a space charge dominated regime), a spectrometer, and a transverse deflecting cavity for slice emittance and energy spread measurements and full longitudinal phase space characterization. Although at the relatively low energy of the gun space charge forces are still dominant, measurements of the beam during Phase I will permit comparison with simulation results and the continuation of photocathode studies. The right part of Figure 1 shows Phase I layout.

Table 1: VHF-Gun Main Requirements

Parameter	Value	Comments
Rep. rate [MHz]	Up to ~ 1	Different oper. modes
Charge per bunch [pC]	~ 20-300	Different oper. modes
Norm. emittance [μm]	~ 0.2- 0.6	Increasing with charge
Gun exit energy [keV]	>~ 750	Space charge control
Gradient at cathode at photoemiss. [MV/m]	>~ 19.5	Space charge limit; max. brightness limit
Bunch length [ps] and current profile control	~ 1 to ~60	Space charge control; different oper. modes
Cathode/gun area mag. field compatibility		For emittance compensation
Dark current [μA]	< ~ 0.4	Radiation. damage
Operational vacuum pressure [Torr]	$\sim 10^{-10}$ - 10^{-9}	High QE cathode lifetime
Cathode loadlock		'Quick'cath. swapping
Reliability	high	User facil. compatible

Finally in Phase II, a room temperature pulsed linac and a buncher cavity are added, and most of the diagnostics of Phase I, after some modifications, are moved downstream the linac. The linac accelerates the beam up to about 30 MeV such that space charge forces become sufficiently small for reliable measurements of beam brightness.

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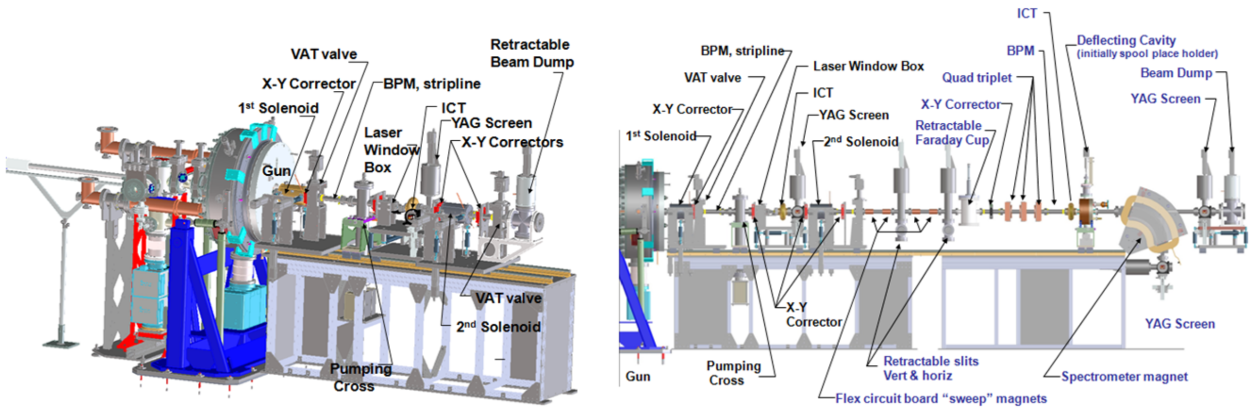

Figure 1: APEX layouts with main components in evidence. Left: Phase 0. Right: Phase I.

The ultimate task of Phase II is to demonstrate the capability of an injector based on the VHF gun to delivery beams with the required quality specified in Table 1. Figure 2 shows Phase II layout. While APEX Phases 0 and I can operate in CW mode, Phase II runs in pulsed mode with a maximum repetition rate of 10 Hz. Such a choice allows effective demonstration of the VHF beam brightness (a single bunch quality) at a significantly reduced cost.

INSTALLATION STATUS

Phase 0 is completed and successfully commissioned achieving and often exceeding all the gun requirements in Table 1 (with the exception of the emittance to be demonstrated in Phase-II) [5]. Installation of Phase I, with the exception of the transverse deflecting cavity, is now completed (see Figure 3) and being commissioned. The construction of the transverse deflecting cavity, a modified version of the Cornell design [6], is complete (see Figure 4) and the cavity is presently being installed in the Phase-I beamline.

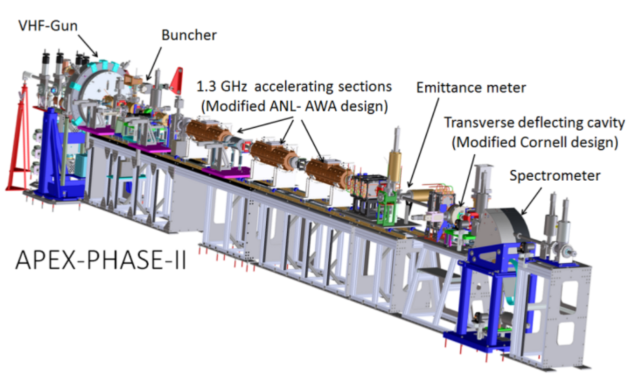

Figure 2: APEX Phase II layout.

Phase II beamline design is complete, with the exception of the buncher cavity whose RF design is completed and the mechanical design is under way. Figure 5, shows a CAD view of the 2-cell 1.3 GHz buncher cavity capable of 240 kV CW with ~ 8 kW of power [7]. The three 1.3 GHz accelerating sections, based on the ANL-AWA design [8], and modified to eliminate dipole and quadrupole field components in the coupler cell, are under fabrication at HiTech Inc. Figure 6 shows a CAD view of the modified section.

Figure 3: The APEX Phase II beamline.

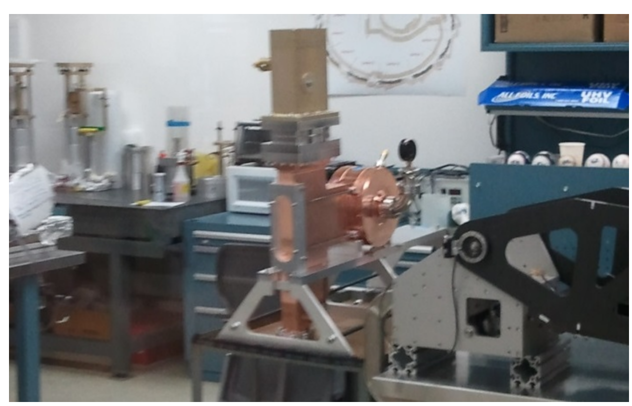

Figure 4: The transverse deflecting cavity ready for installation.

In Phase-II, a single klystron (THALES TV 2022F) generates 25 MW peak power over a 10 μs pulses at 10 Hz for the 3 accelerating sections and the deflecting cavity. The tube is expected to be delivered at LBNL in July this year. The klystron modulator built by DTI Inc.

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successfully underwent the factory acceptance test and is now under delivery.

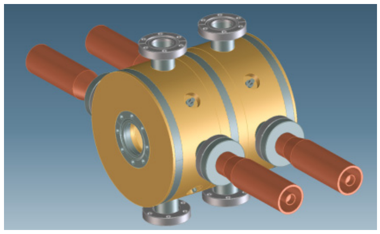

Figure 5: CAD view of the APEX 1.3 GHz buncher.

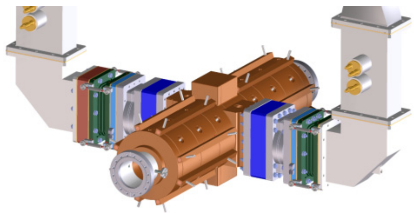

Figure 6: CAD view of the modified ANL-AWA 1.3 GHz accelerating section.

The complex RF distribution system, including a circulator and independent high power attenuators and phase shifters for each of the cavities is fully designed and parts are on order.

The bid for the 10kW CW 1.3 GHz solid state amplifier for the buncher is in its final phase.

PRESENT EXPERIMENTAL RESULTS

Two papers dedicated to recent experimental results of APEX are presented in this conference [9, 10], here some of such results are briefly highlighted.

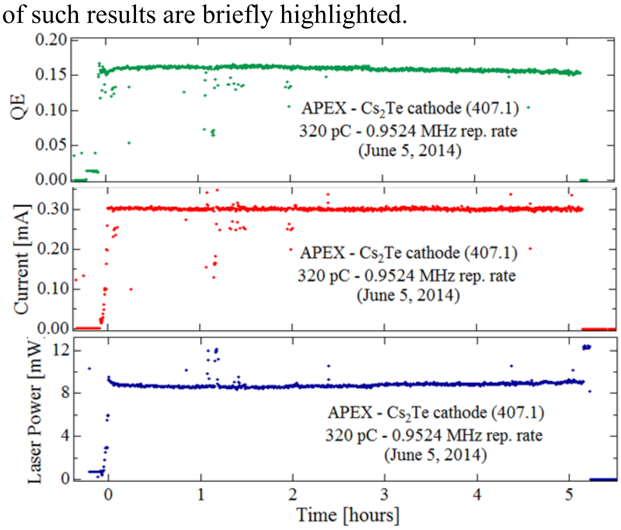

Figure 7: QE measurement for a Cs_2Te cathode. The 1/e lifetime measured from 2 to 5 hours is ~ 2.94 days. More than 5.5 C were extracted. For comparison this is the charge extracted in ~ 13 days at FLASH.

Characterization of Cs_2Te cathodes (fabricated by INFN-LASA) is completed. Figure 7 shows an example of lifetime measurement of a Cs_2Te cathode running at 320 pC per bunch and ~1 MHz repetition rate. In general, the results show that the performance in terms of intrinsic brightness and lifetime of such a cathode is compatible with the operation of a high rep. rate X-ray FEL.

Calibration of diagnostic systems such as the 2-slit emittance meter and the spectrometer is complete and first measurements with such systems have been initiated.

Global and single sub-system jitter characterization is underway, and a number of feedbacks have been implemented for the minimization and control of the various jitters.

The characterization of the dark current from the VHF-gun is now complete and the measured amount is compatible with the operation of a super-conducting linac based facility. Figure 8 shows an example of dark current emission vs. the gradient at the cathode.

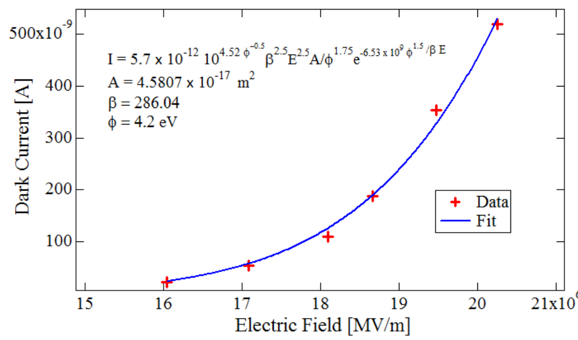

Figure 8: Example of dark measurement (DC) at APEX. At the nominal gradient of 19.5 MV/m the DC is ~ 350 nA satisfying the requirement of Table 1.

FUTURE ACTIVITY AND PLANS

Near future APEX activity includes the test of several different multi-alkali cathodes produced by a collaborating group at LBNL and the 6D characterization of the beam at gun energy. A multi-front strategy for further reducing dark current has been defined and will be tested. In parallel, the installation of Phase-II continues and should be completed by early 2015.

Last, a grant has been awarded to develop high repetition rate ultrafast electron diffraction at APEX [11].

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