A normal conductive RF photo-injector for high repetition rate X-ray free electron lasers (and ERLs)

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Array of 10 configurable FEL beamlines, up to 20 X-ray beamlines
100 kHz CW pulse rate, capability of one FEL having MHz rate
Independent control of wavelength, pulse duration, polarization
Each FEL configured for experimental requirements;
seeded, attosecond, ESASE, mode-locked, echo effect, etc

The LBNL FEL Scheme

Injector
Laser heater
Bunch compressor

CW superconducting linac 2.5 GeV

Beam transport and switching

Low-emittance, MHz bunch rate
photo-gun ≤ 1 nC ≤1 mm-mrad

Laser systems, timing & synchronization

Laser systems, timing & synchronization
NGLS Site at LBNL

Bevatron site

ALS

FEL and X-Ray Beamline Array

Accelerator in Tunnel

Experimental Hall and Laboratory Space

Great Valley Group (Kgv)

Orinda Formation (TO)

Portal

Injector

DESY - Zeuthen Seminar, Berlin, February 8, 2010
An R&D Program and Studies for the Critical Parts

Most of such R&D areas are funded
To achieve the LBNL FEL goals, the electron source should simultaneously allow for:

- repetition rates up to ~ 1 MHz
- charge per bunch from few tens of pC to ~ 1 nC,
- sub $10^{-7}$ (low charge) to $10^{-6}$ m normalized beam emittance,
- beam energy at the gun exit greater than ~ 500 keV (space charge),
- electric field at the cathode greater than ~ 10 MV/m (space charge limit),
- bunch length control from tens of fs to tens of ps for handling space charge effects, and for allowing the different modes of operation,
- compatibility with significant magnetic fields in the cathode and gun regions (mainly for emittance compensation)
- $10^{-9} - 10^{-11}$ Torr operation vacuum pressure (high QE photo-cathodes),
- “easy” installation and conditioning of different kind of cathodes,
- high reliability compatible with the operation of a user facility.
The LBNL normal-conducting design tries to satisfy all the LBNL FEL requirements simultaneously.

- At the VHF frequency, the cavity structure is large enough to withstand the heat load and operate in CW mode at the required gradients.
- Also, the long $\lambda_{RF}$ allows for large apertures and thus for high vacuum conductivity.
- Based on mature and reliable normal-conducting RF and mechanical technologies.
- 187 MHz compatible with both 1.3 and 1.5 GHz super-conducting linac technologies.

Frequency | 187 MHz
Operation mode | CW
Gap voltage | 750 kV
Field at the cathode | 19.47 MV/m
$Q_0$ | 30887
Shunt impedance | 6.5 MΩ
RF Power | 87.5 kW
Stored energy | 2.3 J
Peak surface field | 24.1 MV/m
Peak wall power density | 25.0 W/cm²
Accelerating gap | 4 cm
Diameter | 69.4 cm
Total length | 35.0 cm
The long RF wavelength allows for large apertures and for high vacuum conductivity. The vacuum system has been designed to achieve an operational vacuum pressure down into the low $10^{-11}$ Torr range. NEG pumps are used (very effective with H$_2$O and O$_2$). This arrangement will allow testing a variety of cathodes including "delicate" multi-alkali and/or GaAs cathodes.

Cathode area designed to operate with a vacuum load-lock mechanism for an easy in-vacuum replacement or “in situ” reconditioning of photocathodes.

The nominal laser illumination configuration for the cathode is quasi-perpendicular with laser entrance in the beam exit pipe.

An additional 30 deg laser entrance port has been added to allow testing of more exotic cathodes (surface plasma wave cathodes, ...).
PEA Semiconductor: **Cesium Telluride Cs₂Te** (used at FLASH for example)
- <~ps pulse capability
- relatively robust and un-reactive (operates at ~ 10⁻⁹ Torr)
- successfully tested in NC RF and SRF guns
- high QE > 1%
- photo-emits in the UV ~250 nm (3rd or 4th harm. conversion from IR)
- for 1 MHz reprate, 1 nC, ~ 10 W 1060nm required

  • Cathodes from INFN-LASA in Milano
  • Laser from Q-Peak

PEA Semiconductor: **Alkali Antimonides** eg. SbNa₂KCs, CsK₂Sb, ...
- <~ps pulse capability  (studied at BOING, INFN-LASA, BNL, Daresbury, LBNL, ...)
- reactive; requires <~ 10⁻¹⁰ Torr pressure
- high QE > 1%
- requires green/blue light (eg. 2nd harm. Nd:YVO₄ = 532nm)
- for nC, 1 MHz reprate, ~ 1 W of IR required

  • R&D for the development at LBNL
  • Laser from LLNL

**Possibility of testing other cathodes**
Ongoing Beam Dynamics Studies

- EXAMPLE: No pre-buncher or buncher. Just main linac cavities
- Velocity bunching by de-phasing the first cavity
- Emittance compensation by a single solenoid (plus embedded bucking coil)

- Multi-Objective Genetic Algorithms optimization, trading between final emittance and bunch length.

- Work in progress but already showed the VHF gun capability to operate in a FEL scheme

ASTRA – 10k particles

VHF Gun

Solenoids

1.3 GHz Tesla-like cavities

VHF Gun 1.1
10 pC

- Generation 16
- Generation 33
- Generation 36

Pareto Optimal Curve for VHF Gun 1.1
Rectangular Transverse an Longitudinal Spatial Dist.
0.5 nC - 1 μm/(rms mm) thermal emittance

ASTRA – 10k particles

48th ICFA Advanced Beam Dynamics Workshop on Future Light Sources - SLAC, March 2, 2010
A VHF (144 MHz) gun is used at the ELSA 19 MeV linac and produces high charge-low emittance beams within a 150 µs macropulse at 10 Hz repetition rate.

The Boeing gun has achieved 25% duty cycle operation at 433 MHz.

A Los Alamos/AES completed the RF test of a 700 MHz normal-conducting RF gun where a sophisticated and state of the art cooling system allows the gun to operate in CW mode.

A 700 MHz CW normal conducting gun was studied at JLAB.

A 144 MHz CW normal conducting gun was studied at BNL.
• The cavity design finalized
And in construction!

• Most of the cavity is being fabricated at the LBNL mechanical shop

• Fabrication completion in early spring 2010.
• First cold RF test successfully performed.
The 120 kW CW RF amplifier required to operate the VHF gun is being developed and manufactured by ETM Electromatic.

Expected delivery at LBNL in March 2010
All the photo-injector system will be accommodated in the existing ALS Beam Test Facility (BTF) for full characterization. The BTF footprint is large enough to accommodate also the structures to accelerate the beam to few tens of MeV.
In phase I, only the gun, the vacuum load lock system and a low energy beam diagnostics installed in the BTF

Fully funded (to be completed by 2010)

- Perform cold and full power RF tests of the VHF cavity
- Demonstrate the system vacuum performance
- Install and characterize the first generation cathode.
- Characterize the electron beam at the gun energy (750 kV) at full repetition rate
Requires funding continuation

- Develop and install accelerating section for few tens of MeV energy

- Develop and install high energy diagnostic beamline

- Perform full characterization of the beam parameters at high energy (probably at low repetition rate)
Does the cavity go through the door?

Yes, it does!!!
The VHF Injector Team


The VHF Gun References


