Research and development of photocathodes sensitive to visible laser beams for photoinjector applications

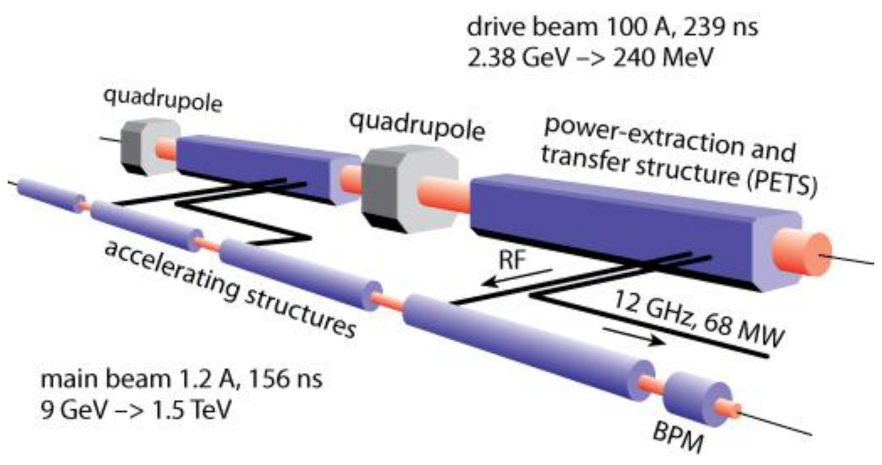
Irene Martini, Eric Chevallay, Valentin Fedosseev, Christoph Hessler, Mikhail Martyanov
CERN, CH-1211, Geneva 23, Switzerland

Abstract

The high brightness requirements for electron sources, e.g. for Free Electrons Lasers, have validated the photoinjectors option at the expense of the thermionic gun electron source.
In a photoinjector electron bunches are generated by shooting with laser pulses a photocathode (PC) installed inside an extracting and accelerating structure.
Photoinjectors produce transversely and longitudinally well-defined electron beams which, in combination with high electric field, lead to achieve high brightness[1]. In order to produce a reliable source which fulfills the CLIC requirements, a strong research and development program on lasers and photocathodes is an ongoing activity at CERN.

CLIC Project

CLIC (Compact Linear Collider) is a study project for a linear accelerator designed for electron-positron collisions up to a nominal center-of-mass energy of 3 TeV. Its unique feature is the two beams acceleration scheme: a drive beam is conceived to supply with the RF power the main beam accelerating structures. The 3rd CLIC Test Facilities (CTF3), located at CERN, aims to demonstrate the technical feasibility of such compact collider.

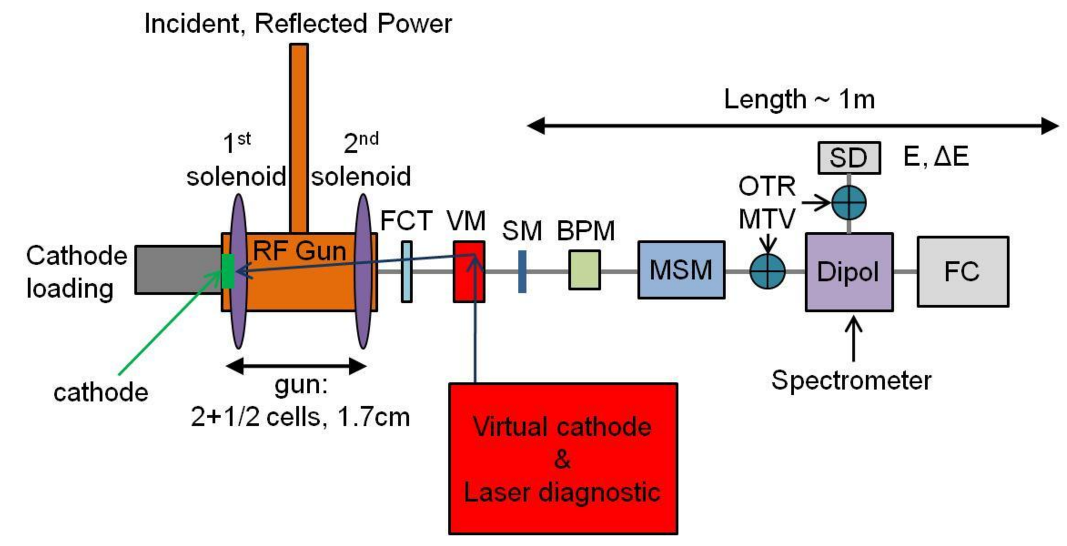


The two beams CLIC accelerating scheme.

PHIN Photoinjector

The PHIN photoinjector has been developed to study the feasibility of a laser-based electron source for the CLIC drive beam. Currently the drive beam of the CTF3 is produced using a thermionic electron gun and a sub-harmonic bunching system. This baseline design creates the required time structure but generates parasitic satellite bunches which cause beam losses and radiation issues. With the PHIN RF gun and the phase-switching set-up installed on the laser bench, satellite-free beams are produced[2]. In the table the nominal PHIN parameters are shown as well as the CLIC goals.
The main challenge is to achieve long lifetimes with high bunch charge and long trains[3].

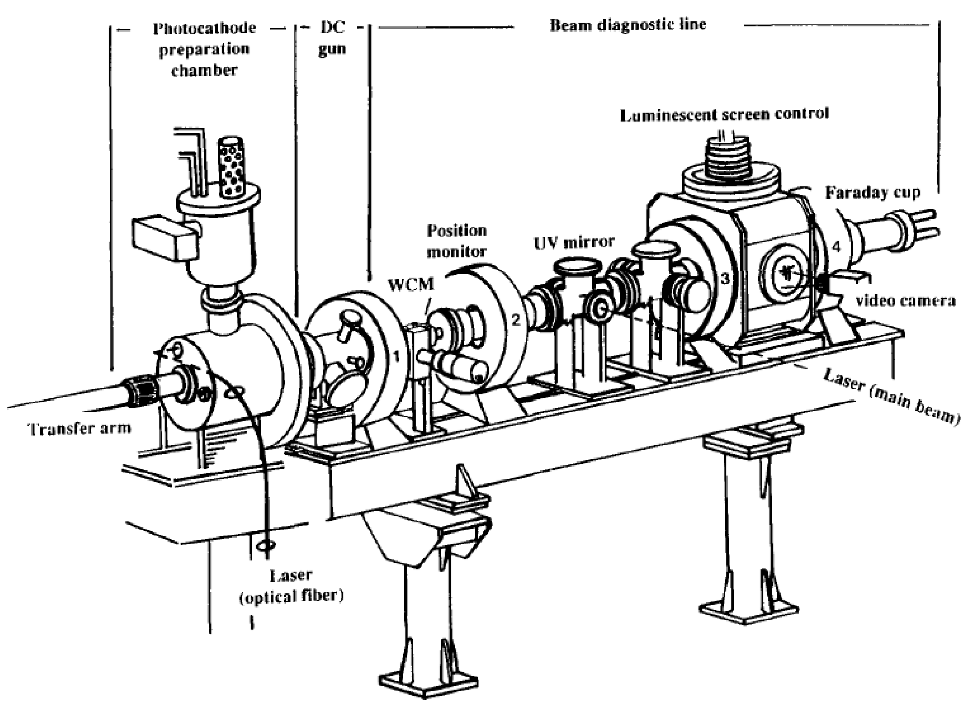
Parameter	PHIN	CLIC
Charge/bunch (nC)	2.3	8.4
Train length (µs)	1.2	140
Bunch spacing (ns)	0.66	2.0
Bunch rep. rate (GHz)	1.5	0.5
Number of bunches	1800	70000
Macro pulse rep. rate (Hz)	5	50
Charge/train (µC)	4.1	590
Beam current/ train (A)	3.4	4.2
Bunch length (ps)	10	10
Cathode lifetime (h) at QE>3% (Cs_2Te)	>50	>150



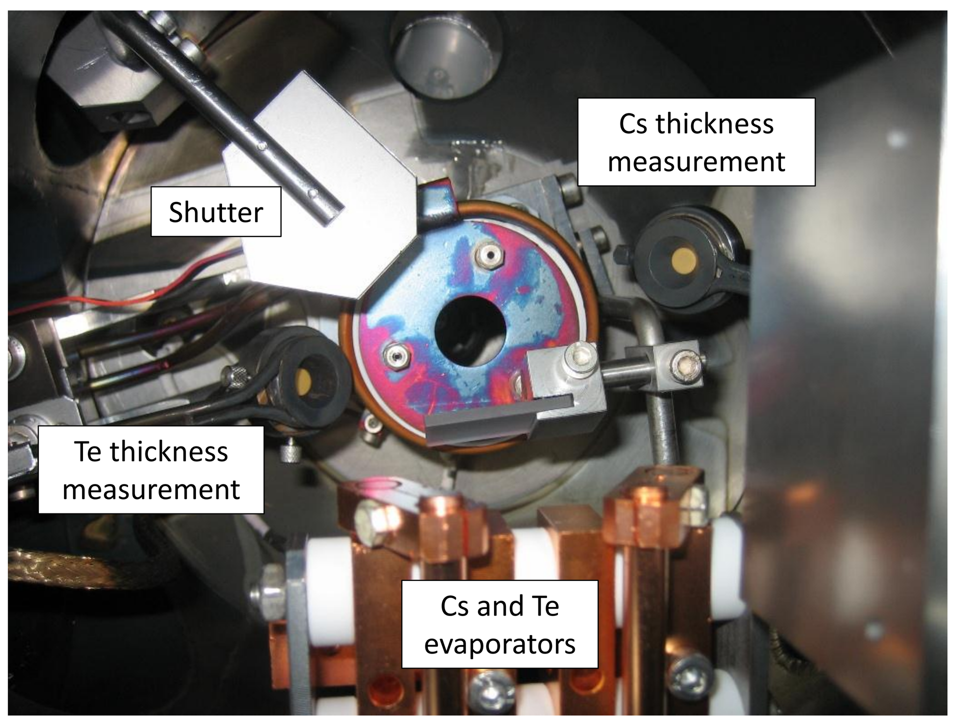
The PHIN layout: fast current transformer (FCT), vacuum mirror (VM), steering magnet (SM), beam position monitor (BPM), multi-slit mask (MSM), optical transition radiation screen (OTR), gated camera (MTV), segmented beam dump (SD), Faraday cup (FC).

Photocathodes Production and Test

The photoemission laboratory installation is used for photocathodes production and preliminary studies before the tests at the PHIN photoinjector. In the preparation chamber the PCs are produced by co-evaporation (mostly Cs_2Te thin film deposited on a copper plug)[4]. The PC is afterwards illuminated with laser pulses (λ=266 nm for Cs_2Te photocathodes, i.e. the 4th harmonic of a Nd:YAG laser) and the electron bunches accelerated by a DC gun. The diagnostic line allows the PC characterization and the electron beam diagnostics (e.g. charge/bunch measurement).



Photoemission laboratory layout.



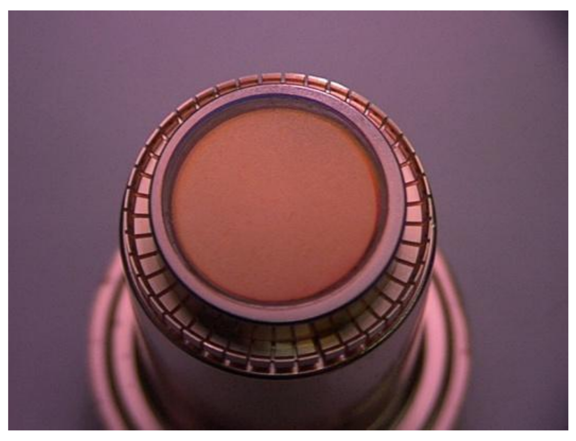
Deposition set-up: the stoichiometric ratio is controlled by measuring the thickness.
On line QE measurements are performed shooting with the UV laser.

Quantum Efficiency

QE (number of electrons/number of photons) is the main feature of photocathodes. Given the wavelength λ, the laser pulse energy E and the bunch charge Q, it is defined as:

$$QE\ (\%) = \frac{124 \times Q\ (nC)}{\lambda\ (nm) \times E\ (\mu J)}$$

A photocathode (Cs_2Te on copper substrate).
The maximum measured QE is over 20%.



Visible Laser Beams

The 4th harmonic generation crystal, used to produce UV beams, cannot withstand the long laser pulse trains needed for reaching nominal CLIC parameters. Such damage is not a problem for the 2nd harmonic generation crystals.
Moreover using visible laser beams leads to a more efficient photoemission process:
1) Assuming an equal QE value, lower pulse energy is needed compared to the UV range to produce the same bunch charge.
2) The suppression of the crystal for harmonic generation of UV beam increases the conversion efficiency of the laser set-up.
Lastly, the visible beams transport is more efficient due to a less complicated laser set-up along with the availability of higher quality optics.

Conclusions/Outlook

In order to produce the required electron pulses (high bunch charge and long length trains), light in the visible range (from green to near infrared) is needed. Lasers generating visible light could be used routinely if appropriate photocathodes are available.
Different photocathodes sensitive to visible laser beams will be produced and tested by photoemission laser probing and surface analysis. In order to find the best solution various materials and production techniques will be considered.

[1]G. Suberlucq, "*Technological challenges for high brightness photo-injectors*", Proceeding of EPAC 2004, Lucerne, Switzerland
[2] M. Catsari et al., "*High charge PHIN photoinjector at CERN with fast phase switching within the bunch train for beam combination*", Proceedings of IPAC 2011, San Sebastian, Spain
[3] C. Hessler et al.," *Lifetime studies of Cs_2Te cathodes at the PHIN RF photoinjector at CERN*", Proceedings of IPAC 2012, New Orleans, Louisiana, USA
[4] E.Chevallay, "*Experimental results at the CERN Photoemission Laboratory with Co-deposition Photocathodes in the Frame of the CLIC Studies*", CTF3 Note 104 (2012)

LA³NET is funded by the European Commission under Grant Agreement Number GA-ITN-2011-289191