EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ATS-2012-260

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Presented at: IPAC12, New Orleans, US, 20-25 May 2012

Geneva, Switzerland,
26 September 2012

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The PHIN photoinjector has been developed to study the feasibility of a photoinjector option for the CLIC (Compact LInear Collider) drive beam as an alternative to the baseline design, using a thermionic gun. The CLIC drive beam requires a high charge of 8.4 nC per bunch in 0.14 ms long trains, with 2 ns bunch spacing and 50 Hz macro pulse repetition rate, which corresponds to a total charge per macro pulse of 0.59 mC. This means unusually high peak and average currents for photoinjectors and is challenging concerning the cathode lifetime. In this paper detailed studies of the lifetime of Cs_2Te cathodes, produced by the co-evaporation technique, are presented with respect to bunch charge, train length and vacuum level. Furthermore, the impact of the train length and bunch charge on the vacuum level will be discussed and steps to extend the lifetime will be outlined.

INTRODUCTION

The drive beam of the 3rd CLIC Test Facility (CTF3) at CERN [1] is currently being produced using a thermionic electron gun and a sub-harmonic bunching system, which creates the required time structure for the CTF3 beam combination scheme [2]. However, the disadvantage of this baseline design is the generation of parasitic satellite bunches, which cause beam losses and radiation issues. To overcome these limitations, the PHIN photoinjector [3] was constructed to study its feasibility as an alternative to the CTF3 thermionic electron gun. It has been shown that PHIN can produce practically satellite-free beams with the required time structure [4, 5].

After the demonstration of most of the PHIN design parameters [5], the focus of the PHIN studies has now shifted towards feasibility studies for the CLIC drive beam, although the gun was not designed for this purpose. The CLIC drive beam requires a high bunch charge of 8.4 nC and 140 µs long pulse trains with 2 ns bunch spacing and a macro pulse repetition rate of 50 Hz (Table 1). The main challenge for a photoinjector is to achieve these parameters together with a sufficient long cathode lifetime. In this paper the results from detailed lifetime studies of Cs_2Te cathodes during the PHIN run in September 2011 will be presented.

PHIN PHOTOINJECTOR

Layout

The PHIN photoinjector is installed at an off-line test stand at CERN (Fig. 1). It consists of a 2.5 cell cavity operated at 3 GHz and two solenoids, which provide the focussing of the electron beam. The test beam line contains various diagnostic elements including a fast current transformer and a Faraday cup for beam current measurements. The electron beam is produced by illuminating the Cs_2Te photocathode with an ultra-violet (UV) laser beam, which is generated by a powerful frequency-quadrupled Nd:YLF laser system [6].

Table 1: PHIN and CLIC Design Parameters

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
Charge stability	<0.25%	<0.1%
Cathode lifetime (h) at QE > 3% (Cs_2Te)	>50	>150

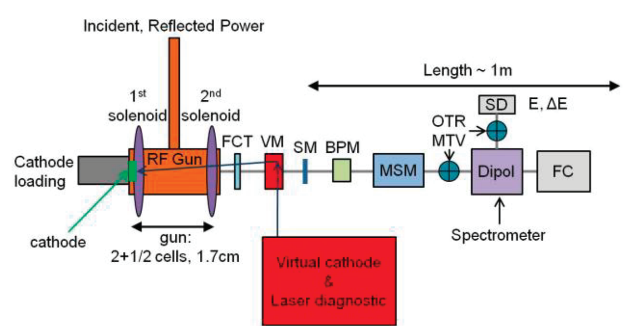

Figure 1: Layout of PHIN. Fast current transformer (FCT), vacuum mirror (VM), steering magnet (SM), beam position monitor (BPM), multi-slit mask (MSM), optical transition radiation screens (OTR), gated cameras (MTV), segmented beam dump (SD), Faraday cup (FC).

Photocathodes

The photocathodes, which are used at PHIN, are produced by the co-evaporation technique in the CERN photoemission laboratory [7] and transported to PHIN in an ultra-high vacuum (UHV) vessel.

Improvement of the Vacuum System

The PHIN gun itself is also held under UHV conditions. During previous PHIN runs the static pressure was around 1.8e-10 mbar and the dynamic pressure during beam operation in the range of ~4e-9 mbar peaking to ~2e-8 mbar during breakdowns. Since previous studies indicated a correlation between the lifetime and the vacuum level [5], it was decided to improve the vacuum by activating an already existing (but never before activated) NEG coating in a vacuum chamber surrounding the gun cavity. This chamber is connected by 22 holes with 4 mm diameter in the gun cavity to the interior of the gun [8]. Due to the activation and the bake-out, the static vacuum level at the outlet of the gun could be modestly improved to 1.3e-10 mbar. The dynamic vacuum level, however, has been improved to 1.6e-9 mbar under similar beam conditions as in the past. Furthermore, much less break-downs have been observed, which also helped the RF conditioning of the gun.

CATHODE LIFETIME STUDIES

Under these improved vacuum conditions, detailed lifetime studies have been carried out. The lifetime depends on different beam properties such as bunch charge, train length and repetition rate and on the level of the dynamic vacuum, which itself depends on the beam properties.

Impact of Beam Properties on the Vacuum Level

To study these dependencies in more detail, measurements of the vacuum level as a function of the bunch charge has been carried out (Fig. 2). The measurement shows that the vacuum level can be maintained up to the nominal bunch charge of PHIN of 2.3 nC. The pressure increase above this value is probably due to beam losses inside the gun. However, PHIN was not designed for such high bunch charges and a gun specially designed for CLIC with a lower frequency of e.g. 1 GHz that is needed for long pulse operation, could have better pumping properties due to larger aperture sizes.

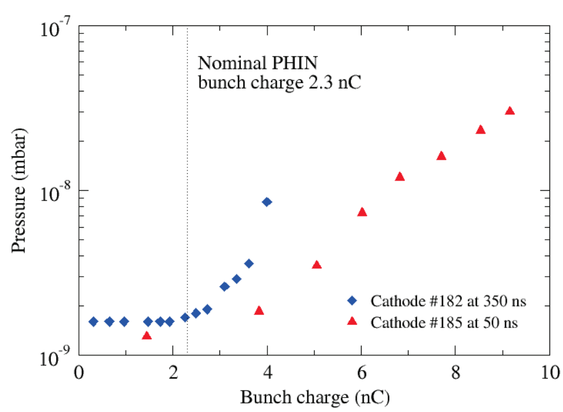

Figure 2: Measurement of the vacuum level as a function of the bunch charge. The pressure can be maintained on a low value up to the nominal bunch charge of PHIN.

A measurement of the vacuum level as a function of the train length shows that the pressure increases with increasing train length when the beam transport in the beam line is not optimized (Fig. 3). This pressure increase is due to beam losses in the beam line between the fast current transformer and the Faraday cup. If the beam transport is optimized so that there are practically no beam losses, the vacuum can be maintained at a constant level. However, it is difficult to predict if the same would be true for 140 µs long trains as needed for CLIC, which cannot be produced with the current system.

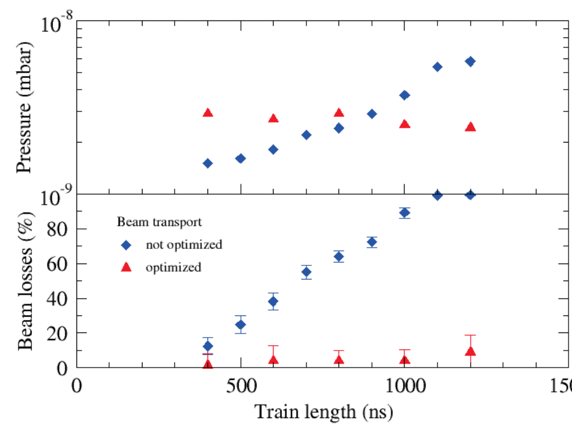

Figure 3: Measurement of the vacuum level and the beam loss between the fast current transformer and the Faraday cup as a function of the train length (~2.3 nC nominal bunch charge). The pressure can be maintained constant if the beam losses in the beam line are small. The red curve is partially above the blue curve, because the base pressure was higher, due to previous measurements.

Impact of the Vacuum Level on the Lifetime

To determine the cathode lifetime, the electron beam current and the laser beam energy were measured with the fast current transformer and an energy meter, and the quantum efficiency (QE) was computed. Measurements for different bunch charges and train lengths are shown in Fig. 4 together with the recorded vacuum data. For low bunch charges up to 2.3 nC the QE is rather constant and the lifetime therefore within the specifications. For a charge of 4 nC/bunch, however, the QE decreases rapidly with 1/e lifetimes of 24±6 h and 46±24 h. These short lifetimes are clearly correlated with high vacuum levels in the 1e-8 mbar range, whereas long lifetimes correspond to lower vacuum levels. Both measurements with low bunch charges of 2 - 2.3 nC but different train lengths of 350 and 700 ns yield to long lifetimes, which cannot be distinguished. These results are in agreement with the dependency of the vacuum level on the bunch charge and train length presented above.

To decouple these effects, measurements of the cathode lifetime under different vacuum conditions but with the same bunch charge and train length are shown in Fig. 5. These measurement data were acquired during the PHIN runs in September and March 2011 with and without activated NEG coating, respectively. The dynamic

ISBN 978-3-95450-115-1

vacuum level was substantially improved, which led to a drastic increase of the cathode lifetime from 38±11 h to 250±115 h. With an initial QE of 10% and an extrapolated single exponential decay this yields a total cathode lifetime of 300 h above 3% QE, which is well within the CLIC specifications.

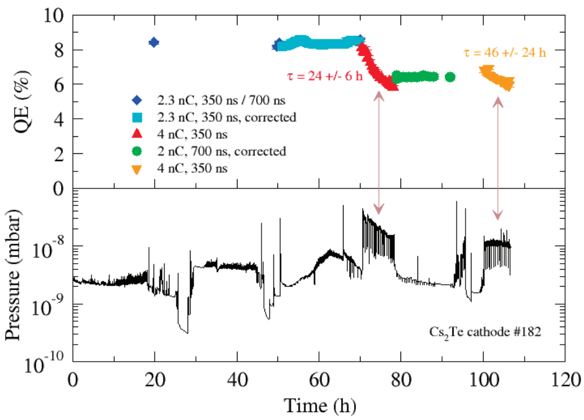

Figure 4: Measurement of the quantum efficiency and the vacuum level as a function of time for different bunch charges and train lengths. It is evident that short lifetimes correspond to high vacuum levels.

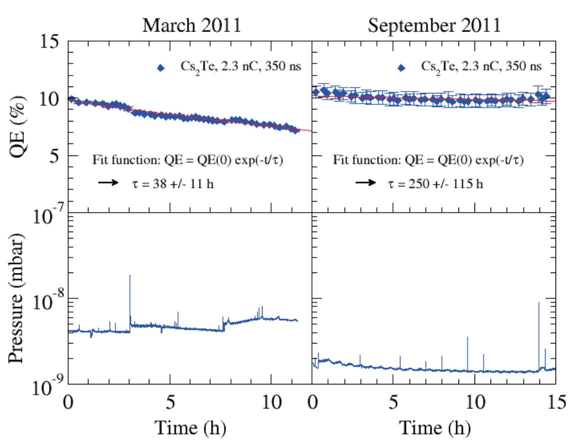

Figure 5: Comparison of QE measurements with the same beam properties from the PHIN runs in March 2011 (NEG coating not yet activated) and September 2011 (NEG coating activated) and the vacuum data. The lifetime has been significantly improved as well as the dynamic vacuum level.

HIGH CHARGE PRODUCTION

Within the scope of these lifetime studies, high charge production tests have been performed at PHIN. Using a large beam size of 1.8 mm x 1.25 mm (1σ) and 50 ns long trains, a new record bunch charge at PHIN of 9.2 nC has been achieved (Fig. 6), which is above the CLIC requirements.

CONCLUSION AND OUTLOOK

The presented studies show that the cathode lifetime can be substantially improved by better vacuum conditions. It is therefore planned to add an additional NEG cartridge pump, which is estimated to further improve the vacuum in the RF gun.

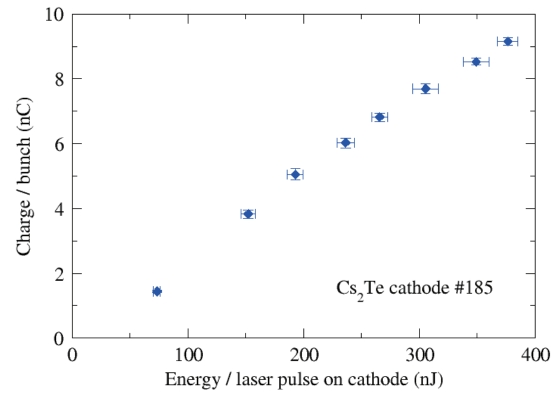

Figure 6: Measurement of the bunch charge using 50 ns long macro pulses. A new record bunch charge at PHIN of 9.2 nC has been achieved.

Recent measurements with co-deposition Cs_3Sb cathodes sensitive to green light indicate similar lifetimes as for Cs_2Te cathodes. This could reduce the complexity of the laser system and would be another important step towards the feasibility of a photoinjector for CLIC. The investigation of the PHIN photoinjector performance with Cs_3Sb cathodes has started. However, the final proof of feasibility of a photoinjector for the CLIC drive beam can only be achieved with a new 1 GHz RF gun specially designed for the CLIC beam parameters.

ACKNOWLEDGMENT

The authors would like to thank Paolo Chiggiato for valuable discussions and the vacuum, beam instrumentation and RF groups for their support.

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