STUDY OF THE PERFORMANCE OF Cs_2Te CATHODES IN THE PHIN RF PHOTOINJECTOR USING LONG PULSE TRAINS

C. Hessler, E. Chevallay, S. Doebert, V. Fedosseev, F. Friebel, I. Martini, M. Martyanov, H. Neupert, V. Nistor, M. Taborelli, CERN, Geneva, Switzerland

Abstract

The drive beam of CLIC requires unusually high peak and average currents which is challenging for the electron source. As an alternative to the thermionic electron gun foreseen in the baseline design, a photoinjector option is under study at CERN using the PHIN photoinjector, which was designed for a bunch charge of 2.3 nC and 1200 ns train length. During operation with nominal train length in 2014, a large pressure increase in the vacuum system, attributed to a heating of the Faraday cup, caused a degradation of the photocathode. To overcome this problem a vacuum window has been installed to separate the Faraday cup from the rest of the vacuum system. In addition the train length has been further increased to 1600 ns to advance the beam parameters towards CLIC requirements. In this paper recent improved photocathode lifetime measurements carried out under these new conditions will be presented and compared with earlier measurements. Furthermore, the utilized Cs_2Te cathode has been analyzed with X-ray Photoelectron Spectroscopy (XPS) before and after its usage in PHIN to get a better understanding of photocathode surface deterioration effects, which will also be discussed.

INTRODUCTION

The future e^+e^- collider CLIC [1] is based on a novel two-beam acceleration scheme consisting of two main beam linacs and one or two drive beam accelerators. The latter one generates the 12 GHz RF power needed to accelerate the main beam, and requires therefore high peak and average currents. In the baseline design, the drive beam is foreseen to be produced by a thermionic electron gun and a sub-harmonic bunching system [2], which however generates parasitic satellite pulses. These satellite pulses get lost during the acceleration process, which can create radiation issues and will reduce the system power efficiency.

A potential solution for these issues could be to use a photoinjector as the drive beam source, which can produce the electron beam with the required time structure for the CLIC beam combination scheme and which eliminates the need of a bunching system, as it was demonstrated at the high-charge photoinjector PHIN [3].

PHIN is currently used to study the feasibility of the photoinjector option for the CLIC drive beam, but originally it was designed for the usage at the CLIC Test Facility 3 (CTF3). As a consequence, its parameter set differs from the CLIC requirements (Table 1) and considerable efforts have been made to improve its parameters in recent years [4] and are still on-going. The CLIC drive beam parameters, but also the PHIN parameters, are challenging for a photoinjector, especially the combination of high bunch charge, long trains and short bunch spacing. This unique parameter set has a strong impact on the photocathode lifetime and operation of PHIN was not always without problems in the past. During operation with the nominal train length e.g. in 2014 a large pressure increase in the vacuum system by one order of magnitude has been observed in conjunction with a short photocathode lifetime of 55 h (Fig. 1). It was assumed that the vacuum deterioration and resulting from that the cathode degradation was caused by a heating of an uncooled Faraday cup. Measures to overcome this problem and to prepare the system for even higher beam intensities and their effect on the photocathode performance are discussed in this paper.

Table 1: PHIN and CLIC Design (and Achieved) Parameters

Parameter	PHIN	CLIC
Charge / bunch (nC)	2.3 (9.2)	8.4
Train length (μs)	1.2 (1.6)	140
Bunch spacing (ns)	0.66	2.0
Bunch rep. rate (GHz)	1.5	0.5
Number of bunches	1800 (2400)	70000
Macro pulse rep. rate (Hz)	5 (5)	50
Charge / train (μC)	4.1 (5.5)	590
Beam current / train (A)	3.5	4.2
Bunch length (ps)	10	10
Charge stability	<0.25% (<1%)	<0.1%
Cathode lifetime (h) at QE > 3% (Cs_2Te) or QE > 0.5% (Cs_3Sb)	>50 (>300)	>150
Norm. emittance (μm)	<25 (14)	<100

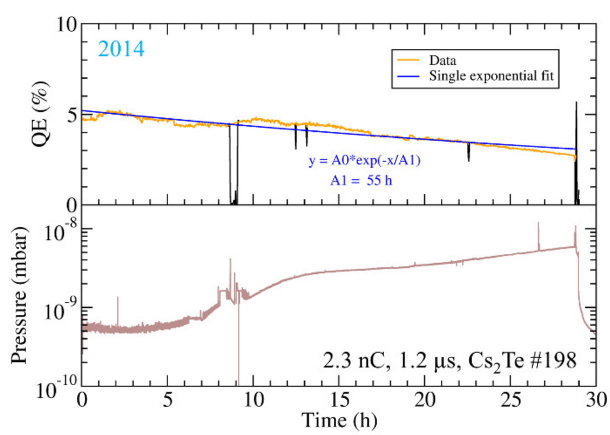

Figure 1: Pressure increase and short cathode lifetime measured in 2014.

ISBN 978-3-95450-147-2

EXPERIMENTAL SETUP

The PHIN photoinjector is installed at an off-line test stand at CTF3 (Fig. 2). It consists of a 2.5 cell RF cavity operated at 3 GHz and two solenoids, which provide the focusing of the electron beam. A test beam line is available with various diagnostic elements for beam measurements. The electron beam is produced by illuminating either a Cs_2Te photocathode [5] with an ultra-violet (UV) laser beam or a Cs_3Sb cathode [6] with a green laser beam, both generated by a powerful Nd:YLF laser system [7]. In the studies described in this paper Cs_2Te cathodes were used.

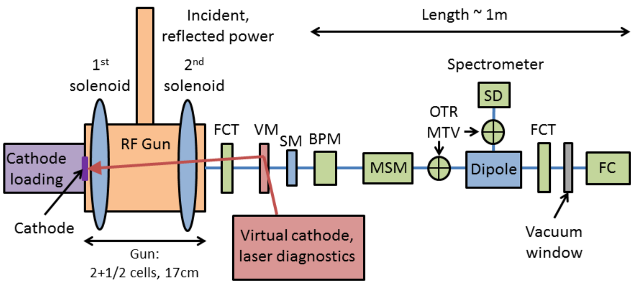

Figure 2: Layout of PHIN. Fast current transformers (FCT), vacuum mirror (VM), steering magnet (SM), beam position monitor (BPM), multi-slit mask (MSM), optical transition radiation screens (OTR), gated cameras (MTV), segmented beam dump (SD), Faraday cup (FC).

To minimize the impact of the gas load produced by the heated Faraday cup, which is used as beam dump and for measuring the beam current, onto the photocathode, a 200 µm thin 316L stainless steel vacuum window has been installed to separate the Faraday cup from the rest of the vacuum system. A first attempt with such a window and by operating the Faraday cup in air has been already performed in 2013. However, the Faraday cup signal showed a strong ringing due to a poor RF continuity and its usability was therefore limited. To overcome this issue the Faraday cup was kept under vacuum in a separate sector in 2015.

PHOTOCATHODE LIFETIME STUDIES

With this new configuration of the vacuum system photocathode lifetime studies have been performed at PHIN using Cs_2Te cathode #203. During these studies the electron beam current and the laser beam energy have been measured and the quantum efficiency (QE) of the photocathode computed. For these measurements the train length has been extended the first time beyond the design value to 1.6 µs.

A measurement with 2.3 nC per bunch and 0.8 Hz macro-pulse repetition rate over 110 h is shown in Fig. 3. In contrary to previous measurements the QE stayed rather constant and it is not possible to fit an exponential to the data. Therefore, the 1/e lifetime must be very long compared with previous measurements over similar time spans resulting in 1/e lifetimes up to 300 h [8]. The oscillations visible on the measured QE curve are due to a problem with the air-conditioning in the laser laboratory. Furthermore, the RF phase was slowly drifting, probably also due to non-optimal temperature stability, causing the slow variations on the QE curve. The vacuum measured at the exit of the gun was excellent and went down during the measurement to a low 10^{-10} mbar level. In the Faraday cup sector an equilibrium pressure of $4{\cdot}10^{-6}$ mbar was reached, which confirms the high desorption from the Faraday cup.

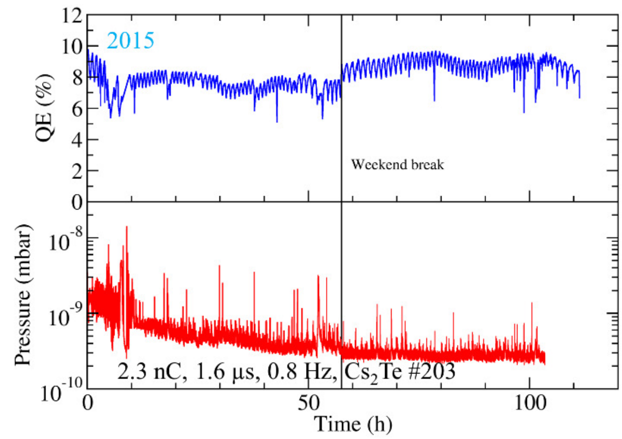

Figure 3: Lifetime measurement of Cs_2Te cathode #203 with 2.3 nC/bunch, 1.6 µs train length and 0.8 Hz macro-pulse repetition rate.

A second lifetime measurement has been performed with the same train length, similar bunch charge (2 nC), but with 5 Hz macro-pulse repetition rate and shows similar results (Fig. 4): The QE seemed initially to decrease, but this was only caused by a drifting RF phase. By correcting the phase the initial QE value could be restored and kept constant. The vacuum level was slightly higher at $6{\cdot}10^{-10}$ mbar but still very good.

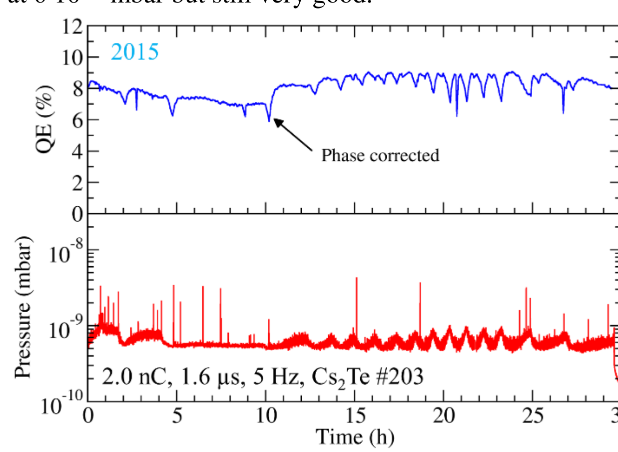

Figure 4: Lifetime measurement of Cs_2Te cathode #203 with 2.0 nC/bunch, 1.6 µs train length and 5 Hz macro-pulse repetition rate.

PHOTOCATHODE SURFACE ANALYSIS

The chemical surface composition of different photocathodes used at PHIN, including cathode #203, has been analyzed with X-ray Photoelectron Spectroscopy (XPS) in order to get a better understanding of the deterioration effects [8-10]. These XPS measurements were performed

ISBN 978-3-95450-147-2

in the XPS apparatus of the CERN vacuum group and the cathodes were transported to this setup under UHV conditions using a dedicated transfer vessel.

Cathode #203 has first been analyzed directly after the production. The XPS spectrum (Fig. 5) shows only peaks for Cs, Te and Cu (from the substrate), with a ratio of Cs to the single Te^{2-} component of 2.1, which is in good agreement with the expected stoichiometry of Cs_2Te [8]. No oxygen contamination was found.

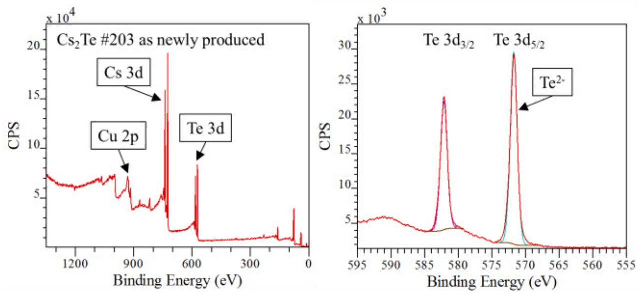

Figure 5: XPS spectrum (wide range and Te region) of cathode #203 as newly produced [8].

Cathode #203 was analyzed a second time after its usage in PHIN for lifetime measurements described in the previous section. In addition to Cs, Te and Cu also an oxygen contribution has been measured (Fig. 6). The Te region of the XPS spectrum shows for the used cathode not a clean doublet structure as for the fresh cathode, but a structure which could be well fitted with a peaks model consisting of the Te^{2-}, Te^{0} and Te^{6+} components. These peaks are attributed to Cs_2Te, metallic tellurium and TeO_3. The analysis of the spectrum in the O1s peak region revealed the coexistence of two contributions: Oxygen as bound in TeO_3 and as bound in cesium oxide [8].

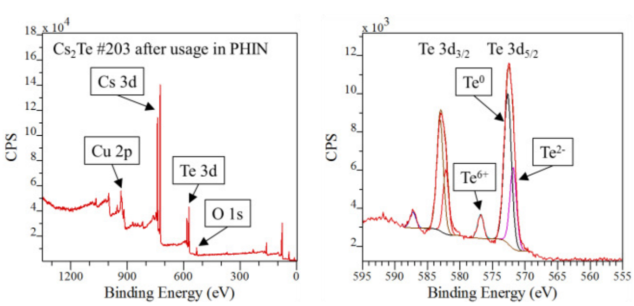

Figure 6: XPS spectrum (wide range and Te region) of cathode #203 after usage in PHIN 2015 [8].

If these results are compared with the XPS measurement of cathode #198 after its operation in PHIN in the old configuration of the vacuum system (without vacuum window) in 2014, then differences can be seen (Fig. 7): The Te region shows instead of the metallic tellurium and the Te^{6+} component a Te-rich phase (Te^{x-}) with unknown stoichiometry and a Te^{4+} component forming TeO_2 [8]. However, it is not clear if these differences are related to different deterioration processes due to the different environmental conditions in the vacuum system, or if the Te-rich phase was already present in cathode #198 after the production, since this cathode was not analyzed with XPS as newly produced.

More XPS studies on fresh and used Cs_2Te cathodes are certainly needed to get a better understanding of the variation of the stoichiometry during the production process and of the degradation processes during beam operation.

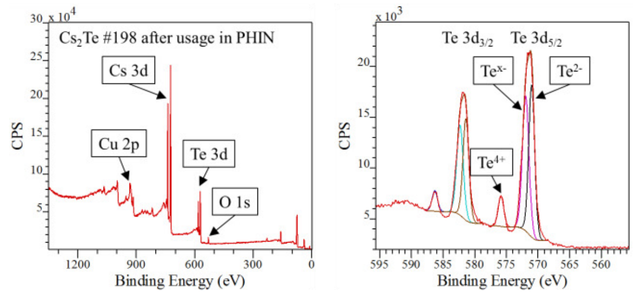

Figure 7: XPS spectrum (wide range and Te region) of cathode #198 after usage in PHIN 2014 [8].

CONCLUSION

The lifetime studies presented in this paper showed that the separation of the Faraday cup from the rest of the beam line can result in excellent cathode lifetimes. It seems reasonable to assume that previous lifetime measurements were limited by operating the RF gun "unnaturally" close to the beam dump, which might be not the case in any real-world application. However, this study was performed only with a single cathode, and it could be that the long lifetimes were due to a very good quality of this cathode. More measurements are needed to verify the reason for the excellent lifetimes.

The presented measurements could show that the QE is constant within ~100 h. For a real measurement of the cathode lifetime a longtime operation of PHIN would be required, which is not possible because PHIN can be operated only once per year for ~4 weeks. The reason for this operation mode is that PHIN shares the klystron with the CTF3 probe beam photoinjector, which needs to be in daily operation.

Furthermore, it would be interesting to increase the train length further to the maximum klystron pulse length of 5 µs to approach closer to CLIC requirements. However, the obstacle for performing this measurement is also the mode of operation of PHIN, since a very long RF conditioning period would be needed to increase the train length. In addition for 5 µs trains a beryllium vacuum window would be required [11].

The XPS measurements showed that XPS analysis is a powerful tool for studying photocathode degradation processes. Also for this study more measurements would be needed to draw a conclusion.

ACKNOWLEDGEMENT

The authors would like to thank M. Brugger and M. Delonca for their work on the vacuum window for PHIN. This project has received funding from the European Union's Seventh Framework Program for research, technological development and demonstration under grant agreements 289191 (LA3NET) and 291783 (COFUND).

ISBN 978-3-95450-147-2

REFERENCES

[1] A Multi-TeV linear collider based on CLIC technology: CLIC Conceptual Design Report, edited by M. Aicheler et al., CERN-2012-007.

[2] P. Urschütz *et al.*, "Beam dynamics and first operation of the sub-harmonic bunching system in the CTF3 injector", in *Proc. EPAC'06*, Edinburgh, UK (2006), p. 795.

[3] M. Csatari Divall *et al.*, "Fast phase switching within the bunch train of the PHIN photo-injector at CERN using fiber-optic modulators on the drive laser", Nucl. Instr. and Meth. A 659 (2011), p. 1.

[4] C. Hessler *et al.*, "Recent developments at the high-charge PHIN photoinjector and the CERN photoemission laboratory", in Proc. I*PAC'14*, Dresden, Germany (2014), p. 695.

[5] C. Hessler *et al.*, "Lifetime studies of Cs_2Te cathodes at the PHIN RF photoinjector at CERN", in *Proc. IPAC'12*, New Orleans, LA, USA (2012), p. 1554.

[6] C. Hessler *et al.*, "Recent results on the performance of Cs_3Sb photocathodes in the PHIN RF-gun", in Proc. *IPAC'15*, Richmond, VA, USA (2015), p. 1699.

[7] M. Petrarca *et al.*, "Study of the powerful Nd:YLF laser amplifiers for the CTF3 photoinjectors", IEEE J. Quant. Electr. 47 (2011), p. 306.

[8] I. Martini, "Characterization of Cs-Sb cathodes for high charge RF photoinjectors", PhD thesis, Politecnico di Milano, Milano, Italy (2015).

[9] I. Martini *et al.*, "Surface characterization at CERN of photocathodes for photoinjector applications", in Proc. *IPAC'15*, Richmond, VA, USA (2015), p. 1703.

[10] I. Martini *et al.*, "X-ray photoemission spectroscopy studies of cesium antimonide photocathodes for photoinjector applications", Phys. Proc. 77 (2015) p. 34.

[11] M. Brugger, M. Delonca, and C. Hessler, CERN internal report, EDMS #1287386 (2013).

ISBN 978-3-95450-147-2