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Within the CLIC (Compact Linear Collider) project, feasibility studies of a photo injector option for the drive beam as an alternative to its baseline design using a thermionic electron gun are on-going. This R&D program covers both the laser and the photocathode side. Whereas the available laser pulse energy in ultra-violet (UV) is currently limited by the optical defects in the 4thharmonics frequency conversion crystal induced by the0.14 ms long pulse trains, recent measurements of Cs3Sbphotocathodes sensitive to green light showed their potential to overcome this limitation. Moreover, using visible laser beams leads to better stability of produced electron bunches and one can take advantages of the availability of higher quality optics. The studied Cs3Sbphotocathodes have been produced in the CERN photo emission laboratory using the co-deposition technique and tested in a DC gun set-up. The analysis of data acquired during the cathode production process will be presented in this paper, as well as the results of lifetime measurements in the DC gun.

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Within the CLIC (Compact Linear Collider) project, feasibility studies of a photoinjector option for the drive beam as an alternative to its baseline design using a thermionic electron gun are on-going. This R&D program covers both the laser and the photocathode side. Whereas the available laser pulse energy in ultra-violet (UV) is currently limited by the optical defects in the 4th harmonics frequency conversion crystal induced by the 0.14 ms long pulse trains, recent measurements of Cs_3Sb photocathodes sensitive to green light showed their potential to overcome this limitation. Moreover, using visible laser beams leads to better stability of produced electron bunches and one can take advantages of the availability of higher quality optics. The studied Cs_3Sb photocathodes have been produced in the CERN photoemission laboratory using the co-deposition technique and tested in a DC gun set-up. The analysis of data acquired during the cathode production process will be presented in this paper, as well as the results of life-time measurements in the DC gun.

INTRODUCTION

The 3rd CLIC Test Facility (CTF3) at CERN [1] is currently operated with a drive beam produced using a thermionic gun and a sub-harmonic bunching system. This baseline setup creates the required time-structure but generates also parasitic satellite bunches, which cause beam losses and radiation issues. The PHIN RF photoinjector has been developed at CERN to overcome this issue and to demonstrate the feasibility of a laser-based electron source for the CTF3 drive beam. With the PHIN RF gun and the phase-switching set-up installed on the laser bench, satellite-free beam production has been demonstrated [2]. The focus of the studies at PHIN has now shifted towards feasibility studies for the CLIC drive beam, whose beam parameters are more demanding and cannot be completely achieved with PHIN (Tab.1). Therefore, the studies at PHIN are complemented by studies in the DC gun at the CERN photoemission laboratory.

The main challenge for a drive-beam photoinjector is to achieve high bunch charges, long trains and high bunch repetition rates together with sufficiently long cathode lifetimes. For nominal PHIN parameters lifetimes of up to 300 h could be achieved with Cs_2Te cathodes using UV light [3]. For 140 µs long trains as needed for CLIC, however, the UV generation is a major issue, which is not yet solved. To overcome this issue, cathodes sensitive to green laser light, such as Cs_3Sb, have been produced and tested.

Table 1: CLIC and PHIN design parameters.

Parameter	**CLIC**	**PHIN**
Charge/bunch (nC)	8.4	2.3 (nominal) 9.2 (achieved)
Bunch length (ps)	10	10
Bunch rep. rate (GHz)	0.5	1.5
Number of bunches	70000	1800
Train length (µs)	140	1.2
Charge/train (µC)	590	4.1
Macro pulse rep. rate (Hz)	50	5
Charge stability (%)	<0.1	<0.25
Beam current/train (A)	4.2	3.4
Cathode lifetime (h) at QE>3% (Cs_2Te), QE>0.5% (Cs_3Sb)	>150	>50

CATHODES PRODUCTION BY CO-DEPOSITION

The cathodes have been produced and characterized at the CERN photoemission laboratory, where a dedicated preparation set-up and a 70 keV DC electron gun including a diagnostic beam line are available [4]. For measuring the electron beam current a Wall Current Monitor (WCM), a Fast Current Transformer (FCT) and a Faraday Cup (FC) are installed.

Co-deposition Process

The photoemissive layer is produced by the co-deposition process, which is also routinely used for Cs_2Te cathodes at CERN [4]. By evaporating Cs and Te (or Sb) at the same time, the metallic elements can mix together in the vapour phase and deposit as a compound onto the substrate, which results in excellent quantum efficiencies (QE) [4].

The stoichiometric ratio of the vapour mixture is controlled by two different thickness monitors, which are masked from the other element of the vapour flow, respectively. By illuminating the Cs_3Sb cathode with a green laser beam (UV for Cs_2Te) during the deposition cycle it is possible to monitor the QE and optimize the process by adjusting the evaporators' power supplies.

Figure 1 shows the typical behaviour of the stoichiometric ratio during the deposition in relation with the QE trend over time. A final QE measurement and a QE scan of the cathode surface are performed in the DC gun under realistic beam conditions after each cathode fabrication.

The rise of the QE during the first hours of electron beam generation in the DC gun, already observed for Cs_2Te cathodes [5], is relevant for Cs_3Sb cathodes (Fig. 2). This behaviour can lead to an improvement of almost up to a factor two of the initial QE value.

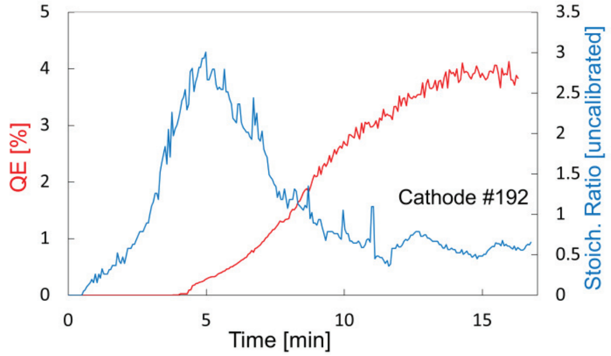

Figure 1: Co-deposition process on cathode #192.

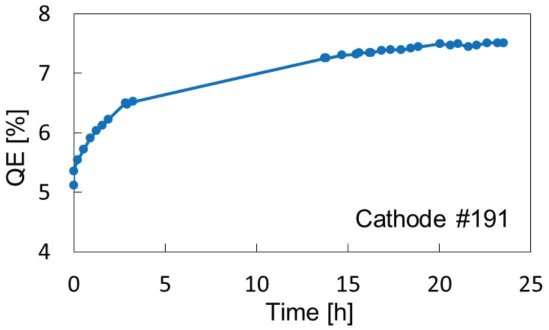

Figure 2: QE improvement for cathode #191.

Overview Over the Produced Cs_3Sb Cathodes

A summary of the Cs_3Sb cathodes produced at CERN by co-deposition so far is shown in Tab. 2. Excellent QE values of up to 7.5% have been obtained. An analysis of the production data did not show an obvious correlation between the QE and the final stoichiometric ratio or the evaporated quantity. Both for thick layers (#191) as well as very thin layers (#193), good QE values could be achieved. The final stoichiometric ratio can differ by a factor of 3.5 for similar QE values (#188 and #192). What might be important for achieving good QE values is the evolution of the stoichiometric ratio during the deposition cycle. For a detailed analysis more production data is needed.

CATHODE LIFETIME MEASUREMENTS

In addition to the QE, the cathode lifetime is the most important parameter of photocathodes, and related to that the produced integrated charge. Within the scope of the presented studies, the lifetimes of two Cs_3Sb cathodes (#188 and #192) were measured in the DC gun at the photoemission laboratory, probing them with green (532 nm) radiation of a Q-switched high repetition rate (up to 2 kHz) Nd:YAG laser (Quantronics model 532-DP). The electron bunch charge and the laser power were measured with a Fast Current Transformer (FCT) and a laser power meter, respectively, and therefrom the QE was computed. During the measurements the laser power was adjusted for keeping the photoelectron current at a chosen constant value: 1 μA (low average current measurement) and 120 μA (high average current measurement).

Table 2: Cs_3Sb cathodes produced by co-deposition.

No.	Initial QE (%)	Max QE (%)	Evaporated Cs (nm)*	Evaporated Sb (nm)*	Final stoich. ratio*
178	0.3	0.5	120	18.4	2.9
179	1.4	2.3	156	24.5	1.74
180	0.6	1.0	52	14.4	0.82
187	0.3	0.4	67.6	4.7	4.9
188	1.3	2.2	152	17.8	2.3
189	2.3	4.4	64	15	1
191	5.4	7.5	156	14	1.7
192	2.0	2.7	9.7	3.5	0.66
193	4.2	5.8	10.8	7.6	0.66

*uncalibrated

Low Average Current measurement

Cathode #188 generated a total charge of 321 mC at an average current of 1 μA over almost 4 days. Since this cathode was previously used for electron production, its QE at the beginning of the lifetime measurement was much lower than the fresh cathode QE listed in Tab. 2. The pressure in the DC gun was below the detection limit of the vacuum gauge ($p<10^{-11}$ mbar) for the whole duration of the experiment.

Figure 3 shows the QE decay for cathode #188 at 1 nC bunch charge. The QE dropped from 0.57% to 0.50% in 90 hours, leading to a 1/e cathode lifetime of 530 hours. The extrapolated lifetime is a factor of 3 higher than the lifetime previously measured at the PHIN photoinjector with a Cs_3Sb cathode and the same average current [6]. However, the vacuum in the DC gun was at least two orders of magnitude better than in PHIN and a larger impact on the lifetime would have been expected.

High Average Current measurement

Cathode #192 was tested at high average current (120 μA) using a larger beam size (σ~1.5 mm). The total extracted charge is 33 C over 3 days. Despite some peaks due to breakdowns, the pressure in the gun stayed below $8*10^{-11}$ mbar during the experiment. Figure 4 shows the rapid QE decreasing from 2.07% to 0.09% in 75 hours. The 1/e lifetime is ~19 h.

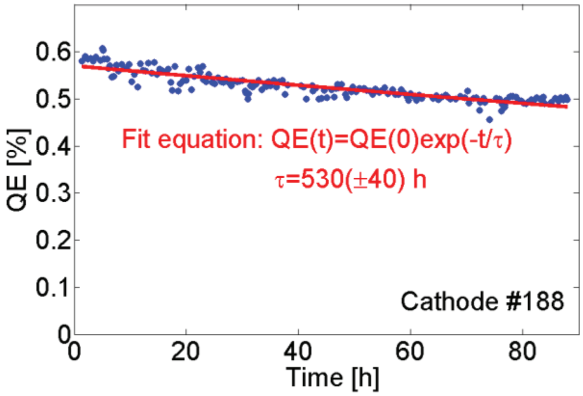

Figure 3: Cathode #188 tested at 1 μA average current.

This significantly lower lifetime is related to the high electron beam current. Photocathode degradation is in general due to chemical poisoning (residual gas contamination, mainly oxidation) and radiation damage (mainly ions bombardment) [7]. Whereas the detrimental reactions due to the background vacuum level and stimulated desorption generated by field emitted electrons are independent of the beam properties, contamination related to beam losses induced desorption and damage for ion back bombardment depends on the beam current. The much shorter lifetime compared with the low average current measurement can therefore be attributed to the dynamic vacuum level. Similar lifetimes have been observed at PHIN in the past when the vacuum level was ~$4*10^{-9}$ mbar, but the average beam current much lower. The reason why with a better vacuum a similar lifetime is achieved in the DC gun might be explained with ion back bombardment, which is more relevant in DC than RF guns [8].

In Fig. 5 QE maps are shown, resulting from scans of the cathode surface with a pencil laser beam, after the cathode production (left) and after the high average current measurement (right). The initial flat top distribution experienced an overall QE reduction, which can be attributed to poisoning of the cathode due to the beam induced high vacuum level. In addition there is a peak with QE=0.8% in the centre of the cathode, where the laser beam hits the cathode. The transversal dimensions of this peak are comparable with the estimated laser beam spot size. One possible explanation of this peak might be a laser cleaning process, which is in competition with the QE degradation. The same behaviour was already observed during high current electron beam production with Cs_2Te and UV laser beam in the same setup [5].

CONCLUSION AND OUTLOOK

With the co-deposition process high quality Cs_3Sb cathodes were produced, which represent an important step forward in the photoinjector R&D programme within the CLIC project. Further investigations of the photoemissive layer with XPS analysis are planned to get a better understanding and a subsequent improvement of the co-deposition production process. The lifetime measurements in the DC gun setup have shown very promising results for Cs_3Sb cathodes at low average beam current. As a result of the quick degradation of the thin cathode #192 under high average beam current, it may be considered to study cathodes with thicker photoemissive layers.

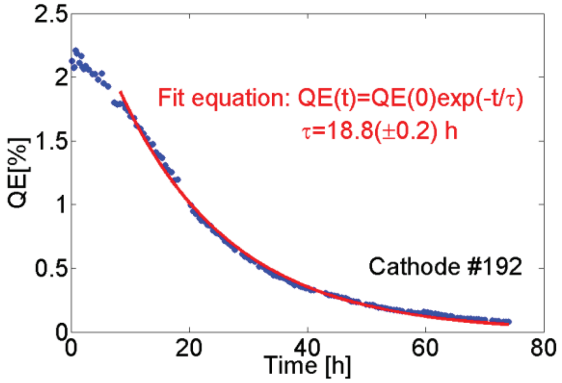

Figure 4: Cathode #192 tested at 120 μA average current.

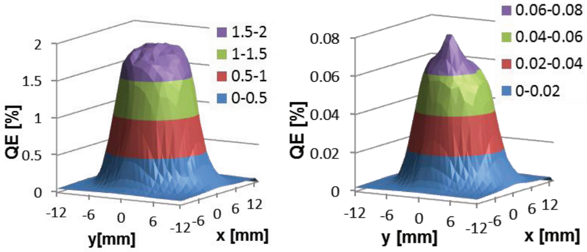

Figure 5: QE map of Cathode #192 before (left) and after (right) measurement at 120 μA.

The recently produced cathodes are foreseen to be tested in the PHIN RF photoinjector with beam parameters beyond the nominal PHIN values to get closer to CLIC requirements. However, the final proof of feasibility of a photoinjector as the CLIC drive beam source can only be achieved with a RF gun specially designed for CLIC parameters.

ACKNOWLEDGMENT

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REFERENCES

[1] G. Geschonke, A. Ghigo, CTF3 Note 2002-047, CERN, Geneva (2002).

[2] M.Csatari Divall et al., Nucl. Instr. And Meth. A 659 (2011) p. 1.

[3] C.Hessler et al., Proc. IPAC'12, New Orleans (2012) p. 1554.

[4] E. Chevallay, CTF3 Note 104, CERN (2012).

[5] E. Chevallay et al., CTF3 Note 020, CERN (2001).

[6] C. Hessler et al., to be published

[7] R. Barday, K. Aulenbacher, AIP Conf. Proc., Vol. 915, pp. 1019-1024 (2007).

[8] R.P. Filler III et al., Proc. PAC'05, Knoxville (2005).