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PHOTO-CATHODES FOR THE CERN CLIC TEST FACILITY

E. Chevallay, J. Durand, S. Hutchins, G. Suberlucq, H. Trautner

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Since 1993 the CLIC Test Facility (CTF) has used laser-illuminated Tellurium Alkali photo-cathodes as intense electron sources (up to 50 nC in 10 ps), for the Drive Beam of a two-beam accelerator. These cathodes have been produced and tested in our photo-emission laboratory and transported under vacuum to the CTF. They are placed in a 3 GHz RF gun with a 100 MV/m electric field. This RF gun produces a train of 48 pulses, each of 13.4 nC charge and 10 ps length. The CTF Probe Beam has used air-transportable cesium iodide + germanium photo-cathodes in another RF gun, which produces a single pulse of the same duration but with only 1 nC charge. The optical damage threshold in the laser is the main limitation of energy available on the photo-cathode. From an operational point of view, the photo-cathode lifetime is defined to be the time during which the cathode is able to produce the nominal charge with the nominal laser energy. After having recalled the main characteristics of the photo-cathodes tested, this note describes in more detail the performance obtained in operation. The possibility of photo-cathode production at the RF gun in a simplified evaporation chamber will also be discussed.

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1 INTRODUCTION

The CLIC Test Facility (CTF) produces and tests two different electron beams: one, with a high charge (up to 640 nC in 48 pulses), called the "Drive Beam" (DB) is used to produce 30 GHz radio frequency power. The other, called the "Probe Beam" (PB), with a lower charge of 1 nC in a single pulse, is used to sample the 30 GHz accelerating fields. A summary of results from CTF-II is reported in [1]. The electron source for each beam is a 3 GHz RF gun equipped with a laser-driven photo-cathode. The photo-cathode requirements are closely related to the electron beams and the laser characteristics.

2 PHOTOCATHODE REQUIREMENTS

2.1 *Electron beam specifications*

The electron beam specifications are summarized in Table 1. The repetition rate was reduced from 10 to 5 Hz to improve the vacuum in the DB RF gun and consequently to improve the photo-cathode lifetime.

Table 1 : Electron beams specifications.

		DB	PB
Charge per bunch	nC	13.4	1 - 2
Number of bunches	-	48	1
Pulse width FWHM	ps	10	10
Δt between pulses	ps	330	-
Charge stability	% rms	1	5
Jitter laser / RF	ps	± 1	± 1
Jitter DB / PB	ps	± 1	± 1
Delay PB / DB	ns	-	14
Cathode electric field	MV/m	100	70
Repetition rate	Hz	5	5

2.2 *The CTF-II laser system*

The laser (Fig. 1 and Ref. 2) is a "Master Oscillator-Power Amplifier" (MOPA) system in which 2 pulses are selected from a 250 MHz Nd:YLF mode-locked oscillator. The pulses are 8 ps and they have an energy of 0.5 nJ per pulse. They are amplified in a Regenerative Amplifier (RA), followed by power amplifiers to 7 mJ per pulse. The power density is 10 GW/cm^2 at the final power amplifier. This is close to the damage threshold since the beam is limited to 4.5 mm diameter due to the size of the components. The wavelength is converted from 1047 nm to 262 nm (the 4th harmonic). The 2 UV pulses are then progressively "split" with appropriate delays in a "Pulse Train Generator" (PTG) to produce the DB train of 48 pulses with 333 ps separation. The separation is exactly one 3 GHz RF period so that each light-pulse will illuminate the photo-cathode at the same RF phase and the resulting electrons will then be equally accelerated. The timing for the laser and the 3 GHz RF generator are synchronized.

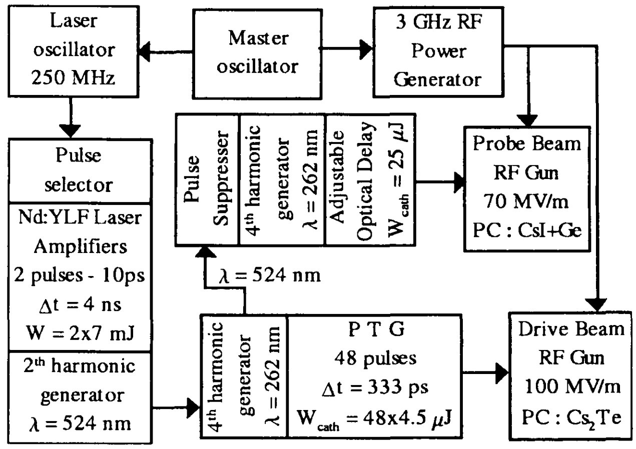

Figure 1: Laser layout for the Probe and Drive Beam

The residual green light from the initial 4[th] harmonic generator is used to produce a pulse for the PB. This initially passes through a Pockels cell that rotates the polarization of the second green pulse by 90°, this is then rejected by a polarizing plate. The remaining pulse is converted to UV.

The two light beams are imaged to their respective cathodes, for the DB the distance is 32 m with a magnification of 2x. The PB is delayed to arrive at the accelerating section in the linac when the 30 GHz power has been generated, making its path length equal to 36 m.

Finally, 48 pulses of 4.5 μJ at 262 nm arrive at the DB photo-cathode, and a single pulse of 25 μJ with the same wavelength on the PB photo-cathode.

2.3 Photo-cathode requirements

The photo-cathodes are characterized by their quantum efficiency (QE, the ratio of emitted electrons to incident photons) at a given wavelength and by their lifetime under operating conditions. Taking into account the available laser energy, QE must be greater than 1.5 % at 262 nm for the DB, and greater than 0.02 % for the PB at the same wavelength. The lifetime required is at least one week for an electric field in the DB RF gun of 100 MV/m. When a new cathode is installed in the PB RF gun to be operated at a field of 70 MV/m, it is necessary to bake-out the gun due to air contamination. For this reason, the lifetime must be at least one month for continuity of operation. The charges produced must be linearly related to the laser energy up to 640 nC (48 pulses of 13.4 nC) for the DB and 2 nC for the PB. In both cases, the time response must be less than a few ps.

3 PHOTO-CATHODES TESTED IN THE RF GUN

The photo-cathodes are produced and tested in a separate photo-emission laboratory. Only cathodes with properties near-nominal are installed in the CTF guns. Metallic cathodes were also tested [3], a magnesium cathode could be a candidate for the PB, but its QE is low and it has a high dark current. In the context of an informal collaboration with the Stanford Linear Accelerator Center, non-activated GaAs cathodes were tested in the DB gun with electric fields up to 87 MV/m. An activation process for GaAs is under development. The results are reported in [4,5].

Between December 1990 and October 1993 CsI photo-cathodes were used because they can be transported in air [6]. Unfortunately, their photo-emission threshold is high (6.3 eV) involving the use of the fifth harmonic of a Nd:YLF laser (λ=209 nm). This wavelength was found to be impractical, so the possibility of using photo-cathodes at the fourth harmonic (λ=262 nm) were investigated, and a system for transferring the cathodes under vacuum was developed. At this wavelength alkali photo-cathodes are able to produce high charges, and many were tried in the photo-emission lab [3]. Two kinds which matched our laser equipment and the CTF specifications were selected. The first type, for the PB, is a cesium iodide cathode with a coating of germanium. This cathode can be transported in air at the expense of a moderate QE at 262 nm. For the DB, cesium telluride was chosen because of its high QE at 262 nm and long lifetime, but it must be transported under vacuum. The complete results for these two cathode types are reported in [7,8]

3.1 CsI+Ge photo-cathodes

A thin 2 nm coating of germanium over a CsI cathode decreases the QE at 213 nm by a factor of 10, but improves it at 262 nm from $7x10^{-5}$ to 0.13 % [3]. This coating does not change the air exposure property of the CsI. To improve adhesion, a 200 nm layer of aluminum is deposited on the copper cathode plug before the 350 nm CsI layer, which is then coated with 2 nm of Ge. These photo-cathodes are stored in a desiccator. Finally they are installed, in air, in the RF gun which is then baked to 150°C to improve the vacuum. These cathodes require a delicate conditioning process using high electric fields and laser pulses to remove the oxidized surface without destroying the thin germanium layer. After 10 to 15 hours of processing, the QE reaches up to 0.2 % with an electric field of 70 MV/m. The lifetime is quite long: the time constant τ (the time to drop down to QE_{max}/e) is more than one year. In the PB gun, the same cathode has been used since October 1996.

3.2 Alkali telluride photo-cathodes

Four kinds of alkali telluride photo-cathodes were produced and tested on different substrates: Cs_2Te, K_2Te, Rb_2Te and RbCsTe. Only the first one is routinely used in the DB RF gun. All require UV light (λ < 270 nm) for operation.

Cs_2Te : about 10 nm of Te is deposited at room temperature on various substrates (Cu, Mo, Mg). The Cs is evaporated with the substrate at 110 °C until the photo-emission reaches a maximum. Typically 15 nm of Cs gives a QE of 7 %. These cathodes are very robust compared to the alkali antimonide cathodes. The working pressure is about 10^{-9} mbar. The main contamination comes from oxygen [9]. A satisfactory behavior was observed in the RF gun up to 127 MV/m. At this field level, the initial QE is close to 10 %. The QE drops during the first 50 hours with a $\tau \approx 40$ hours, followed by a slower decrease with a $\tau \approx 350$ hours. The time response is less than 2ps; the measurement is limited by the resolution of the streak camera. An electric field dependence of the QE was observed this is probably a Schottky effect [10], and seems to be independent of the Cs_2Te photo-cathode aging rate.

K_2Te : This was found to be a robust photo cathode, but with a QE between 1 to 3 % at 262 nm.

Rb_2Te and RbCsTe : About the same properties as Cs_2Te

cathodes. These cathodes seem very promising for QE rejuvenation after exposure to air. Nevertheless their performance in the RF gun must be demonstrated.

The photo-cathode substrate : Various kinds of substrates have been used : molybdenum, magnesium, and copper, the best results were obtained with Mo and Mg. Due to its higher dark current Mg was eliminated. In terms of charge availability, (QE > 2 % during a few weeks), the substrate is not so important. The second slope of the lifetime curve seems to be almost independent of the substrate.

Between November 1993 and July 1998, 50 alkali photo-cathodes were produced. Twenty eight were used in the RF gun : 26 Cs_2Te, 1 K_2Te and 1 Rb_2Te. Table 2 summarizes the statistics (mean and standard deviation values) for the produced and used alkali photo-cathodes. The cathodes were measured in the DC gun at electric fields between 6 and 9 MV/m. R is the layer thickness ratio of alkali over tellurium. T is the total time of the photo-cathode in the RF gun, and $\tau_{QE>2\%}$ is the time during which the QE is greater than 2 %. About 30 % of the time mentioned in Table 2 was with RF power and laser. The vacuum pressure was about 10^{-9} mbar.

Table 2: Alkali photo-cathodes : Production and use.

Cathode type		Cs_2Te			All	
Substrate type		Cu	Mo	Other		
Production	Numb.	31	6	8	52	-
	QE_{MOY}	4.7	8.8	7.8	5.8	%
	QE_{STDV}	1.9	3.8	2.5	3	%
	R_{MOY}	1.2	1.5	2.6	1.6	-
	R_{STDEV}	0.5	0.2	2.5	1.3	-
Used in the CTF 70 < E < 125 MV/m	Numb.	15	6	5	28	-
	T_{TOTAL}	362	160	142	693	days
	T_{MOY}	24	27	28	25	days
	T_{STDEV}	23	23	24	22	days
	$\tau_{QE>2\%}$	20	17	14	19	days
	τ_{STDEV}	23	17	14	17	days

4 PHOTO-CATHODE PREPARATION

Three kinds of photo-cathode preparation can be identified depending on the QE and lifetime specifications. When high charge (> 10 nC per pulse), high QE and long lifetime are required (as for CTF DB), the cathode should be prepared by real time monitoring of the QE, then transported and installed in the RF gun in an ultra-high vacuum environment. For up to 1 nC per pulse, CsI+Ge photo-cathodes which can be transported in air give good performances, and lifetimes of a few months. For 1 to 10 nC per pulse it may be possible to produce photo-cathodes using more simple methods. One method would be to prepare the photo-cathode for a high QE, transport in air, then rejuvenate it in the RF gun, or in a vacuum chamber attached to the RF gun. We have tried two different rejuvenation processes: heating, and ion-bombardment etching. A Rb_2Te cathode was exposed to air during 7 minutes and its QE dropped to 10^{-5}. After heating to 200°C in vacuum, the QE improves to 0.5 %. We did not observe any further QE change during 1 week. Another RbCsTe cathode was exposed to air for 2 minutes, its QE dropped down to 0.1 %. After ion bombardment cleaning, its QE improved to 0.7 %.

The second possibility to obtain a medium charge i.e. a medium QE, is to prepare the photo-cathodes in a simplified preparation chamber linked to the RF gun. By monitoring only the layer thickness, the production of photo-cathodes with a QE between 1 and 3 % is possible. Such a cathode, with an initial QE of 2.5 %, has been used in the DB for 78 days with a QE > 2 %.

5 CONCLUSIONS

Cs_2Te and CsI+Ge cathodes fulfil the drive and probe beam CTF-II specifications. The Rb_2Te cathode, using a rejuvenation process, may be a good alternative to Cs_2Te. It is possible to produce Cs_2Te cathodes in an easier and cheaper way by monitoring only the layer thickness, this is however obtained at the expense of a lower mean QE.

A new vacuum chamber will be attached to the PB RF gun to enable laser alignment of the PB. This chamber will be equipped for a simplified cathode production and rejuvenation.

6 REFERENCES

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