First Operation of a Femtosecond Laser Driven Photo-injector

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Abstract

CANDELA photo-injector is a two cell S-band photo-injector. The copper cathode is illuminated by a 200 fs Ti:sapphire laser. This paper presents the preliminary experimental results. Measurements of the beam charge as a function of the laser/RF phase, the laser pulse energy, and the accelerating field are presented.

1 INTRODUCTION

CANDELA photo-injector is a two decoupled cell 3 GHz RF gun. Its design is described in references [1, 2, 3]. The Ti:sapphire laser system designed by the "Institut d'Optique Théorique et Appliquée" at Orsay is presented in reference [4]. The RF conditionning of the gun and the dark current measurements are reported in reference [5]. This present paper concentrates on the first experimental results about photo-electrons. The preliminary experiments reported were done during the fourth trimester of 1993. Since the laser illuminating the cathode has a pulse length of 200 fs, and since all other photo-injectors in the world have lasers with pulse length longer then 1 ps [6], this experiment can be considered as the first photo-injector driven by a "femtosecond" laser.

The only measurable parameter at the time of the experiments was the pulse charge. Therefore the results presented here show the variation of the charge with the following parameters: laser/RF phase, laser energy, and accelerating field.

2 EXPERIMENTAL SETUP

The gun described in reference [3], is powered by an old THOMSON TV2013 that can deliver a maximum measured peak power of 2.6 MW. This power is shared between the two cells in a way that the peak accelerating field is equal in the two cells. Its value at full power is 65 MV/m. In these preliminary experiments, the RF phase between the two cells was kept fixed.

Right at the gun exit, a wall current monitor (WCM) allows to measure the peak current and the position of the beam. The beam then goes into a coaxial Faraday cup having a 3 GHz bandwidth. The signal from the WCM and the Faraday cup are recorded on a TEKTRONIX TDS520 oscilloscope. Figure 1 shows a schematic of the experimental arrangement.
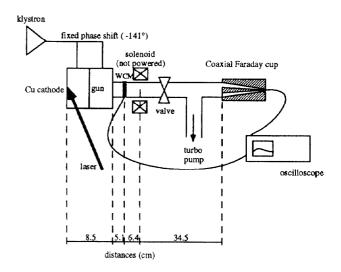

Figure 1: *Experimental setup*

The laser is a Ti:sapphire laser described in reference [4]. It produces one single pulse (at 12.5 Hz), 200 fs long with an energy of 225 μJ at 260 nm. The optical path between the laser room and the gun cathode (around 25 m long) includes several lenses that were not covered by an anti-reflection coating at the time of the experiment. The overall efficiency of the light transport was therefore as low as 50%. The laser light is injected into the gun via one of the two 54°30' entry port. The laser is focused onto the cathode and its size is roughly estimated to be 5 mm.

The laser is synchronized to the RF frequency via an

electronic feedback loop that is driving a piezo-electric transducer that adjusts the laser oscillator cavity length. Due to problems with the mounting of the cavity mirror on the piezo transducer, the overall bandwidth of the feedback loop was not large enough to ensure a small jitter between the laser and the RF wave. This jitter was typically 40 ps rms. This fact made the measurements very uneasy, since this jitter led to large amplitude fluctuation of the signal.

3 EXPERIMENTAL RESULTS

3.1 Typical signal

Figure 2 shows a typical signal of the photo-current pulse seen by the Faraday cup. The width of the signal is due to the long cable that transports it to the control room.
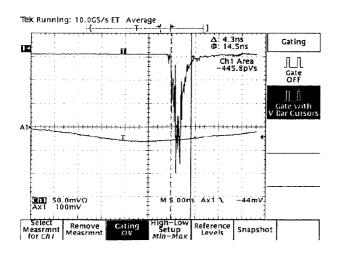

Figure 2: *Typical Faraday cup signal from a photo-current pulse (top trace)*

3.2 Charge vs. relative laser/RF phase

Only a certain span of the relative phase between the laser and the RF wave allows acceleration of the electrons emitted by the photocathode. Figure 3 presents the extracted charge as a function of the laser/RF phase, showing that the possible phases only span over 120 degrees. The triangular shape of this curve is due to a rather large spot size when compared to the beam aperture of the cavity. If the phase is not optimized, the outer electrons are easily scraped by the cavity aperture. This explanation is supported by a simulation made with the PIC code PRIAM [7]. If the laser spot size is made smaller, the shape of the curve "current vs. phase" looks like a trapezoid.

3.3 Charge vs. laser energy

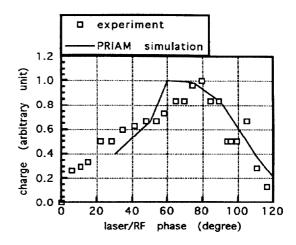Figure 4 shows the charge as a function of the laser energy on the cathode, measured both by the Faraday cup

Figure 3: *Charge vs. relative phase between laser and RF*

and the WCM. The slight discrepancy between the two measurements is due to the fact that the WCM signal is recorded on one of the four outputs, while beam was not well centered. From the slope of the Faraday cup curve, it is possible to calculate the effective quantum efficiency of the cathode. Its value is 5×10^{-6}, which is already rather high for copper. It should be noted here that this set of measurements was made for a rather low accelerating field of 55 MV/m.
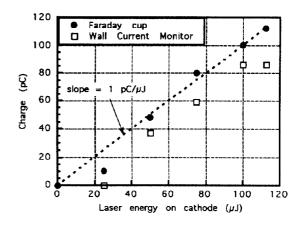

Figure 4: *Charge vs. laser energy*

3.4 Charge vs. accelerating gradient

Figure 5 shows the variation of the charge with the accelerating gradient. The fit shown on the figure represents Schottky law. According to this law, the emitted current

is expressed by:

$$J = aI(h\nu - \phi + \sqrt{\beta E})^2 \qquad (1)$$

where a is a constant, I is the laser energy, $h\nu$ the photon energy, ϕ the work function of the cathode materiel, β the field enhancement factor and E the electric field on cathode. Similar behaviour was also measured at Brookhaven [8].

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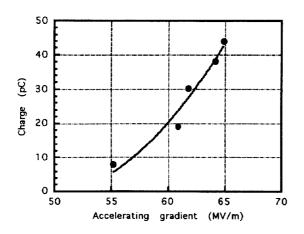
Figure 5: *Charge vs. accelerating gradient*

4 CONCLUSION

The first photo-electrons produced by a femtosecond laser driven RF gun were measured. A total charge of 0.11 nC was extracted under moderate accelerating field. A separate measurement has shown that due to Schottky effect, going to higher field would increase by a rather large factor the emitted charge. As we install the beam transport line and the various diagnostics, other beam characteristics will be measured.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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