CANDELA PHOTO-INJECTOR EXPERIMENTAL RESULTS

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Abstract

The CANDELA photo-injector is a two cell S-band photo-injector. The copper cathode is illuminated by a 500 fs Ti:sapphire laser. This paper presents energy spectrum measurements of the dark current and intense electron emission that occurs when the laser power density is very high.

Introduction

The CANDELA photo-injector is an RF gun made of two decoupled 3 GHz cells [1, 2, 3]. The Ti:sapphire laser system used to illuminate the photocathode was designed by the "Institut d'Optique Théorique et Appliquée" at Orsay [4]. CANDELA was first operated at the end of 1993, thus being the "first femtosecond laser driven photo-injector" [5]. A maximum charge of 0.11 nC was extracted corresponding to an effective quantum efficiency of 5 $\times 10^{-6}$. Since these experiments, we have had several problems with the laser system, so that we could not do many new experiments. The results presented in this paper are divided in two parts: new measurements on dark current, especially the energy spectrum and new measurements on photo-electrons, showing that above a certain laser power density, intense electron emission is observed.

Experimental setup

The gun is powered by an old THOMSON TV2013 klystron that can deliver a maximum measured peak power of 2.6 MW. This power can be shared between the two cells with an arbitrary ratio. The RF phase between the two cells can be freely adjusted by a high power phase shifter.

As shown in figure 1, the gun is followed by a short beamline including the different diagnostics used to measure the parameters of the beam (charge, position, transverse density, emittance, energy, energy spread and bunch length). Not all the diagnostics were completed at the time of the experiments. Only the following ones were available: 2 wall current monitors (WCM) to measure the charge and position of photo-electron pulses, a coaxial Faraday cup for charge measurement on the straight line behind the first dipole, a slit with isolated jaws to measure the energy, and a fluorescent screen with a TV camera for beam transverse observation.

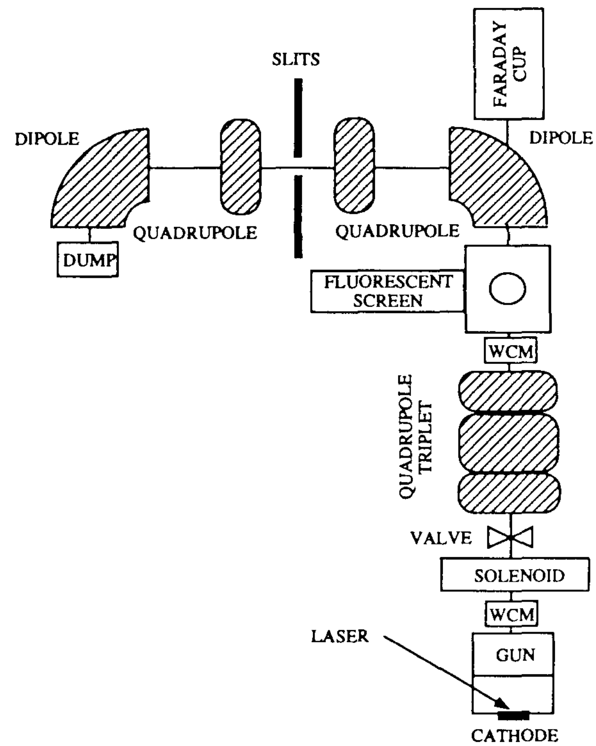

Figure 1: Experimental setup

The laser is a Ti:sapphire laser described in reference [4]. It produces one single pulse (at 12.5 Hz), with an adjustable duration from 150 fs to 15 ps, with a maximum energy of 2.5 mJ at 800 nm. Figure 2 presents an autocorrelation trace of a 280 fs pulse produced at 800 nm. 225 μJ of UV light (260 nm) is then obtained through third harmonic generation in BBO crystals. Though no pulse length measurements can be done on UV pulses, one can assume that due to dispersion in the crystals, the laser is somewhat longer (typically 500 fs). The optical path between

*Present address: GANIL, BP 5027, F-14021 Caen the laser room and the gun cathode (around 25 m long) includes several lenses and mirrors. The overall measured efficiency of the light transport system is 75%. The laser light is injected into the gun via one of the two 54°30' entry ports. The laser is focused onto the cathode and different spot sizes can be obtained by changing the last lens position. No UV camera was available to measure the exact spot size.

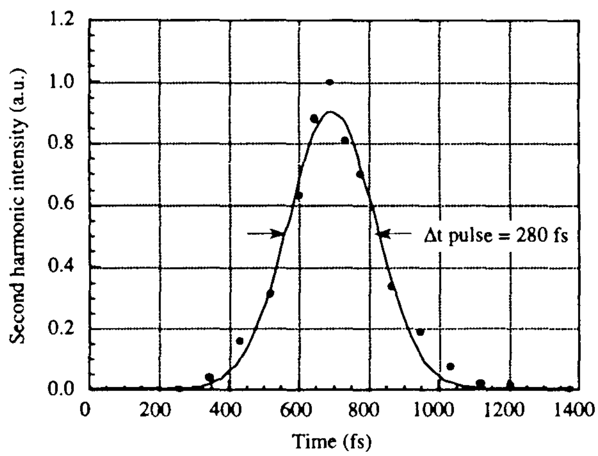

Figure 2: Autocorrelation trace of the IR laser pulse

Normally, the laser is synchronized to the RF frequency via an electronic feedback loop that is driving a piezoelectric transducer that adjusts the laser oscillator cavity length. However, at the time of experiments reported here, this system was not working, so that the relative phase between the laser and the RF was random.

Dark current measurements

When an RF cavity is submitted to very high fields, electrons are emitted through the field emission process. Some of them are captured and accelerated, thus resulting in a parasitic current named dark current. Results on the dark current measurement of the CANDELA RF gun have already been published [6]. However, at the time of these first measurements, it was not possible to measure the energy spectrum of this dark current. These spectra are now obtained by reading the current flowing through one of the two jaws that obtruct the vacuum chamber after the bending magnet (see fig. 1). This method allows a resolution of 5%. Figure 3 shows three spectra obtained when only the first cell is powered at different levels. They all have the same shape, with two peaks. The lower energy peak corresponds to electrons directly emitted by the cathode, as shown by PARMELA [7] simulations. The high energy peak corresponds to electrons emitted by the exit nose of the cavity, accelerated backward to the cathode, backscattered with most of their impinging energy and fully accelerated again, thus having almost two times the energy of the electrons directly emitted by the cathode. This explanation is sustained by simulations done with the code TW-TRAJ [8].

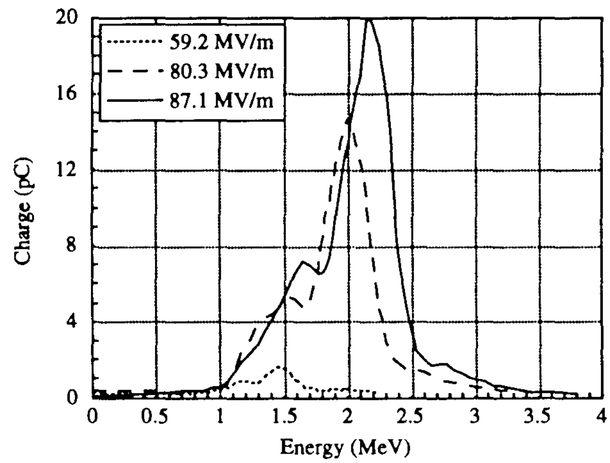

Figure 3: Energy spectrum of the dark current emitted by the first cell for three different peak accelerating fields

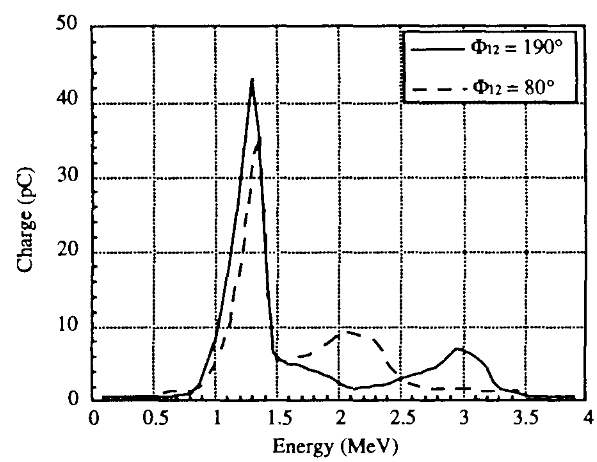

Figure 4: Dark current spectrum from the complete gun for two different phase shifts between the cells

The energy spectrum of the dark current extracted from the complete gun is more difficult to interpret. Figure 4 shows two spectra obtained for two different phase shifts between the two cells. The low energy peak is independent of the phase and therefore is probably due to the second cell entrance nose. The high energy peak depends on the phase and thus comes from electrons emitted in the first cell, either by the cathode or by the exit nose. The peak centered around 3 MeV probably comes from electrons emitted by this exit nose and backscattered by the cathode, since simulations show that cathode electrons can have at maximum an energy of 2.35 MeV.

These energy spectra exhibit somewhat more complicated shapes than the spectra measured on the Brookhaven RF gun [9]. This is due to the noses of the cavities and the facility to vary the phase between the two cavities.

Photo-electrons measurements

Since the first photo-electron measurements reported in reference [5], very few new measurements could be made. The only new result is the observation of an intense electron emission above a certain laser power density. Figure 5 shows the charge and pulse length observed on the oscilloscope as a function of the laser energy. In the low laser fluence regime, the full width pulse length is 1 ns (limited by cable and oscilloscope bandwidth) corresponding to the normal photoemission process, with an efficiency of 1 pC/μJ, as was already measured before [5]. Above a certain energy treshold, the pulse length suddenly increases to 50 ns, and the emitted charge becomes very high (up to 35 nC). This phenomena has already been observed at Brookhaven [10] where the intense electron bursts were also measured to be around 50 ns long, and the laser fluence threshold for their production was 10^9 W/cm^2.

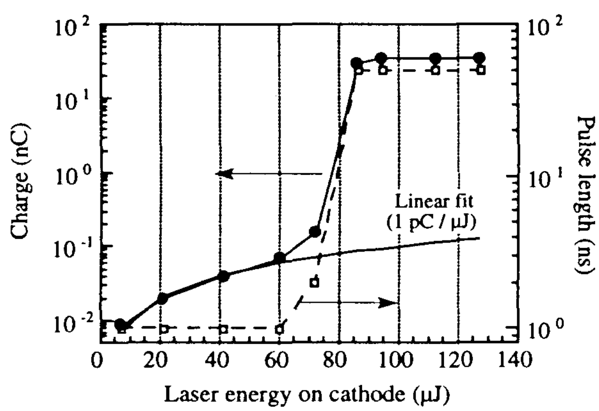

Figure 5: Charge and pulse length as a function of laser energy

In our experiment, we could not measure precisely the laser spot size. If we suppose the same fluence threshold as Brookhaven, we can infer from figure 5, a laser spot radius of 2 mm, which sounds reasonable.

By changing the position of the last grating in the laser compressor, it is possible to vary the laser pulse length in the range 0.5 - 15 ps. By lengthening the pulse, we checked that it was possible to suppress the intense emission process. If we increased the laser spot size, the energy necessary to obtain the intense emission was changed. These two facts confirm that the intense emission is related to laser power density.

As we tried to maximize the extracted charge in the normal photoemission process by enlarging the laser spot size, the largest charge obtained was 240 pC. In practice, this intense emission process limits the use of very short intense laser pulses with low quantum efficiency cathodes. For example, with a 2 mm spot diameter, which would normally be required in CANDELA gun (knowing that the cavity aperture is only 10 mm), the maximum charge that one can extract in the photoemission regime is limited to 16 pC, assuming a quantum efficiency of 5×10^{-6}. Even if one operates the gun at very high gradient on the cathode, thus taking advantage of the Schottky effect, the charge will still be limited to less than 200 pC. For this reason, the copper cathode will soon be replaced by a dispenser cathode that has a measured quantum efficiency of 5×10^{-4} [11].

Conclusion

This paper described two sets of measurements done on CANDELA rf gun: the dark current spectrum and the intense emission process obtained for large laser fluence. This phenomenon not well understood so far, limits the maximum extractable photemitted charge. It can be avoided by the use of more efficient cathodes.

Acknowledgements

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