CANDELA PHOTO-INJECTOR EXPERIMENTAL RESULTS WITH A DISPENSER PHOTOCATHODE*

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Abstract

The CANDELA photo-injector is a two cell S-band photo-injector. The dispenser photocathode is illuminated by a 500 fs pulse from a frequency-tripled Ti:sapphire laser. In this paper we report charge measurements showing that the dispenser photocathode has a quantum efficiency as high as 10^{-3}. This efficiency decreases with a lifetime of 12 hours, but can be recovered by heating the cathode during 5 minutes.

I. INTRODUCTION

The CANDELA photo-injector is an RF gun made of two decoupled 3 GHz cells [1], [2], [3], [4]. The laser system used to illuminate the photocathode is a Ti:sapphire laser designed by the "Institut d'Optique Théorique et Appliquée" at Orsay [5]. CANDELA was first operated at the end of 1993 [6], with a copper photocathode. A maximum charge of 0.11 nC was extracted corresponding to an effective quantum efficiency of 5×10^{-6}. For laser fluences larger than 1 GW/cm^2, very high charge can be produced (up to 35 nC), but in this case the pulse length is increased to 50 ns [7]. Since this "intense emission" process limits the maximum charge that can be obtained in the normal photoemission regime, we replaced the copper photocathode by a dispenser cathode that has a quantum efficiency more than 100 times better [8]. This paper presents the first results obtained with this cathode.

II. CATHODE CONDITIONING

The dispenser cathode (S-type) is normally used as a thermionic cathode in klystrons and electron guns for linear accelerators. The cathode we are using has a non-standard diameter of 9.2 mm, and was fabricated for us by THOMSON TTE (Velizy), according to their standard fabrication procedure. The cathode consists of a porous tungsten matrix impregnated with barium calcium aluminate (4 BaO, 1 CaO, 1 Al_2O_3). This W matrix is heated via a filament. A thin molybdenum jacket is used to diminish heat losses (see figure 1).

The details of the cathode mounting in the gun cavity have already been reported [3]. The RF contact is made via a tungsten spring. In order to keep the required cathode heating power at a reasonable level, the part of the cavity in contact with the spring, is made of stainless steel which has a low thermal conductivity (see fig. 1).

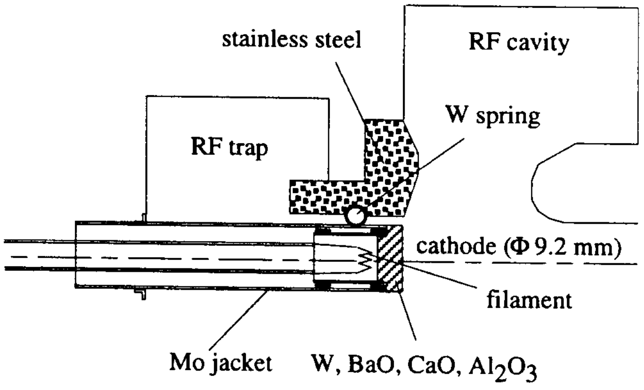

Figure. 1. Schematic of the cavity with dispenser cathode

The cathode first needs to be conditioned to 1200°C, in order to break the alumina and oxides molecules, so that free atoms of Ba and Ca can diffuse to the surface. During this conditioning, one has to maintain a vacuum pressure not higher than 10^{-6} mbar. But since the outgassing is quite significant during this procedure, it can not be done inside the gun due to the limited pumping speed. However, since it was shown before that this cathode could sustain exposure to air without losses in photoemissive properties [8], the conditioning is made in a specific vacuum chamber, with a pumping speed of 400 l/s. After conditioning, which lasts for about 5 hours, the cathode is installed in the gun. This latter operation takes around one hour.

After the cathode installation, the gun is baked out at 150°C for three days. Then, the cathode should be slightly reconditioned. This is done by heating it to 1100°C for 5 minutes. This corresponds to a heating power of 56 W. These two operations should be done each time the gun and cathode have to be exposed to air.

III. LASER AND BEAMLINE

The laser is a Ti:sapphire laser described in reference [5]. It produces one single pulse (at 12.5 Hz), with an adjustable duration from 150 fs to 15 ps, and a maximum energy of 200 μJ at 260 nm.

The laser synchronization and modelocking starter systems have been improved since the description given in reference [5]. Originally, the starting of the modelocking and the synchroniza-

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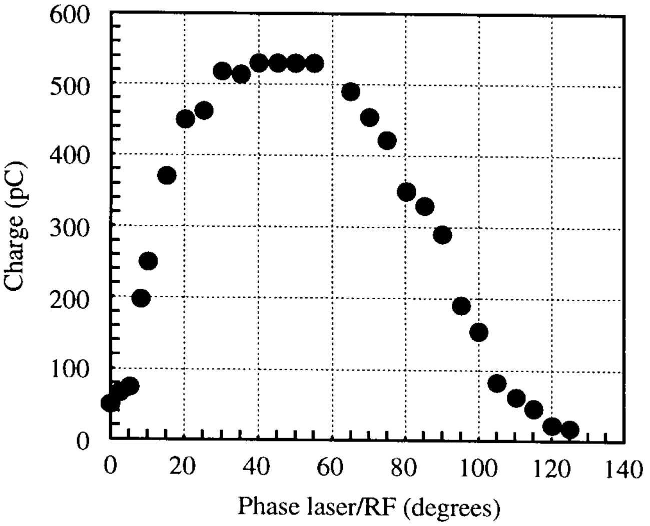

Figure. 2. Charge vs. laser/RF phase

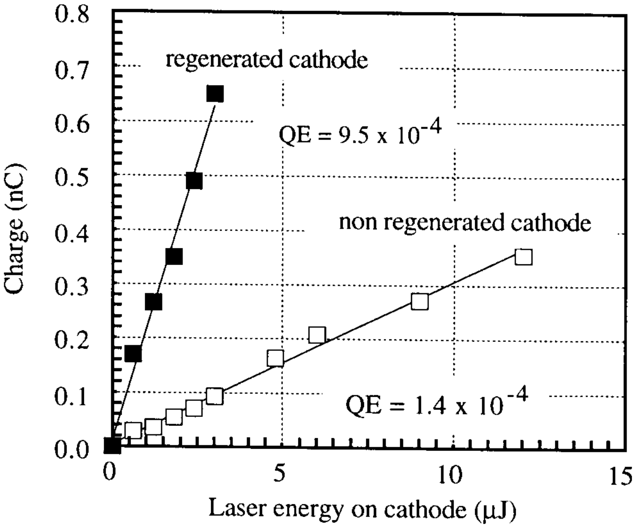

Figure. 3. Quantum efficiency of dispenser cathode

tion of the laser frequency with the RF master oscillator were made via a single piezo-electric transducer on which one of the mirrors of the laser oscillator cavity was mounted. These operating conditions were not very comfortable, since very often we lost the modelocking operation while trying to lock the laser to the RF frequency. To improve this situation, we decoupled the two functions. The modelocking starter is now made with a pair of oscillating Brewster plates [9]. The synchronization is still achieved via a piezo-electric transducer and the slow thermal drifts are compensated by a translation stage driven by a DC motor. This new system proved very efficient and reliable.

The beamline including the beam diagnostics devices is described in reference [7]. At the time of measurements presented here, the first wall current monitor located right at the gun exit was not available. The charge measurements reported in the next sections were made with the coaxial Faraday cup situated about 1 m downstream of the gun, and an integrator. They were obtained in the following conditions:

- the laser pulse length is set to the sub-picosecond regime
- the laser illuminates the cathode with a 54.5 degrees angle with respect to normal incidence
- only the first cell of the gun is powered with 1.06 MW, which corresponds to a peak on axis field of 68 MV/m and a cathode field of 50 MV/m
- the relative phase between laser and RF is chosen to optimize the extracted charge. The typical dependence of the charge with this phase is shown on figure 2.

IV. QUANTUM EFFICIENCY AND LIFETIME

Figure 3 shows the measured charge as a function of the laser energy on cathode. The slope of these curves gives the effective quantum efficiency (QE) including the potential losses in the beam transport. Two different curves corresponding to two different situations are shown. The lower efficiency curve is obtained with the photocathode at room temperature after several hours spent in the gun at a residual static vacuum pressure better that 10^{-10} mbar (a few 10^{-9} with RF on). In these conditions the efficiency is just slightly above 10^{-4}. In order to improve the efficiency by almost one order of magnitude, it is necessary to regenerate the cathode prior to operation. This is done by heating it to around 700°C, during five minutes (this corresponds to 25 W of heating power). After letting the cathode cool down during 15 minutes, it is ready to operate. In these conditions, the QE almost reaches 10^{-3}, which is better than any pure metallic cathode[1]. Due to the pollution caused by the residual gas, the QE then drops with time. If the lifetime is defined as usual as the time necessary to decrease the QE by a factor 1/e, the cathode operated at cavity temperature (31°C), has a lifetime of only two hours. However, the lifetime is improved drastically by slightly heating the cathode during operation. The temperature should of course stays below the thermoemission threshold. In our case we use 6 W of heating power. Under these conditions, the lifetime is increased to more than 12 hours. At any time one can recover the original QE by regenerating the cathode according to the procedure described above.

V. SATURATION

The charge that can be extracted from the photocathode is limited by space charge effects. When the charge increases, the self field of the bunch can balance the accelerating field, so that no more charge can be extracted. Since the laser transverse profile is not uniform, but closer to Gaussian, the charge reaches the limit in the center of the cathode first. As explained by Hartman et al. [10], the charge can still be increased till the limit is reached also on the edge. See figure 4 for the results corresponding to the dispenser cathode with and without regeneration.

During these experiments, we did not have any camera to monitor the laser transverse profile. However, by fitting the experimental data of figure 4 with the theoretical model of the saturation effect as described in reference [10], it is possible to infer the spot size. Figure 4 shows the result of this fit assuming a laser profile with a gaussian distribution truncated at $\pm 3\ \sigma$.

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[1] Magnesium for example has an efficiency of 5×10^{-4}[11]

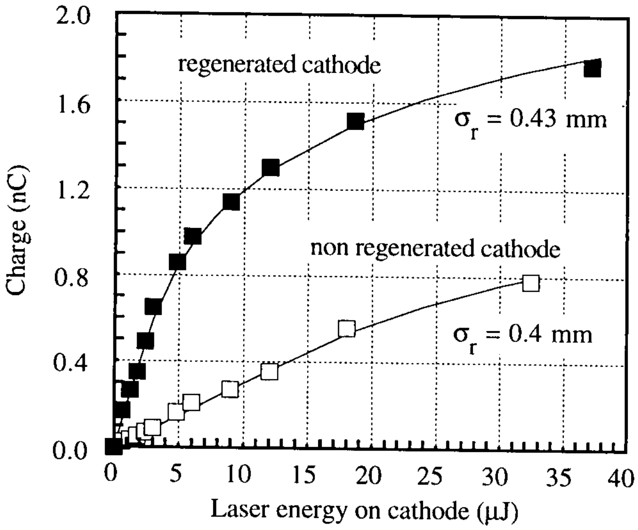

Figure. 4. Charge saturation

VI. FUTURE PROSPECTS

In the near future, the other parameters of the beam will be measured, especially the pulse length and emittance. The pulse length will be measured by observing, with a streak camera (resolution $<$ 2 ps), the Cerenkov light produced by a 300 μm thick sapphire. The emittance will be measured both with the three gradient method and with the ”pepper-pot” method.

VII. CONCLUSION

This paper has described the first use of a dispenser photocathode in a S-band RF gun. It is shown that this type of cathode when properly conditioned and operated, has a quantum efficiency of 0.1 %, which is better than that of pure metallic cathodes. The lifetime of this cathode is larger than 12 hours, and the original quantum efficiency can be recovered in 20 minutes, by heating. A total charge of 1.8 nC was measured, only limited by saturation effects due to the relatively small spot size.

VIII. ACKNOWLEDGEMENTS

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