POWER TESTS OF A PLD FILM MG PHOTOCATHODE IN A RF GUN

G. Gatti, L. Cultrera, F. Tazzioli, INFN/LNF, Frascati, Roma, A. Perrone INFN-Lecce (Lecce University), P. Musumeci, J. Moody, UCLA, Los Angeles, CA

Abstract

Metallic film photo-cathodes are rugged, have a fast response and good emission uniformity. Mg has also a relevant Quantum Efficiency (QE) in the near UV. A cathode suitable for a 1.5 cells S-band RF gun has been produced by depositing an Mg film on Cu by Pulsed Laser Deposition (PLD) technique. After different optimizations, stable good results have been reached in the low field measurement scenario. A sample was deposited on a gun flange and tested in the 1.6 cell injector at UCLA Pegasus facility to prove cathode resistance in a high field environment. The results are described.

INTRODUCTION

Mg films deposited by PLD have shown a long term stability performance in the framework of low field testing [1]. Advantages are good uniformity of emission through the surface (better than 20%) and a QE response in the near UV one order of magnitude higher than conventional copper cathodes. Performances in high field environment have still to be proved. Troubles could be given by poor adhesion of the film to the substrate, both during normal operating conditions and especially during the gun conditioning process. In fact, the frequent strong arch events could remove completely the coating from the substrate. That is why the power test represents the key step for proving the convenience in the use of this deposition technique for realization of cathodes suitable for rf photo-injectors.

CATHODE PREPARATION

Deposition is achieved in UHV chanber using the UCLA/BNL type 1.6 cell gun back flange as a substrate ablating a Mg rotating target surface by mean of a XeCl excimer laser. The ejected material impinges on the substrate, located in front of the target itself at 5.5 cm distance. Laser wavelenght is 308 nm and pulse lenght is 30 ns. Deposition took place in vacuum environment whose pressure was 5E-8 mbar. 5000 laser shots were delivered in order to remove the polluted layers of the target; during this time, the substrate was shielded to avoid contaminants. Afterwards, the deposition took place using a mask for delimiting the area to be covered. The sample taken in consideration here under test has been deposited through 30000 shots with a fluence of 10 J/cm^2, for a final thickness of about 0.5 μm.

INSTALLATION AND CONDITIONING

After deposition, the cathode has been shipped for being installed inside Pegasus photo-injector at UCLA. Since no closed gas environment has been used for transportation, the sample is expected to be polluted. In fact the formation of the oxide layer over Mg, when exposed to air is very fast, as proven for the samples tested in low field environment [2]. As widely known, it is necessary, after exposure to air, to operate a surface activation (e.g. laser cleaning) in order to recover the high Mg QE. During the installation of the cathode, the gun was easily tuned through the standard capacitive back flange deformation. After a visual inspection, and standing to the good vacuum conditions (pressure better than 1E-8 mbar) it can be stated that mechanical stress in the cathode addressed by the tuning process didn't affect the Mg film in a negative way. Afterwards, no difference was noted in the conditioning process respect to the copper case, while scratches on the cathode surface [3] would have generated strong archs, making conditioning very slow, and probably impossible to get to high fields. After conditioning process, the RF gun was able to operate routinely at 100 MV/m peak field for some months, and the Mg cathode is still installed in order to test its long term resistance.

DARK CURRENT MEASUREMENT

The experimental apparatus, showed in Fig.1 is composed by the gun, focusing solenoid and Faraday cup (FC), plus the signal acquisition section.

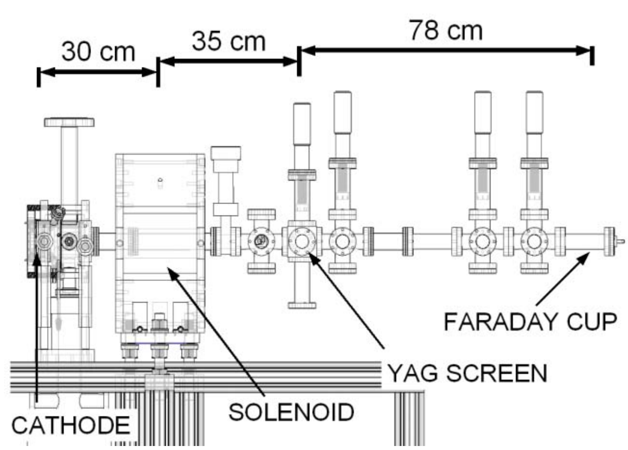

Figure 1: Measurement setup layout.

The current coming out of the FC was read by mean of a noise filter and an oscilloscope. Obviously, the current pulse was occuring during the RF pulse duration, 1.5 μs long in this case. Moreover, inside this time slot, the dark current structure is given by a train of pulses centered on the RF peak field [4]. Inside this framework the dark current was measured integrating all the peak contributions over the RF pulse duration giving average current values on the order of some μA (charge of some pC). This situation can be modelled modifying conventional Fowler-Nordheim formula for a sine wave variable field case[3]

$$\bar{I}_F = \frac{5.7X A_e (\beta E_0)^{2.5}}{\phi^{1.75}} \exp\left(\frac{-6.53X10^9 X\phi^{1.5}}{\beta E_0}\right)$$

It was not necessary to change the focusing strenght of the solenoid, in order to collect all the charge in the FC for different field values. I.e. the solenoid field was hence fixed at 1300 kG where the charge was maximum.

In Fig.2 it is shown the value of the collected current vs. the applied peak field.

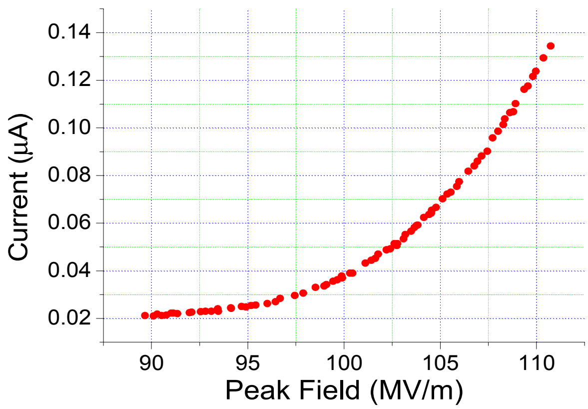

Figure 2: Darck current vs. accelerating RF field.

In order to extract information from this measurement, some assumptions have to be done. First of all it is assumed that the main contribution for the current comes from the cathode area, and the other zones emitted electrons are not delivered by the system to the FC [4]. Afterwards, some assumptions on the cathode work function φ can be done to get an estimate of the cathode field enhancement factor β and emission effective area A_e. Putting the previous data in the form of a Fowler plot, Fig.3 is obtained.

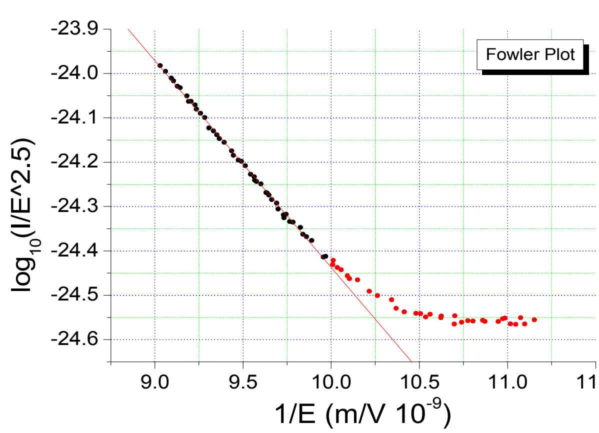

Figure 3: Fowler plot of the cathode dark current.

What theory states is a linear behaviour for the Fowler-Nordheim plot. Moreover it can be seen that for large field values, the curve becomes linear as expected. It could be assumed that the "shoulder" of the plot is given from an intermediate level in which different areas start to emit at a different field level, according to their local geometric enhancement factor. Above this treshold, the total emission area stays the same, and the cathode emission finally obeys Fowler-Nordheim theory. Here it will be considered just the part of the curve above the treshold. A linear fit of such a plot gives the values for the field enhancement factor and the emission area. Just an assumption on the working function of the cathode is necessary. Taking in account that for clean Mg the working function is 3.6 eV [2], what can be expected is a higher value generated by the oxide layer. Moreover, past quantum yield measurements on oxided samples conducted with 4.66 eV photons [5] (266 nm wavelenght) showed that in this case the work function is above the photon energy, with a two-photon emission response (4.66 eV $<\varphi<$ 9.32 eV).

Plotting the enhancement factor versus the workfunction, the situation is the one depicted in Fig. 4.

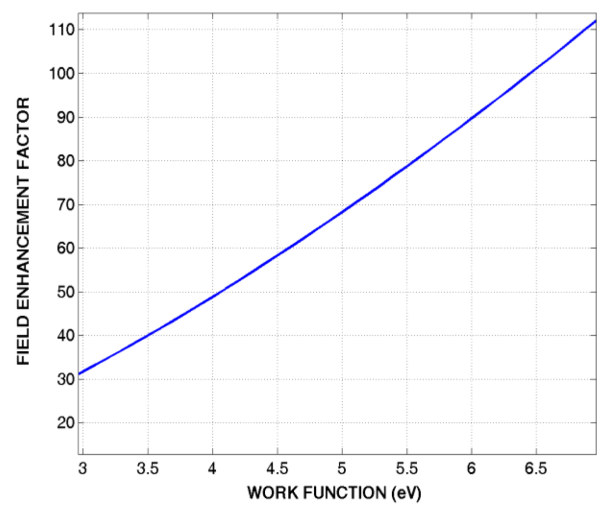

Figure 4: Field local enhancement factor vs. work function.

It is known from literature [3], that acceptable values for the enhancement factor are within the interval 40-100, for normal surface roughnesses. This would bring a workfunction greater than 3 eV, as already stated.

QE MEASUREMENT

Dark current measurement was followed by the quantum efficiency evaluation. The cathode was illuminated by a Ti:Sa laser (Pegasus photo-injector driver), able to deliver up to 10 μJ on its third harmonic (266 nm) on a time duration of 30 fs FWHM. The spot size on the cathode was set at 0.7 mm radius. Recalling generalized Fowler-Dubridge theory on multi-photon emission [7] it is possible to write the expression for the cathode current as a superposition of different contributions:

$$\boldsymbol{J}(\boldsymbol{r},t)=\sum_{-\infty}^{+\infty}\boldsymbol{J}_{\boldsymbol{n}}(\boldsymbol{r},t)$$

where

$$\boldsymbol{J}_{\boldsymbol{n}}(\boldsymbol{r},t)=a_n(\frac{e}{h\nu})^n A(1-R)^n I(\boldsymbol{r},t)F(\frac{nh\nu-\phi}{kT(\boldsymbol{r},t)})$$

Here A is the Richardson coefficient, e the electron charge, $(1\text{-}R)^n$ the nonlinear bulk absorption coefficient, T is the sample temperature, I the laser intensity, and F is Fowler function a_n is an empyrical parameter linked to the probability for the n-photon emission. Dropping out the zero order one (i.e. thermoionic emission) the dominant contributions are the n-th where nhυ>φ. For low enough intensity, the dominant term is given by the lower order multi-photon emission above the treshold (work function). This information can be very useful in order to give an estimate of the cathode working function. In fact, looking at the emitted charge versus incident laser energy (Fig. 5).

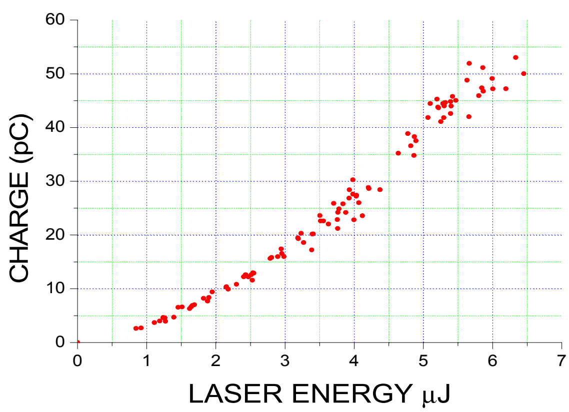

Figure 5: Cathode Quantum yield at 266 nm.

It is straightforward to notice that the emission plot has a nonlinear behaviour, most likely quadratic. This is a proof that the sample got oxided, increasing its work function to a value higher than the single photon energy and lower than two-photon energy at 266 nm (at 90 MV/m). This measurement proves the need for a future surface activation process. The peak QE in this case is 3E-5; anyway the quantum yield here expressed is not laser intensity indipendent as for the linear photo-emission [7] , so it is a parameter to be specified together with the working intensity level.

In the near future it will be operated a surface activation by mean of laser irradiation. During this operation, the laser fluence will be set slightly above the surface ablation treshold in order to remove only the oxide layer and not to damage the actual cathode. Special care will be addressed in setting up such a procedure, because the Mg cleaning treshold was retrieved in the low field testing (Pth≈0.1 GW/cm^2), operating with ps laser pulses. Several studies [8] reveal different phenomenas occuring when a metal surface is irradiated in the picosecond rather than the femtosecond regime. That is why classical empyrical scaling laws, such as

$$P_{Th}\propto\sqrt{\tau_{PULSE}}$$

would give a rough approximation of the right power to be delivered on the sample.

CONCLUSIONS

PLD Mg cathode has shown to be resistant in the RF gun environment, withstanding the conditioning process. As expected, dark current and quantum efficiency show that the cathode work function rose for effect of the oxide layer generated by air exposure. A surface activation through laser irradiation will be made soon in order to restore clean Mg QE. Special care must be addressed in this task, using femtosecond laser pulses, since conventional scaling laws cannot be applied. Further tests on this sample are foreseen.

REFERENCES

[1] L. Cultrera et al., Appl. Surf. Sci. 2007.
[2] H. Sommer, “Photoemissive Materials”, New York, Wiley 1968.
[3] J. W. Wang and G. A. Loew, “Field emission and rf breakdown in high gradient room-temperature linac structures”, SLAC-PUB-7684, 1997.
[4] I. Bohnet et al., “Dark current measurement at the PITZ rf gun” , Proc. of DIPAC 2003.
[5] G. Gatti et al., proc. of PAC 2005, 1350.
[6] L. Cultrera et al., Proc. of Linac 2006, 356.
[7] Bechtel et al., Opt. Commun. 13, 56 (1975).
[8] A. Semerok et al., Appl Surf. Sci. 138-139 (1999) 311-314.

1-4244-0917-9/07/$25.00