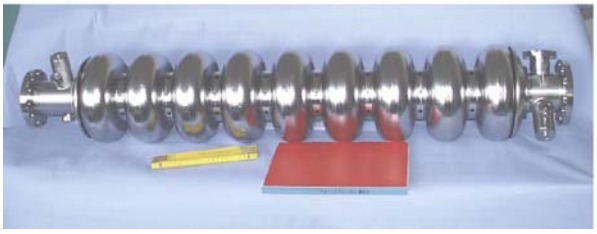
EU contract number RII3-CT-2003-506395 CARE-Conf-06-062-SRF

SRF 

METAL FILM PHOTOCATHODES FOR HIGH BRIGHTNESS ELECTRON INJECTORS

G. Gatti, L. Cultrera, F. Tazzioli, C. Vicario,
INFN-LNF, Frascati (Roma) Italy.
A. Perrone ,
Lecce University, Physics Dept. and INFN, Lecce, Italy.
C. Ristoscu,
Laser Dept., National Institute for Laser, Plasma and Radiation Physics, Bucharest-Magurele, Romania.
J. Langner, M. Sadowski, P. Strzyzewski.
IPJ-Swierk,Warsaw, Poland.
S. Orlanducci, A.Fiori,
Dip. Scienze Chimiche and INFN, Rome University Tor Vergata, Roma, Italy

Abstract

Advanced high brightness injectors require photocathodes with fast response, high quantum efficiency and good surface uniformity. Both Mg films deposited by laser ablation and Pb films deposited by vacuum arc could satisfy these requirements. Their emission and morphology are compared.

Proceedings of EPAC 2006, Edinburgh, Scotland

Work supported by the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395)

METAL FILM PHOTOCATHODES FOR HIGH BRIGHTNESS ELECTRON INJECTORS

G. Gatti*, L. Cultrera, F. Tazzioli, C. Vicario, INFN-LNF, Frascati (Roma) Italy.
A. Perrone , Lecce University, Physics Dept. and INFN, Lecce, Italy.

C. Ristoscu, Laser Dept., National Institute for Laser, Plasma and Radiation Physics, Bucharest-Magurele, Romania.
J. Langner, M. Sadowski, P. Strzyzewski. IPJ-Swierk,Warsaw, Poland.
S. Orlanducci, A.Fiori, Dip. Scienze Chimiche and INFN, Rome University Tor Vergata, Roma, Italy.

Abstract

Advanced high brightness injectors require photocathodes with fast response, high quantum efficiency and good surface uniformity. Both Mg films deposited by laser ablation and Pb films deposited by vacuum arc could satisfy these requirements. Their emission and morphology are compared.

INTRODUCTION

The main requirements on photo-cathodes for the advanced electron sources of ultra-bright electron beams are prompt response, high QE, defined as the number of emitted electrons per incident photon, at wavelengths affordable by existing lasers, low thermal emittance and reasonable lifetime [1][2]. Metallic cathodes are fast (tens of femtoseconds range) but their QE is rather low as compared with alkali semiconductors. These however have a slower response and their lifetime is short. In addition they are delicate to handle, requiring UHV both during transport and in operation. Metals are sturdier and a few of them, such as Mg,Pb,Y have reasonable QEs at near UV wavelength. Bulk Mg cathodes are already in use in some injectors. Mg disks inserted by press fitting in the end Cu plate of a RF gun cavity have shown problems of RF breakdown at the junction [3]. Moreover, QE uniformity over the irradiated area can be remarkably not uniform [4]. High quality metal films deposited directly on the gun plate could circumvent such problems. Sputtered Mg films have already been tested. They are rugged and exposition to air forms a protective oxide layer that can be easily removed by laser ablation (laser cleaning) [5]. However, when tested in the very high electric fields of a RF gun, the sputtered Mg films have been damaged by discharges during RF conditioning process [6]. This is attributed to poor quality of the film, especially regarding uniformity and adhesion. A key parameter determining the quality of a deposited film is the kinetic energy of the particles impinging on the substrate. Therefore it is worthwhile to study alternative deposition processes with inherent higher particle energies, as pulsed laser deposition (PLD) [7] and vacuum arc discharge [8].

* Giancarlo.Gatti@lnf.infn.it

FILM DEPOSITION TECHNIQUES

The PLD deposition apparatus is made up of an UHV chamber containing the Mg target to be ablated and the substrate to be coated. A powerful pulsed laser beam from a XeCl excimer laser (wavelength = 308 nm, pulse duration= 30 ns), injected through a quartz window, impinges on the target and forms a plume of Mg vapour. The substrate is placed in the plume cone at a suitable distance from the target. More details are reported in [9].

An advantage of the PLD method with respect to magnetron sputtering is the high kinetic energy of the evaporated material particles reaching the substrate surface. The kinetic energy distribution depends on various parameters, mainly the laser fluence. With our experimental conditions, one may estimate an average of 50 eV against 10 eV in magnetron sputtering. The high kinetic energy enhances adhesion of the coating material to the substrate. Drawbacks are the presence of droplets on the surface and limited film thickness. I.e. PLD films are limited to a few microns, while other techniques can easily grow films to a larger thickness (20 microns). Anyway different improvements have been achieved and are in course to overcome these issues.

The Vacuum Arc deposition technique is an interesting alternative because the kinetic energy of the particles is high, certainly more than in sputtering technique PLD [10]. Moreover, being the projectiles charged, it consents efficient filtering of neutral droplets. Both techniques afford the advantage of clean vacuum environment. A complete stand for the deposition of Pb films is already operative at IPJ-Swierk Laboratories. Recently it has been demonstrated that the cathodic arc can be operated under UHV conditions thus strongly reducing contaminations by residual gas impurities.

EXPERIMENTAL APPARATUS

The QE measurement and laser cleaning apparatus consists of a test HV chamber, at 10^{-6} Pa background pressure, containing a vacuum diode of which the film to be tested constitutes the cathode. An UV 266 nm laser pulse, 30 ps duration, from a mode-locked frequency quadrupled Nd:Yag laser, is injected through a quartz window and excites the cathode. Accelerating electric fields up to 2 MV/m can be applied to the diode. The laser

beam crosses the anode through a fine copper wire mesh and illuminates the cathode at normal incidence. The emitted charge is sent via a coaxial cable to the input of a high speed oscilloscope or to a high sensitivity charge amplifier.

The measuring apparatus has been recently improved by building a new chamber with multiple ports that allows online mass spectrum analysis and illumination of the sample either at 0 or 70 degrees incidence. The larger angle avoids the usual anode mesh and allows studying the effect of laser beam polarization on emission.

SAMPLE PREPARATION

PLD Films

The PLD technique makes multilayer deposition of different materials viable within the same session, by using composite targets. That allows covering of the film with a thin layer, for protection tasks, or, alternatively, to enhance emission yield. A graphite protective layer has been tested. In that case, the target is Mg-C, with a Mg belt surrounding a Graphite core. The laser beam was shifted in succession from one zone to the other. The deposition parameters of two of these samples are shown in Table 1.

We have produced films with thickness from 0.2 to 2 microns covered with a 20 nm protective layer either of magnesium oxide or graphite. The Mg protective layer was grown by ablating the Mg target at 20 Pa oxygen atmosphere. The deposition parameters of a Mg-C sample are listed in Table 1.

Table 1. Deposition paramenters of the PLD deposited sample labeled Mg LE003.

SAMPLE	LE003
TARGET	Mg-C
SUBSTRATE	Cu
T-S DISTANCE	4.5 cm
LASER SPOT SIZE	1.1 mm^2
LASER FLUENCE	10 J/cm^2
DEPOSTION PRESSURE	$3.3x10^{-6}$ Pa
LASER PULSES	30000 on Mg & 9000 on C

Vacuum Arc Films

The Vacuum Arc Pb films have been deposited at IPJ Swierk Laboratories with the same apparatus used for the tests of the cathode for the SC RF gun project [8]. A collaboration between LNF and IPJ is in course to set up a similar apparatus for the deposition of Mg films.
(parametri del film)

MEASUREMENTS

A computer controlled laser cleaning procedure has been implemented in order to clean the surface gradually and uniformly, thus avoiding film deterioration.

PLD Mg

The laser beam was focused on the cathode surface, the laser spot having a diameter of about 300 μm. Once fixed the mean energy of the laser pulses to have an energy density of about 300 μJ/ mm^2, each cleaning step was carried out performing a double scanning raster on the irradiated area having size approximately 2x2 mm^2.

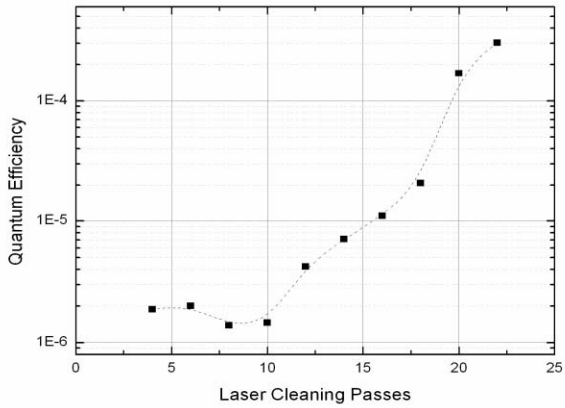


Figure 1:. QE versus number of cleaning scans.

After activation process, the laser beam diameter is enlarged to cover the emitting spot and its energy is strongly decreased to perform QE measurements far from space charge saturation limit. Improvements in measured QE on number of cleaning steps is reported in Fig.1.

Finally, QE values of few 10^-4 have been obtained with repeatable procedure. Unless unspecified all emission measurement were performed with an electric field equal to 1 MVolt/m.

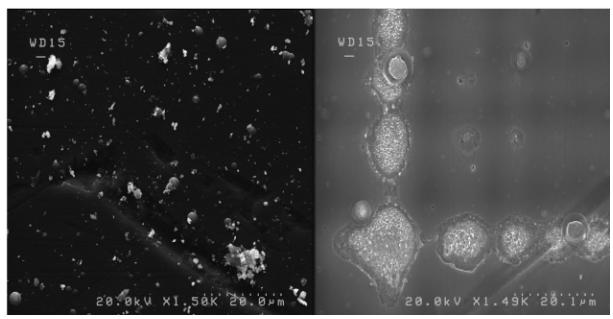


Figure 2: Left picture: As deposited sample surface; Right picture: after laser cleaning.

SEM analysis has been performed on sample surface before and after laser cleaning. The laser beam diffracted by the anode mesh creates a shadow network of high and low energy density lines that perturbs uniformity of cleaning process (calculations show 30% standard deviation in energy density through the surface).
Moreover, the laser beam can act morphological and even structural changes over the surface of the film. In Fig. 2 we show the SEM pictures before and after cleaning.

It is to be noticed that the cleaning action has removed the major part of droplets, and that in this case surface looks very smooth: darker and brighter lines are due to

the diffraction pattern described above, and are not due to uniformity of the film itself.

Vacuum Arc Pb

The performance of Pb as to emission efficiency is similar to the one of Mg, as expected from the close value of the two workfunctions, but the different sample synthesis technique leads to different surface morphology. A 2 μm thick film was measured.

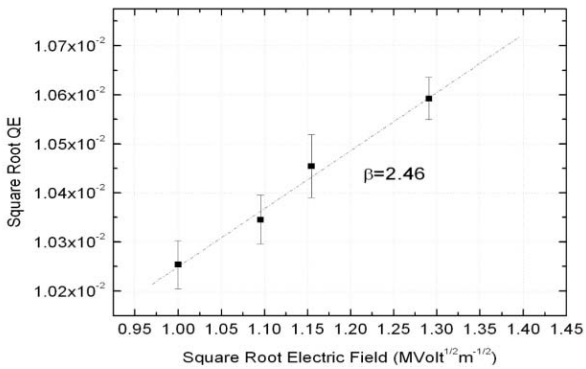


Figure 3: Pb QE vs. extraction field.

Both the environment and the cleaning procedure were the same as for the Mg case. Moreover, after laser cleaning, some QE versus field measurments were conducted, in order to calculate the β factor of field enhancement, in tight relation with roughness of the surface [12]. Maximum QE reached by Pb was slightly above 10^-4, as foreseen. These results are shown in Fig.3, with a final computed β of 2.46.

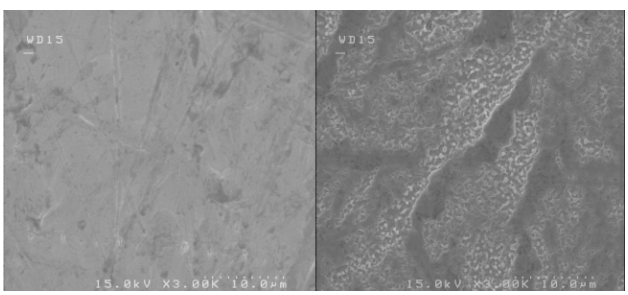


Figure 4 : Left picture: As deposited Pb sample; Right: after laser cleaning.

Post measurements analysis was performed once again by SEM. Microscopic analysis put in evidence a very good surface quality, on the untouched part of the surface. in Fig. 4 on a space scale of some micron. In the comparison between virgin surface, and after laser cleaning we can observe a changing in the surface structure, more evident in the areas of diffraction fringes maxima.

Final RF Gun Cathode

One of the goals of our research is the construction of a cathode suitable for operation in an RF gun.The cathode for the UCLA-BNL type 1.6 cells RF gun is obtained by deposition of a disk of emissive material on the central zone of the 10 cm diameter Cu end flange. Deposition tests of Mg films on dummy flanges by PLD have been successfully performed after different improvements on deposition of thick films. The final cathode is in course of construction and power tests in an RF gun are foreseen.

CONCLUSIONS AND OUTLOOK

Metallic Films produced by Vacuum Arc or PLD are promising candidates for the photocathodes required by high brightness electron sources.

Deposition parameters to obtain uniform and high QE films have been determined. A protective thin layer of graphite or MgO allows easy handling and conservation of the cathodes before installation in the RF gun.

The construction of a cathode to be tested at full power in an RF gun is in course.

ACKNOWLEDGEMENTS

This work is partly supported by
a) MIUR, Progetti Strategici, DD1834;
b) European Contract RII3-CT-PHI506395 CARE and contract no. 011935 -EUROFEL

REFERENCES

[1] Technical Design Report for the SPARC Advanced Photoinjector.http://www.lnf.infn.it/acceleratori/sparc
[2] W. Graves et al., Proc. of PAC conference, Chicago 2001
[3] X. J. Wang, M. Babzien, R. Malone, Z. Wu, LINAC 2002 Conference (2002) .
[4] D. T. Palmer, Ph.D. thesis, Stanford University, Dpt of Applied Physics, 1998.
[5] T. Srinivasan-Rao, J. Schill, I. Ben Zvi, M. Woodle, Rev. Sci. Instrum.,Vol 69, No 6, June 1998,2292-96.
[6] X.J. Wang et al, Linac 2002 Conference,142.
[7] Pulsed laser deposition of thin films, Ed. D.B. Chrisey, Wiley, New York, 1994.
[8] R. Russo et al, Supercond. Sci. Technol. 18 (2005) L41-44.
[9] L.Cultrera et al., Applied Surface Science 248 (2005) 397-401.
[10] A. Cianchi et al. Proc of EPAC 2004,1021-1023, Lucerne, Switzerland
[11] J.Smedley et al., PAC 2005 Conference
[12] W. Graves et al., Proc. of PAC conference, Chicago, USA 2001,2227-2229