MAGNESIUM FILM PHOTOCATHODES FOR HIGH BRILLIANCE ELECTRON INJECTORS

G. Gatti, F. Tazzioli, C. Vicario, INFN-LNF, Via E. Fermi 40, 00044 Frascati (Roma) Italy

I. Boscolo, S. Cialdi, University and INFN, Via Celoria 16, 20133 Milano, Italy

L. Cultrera, A. Perrone , Lecce University, Physics Dept. and INFN, Via per Arnesano, 73100 Lecce, Italy

M. Rossi, Rome University La Sapienza, Dip. di Energetica,Via A. Scarpa 16, 00101 Roma, Italy

S. Orlanducci, M. L. Terranova, Dip. Scienze Chimiche and INFN, Rome University Tor Vergata, Via della Ricerca Scientifica, 00133 Roma, Italy

Abstract

Advanced high brilliance electron injectors require photocathodes having low thermal emittance, high quantum efficiency (QE) and prompt response. They should be easy to handle and capable of working in the very high electric fields of a RF gun. Magnesium films deposited by laser ablation and sputtering techniques are discussed and QE measurements are presented.

INTRODUCTION

Advanced injectors of ultra-bright electron beams require photo-cathodes having prompt response and high QE at near UV wavelengths (266 nm) [1]. Metallic cathodes are fast (tens of femtoseconds range) but their QE, defined as the number of emitted electrons per incident photon, is rather low (order of 10^{-5} for Cu). Cesiated semiconductors show a higher QE but their response is slower and the lifetime is short. In addition they are delicate to handle, requiring UHV both during transport and in operation. Among metals, Mg has a premium QE, up to 10^{-3}. The higher QE would ease the requirements on the driving laser. Therefore it has been widely tested both as bulk and in the form of films. 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 [2]. Moreover, the distribution of QE varies over the emitting spot [3]. These problems could be overcome if a Mg film is deposited directly on the gun plate, provided that the film has good uniformity and adhesion to the substrate. Sputtered Mg films have been tested at low fields in a DC diode [4]. These films were 20 microns thick and deposited on Cu substrates in a 10^{-5} Pa background pressure. It was found that they are rugged and have a high QE. Exposition to air forms a protective oxide layer that can be easily removed by laser ablation (laser cleaning). However, when tested in the very high electric fields of a RF gun, the sputtered Mg films have been quickly degraded by RF discharges at the boundary. This is attributed to bad 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 we decided to study alternative deposition processes with inherent higher particle energies, as pulsed laser deposition (PLD) [5].

EXPERIMENTAL CONDITIONS

The sputtering technique is well known, so we will summarize only the PLD method that is less familiar. The PLD deposition method apparatus consists 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 (Fig. 1). More details are reported in [6].

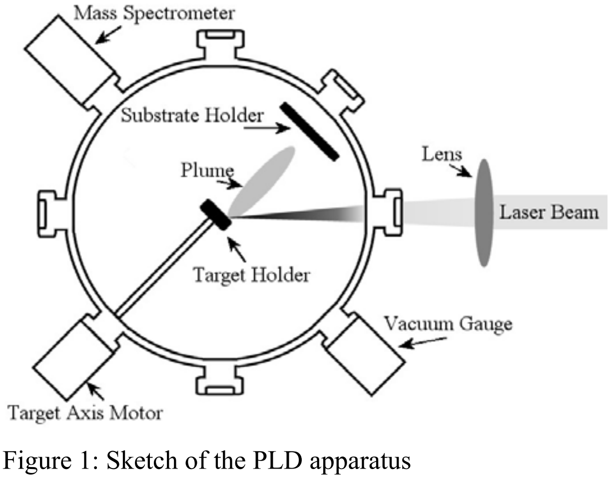

Figure 1: Sketch of the PLD apparatus

The main advantages of the PLD method, compared with the magnetron sputtering process, are the absence of gases to sustain the discharge and the high kinetic energy of the evaporated material particles reaching the substrate surface. The kinetic energy distribution depends on various parameters, principally the laser fluence. With our experimental conditions, one may estimate an average of 50 eV to be compared with 10 eV in magnetron sputtering. The high kinetic energy favours the adhesion of the coating material to the substrate. Droplets of material may form on the coated surface during deposition, unless particular masks and geometries are employed. Sputtered films can be grown to large thickness (20 microns), while PLD films are limited to less than two microns.

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 1 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 is similar to the one described in more detail in [7]. The laser cleaning is performed by focusing the beam to a 300 micron diameter and scanning it across the emitting area (2 mm diameter) by means of a movable mirror placed on a gimbal mount driven by motors.

SAMPLE PREPARATION AND MEASUREMENTS

Sputtered films.

We have acquired sputtered films from the same industry cited in the literature [3] to establish a term of comparison of our results with those reported there. The tested films were 10 microns thick and were shipped to us in pressurized envelopes under Nitrogen. We have measured them as received, without any polishing. It was easy to remove the thin layer of oxides and other compounds that had formed on the surface. However, the maximum QE we measured (10^{-4}) was an order of magnitude lower than that reported in [4]. This value, measured at low electric field, is a lower limit and can be improved. It is anyway satisfactory because the Cu cathodes commonly used can hardly reach this value with very special treatments. The structure of the films, analysed with an AF microscope, was crystalline with well-ordered columnar structure. Resistance to laser radiation was high. After bombardment with about 10^4 shots at 500 µJ/mm^2 laser energy density, the ablated depth was less than 1 micron.

A large film thickness consents a deeper cleaning ablation. This is important because the cleaning must be repeated periodically to re-activate the cathode, even in the RF gun UHV operating conditions

PLD films.

We have produced two sets of films. The first consisted of thin films, about 200 nm thick, covered with a 20 nm of magnesium oxide layer. The protective layer was grown by ablating the Mg target at 20 Pa oxygen atmosphere. The parameters of the deposition are listed in Table 1. The removal of the protective oxide layer is performed by scanning a focused (300 µm diameter) laser beam over the emitting spot (2 mm diameter), with an energy density of about 300 µJ/ mm^2.

Table 1: Thin PLD films deposition parameters

Sample	**1**	**2**
Target	Mg	Mg
Substrate	Cu	Cu
Target-substrate distance	6 cm	6 cm
Laser spot size	1.2 mm^2	1.2 mm^2
Base pressure	5 x 10^{-6} Pa	5 x 10^{-6} Pa
Laser pulses		
Cleaning	2000	2000
Deposition	10000	10000
Covering	2000	2000
Laser Fluence	5 J/cm^2	9 J/cm^2
QE	2.5x10^{-6}	5x10^{-6}

After activation, the laser beam diameter is enlarged to cover the emitting spot and its energy is strongly decreased to perform the QE measurement. Before activation, the response curve of charge versus laser energy is quadratic, due to the oxide layer. After its ablation the curve becomes linear, indicating a one-photon emission process. The low thickness of the films favours punch through during laser cleaning. The maximum QE achieved with thin films was 5x10^{-6}, very low. This poor performance was attributed to oxidation of the film in depth during the covering process. To avoid this drawback it was decided to deposit thicker films, about one micron, and to cover them with a thin layer of graphite, thus avoiding oxidation. One of the advantages of the PLD technique is the possibility of depositing different materials in succession in the same deposition session, by using composite targets. In our case, the target was 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 2.

Table 2: Thick PLD films deposition parameters

Sample	**3**	**4**
Target	Mg-C	Mg-C
Substrate	Cu	Cu
Target-substrate distance	4.5 cm	4.5 cm
Laser spot size	0.9 mm^2	0.9 mm^2
Base pressure	5 x 10^{-6} Pa	5 x 10^{-6} Pa
Laser pulses Cleaning Mg Deposition Mg Cleaning C Deposition C	 5000 30000 1000 2000	 5000 30000 2000 3000
Laser Fluence	6 J/cm^2	10 J/cm^2
QE	5x10^{-5}	3x10^{-4}

The structure and morphology of the films analysed with AFM and SEM, turns out to be a conglomerate of amorphous lumps of material, with interstices. The uniformity and compactness of the film depend on the laser fluence. The analysis of the composition distribution on the film surface by EDX indicates that the graphite was not completely removed by the laser cleaning, probably due to its filling the interstices.

The highest QE of these thick films, measured after laser cleaning, was 3 x 10^{-4}, quite satisfactory. It is connected with a large value of laser fluence. Therefore the direction of development is toward larger thickness and higher fluence.

THE EFFECTIVE CATHODE

The study of film deposition on the central zone of the 10 cm diameter Cu end flange of an S-band RF gun, to form the effective cathode, is in course. Deposition by sputtering requires a mask to select the zone to be coated. It is straightforward and has already been implemented elsewhere [8].

Deposition of PLD films on such a large plate poses harder problems because the ablating laser beam has to impinge on the target nearly flush with its surface, at a very large angle with respect to the plume direction. This configuration needs development.

CONCLUSIONS AND OUTLOOK

The described tests and previous experience by others suggest that Mg films produced by sputtering or PLD are good candidates for high QE metallic photocathodes that can work in moderate vacuum.

Sputtered films can be grown to large thickness, have good uniformity and are very resistant to laser radiation. The proposed further development effort is to improve the adhesion to the substrate.

PLD films promise better adhesion but, at the actual stage of our experience, their structure is still irregular and the film surface is too easily and unevenly ablated by the cleaning laser beam. Further research is planned to find the right deposition parameters to achieve thicker, more compact and harder PLD films. We have found that a protective thin layer of graphite allows easy handling and conservation of the cathodes before installation in the RF gun.

Our final goal is to implement an effective cathode and test it in the very high fields of a RF gun.

REFERENCES

[1] Technical Design Report for the SPARC Advanced Photoinjector. http://www.lnf.infn.it/acceleratori/sparc/
[2] X. J. Wang, M. Babzien, R. Malone, Z. Wu, LINAC 2002 Conference (2002) .
[3] D. T. Palmer, Ph.D. thesis, Stanford University, Dpt of Applied Physics, 1998.
[4] T. Srinivasan-Rao, J. Schill, I. Ben Zvi, M. Woodle, Rev. Sci. Instrum.,Vol 69, No 6, June 1998, 2292-96.
[5] Pulsed laser deposition of thin films, Ed. D.B. Chrisey, Wiley, New York, 1994.
[6] L.Cultrera et al., accepted by Applied Surface Science.
[7] I. Boscolo et al.,J. Appl. Phys.,Vol 87,N0. 8, April 2000, 4005-4006.
[8] X.J. Wang, IX Linac Conference, Chicago 1998, 866.