METAL-BASED PHOTOCATHODES FOR HIGH-BRIGHTNESS RF PHOTOINJECTORS

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Abstract

Advanced high brightness RF gun injectors require photocathodes with fast response, high quantum efficiency and good surface uniformity. Metal films deposited by various techniques on the gun back wall could satisfy these requirements. Two new deposition techniques have been recently proposed, i.e. pulsed laser ablation and vacuum arc discharge. Several samples of various materials have been deposited by both techniques. The emission performance and morphological changes induced on the cathode surface by laser beam are compared and discussed.

INTRODUCTION

The main trend in electron sources of ultra-bright electron beams is the use of an RF gun photo-injector. The requirements for photo-cathodes are prompt response, high quantum efficiency (QE), defined as the number of emitted electrons per incident photon, at wavelengths affordable by existing lasers, low thermal emittance [1] and long lifetime. Metallic cathodes are fast (tens of femtoseconds range) but their QE is rather low as compared with alkali semiconductors. Drawbacks of alkalis are slower response and short lifetime. In addition, they are delicate to handle, requiring UHV both during transport and in operation. Metals are rugged and a few of them, such as Cu, Mg, Pb, Y have reasonable QEs at near UV wavelength (266 nm). Bulk Cu and Mg cathodes are already in use in several photo-injectors. The Cu back flange of 1.6 cells RF guns has been used directly as photo-cathode. With accurate cleaning procedures Cu can attain a QE in the order of 10^{-4} and good emission uniformity [2]; on the contrary, 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 distribution 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 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 [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].

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 and pulsed laser beam (in our case a XeCl excimer laser with λ = 308 nm, τ= 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].

In the PLD process the high kinetic energy of the evaporated material particles reaching the substrate surface enhances the adhesion of the coating material to the substrate. Drawbacks are the presence of droplets on film surface and reduced film thickness. PLD films are limited to a few microns, while other techniques can easily grow films to a larger thickness (20 microns). Anyway our experience shows that the laser cleaning activation tends to remove the droplets by changing the morphology of the irradiated zone [10]. Moreover, the cleaning of samples that are not too deeply oxidized removes only a few tens of nm of oxide from the surface. Therefore a thickness of a couple of microns is deemed sufficient to guarantee a long lifetime.

The vacuum arc deposition technique is an interesting alternative because the kinetic energy of the particles is also high [11]. Moreover, being the projectiles charged, it consents efficient filtering of neutral droplets. 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 UHV 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.

SAMPLE PREPARATION

Mg Films Grown by PLD

The PLD technique makes multi-layer 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 translated 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 of 200 nm-thickness covered with a protective layer of graphite. Others depositions were carried out in low-pressure He (1-5 Pa) in order to make use of the "*plume confinement*" effect to deposit films with a few micron thickness [12]. Typical deposition parameters of Mg samples are listed in Table 1.

Table 1: Deposition Parameters of the PLD Deposited Sample Labelled MgLE003 and MgLE009

Sample	MgLE003	MgLE009
Target	Mg-C	Mg
Substrate	Cu	Cu
T-S Distance	4.5 cm	3.5 cm
Laser Spot Size	1.1 mm^2	0.9 mm^2
Laser Fluence	10 J/cm^2	10 J/cm^2
Depostion Pressure	UHV ($3.3x10^{-6}$ Pa)	He (5 Pa)
Laser Pulses	30000 on Mg & 9000 on C	50000

Pb Films Grown by Vacuum Arc

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]. Collaboration between LNF and IPJ is in course to set up a similar apparatus for the deposition of Mg films.

MEASUREMENTS

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

Mg Films Grown by PLD

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 $\mu J/mm^2$, each cleaning step was carried out performing a double scanning raster on the irradiated area having size approximately 2.4x2.4 mm^2.

After activation process, the laser beam diameter is enlarged to about 1 mm and its energy is strongly decreased to perform QE measurements far from space charge saturation limit.

In Fig. 1 we show the maximum values of QE obtained for various samples.

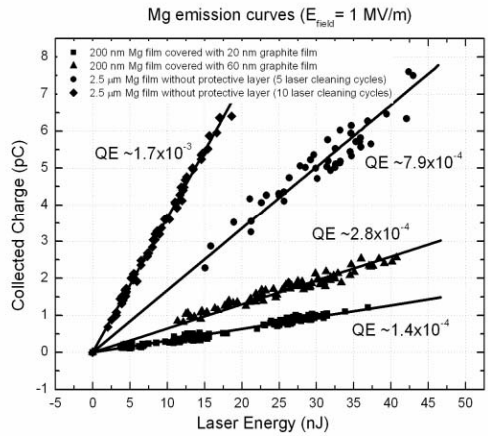

Figure 1: Highest achieved QE values for various PLD Mg grown samples.

Scanning Electron Microscopy (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 perturb uniformity of cleaning process (calculations show 30% standard deviation in energy density through the surface).

Moreover, the laser beam can produce morphological and even structural changes over the surface of the film [10]. In Fig. 2 we present 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 they are not due to uniformity of the film itself.

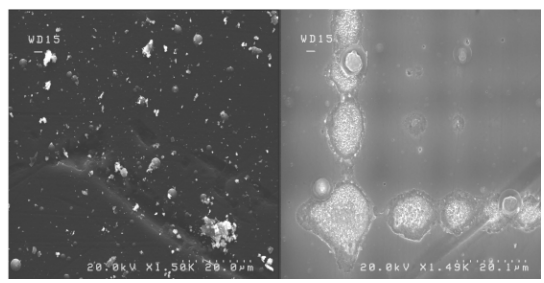

Figure 2: Left picture: as deposited sample surface; Right picture: after laser cleaning.

Moreover, we have found that Mg films undergoing laser cleaning under vacuum show a strong transient rise of their QE and then a decrease to a stable high value of about 10^{-3} that lasts for several days. This is shown in Fig. 3. It remains to be tested whether a film of such a thickness can withstand the discharges during RF conditioning.

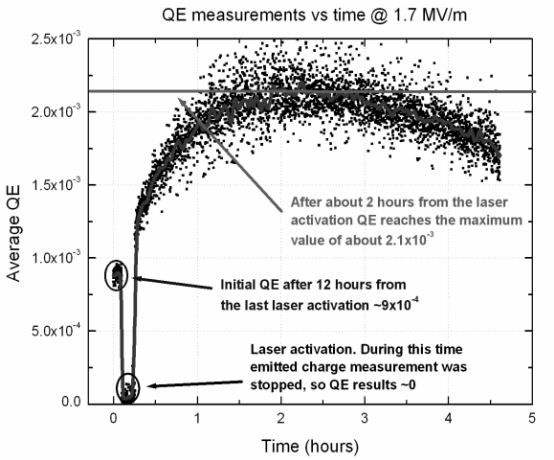

Figure 3: QE of Mg thick sample vs. time after the laser cleaning.

Pb Films Grown by Vacuum Arc Discharge

A 2 μm thick film was deposited by vacuum arc discharge on Cu substrate and its QE has been measured.

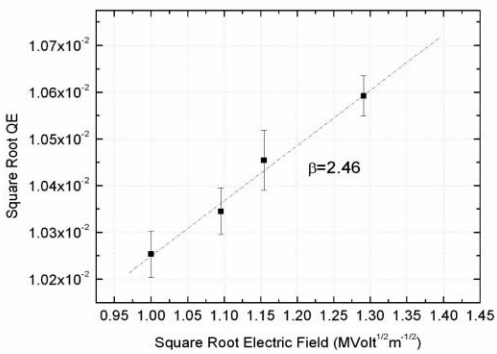

Figure 4: Pb sample QE vs. extraction field and β evaluation.

Both the environment and the cleaning procedure were the same as for the Mg case. Moreover, after laser cleaning, some QE vs. electric field measurements were conducted, in order to calculate the β factor of field enhancement, in tight relation with roughness of the surface [13]. Maximum QE reached by lead film was slightly above 10^{-4}, as foreseen. These results are given in Fig. 4, with a final inferred β of 2.46.

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. By comparing virgin surface and after laser cleaning we can observe a changing in the surface structure, more evident in the areas of diffraction fringes maxima (Figure 5).

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 in optimized conditions for deposition of thick films. The final cathode is in course of construction and power tests in an RF gun are foreseen.

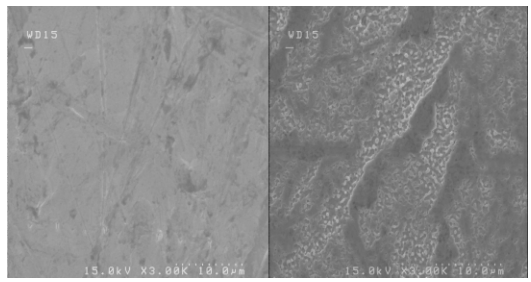

Figure 5: Left picture: as deposited Pb sample; Right: after laser cleaning.

CONCLUSIONS AND OUTLOOK

Metallic films produced by vacuum arc discharge or PLD are promising candidates for the photo-cathodes required by high brightness electron sources. PLD films deposition parameters to obtain uniform and high QE have been determined. A protective thin layer of graphite or oxide allows easy handling and conservation of the cathodes before installation in the RF gun.

The preparation of an Mg film based cathode to be tested at full power in an RF gun is in course.

ACKNOWLEDGEMENTS

This work has been partially supported by MIUR.-Progetti strategici, DD 1834; by European contract no. 011935 EUROFEL and RII3-CT-PHI506395-CARE.

REFERENCES

[1] W. Graves et al., Proc. of PAC01, (2001) 2227-2229
[2] D. T. Palmer et al., PAHBEB workshop, Erice (2005), in press.
[3] X. J. Wang et al., Proc. of LINAC02, (2002) 142-144.
[4] D. T. Palmer, Ph.D. thesis, Stanford University, Dpt of Applied Physics, 1998.
[5] T. Srinivasan-Rao et al., Rev. Sci. Instrum., **69**, (1998) 2292-2296.
[6] T. Srinivasan-Rao et al., Proc. of PAC97, (1997) 2790-2792.
[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] G. Gatti et al., PAHBEB workshop, Erice (2005), in press.
[11] P. Strzyzewski et al., Proc of EPAC06, (2006) 3205-3207.
[12] A. Pereira et al., Thin Solid Films, **497**, (2006) 142-148.
[13] J. Smedley et al., Proc. of PAC05, (2005) 2598-2600.