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Mg-based photocathodes prepared by ns, ps and fs PLD for the production of high brightness electron beams

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ABSTRACT

Mg-based films have been prepared by pulsed laser deposition technique for photocathode applications. We have investigated the influence of pulse laser duration on morphology and photoemissive properties. Two laser sources have been used, generating pulses of 30 ns at 308 nm (XeCl excimer laser), 5 ps and 500 fs at 248 nm (KrF excimer laser) to grow Mg films onto Si and Cu substrates in high vacuum ($\sim 10^{-7}$ Pa) and at room temperature. Morphological investigations carried out by scanning electron microscopy (SEM) have revealed that, in our experimental conditions, the number and the mean size of the droplets on the films surfaces decreases as the pulse laser duration shortens. The contamination level of Mg film surfaces have been studied by energy dispersive X-ray spectroscopy (EDX). The photoelectron performances in terms of quantum efficiency (QE) and emission stability have been tested in a UHV DC photodiode cell (10^{-7} Pa). Measures of the QE of the samples surfaces have revealed a decrease on the initial value for Mg-based photocathodes prepared by fs laser (from 7.8×10^{-4} to 6.6×10^{-4}) PLD with respect to ps (from 6.2×10^{-4} to 7.4×10^{-4}) and ns lasers (from 5.0×10^{-4} to 1.6×10^{-3}). A comparison among Mg-based photocathodes prepared by ns, ps and fs PLD for the production of high brightness electron beams has been presented and discussed.

1. Introduction

High brightness electron beams are of strong interest for photo-injectors uses, such as self-amplified free electron laser (SASE FEL), linear accelerator with energy recovery, fourth generation light sources and laser-driven plasma wake field accelerators [1]. For all the different photo-injector systems, the photocathodes play a key role. The choice of material used for the photocathode is very important for the quality of electron beams produced. Generally speaking, two classes of materials have been used for photocathode applications, namely semiconductors and metals.

The quantum efficiency QE is defined as the ratio of the number of photo-emitted electrons, N_e, to incident photons, N_p:

$$QE = \frac{N_e}{N_p}$$

The quantum efficiency can be also expressed as follows:

$$QE = \frac{q/e}{E/h\nu}$$

where q is the collected charge; E is the energy incident on the cathode; e is the electron charge, and ν is the laser frequency.

Semiconductive photoemitters are very sensitive to contaminations and must be operated only in UHV environments ($p < 10^{-8}$ Pa). Moreover, they usually have a long response time and short lifetime but they have a high quantum efficiency value [2]. Metallic photoemitters are rugged with respect to residual gases contamination and electrical breakdown problems, they have a long lifetime and short response time but they have a relatively low QE value ($\sim 10^{-4}$ in the UV range) due to their high reflectivity and electron–electron scattering that reduce the escape depth [3].

Among metals, magnesium seems to be the best candidate due to its low work function (3.66 eV) and its reasonable quantum efficiency ($>5 \times 10^{-4}$) [4].

In the present work, Mg-based photocathodes have been prepared in ns, ps and sub-ps regimes by pulsed laser deposition

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(PLD). PLD technique allows a strong adhesion of the material to the substrate because of high kinetic energy (up to several keV) of ablated chemical species reaching the substrate [5].

The laser cleaning process is one of the methods proposed to improve the quantum efficiency of metallic photocathodes.

Investigations on morphological and photoemissive proprieties of Mg-based photoemitters prepared by PLD in different regimes have been performed.

The aim of this paper is to investigate the photoelectron performances and the surface morphology of Mg-based thin films prepared by PLD using excimer lasers with different pulse duration: ns, ps and fs.

2. Experimental details

2.1. Pulsed laser deposition apparatus

The scheme of the apparatus used for PLD experiments is shown in Fig. 1. Pure magnesium targets (99.99%) were irradiated by two different types of excimer lasers: XeCl (λ = 308 nm, τ = 30 ns) or KrF (λ = 248 nm, τ = 500 fs or 5 ps). The ablated materials were collected on silicon or copper substrates placed parallel and in front of the target. Before the deposition, the vacuum chamber is baked in order to increase the desorption rate of water vapors and other contaminants with the aim to improve the quality of the vacuum.

The deposition parameters of the samples deposited by different laser pulse durations, chosen after systematic parametric studies, are shown in Table 1.

Depositions in the same experimental conditions were performed on Si substrates to measure the thickness of Mg films as well as on Cu in order to measure the quantum efficiency.

2.2. Laser cleaning and QE measurements

The QE measurements and the process of laser cleaning were performed in a photodiode cell. The vacuum chamber, in which the photodiode cell was inserted, was evacuated at a base pressure of about 2×10^{-7} Pa by means of an ion pump. The quality of the vacuum was controlled by a quadrupole mass spectrometer.

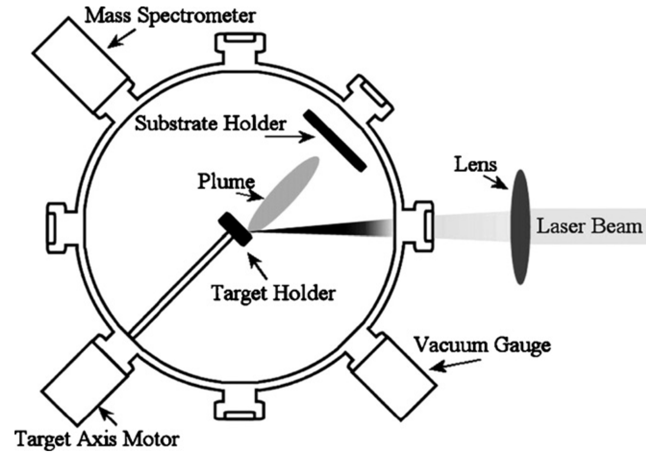

Fig. 1. Pulsed laser deposition apparatus.

The photodiode cell (Fig. 2) consisted of a structure in which a distance of 3 mm separates the cathode to the anode. The Mg film occupied the cathode position and was electrically grounded. The anode plate was biased with high DC voltages up to 5 kV thus allowing the generation inside the gap of intense electric field of about 1.7 MV/m. In order to illuminate the cathode and for precise alignment of UV laser beam (λ = 266 nm, τ = 30 ps), on the cathode surface, the anode plate was machined with two symmetric holes having a diameter of 4 mm and forming an angle of 72° with respect to the normal of the cathode surface.

For the laser cleaning treatments, the focused laser beam was scanned over an area of about 2.4 mm × 2.4 mm, with the laser beam having a diameter on the cathode surface of about 300 μm and energy of about 25 μJ per pulse (power density was about 3 GW/cm^2). Such value of the power density was experimentally determined as the threshold for the ablation of the oxidized layers during preliminary tests. The power density threshold value for the ablation was deduced looking at the vacuum level of the UHV

Table 1
Experimental parameters used for the deposition of Mg films prepared by different laser pulse durations on Cu substrates

Sample	Laser pulse duration	Target	Substrate	T–S distance (cm)	Base pressure (Pa)	Laser pulses for deposition	Laser pulses for cleaning	Laser fluence (J cm^{-2})	Film thickness (nm)
#1	500 fs	Mg	Cu	5.5	4.8×10^{-6}	30000	3000	1.97	120
#2	5 ps	Mg	Cu	5.5	1.7×10^{-5}	30000	3000	2.13	360
#3	30 ns	Mg	Cu	3.5	5.0×10^{-6}	50000	5000	10	2500

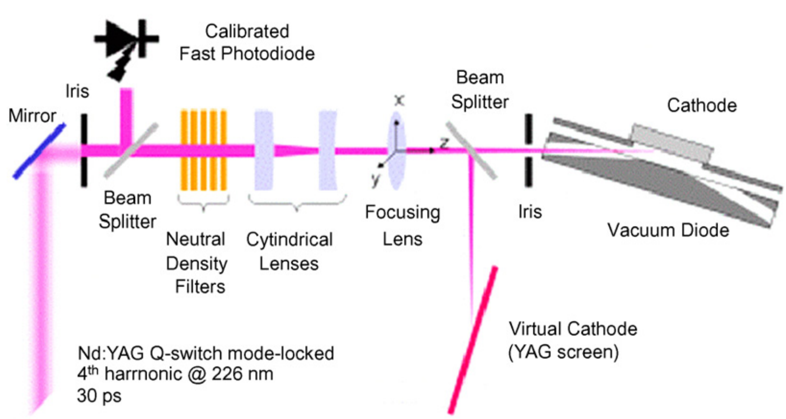

Fig. 2. Detailed scheme of the apparatus for laser cleaning and quantum efficiency measurements.