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Deposition of Y thin films by nanosecond UV pulsed laser ablation for photocathode application

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ABSTRACT

In this work, yttrium (Y) thin films have been deposited on Si (100) substrates by the pulsed laser deposition technique. Ex-situ morphological, structural and optical characterisations of such films have been performed by scanning electron microscopy, X-ray diffractometry, atomic force microscopy and ellipsometry. Polycrystalline films with a thickness of 1.2 μm, homogenous with a root mean square roughness of about 2 nm, were obtained by optimised laser irradiation conditions. Despite the relatively high thickness, the films resulted very adherent to the substrates. The high quality of such thin films is important to the synthesis of metallic photocathodes based on Y thin film, which could be used as electron sources of high photoemission performance in radio-frequency guns.

1. Introduction

Electron sources based on photoemission have opened, for a long time, the possibility of obtaining high brightness electron beams for developing X-ray FEL. The realisation of these advanced light sources demands electron bunches with high current density and very low transverse emittance values [1–4].

The emittance of the electron beam at the end of a radio-frequency (RF) photoinjector is ascribed to different contributions such as space charge effects of the bunch (i.e. self-repulsion among the charges), not ideal acceleration fields and thermal emittance. While the first two emittance contributions can be adjusted by controlling the photoinjector parameters, the thermal emittance is an intrinsic contribution of the cathode that depends on the morphological and structural properties of the cathode surface.

A classical example that indicates the role of the cathode surface is the copper bulk, largely utilised in RF photoinjectors, because it has a high chemical inertia and also because the quality factor of accelerating cavities, made of copper, is preserved. Copper, usually irradiated by a wavelength of 266 nm (equal to a photon energy of 4.7 eV), has a low quantum efficiency of a few 10^{-5}. Such material has the advantage of having a very low thermal emittance, about 0.3 μmrad/mm, computed taking into account the three-step Spicer model [5]. Nevertheless, the experimental value of the thermal emittance of the copper is more than twice the theoretical value [6]. The main reason of such a discrepancy is due to the surface features of the cathode, particularly the roughness.

Nowadays several research groups are investigating the potentiality of metallic photocathodes based on materials alternative to the conventional copper [7–11]. The deposition of a thin metallic film on a small area of the copper flange is an interesting strategy to preserve the quality factor of the RF cavity.

The pulsed laser deposition (PLD) technique has generated very interesting results for photocathode synthesis based on metallic thin films [12,13]. The main difference with other deposition techniques is that deposition via laser ablation is able to obtain very clean thin films, since the fast local heating minimises film contamination. Moreover, films are very adherent to the substrates even at room temperature due to the high energy species of the plasma plume [14,15]. These energetic particles can organise themselves when they arrive at the substrate, resulting in a very compact and adherent thin film.

Another advantage of this technique is the nanometric control of the film thickness, achievable through a priori calibration of the deposition rate of the material.

Yttrium is a very interesting metal due to its low work function (~3.0 eV), which allows one to use even the visible radiation to induce photoemission. This property is important for two reasons: first is the possibility of driving the photoemission by the second harmonic of a solid state laser with short pulses such as the Ti:sapphire laser (at the visible wavelength of 400 nm, with a photon energy of 3.1 eV). This

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Table 1
PLD experimental conditions for Y thin film deposition.

Target		Y
Substrate		Si (100)
Substrate temperature		300 K
Target-substrate distance		6 cm
Laser spot size		2 mm
Laser spot area		3.14 mm^2
Laser pulse duration		7 ns
Laser energy on the target		90 mJ
Laser fluence		3 J/cm^2
Power density		0.4 GW/cm^2
Laser wavelength		355 nm
Repetition rate		10 Hz
Background pressure		4.7×10^{-6} Pa
Laser shots	Cleaning	2×2000 per track
	Deposition	$2 \times 20{,}000$ per track
Film diameter		3 mm
Film thickness		1.2 μm

means more available and stable laser energy to induce the photoemission. The second reason is the reduced thermal emittance of the material whose value is even lower than the theoretical value of copper.

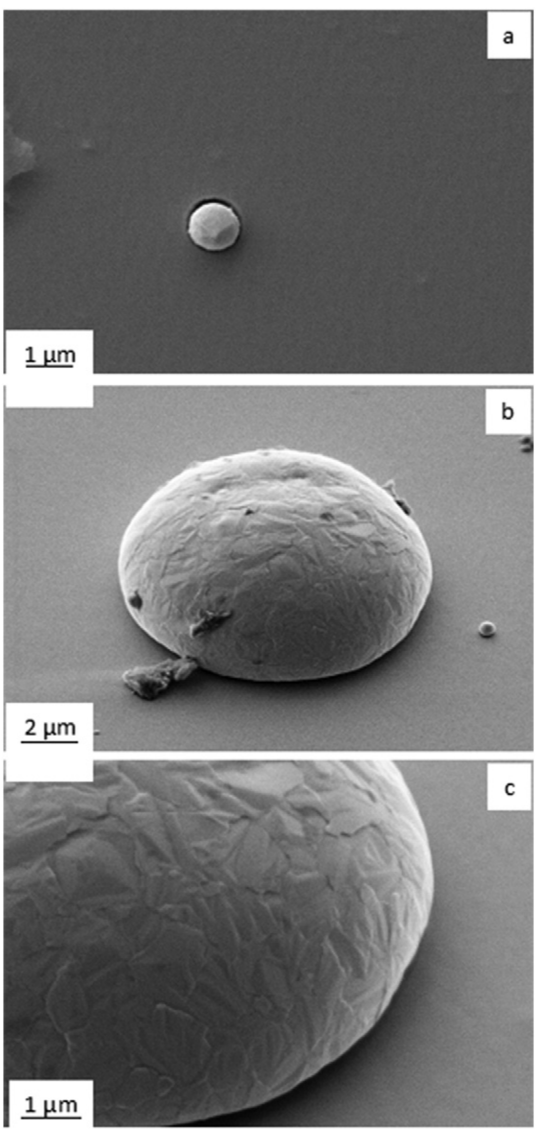

Fig. 1. SEM micrographs of Y thin film: a) image of the top view; b) image of a droplet obtained by tilting the sample to 45°; c) image of the droplet at higher magnification.

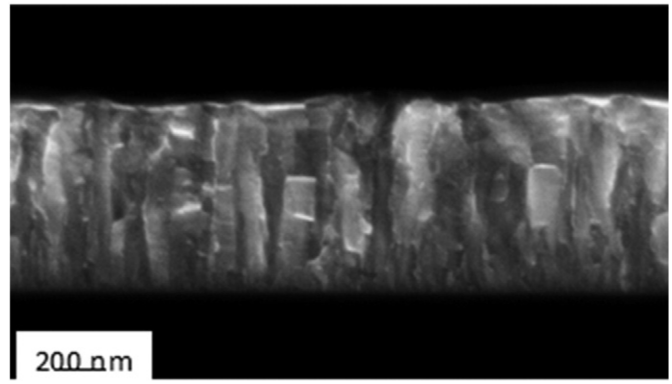

Fig. 2. Cross-sectional image of the Y thin film.

In this work, Y thin films were deposited by PLD by a laser wavelength of 355 nm, paying particular attention to the deposition parameters to obtain a thick film of at least 1 μm thickness. Even if, for metals, the photoelectric effect is confined in a few layers from the surface; a large thickness is mandatory in order to obtain the film free from the copper substrate roughness. Moreover, such thick film has the possibility of removing the impurities and contaminants from the cathode surface by laser cleaning processes [12,16].

It is worth saying that, despite such a thickness, the films have to be characterised by a low roughness, to reduce the cathode thermal emittance contribution, and they have to be very adherent to the substrate to support the stress due to the high gradient of accelerating fields (up to 100 MV/m) when inserted into a RF gun.

2. Experimental setup

Depositions were performed in a typical PLD high vacuum system described elsewhere [16]. Ablation of Y pure target (99.99%) was achieved using the third harmonic of a Q-switched Nd:YAG laser (Continuum Powerlite-8010, $\lambda = 355$ nm, $\tau = 7$ ns) operating at a frequency repetition rate of 10 Hz. All the deposition conditions are listed in Table 1.

The films were grown on Si (100) substrates without removing the native oxide layer.

After a detailed parametric study, the operating laser fluence was fixed at 3 J/cm^2 using an energy attenuator and a telescopic lens.

With the aim of cleaning the target surface from undesired impurities due to the air exposure, a laser cleaning treatment, before the

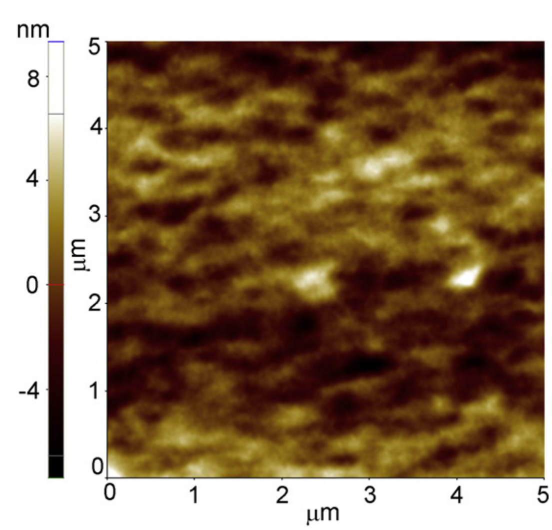

Fig. 3. AFM image of the Y thin film.