Comparison of Mg and Y thin film photocathodes on Cu substrates obtained by the pulsed laser deposition technique

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Research on the development of high brightness electron beams is nowadays required in many fields, for example in the new generation of X-FELs and in the development of plasma-based accelerators [1,2]. Radio-frequency (RF) photoinjectors are commonly used to produce electron beams for such applications. Copper is the most used photocathode in the RF-guns operating in the S-band (i.e. 2.856 GHz) because the quality factor of cavities, made of Cu, is preserved. This material has a high chemical inertia against surface contamination processes and it is able to sustain high gradients of electric fields. Nevertheless, Cu bulk does not have such a good quantum efficiency in principle due to its high work function.

Magnesium and Yttrium are studied as alternative and promising materials to Cu due to their higher photoemission performances attributed, in particular, to their lower work functions which depend also on the morphology and structure of the materials [3].

The pulsed laser deposition (PLD) technique has proven to be very promising for metallic thin film deposition [4–6]. It has been shown and reported in many studies that the deposition of Mg or Y thin films in a small area of the Cu flange centre improves the photoemission performances of the cathode, preserving the quality factor of the RF cavity. Moreover, the deposition of thin film is a good solution to avoid small discontinuities when different bulk materials are mechanically inserted in the copper flange. The presence of such discontinuities, in fact, has provoked undesired discharges in the RF cavity, decreasing the quality of the photo-extracted electron beam. Figure 1 shows the values of the collected charge versus the laser energy carried out on Mg, Y thin films and Cu bulk. The data show a linear relationship between collected charge and laser energy, indicating that the photoelectron emission process occurs mainly via one-photon absorption mechanism and without any space charge effect. The continuous line is the data fitting curve whose slope is utilised to compute the quantum efficiency, defined as the ratio of the number of photoemitted electrons, N_e, to the number of the incident photons, N_Φ, which can be expressed by the following equation:

$$QE = \frac{N_e}{N_\Phi} = \left(\frac{qh\nu}{eE_L}\right) \tag{1}$$

where q is the collected charge, e is the electron charge, E_L is the laser energy arriving on the cathode, and is the photon energy. A QE of 1.8×10^{-3} for the Mg photocathode and 3.3×10^{-4} for the Y photocathode were found, higher than that of Cu bulk, 1.1×10^{-5}, as reported in the inset of Fig. 1. The QE of Mg was higher than that of Y by a factor of about 5, in contrast to the work function of the materials, which is lower for Y (see Table 1). A material with a lower work function would be expected to produce a higher QE, but this is not the case with these two metals. The experimental values of QE were compared with the theoretically ones obtained by Spicers three-step model for metal photoemission by utilizing the equation reported in Ref. [7]:

$$QE(\nu) \simeq \frac{1-R(\nu)}{1+\lambda_{\text{opt}}/\lambda_{e-e}}\ \frac{(h\nu-\phi_{\text{eff}})^2}{8\phi_{\text{eff}}(E_{\text{F}}+\phi_{\text{eff}})} \tag{2}$$

where R is related to the reflectivity of the surface material which depends on the photon wavelength, λ_{opt} is the optical absorption length which depends on the photon wavelength, λ: $\lambda_{\text{opt}} = \lambda/4\pi k$ where k is the imaginary part of the complex index of refraction. Moreover is the electron-electron scattering length or electron mean-free path between collisions with valence electrons, E_{F} is the Fermi energy and ϕ_{eff} is the effective work function of the material. The physical parameters of Cu, Mg and Y, used to compute QE, are reported in Table I. By assuming a value of R=0.4 for all the materials, we have utilized a $\lambda_{e-e} = 40$ Å for Cu and Mg in according with Ref. [7] and a lower value of 10 Å for Y due its higher resistivity as discussed in a previous article [8]. The theoretical QE values result to be 1.5×10^{-5} and

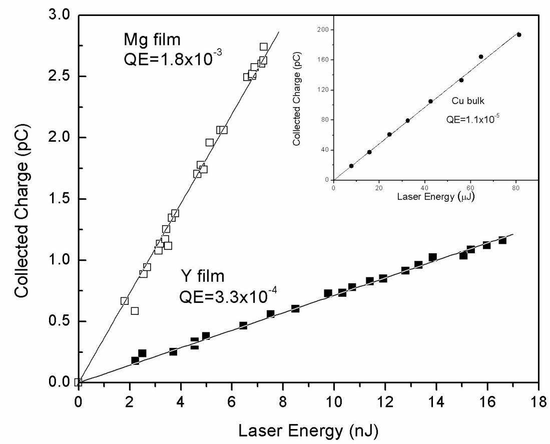

Figure 1. Collected charge as a function of the laser energy for the photocathodes based on Mg thin film (white squared), Y thin film (black squares) and Cu bulk in the inset (black circles). Continuous lines are the data-fitting curves. The QE is computed by Eq. (1).

	k [266 nm]	E_F (eV)	ϕ (eV)	ρ ($\Omega\,$m)	$\lambda_{\rm opt}$ (Å)	λ_{e-e} (Å)	$QE_{\rm th}$	$QE_{\rm exp}$
Mg	1.8	7.1	3.6	4.45×10^{-8}	106	40	6.7×10^{-4}	1.8×10^{-3}
Y	1.2	6.0	3.1	59.6×10^{-8}	176	10	3.8×10^{-4}	3.3×10^{-4}
Cu	1.7	7.0	4.5	1.70×10^{-8}	126	40	1.5×10^{-5}	1.1×10^{-5}

Table 1
Physical parameters used to compute the QE for Mg, Y Cu photocathodes.

6.7×10^{-4} for Cu and Mg, respectively and 3.8×10^{-4} for Y. The discrepancy between the theoretical and the experimental values of QE could be ascribed to the structure and morphology of the material which influence the nominal work function.

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