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Investigation of the intermediate layers located between niobium substrate and lead films destined for superconducting photocathodes

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ABSTRACT

The paper presents the recent studies carried out at National Centre for Nuclear Research (NCBJ) focused on improving adhesion between Pb films and Nb substrate. The impact of additional intermediate layers of Ti and Sn on the adhesion properties was also discussed. Structural and microstructural properties of the layers were investigated by using Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-ray Spectroscopy (EDS). Tribological properties of the deposited layers were examined by using a profile measurement gauge and the scratch test techniques. It has been shown that the Pb layer deposited on Ti intermediate layer is characterized by the best properties in terms of smoothness and surface continuity. Apart from the classical tribological properties investigation, we demonstrated much better adhesion of a Pb layer to the Nb substrate covered with an interlayer of Ti or Sn compared to a Pb film deposited directly on Nb. Reported results prove the possibility of improvement of the lead film adhesion parameters and discuss a new development path for further work in this area.

1. Introduction

High Brightness Electron Injectors techniques play an important role in the development of Free Electron Lasers (FELS) and Electron Positron Linear Colliders. Ongoing research and development programs focus on the studies of a 1 mA-class, fully superconducting radio-frequency (SRF) electron photo-injectors. This effort is an integral part of the upgrading programme of the European X-ray Free Electron Laser (XFEL) located at Deutsches Elektronen Synchrotron (DESY) in Hamburg. The injector is expected to produce electron bunches of normalized emittance which does not exceed 1 μrad, with charges up to 1 nC. Continuous Wave (CW) option and long pulse operation regimes of the device are also envisioned [1]. An efficient and durable Radio Frequency (RF) electron gun is the most critical and demanding part of the injector. The concept of RF, fully superconducting (sc), hybrid Nb-Pb electron injectors for linear sc accelerators were proposed and developed within the last decade of research [2–5]. Pb layers deposited on Nb substrate are considered as one of the best candidates for photocathodes in superconducting electron sources in linear superconducting accelerators which drive free electron lasers [4]. To overcome the problem of too low quantum efficiency (QE) of Nb, which is the most common superconductor material used for RF cavities in accelerating structures, it has been proposed to use a photocathode based on Pb layers deposited on Nb substrate [5].

However, one of the biggest challenges in this area is to improve adhesion of the Pb layers. It is well known that the development of technology, characterized by a good quality of the obtained coatings [6,7] as well as their good adhesion [8], is very important from the point of view of possible applications. Many different techniques have been used for the development and improvement of this property. Among many, one may cite for example: ultra-high-vacuum (UHV) arc deposition [4,5,9], magnetron sputtering [10], pulsed laser deposition (PLD) [11–17] and thermal evaporation (TE) [4,11] techniques.

Despite the successful creation of a lead layer with high quantum efficiency (QE ≈ $5.4 \cdot 10^{-3}$ at a laser beam wavelength 193 nm) [4] in UHV arc it is known that UHV arc deposition supplemented by droplets filtering or by subsequent layer melting and recrystallization in high intensity pulsed plasma beams is efficient in smoothing lead films but not in securing a good adhesion parameter [4].

Metal surface layers created by using PLD coating exhibit strong adhesion to substrates. However, Pb films made in such a way contain many micrometric droplets [11–17]. The droplets typically enhance the

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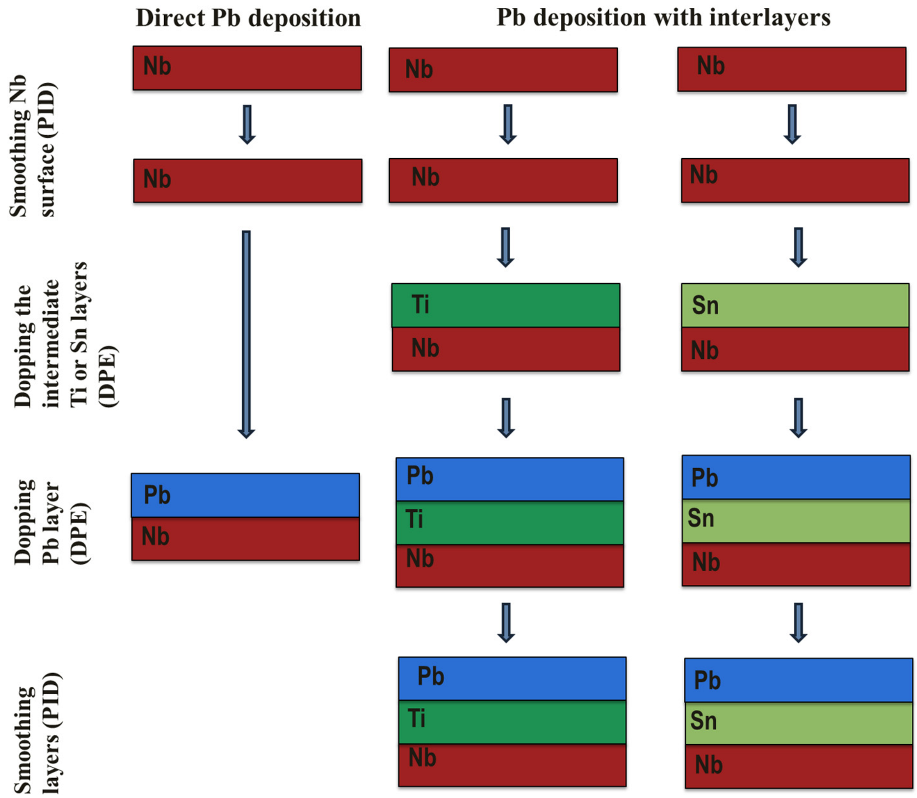

Fig. 1. Schematic view of the diagram aiming to improve Pb film adhesion to the Nb substrate by direct Pb dosing or by using Ti or Sn interlayers.

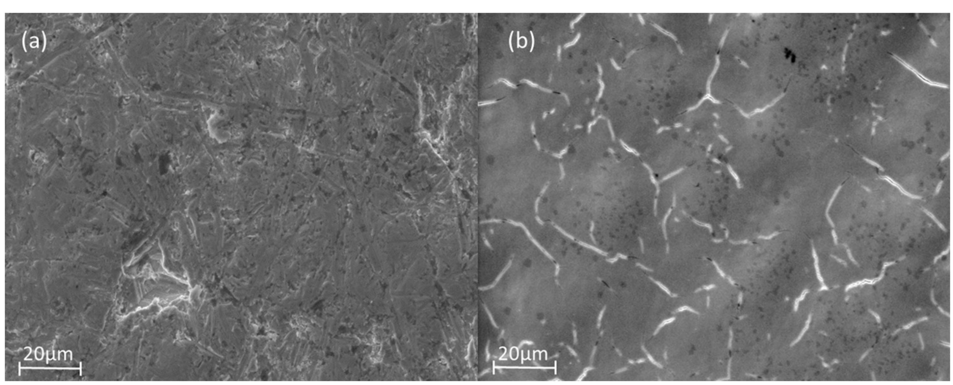

Fig. 2. SEM images of the a) as delivered Nb substrate and b) Nb substrate after 5 PID pulses with 7 J/cm^2.

unwanted electron dark current in a strong RF field. This is related to the fact that the quantum efficiency of lead films deposited by using PLD is limited to below $7.3 \cdot 10^{-5}$ at 266 nm after laser cleaning [15,17].

At the same time, TE allows preparation of more uniform films without droplets however, it is known that Pb films produced by evaporation suffer from very low adhesion to Nb [11].

As it can be seen, all the methods mentioned above have some disadvantages, which makes it challenging to obtain a smooth surface while maintaining proper adhesion properties.

Choosing the best method is not the only difficulty that must be overcome. The main obstacle in achieving good adhesion between niobium and lead is the difference in their physical properties, particularly in melting and boiling temperatures and in thermal expansion coefficients. These metals show also strong tendency to oxidize or to form nitrides [17].

For this reason, in this paper we present an improvement of Pb layer adhesion by implementing two different approaches. The first one depends on using the high intensity pulsed plasma ion beams (HIPPB) technique generated in a rod plasma injector (RPI) [18,19]. This method allows multiple melting of the niobium substrate combined with doping it with lead, to obtain a graded layer between the Nb substrate and the Pb film. Second approach is based on the creation of the intermediately graded layers of titanium or tin. This is because, tin and lead elements have similar melting and boiling points. On the other hand, titanium is considered as an interesting candidate for the interlayer as it forms solid solution with niobium. In order to generate intermediate layers, HIPPB technique was applied by using RPI [18,19]. Also in this case the substrate is repeatedly melted and gradually dosed with alloying additions in subsequent depositions of the intermediate layers at properly modified coating parameters.

2. Experimental

In this study, the 10 × 10 × 1.5 mm^3 niobium substrates with of 99.9 wt% purity, supplied by Goodfellow Ltd., were modified by using