DEPOSITION OF LEAD THIN FILMS USED AS PHOTO-CATHODES BY MEANS OF CATHODIC ARC UNDER UHV CONDITIONS*

P. Strzyzewski#, J. Langner, M.J. Sadowski, J. Witkowski, SINS, 05-400 Otwock-Swierk, Poland
S. Tazzari, INFN Roma2, 001333 Roma, Italy
R. Russo, Istituto di Cibernetica del CNR and INFN-Na, Italy
J. Sekutowicz, DESY-MHF, 22-603 Hamburg, Germany
J. Smedley, T. Rao, BNL, Upton, New York

Abstract

The cathodic arc technology has been used for various technical purposes for many years. Recently, it has been demonstrated that the cathodic arc can be operated under ultra-high vacuum (UHV) conditions and it might solve the problem of the oxygen contamination coming from water remnants. It opens a new road to many applications where very pure metallic and/or superconducting films are needed. The paper reports on recent experimental studies aimed at the deposition of superconducting films of pure lead (Pb) by means of the UHV cathodic arc. Such layers can be used as photo-cathodes needed for modern accelerator injectors. The system configuration, used for thin film deposition inside the 1.3 GHz RF Gun designed at DESY, is described. The paper presents also the main results of Pb-films measurements, which were performed by means of SEM, SIMS and GD-OES techniques.

INTRODUCTION

Although pure niobium has proven to be a good superconductor, it is a comparatively poor photo-emitter, with a typical Quantum Efficiency (QE) of $\sim 10^{-5}$ for 266 nm radiation [1]. Therefore, it was proposed to investigate pure lead as a candidate for a superconducting cathode material for an RF gun, in connection with the eventual goal of constructing a hybrid lead-niobium cavity. A previous paper [2] described this idea and explains why a lead film deposited by means of cathodic arc was chosen for further investigations.

Vacuum cathodic arc technology is widely used in scientific laboratories and industry in order to produce different coatings on various surfaces. The deposition of pure and clean metal films of different types as well as possibility of the vacuum arc operation within a reactive-gas environment (in order to form compound films, such as nitrides, oxides and carbonaceous layers), make this technology very attractive. Appropriate surface layers can be formed on constructional parts of complicated shapes, ensuring high bonding strength and corrosion resistance. In a comparison with other deposition techniques, e.g. the known Physical Vapor Deposition (PVD) processes when ions have energy of a few eV, vacuum arc discharges can produce ions of higher kinetic energies ranging from about 15 eV to about 150 eV [3]. It results in the formation of a denser film and it strongly reduces surface defects, such as voids and columnar growth. The main drawback is represented by the production of micro-droplets in the near-cathode space, which become embedded in the film and increase its surface roughness. In order to eliminate the micro-droplets from vacuum-arc plasmas, one can apply different magnetic filters. The main idea is to separate the plasma stream by means of an appropriate magnetic field and to eliminate micro-droplets, which (due to their large masses) move from the cathode along almost straight lines.

A new concept of the deposition of thin superconducting layers, by means of arc discharges under Ultra-High Vacuum (UHV) conditions, was proposed several years ago [4, 5]. In connection with CARE program of the SINS and Tor Vergata groups concerning the construction of large linear accelerators a considerable progress in the development of cathodic arc technology has been achieved recently, including achievement of effective elimination of micro-droplets in planar-arc facilities. The previous report [6] described concepts of 2 types of the magnetic filters suited for UHV conditions. Some experimental research on such magnetic filters is still under realization, in order to improve efficiency of micro-droplets filtering and plasma transport through the magnetic channel. In fact the filters with the water cooling system work very stably and their constructions enable a long-lasting operation. Another paper [7] has described residual gas measurements in a vacuum chamber at the UHV conditions: before, during and just after vacuum arc deposition process. Moreover, a comparison of gas compositions between HV and UHV has been presented. Such an analysis is very important when very clean layers of getter metals are needed (e.g. superconducting niobium films). Filtered vacuum arc technology in UHV opens a new road to many applications when very pure metallic and/or superconducting films are needed.

*We acknowledge a partial support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" program (CARE, contract number RII3-CT-2003-506395).

p.strzyzewski@ipj.gov.pl

EXPERIMENTAL SET-UP

A typical plasma arc source with a planar cathode consists of a "planar" (in fact a truncated cone) cathode fixed upon a water-cooled support placed inside a vacuum chamber. To reduce an amount of micro-droplets the use is often made of a special magnetic filter, which collects the micro-droplets and deflects a plasma-ion stream. Such planar arc sources were constructed both at the Tor Vergata laboratory in Rome and at the IPJ in Swierk. The detailed description of their constructions and performance can be found in our previous papers [4-7].

The facility was equipped with an oil-free pumping system consisting of a two-stage fore-vacuum pump and a turbo-molecular pump. The achievement of very good vacuum has been of primary importance, because the previous studies showed that thin niobium films, as deposited by arc discharges under UHV conditions, have properties comparable with the pure bulk niobium [8]. In our UHV facility the basic pressure < 10^{-11} hPa was achieved after 24 hours of baking at 150°C. Moreover, a laser triggering system provided the ultra-clean and reliable ignition.

In order to perform the deposition of a lead film on a cathode region of the 1.3-GHz niobium superconducting cavity, some modifications of existing facility were done. The main difficulty was connected with necessity of the arc plasma transport through the channel of very small diameter and about 1 m in length. Moreover, the plasma channel had to be shield against external electric field used for biasing of the RF gun. The final construction of the facility is presented in Figure 1.

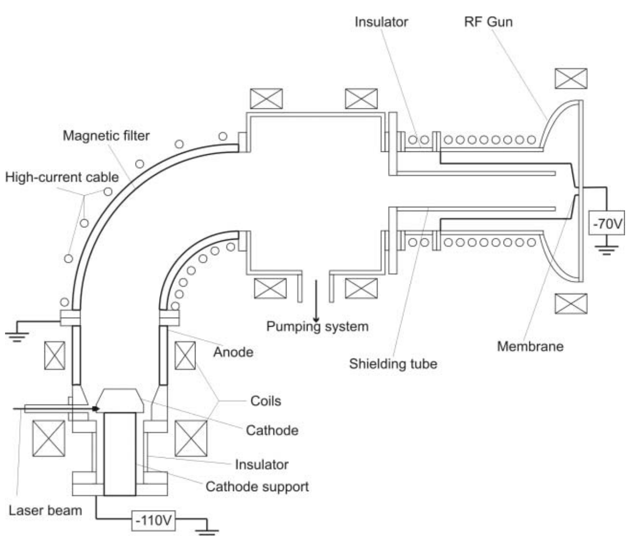


Figure 1: Scheme of a UHV arc facility with a planar cathode and a knee-type magnetic filter.

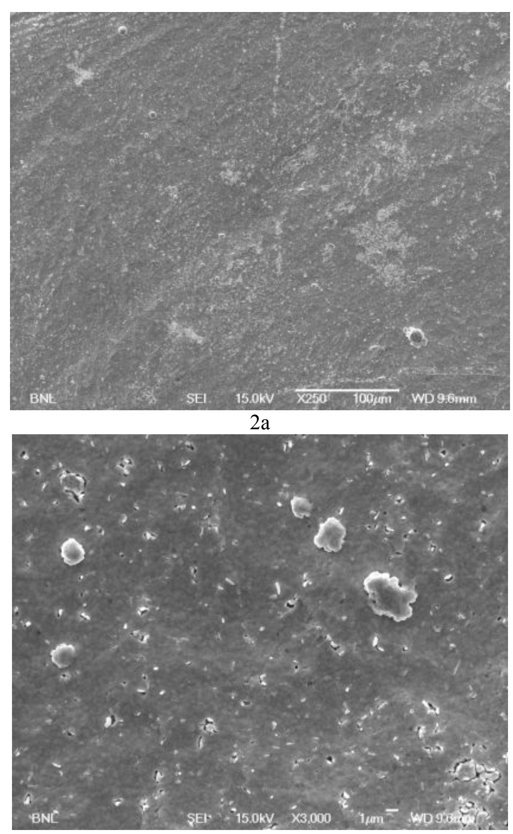
PB FILMS CHARACTERISATIONS

Formation of Nb and Pb Films

The sample holder or RF gun is electrically insulated from walls of the vacuum chamber, so that a bias of 20-100 V, both in DC and kHz pulse regime, can be applied to the coated substrates. The lowest possible arc current for the stable operation in the applied DC mode has been found to be about only 23 A for lead, while the available cooling system of the anode has an upper limit of the arc current equal to about 140 A. The deposition rate achievable with the system is about 0.5 nm/s and decreases with increasing of length between cathode and place of deposition. The sample temperature during depositions is usually recorded by means of thermocouples and not exceeds 100 °C. The pressure usually increases to 10^{-6} -10^{-7} hPa when the arc discharge starts and it remains almost stable at the latter value throughout the deposition process.

Pb Thin Films Characterizations

Scanning Electron Microscopy (SEM) is a very useful tool to perform the surface quality inspection for small-scale defects and to look at the surface structure. Figures 2a and 2b show the SEM pictures of lead layers, which were taken with different magnifications. One can see that surface presented on the Figure 2a is very homogeneous and dense. A lack of micro-droplets upon the surface is the confirmation of good plasma filtering. Using the higher magnification (Figure 2b) it is possible to analyze the surface structure. The roughness of the arc deposited Nb samples on sapphire was found to be of the order of few tenth of a nm.



2a

2b

Figure 2: SEM pictures of the surface of a lead film, which was arc-deposited upon the copper substrate.

Information about the surface chemical composition and depth profile were obtained by means of a time-of-flight (ToF) SIMS mass-spectrometer, delivered by the Ion-ToF GmbH, Muenster, Germany. Secondary ions emitted from the bombarded surface were mass-separated and counted with the ToF analyzer. Result of the depth profile measurement of Pb-film is presented in Figure 3. One can easily see that the deposited layers were clean enough. Chemical compositions of the deposited layer consisted mainly of the pure metal. The presence of some heavy impurities (like Cs, Na and K species) has also been confirmed, but their amounts were very low (not shown in this scale). A characteristic feature of the deposited Pb layer is a relatively high level of the oxidation in the near-surface layer.

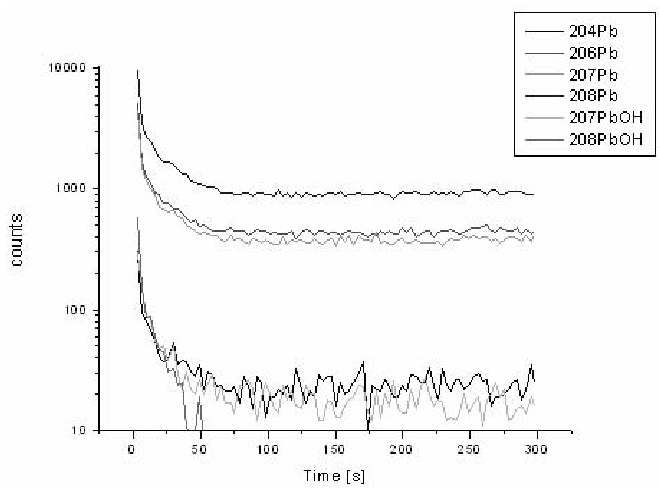


Figure 3: Result of SIMS measurement of Pb layers.

An alternative method to determine the purity of our films appeared to be a Glow Discharge – Optical Emission Spectroscopy (GD-OES) technique. It is generally used for the quantitative determination of surface coatings, hidden interfaces, layers and depth profiles. For measurements to be described below the use was made of a JOBIN-YVON 8000RF device. The result has been shown in Figure 4. A comparison of GD-OES results with those obtained by means of SIMS (presented in Fig. 3b) can be performed. The presented results have also confirmed the high cleanliness of the Pb superconducting film deposited by means of the UHV cathodic arc technology.

CONCLUSION

On the basis of the experimental studies described above, it can be concluded that the deposition processes, which are realized by means of arc discharges performed under the UHV conditions, can guarantee a very low level of unwanted impurities within the deposited films. It opens a new road to many applications where dense, high-quality and very pure metallic-films are needed, e.g. in superconducting technologies, micro-electronics, nanotechnology, medicine etc.

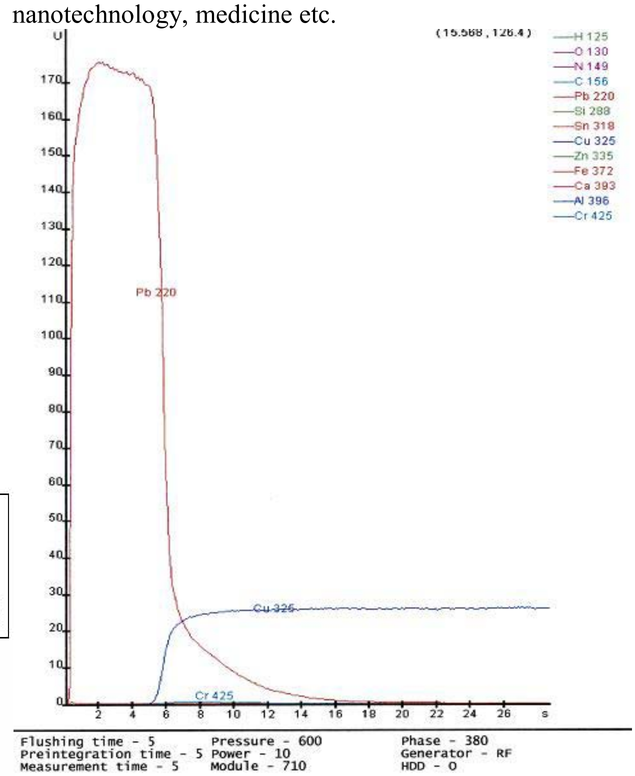


Figure 4: GD-OES analysis of the Pb layer profile, which was deposited upon the Cu-substrate.

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