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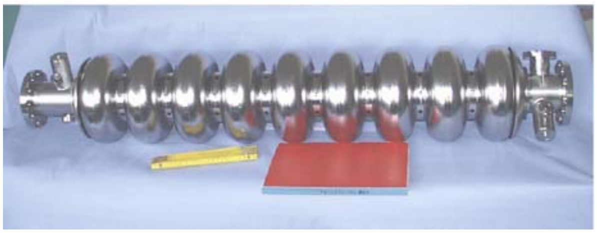

ULTRA HIGH VACUUM CATHODIC ARC FOR DEPOSITION OF SUPERCONDUCTING LEAD PHOTO-CATHODES

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Abstract

The paper presents 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 RF Gun designed at DESY is also described. The paper presents also the main results of Pb-films measurements, which were performed by means of SEM and SIMS techniques.

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The paper presents 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 RF Gun designed at DESY is also described. The paper presents also the main results of Pb-films measurements, which were performed by means of SEM and SIMS techniques.

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1. INTRODUCTION

One can observe a continuous interest in applications of superconducting thin films in modern science and technology. Such layers can replace superconductor structures based on the bulk technology, e.g. one can use accelerator RF cavities made of copper coated with thin niobium (Nb) films (instead of bulk Nb). The advantages of the Nb/Cu technique, in a comparison with the former one, are mainly better thermal conductivity at the same mechanical strength, much lower sensitivity to external magnetic fields and considerable reduction of the manufacturing costs. Hence, the superconducting thin films can be applied as new approaches in accelerator technologies. One of them is the production of photo-cathodes used as effective sources of electron beams.

The deposition of superconducting thin films is not a trivial issue. Some metals (like Nb), which in the bulk forms can be cooled down to cryogenic temperatures and reveal superconductivity, sometimes do not reveal such properties when used in the form of thin layers. There are two main factors which can influence on the layers superconductivity: a quality (mainly density and surface homogeneity) and high purity during the deposition processes. In order to fulfill the above requirements, 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 [1]. This approach may solve the problem of the elimination of oxygen contamination coming from water remnants. Within a frame of the CARE program (concerning the construction of large linear accelerators) two research groups from the SINS (Swierk, Poland) and University of Tor Vergata (Rome, Italy) have achieved a considerable progress in the development of cathodic arc technology [2]. One of the achievements appears to be an effective elimination of micro-droplets in UHV planar-arc facilities. The previous reports [3-4] described concepts of 2 types of the magnetic filters adapted to UHV conditions. Some experimental research on such magnetic filters is still under realization, in order to improve efficiency of the micro-droplets filtering and plasma transport through magnetic channels. In fact, the filters with the water cooling system work very stably and their constructions enable the long-lasting operation. Another paper [5] described residual gas measurements in a vacuum chamber at the UHV conditions, i.e. before, during and just after the vacuum arc deposition process. Such an analysis is very important when very clean layers of getter metals are needed (e.g. superconducting niobium films). Filtered vacuum arc technology at the UHV conditions opens a new road to many applications when very pure metallic and/or superconducting films are needed.

Although pure niobium has proven to be a good superconductor, it is a comparatively poor photo-emitter, with the typical quantum efficiency (QE) of $\sim 10^{-5}$ for the 266-nm radiation. Therefore, it was proposed to investigate pure lead (Pb) as a candidate to form a superconducting cathode for a RF gun working as a source of electron beams, in connection with an eventual goal of constructing a hybrid lead-niobium cavity. A paper [6] described that idea and explained why a lead film deposited by means of the UHV cathodic arc was chosen for further investigations.

2. EXPERIMENTAL SET-UP

The crucial role during the formation of thin superconducting layers is played by cleanliness of the deposition process. In order to achieve good properties of the superconducting film, the partial pressures of water, nitrogen, oxygen, CO_2, hydro-carbides etc., must remain below 10^{-9} hPa during the whole deposition process. The pumping system must, therefore, be totally oil-free and all parts of the deposition system must be designed and built in accordance with the UHV-technology requirements. In our case, all vacuum chamber components and accessories, as well as all vacuum connections, were manufactured using only high purity materials: stainless-steel, OFHC copper and high-quality ceramics shielded from the arc. The basic pressure of the order of 10^{-10} hPa was reached after one night baking of the whole system at a temperature of 150 °C. The facility was equipped with a laser triggering system, which can guarantee the ultra-clean and reliable ignition. Moreover, the composition of residual gases before and during coating can be monitored by means of a Residual Gas Analyzer.

Our planar plasma arc source consists of a "planar" (in fact a truncated cone) cathode fixed upon a water-cooled support placed inside a vacuum chamber, shown in Fig. 1.

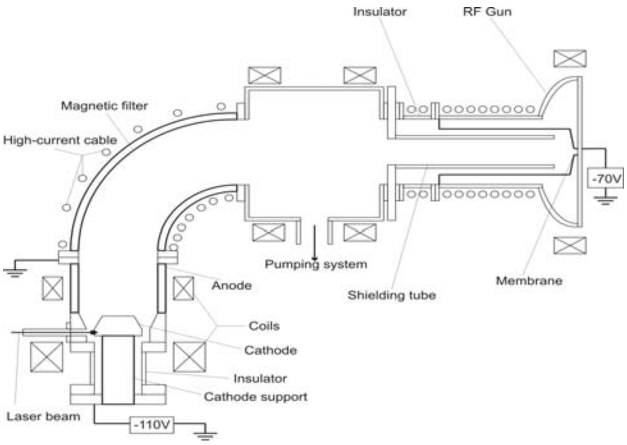

Fig.1. Scheme of a UHV filtered planar cathode arc facility equipped with an RF Gun to be coated.

To reduce an amount of micro-droplets the use is made of a special magnetic filter, which deflects a plasma-ion stream and collects the micro-droplets on the walls. 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 construction and performance can be found in our previous papers [1-3].

A general view of the described experimental facility is presented in Fig. 2.

Fig.2. Picture of the planar arc facility equipped with the magnetic filter (without external coils) and the RF Gun.

In order to perform the deposition of a lead film upon a cathode plate of the 1.3-GHz niobium superconducting RF Gun, some modifications of existing facility were done. The main difficulty was connected with the optimization of the arc plasma transport through the channel of a small diameter and about 1 m in length.

3. FORMATION OF Pb LAYERS

Another problem which had to be solved was related with necessity of the RF Gun bias connection and its rather cylindrical shape. In that configuration a wall potential played an important role and the plasma transport through the RF Gun channel was impossible. In order to shield the plasma channel against external electric field a special shielding tube, which was kept on ground potential, was applied (see Fig. 1). It was about 25 cm in length and almost 5 cm in the inner diameter. Unfortunately, as one could expect, the effective plasma transport was relatively low, due to shielding tube geometry (the small diameter and a relatively large length) and high plasma losses upon the tube walls. To investigate these effects, some measurements of the plasma ion current density were performed along the z-axis of the described tube. Results obtained by means of a ring-shaped ion collector of about 3 cm in diameter, which was placed at different distances, are presented in Fig. 3.

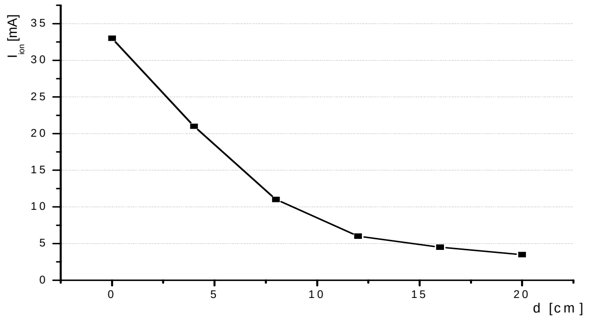

Fig.3. Values of the measured ion-current density inside the investigated shielding tube.

A sample holder or the RF gun was electrically insulated from walls of the vacuum chamber, so that a bias of 20-100 V, both in DC and kHz-pulse regimes, could be applied to the coated substrates. At the lead deposition the lowest possible arc current for the stable operation in the applied DC mode was found to be about only 23 A only, while the available cooling system of the anode enables to achieve an upper limit of the arc current of about 140 A. The deposition rate achievable within the described system is about 0.5 nm/s, but it decreases with an increase in a distance between the cathode and the deposition plane. The sample temperature during depositions is usually recorded by means of thermocouples and it does not exceed 100 ^{o}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 whole deposition process.

4. CHARACTERIZATION OF THIN Pb FILMS

The 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. The SEM picture of lead layer is presented in Fig. 4.

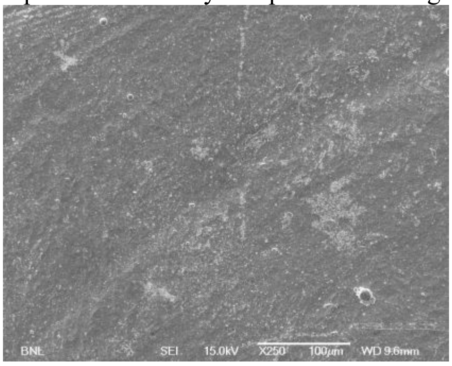

Fig.4. SEM pictures of the surface of the lead film, which was arc-deposited upon the copper substrate.

One can easily see that surface presented in Fig. 4 is very homogeneous and dense. A lack of micro-droplets upon the analyzed surface is a proof of an efficient plasma filtering. Using the higher magnification (not shown in the paper due to its volume limitations) it is possible to analyze the surface structure. The roughness of the Pb layers arc-deposited upon a sapphire was found to be of the order of few tenth of a nanometer.

Information about the surface chemical composition and depth profile were also obtained by means of a time-of-flight (ToF) SIMS mass-spectrometer produced by the Ion-ToF GmbH, Muenster, Germany. Secondary ions emitted from the bombarded surface were mass-separated and counted with the ToF analyzer. Results of the depth profile measurement of Pb-film are presented in Fig. 5.

From the recorded curves one can easily see that the deposited layers were clean enough. The chemical composition of the deposited layer was mainly of the pure metal. The appearance of some heavy impurities (like Cs, Na and K species) has also been observed, 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.

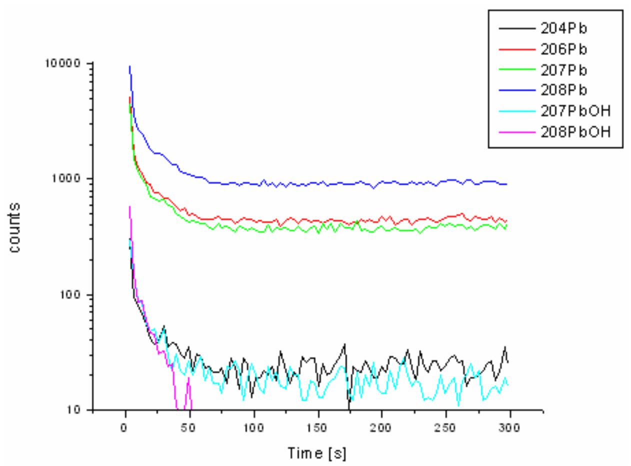

Fig.5. Results of SIMS measurements of the arc-deposited Pb layer.

An alternative method to analyse the purity of the deposited films, namely a Glow Discharge – Optical Emission Spectroscopy (GD-OES) technique, has also been applied. The obtained GD-OES results, not presented in the paper due to its volume limitations, have also confirmed the high cleanliness of the Pb superconducting films, which were deposited by means of the described UHV cathodic-arc technology.

CONCLUSIONS

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 various superconducting technologies, micro-electronics, nanotechnology, medicine etc.

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