INVESTIGATION OF LASER-CLEANING PROCESS ON LEAD PHOTOCATHODES *

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Abstract

To verify the process of laser-cleaning on metal cathodes we performed a combined photoemission (PE) and scanning electron microscope (SEM) study. We followed the laser-cleaning procedure on thin Lead films arc-deposited on Mo-substrates by means of photoemission in the photon energy range of 16 – 140 eV and determined the surface roughness before and after laser irradiation with white-light-interferometry. After the cleaning procedure the morphology of the samples was as well analyzed by means of SEM. The aim of the performed experiment was to find an optimal cleaning procedure for Lead cathodes within a sc rf photoelectron injector and study its influence on the electron emission from the Lead films.

INTRODUCTION

Laser irradiation of metal cathodes to enhance quantum efficiency is a well established procedure. If the laser energy density is kept below damage threshold, the quantum efficiency of the clean metal surface can be achieved without changing the surface morphology.

Due to transportation in air, adsorption of Oxygen, water and organic molecules takes place at the Lead surface. The adsorption of Oxygen and water leads to the built up of an oxide layer, in the case of Lead this layer protects the subjacent material against further oxidation. Adsorption of elements from the right side of the periodic table (e.g. Oxygen) increases the work function and therefore lowers the quantum efficiency of the cathode. In the experiment described below we were able to show that the use of a KrF Eximer laser is suitable to remove the passivating oxide layer without an increase of the surface roughness.

EXPERIMENTAL DETAILS

Mo-samples of different surface roughness were covered with Lead by means of the arc-deposition technique at NCBJ at Swierk, Poland [1]. This technique was found to produce the best films necessary to achieve high quantum efficiency and a smooth surface [2]. In order to avoid annealing, the deposition was done in intervals of 5 or 15 sec deposition followed by an 1800 sec pause, resulting in films of about 100-200 nm thickness.

The covered samples were sealed in an Argon atmosphere and shipped to HZB. Before mounting the samples into the Angular Resolved Photoelectron Emission Spectroscopy (ARPES) apparatus the samples micro-roughness was investigated using a Micromap Promap 512 white light interferometer (Mirau type objective, magnification 20x) [3, 4]. This allows to investigate the micro-roughness on a spatial frequency range of 235.2 – 1.6 μm^{-1}.

In the next step the samples were mounted on an Omicron sample holder and transferred into the ARPES chamber. The ARPES experiment was performed in the photon range of 16 eV to 140 eV at the Berliner Elektronenspeicherring fuer Synchrotronstrahlung (Bessy II) beamline UE112-PGM-2a within the "ARPES 1^2" endstation using the hemispherical electron energy analyzer Scienta R8000 with an angular resolution of 0.3° and energy resolution of about 10 meV. The base pressure of the UHV chamber is kept in the 10^{-10} mbar range. During laser irradiation the pressure in the preparation chamber increased up to $5{\cdot}10^{-8}$ mbar, the base pressure in the analysis chamber was found constantly around $9{\cdot}10^{-11}$ mbar. No external cooling or heating of the sample was used during the laser cleaning procedure and Photoelectron Emission (PE) measurements. The angular and energetic distribution of the photo emitted electrons was determined prior to the laser cleaning process because a crucial photocathode parameter in the electron injector is the intrinsic emittance, which strongly depends on the angular and energetic distribution of the emitted electrons.

A smooth sample with an average roughness of 4 – 6 nm was than chosen for the cleaning procedure.

For laser irradiation the sample was positioned in the preparation chamber in front of a fused silica window. The laser cleaning was performed by means of a KrF Excimer laser at 248 nm with a pulse length of 5 ns (Coherent Xantos XS).The laser beam was imaged with a f = 1 m lens located 2 m in front of the sample. The spot size on the sample was checked by means of a CCD camera (together with a converter crystal) located at the same distance as the sample. A green alignment laser was sent collinear with the UV beam allowing for an easy alignment on the sample surface.

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The cleaning steps were performed with different illumination intensities which were set by inserting metallic filters in the beam path. A slight degeneration of the metallic coating of the filter was observed during the illumination. Therefore the laser power reading was taken before and after the cleaning step ensuring an increase of below 10%. Each cleaning step was performed with a number of $3{\cdot}10^5$ pulses at a repetition rate of 500 Hz. From the CCD camera the illuminated area was determined to approximately 19 mm^2. After each irradiation step the sample was moved into analysis position for ARPES measurements.

To analyze the initial and final state of the film morphology SEM-measurements were done at FHI Berlin. The SEM measurements were performed with a Hitachi S-4800 (FEG cold) with high voltage at 2.5 kV and the EDX analysis with high voltage at 15 kV within the same apparatus with an EDAX Genesis V6.10.

RESULTS

White light interferometry

Mo-Samples samples of different roughness were produced by means of optical polishing by Pilz-Optics. After revealing the surface roughness, the samples were arc-deposited with Lead. The roughness was examined again and no change was found to the initial situation. After laser irradiation the average roughness was as well determined. The result did not differ from the as deposited film, showing that the sample was not severely damaged during the experiment.

SEM

SEM measurements of non irradiated samples reveal that Lead covers the Mo substrate surface and the topmost Pb layer exhibits holes in which small Pb particles are found. Figure 1 shows the initial state of the Lead film, an overview and high resolution measurement is shown. The morphology in figure 1 is almost alike the situation after irradiation shown in figure 2.

The SEM measurements performed after the laser cleaning procedure, see figure 2, exhibit that the particles and edges are smoother in the irradiated area whereas in the close proximity the particles are rough around the edges and more small particles are found, see for comparison figure 3.

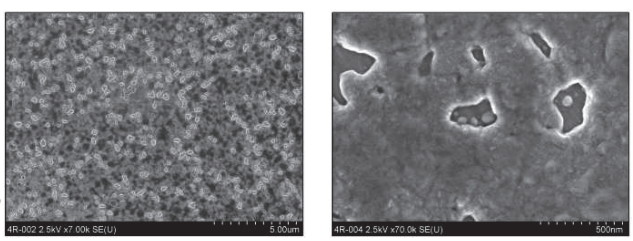

Figure 1: SEM picture of a Lead surface before the laser cleaning procedure. Scale: 5.0 μm left and 500 nm right.

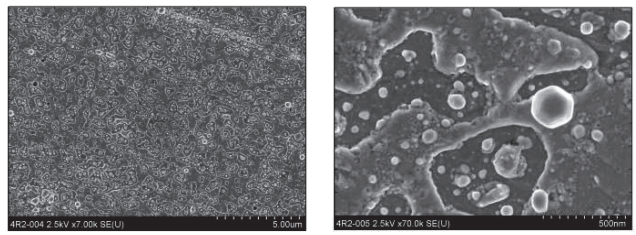

Figure 2: SEM picture of a Lead surface after the laser cleaning procedure at irradiated area. Scale: 5.0 μm left and 500 nm right.

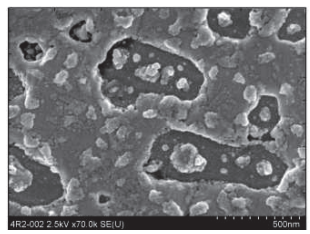

Figure 3: SEM picture of a Lead surface of an laser irradiated sample at a non-irradiated area. Scale: 500 nm.

ARPES

Using a photon energy of 140 eV it is possible to follow the Lead 5d states, at 18.1 eV and 20.7 eV binding energy, and Molybdenum 4p states, 30.8 eV and 32.6 eV binding energy [5]. During the laser treatment no Molybdenum correlated peaks appeared. It is assumed that the Lead film still covers the Mo substrate completely after laser irradiation.

Prior to the laser cleaning process two doublets are found, see figure 4 spectra a. The peaks at 17.9 $\pm$ 0,5 eV and 20.5$\pm$ 0.5 eV originate from metal Pb 5d states and the second doublet at 19.2 $\pm$ 0.5 eV and 21.8 $\pm$ 0.5 eV originates from oxidized Pb. The metallic doublet shows the characteristic spin-orbit coupling of 2.6 eV. Figure 4 shows the change in the PE-spectra during the laser cleaning. Four irradiation cycles were performed with increasing laser fluence: 0.024 mJ/mm^2, 0.09 J/mm^2, 0.19 mJ/mm^2 and 0.32 mJ/mm^2. Significant changes are only seen after the last cleaning step, with a fluence of 0.32 mJ/mm^2. The scan b taken after the last cleaning step shows no intensity originating from the oxidized state, see figure 4.

The angular distribution of the emitted electrons was measured for two samples of different roughness at 16 eV. Here, no significant change in the angular distribution was observed. As well the cleaning procedure itself showed no influence on the angular distribution. But since the emitting process in the gun will take place at much lower photon energies this have to be investigated seperatly.

SUMMARY

A combined SEM, PE and white light interferometry study was performed to analyze the laser-cleaning procedure of Lead films as performed in electron injector cavities. The Lead coating was prepared by arc-deposition.

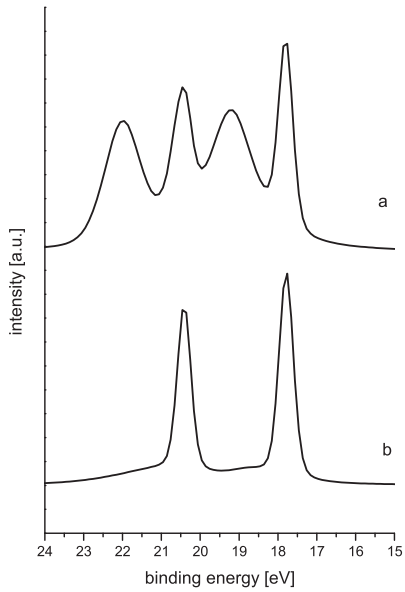

Figure 4: PE measurements: a) after laser irradiation as discribed above with fuences of 0.024 mJ/mm^2, 0.09 mJ/mm^2, 0.19 mJ/mm^2 and b) after 10 min laser irradiation with a fluence of 0.32 mJ/mm^2.

White light interferometry and SEM- measurements were used to analyze the overall roughness and morphology of the sample.

The films were exposed to air for some time, resulting in a contamination of the surface. Lead is known to build up an oxide layer which secures the Lead below from further oxidation. This is in good agreement with the PE measurements revealing two Pb species present on the surface prior to irradiation treatment. Laser irradiation of the Lead cathodes under the described circumstances removes the oxidized species. Measurements performed by Smedley et al. showed that by laser irradiation of roughly the same fluence as used in this work, the Lead cathode performance increased as a results of the work function change, which now proved to be due to the remove of the oxide layer [2]. SEM revealed that the experiment was performed below the threshold laser density which leads to the melting of the coating as shown in [2].

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