Preparation of Pb-photocathodes at National Centre for Nuclear Research in Poland – State of the Art

J. Lorkiewicz[1]*, I. Cieślik[1], P. J. Czuma[1], A. M. Kosińska[1], R. Nietubyć[1], J. Sekutowicz[2]

[1] *National Centre for Nuclear Research (NCBJ), A. Soltana 7, 05-400 Otwock-Świerk,Poland*

[2] *Deutsches Elektronen Synchrotron (DESY), Notkestrasse 85, D 22607 Hamburg, Germany*

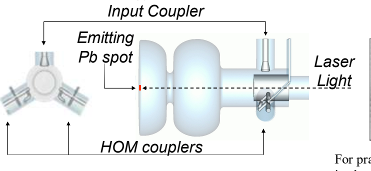
Abstract

R&D activities related to preparation of the superconducting Pb photocathode layer on niobium substrate are ongoing at the National Centre for Nuclear Research (NCBJ) in cooperation with DESY, HZDR, HZB, BNL and other research institutes. The activities are part of the R&D program at DESY for the cw-upgrade of E-XFEL and for the newly approved free electron laser facility PolFEL to be built and operated at NCBJ. The optimization results obtained for the lead deposition on niobium and smoothing of the coated layers are reported . The photocathodes samples were tested for their surface morphology, microstructure and quantum efficiency in terms of the impact on the operation of all-superconducting RF electron injector, proposed for both facilities.

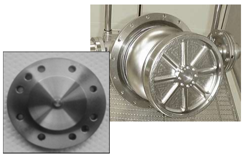
Introduction

A concept of a Nb-Pb hybrid superconducting radio frequency (SRF) niobium electron photoinjector with a thin-layer photocathode of lead was proposed in the last decade. It was dedicated to linear superconducting accelerators which provide typically up to 1 mA mean current in 10^5 Hz repeated, 1 nC bunches to a free electron laser undulator. The lead photocathode can be deposited on the back wall of a RF cavity using ultra high vacuum (UHV) cathodic arc coating. This deposition method is characterized by absence of residual gas impurities and possible increase of the energy of lead ions incoming to a negatively biased target. The usefulness of the photocathodes reached by this method was confirmed by a proof-of-principle test in laboratory conditions. The photocathode excited with a laser ultraviolet beam of 195 nm emitted photoelectrons with quantum efficiency (QE) pretty close to its theoretical value (0.54%). The following studies, however, revealed that QE depends substantially on cathode deposition parameters and photo-injector preparation. For some of 100 nm thick Pb films quantum efficiency grew dramatically after UV laser beam cleaning with a side effect of lead film modification due to local melting. These measurements indicated that assuring a film smoothness and homogeneity at sufficiently high thickness is necessary to operate a gun of this type.

The morphology and microstructure of a lead thin layer after deposition is strongly determined by presence of micro-droplets coming from erosion of the cathode in a coating arc device. At RF field gradient in accelerating structure up to more than 40 MV/m, microdroplets and other protruding surface irregularities can disturb locally the field intensity and initiate field emission or dark current. In addition they can influence adversely the photoemission process and reduce quantum efficiency. The reduction of droplets number can be performed by lead plasma flux filtering during the deposition or by the film annealing and recrystallization after deposition. The presentation reports on the current status of works at NCBJ and collaborating institutions aimed at optimization of lead photocathodes smoothness and thickness. It is the first stage of implementation of a four-years project connected with preparation, optimization and testing of complete 1.3 GHz SRF photoinjectors based on TESLA technology.



Scheme of a TESLA-type 1.6-cell RF injector with a thin-layer Pb photocathode



For practical reasons thin-film lead photocathode is deposited on the tip in the centre of a small-size niobium plug (left) which is next mounted in a back wall of a 1.6-cell RF resonator (right)

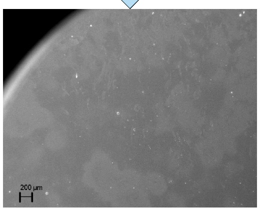
Different approaches to thin-film lead photocathode preparation: 1. filtered and 2. non-filtered UHV arc deposition

Lead films deposited in cathodic arc with 30⁰-bent magnetic filter of microdroplets

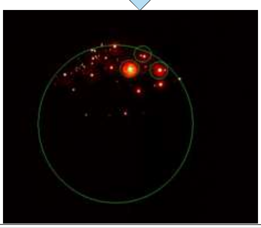
Coating parameters:

deposition rate	thickn.	substrate bias	impurities (EDS results)	morphology	pump
200 nm/min.	2µm	-70 V	C-2 wt % O-1 wt %	≈15 per mm² of spherical, extrusions (up to 30 µm in diam.) against uniform layer	turbo

Angular magnetic filters were designed to remove droplets from metallic plasma stream before deposition. Metal plasma is guided by axial magnetic field along a curved plasma duct. Most of the droplets strike the duct wall due to high mass-to-charge ratio. Some of them, however, are dissipated and reach the target in spite of optimized geometry of the coating system. Lead droplets up to 30 µm in diam are present in the SEM image above. . The target which containes a niobium substrate is biased with negative dc voltage (-50 V to -100V) which enables energetic deposition, good film density and adhesion.



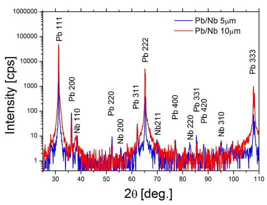
SEM image of a Nb-Pb photocathode with 2 µm Pb film with spherical extrusions which become centres of field emission.



Dark current imaging at 18.5 MV/m from a filtered UHV arc coated electrode. Performed at HZB (Courtesy R. Barday).

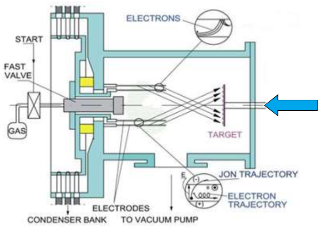
Dark current in SRF e gun from the shown circular surface of diam 10 mm is typically 200 nA

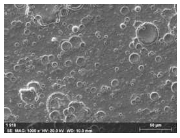
Pb layers on Nb substrate: crystallinity

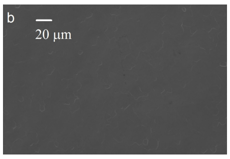


The microstructure and crystalite orientation of lead layers obtained by two different methods were studied by Cu Kα (λ=1.541837 Å) x-ray diffraction scans taken in a large angle (25deg-110deg) Bragg-Brentano (Θ/2Θ) mode. The blue plot corresponds to a 5 µm Pb film reached in the filtered arc, whereas the red one – to a 10 µm lead layer obtained by re-melting in IBIS device. The latter film is more tight – its spectrum does not contain Nb lines. On the other hand it is also strongly textured with its [111] direction perpendicular to the film Surface.

Layer post-processing in a rod plasma injector





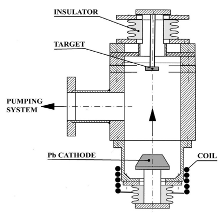


The rod plasma injector -IBIS at NCBJ is destined for surface treatment with 1 µs argon plasma ion pulses of 1 to 7 J/cm. To reach planar and continuous lead films their starting thickness had to be matched to ion beam fluency. To this end the flow of 1 µs long heat pulses through a lead layer thicker than 10µm was modeled and calculated It appeared from he heat flow calculations that treating 18-20 µm Pb film with 5-6 ion pulses 1.5J/cm² in fluence assures smooth (to within 1 µm), complete Pb layer (see the SEM image above).

At the time being, Nb-Pb photocathodes reached by described here 2-step coating and post-processing procedure show the best functional features:

1. Quantum efficiency not far from theoretical predictions (eg. $2.2 \cdot 10^{-3}$ at w vawelength 200 nm).
2. Quality factor of a complete 1.3 GHz SRF XFEL injector with a Nb-Pb cathode reached in this way is acceptable though significantly lower than for the injector without Pb photocathode coating. See the plot on the right.

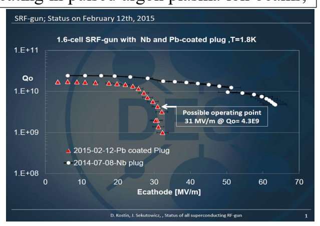
Non-filtered UHV arc deposition of Pb films



Pb coating parameters in non-filtered arc :

deposition rate	thickn.	substrate bias	impurities (20 keV EDS results)	morphology	pump
3 µm/min.	1µm up to 20µm	-70 V	C-2 wt % O-1 wt %	≈10⁴ per mm² of extrusions (up to 80 µm in diam. and 15 µm high) formed as craters or semispheres, etc.	turbo

Using a non-filtered UHV coating device which consists of a simple, planar arc system with cathode-to-target distance of merely 12 cm and without any droplets filtering mechanism results in enormous number of extrusions congealed in different forms. Such non-filtered lead films need additional post-processing to make them planar. Remelting and flattening of these layers are reached by treating in pulsed argon plasma ion beams,



Acknowledgment

Thanks are due to all the many collaborators of DESY, Thomas Jefferson National Accelerator Facility (TJNAF), Helmholtz Zentrum Berlin (HZB), Helmholtz Zentrum Dresden Rossendorf (HZDR) and NCBJ who participated or supported the project. Investigations were supported by „PolFEL – Polish Free Electron Laser" cofounded by European Regional Development Fund.

European Funds
Smart Growth

Republic of Poland

European Union
European Regional Development Fund