

QE TESTS WITH NB-PB SRF PHOTOINJECTOR AND ARC DEPOSITED CATHODES*

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Abstract

The ultimate goal of our presented here effort is to build a hybrid superconducting Nb photoinjector with the cathode made of lead, which demonstrates superior quantum efficiency (QE) compared to other metallic superconducting elements. In this contribution, we report preparation of the second QE test with the prototype of hybrid lead/niobium superconducting RF (SRF) photoinjector at 2K. The QE tests at room temperature and the SEM surface analysis of nine Pb cathodes, deposited under various conditions at three different deposition setups, are discussed too in this contribution.

INTRODUCTION

Motivation

A concept of the Pb/Nb hybrid SRF injector with a superconducting lead cathode was first discussed in 2005 [1] and the progress since then was reported in 2007 [2]. The photo-emission properties of lead were studied extensively in parallel. The result of these former studies has been summarized in [3]. The conclusion from many QE tests, both at 300 K and 4.2 K, was that such a SRF injector has the potential to deliver ~1 mA average current and ~1 nC charge/bunch. Figure 1 shows layout of the 1.3 GHz SRF injector as proposed in [2].

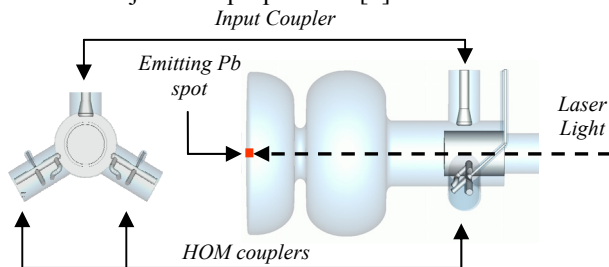


Figure 1: 1.6-cell SRF-injector cavity with 2 HOM couplers and an input coupler.

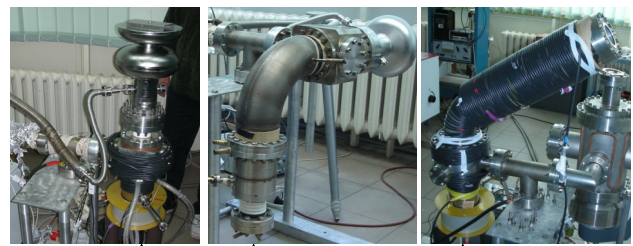
The technology of superconducting film deposition by means of the filtered cathodic arc offers an excellent approach to producing metallic films with an appropriate structure. It is distinguished from the other methods by the high energy of ions incoming to the target and by an absence of residual gas impurities. This results in formation of relatively clean, dense and uniform coating. Preliminary measurements of thin Pb layers, which were

deposited by means of proposed technique at INS have already shown that such lead layers demonstrate both the highest QE and the best surface quality, in comparison with those deposited by means of other techniques.

The goal of the research program reported here is to build an ultra high vacuum cathodic arc deposition facility dedicated to niobium coating with lead and to establish the Pb/Nb coating technology. This effort should lead us to the repetitive and reproducible lead deposition in the photoinjector cavities.

Deposition Setups

Figure 2 shows three setups built at INS-Swierk for the arc-deposition of lead cathodes on samples and on the back walls of SRF injector cavities [4]. The straight setup allows for the thicker coating, which usually contains droplets. The 90°-bent one filters out the droplets from the coated surface but the coating is usually very thin. The third setup with 30°-bend compromising advantages of two previously used, has been built very recently.



Location of the heater with lead stub for plasma formation

Figure 2: Arrangements for plasma arc-deposition; straight (left), with 90°-bend (mid) and 30°-bend (right).

SAMPLES AND COATING IN 2009

Eight niobium samples were manufactured at TJNAF in Spring 2009, four were made of the poly-crystalline and four of smoother mono-crystalline material. We plan to use the large-grain niobium for the back plates of injectors to reduce the intensity of dark current. All samples were chemically cleaned with Buffered Chemical Polishing (BCP), similarly to the procedure used for superconducting niobium cavities. The samples were coated in June and then in September 2009 at the straight and 90°-bend setup. The coating conditions are listed in Table 1. To find out an influence of the length of plasma arc, we positioned samples at two locations, which correspond to the coating distance for the half-cell and 1.6-cell injector cavity. Both types of cavities have been

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Table 1: Coating parameters in 2009

No	Time [s]	Nb type	Distance	Setup	Pump
1	1800	poly	1.6 cell	Straight	oil
2	1800	poly	1.6 cell	Straight	oil
3	1800	mono	1.6 cell	Straight	oil
4	2700	poly	1.6 cell	90°-bend	dry
5	2700	poly	1.6 cell	90°-bend	dry
6	2700	mono	0.5 cell	90°-bend	dry
7	2700	mono	0.5 cell	90°-bend	dry
8	6000	poly	1.6 cell	90°-bend	dry

built and are used for our R&D program. We used two types of vacuum pump (see last column).

SEM ANALYSIS AND QE TESTS

SEM analysis and QE prior to laser cleaning

The QE test and surface analysis with a scanning electron microscope (SEM) of the samples were performed at BNL. The QE test and the SEM inspection were done first for the as-delivered samples and then after the laser cleaning. Figure 3 shows SEM pictures of as-delivered samples No 1 and 5. Many droplets with diameter up to 80 μm can be seen on sample No 1, which was deposited at the straight setup. As expected, the coating of sample No 5 did not show droplets. This coating was thin: ~ 100 nm based on energy dispersive x-ray spectroscopy (EDS). Black marks and spots on the picture depict uncoated Nb area. The measured QE as function of the photon energy for these samples, prior to the laser cleaning, is plotted in Figure 4.

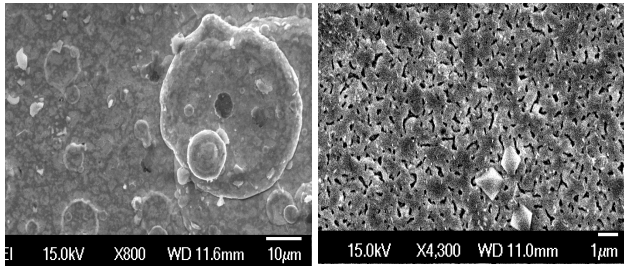


Figure 3: SEM pictures of as-delivered sample No 1 (left) and sample No 5 (right). Note different scale.

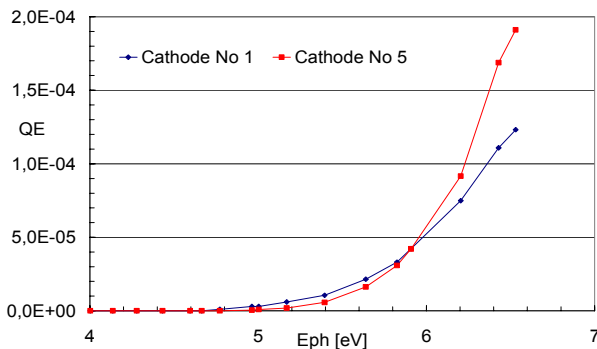


Figure 4: QE vs. photon energy for samples prior to the laser cleaning.

SEM and QE after the laser cleaning

The laser cleaning procedure was performed with per-pulse energy density of 0.2 mJ/mm^2 in three steps, each of 1500 pulses. After each cleaning step, QE increased, and in some cases in total QE was enhanced by factor of 20. Although the increase was significant, QE was still lower by factor of 2 as compared to the best cathode we measured in 2006, which was coated at very short distance. Fig. 5 shows QE for samples 1 and 5 after the laser cleaning and the best QE for arc-deposited cathode. An explanation to that came when we performed SEM investigation of the laser cleaned areas. The SEM picture of sample No 5 is shown in Figure 6. The cleaning procedure, though it increased significantly QE, led to strong modification of the Pb coating by the melting process. The Pb films have been converted to kind of a “labyrinth”, and the emitting areas were coated with lead in 60% at most. We think, that big fraction of the missing factor of 2 in QE is due to the uncoated area.

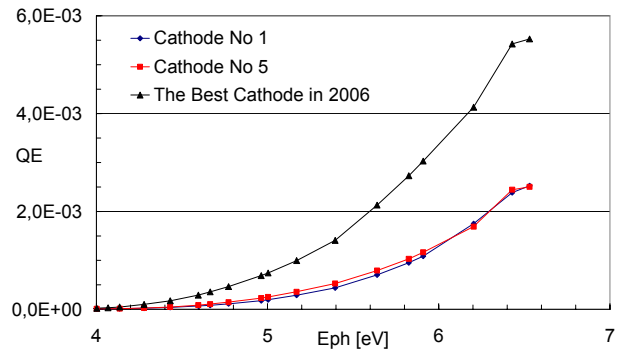


Figure 5: QE vs. photon energy for samples after the laser cleaning and for the best arc-deposited cathode measured in 2006 [3].

Surface Contamination

EDS spectra of samples coated when the “oil” pump was used demonstrate strong carbon contamination. An example of the measured EDS spectrum for sample No 3 is shown in Figure 7. All samples coated with “dry” pump have a much smaller carbon peak. The initial presence of carbon does not influence the emitting properties of a sample after an extensive laser cleaning causing the melting (see Fig. 5). This suggests that carbon is removed during the melting process. For thicker films or less aggressive cleaning, when the bottom part of layer will not melt, carbon and other impurities may degrade superconducting properties of the film. We will use in the future only “dry” pumps for the setup.

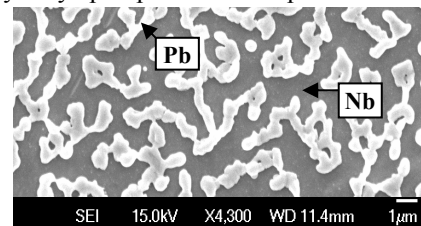


Figure 6: SEM picture of sample No 5 after laser cleaning.

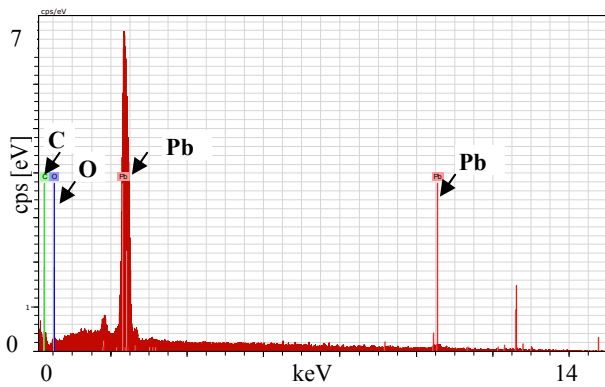


Figure 7: Example of the x-ray spectrum (with 15 keV electrons) for sample coated when “oil” pump was used.

30°-BEND SETUP AND COATING IN 2010

To increase the efficiency of ion transport towards the target as compared to 90°-bend, we replaced it with new 30°-bend.

The recently coated three samples (deposition time 10, 20 and 30 min.) at the new setup do not demonstrate droplets on the surface. The coating thickness was for all samples ~ 100 nm and the surface pitting was still not significantly improved. The 30-min. deposited cathode was laser cleaned for 30 minutes with low energy density (0.01 mJ/mm^2) pulses at 300 Hz rep. rate. This cleaning was gentle enough to leave the surface morphology unchanged (Fig. 8). The final QE was 0.33% at 190 nm (Fig. 9); this is superior to the cathodes discussed earlier yet still $\sim 30\%$ below the best measured cathode. There are likely two contributing factors to this. First, the surface is not fully covered. Second, the residual carbon and oxygen were reduced by the laser cleaning but not eliminated, suggesting that this gentle cleaning may not be sufficient.

At 5 keV incident electron energy, the EDS spectrum yielded 90.4% Pb, 6.2% C and 3.3% O by weight prior to laser cleaning and 93% Pb, 4.5% C and 2.5% O after cleaning. Further exposure at this low energy density did not increase the QE, suggesting that the optimum case would be a thicker film and somewhat more aggressive cleaning. To increase thickness of the coating we will need further modification of the setup. We will also investigate the reason of high carbon content in the films.

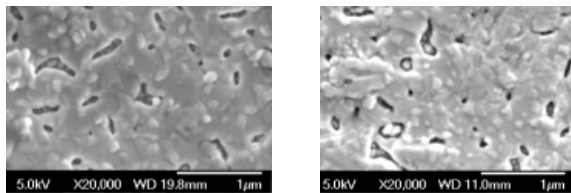


Figure 8: SEM images of cathode deposited with the 30°-bend: before (left) and after (right) laser cleaning.

Coating of the 1.6-cell cavity

The 1.6-cell cavity was coated very recently at the new setup (Fig. 10). The coating was done in two steps, each 30 min. The cavity will be tested at TJNAF. At first, we

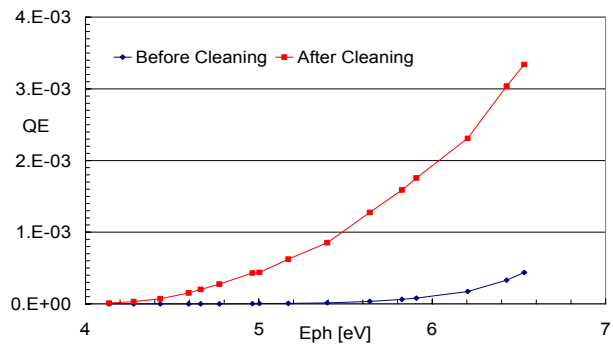


Figure 9: QE vs. E_{ph} before and after the laser cleaning.

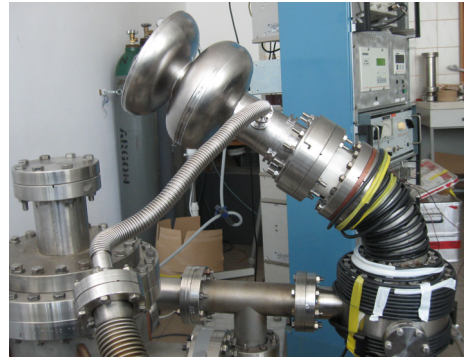


Figure 10: 1.6-cell cavity assembled for coating.

will test the SRF properties of the cavity. In 2008 and 2009 this cavity was tested up to 45 MV/m at the lead spot, which was deposited with 90°-bend setup in 2008. The QE test at 2K in January 2010, with the same Pb spot, was not very successful for two reasons. First, the cavity was strongly contaminated with particulates falling from the long tube holding it in the vertical cryostat. This caused that cavity reached only 13 MV/m on the cathode. Second, the lead spot demonstrated QE lower by factor of 20 then the expected value. This could be due to an accidental exposing of the cathode to the BCP acids during many chemical treatments and/or to the throughout oxidation of the very thin Pb layer. The new coating should be thicker. We plan to conduct the SRF and QE tests by the end of June this year.

ACKNOWLEDGMENT

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