

CRYOGENIC TEST OF THE Nb-Pb SRF PHOTOINJECTOR CAVITIES

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Abstract

In this contribution, we report progress on the development of a hybrid lead/niobium superconducting RF (SRF) photoinjector. The goal of this effort is to build a Nb injector with the superconducting cathode made of lead, which demonstrated in the past superior quantum efficiency (QE) compared to Nb. Three prototype hybrid devices, consisting of an all-niobium cavity with an arc-deposited spot of lead in the cathode region, have been constructed and tested. We present the cold test results of these cavities with and without lead

INTRODUCTION

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 last time reported in 2007 [2]. The photo-emission properties of lead were studied extensively in parallel. The result of these 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 bunches up to $10^5/s \sim 1$ nC, when the superconducting arc-deposited cathode is irradiated with a laser power of 0.4 W at a wavelength of 213 nm.

In 2008, we performed several cryogenic tests on two half-cell and one 1.6-cell high purity Nb cavities of the TESLA shape. All preparation steps and tests took place at TJNAF. The tested cavities are shown in Figure 1.



Figure 1: 1.3 GHz two half-cell and 1.6-cell SRF-gun cavities.

FIRST REFERENCE TEST IN 2008

Cold Test without Coating

All three cavities have been treated with the standard BCP acid mixture. The removed layer was at least $30 \mu\text{m}$ to ensure the complete removal of the residual lead from

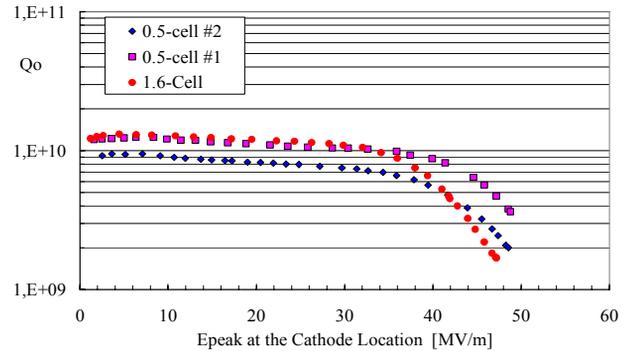


Figure 2: The first reference test results at the beginning of 2008.

previous coatings from the back wall. The best results achieved for the base line tests are displayed in Figure 2.

FIRST COLD TEST IN 2008 WITH Pb

Cathode

In the hybrid Pb-Nb gun, a small emitting spot of lead ($\varnothing < 3$ mm) will be located in the center of the back wall of the 0.6-cell or a 1.6-cell cavity. The operating electric field on the lead cathode will not exceed 50 MV/m. At this field, the emitting spot will be exposed to a very low magnetic flux of only 3.5 mT.

Deposition Setup

Figure 3 shows the setup built at the Soltan Institute for the arc-deposition of lead cathodes onto the back walls of both half-cell and 1.6-cell cavities [4]. The mask for the coating, shielding the whole inner wall of the cavity except for the cathode location, is shown in Figure 4a.



Figure 3: Setup for the plasma arc-deposition with the 1.6-cell cavity prepared for coating.

The chemical treatment and high pressure water rinsing (HPR) for a coated cavity is complicated. The deposited lead spot, with a typical of less than one μm , needs to be protected from the acids and water jets. We built special protecting masks for these two preparation steps, which are necessary for achieving high gradients with niobium cavities. The masks are shown in Figure 4b.

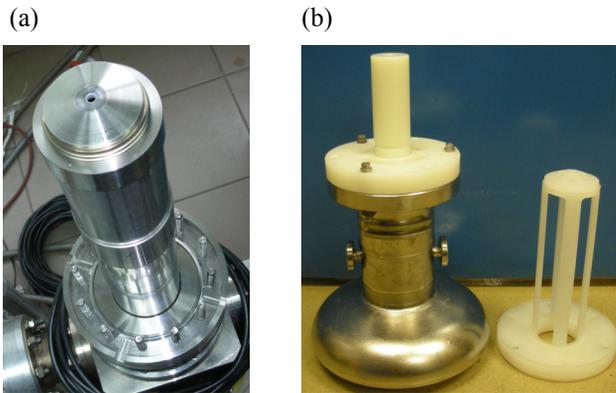


Figure 4: (a) Mask for coating with Ø 3 mm aperture for the cathode. (b) Masks for the surface cleaning of coated cavities.

Figure 5 displays the final result for the 1.6-cell cavity with the Ø 3 mm lead spot at the center of the back wall. The tests of two other cavities showed similar performance. The disappointing results were due to the so called “Q-disease” caused by hydrogen from the air intestinally dissolved in the heated niobium wall during the plasma deposition of the lead. In addition, our tests indicated that chemical treatment and high pressure water rinsing are challenging for the coated cavities and need to be improved in the future. We observed during the testing of the cavities several multipacting levels and strong electron loading (radiation) indicating that neither coating nor cleaning were done in the proper way.

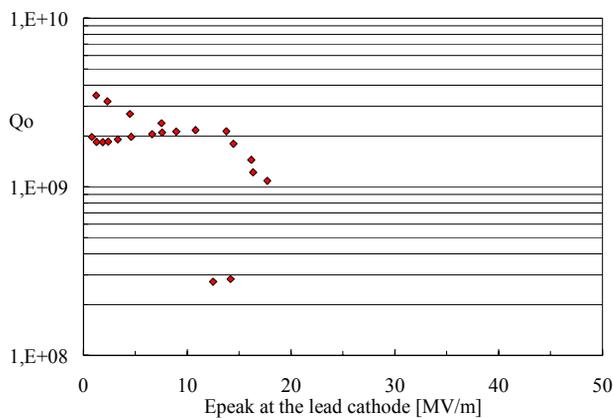


Figure 5: Cold test result for 1.6-cell cavity after the first coating in 2008, indicating Q-disease.

SECOND REFERENCE TESTS IN 2008

The poor results forced us to repeat the coating procedure. All three cavities were heat treated at 600 °C in a vacuum furnace after the lead spots were removed by

bulk BCP. The heat treatment released substantial amount of the hydrogen from the niobium walls. After a final BCP and HPR the cavities were re-tested and subsequently sent to the Soltan Institute for a new coating. The second base line test results are shown in Figure 6. All cavities reached gradients at the cathode location above 50 MV/m, but the intrinsic quality factor Q_0 was for the two half-cell cavities slightly lower than during the previous baseline test. This might be due to insufficient BCP treatment, but the performance was still good enough for further studies.

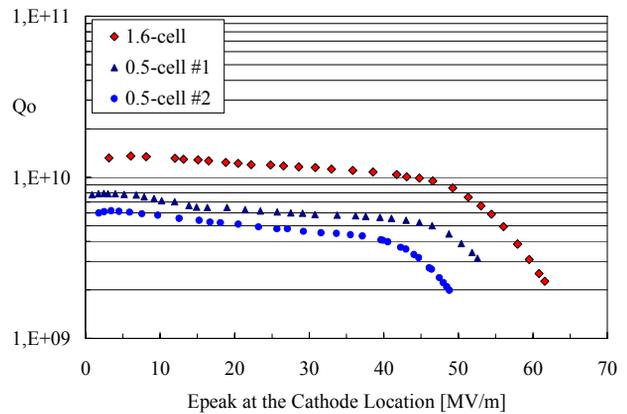


Figure 6: Result of the second baseline tests.

SECOND COLD TESTS IN 2008 WITH Pb

We equipped the setup for the deposition with a chamber for N_2 gas surrounding the cavities during the second coating series in September 2008. That coating was done in a pulse mode to keep temperature of the coated cavities below 33°C. The plasma arc was switched on for 3 minutes and then switched off for 40 min to cool down the cavity to room temperature of 25-28°C. This cycle was repeated up to 15 times. The coated cavities, shown in Figure 7, were shipped to TJNAF for the preparation and tests, which took place in December 2008. The performance of two half cells was somehow better, but still not satisfactory (Fig. 8). These cavities, after removal of the lead spots were sent back to the Soltan Institute for re-coating. The third coating was done in February 2009. No tests have been done yet.

There was substantial improvement in the performance of 1.6-cell cavity after it was coated in September 2008.

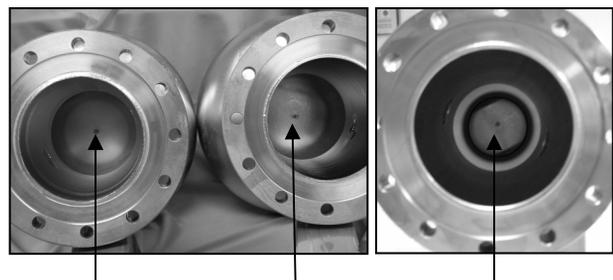


Figure 7: Coated cavities, half-cells left picture, 1.6-cell right picture. The arrows indicate lead spots on the back walls.

That cavity achieved 46 MV/m, missing our final goal by 4 MV/m only. That cavity will be used to repeat the QE and quench tests at high gradient and 2K.

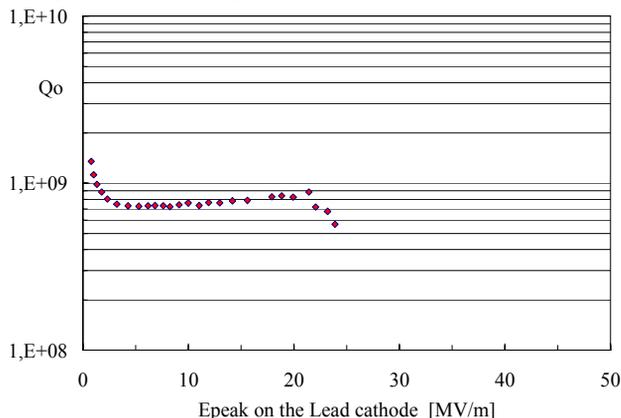


Figure 8: Test result with Pb spot for 0.5-cell #1.

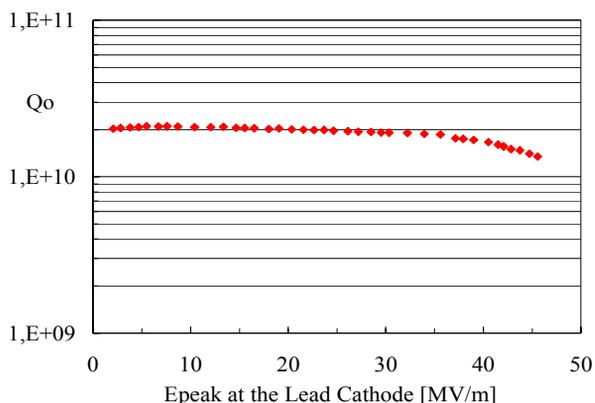


Figure 9: Test result with Pb spot for 1.6-cell cavity.

FUTURE PLANS

As mentioned above we will use the 1.6-cell cavity for exploring the QE of the lead and an intrinsic Q variation during irradiation of the cavity with laser at cryogenic temperatures. Afterwards, that cavity will be mechanically modified and assembled in a LHe vessel allowing for installation in a horizontal cryostat for further investigation at BESSY in Berlin. Our common goal with the BESSY group is the generation of an electron beam for emittance measurements. We are planning to conduct this test in 2010.

The two re-coated 0.5-cell cavities are presently at DESY for coating inspection and they will be shipped to TJNAF by the end of April 2009. We expect to complete the cleaning and testing of these cavities by the end of this year.

A second 1.6-cell cavity has been built at TJNAF. This cavity was first used for the test of a new coaxial coupling device, which will be needed for the hybrid injector proposed in [1, 2] and which can be used for other superconducting cavities. First experiments of this device are reported elsewhere in these Proceedings. This cavity

will be used for the SRF injector R&D as soon as tests of the coupling device will be finished successfully.

The coating process needs further studies. Five small cathodes made of poly and mono-crystal niobium were built recently at TJNAF. These cathodes, after lead deposition at various coating parameters, will be shipped to BNL for the QE tests. With these experiments we hope to optimize parameters for the lead deposition on the back walls of cavities.

Finally, two “plug cavities” fabricated at TJNAF and reported in [2], are mechanically modified to accept new, smaller diameter plugs, with and without lead coating; the plugs were already prepared in 2008.

ACKNOWLEDGMENT

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