SRF GUN CAVITY R&D AT DESY

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Abstract

SRF Gun Cavity is an ongoing accelerator R&D project at DESY, being developed since several years. Currently several SRF gun cavity prototypes were simulated, built and tested in our Lab and elsewhere [1] – [11]. Lately the 1.6 cells niobium cavity with Pb thin film cathode was tested in a vertical cryostat with a different cathode plug configurations. Cathode plug design was improved, as well as SRF gun cavity cleaning procedures. Results of the last cavity performance tests are presented.

INTRODUCTION

Goal of this R&D is to prove feasibility of all-superconducting electron source, delivering low emittance beams for FLASH / XFEL like facilities [12] – [15]. We began this R&D several years ago aiming for 1 mA current with 1 nC bunches at 1 MHz repetition rate, but:

- LCLS showed in 2009 that SASE process can take place with charge, as low as 20 pC.
- Experiments listed in the Scientific Case, which inspires the CW operating LCLS II project at SLAC, will nominally use photons generated by 100 pC bunches at 100 kHz repetition rate.

Both, led us to a revision and less demanding SRF-injector parameters in our project. We assume currently that generated electron current will be ≤ 10 µA.

SRF GUN CAVITY

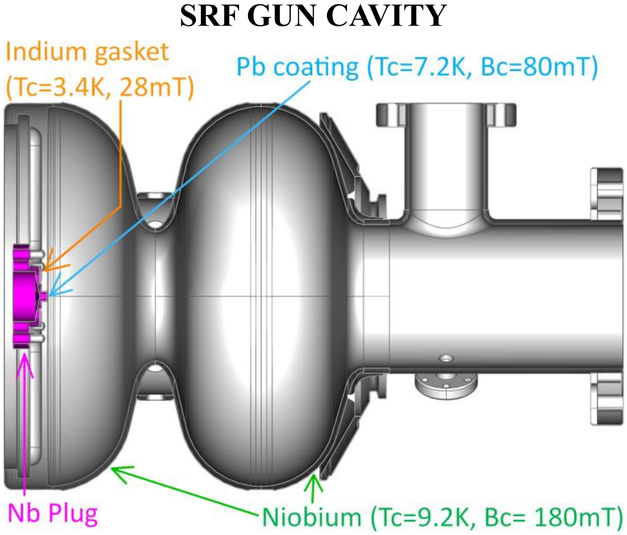

Figure 1: SRF gun cavity with a cathode plug.

In Figure 1 the 1.6 cells SRF gun cavity is presented. Figure 2 shows the cavity in a vertical test cryostat insert at DESY, Hamburg. The cavity was tested with two indium sealed niobium cathode plug (see Fig. 3) configurations: pure niobium plug and a plug coated with lead. The SRF gun cavity was electropoished at DESY before cathode plug insertion. Then the cavity was baked at 90ºC and installed in a vertical cryostat test insert with a movable input antenna (see Fig. 2), enabling variable coupling.

Figure 2: SRF gun cavity in a vertical test cryostat insert at DESY, Hamburg.

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Cathode Plug

Pb-coated [16] – [18] cathode plug is shown in Figs. 3 and 4. All plug designs use indium sealing. New plug has liquid helium (LHe) cooling channels to facilitate the plug cooling. Pb-coating of the cathode post is done by the arc-deposition at NCBJ Świerk. Figure 5 shows lead deposition quality reference picture: much smaller droplets: ø < 20µm and height of few µm.

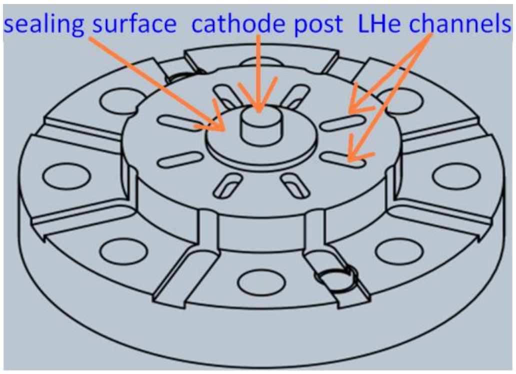

Figure 3: Cathode plug configuration.

Figure 4: SRF gun niobium cathode plug.

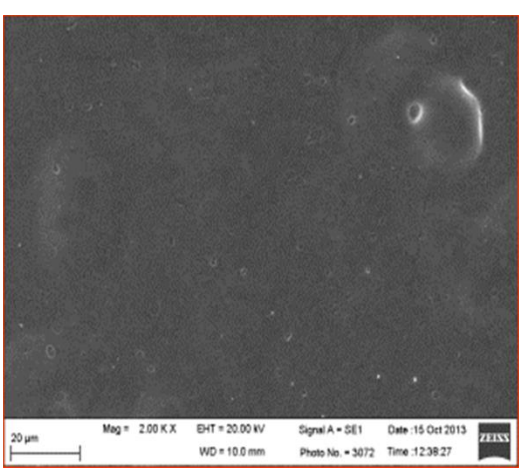

Figure 5: SRF gun niobium cathode plug coating.

RF MEASUREMENT RESULTS

Because of movable input antenna, CW measurement with β=1 was possible. The field probe is placed on the same side as the antenna (see Fig.1 and 2), which makes frequency lock somehow more difficult. The test was performed at 1.8 K.

The cavity showed low field quality factor of Q_0 = 1.74×10^{10} and reached accelerating gradient of E_{acc} = 18 MV/m, corresponding to the cathode field of $E_{cathode}$ = 34.2 MV/m. The limits were the breakdown (BD) and high cryogenic losses (low Q_0 at the high field). The field emission (FE) onset was $E_{acc.FE.on}$ = 10 MV/m, and the measured radiation was up to 0.1 mGy/min with a 1 liter gamma chamber placed on the top of the cryostat. Test up to highest possible field degrades the cavity performance, but it could be restored after BD or warming-up to 120 K and cooling to 1.8 K again. The cavity has a stable FE behavior, with some low RF power processing (LPP) needed during the first power rise, but without further FE related degradation afterwards. The cavity performance with coated plug is degraded compared to the test with uncoated plug. Such a performance drop is clearly understandable (coating).

RF Measurement Data

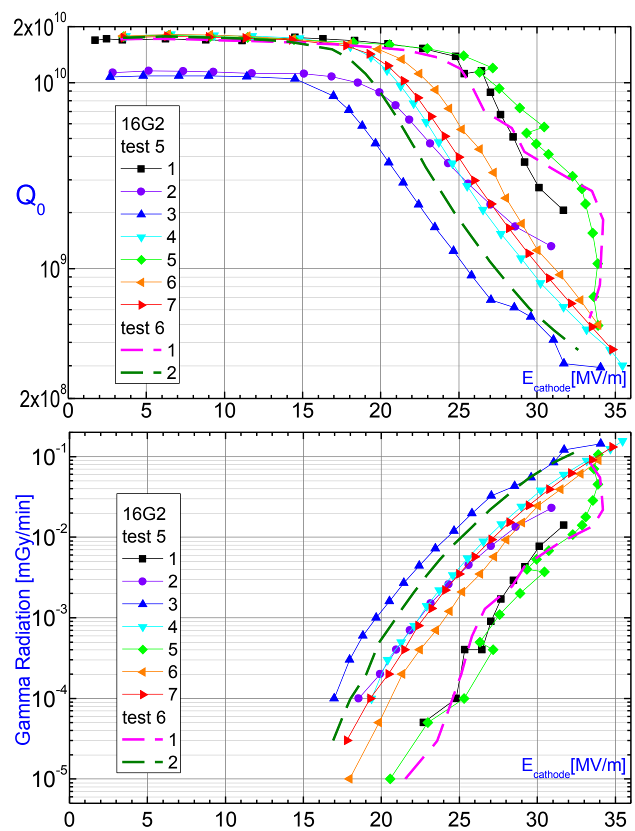

Figure 6: SRF gun cavity with a Pb coated Nb cathode plug: last CW RF Tests at T = 1.8 K at DESY.

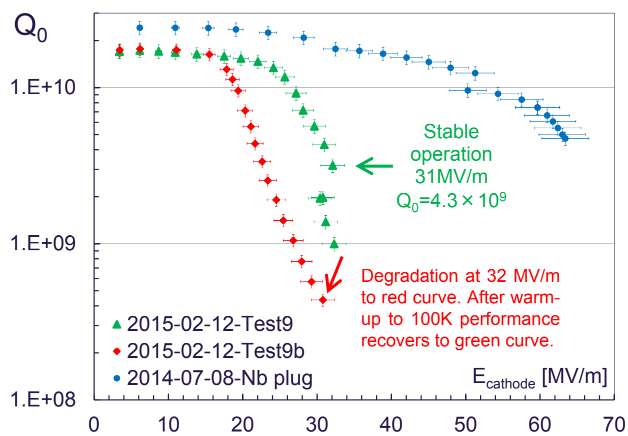

Figure 7: SRF gun cavity CW RF tests summary: blue dots – pure Nb plug, green triangles and red dots – Pb coated Nb cathode plug.

The cavity CW RF test data are presented in Fig.6 and 7, where Fig.6 shows last 2 tests (tests 5 and 6 at DESY) data plots $Q_0(E_{cathode})$ and X-rays($E_{cathode}$) and Fig.7 summarizes all important milestones in cavity testing.

DESY Test 5 (Fig.6) curves:

1. Stopped without BD. FE onset 12 MV/m.
2. Q_0 decreased, stopped with plug heat-up effect (degradation).
3. Q_0 decreased. BD (first time).
4. Q_0 increased at low Eacc after BD. BD.
5. After warm-up/cool-down. FE onset 11 MV/m, stop/wait at 14 and 16 MV/m. Degradation at the end.
6. After warm-up/cool-down. FE onset 9 MV/m, low field $Q_0 = 1.8\times10^{10}$.
7. FE onset 9 MV/m, same low field Q_0. Some performance degradation effect.

DESY Test 6 (Fig.6) curves:

1. Q_0 degradation with high cryogenic losses, BD at 18.5 MV/m.
2. Q_0 decreased. High cryogenic losses, no BD.

All CW RF tests are done at T = 1.8 K.

OUTLOOK

For the significantly reduced beam current of ca. 10 µA the laser specification became much less demanding. With following initial assumptions:

- Lead QE = $2\cdot10^{-4}$ at 260nm (half of the best QE, measured at BNL, [16] – [18])
- q/bunch = 100pc (300pc)
- $f_{rept.}$ = 100kHz (33 kHz)

the required laser power on the cathode will be 0.24 W at 260 nm, 2.4 (7.2) µJ/pulse, plus shaping and transport (×10) plus conversion to 4th harmonic (×10) = 24 W at IR. With a beam power ~ (100 pC × 15 MV/m × 0.2 m × 100 kHz) ~ 30 W and wall losses ~ $(15\text{ MV/m} \times 0.2\text{ m})^2$ / (180 Ω × 4×10^9) ~ 12 W a total RF-power (at $E_{cathode}$ = 30 MV/m, E_{acc} = 15 MV/m) ~ 42 W. Matched Q_{load} is 1.2×10^9 for this operation point. It is too high for the operation because of microphonics. One can decrease it by a factor of 100 and raise the input power to ~ 4.2 kW (still fine for TTF3 type input power coupler) to enable better amplitude and phase stability.

SUMMARY

- SRF gun development is an ongoing accelerator R&D program at DESY since 2006. Several SRF cavity options were simulated, and two 1.6-cell were built at DESY and JLab (Fig.1,2).
- Recently, the 1.6-cell niobium cavity was tested in a vertical cryostat with improved plug (cooling and coating, Fig.3,4), reaching 63 MV/m with Nb-plug and 32 MV/m with Pb-coated plug (Fig.7).
- The vertical tests of the prototype cavity 16G2 showed that stabile operation with Pb-coated cathode is possible for Ecathode of 25 .. 30 MV/m (Fig.7).
- Not yet is clear why the degradation happened and what prevents operation at higher gradients.
- We plan to investigate other emitting materials (for example 40 nm thin layer of GaN).
- Long term operation with laser will be very useful to learn more about durability of the coating and stability of the cavity performance.

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REFERENCES

[1] T. Kamps, R. Barday, A. Burrill, A. Neumann, S. Schubert, M. A. H. Schmeisser, J. Voelker, J. Sekutowicz, J. Teichert, R. Nietubyc, P. Kneissel, J. Smedley, I. Will, R. Xiang, "Characterization of a superconducting Pb photocathode in a SRF photoinjector cavity", P3 Workshop, LBNL, USA, 3-5.11.2014.

[2] A. Neumann, "Towards a 100mA Superconducting RF Photoinjector for BERLinPro", 16th International Conference on RF Superconductivity, Paris, France, 2013.

[3] R. Barday, et al., "Characterization of a Superconducting Pb Photocathode in an SRF Photoinjector", submitted to PRST-AB: Cavity, August 2013.

[4] A. Neumann, W. Anders, A. Burrill, A. Frahm, T. Kamps, J. Knobloch, O. Kugeler, E. Zaplatin, "SRF Photoinjector Cavity for BERLinPro", Proceedings of IPAC2013, Shanghai, China.

[5] A. Burrill, W. Anders, T. Kamps, J. Knobloch, O. Kugeler, P. Lauinger, A. Neumann, J. Sekutowicz, P. Kneisel, R. Nietubyc, "RF Measurements of the

ISBN 978-3-95450-178-6

1.6 Cell Lead / Niobium Photoinjector In HoBiCaT", Proceedings of IPAC2013, Shanghai, China.
[6] R. Barday, T. Kamps, O. Kugeler, A. Neumann, M. Schmeißer, J. Voelker, J. Sekutowicz, R. Nietubyc, J. Smedley, P. Kneisel, "Characterization of a Superconducting Pb Photocathode in a SRF Gun Cavity", Proceedings of IPAC2013, Shanghai, China.
[7] A. Burrill, W. Anders, A. Frahm, J. Knobloch, A. Neumann, G. Ciovati, W.A. Clemens, P. Kneisel, L. Turlington, "First Horizontal Test Results of the HZB SRF Photoinjector for BERLinPro", in Proc. 6th International Particle Accelerator Conference, IPAC2015, Richmond, VA, USA.
[8] T. Kamps, W. Anders, M. Dirsat, A. Frahm, J. Knobloch, O. Kugeler, A. Neumann, T. Quast, M. Schenk, M. Schuster, T. Rao, J. Smedley, J. Sekutowicz, P. Kneisel, I. Will, R. Nietubyc, "SRF Gun Development for an Energy-Recovery Linac based Future Light Source", Proceedings of SRF2009, Berlin, Germany.
[9] J. Sekutowicz, J. Iversen, D. Klinke, D. Kostin, W. Möller, A. Muhs, P. Kneisel, J. Smedley, T. Rao, P. Strzyżewski, Z. Li, K. Ko, L. Xiao, R. Lefferts, A. Lipski, M. Ferrario, "Status of Nb-Pb Superconducting RF-Gun Cavities", Proceedings of PAC07, Albuquerque, New Mexico, USA.
[10] J. Sekutowicz, J. Iversen, D. Klinke, D. Kostin, W.-D. Möller, I. Ben-Zvi, A. Burrill, J. Smedley, T. Rao, J. Langner, P. Strzyżewski, P. Kneisel, R. Lefferts, A. Lipski, K. Szałowski, K. Ko, L. Xiao, M. Ferrario, J. B. Rosenzweig, "Nb-Pb Superconducting RF-Gun", Proceedings of EPAC 2006, Edinburgh, Scotland.
[11] J. Sekutowicz, et al., "Nb-Pb Superconducting RF-gun", TESLA-FEL Report 2005-09, DESY, 2005.
[12] H. Weise, "The TESLA X-FEL Project", in Proceedings of EPAC 2004, Lucerne, Switzerland.
[13] http://xfel.desy.de/.
[14] J. Sekutowicz, V. Ayvazyan, J. Branlard, M. Ebert, J. Eschke, T. Feldmann, A. Gössel, D. Kostin, M. Kudla, F. Mittag, W. Merz, C. Müller, R. Onken, I. Sandvoss A. Sulimov, E. Schneidmiller, M. Yurkov, W. Cichalewski, W. Jalmuzna, D. Makowski, A. Piotrowski, K. Przygoda, K. Czuba, J. Szewinski, "Feasibility of CW and LP Operation of the XFEL Linac", The 35th International Free-Electron Laser Conference, FEL 2013, New York, NY, USA, August 25-30, 2013.
[15] J. Sekutowicz, V. Ayvazyan, M. Barlak, J. Branlard, W. Cichalewski, W. Grabowski, D. Kostin, J. Lorkiewicz, W. Merz, R. Nietubyc, R. Onken, A. Piotrowski, K. Przygoda, E. Schneidmiller, M. Yurkov, "Research and Development towards Duty Factor Upgrade of the European X-Ray Free Electron Laser Linac", in PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 18, 050701 (2015), Published by the American Physical Society, 2015 (PhysRevSTAB.18.050701).
[16] J. Smedley, et al., "Lead Photocathodes", PRST-AB, Volume 11, No. 1, 2008, DOI: 10.1103 / PhysRevSTAB.11.013502.
[17] J. Smedley, et al., "Photoemission Tests of a Pb/Nb Superconducting Photoinjector", Proceedings of PAC07, Albuquerque, New Mexico, USA.
[18] J. Smedley, et al., "Photoemission Properties of Lead", Proc. EPAC 2004, Lucerne, Switzerland.