DEMETRA ACTIVITY REPORT 2017

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1 Aim of the experiment and introduction

The DEMETRA experiment is dedicated to the modeling, development and test of RF structures devoted to acceleration with high gradient of particles through metal and dielectric devices. The team of the Laboratori Nazionali di Frascati (LNF) has been involved in different research studies including the simulation and construction of RF structures performed in the framework of the INFN-LNF, SLAC (USA), KEK (Japan) and UCLA (Los Angeles) collaboration [1, 2]. In spite of the delay in the availability of founds experienced in 2017, a relevant fraction of the R&D was devoted to investigate new coatings and also manufacturing techniques to improve the maximum sustainable gradients in normal conducting RF structures operating at X-band (11.424 GHz), trying to minimize the breakdown and the dark current [3, 4]. In particular, within 2017, the LNF team performed simulations of different accelerator devices, manufactured two new RF structures and continued the growth and the characterization of metallic coatings based on transition metals oxides

2 Simulations of copper RF structures

The demand of high-brightness electron beams is continuously increasing: advanced accelerators, linear colliders, X-ray free-electron lasers (FELs), etc. The present R&D in the cryogenic copper technology (working conditions 50 K) will enable a variety of new applications, thanks to accelerating gradients over twice the value achieved with standard technologies. As an example, for S band frequency, the cryogenic copper technology allows to reach values of field gradient > 250 MV/m with an increase of a factor of 25 in the beam brightness [5, 6]. This new technology will permit more compact and affordable accelerators useful in many critical areas and interdisciplinary applications. Also for this reason, in collaboration with SLAC, we already designed in the past an innovative compact mode launcher with no RF multipolar fields suitable to power on axis a radiofrequency photo-injector in S-band or X-band. With this structure it is possible to remove the cavity coupler from the full cells and minimize the magnetic field on the coupling aperture, reduces the pulse heating and the breakdown rate in this device.

The design of the S-band mode launcher has been also optimized to match a cell gun developed at UCLA [7]. Since this mode launcher couples the RF power with an on axis scheme allowing higher gradients and minimizing both the dipole and quadrupole components in the RF-Gun [8, 9] it can be efficiently used for high brilliance applications. The mode launcher joined to the S-band gun is showed in Figure 1. A similar device has been also designed in X-band. Simulations show that for a transmitted RF power of 200 MW, the surface peak electric field is 20 MV/m and the magnetic field 80 kA/m, which corresponds to a pulse heating of 3 C for a 5 s pulse. This compact mode launcher and its entire feeding network match a box with a transverse dimension of 0.25x0.25 m^2 for a typical X-band device and one of 0.5x0.5 m^2 for the S-band case.

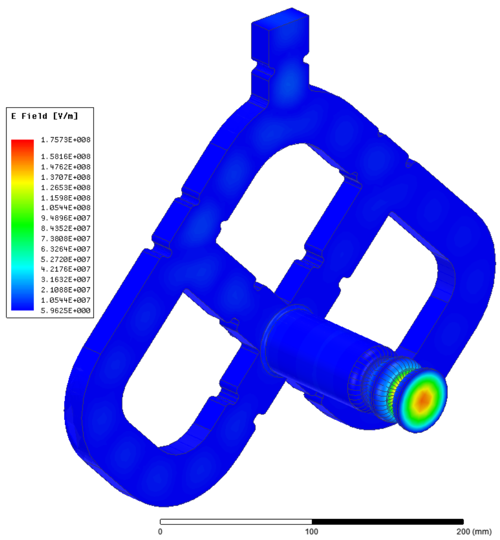

Figure 1: The mode launcher with compensated quadrupole components connected to the S-band gun.

In 2017 we continued the feasibility studies of open-like structures. A 3-cell test section has been studied and optimized for a high gradient operation. In Figure 2 is showed the electric field of an open-like 3-cells test cavity. The rounding between the cell and flat surface have been specifically studied to reduce the surface maximum magnetic field and, by consequence, the pulse heating in this critical region. As showed in Figure 2 the radius of the optimized rounding is equal to 0.5 mm. Moreover, the transverse dimension of the cavity has been optimized to reduce the maximum electric and magnetic field. For a ratio of 0.875 between the x dimension and the y dimension the high gradient figures of merit have been minimized. The electric maximum surface field obtained is 190 MV/m, the magnetic maximum field 0.3 MA/m and the modified Poynting vector 2.11 MW/mm^2.

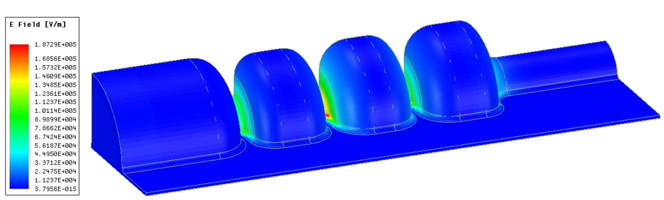

Figure 2: The electric field of the open-like 3-cells test cavity. The field is neutralized for the input power of 10 MW.

In Figure 3 we show the maximum surface magnetic field on the rounding region of the central cavity as obtained by the simulations. This section will be realized as two half parts on the longitudinal axis and innovative solutions (TIG welding and EBW) are under consideration to join the two parts of this open structure.

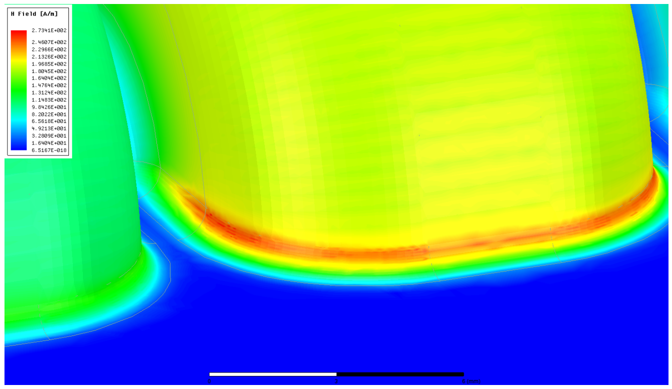

Figure 3: The maximum surface magnetic field on the rounding of the central cavity of the structure shown in Figure 2. The field is neutralized for the input power of 10 MW.

Other simulations have been also performed to support the researches of the LNF. The most important are those regarding the coupling impedance for FCC-ee design report and the Beam Position Monitor (BPM) for the ELI project, see Figure 4. For the latter a general methodology for virtual calibration has been developed. A correction algorithm for compensation the non-linearities in charge measurements by means of a strip-line BPM has been developed [10, 11]. The correction algorithm proposed is based on a polynomial fit of the simulation results. The order of the polynomial equation is four for both the x and y coordinate. Therefore, a total of 15 coefficients were necessary to correct non-linearities. In the full acceptance area of 196 mm^2 the maximum error between the correction algorithm based on the simulation results and experimental data is 5.4%. This error is mainly due to the manufacture accuracy of the BPM and/or to the different gain level of the electronics channels.

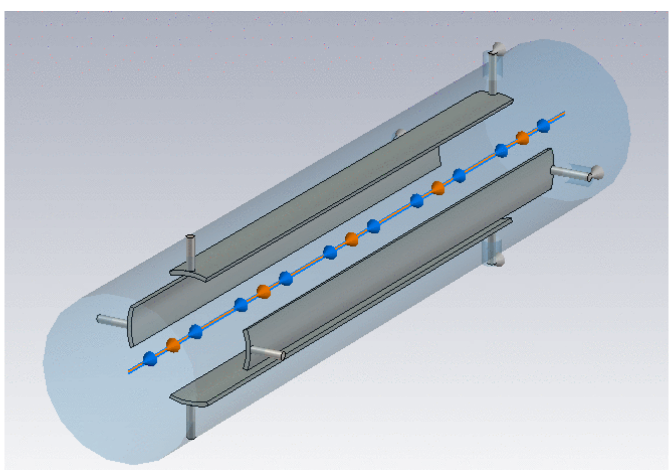

Figure 4: A 3D model of the strip-line Beam Position Monitor designed for ELI_NP test facility.

3 Manufacture of copper RF structures

The design of accelerator components such as RF cavities suitable to minimize breakdown depends on materials, surface processing techniques, but also geometry so that it is necessary to understand and predict the breakdown behaviour of practical structures, but also identify alternative materials and manufacturing techniques. As for the open structure discussed in section 1, we attempted in general to improve the performance of X-band accelerating structures in terms of manufacturing approaches alternative to brazing such as electroforming, or electron beam welding (EBW). Indeed, to improve high power performances, e.g. the discharge rate, fabrication procedures need to avoid heating of these devices at high temperature as it happens in conventional vacuum brazing technique or using materials with a high fusion temperature. Moreover, for the standard brazing procedure a high temperature is required in order to obtain a joint with good mechanical and vacuum tight properties. Generally, a temperature of at least 700-800 °C for copper is needed. However, this temperature modifies the morphological properties of the material, unavoidably affecting its quality in terms of RF performance. As a consequence, low temperature procedures (or hard bonding) have to be considered. Among the different possibilities we selected the Electron Beam Welding (EBW) procedure whose main advantage is the low thermal energy transferred to the piece under manufacturing. In addition, the method is characterized by the total absence of other metals generally present in the joint among cells, when the brazing process is used. We have designed and fabricated a three cells standing wave copper structure operating at 11.424 GHz sealed with the EBW approach, that is under test at SLAC. We also manufactured another accelerating sections using the Tungsten Inert Gas (TIG) brazing technique, a really totally innovative technological process. Results are those expected both from the constructive point of view (hard structure) and from the low power RF behavior. Results from high power tests are expected in 2018 but for both the new accelerating devices we are considering the possibility to patent the manufacture procedures. In Figure 5 is showed a photo of the first TIG manufactured hard copper accelerating cavity realized at LNF using the Italian technology

4 Metallic coatings

Modern technologies are enabled by the use of materials that match their demands. Accelerators are also extremely demanding in term of material properties, for breakdown phenomena. Copper is the most studied material in RF applications due to its high electric and thermal conductivity, as well as for the possibility of a high precision machining. Using advanced techniques combining a film deposition and precision electroforming new possibilities may open in this field. Adding a coating, of which we may control composition, internal stress, mechanical properties, roughness, etc., properties of a bulk material like the thermo-mechanical stability may be improved reaching values not attainable by an uncoated material. We considered the possibility to coat copper (and other metals) with a relatively thick film. In this case, the ideal coating material has to show comparable or superior mechanical and chemical-physical properties like conductivity, mechanical resistance and chemical affinity compared to copper. As we discussed in ref. [12], a high-conductivity Mo metallic coating made is an interesting option for high performance accelerator components. Although the Mo conductivity is lower compared to Cu, looking at the results of the Mo breakdown rate the application in high gradient accelerating structures is promising [13, 14, 15]. We are also started to grow and characterize MoO_3 films on flat copper substrates. The great interest towards molybdenum oxides is due to their mechanical resistance, good electrical conductivity and low field emission. Several films with different thickness have been grown in collaboration with the Department of Physics of the University of Tor Vergata (see Figure 6) and characterized at Roma Tor Vergata with STM. Transport properties have been measured with different setups and

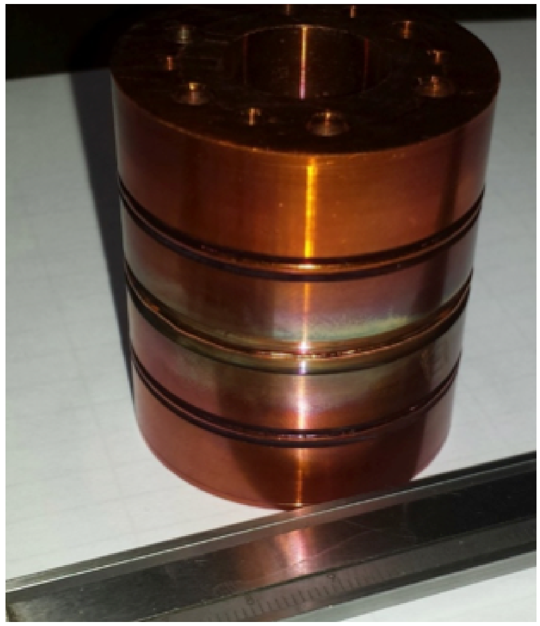

Figure 5: Photograph of the RF cavity working at 11.424 GHz before the test at higher power. This SW structure has been manufactured in copper and assembled with the TIG process.

techniques at the INFN of Napoli, Sapienza, Roma Tre and at the Politecnico of Torino. These characterizations confirm that thin films of molybdenum trioxide, a hard transparent insulator, on a thick copper substrate tend to become conductive while its work function should remain high and constant ($\sim$7 eV). The combination of copper coated by thin oxide films could be used in accelerating devices, to reduce the dark current, (i.e. the emission of electrons from the surface) because of their high work function.

To characterize the proprieties of these films we developed and built a dedicated evaporation setup showed in Figure 6. The stainless steel high vacuum chamber (HV) showed in the figure hosts a tungsten vessel that permit the evaporation using the Joule effect. The substrate on which the film is deposited is placed on the crucible and a screen allows controlling the deposition rate. The thickness of the deposition is measured by a crystal quartz microbalance placed next to the substrate. These MoO_3 films were characterized at the LNF also by X-Ray Diffraction (XRD) techniques to check the presence of ordered crystalline phases.

The transport behavior of MoO_3 samples at low temperature was measured using an optical cryostat with a temperature-controlled liquid He continuous flow down to 20 K. Data show that thin films are conducting while for thickness $>$ 500 nm the temperature dependence of the electrical resistance show a semiconducting behavior. This characterization was performed at INFN Napoli. On the same film we performed also an X-ray Absorption Spectroscopy (XAS) characterization at the Diamond Light Source facility (Oxford), using the x-ray beam available at the B18 beamline. We collected spectra at the K edge of Mo in the continuous scan mode. Four different samples of MoO_3/Cu, with different thickness: 50 nm, 100 nm, 200 nm and 300 nm have been measured. The analysis is in progress and a manuscript is in preparation.

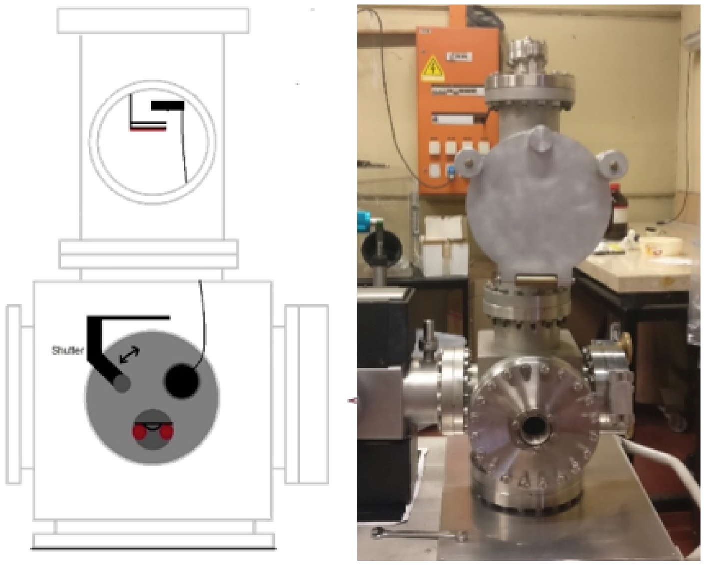

Figure 6: Schematic layout (left) of the evaporation setup inside the HV chamber: on top is placed the sample and the quartz balance. The rotating shutter allows starting and ending the evaporation from the crucible located in the bottom of the chamber. The sample holder inside the HV chamber (right) is also heatable to anneal the film.

5 Manuscripts, INFN notes and thesis published in 2017

1. Belli, E., Castorina, G., Migliorati, M., Novokhatski, A., Persichelli, S., Spataro, B., & Zobov, M. (2017, May). Coupling Impedances and Collective Effects for FCC-ee. In 8th Int. Particle Accelerator Conf.(IPAC'17), Copenhagen, Denmark, 14-19 May, 2017 (pp. 3734-3737). JACOW, Geneva, Switzerland.

2. Giovanni Castorina, Andrea Mostacci, Marco Maroungiu, Giovanni Franzini, Bruno Spataro, and Andriy Nosych. Stripline beam position monitor modelling and simulations for charge measurements. In International Beam Instrumentation Conf. (IBIC'17), Grand Rapids, USA, 20-24 August, 2017.

3. Battiston, R., Burger, W. J., Cafagna, A., Manea, C., & Spataro, B. (2017). A systematic study of laser ablation for space debris mitigation. Journal of Space Safety Engineering, 4(1), 36-44.

4. A. Marcelli, B. Spataro, G. Castorina, Wei Xu, S. Sarti, F. Monforte, G. Cibin, Materials and breakdown phenomena: heterogeneous molybdenum metallic films, Cond. Matter 2, 18 (2017);

5. G. Castorina, A. Mostacci, L. Ficcadenti, L. Palumbo, M. Migliorati and M. Marongiu, B. Spataro, A. Marcelli, F. Cardelli, G. Sorbello, S. Gammino, L. Celona, G. Torrisi, A. Cahill, J. Rosenzweig and V.A. Dolgashev, A TM01 mode launcher with quadrupole field components cancellation for high brightness applications, Proceed. IPAC2018 (submitted)

6. C. Bonavolonta, M. Valentino, M. de Lucia, M. Ambrosio, C. Aramo, S. Macis, I. Davoli, G.

Castorina, F. Monforte, B. Spataro, M. Scarselli, S. Lupi and A. Marcelli, Characterization of the transport properties of MoO_3 films on copper, INFN-17-13/LNF, May 6, 2017

7. PhD Thesis G. Castorina, Microwave accelerating structures: an innovative parallel coupled electron LINAC, University of Catania (January 2018)

8. Villa, F., et al. Generation and characterization of ultra-short electron beams for single spike infrared FEL radiation at SPARC_LAB. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 865 (2017): 43-46.

9. Pompili, R., et al. Experimental characterization of active plasma lensing for electron beams. Applied Physics Letters 110.10 (2017): 104101.

10. E. Belli, M. Migliorati, B. Spataro, S. Persichelli, A. Novokhatski, G. Castorina, and M. Zobov, Coupling Impedances and Collective Effects for FCC-ee. 8th Int. Particle Accelerator Conf. IPAC'17 (Copenhagen, Denmark, 19 May, 2017)

11. G. Castorina, A. Mostacci, M. Maroungiu, G. Franzini, B. Spataro, and A. Nosych. Stripline Beam Position Monitor Modelling and Simulations for Charge Measurements, International Beam Instrumentation Conf. IBIC'17 (Grand Rapids, USA, 20 August, 2017)

12. Pompili, R., Castorina, G., Ferrario, M., Marocchino, A., & Zigler, A. (2018). Guiding of charged particle beams in curved capillary-discharge waveguides. AIP Advances, 8(1), 015326.

6 List of Conference Talks by LNF Authors in Year 2017

1. G. Castorina, Activity Status at LNF-INFN on the high accelerating gradient, Workshop: Tera-Days: Attivitá INFN e prospettive per la radiazione THz e le sue applicazioni (April 5-6, 2017 - Rome)

2. B. Spataro, Status and perspectives on X band structures at INFN-LNF, HG Workshop (June 13-16, 2017- Valencia)

3. A. Marcelli, Metallic films: conductivity properties vs. work function. New opportunities for accelerators and other technological applications, Geneal Seminar LNF (November 3, 2017 -Frascati)

4. A. Marcelli, Metallic films: conductivity properties vs. work function. New opportunities for accelerators and other technological applications, AA&RP workshop (November 15-17, 2017 - Moscow)

7 Acknowledgments

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2. G. Gatti, A. Marcelli, B. Spataro, V. Dolgashev, J. Lewandowski, S.G. Tantawi, A.D. Yeremian, Y. Higashi, J. Rosenzweig, S. Sarti, C. Caliendo, G. Castorina, G. Cibin, L. Carfora, O. Leonardi, V. Rigato and M. Campostrini, X-band accelerator structures: on going R&D at the INFN, Nucl. Instr. Meth. Phys. Res. A 829, 206-212 (2016) http://dx.doi.org/10.1016/j.nima.2016.02.061i

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4. C. Bonavolonta, M. Valentino, M. de Lucia, M. Ambrosio, C. Aramo, S. Macis, I. Davoli, G. Castorina, F. Monforte, B. Spataro, M. Scarselli, S. Lupi and A. Marcelli, Characterization of the transport properties of MoO_3 films on copper INFN-17-13/LNF, May 6, 2017

5. A.D. Cahill, A. Fukasawa, R. Pakter, J.B. Rosenzweig, V.A. Dolgashev, C. Limborg-Deprey, S. Tantawi, B. Spataro, G. Castorina, RF design for the TOPOGUN photogun: A cryo-normal conducting copper electron gun- High Brightness Beam Workshop 2016 (Cuba, l'Avana March 28, 2016) submit to NIM A (2016)

6. Technical Design Report for the SPARC Advanced Photoinjector, Eds. L. Palumbo and J. Rosenzweig, www.lnf.infn.it

7. J.B. Rosenzweig, A. Cahill, V. Dolgashev, C. Emma, A. Fukusawa, R. Li, C. Limborg, J. Maxson, P. Musumeci, A. Nause, R. Pakter, R. Pompili, R. Roussel, B. Spataro, and S. Tantawi, Next Generation High Brightness Electron Beams From Ultra-High Field Cryogenic Radiofrequency Photocathode Sources, submit. to Phys. Rev. Special Topics - Accelerators and Beams (2016) preprint arXiv:1603.01657 (2016).

8. G. Castorina et al., A Compact Mode Launcher for New Generation RF Photoinjectors and High Brightness Applications, in submitted to: Proc. of International Particle Accelerator Conference (IPAC18), Vancouver, Canada: JACOW, 2018.

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