Carbon coatings for the electron cloud mitigation in particle accelerators

N. Bundaleski,*[a] P. Costa Pinto,[b] A.R.G.E. Pires[a], P.M.A. Guerreiro,[a] Y. Delaup,[b] M. Himmerlich,[b] C.F. Adame[a], N. Bundaleska,[c] E. Felizardo,[c] A. Dias,[c] E. Tatarova,[c] O.M.N.D. Teodoro[a]

[a] Cefitec, Nova School of Science and Technology, UNL, Caparica, Portugal;
[b] European Oranisation for Nuclear Research (CERN), Geneva, Switzerland;
[c]IPFN, Instituto Superior Técnico, UL, Lisbon, Portugal

Formation of an electron cloud (e-cloud) is the major limitation of the beam luminosity in modern accelerators of positive particles: it can induce beam instabilities, pressure rise, and additional heat loads of these cryogenic machines. One of the most efficient strategies in mitigating the e-cloud formation is coating the inner walls of accelerator tubes with amorphous carbon (a-C) with high graphitic content, which are characterized by both low secondary electron yield (SEY) and sufficient chemical inertness to maintain its secondary electron emission properties during the exploitation period. Deposition of tube walls by a-C by hollow cathode discharge gave excellent results at Super Proton Synchrotron at CERN [1]. A similar technology is now being employed within the High Luminosity upgrade of the Large Hadron Collider (HL-LHC) at CERN and is also planned for the future Electron Ion Collider (Brookhaven National Laboratory, USA) [2].

The major drawback of this approach is a possibility of the contamination of a-C coatings by hydrogen, which may increase the maximum SEY above the limit for the e-cloud formation (being about 1.1-1.15 for HL-LHC). The contamination can occur due to the presence of hydrogen precursors within the discharge, or directly from the substrate exposure to the residual gas. It is of highest interest to optimize the coating process, in order to secure high graphitic content and reduced amount of different impurities under production conditions that imply reduced pumping speed and inability to perform vacuum baking prior to a deposition. At the same time, for some particular applications (such as for the kicker magnets at HL-LHC), a trade-off between the reduced electrical conductivity of the coating and its SEY has to be made. That can be achieved by deliberate introduction of hydrogen into the discharge gas during the deposition [3].

This talk will be dedicated to the experimental investigation of the hydrogen contamination mechanisms during the magnetron sputter deposition in the case of deliberately introduced hydrogen and the natural contamination from the residual gas in a High Vacuum system. We will discuss the influence of operating parameters (discharge power, operating pressure) of magnetron sputter deposition of a-C films on their contamination and the secondary electron emission properties. The effect of nitrogen incorporation into the coatings will be also addressed.

In the last part of the talk, an alternative approach based on the electrophoretic deposition of pure and N-doped graphene will be also introduced. The potential advantage of these coatings is in their exceptional chemical inertness accompanied by the low SEY.

Acknowledgements

This work was funded by the Portuguese Foundation for Science and Technology (FCT) via Grants No. UIDB/00068/2025, UID/50010/2025, UID/PRR/50010/2025, UID/PRR2/50010/2025 and LA/P/0061/2020.

References

[1] C.Y. Vallgren et al., Phys. Rev. ST Accel. Beams 14 (2011) 071001
[2] F. Willeke, Electron Ion Collider Conceptual Design Report (2021) Oak Ridge, TN, USA
[3] P. Costa Pinto et al. IPAC ’26 https://indico.jacow.org/event/95/contributions/13036/attachments/2330/8670/MOP7102_edited_version.pdf
[4] C.F. Adame et al., J. Vac. Sci. Technol. A 41 (2023) 043412
[5] N. Bundaleski et al., Int. J. Mol. Sci. 24 (2023) 12999
[6] Y. Delaup et al., Surf. Coat. Technol. 517 (2025) 132841

* Corresponding author: n.bundaleski@fct.unl.pt; phone +359 920 552-850; fax +359 212 948 549