IMCA (Innovative Materials and Coatings for Accelerator).

M. Biagini, R.Cimino (Resp. Naz.), L.Gonzalez (Ass), S. Guiducci,
R. Larciprete (Resp. Loc. & Ass.), A. Di Trolio (Ass).

The IMCA project was started in 2010 in order to develop new materials and coatings with stable and sufficiently low SEY (Secondary Electron Yield) to guarantee full operation of present and future accelerator machines. This issue, in fact, is crucial in controlling Electron Cloud (EC) formation and in reducing its effects, that are well known to be a potential bottle-neck in the performances obtainable from particles accelerators. Frascati has a long-standing experience in qualifying materials in terms of surface parameters of interest to e-cloud issues. We are routinely measuring SEY, its dependence on electron energy, temperature and scrubbing dose. We are now able to characterize "in situ" the surface chemical composition and eventual modifications occurring during electron or photon irradiation by using XPS with a conventional X-ray source. Our experimental measurements of the relevant parameters can be also confidently compared to simulations, curried out by running EC codes, in order to elucidate the final consequences on machine performances. Such a combined characterization effort is also suggesting ways to produce low SEY materials coatings. This issue is particularly important in view of the foreseen LHC luminosity upgrades, the ongoing research on Future Circolar Collider (FCC) and ILC- Damping ring studies, where e-cloud issues are expected to be present.

We have two running setups: both are now routinely working, operating in UHV conditions being steadily in a vacuum better than 1×10^{-10} Torr after bake-out. The two set-ups are based on UHV μ-metal chambers, with less than 5 mG residual magnetic field at the sample position. Both are equipped with an Omicron LEED; an electron gun to measure SEY; a Faraday cup to characterize beam currents and beam profiles and both can prepare samples (clean surfaces, thin layers produced with different growing techniques) that can be inserted in the measuring system without breaking the vacuum. One system, built in collaboration with CNR, is designed to deposit thin films and analyze their SEY in connection with XPS at room or higher temperature. This is done by using an X-ray, a UV source and an Omicron electron energy analyzer to acquire photoemission spectra and to obtain chemical information on the studied surface. The other system is optimized to perform SEY experiment at cryogenic temperature (down to 8 K) and angle resolved VUV photoemission studies. For this reason has been equipped over the years with an OMICRON AR65 angle-resolving electron energy analyzer and a monochromatic VUV source.

Since June 2015 and thanks to the IMCA activities we are participating to the four year EU H2020 project EuroCirCol, which is mainly founding young researchers (with us from 2016) to perform the necessary RD to launch a design study of a proton proton Future Circular collider (FCC-hh). We are task leader in WP 4.4 on "Beam Induced Vacuum studies" and we are upgrading the existing facilities to tackle the experimental challenges required in this working package. The work will continue and enhance the competences developed within IMCA, keeping Frascati laboratory at the forefront in this world wide research collaboration.

In 2015 we have addressed a series of issues studying different materials and material properties. Such activity not only is promoting our Material Science Laboratory in Frascati as one of the most advanced Laboratories in this field, but also provided a quite comprehensive understanding on the physical phenomena governing the SEY and its variations during the various surface modifications [1, 2].

During this year we finalized the detailed study on the Low Energy (LE) part of a SEY curve. In response to some debate in the recent literature on the capability to correctly measure such (LE)-SEY as first reported by our group [3], we solved this apparent controversy showing and confirming that the LNF SEY set-ups can correctly measure SEY down to very low energy above the sample work function W_s. This work is also of interest to the spacecraft community [4]. The notion that our set-ups are unique and capable to measure LE-SEY has been also used, in collaboration with CERN, to understand the importance of using realistic and experimentally derived LE-SEY values instead of the "usual" parametrization in e^-cloud simulations [5].

We continued the study initiated by our group of the detailed mechanisms governing the SEY in Carbon films as a function of their structure, going from amorphous Carbon to a more ordered graphitic layer [6]. A multi-technique approach was used to follow the $sp^3 \longrightarrow \mathrm{sp}^2$ structural reorganization while the SEY curves as a function of the kinetic energy of the incident electron beam were measured in parallel. We found that an amorphous C layer with a thickness of a few tens of nanometers is capable to modify the secondary emission properties of the clean copper surface, reducing the maximum yield from 1.4 to 1.2. A further SEY decrease is observed with the progressive conversion of sp^3 hybrids into six-fold aromatic domains. Then our results demonstrate that a moderate structural quality of the C layer is sufficient to notably decrease the SEY approaching the secondary emission properties of graphite as shown in fig. 1.

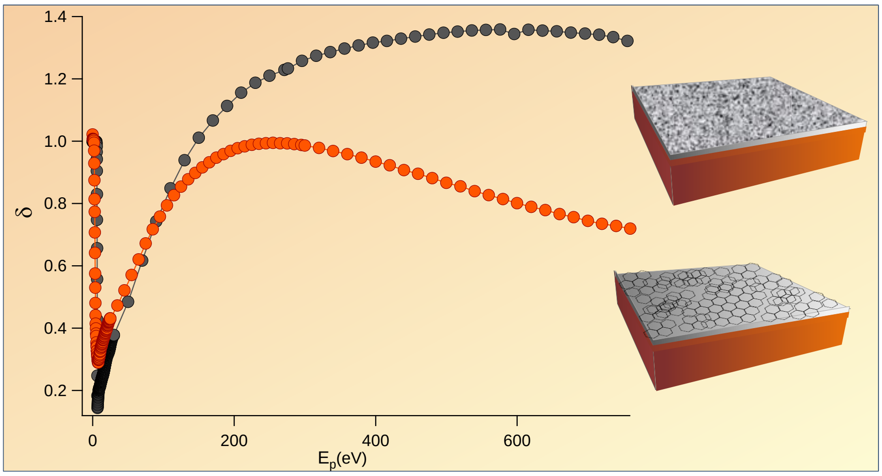

Figure 1: SEY curves measured on the bare Cu substrate (top) and "in situ" deposited amorphous C film thermally annealed at 1070 K (bottom). [6].

In collaboration with F. Schäfers, head of the optics group in HZB BESSY-II, Berlin, we continue approaching with the best "state of the art" available tools, the study of Reflectivity and Photoelectron Yield of technical materials [7]. This study is of extreme relevance not only since it gives important input parameters to track the seedings of electrons in e^- cloud simulations, but, it is even more important in machines where single bunch instabilities are expected as induced by the mere presence of a high density of electrons in the beam pipe [1]. We show that the use of such an highly performant equipment developed to carry out accurate metrology at wavelength (i.e. by using monochromatic light) on optical elements is one of the only viable technique to experimentally measure the required technical surface properties. Moreover, putting together competences in Synchrotron radiation (SR), material science and accelerator physics is extremely important for FCC design study. Scientists at CERN are currently studying the feasibility of a 100 Tera-electron-volt (TeV) particle accelerator that produces 7 times higher energy per collision than the Large Hadron Collider (LHC). Compared to the LHC, this future collider would have a circumference nearly 4 times longer and radiate 1000 times the power, delivering an unprecedented amount of heat. Cooling the collider by using current methods would be prohibitively expensive. But a new cooling scheme based on the capability of the accelerator walls to efficiently reflect the SR flux impinging on them, seems a viable solution to render the future accelerator project more sustainable. The details of this proposal have been published in Physical Review Letters [8]. Very briefly it is proposed to coat the interior of the copper tube with a thin layer of carbon that reflects all the incident radiation. The surface structure of the carbon coating is designed so that the radiation, and the heat it carries, is transported away from colder regions towards periodically placed room-temperature absorbers, which are easier and cheaper to cool than the tube itself. A complex and detailed experimental validation is than needed to assess if an highly reflecting beam screen surface can provide a viable and solid solution to be eligible as a baseline design in FCC-hh projects to come, rendering them more cost effective and sustainable.

Always in the framework of FCC-hh RD we started looking at the surface properties of high temperature superconducting (HTS) materials in terms of SEY, Reflectivity and Photoyield. Such coatings could be used for the inner wall of the accelerator vacuum vessel in order to control and decrease the overall machine impedance budget, which is extremely demanding. Of course such HTC films, if in use must also be compliant with all the other requirements a surface must fulfill to be exposed to such very intense proton beam, and our is one of the best equipped laboratory to analyze such properties in details.

The collaboration has, in the last years, included researchers of other sections with recognized international experience in the study of impedance and related effects on machine performance. In fact, the challenges offered by the new high intensity machines show a clear link between e-cloud and wake-fields issues. Within our project, the group of Rome 1 (Mauro Migliorati, Giorgia Favia, Andrea Mostacci, Luigi Palumbo, Letizia Ventura) is extremely active in calculating impedance issues of key interest in many and different machines aspects. In parallel, the group of Napoli (formed by R. Fedele, F. Galluccio, M.R. Masullo and V. Vaccaro), is developing, within the collaboration, a new laboratory method to measure the coupling impedance of high-Q insertion devices below the beam pipe cut-off frequency, when the classical wire method is not reliable. This method should allow a quick and very accurate evaluation of the impedance budget of various insertion structures. The method has been tested on a pill-box cavity and the first results are in good agreement with simulations and classical theory and the collaboration is now performing more realistic tests on UA9 and LHC collimator prototypes.

Conference Talks

- R. Cimino: "Material Science applied to High Energy Physics Accelerators: Status and Prospectives presented at "What Next LNF: Materia". Frascati, 26 Febbraio 2015.
- R. Cimino: Reflectivity (R) and Photo Yield (PY) in FCC-hh. FCC-hh Design meeting, CERN Geneve (CH) 12-Marzo-2015.
- R. Cimino, R. Kersevan, F.Schfers and V. Baglin: Potential countermeasures against the very large SR heat load in FCC-hh presented at FCC Week 2015 International Future Circular Collider Conference 23 27 March, 2015, Washington DC, USA.
- R. Cimino: "Vacuum and Material Science Challenges for Future Circular Colliders" SInvited talk at: AIV (associazione Italiana Vuoto), Genova May, 20, 2015.
- R. Cimino, V. Corato, A. Di Gaspare, A. Di Trolio, U. Gambardella, R. Larciprete, M. R. Masullo, M. Migliorati and V. Vaccaro: High-Tc superconductors as accelerators wall coatings in FCC-hh: Impedance and compatibility with collective effects issues." presented

at the international Conference on: Frontier Detectors for Frontier Physics, 13th Pisa Meeting on Advanced detectors May, 24- 30, 2015

- R. Cimino: Task 4.4 (INFN-CERN): Study vacuum stability at cryogenic temperature presented at the Eurocircol Kickoff Meeting June, 3, 2015 Geneva, Ch.
- L. A. Gonzalez, R. Larciprete, A. Di Gaspare and R. Cimino, The effect of structural disorder on the secondary emission of graphite presented atThe International Workshop on Functional Surface Coatings and Treatment for UHV/XHV Applications Chester September 30 2015.
- R. Cimino, A. Di Gaspare, A. Gonzalez, and R. Larciprete: " Low Energy Secondary Electron Yield and Material Science studies at LNF for next generation Accelerator systems" presented at: The International Workshop on Functional Surface Coatings and Treatment for UHV/XHV Applications Chester September, 30, 2015.
- Cimino: Electron cloud Effects and Cures lectures given at: CAS (CERN Accelerator School), Wasaw October, 6, 2015.
- R. Cimino: WP4 EuroCirCol (LNF-INFN): Status Report presented at: Eurocircol Meeting November, 19, 2015 Orsay, France.
- R. Cimino: Electron cloud Effects and Cures lecture given at the: "Universita di Napoli Federico II" , December, 15, 2015.

References

1. Roberto Cimino and Theo Demma: "Electron Cloud in Accelerators" International Journal of Modern Physics A,Vol. 29, (2014), 1430023 (65 pages) .
2. R. Cimino et al., "Nature of the Decrease of the Secondary-Electron Yield by Electron Bombardment and its Energy Dependence" Phys. Rev. Lett. 109 (2012) 064801.
3. R. Cimino et al., "Can Low-Energy Electrons Affect High-Energy Physics Accelerators?" Phys. Rev. Lett. 93, 14801 (2004).
4. R. Cimino, A. Di Gaspare, L. A. Gonzalez and R. Larciprete, "Detailed Investigation of the Low-Energy Secondary Electron Yield (LE-SEY) of Clean Polycrystalline Cu and of Its Technical Counterpart" IEEE Transactions on Plasma Science, vol.43, no.9, pp. 2954-2960, (2015).
5. R. Cimino, L. A. Gonzalez, R. Larciprete, A. Di Gaspare, G. Iadarola, and G. Rumolo "Detailed investigation of the low energy secondary electron yield of technical Cu and its relevance for the LHC" Phys. Rev. ST Accel. Beams, vol. 18, pp. 051002-1, 051002-10 (2015).
6. Rosanna Larciprete, Davide Remo Grosso, Antonio Di Trolio and Roberto Cimino: "Evolution of the secondary electron emission during the graphitization of thin C films", Applied Surface Science, Volume 328 (2015) 356 360.
7. F. Dugan, K. G. Sonnad, R. Cimino, T. Ishibashi and F. Schäfers: "Measurements of x-ray scattering from accelerator vacuum chamber surfaces, and comparison with an analytical model"; Phys. Rev. ST Accel. Beams, vol. 18, pp. 040704-040724, (2015).
8. R. Cimino, V. Baglin, and F. Schäfers: "Potential Remedies for the High Synchrotron-Radiation-Induced Heat Load for Future Highest-Energy-Proton Circular Colliders"; Phys. Rev. Lett. 115 264804 (2015).