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Study of the SEY dependence on the electron beams dose and energy

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Summary. — During operation, the internal walls of modern particle accelerators are subjected to synchrotron radiation irradiation and/or electron bombardment. Such phenomena do affect surface properties such as the secondary electron yield, (SEY). A low SEY is a key parameter to control and overcome any detrimental effect on the accelerator performance eventually induced by the build-up of an Electron Cloud (EC). In laboratory experiments SEY reduction (called scrubbing) has been studied as a function of dose but the actual kinetic energy dependence has never been considered as an important parameter. For this reason and given the peculiar behaviour observed for low-energy electrons, we decided to study this dependence accurately. Here we report results of SEY measurements performed bombarding Cu samples obtained from the Large Hadron Collider (LHC) with different doses of electron beams with energy in the range 10–500 eV. Our results demonstrate that the potentiality of an electron beam to reduce the SEY does not only depend on its dose, but also on its energy. Furthermore, since EC build-up was predicted and observed also in the DAΦNE ring, we report some preliminary measurements on the conditioning of Al samples. An overview of future experiments which we will perform in LNF is then given.

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PACS 29.27.-a – Beams in particle accelerators.
PACS 79.20.Hx – Electron impact: secondary emission.

1. – Introduction

In particle accelerators with intense and positively charged beams and/or vacuum chambers of small transverse dimensions, electrons can be produced by the interaction of synchrotron radiation with the walls, by stray beam particles striking chamber walls at grazing angles, or by ionization of residual gas. These primary electrons may be accelerated by the Coulomb potential of the circulating beam producing secondary electrons

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and leading to a formation of an "Electron Cloud" (EC) [1, 2]. These issues have been addressed in many international workshops in recent years [3], since EC are important phenomena occurring at different accelerators.

EC build-up and evolution depend strongly on the surface properties of accelerator walls such as Secondary Electron Yield (SEY), defined as the number of emitted electrons per incident electron. A low SEY is indeed essential for the operation of particle accelerators, since their design luminosity and performance can only be achieved if the SEY is strongly reduced by surface conditioning during initial operations (or commissioning). So, a low SEY will ensure the mitigation of the potentially detrimental effects due to the e-cloud effect. Furthermore, the understanding of the conditioning process may help to make predictions on the conditioning time required to reach accelerator design parameters.

Up to now, SEY reduction (called scrubbing) was studied in laboratory experiments by measuring the electron dose (the number of impinging electrons per unit area on sample surfaces) dependence of the SEY yield. All the available experiments found in the literature have been performed by bombarding technological metal surfaces with electron beams of fixed energies [4-9]. They showed that even at low electron exposure of about $10^{-6}\,\mathrm{C\,mm^{-2}}$ the SEY starts to decrease, reaching its lowest value after about $10^{-2}\,\mathrm{C\,mm^{-2}}$ (in the case of Cu samples).

Although useful, all those investigations neglected other significant aspects as the dependence of the "scrubbing effect" on the actual energy of primary electrons, even if theoretical and experimental studies predict that the electrons in the cloud have a very low energy [3], and that such slow electrons can be reflected from the walls without interacting and scrubbing the surface [4]. Our studies proceed in this direction and in this contribution we present some experimental results obtained by bombarding the surface of a representative Cu sample used in the LHC beam screen with doses of electrons having kinetic energy in the range of 10–500 eV. Our measures show, for the first time in this context, that the potentiality of an electron beam to reduce the SEY (scrubbing effects) does not only depend on its dose, but also on its energy.

Finally, since the build-up of EC was also observed for the DAΦNE ring [10, 11], we perform some preliminary measures on a different material, that is the Al representative of arc vessel of DAΦNE. The results are briefly compared with those existing in the literature since the conditioning of Al surfaces has been widely investigated [12, 13]. Additional work is ongoing to confirm observations at different energies, by characterizing sample chemistry before, during and after irradiation by means of photoelectron spectroscopy. These further experiments will be implemented by using two XUV Beam Lines from DAΦNE Bending Magnet [14], built at LNF, which will allow us to investigate also SEY variations after electron and photon scrubbing for different materials.

2. – Experimental

The data were acquired with a dedicated experimental apparatus which is described elsewhere [15]. Briefly, an UHV μ-metal chamber with less than 5 mG residual magnetic field at the sample position, and a CTI8 cryo-pump ensured a vacuum better than 10^{-10} Torr after bake-out. The samples studied, mounted on a close-cycle Sumitomo cold-finger manipulator, were co-laminated Cu for the LHC beam screen, and Al representative of the arc vessel of the DAΦNE ring accelerator. The electron beam was set to be smaller than $0.25\,\mathrm{mm}^2$ in transverse cross-sectional area and stable in current for energies between 10 and 500 eV, as confirmed by a line profile and by stability tests done by using a homemade 1 mm slot Faraday cup. It has been observed that the beam moves slightly in position during energy scans, forcing us to manually irradiate with the same doses the sample areas neighbouring the investigated (measuring) spot. Such rastering procedure, although time consuming, ensures that the SEY measurements were done on a uniformly irradiated area for every bombarding electron energy. To measure low-energy impinging primary electrons, a negative bias voltage was applied on the sample. Such bias allows us to work at very low primary energy (close to zero eV) while keeping the gun in a region where it is stable and focused.

The electron dose is determined by $D = Q/A = (I_0 t)/A$, where Q is the total charge incident per unit area on sample surface, I_0 is the impinging beam current (generally few nA while dosing the sample) and t is time period during which the sample was exposed to the beam. The area is determined assuming that the electron beam hits the surface sample with a circular spot. Unit chosen here for dose are $\mathrm{C\,mm^{-2}}$. All SEY measurements and electron irradiation have been performed at room temperature and at normal incidence. Uncertainties on the irradiated spot and on the adopted rastering procedure doses have to be considered within 20% of their quoted values. The data acquisition system is a customized LABVIEW program which allows to scan the beam energy from the lowest to the highest value and to acquire beam and sample current in order to calculate SEY.

3. – Results and discussion

Figure 1 shows SEY measurements for LHC-type samples bombarded with different doses of electron beams at the energy of 200 eV (top panel), and 10 eV (bottom panel). These curves agree with those found in literature [4, 6] and are characterized by a maximum value δ_{Max} and the corresponding energy E_{Max} at which it occurs. As reported in the literature, they depend on surface conditions and roughness. At low primary energies, SEY curves show a value below 1, which is independent of δ_{Max} and of the degree of scrubbing, in agreement with previous experimental and theoretical results [4, 6].

Furthermore, in this figure the effect of e^- irradiation on SEY curves is evident. It causes a decrease of the maximum value of SEY curves, δ_{Max}, and a shift of the corresponding energy E_{Max} towards lower energy values. In addition, although samples are conditioned with similar doses, the behaviour of the SEY curves is not the same.

To gain insight into this finding we report in fig. 2 the behaviour of δ_{Max} as a function of electron dose, for samples conditioned with electron beams in a wide range of energies.

The curve obtained while conditioning the sample with 500 eV agrees well with results available in the literature, and shows that, for this energy, an electron dose between $10^{-6}\,\mathrm{C\,mm^{-2}}$ and $10^{-2}\,\mathrm{C\,mm^{-2}}$ is necessary to reduce the yield of LHC samples from 2.1 to 1.10. Furthermore as we showed in [15], the reduction of δ_{Max} *vs.* the dose is the same if samples are conditioned at electron energy of 300 eV and 200 eV.

When the scrubbing energy is lower than 200 eV, the reduction of δ_{Max} with dose proceeds with a slower rate, immediately evident at low doses and this behaviour become more evident when the energy of the primary beams becomes very low. In addition the value of δ_{Max} obtained at the final dose of $10^{-2}\,\mathrm{C\,mm^{-2}}$ is different, as indicated by the orange dot line.

In the case of conditioning with energies of 20 eV and 10 eV, in order to check the consistency of δ_{Max} at the final dose ($10^{-2}\,\mathrm{C\,mm^{-2}}$), we irradiated samples with a dose of $10^{-3}\,\mathrm{C\,mm^{-2}}$ at 200 eV. This dose, which must be summed to the previous ones, shows that SEY is reduced to 1.10 similarly to the case of 200 eV and 50 eV electron

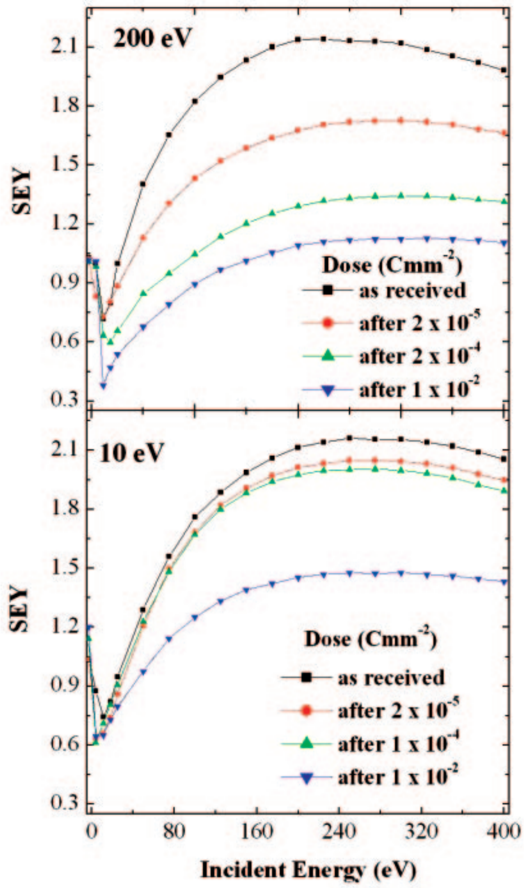

Fig. 1. – SEY measurements for 200 eV (top panel), and 10 eV (bottom panel) impinging electron energy at normal incidence.

bombardment. These measurements have been reproduced on different Cu beam screen samples showing that the conditioning behaviour does not depend on the slightly different sample initial condition (*i.e.* δ_{Max} on "as received" samples).

To the best of our knowledge, these new experimental results are the first of this kind and suggest that the scrubbing efficiency of electrons hitting the accelerator walls depends on their actual kinetic energy, being lower than expected at low energy (< 50 eV). Therefore the time required to obtain a low-SEY surface is consequently different especially when low-energy electron beams are considered. This difference in efficiency with respect to electron energy is consistent with experiments performed in EPA at CERN while conditioning a copper sample with photoelectrons with energies at 100 and 820 eV [16].

After such evidences we launched two parallel and necessary activities: one theoretical and one experimental both aimed at a more detailed modelling of the electron energy distribution in the cloud and on its impact on the commissioning time in modern machines. The theoretical studies, in progress, will be described in future pubblications [17] and show that by optimising the functioning parameters of each individual

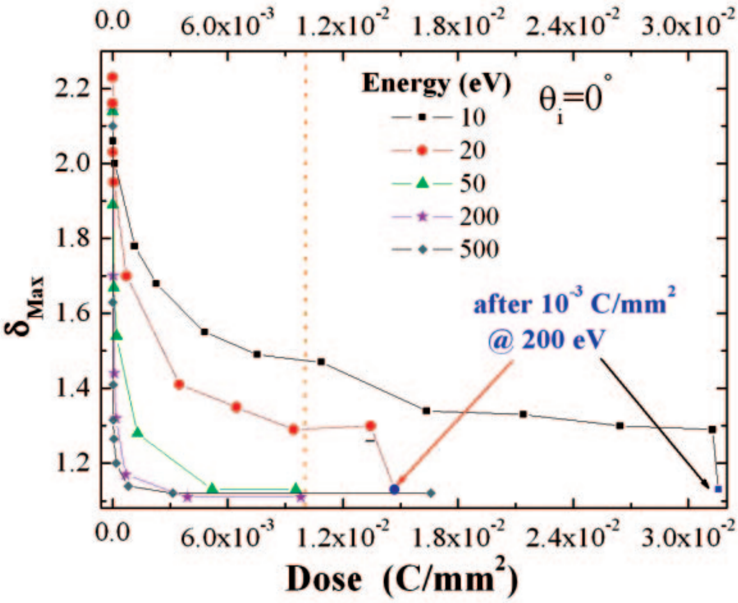

Fig. 2. – δ_{Max} as a function of dose for different impinging electron energies at normal incidence on LHC samples.

machine it is possible to obtain electrons with energies $> 50\,\mathrm{eV}$ inside the cloud which will enhance scrubbing efficiency and reduce conditioning time. Experimental activities aim at measuring the actual energy of electrons involved in the cloud, since it has not been measured accurately, but only simulated [3]. For this reason we decided to develop the optimized Retarding Field Energy Electrometer, shown in fig. 3. A detailed description of the detector with etherodine acquisition technique and of its potentialities has been widely given in [18]. Despite some difficulties in running the detector with the necessary confidence, and some problems related to the gain of the channelplate in use, we are now obtaining encouraging results and hope to mount two of such working detectors in running accelerators, such as DAΦNE and Anka rings [19] to measure the Energy Distribution Curves (EDC) in different places of the accelerators.

Finally, since EC build-up was predicted and also observed in DAΦNE accelerator [10, 11] we performed experiments on Al samples, representative of arc vessel of the DAΦNE. For such samples SEY curves (not shown) are very similar to those showed in fig. 1, although we remark that their acquisition was more critical than for Cu samples, probably because the inhomogeneous oxide film on the as-received Al samples caused an inhomogeneous charging of the sample during measurements. Al surfaces are more reactive than copper ones, so their SEY might strongly vary from one sample to the other depending on surface preparation.

Some conditioning results are shown in fig. 4, where we report the behaviour of δ_{Max} as a function of electron dose, for Al samples bombarded with electron beams of 100 and 200 eV. For comparison we plot also the behaviour of δ_{Max} for LHC-type Cu sample shown in fig. 2. We can observe that δ_{Max} of the as-received Al sample is higher than those of LHC samples, consistently with literature results [12, 13]. Furthermore δ_{Max} reduction

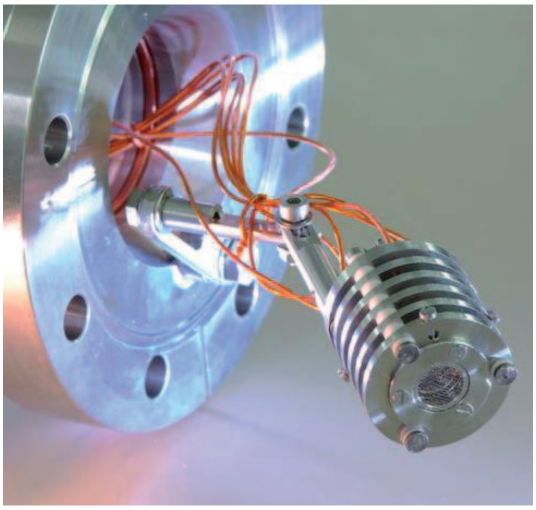

Fig. 3. – Photograph of the LNF-Retarding Field Detector built at LNF mounted on a CF 63 Conflat flange.

vs. dose for Al samples proceeds with a slower rate than for the Cu samples. This behaviour is probably due to the different efficiency of the bombarding beams in removing the oxide surface layer, which is more stable on Al than on Cu surfaces, as widely described in [12, 13] by means of X-ray (XPS) spectroscopy. The scrubbing efficiency is evident also on Al samples. Moreover the final values of δ_{Max} obtained at the dose of

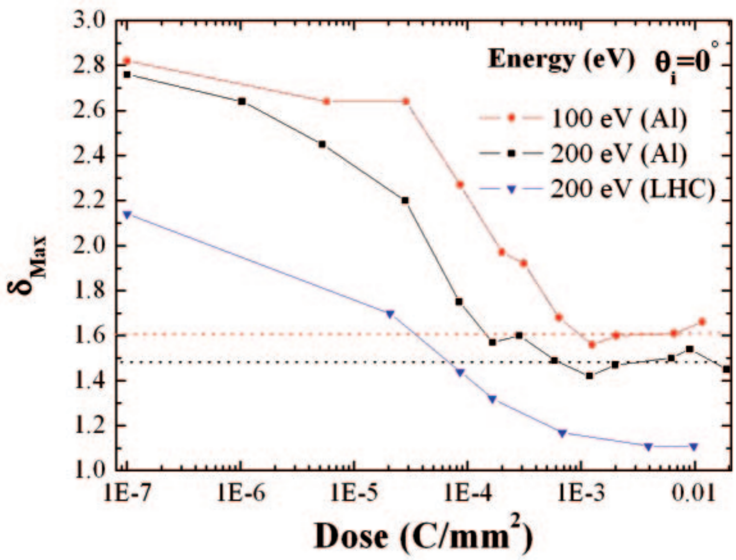

Fig. 4. – δ_{Max} as a function of dose for different impinging electron energies at normal incidence on DAΦNE Al samples.

$10^{-2}\,\mathrm{C\,mm^{-2}}$ are slightly lower than those reported by several authors for experiments performed bombarding similar technical surfaces [12,13] with beams of 100–130 eV, which showed that the SEY of samples did not go lower than 1.8. Our low values of final SEY are anyway consistent with the DAΦNE perfomances in terms of positron accumulated current [11]. Detailed studies are required to understand the observed differences by characterizing samples chemistry before and after irradiation by using photoemission spectroscopy. These investigations will be implemented by using the two XUV beamlines built in LNF, operating respectively in the 35–200 eV (XUV-Low) and 60–1000 eV (XUV-High) ranges [14].

4. – Conclusion

We report experimental results obtained by bombarding Cu samples from LHC with different doses of electron beams in the range of energies 10–500 eV. Our data show clearly that for equal electron doses, it exists a lower scrubbing efficiency for low energy (< 50 eV) electrons compared to the medium energy ones (> 200 eV). The implications of these findings are significant and encouraged us to perform other investigations both thereotical and experimental in order to enhance the understanding of the details of the cloud production and its impact on commissioning time in accelerators. Our thereotical activities will be the subject of future publications [17], while our experimental studies are related to the determination of the actual energy of electrons forming the cloud, since at present it has not been accurately measured, but only simulated [3]. For this reason we are building a retarding field analyser based on etherodine acquisition technique, which is subjected to laboratoratory tests.

Since the e-cloud was predicted and observed also in the DAΦNE ring [10, 11], we also performed experiments on Al samples and compared the results with the existing literature. Further studies are necessary to achieve a deeper understanding of experimental data by using the potentiality of the two XUV beamlines built in LNF [14]. Furthermore, among the possible multipourpose use of such beamlines, our laboratory will be the only one in the world able to analyze SEY variation after electron and photon scrubbing on the same samples for different materials. This is a situation which occurs in real accelerators, but it has never been studied in a laboratory experiment.

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REFERENCES

[1] Izawa M., Sato Y. and Toyomasu T., *Phys. Rev. Lett.*, **74** (1995) 5044.
[2] Ohmi K., *Phys. Rev. Lett.*, **75** (1995) 526.
[3] *Proceedings of Electron Cloud Conference, ECLOUD'02-ECLOUD'04-ECLOUD'07* and references therein, available on JACoW (Joint Accelerator Conference Website) site.
[4] Cimino R., Collins I. R., Furman M. A., Pivi M., Ruggiero F., Rumolo G. and Zimmermann F., *Phys. Rev. Lett.*, **93** (2004) 014801.
[5] Kirby R. E. and King F. K., *Nucl. Instrum. Methods A*, **469** (2001) 1.
[6] Baglin V., Collins I., Henrist B., Hilleret N. and Vorlaufer G., *LHC Project Report* **472**, CERN (2001).

[7] Cimino R. and Collins I. R., *Appl. Surf. Sci.*, **235** (2004) 231; Cimino R., *Nucl. Instrum. Methods A*, **561** (2006) 272.
[8] Scheuerlein C. and Taborelli M., *J. Vac. Sci. Technol. A*, **20** (2002) 93; Scheuerlein C., Taborelli M., Hilleret N., Brown A. and Baker M. A., *Appl. Surf. Sci.*, **202** (2002) 57.
[9] Nishiwaki M. and Kato S., *Vacuum*, **84** (2010) 743.
[10] Vaccarezza C., Cimino R., Drago A., Zobov M., Sculte D., Zimmermann F., Rumolo G., Ohmi K. and Pivi M., in *Proceedings of the Particle Accelerator Conference (PAC05)*, p. 779, available on JACoW (Joint Accelerator Conference Website) site.
[11] Demma T., Cimino R., Guiducci S., Vaccarezza C. and Zobov M., in *Proceedings of European Particle Accelerator Conference (EPAC08)*, p. 1604, available on JACoW (Joint Accelerator Conference Website) site.
[12] Rosenberg R. A., McDowell M. W., Ma Q. and Harkay C., *J. Vac. Sci. Technol. A*, **21** (2003) 1625.
[13] Le Pimpec F., Kirby R. E., King F. K. and Pivi M., *J. Vac. Sci. Technol. A*, **23** (2005) 1610.
[14] Balerna *et al.*, LNF Annual Report 2008 and LNF Annual Report 2009.
[15] Cimino R., Commisso M., Demma T., Grilli A., Pietropaoli M., Ping L., Sciarra V., Baglin V., Barone P. and Bonanno A., *Proceedings of European Particle Accelerator Conference (EPAC08)*, p. 1592, available on JACoW (Joint Accelerator Conference Website) site.
[16] Baglin V., Bojko J., Gröbner O., Henrist B., Hilleret N., Scheuerlein C. and Taborelli M., in *Proceedings of European Particle Accelerator Conference (EPAC2000)*, Vienna, p. 217, available on JACoW (Joint Accelerator Conference Website) site; Baglin V., Collins I. R., Gröbner O., Grünhagel C., Henrist B., Hilleret N. and Jenninger B., in *Proceedings of the XI workshop on LEP-SPS performance Chamonix, 2001*, p. 141, available on CERN website.
[17] Commisso M. and Cimino R., in preparation.
[18] Commisso M., Demma T., Guiducci S., Ping L., Raco A., Tullio V., Viviani G., Cimino R. and Vilmercati P., in *Proceedings of European Particle Accelerator Conference (EPAC08)*, p. 1086, available on JACoW (Joint Accelerator Conference Website) site.
[19] Casalbuoni S., Cimino R., Baglin V. *et al.*, in *Proceedings of European Particle Accelerator Conference (EPAC08)*, p. 2240, available on JACoW (Joint Accelerator Conference Website) site.