

SECONDARY ELECTRON YIELD ON CRYOGENIC SURFACES AS A FUNCTION OF PHYSISORBED GASES

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Abstract

Electron cloud is a serious limitation for the operation of particle accelerators with intense positively charged beams. It occurs if the secondary electron yield (SEY) of the beam-pipe surface is sufficiently high to induce an electron multiplication. At low surface temperatures, the SEY is strongly influenced by the nature of the physisorbed gases and by the corresponding surface coverage. These conditions occur in many accelerators operating with superconducting magnets and cold vacuum sections such as the LHC and RHIC. In this work, we investigated the variation of the SEY of copper, aluminium and electro-polished copper as a function of physisorbed N_2 , CO , CO_2 , CH_4 , Kr , C_2H_6 at cryogenic temperatures. The conditioning by electron bombardment of the surface after the physisorption of H_2O on electro polished copper will also be presented. The results of the various gases are compared in order to find a rationale for the behaviour of the secondary electrons for the various adsorbates.

INTRODUCTION

A key ingredient governing the occurrence of an electron cloud (e-cloud) build up is the secondary electron yield (SEY) of the beam pipe's inner surface, which is influenced by the surface chemical composition and by the adsorbed species. Due to the need of strong bending magnets and wigglers using superconducting technology, the modern accelerators often include cryogenic vacuum sectors, as in the case of the LHC and RHIC. The physisorption of the residual gases such as CO , CO_2 , and CH_4 , which could condense on the copper surface of the LHC beam-screen, held at a temperature between 5 and 20 K, has been investigated in the present work. In addition measurements have been performed with Kr , N_2 and C_2H_6 in order to compare with previous data and clarify the origin of the SEY values. The cryogenic vacuum systems are often unbaked and water is one of the dominant residual gases before cooling. For this reason the SEY conditioning by electron bombardment of a surface covered with physisorbed water has been investigated. The impinging electron beam mimics the effect of beam-scrubbing made in particle accelerators.

EXPERIMENTAL

A UHV compatible cold head enables to cool the sample down to 4.7K. An electron gun produces a beam at energies ranging from 50 to 2500eV impinging perpendicularly on a biased sample surface (-9V bias). A collector (+45V bias), which is coaxial with the gun,

collects the secondary electrons. The total SEY is calculated from the measured collector and sample currents. The beam of the gun is pulsed so that the dose for each measured point is of $0.1nC/mm^2$ to minimize the parasitic conditioning of the surface. For the conditioning after water physisorption a higher current density and 300eV electrons were used. The entire equipment is in a UHV system, which is baked after insertion of the sample to reach a residual pressure in the low 10^{-7} Pa range. The pumping speed of the cold sample surface is measured by using a calibrated conductance and a calibrated pressure gauge. This enables computing the adsorbed quantity of gas injected during a certain time at a given pressure. All coverages have been calculated by assuming a monolayer (ML) as $1 \cdot 10^{15}$ molecules/cm². The samples used for the experiments are laminated oxygen free electrolytic copper (OFE, UNS 10100) (roughness R_z 2.25 μm), electro-polished OFE copper (R_z 0.65 μm), and aluminum (purity 99%). All samples except the electro-polished copper were cleaned in a detergent bath with the procedure used for UHV parts at CERN. Physisorption was performed without further treatment of the surfaces after insertion in UHV.

RESULTS AND DISCUSSION

The SEY of the as-received substrates does not show significant differences between room temperature and 4.7 K. This was expected since the dependence of the SEY on temperature for metals is negligible [1] and the decrease in the order of 0.2 is ascribed to physisorption from residual gases during the cooling process. The variation of the SEY as a function of coverage for physisorbed Kr , N_2 , CO , CO_2 , CH_4 and C_2H_6 was measured on the chemically cleaned copper surface and the data is shown in Figs.1-3. Measurements were reproducible and were performed at least 3 times. The adsorption of Kr exhibits the strongest increase in maximum SEY (δ_{max}) up to 10.4 for 60 ML. This is in agreement with previous experiments [2]. For larger Kr coverages the SEY continues to increase. For the other gases after physisorption the δ_{max} is mostly lower than for the bare air exposed copper surface, a fact which is consistent with the moderate SEY decrease during the cooling phase. The most marked reduction is observed for CO , which reaches the lowest values of $\delta_{max}=1.25$ already at 5ML coverage (the threshold value to provoke e-cloud in LHC is $\delta_{max}=1.3$). The energy E_{max} at δ_{max} is different for different gases. For CO it does not change from the initial value of 200eV of as-received copper, whereas for the other gases it is coverage dependent.

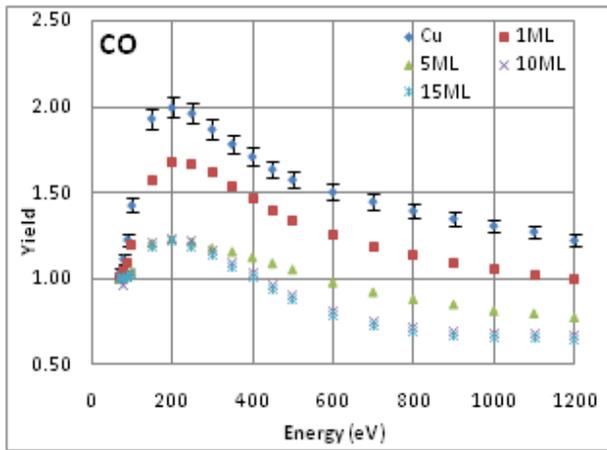


Figure 1: SEY of adsorbed CO as a function of primary energy for different coverages.

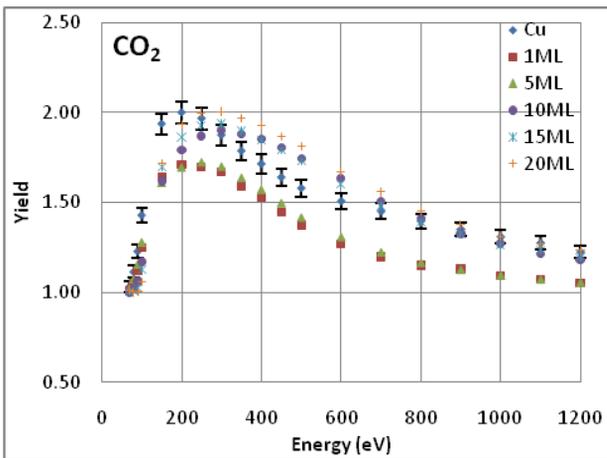


Figure 2: SEY of adsorbed CO₂ as a function of primary energy for different coverages.

The results, obtained for the physisorption, on electro-polished copper and aluminium are similar, except for the initial SEY, which depends on material and surface treatment. The behaviour of δ_{\max} as a function of coverage for the various gases and all substrates is displayed more in details in the figures 3-5. The behaviour for C₂H₆ is close to that of CH₄ with a saturation value of 1.6 for large coverages. All gases except for Kr (not shown) reach a saturation value of δ_{\max} before 30-40 ML. This can be considered as the δ_{\max} of the bulk of the adsorbed species and is found to be independent of the substrate in the cases considered here. The δ_{\max} for N₂ and CO exhibits a clear minimum for coverages in the range 3-5 ML on all substrates. The minimum is less pronounced for CO, at about 5-8 ML. The possible explanations for such a minimum are a strong inelastic scattering of the secondary electrons before emission or an increased roughness induced by the adsorbate. In addition the electronic structure of a very thin layer of adsorbate can be different from that of a thicker bulk-like layer.

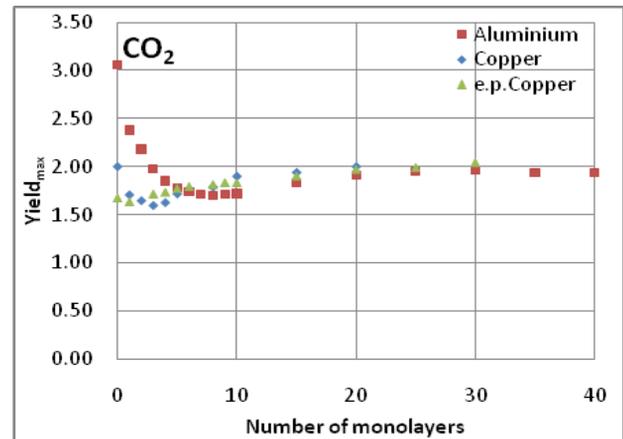


Figure 3: Maximum yield δ_{\max} of physisorbed CO₂ on different substrates as a function of coverage.

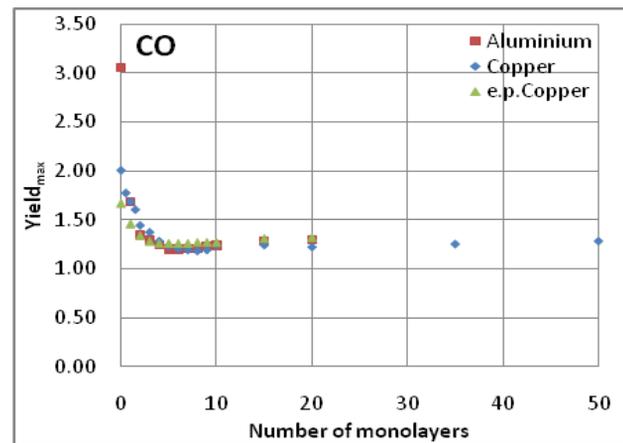


Figure 4: Maximum yield δ_{\max} of physisorbed CO on different substrates as a function of coverage.

For a sufficiently thick layer all the physisorbed species listed above are insulators. Since the SEY of insulators is generally higher than for conductors the low value found for instance for CO was not expected. The physical quantities which influence the SEY and which could explain the difference between the investigated chemical species are: the average energy to create a secondary electron, the average attenuation length of secondary electrons and the range of penetration of the primary electrons exciting the secondary electrons [2]. The energy to create electron-hole pairs, as well as secondary electrons, is related to the insulating gap. This quantity is correlated with the ranking of δ_{\max} of noble gases [2] in the sense if that more energy is necessary to excite the secondary electrons for a larger gap, it leads in turn to a lower SEY. In the present case a ranking of the δ_{\max} for the various adsorbates cannot be explained by a single physical quantity and some of the parameters used in the phenomenological model of reference [2] are unknown for these gases. The gap has an influence on the e-h excitation energy, but also on the attenuation length of the secondary electrons. The escape depth of the secondary electrons and therefore their attenuation length are related to E_{\max} . The differences in E_{\max} between the various

adsorbates are not very large (the largest E_{max} is found at 300eV for CO_2 , which has indeed the highest δ_{max} . A more detailed investigation possibly of other species is necessary to draw more detailed conclusions.

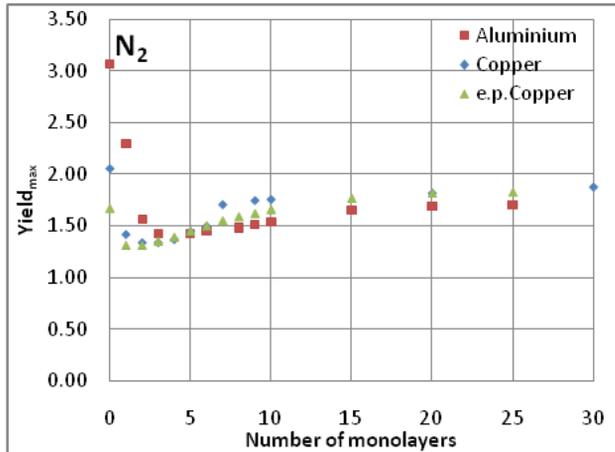


Figure 5: Maximum yield of physisorbed N_2 on different substrates as a function of coverage.

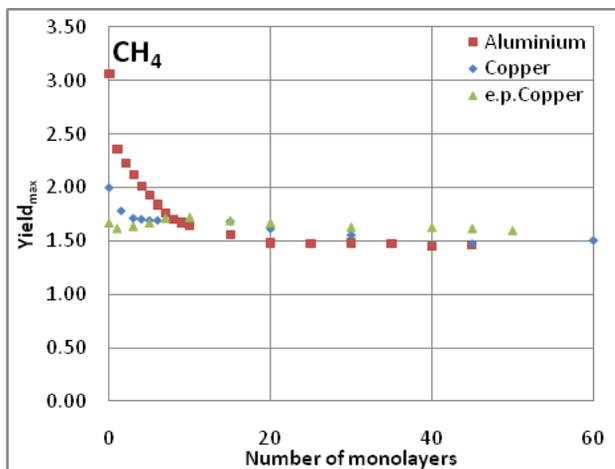


Figure 6: Maximum yield δ_{max} of physisorbed CH_4 on different substrates as a function of coverage.

The conditioning after water adsorption was investigated for a layer of 25 ML on the electro-polished copper sample. The δ_{max} of the surface increases from 1.65 to 2.4 upon physisorption, in qualitative agreement with previous reports [3]. The decrease of δ_{max} as a function of the electron dose is displayed in figure 7. Assuming that the initial phase of the conditioning down to the value of the δ_{max} of the bare surface is ascribed to electron stimulated desorption, one obtains an electron stimulated desorption coefficient of about 0.02 molecules/electron if re-adsorption is neglected. Further decrease of the SEY is due to a generally accepted effect of carbon growth on the surface. Interestingly the two different mechanisms are justified by the change of E_{max} as a function of dose. E_{max} initially decreases from 300eV to 200eV and after $6 \cdot 10^{-3} C/mm^2$ increases again to 300eV. During this experiment the partial base pressure of water in the system rises to

$2.8 \cdot 10^{-8}$ mbar and interruptions of the irradiation immediately induce an SEY increase.

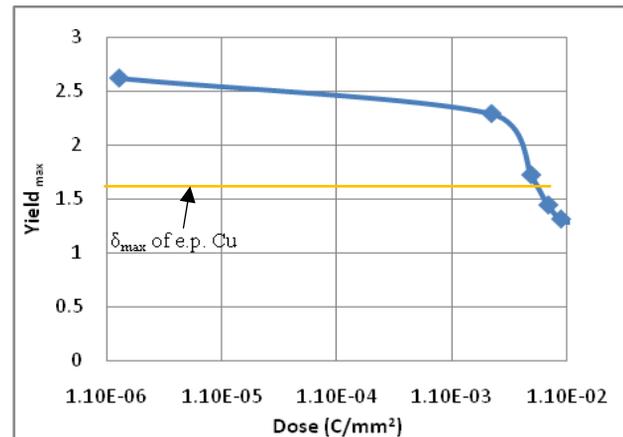


Figure 7: Maximum yield δ_{max} of physisorbed H_2O on electropolished copper as a function of irradiation dose (electrons, 300eV).

CONCLUSIONS

The SEY of the physisorbed layers of N_2 , CO , CO_2 , CH_4 , C_2H_6 and Kr at 4.7K on copper and aluminium show a non monotonic behaviour as a function of coverage. In spite of the fact that such physisorbed layers are insulating, the δ_{max} decreases upon adsorption compared to the value of the bare substrate in all cases, with the exception of Kr . Only CO_2 and N_2 show a minimum as a function of coverage. More investigation on the electronic structure of such thin layers is necessary in order to explain this effect and the saturation value of the SEY as a function of coverage. The consequences for the operation of a cryogenic accelerator vacuum system are that water and CO_2 are the potentially most perturbing adsorbates from the point of view of SEY and hence electron cloud.

REFERENCES

- [1] H. Bruining, *Physics and applications of secondary electron emission*, Pergamon Press (1954).
- [2] J.Cazeau, J.Bozhko, N.Hilleret, Phys. Rev. B 71, 035419 (2005)
- [3] V.Baglin, B.Henrist, E.Mercier, N.Hilleret, C.Scheuerlein, 10th workshop on LEP-SPS performance, p.130, Chamonix, France (2000)