

SEY FROM NOBLE METALS*

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Abstract

The detailed study of the secondary electron yield of technical surfaces for very low electron landing energies (LE-SEY) is a very important parameter to be taken into account to ensure the correct operation of particle accelerators [1]. Despite such interest, LE-SEY (0-30eV) curve has been rarely addressed due to the intrinsic experimental complexity to control very low energy electrons. In this paper, we present an experimental SEY and LE-SEY study carried out on a number of materials of interest for multipacting and electron cloud (e-cloud) mitigation. We also compare here the SEY curves of clean polycrystalline noble metals with those measured on their technical surface.

INTRODUCTION

The accurate determination of the Secondary Electron Yield (SEY) of the materials exposed to radiation is a key issue in the technical design of new particle accelerators [1–8]. The prediction and the minimization of SEY is a strict requirement to limit electron cloud phenomena favoring the stability of machine performances [9–10]. Analogous criticalities concern microwave and RF components for space applications that find one of their most important functional limitations in the multipactor and corona breakdown discharges [11]. In this work we show an experimental study of the SEY and LE-SEY of Au, Ag and Cu which, due to their secondary electron emission properties, are of relevant interest for the realm of e-cloud mitigation and space applications. The comparison of the LE-SEY curves measured from different samples before (as received) and after (clean) UHV surface cleaning qualifies this technique as a tool to characterize the state of the samples surface.

EXPERIMENTAL DETAILS

The experiments were performed at the Material Science INFN-LNF laboratory of Frascati, Roma, with the equipment described elsewhere [1,2,8,10,12]. For the measurements, the samples were inserted in a μ -metal chamber with less than 5mGauss residual magnetic field at the sample position, under ultra high vacuum (UHV) conditions, with a background pressure below 2×10^{-10} mbar. The system is equipped with spectroscopic techniques capabilities such as X-Ray (XPS) and ultraviolet (UPS) photoelectron spectroscopy. A preparation chamber enabling sputtering prepa-

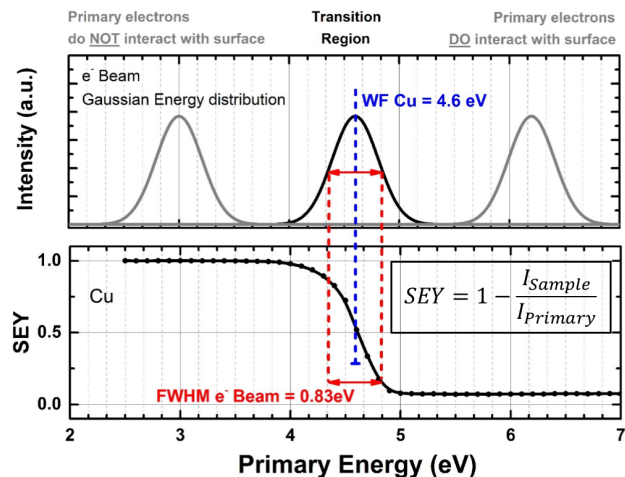


Figure 1: Upper panel: Energy distribution of impinging electrons for primary beam energy set above or below (grey curves) or coincident (back curve) with the sample work function. Lower panel: LE-SEY curve measured on the clean Cu sample.

ration of the samples is also connected to the main analysis chamber.

The Secondary Electron Yield is defined as the ratio of the number of electrons leaving the sample surface (I_{out}) to the number of incident electrons (I_p) per unit area. I_p is measured by applying a positive bias on a Faraday cup, in order to prevent backscattered reemission out to the vacuum. To evaluate I_{out} we measure the sample current to ground I_s . Since $I_{out} = I_p - I_s$, then:

$$SEY = 1 - \frac{I_s}{I_p} \quad (1)$$

For this study, electrons were emitted from the cathode by means of thermionic emission. Their energetic distribution can be assumed to have a Gaussian shape with an energy width FWHM related to the cathode temperature. Such FWHM can play a critical role when the electron primary energy E_p , becomes comparable to it. Fig. 1 shows the LE-SEY measured on polycrystalline clean Cu in the primary energy range $2 \text{ eV} < E_p < 7 \text{ eV}$ above the Fermi level. It can be observed that, for energies $E_p < W_s - \text{FWHM}/2$, primary electrons have not enough energy to overcome the sample work function (W_s) and interact with the sample, hence $I_s \sim 0$ and SEY is artificially calculated from (1) to be unity. On the other hand, when $E_p > W_s + \text{FWHM}/2$ all the electrons emitted from the gun have enough energy to interact with the surface, and hence the SEY is calculated with the relation (1). However, when $W_s - \text{FWHM}/2 < E_p < W_s + \text{FWHM}/2$,

* Work supported by the European Unions Horizon 2020 Research and Innovation Programme under Grant 654305, EuroCirCol Project, and by INFN Group V MICAproject

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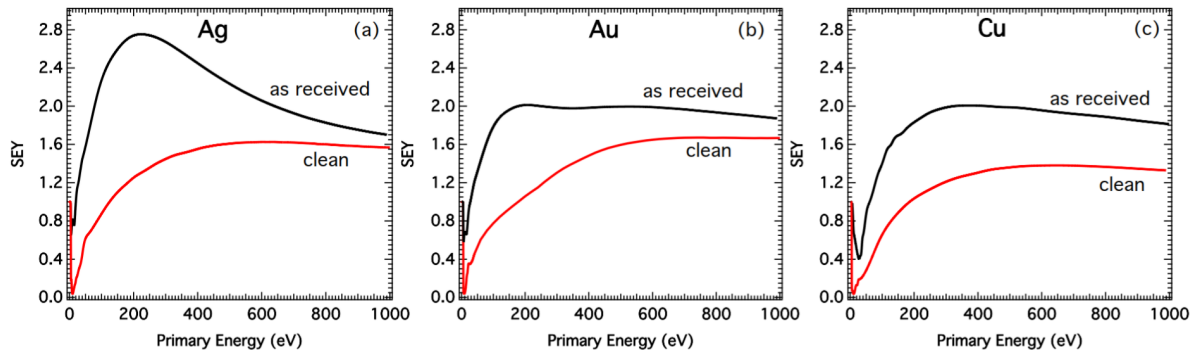


Figure 2: Comparisons between the SEY curves measured for clean (red line) and as received (black line) surfaces of a) Ag b) Au c) Cu polycrystalline samples. In all cases the primary energy is referred to the Fermi level [13].

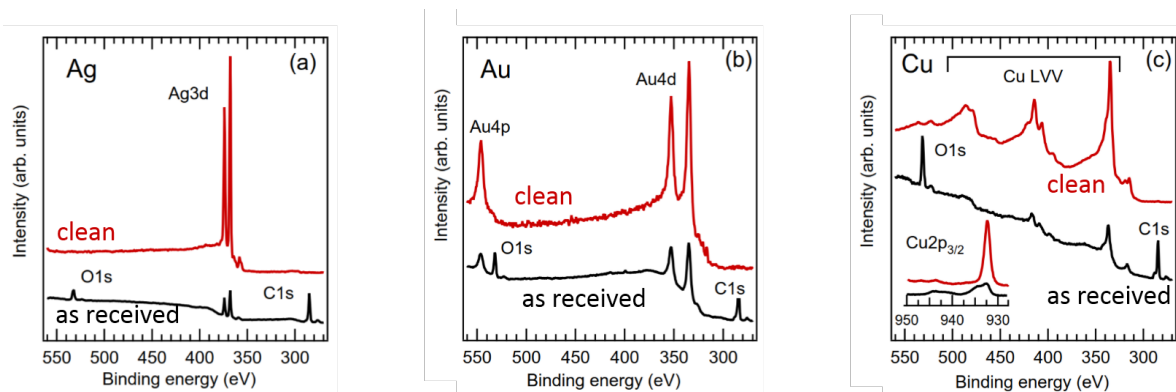


Figure 3: XPS spectra measured on "as received" (red lines) and Ar⁺ sputtered (black lines) a) Ag, b) Au and c) Cu polycrystalline samples. The inset in Fig.3c compares the high resolution spectra measured in the Cu2p_{3/2} spectral region [13].

the number of electrons reaching the surface is not the same as measured by the Faraday cup since, due to the beam energy width, only some of them will have enough energy to interact with the solid. We can affirm that the width of this transition region is equal to FWHM. Nevertheless, this is a "blind region", where some of the impinging electrons interact with the surface and some are repelled, therefore in the region between W_s and $W_s + \text{FWHM}/2$ SEY cannot be accurately determined.

RESULTS

The SEY curves measured on "as received" Au, Ag and Cu samples are shown by the black lines in the upper panel of Fig.2. The SEY_{max} values measured for Ag, Au and Cu are 2.7, 2.0 and 2.1, respectively. In all cases the XPS spectra (black lines in Fig.3) exhibit very intense O1s and C1s core level peaks, which are determined by the presence of surface contamination on the samples. After surface cleaning by Ar⁺ sputtering the level of contamination is brought below the XPS detection limit and correspondingly the SEY decreases for all three metals (red lines in Fig.3). SEY_{max} values measured for clean Ag, Au and Cu are 1.6, 1.7 and 1.3 respectively (red lines in Fig.2). Fig.4 shows LE-SEY measured on all the samples. It can be observed that all clean metals (red lines) show a sharp drop from 1 to values close

to zero within an energy region smaller than 1 eV. The sharp transition gives the vacuum level position for each sample. The measured W_s values measured for Ag, Au and Cu are 4.4 eV, 5.3 eV and 4.6 eV respectively, in good agreement with the literature [14]. When moving to the "as received" samples, the black lines in Fig 4 show that for E_p above the transition region, the SEY remains higher than 0.5 for all metals. In the case of Ag and Au, the LE-SEY shows a minimum in proximity of the transition region followed by a 6 eV wide maximum and by a second minimum, suggesting the presence of a similar contaminating layer on both surfaces which dominates the overall sample behavior. In the case of Cu a continuous SEY decrease together with a net increase of the work function suggests a different chemical environment. This effect can be confirmed by analyzing the XPS O1s/C1s intensity ratio of each surface. It is of the order of 0.6-0.8 for Au and Ag, while it rises to 1.4 in the case of Cu, in agreement with the occurrence of metal oxidation, further confirmed by the Cu2p_{3/2} line shape, which shows a dominating oxide phase (see inset in Fig.3c). The XPS analysis did not show any indication of oxidation on Ag and Au surfaces, suggesting that surface contaminants have a dominating effect on the SEY, even in the absence of surface oxidation.

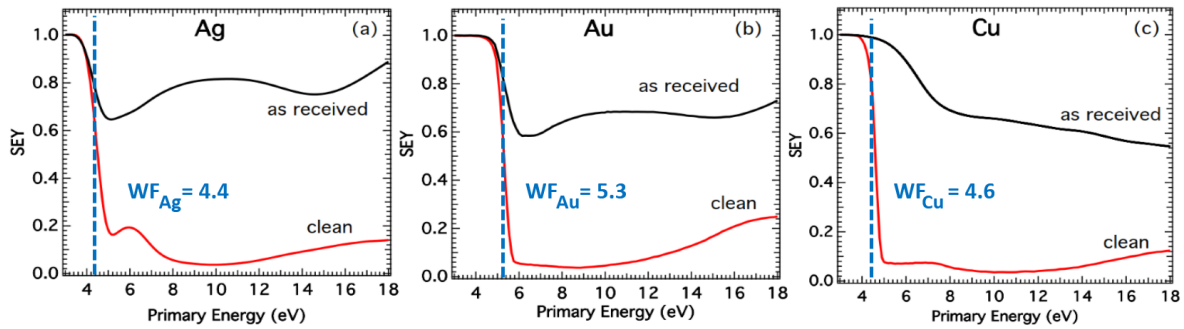


Figure 4: Comparisons between the LE-SEY curves measured for clean (black line) and as received (red line) surfaces of a) Ag b) Au c) Cu polycrystalline samples. In all cases the primary energy is referred to the Fermi Level [13].

In order to analyze the importance that surface contaminants have on SEY, the clean Cu sample was cooled down to 10K and dosed with CO. Fig 5 shows the LE-SEY (a) and SEY (b) measured on the cold Cu sample at CO coverages of 0.5 ML and 1 ML. Results measured at RT are also presented for comparison. The results show that cooling down does not change the SEY behavior of the sample. Fig 5 also shows the SEY results measured on the cold Cu exposed to the UHV residual gas molecules for a prolonged time. The coverage of the sample with contaminating molecules was estimated to be $<0.3\text{ML}$. The presence of such contaminants modifies only the LE-SEY which slightly increases with respect to the clean surface. It can be observed that SEY_{max} increases with increasing CO coverage whereas the inverse behavior is observed at the LE-SEY region. The fine structures which appear in the LE-SEY curve measured at CO coverage of 1 ML indicate that the signal is dominated by the adsorbed CO and will be the subject of a future investigation. The comparison between the curves taken with and without adsorbed CO indicates that a coverage of 1 ML is sufficient to deeply modify the LE-SEY curve proving the high surface sensitivity of this technique.

CONCLUSION

We have shown that the surface chemical state is a key factor in determining the metal SEY and LE-SEY curves. Whereas clean metals exhibit SEY values that do not exceed 1.6 and are even lower in the case of copper, the presence of a contaminating layer can rise SEY_{max} well above 2. More interestingly, the LE-SEY curves show heavy changes in the presence of adsorbates even at submonolayer coverage. Our results demonstrate that for very slow electrons the LE-SEY curve allows an easy measurement of the sample work function. Then SEY and LE-SEY are valid spectroscopic tools, that, with a limited experimental requirement, can be used both to determine the response of materials to external excitation in terms of secondary electrons emission and also as flexible and sensitive diagnostics to state surface cleanliness and to follow surface reactions, desorption and ultrathin layer growth.

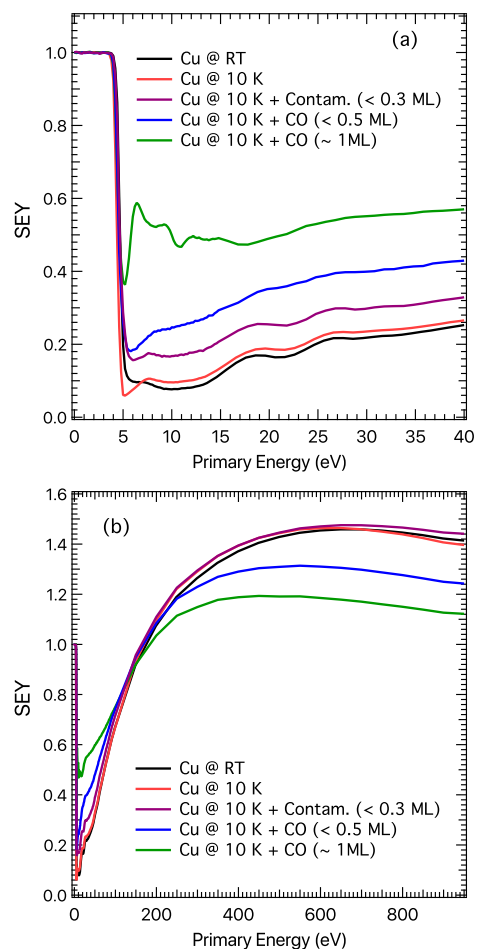


Figure 5: a) LE-SEY and b) SEY curves measured at 10 K on a polycrystalline Cu sample clean (red) and in the presence of 0.3 ML of adsorbed residual gases (purple) and of about 0.5 ML (blue) and 1 ML (green) of adsorbed CO. The LE-SEY and SEY curves measured on the clean sample at RT are shown for comparison (black). In all cases the primary energy is referred to the Fermi level [13].

ACKNOWLEDGEMENTS

The authors would like to thank staff of Dafne-light for technical support.

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