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VACUUM CHAMBER SURFACE ELECTRONIC PROPERTIES INFLUENCING ELECTRON CLOUD PHENOMENA

R. Cimino[1,2] and I.R. Collins[1]

Abstract

In the vacuum science community, it is now commonly accepted that, for the present and next generation accelerators, the surface electronic properties of the vacuum chamber material have to be studied in detail. Moreover, such studies are of valuable help to define the cleaning procedures of the chosen materials and to identify the most efficient vacuum commissioning. In the case of the Large Hadron Collider (LHC) the proton beam stability, in the presence of an electron cloud, is analysed using Beam Induced Electron Multipacting (BIEM) simulations requiring a number of surface related properties, such as photon reflectivity, electron and photon induced electron emission, heat load, etc. and their modification during machine commissioning and operation. Such simulation codes base their validity on the completeness and reliability of the aforementioned input data.

In this work we describe how a Surface Science approach has been applied to measure, total electron yield (SEY) as well as energy distribution curves excited by a very low energy electron beam (0-320 eV), from the industrially prepared Cu co-laminated material, the adopted LHC beam screen material, held at cryogenic temperatures (about 10K). The data show that the SEY converges to unity at zero primary electron energy and that the ratio of reflected to secondary electrons increases for decreasing energy below about 70 eV, and becomes dominant below electron energies of about 20 eV. These observations lead to the notion of long–lived low-energy electrons in the accelerator vacuum chamber, which could be an issue for the LHC, damping rings and future accelerators.

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Vacuum chamber surface electronic properties influencing electron cloud phenomena.

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PACS: 79.20.Hx Electron impact: secondary emission;
29.27.Bd Beam dynamics; collective effects and instabilities;
41.75.Lx Advanced accelerator concepts

The build-up of an electron cloud and beam induced electron multipacting was first observed in the ISR more than 25 years ago [1]. Since then, a significant theoretical effort has been made to understand and predict electron cloud phenomena and its impact on various machines [2]. In addition, a number of experimental observations of electron cloud effects have been reported to occur on different accelerators [2]. Relevant to the building and the commissioning of the LHC, an on-going experimental and theoretical campaign was launched in 1997 to identify the potentially detrimental effects of electron cloud phenomena on the machine performance and to identify possible remedies [2]. A significant number of combined experiments and simulations observe and predict multipacting effects induced by the build-up of an electron cloud in the SPS once an LHC type beam is injected [3]. Such experiments and simulations also provide convincing evidence that the observed electron cloud effects are indeed to be expected in the LHC, not only inducing undesirable pressure rises, but more importantly affecting the acceptable heat load in the cryogenically cooled arcs of the machine [2]. In the LHC the heat load budget is an extremely relevant parameter since the arc magnets are held at 1.9 K. To intercept the synchrotron radiation emitted by the proton beam and to carry the image currents a beamscreen (BS) is inserted into the cold bore (vacuum envelope) and held at a temperature between 5 and 20 K. The nominal cooling power available to keep the BS within the foreseen temperature interval is 1.17 W/m [4] of which 0.2 W/m are used to dissipate the SR heat load when the proton beam is accelerated to the foreseen energy of 7 TeV and 0.2 W/m are used to dissipate the resistive wall induced heat load. Simulations show [5] that electron cloud activity does indeed induce an additional heat load depending on a number of the vacuum chamber material surface conditions and electronic properties. To correctly predict such extra heat load in the LHC, it is then essential to determine accurately the secondary electron yield (SEY) at cryogenic temperatures (eventually in presence adsorbed gas), the energy distribution of the emitted electrons as excited by photons and by electrons and the ratio between true secondaries and reflected electrons. In this paper we focus mainly on electron induced electron Energy Distribution Curves (EDC) from low temperature surfaces (~10K) and try to disentangle in those EDC the percentage of reflected electrons contributing to the total SEY. It has been recently debated that a significant electron reflected component results in a near doubling of the electron cloud induced heat load [5,6]. In this study primary electron beam of energy between zero and 320 eV were used. Particular attention was paid to the effects of low energy electrons (from 0 to around 50 eV) since it has been reported that the energy distribution of the electrons impinging on the wall and playing a role in inducing electron cloud effects is peaked at very low energy (from 0 to 20 eV) and does not extend significantly over 300 eV [7].

The analyses of the electron induced electron EDC at low primary energy requires a suitable experimental set-up designed to limit the residual magnetic field near the sample, which can indeed deviate low energy electrons. For our experiments we used a specially built UHV μ-metal chamber with less than 5mGauss residual magnetic field at the sample position, pumped by a CTI8 cryo-pump to ensure a vacuum better than 10^{-9} Torr without bake-out. Ion pumps are not used due to their detrimental stray magnetic field.

A Spectaleed Omicron LEED/Auger Retarding Field Analyser (RFA) system was specially modified to be able to collect angle integrated EDC with RF filtering and computer control while using the gun in LEED mode, i.e. with a low energy focused beam. The e^- gun provided a small (less than a 1 mm^2) and stable (both in current and position) beam spot on the sample, in the energy range from 30 to 350 eV. The sample is attached to a close cycle Sumitomo cold finger manipulator specially designed and built by CryoVac to damp the cryostat vibrations to less than 10 μm in all directions and obtain a stable temperature on the sample between 8 and 400 K. The samples studied were all part of the final production of co-laminated Cu for the LHC beamscreen (BS), including all cleaning stages, hence are representative for the real surface ‘seen’ by the proton beam in the machine. To measure low energy impinging primary electrons, a bias voltage was applied on the sample. Such a bias allows one to work at very low primary energy (close to 0 eV) while keeping the gun in a region where it is stable and focused, as measured by a line profile on a 1mm slot Faraday cup. The applied bias also allows one to eliminate from the data the secondaries produced by the analyser. Different bias and geometrical conditions have been used to crosscheck the existence of any spurious effects on the measured data caused by the possible presence of electric field lines induced by the sample bias. While distorted line-shapes (both EDC and SEY) have indeed been observed when significantly altering the geometry of the ground surrounding the sample and while going significantly off normal incidence, the data presented here are inherently consistent and reproducible to be inferred to be free from artefacts.

In fig.1 we report a sub-set of EDC taken as a function of primary energy from an as-received Cu, held at ~10 K. Experimental observations show that electron bombardment on an as-received surface changes its electronic properties. This phenomenon, called "scrubbing" has been carefully studied in the case of the LHC type beamscreen material [2,8] and it was shown to gradually reduce the SEY from a starting value of around 2.2 to a final one of around 1.1 (after more than $1x10^{-3}$ C/mm^2). For the purpose of this paper we want to analyse a stable surface, i.e. a surface with a SEY that does not change with electron dosing, hence we collected all our data from a fully scrubbed surface obtained by dosing with more than $1x10^{-2}$ C/mm^2 400 eV electrons. Those results, obtained at low temperature, are consistent with the one previously measured at room temperature [9] partially supporting the extrapolation to low temperature of the available room temperature EDC data. Any possible sharpening of the secondary electron emission structure due to lower thermal broadening of the emitted electrons at low temperatures is masked by the limited energy resolution, close to 1 eV, of our RFA; a careful line-shape analysis of low temperature -EDC would require a higher resolution analyser. From the available data it is clear that at primary energies higher than 100 eV the main contribution to the EDC is given by the electrons emitted with 0 to 15 eV kinetic energy and only a negligible part of the observed spectrum is due to electrons elastically reflected from the surface at kinetic energies equal to the one of the impinging primary beam. When lowering the primary energy the contribution of the reflected component increases with respect to the secondaries being the dominating component at low (<20 eV) primary energy. From the available data it is possible by simple numerical integration, to extract the ratio between secondary and reflected electrons for each primary energy. In this paper the distinction present in the literature, [10] between "true secondaries" and "rediffused" electrons is suppressed since we considered it not necessary for our analysis and especially for spectra taken at low primary energy. Moreover, the separation between true secondaries and rediffused electrons is somewhat arbitrary.

We then consider that all the electrons emitted between 0 eV and the onset of the clear peak at the energy of the primary electron beam as secondary electrons, while the integral under the peak gives the amount of electrons specularly reflected.

Performing this analysis at all measured energies it is then possible to extract the percentage of reflected and secondary electron component in the EDCs as a function of primary energy.

This is shown in fig.2 where it is clear how, at energies below 20 eV the reflected component becomes dominant and is essentially the only one surviving in the EDC exited with close to zero primary energy. This analysis shows that the EDC of the emitted electrons is dominated by reflected electrons at low (<20 eV) primary energy. It then becomes extremely important to measure, in the same energy range, the SEY.

We show in fig. 3 SEY measurements on the same sample and in identical conditions used to measure the EDC. Such SEY data and the EDC analysis shown in fig. 2 make possible to determine the percentage of reflected electrons per impinging beam. The low energy part of the SEY spectrum has been seldom measured [9,11] and has never been discussed in great detail, possibly due to the experimental uncertainties and difficulties in using an electron gun to deliver a stable and well focused beam at low energies (0-20 eV) in presence of the earth magnetic field and other local sources like ion pumps. In our set-up we are able to measure the SEY in two independent modes as seen in the following: SEY= δ = Ie/Io = (Io-Is)/Io where Ie is the current due to electrons emitted by the sample and collected, in our set-up by the RFA; Io is the impinging electron current as measured by a specially assembled Faraday cup which could be placed in front of the beam without braking the vacuum or altering the set-up; Is is the drain current measured from sample to ground. The sample current Is was measured by a Keithley electrometer. Ie has been independently estimated scaling the integral of each EDC measured by the RFA from counts. The two methods to measure SEY as a function of primary energy gave consistent and similar results, supporting the validity of our experimental procedure. In fig. 3 we show such measured SEY from close to zero primary energy to 320 eV. From the data and the superimposed contributions of the reflected electron and the secondary electron components, we can clearly conclude that, at low energy most of the impinging electrons are reflected by the Cu surface, giving a SEY close to unity approaching primary electron beam zero energy. The value of the observed minimum in δ and its energy position has been seen to depend on the actual sample and its conditions (temperature, scrubbing etc.), while the overall shape is conserved and δ close to unity measured at low primary energy in all cases. Our data are consistent with published data [9] confirming not only the importance of the reflected electrons at low primary energy but more importantly suggesting, for the first time in this context, that very low electrons may have long survival time inside the accelerator vacuum chamber due to their high reflectivity. This notion may well explain why in the KEK B factory [12] and SPS [3] a memory effect has been observed. Namely, the electron cloud build-up during the passage of a batch is enhanced by the passage of the preceding batches even if the time interval between the two trains is quite long (as long as 550 ns in the SPS). Preliminary results [13] obtained by implementing these experimental data into BIEM simulations indicate an increased heat load for the LHC. The high electron reflectivity at low energy presented here could also be of relevance to electron cloud effects on damping rings and more in general on future accelerators.

In conclusion, these data suggest the need to consider, as a pessimistic estimate, a value of the secondary yield close to unity for zero energy of impinging electrons, hence a reflected component close to 100%.

Further studies should be carried out on closer to reality low temperature samples with an adsorbed gas layer on the surface; such a layer is expected to be present on the beamscreen surface due to the closed geometry of the arc beam vacuum system. The presence of this gas may significantly change the SEY, the electron scrubbing efficiency, EDC and the true secondary to reflected electron ratio.

Acknowledgments

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Figure Captions:

Figure 1: Some selected EDC of fully scrubbed Cu surface at ~10 K as a function of impinging primary electron energy.

Figure 2: Secondaries and reflected electrons from a fully scrubbed Cu surface at 9 K as a function of primary electron energy.

Figure 3: Total SEY (▯) and contribution to it of secondaries and reflected electrons from a fully scrubbed Cu surface at 9 K as a function of primary electron energy.

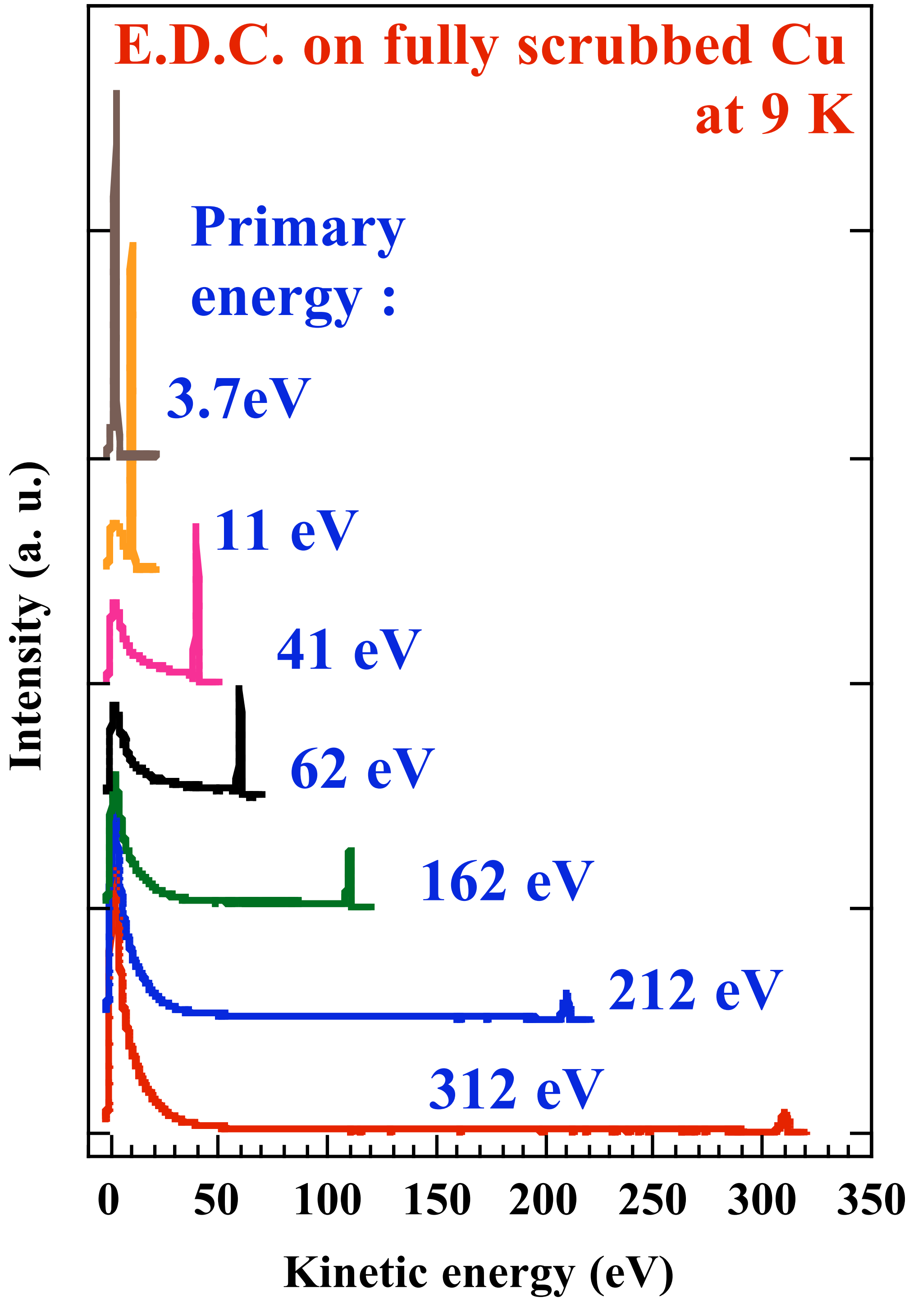
E.D.C. on fully scrubbed Cu at 9 K
Primary energy :
3.7eV
11 eV
41 eV
62 eV
162 eV
212 eV
312 eV
Intensity (a. u.)
0
50
100
150
200
250
300
350
Kinetic energy (eV)

Figure 1

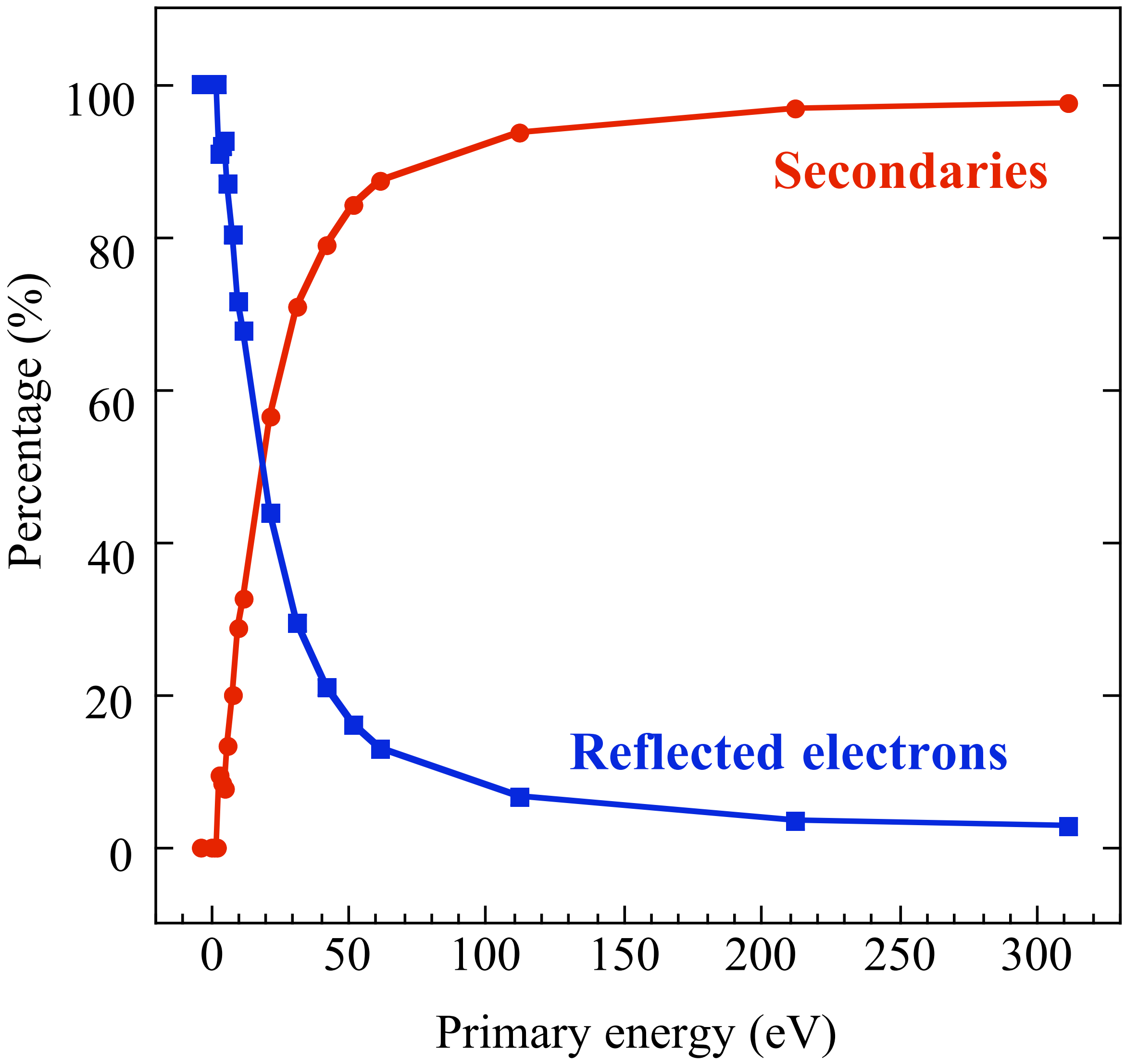
Percentage (%)
100
80
60
40
20
0
0
50
100
150
200
250
300
Primary energy (eV)
Secondaries
Reflected electrons

Figure 2

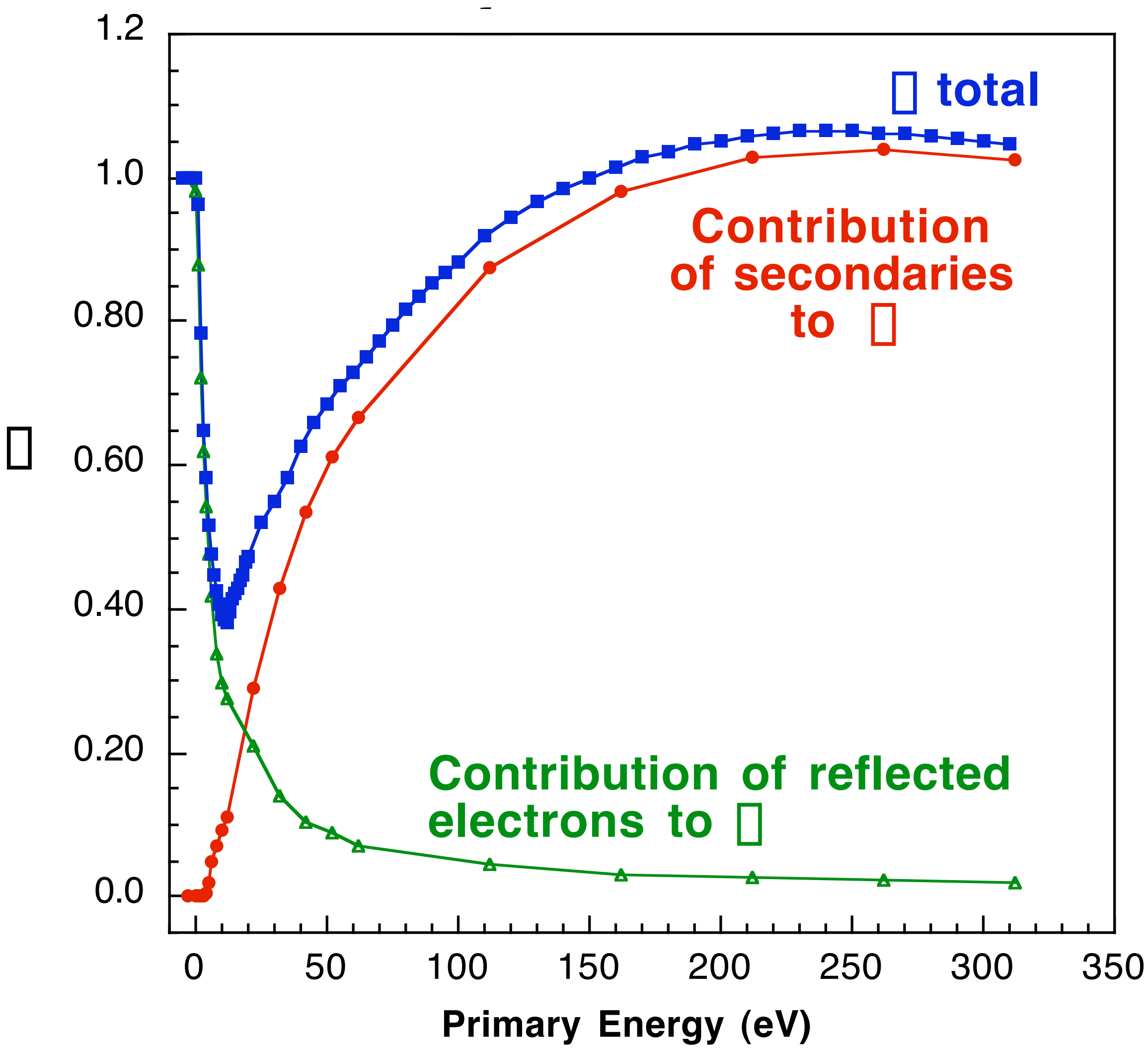
□ total
Contribution of secondaries to □
Contribution of reflected electrons to □
□
1.2
1.0
0.80
0.60
0.40
0.20
0.0
0
50
100
150
200
250
300
350
Primary Energy (eV)

Figure 3

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