Monte carlo simulation of positron induced secondary electrons in thin carbon foils

L H Cai, B Yang, C C Ling, C D Beling and S Fung*

Department of Physics, The University of Hong Kong, Pokfulam Road, Hong Kong S.A.R., PR China

E-mail address: sfung@hkucc.hku.hk

Abstract. Emission of secondary electrons induced by the passage of low energy positrons through thin carbon foils was studied by the Monte Carlo method. The positron and electron elastic cross sections were calculated by partial wave analysis. The inelastic positron-valence-electron was described by the energy loss function obtained from dielectric theory. The positron-core-electron interaction was modelled by the Gryzinski’s excitation function. Positron transport inside the carbon foil was simulated in detail. Secondary electrons created by positrons and high energy secondary electrons through inelastic interactions were tracked through the foil. The positron transmission coefficient and secondary electron yielded in forward and backward geometry are calculated and dependences on positron energy and carbon foil thickness are discussed.

1. Introduction
Monte Carlo methods have been extensively used to simulate the interaction between electrons with solids for several decades [1,2] and it has been applied to study the interactions between positron and aluminium [3, 4], copper [3] and gold [4]. The start signal is triggered by the secondary electrons generated by positrons passing through a thin carbon foil [5]. Although secondary electrons from thin carbon foil have been used in various types of time of flight mass spectrometers to provide a start signal, most of these experiments are induced by ions [6, 7]. Few results on positron induced secondary electron emission from carbon foil have been published by now.

In present work, we first describe the elastic and inelastic cross sections that are used for the Monte Carlo simulation. We calculated the secondary electron yield (SEY) and positron transmission coefficient of varied foil thickness. The energy distribution and angular distribution of forward positrons and secondary electrons are calculated.

2. Method
The Mott cross-section was adopted in the present simulation, for which the scattering induced phase shift of the electron spin was obtained by solving the Dirac equation [8]. Considering the correlation-polarization potentials at low energies and the exchange potential for electrons, the differential elastic cross sections of positron and electron are calculated [9] (see figure 1). Because the potentials for electron and positron are significantly different, the total elastic cross sections varied much at low energy (especially lower than 2 keV), as showed in figure 2. With increasing energy, the difference in elastic cross sections between electron and positron became smaller.
For low energies, the conduction band excitations via plasmons excitation and electron hole pair creation are the dominant energy loss processes. Dielectric function model are extensively used to describe this process [10]. In this model, Energy Loss Function (ELF) Im\[\frac{-1}{\varepsilon(q,\omega)}\], determines the probability function of transferring energy \(h\omega\) and moment \(hq\) to the target sample. The Inelastic Mean Free Path (IMFP) can be calculated from integrating over particular region of \((q,\omega)\) plane, i.e.

\[
\lambda_{\text{in}}^{-1} = \int \tau(E,\omega)d\omega
\]

where \(hq^\pm = \sqrt{2m(E \pm h\omega)}\) is originated from the energy-momentum conservation.

The mean energy loss per unit length or stopping power, is given by [10]:

\[
S(E) = \int \omega \tau(E,\omega)d\omega .
\]

Ashley [10] proposed a simple momentum-dependent ELF, in which the influence of single particle interaction was considered for large momentum transfer. For small momentum transfer, interaction with plasmons was considered. The plasmons interaction was obtained from the optical data which was available in Ashley et. al. [11].

Considering the inner shell excitation, the total inelastic cross section for intermediate and high energy positrons was obtained from the Gryzinski’s binary encounter theory [12]. The binding energies used in this paper were cited from reference [13], which took the atomic shielding effect into consideration.

Here, the dielectric function model was used to describe the inelastic collisions for projectile’s energy is less than 2keV. The Gryzinski’s excitation function is used for the remaining high energy range. Monte Carlo modeling of positron is similar to electron transport through the solid [1, 2]. Each positron and electron excitation is tracked step by step until it leaves the foil or its energy is less than 20 eV. The energy and the ejection angle of the positrons and the secondary electrons emitted from the surface are recorded.

3. Results and discussion

Positron induced secondary electron emission from thin carbon foils was investigated with different foil thicknesses between 10nm and 40 nm. Most of the positrons would penetrate through carbon foils. The secondary electron yield (SEY) is defined as the number of secondary electrons over the number of positrons. As shown in figure 3, the SEY varied with the foil thickness. It was observed that the thinnest foil (10 nm) had the lowest value. However, the SEY of the 30 nm thickness sample had the
The highest SEY if the positron incident energy was not larger than 5 keV. The 40 nm foil had the highest SEY when the positron incident energy was larger than 8 keV.

Figure 3. The thickness dependent secondary electrons yield of various energies positrons

Figure 4. Positrons induced secondary electron yield and the transmission coefficient in carbon foil (30 nm thick)

Taking the 30 nm thickness case as an example, the transmission coefficient increased with the positron energy. It is worth stating that this value should be larger than experimental data, because back scattering from the surface was not considered in the simulation. The low energy positrons would have significant energy drop after passing through the foil while the high energy positrons would have little change (figure 5). Most of the positrons ejected from the foil at an angle of around 9 degrees (figure 6). The angular distribution became more dispersive as the incident positron energy decreased.

Figure 5. Normalized energy distribution of positrons passing through the thin carbon foil (30 nm thick).

Figure 6. Normalized angular distributions of positrons passing through the thin carbon foil.

The energy of the forward emitted secondary electrons was usually lower than 60 eV. This result coincided with the findings of secondary electron spectra [14]. The energy of secondary electrons induced by different incident energies did not vary too much (figure 7). This was possibly because most of the secondary electrons emitted were confined in a thin region close to the sample surface [15].

If the incident positron is at 5 keV, the positron energy would decrease with the carbon foil thickness because of the inelastic interaction (figure 8). The foil thickness did not affect the energy distribution of the secondary electrons. Most of the secondary electrons had energy around 5 eV, as shown in figure 9. Similar to positron, the secondary electron angular distribution became more dispersive with foil thickness. Considering the secondary electrons yield and the positron energy and angular distribution, the 20 nm carbon foil seems to be the optimum choice.

4. Summary
Secondary electron induced by positrons was simulated by the Monte Carlo program. High secondary electron yields suggesting that it is promising to use the secondary electrons from carbon foils to start...
the lifetime counting. The energy of positrons decreased after penetrating through the carbon foil. The positrons’ ejecting angle would deflect a little after passing through the foil. The secondary electron energy distribution was independent of the positron incident energies and the thickness of carbon foil.

![Figure 7. Normalized secondary electrons energy distribution.](image1)

![Figure 8. Normalized energy distribution of positrons passing through various thicknesses of carbon foils.](image2)

![Figure 9. Normalized energy distribution of secondary electrons induced by 5 keV positrons.](image3)

![Figure 10. Normalized angular distribution of secondary electrons induced by 5 keV positrons.](image4)

References

[1] Shimizu R and Ding Z J 1992 Rep. Prog. Phys. **55** 487
[2] Dapor M 2003 Electron-beam interactions with solids (Berlin: Springer)
[3] Valkealahti S and Nieminen R M, 1983 Appl. Phys.A **32** 95
[4] Bentabet A and Fenineche N 2009 J. Phys. : Condens. Matter **21** 095403
[5] Chen D, Zhang J D, Cheng C C, Beling C D and Fung S 2008 Appl. Surf. Sci. **255** 122
[6] Ogawa H, Ohata T,Sakamoto N and Kaneko T 2007 Phys. Rev. A **76** 532
[7] Ritzau S M and Baragiola R A 1998 Phys. Rev. B **58** 2529
[8] Mott N F 1929 Proc. R. Soc. Lond. A **124** 425
[9] Salvat F, Jablonski A and Powell CJ 2005 Comput. Phys. Commun. **165** 157
[10] Ashley J C 1990 J. Electron. Spectrosc. Relat. Phenom. **50** 323
[11] Ashley J C 1979 Thin Solid Films **60** 361
[12] Gryzinski M 1965 Phys. Rev. **138** A305
[13] Thomas D 1997 Binding energies of electrons in atoms from H (Z=1) to Lw (Z=103) Available from: [http://www.chembio.uoguelph.ca/educmat/atomdata/bindener/elecbind.htm](http://www.chembio.uoguelph.ca/educmat/atomdata/bindener/elecbind.htm).
[14] Joy D C, Prasad M S and Meyer H M 2004 Journal of Microscopy **215** 77
[15] Knights A P and Coleman P G 1995 Appl. Surf. Sci. **85** 43