Thickness Dependence of Positron Induced Secondary Electron Emission in Forward Geometry from Thin Carbon Foils

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Abstract

Secondary electron (SE) emission from thin carbon foils induced by 1-20 keV positrons has been investigated over a range of nominal foil thicknesses from 1.0 to 5.0 μ g/cm^2. The measurement of SEs was carried out in forward geometry using a microchannel plate as a detector. The SE yield γ has been measured as a function of beam energy and compared with our Monte Carlo simulation results. We also present in this paper the material parameter $\Lambda = \gamma/(\mathrm{d}E/\mathrm{d}x)$ and the emitted SE energy spectra. For incident positron energy of 5 keV or higher, the distribution is found to be characterized by the Sickafus form, AE^{-m} and m is close to 1. For low energy incident positrons however, another form, $Bexp(-E/t)$, is proposed for describing the SE distribution.

Introduction

Secondary electron (SE) emission from material surfaces under ion bombardments is one of the very important and fundamental phenomena and has been studied both experimentally and theoretically for a long time [1,2]. It has received a great deal of attention in the past because it gives an insight into the Physics of electron-solid interactions [3] and has many applications such as electrical discharges, surface analysis and space environment [4]. In our previous work [5], we also gave a novel design of a cylindrically symmetric VEPALS system based on secondary electron (SE) emission from carbon foil.

Ion induced SE emission is generally attributed into two distinguishable processes. For ion velocity less than 10^7 cm/sec, SEs will be generated mainly by the potential emission which can occur by three mechanisms: Auger neutralization (AN), interatomic Auger process (Auger deexicitation) and plasmon excitation [6-9]. Ions with higher velocities eject electrons by kinetic mechanism in which SEs result from the transfer of kinetic energy from the incoming projectile [2]. The kinetic energy lost by the projectile is transferred to the target electrons by distant collisions and close collisions. The distant collision produce a number of slow excited electrons and is supposed to be proportional to the energy loss of the incident ions. The close collision is the binary interaction between the projectile and target electron, in which a large energy is transferred to generate δ-electrons [2]. After undergoing elastic collisions with other target electrons and being directed to the solid surface, those SEs with enough energy may overcome the surface barrier and emit from the surface. It has been proved for some ions, like proton, that the SE yield per projectile, γ, is proportional to the electronic stopping power of the target material, S_e, i.e. $\gamma = \Lambda S_e$, Λ is called material parameter [10].

Sickafus [11-13] examined the log-log display of SE number versus emitted SE energy in the region $10 \leq E \leq 1000\ eV$ and found a linear behavior: $N(E) = AE^{-m}$, where N is the number of emitted SE, E represents the SE energy, and A and m are constants for a material at a particular incident ion energy E_B. Sickafus found the constant m to be typically 1. Matthew et al. measure different samples to find m within 0.5~1.5 [14] and their Monte Carlo simulation of the SE background in the range from 200 eV to 2000 eV also showed that the background could be characterized by the Sickafus form, with m close to unity [15]. N. Overton et al used a 2 keV incident positron beam to bombard copper and found $m \approx 2$ [3].

In this paper, we will present s SE yield, positron transmission, material parameter and SE energy distribution by using a positron beam of $1 \sim 20\ keV$ on carbon foil with different thickness. The experimental procedure and set-up is described in the next section.

Experimental

Fig. 1 shows the schematic layout of the experimental setup. The incident positron beam (focused to ~1 mm) used for this work is produced by the low energy positron beam facility at the University of Hong Kong with a 50mCi ^{22}Na source [16]. A C- foil with different nominal thickness ranging from 1.0 to 5.0 μ g/cm^2 (made by Arizona Carbon Foil Co., Inc.) was mounted on a tungsten mesh. In fact, in another paper of ours under review in which we studied the stopping power of positrons by a carbon foil, we observed that the actual thickness of the carbon foils was indeed proportional to the nominal thickness. Indeed, our result agreed with Allegrini et al [17]. Two retarding grids analyzers for biasing off the transmitted beam positrons and the emitted SEs in the forward direction were placed behind the foil. The phosphor screen was used to visualize the positrons and SEs. The positron and SE counts N were detected from the charge deposited on the MCP's phosphor screen and counted using standard electronics.

Monte Carlo simulation

Monte Carlo simulation was developed to study the positron interaction with the carbon. In our simulation, positrons would experience elastic and inelastic collisions during their path through the carbon foil and the energy loss during the inelastic collision would be transferred to generate a secondary electron. the trajectories of the positrons and SEs are tracked until they come out of the foil or their energies are lower than the critical energy. The elastic cross sections were calculated by partial wave analysis. The inelastic positron-valence-electron scattering was described by the energy loss function obtained from dielectric theory. The positron-core-electron interaction was modelled by the Gryzinski's excitation function.

Results and discussion

The SE yield per incident projectile was measured for different target thicknesses as a function of positron energy. It has to be mentioned here that the yield data in our experiments are relative values due to the uncertainty about the efficiency of MCP for positrons and electrons. As already shown in Fig. 2, the SE yields reach the maximum at 1.5 keV and then drop when the beam energy increases. For all the foils, the SE yields saturate to a constant value at energies above 15 keV. It is worth noting that at low incident energy, the thinner foil gets a higher SE yield while above 3 keV more SE emit from a thicker foil. The inner plot of Fig. 2 is our Monte Carlo simulation results which show a very good agreement of the trend and different behaviors between low and high incident beam energy. We have compared our present results with the two numerical simulation codes developed by Caen and Brussels which were used to simulate the electron yield induced by electrons in carbon foil [17]. These are indeed in reasonable agreement in terms of general trend -- except for the peak position.

For evaluating the material parameter Λ, the electronic stopping power for positrons in carbon foil has been calculated using the formula by Batra [16]. Fig. 3 presents the forward material parameter Λ as a function of positron energy. It is difficult to conclude from our experimental result that Λ is constant. A. Dubus et al [17] measured the backward and forward Λ for different carbon foil thicknesses (8, 30.1, 302, 1025 μ g/cm^2) as a function of incident proton energy ranging from 1 to 8 MeV and suggested that the forward specific yield Λ cannot be considered as a constant. They also found for their thinnest foils (8 μ g/cm^2) Λ slightly decreases with incident proton energy and the thicker foil gets larger Λ above a certain proton energy [17]. A similar trend can be found for all foils in our experiments when the positron energy is above 3 keV.

The normalized energy distribution of SE emitted in forward direction from carbon foils using an incident positron beam of 20 keV was obtained in Fig. 4. Unlike the results of N. Overton when they used 2 keV positron beam to bombard copper [3], the high energy tail of SE in our result is quite short and the main peak is within 10 eV. Fig. 5 shows a log-log plot of the experimental data of 5.0 μ g/cm^2 carbon foil bombarded by 5, 10, 15 and 20 keV positron beam. The fitted lines in Fig. 6 show clearly the linear nature of our data. It also means that the power law of Sickafus form is suitable for describing the SE distribution above positron energies of 5 keV . The corresponding values of m are given in Table. 1. All four values are within the range of 0.5 to 1.5 as suggested by Matthew et al. [14]. It also seems that the value of m is close to 1 when the positron energy becomes larger.

However, there is a large departure from linearity for the SE distribution for positron energies below 2 keV . As shown in Fig. 6, the fitted curve indicates an exponential law: $Bexp(-E/t)$. Our fitted results show that the value of t lies between 2.5 and 3.0 for 2 keV positrons in carbon foil.

To explain this phenomenon, we may assume that the SE distribution under high energy ion bombardment follows the formula below:

$$\frac{dN}{dE} = AE^{-m} + Bexp(-E/t)$$

Where A, B, m and t are constant for a material at a particular incident ion energy E_B. We assume that t and m are functions of the electronic stopping power S_e. The exponential form may be related to the distant collision or the low energy cascade, while the Sickafus form may come from the close collision. Since the exponential form will converge to zero much more quickly, the SE distribution can always be presented by Sickafus form above some certain SE energy. In our experiments, at low incident beam energy like 2 keV, the stopping power S_e is large, as well as t and m. So the exponential form will be dominant particularly in the small SE energy range. However, at high incident beam energies, t and m decrease with S_e, which makes Sickafus form dominant in the relevant region. The decrease of value for m with primary incident positron energy was also confirmed theoretically and experimentally by M. Dapor [18] and N. Overton [19].

Fig. 7 shows our simulated SE energy spectrum for 5 keV positrons incident on foils with thickness from 10 to 40 nm. The upper and lower panel present the same data plotted in different ways. From the upper panel, we can see that the energy spectrum is broader than our experimental result and the main peak area is within 30 eV. It can be also concluded that the thicker foil has a longer tail in its spectrum. The lower panel is the log-log plot of the simulated data. We can see clearly that the Sickafus law shows up only when energy is above 10 eV.

Conclusion

We have presented in this work experimental results for SE yield. The SE yield drops to constant values at energies above 15 keV for all foils with different thickness. The material parameter Λ is also calculated and is found to vary with the incident positron beam energy. We finally propose a simple formula to explain the different behavior of SE energy distribution under different incident positron beam energies.

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Figure Captions:

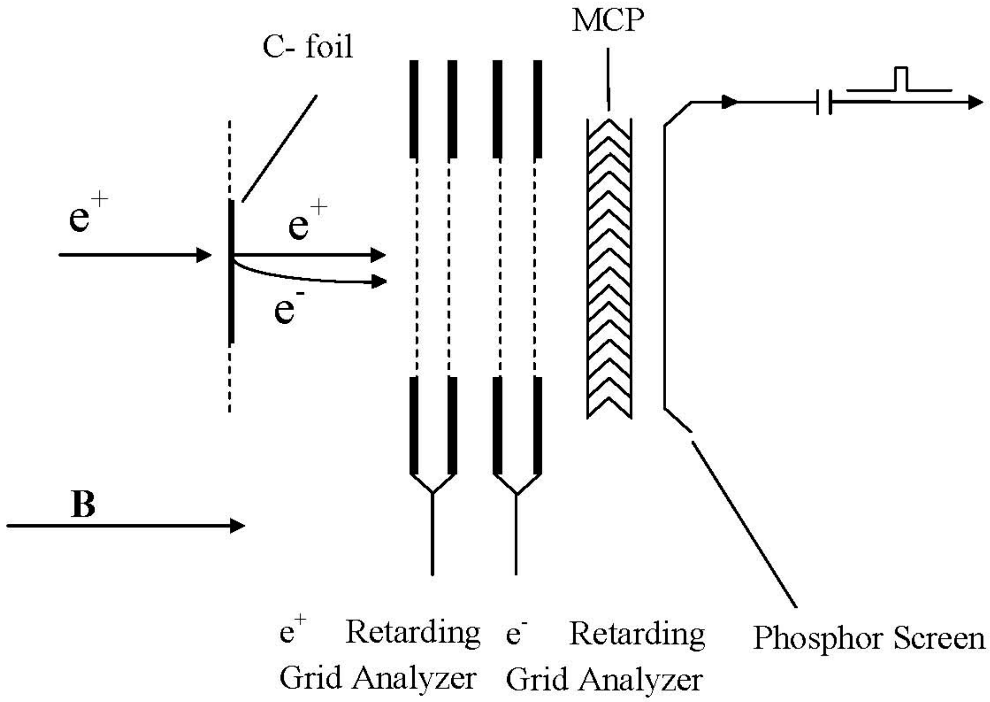

Fig1. Schematic diagram showing the experimental setup

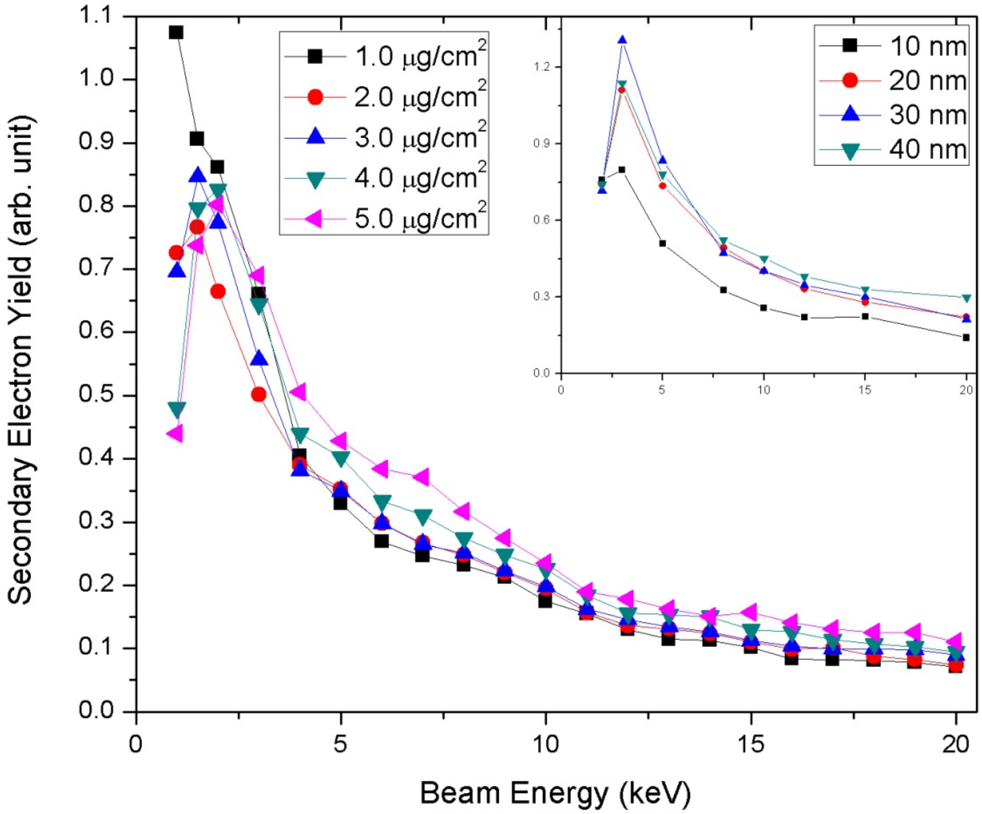

Fig2. SE yield as a function of positron energy on carbon foils with different thicknesses

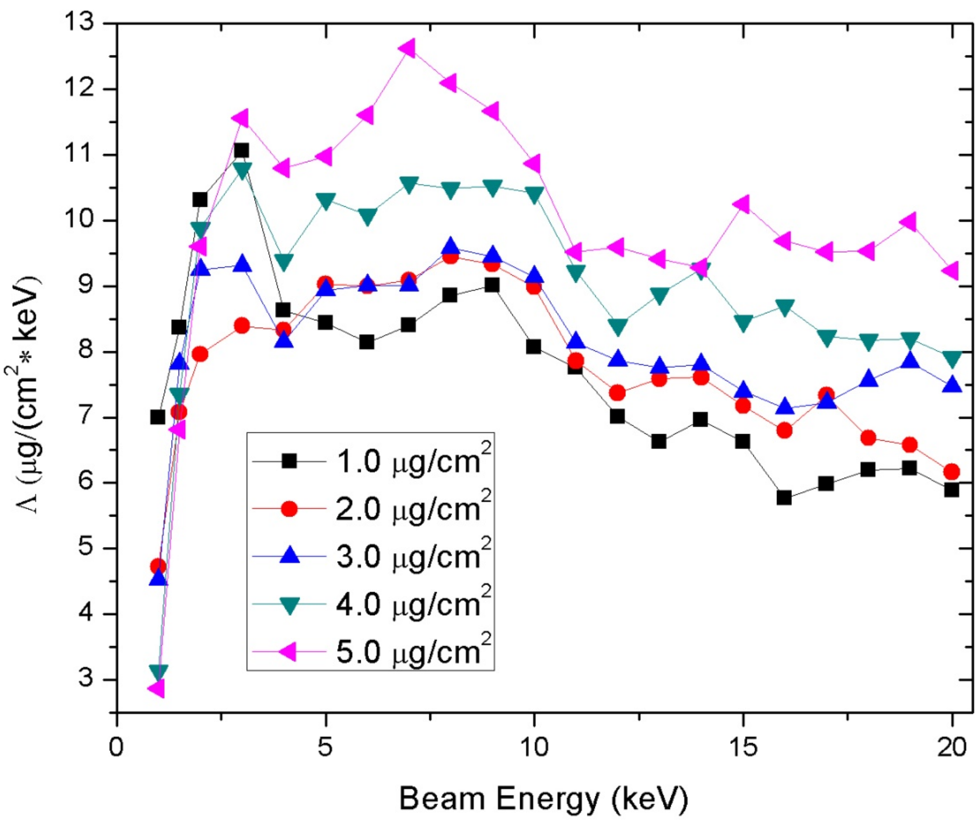

Fig3. Material parameter Λ as a function of positron energy on carbon foils with different thicknesses

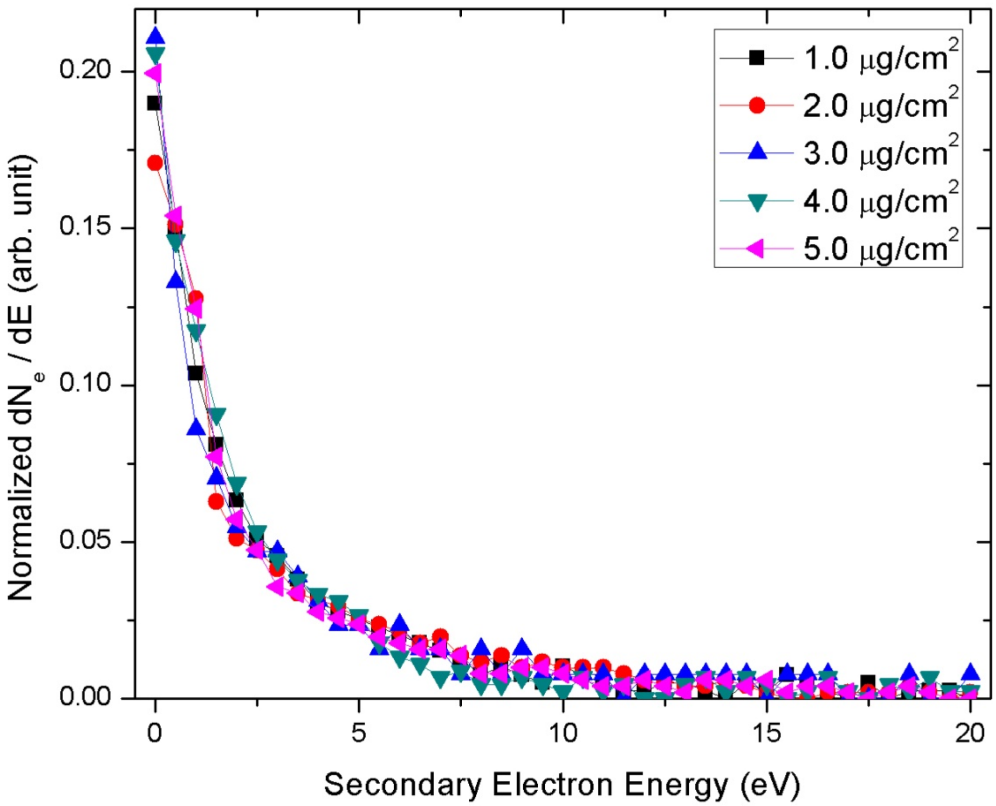

Fig4. Normalized SE energy distribution as a function of SE energy on carbon foils with different thicknesses

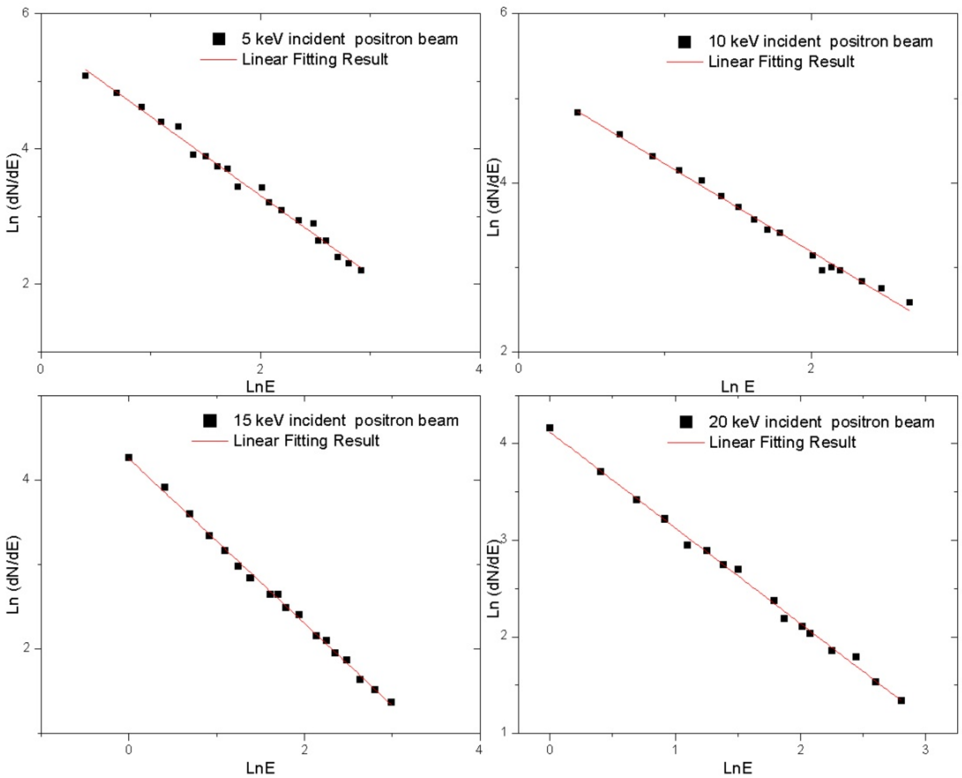

Fig5. Log-log plot of SE distribution for 5.0 μg/cm^2 foil bombarded by 5, 10, 15 and 20 keV positron beam. Black points are experimental data. Red lines are fitted result

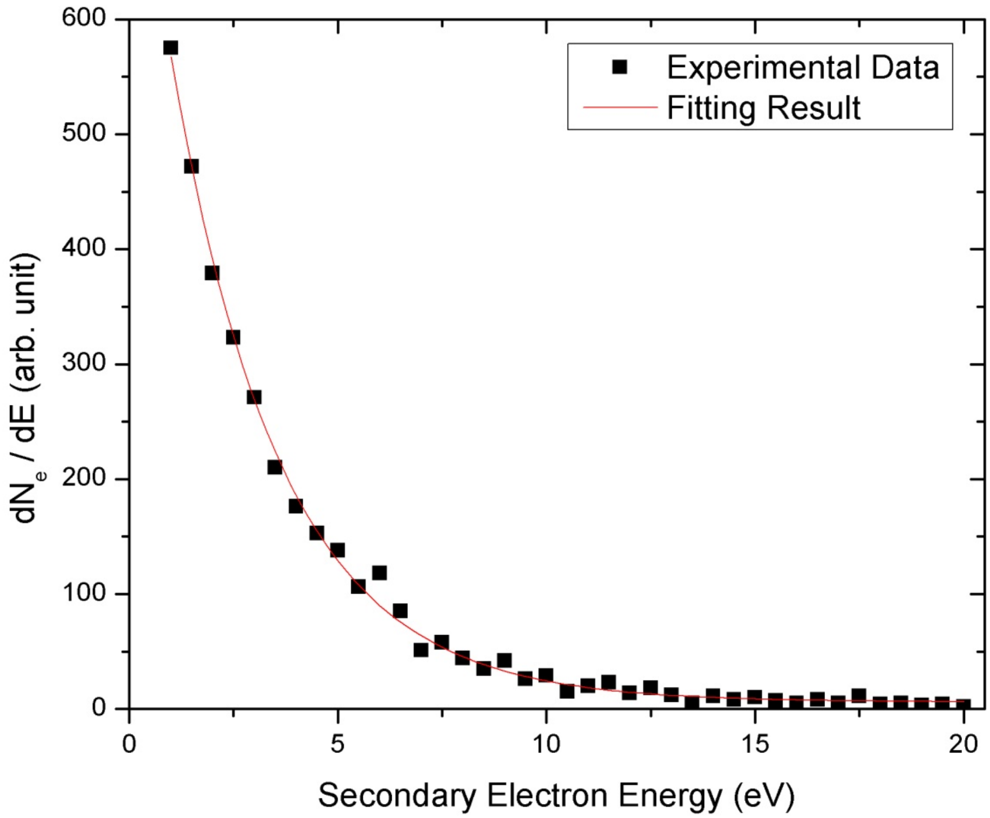

Fig6. SE distribution for 5.0 μg/cm^2 foil bombarded by 2 keV positron beam. Black points are experimental data. Red lines are fitted result.

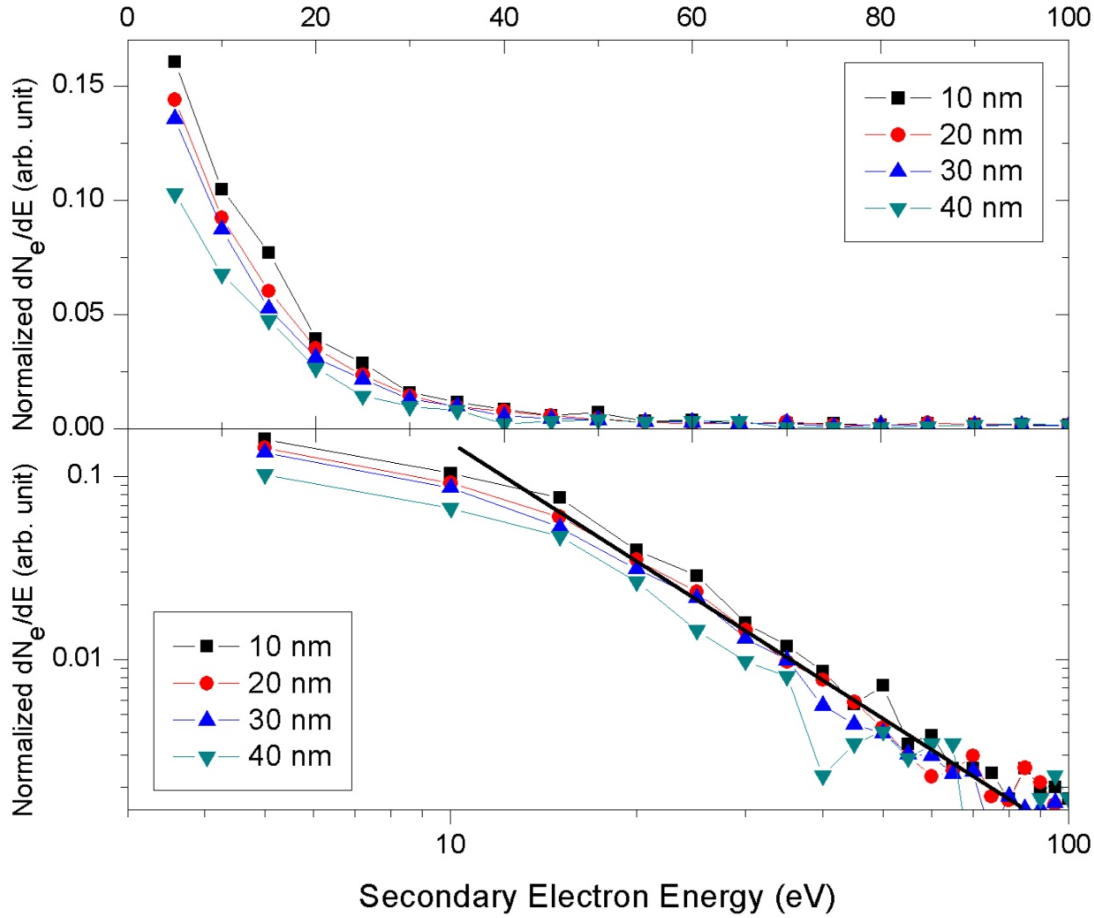

Fig7. Monte Carlo simulation results of SE energy distribution for 5 keV positrons passing through different foils.

Table Captions:

Positron Beam Energy (keV)	5	10	15	20
m	1.17	1.04	0.97	0.99

Table1. Values of m for SE distribution from 5.0 μg/cm^2 foil bombarded by 5, 10, 15 and 20 keV positrons