Positron annihilation lifetime spectroscopy based on secondary electron emission from carbon foil

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Abstract. Using the emission of secondary electron (SE) from a thin carbon foil in transmission geometry guided by a strong radial electric field in the region between the foil and the sample under investigation, a new variable energy positron annihilation lifetime spectroscopy (PALS) system is being implemented. To this end, the SE emission from a carbon foil of 30nm thick has been investigated in transmission geometry. Considerable emission of SE from the foil with peak energy of about 5eV is observed. We have found that both the energy loss and dispersion of the positrons after transmission through the carbon foil are small enough for the proposed positron lifetime-depth profiling PALS system to be realised. These experimental results and the timing simulations of Cai et. al. [1] indicate that the proposed variable PALS based on secondary electrons generated by carbon foil have a high time resolution.

1. Introduction

The major difficulty of developing variable energy Positron Annihilation Lifetime Spectroscopy (PALS) is the lack of a natural start signal of the spectroscopy to indicate that the positron entered the sample [2]. In the previous work [3], our group suggested an innovative design of variable energy positron annihilation lifetime spectroscopy based on the emission of secondary electron (SE) from a carbon foil. The design is of cylindrical symmetry along the y-axis and involves 4 parts. Figure 1 shows the schematic layout of our proposed design of the variable energy PALS. In the first part, a layer of carbon foil is mounted on a grounded tungsten mesh, which is perpendicular to the direction of the positron beam. The second part is a needle mounted behind the centre of the carbon foil and the tungsten mesh. The needle just touches the surface of the sample to ensure that the latter is electrically grounded. This needle-sample arrangement provides a radial electric field which deflects outwards the secondary electrons from the carbon foil. To enhance the effect of the radial electric field, an annular electrode at 2kV is provided around the sample as the third part of the system. The last part is a microchannel plate (MCP), placed behind the needle-sample arrangement to detect the secondary electrons that pass through the space between the sample and the annular electrode. The secondary electrons so detected give rise to the start signal for the variable energy PALS.

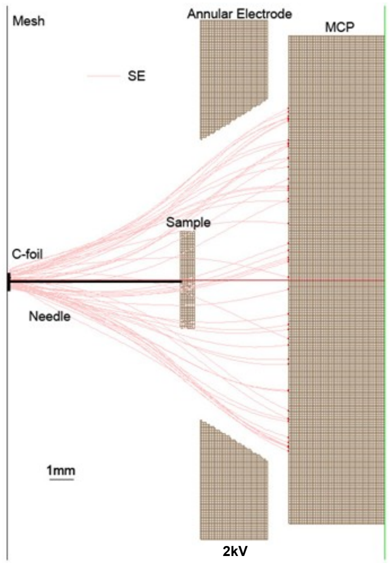

Figure 1. Schematic layout of our proposed design of the variable energy PALS

2. Experimental

To investigate the feasibility of using the secondary electrons generated from carbon foil as a start signal for the spectroscopy, an experiment is set up as shown in figure 2. A variable energy incident positron beam is produced by the slow positron beam facility at the University of Hong Kong. A 30nm thick carbon foil from Arizona Carbon Foil Co., Inc. was mounted on a grounded tungsten mesh. Two retarding grid analyzers for biasing off the positrons and generated secondary electrons were located behind the carbon foil. The phosphor screen visualized the profile of positrons and generated secondary electrons. A digital camera was remote-controlled to take photos of the positron beam and generated secondary electrons.

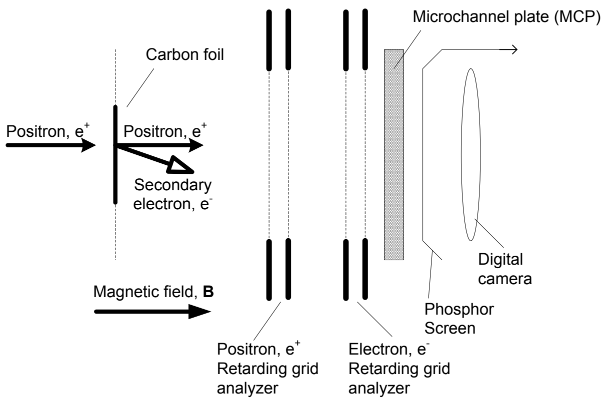

Figure 2. Schematic layout showing the experimental setup

3. Results and discussion

The energy spectrum of the generated secondary electrons with different positron beam energies is obtained as shown in figure 3. A peak energy around 5eV is observed and it undergoes a rapid drop in intensity so that nearly no contribution above 40eV is seen. The energy loss and dispersion for 2keV, 5keV and 10keV of positron are shown in figure 4. For the beam energy less than 10keV, there is a significant energy loss for positrons. There are 1keV energy loss for 2keV positron beam and 0.5keV for 5keV positron beam respectively. When the positron beam energy increases, the energy loss decreases significantly. The reason is due to the high transmission rate of energetic positrons. The energy dispersion also exhibits a similar pattern. Although there is little energy loss and energy dispersion for the 10keV positron beam, the energy of transmitted positron beam is still close to its incident energy so that we could still make use of the beam profile for depth profiling.

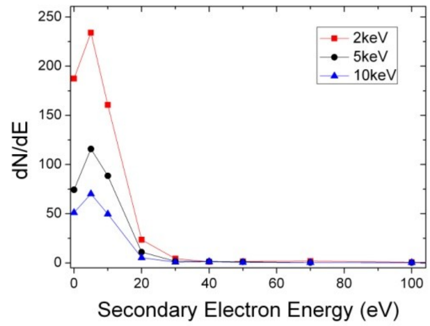

Figure 3. Energy spectrum of secondary electrons for incident positron beam energies of 2keV, 5keV and 10keV.

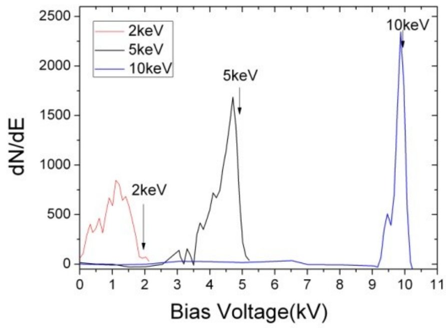

Figure 4. Energy spectrum of the transmitted positron beam for incident energies of 2keV, 5keV and 10keV.

There is a difference of the positron beam profiles with and without carbon foil respectively for positrons with an incident energy of 2keV. When the positron beam energy increases, there is less scattering of positron from the beam axis. For calculating the scattering angle of the positrons, the normal distribution $I(r) = A\exp[-\ln 2\frac{r^2}{r_i^2}]$ is used to fit the curves of beam profiles where r_1 and r_2 are the half widths at half maximum intensity for the non-scattered and scatted beams respectively.

The resultant beam profile is assumed to be a convolution of the unscattered beam profile and the scattering disc of radius $d\tan\theta$, θ is the average scattering angle and d is the distance from the carbon foil to the microchannel plate. As a result,

$$\theta = \tan^{-1}\left(\frac{\sqrt{r_2^2 - r_1^2}}{d}\right) \tag{1}$$

The calculated results for 2keV, 5keV and 10keV positron beams are shown in table 1.

Table 1. Average positron scattering angles and maximum secondary electrons emission

Positron beam energy	Energy loss	Fraction of energy loss	Transmitted fraction	Calculated positron scattering angle	Maximum Secondary electrons emission
2 keV	1 keV	50%	40%	4°	61°
5 keV	0.5 keV	10%	64%	7°	60°
10 keV	0.13keV	1.3%	76%	5°	64°

To calculate the emission angle of the secondary electrons, the spiral motion of the secondary electrons in the axial magnetic field of the beam has to be taken into account because these are low energy electrons. The cyclotron radius $\frac{mv_\perp}{Be}$ is convoluted in giving the maximum angle θ_{max} of emission as:

$$\theta_{max} = \tan^{-1}\frac{v_{\perp}}{v_{//}} = \tan^{-1}\left(\frac{Be\sqrt{r_3^2 - r_1^2}}{\sqrt{2mE}}\right) \quad (2)$$

Where $v_{\perp}$ is maximum transverse velocity of secondary electrons and $v_{//}$ is the beam axis velocity which can be obtained from the average forward positron beam energy of 5eV. The calculated results are listed in table 1. According to the work from Sigmund, the secondary electrons follow a cosine θ distribution [4]. As a result, we assume that the average scattering angle can be calculated as 45°.

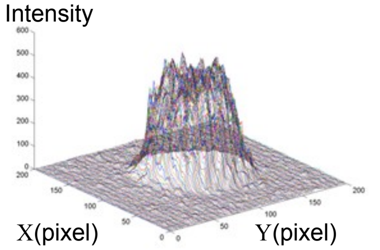

Figure 6. Beam profile without carbon foil

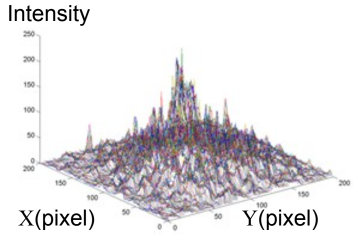

Figure 7. Beam profile with carbon foil

A simulations using SIMION [5] for testing the resolution of the variable energy PALS was performed by Cai et. al [1]. Timing simulations were carried out using typical set of 5eV SEs with uniformly distributed scattering angles up to 65°. The results of the simulation are shown in figure 8. A full width at half maximum (FWHM) dispersion in the time of flight (TOF) spectrum of 40ps is observed. The transmitted positrons were taken to be uniformly scattered within an angle of 10°. The time of flight spectrum for a 5keV beam is shown in figure 9 where the full width at half maximum dispersion is only 15ps.

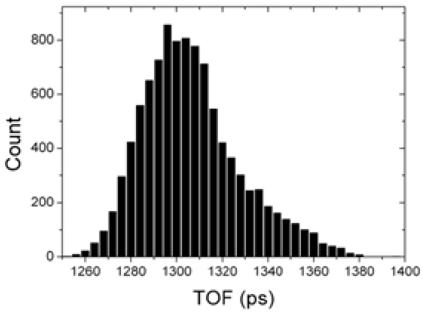

Figure 8. Simulation result of time of flight (TOF) for secondary electrons with kinetic energy 5eV

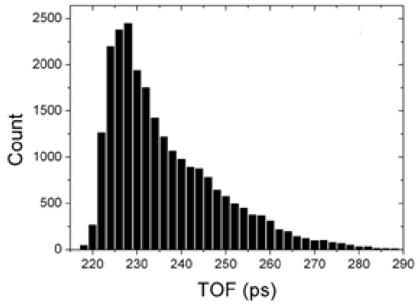

Figure 9. Simulation result of time of flight (TOF) for positrons with an incident energy 5keV

In conclusion, the results from calculations and simulations strongly suggest that the proposed variable PALS based on secondary electrons generated by carbon foil is able to achieve a time resolutions of less than 200ps.

References

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