DEPTH PROFILING OF ALUMINIUM METAL USING SLOW POSITRON BEAM

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Abstract

Slow positron beam Doppler-broadening technique was used to study depth profiling of aluminium metals sample. The variation of the line-shape parameters with incident positron energy was studied. Also, the depth profile of the S parameter was investigated. The positron implantation profile and backscattering fraction for aluminium sample was studied theoretically using data obtained empirically by Monte Carlo simulation. Results obtained revealed that aluminium metal has high S parameter in the surface and near surface regions and low S parameter in the bulk. The value of the S parameter decreased from the surface region reached a minimum at S = 0.292 and started to increase. While the W parameter increased and reached a value of 0.199 and started to decrease. The calculated positron implantation profile decreased with increase in the energy of the incident positrons but the implantation profile depth increased with an increase in the energy of the incident positrons. The results further revealed that the backscattering fraction increased with increase in the energy of the incident positrons.

Keywords: *Material, positron annihilation, structure and vacancy.*

Introduction

Positron annihilation techniques are very vital analytical tool in condensed matter and materials physics. In the last two and half decades, positron annihilation spectroscopies have been developed as an established technique for the study of bulk, surface, crystalline and microcrystalline properties of solids (Osiele et al; 2004, Hautakanges et al; 2005, Adbel-Hady, 2004, Dryzek, 2003, Harting et al; 1999, Suzuki et al; 2001, Pujari, et al; 2002). Positrons are very sensitive in the detection of open volume defects such as vacancies, vacancy clusters, microvoids or dislocations. Positron annihilation techniques has the advantages of being non-destructive and they do not require special sample preparations. When positrons enter a condensed matter, they thermalize easily by losing their kinetic energy until thermal equilibrium is achieved with the environment. This process takes place in about 10^{-12}s. When thermal equilibrium is achieved, the positrons start to diffuse in the material. The diffusing positrons are attracted by both negatively charged and neutral defects, where they are trapped. When a diffusing positron comes in contact with an electron, they annihilate each other with the emission of two gamma photons each of energy 511keV. The properties of the emitted photons such as energy, time of emission, and angle of emission provide information about the solid where the annihilation takes place. The trapping of positrons into defects causes changes in the measured positron annihilation characteristics such as the positron lifetime, the energy and the angular correlation of the annihilation quanta. Doppler broadening is sensitive to the momentum distribution of the electrons at the annihilation sites (Eicher et al; 1997). Annihilation of positrons with electrons in solids yields information on the momentum distribution of these electrons. The electronic momentum distribution is reflected in the Doppler broadening of the 511keV peak. Positron annihilation with low-momentum valence or conduction electrons results in a small Doppler shift, contributing to the wings of the 511keV-peak characterized by the S and W parameters. The S parameter indicates the relative contribution from the valence or conduction electrons while the W parameter represents the relative contribution from core electrons. The S and W parameters can be considered as specific bulk property of every material (Van Huis et al; 2002). At a vacancy, the electron momentum is decreased locally, which is characterized by a higher S parameter and a lower W parameter than in the bulk (Hautakangas et al; 2005). In the use of the angular broadening technique, the calculation of the positron implantation profile is necessary, for the analysis of the experiments to get a better understanding of positron behaviour in the solid. The implantation profile is the depth distribution of the thermalized positrons before diffusion (Ghosh, 1995).

In this paper, depth profiling of aluminium metal is carried out using slow positron beam. The experimental positron annihilation study is complemented with the theoretical study of the mean positron depth, positron implantation profile and positron back scattering fraction which cannot be obtained directly from experiments.

2. Methodology

2.1 Experimental Work

The Doppler broadening of positron annihilation study was carried out at the slow positron beam at the Department of Physics, University of Cape Town, South Africa. The detailed description of the beam is given elsewhere (Britton et al; 1997). The experiment was performed with slow positron beam in ultrahigh vacuum using ^{22}Na as the positron source and tungsten moderator. Aluminium sample disc that is 8mm in diameter and 2mm thick supplied by Goodfellow Scientific Company, U.K was placed in the beam. A magnetic field provided by the coils surrounding the tube guided the positrons from the ^{22}Na source onto the sample. The energy of the incident positrons was varied between 0.2 and 15keV. When the positrons enter into the sample, they annihilate with the electrons in the sample by emitting two gamma photons each of energy 511 keV. When the positrons annihilate in the aluminium sample, the high purity germanium detector with energy resolution of 1.3keV picks up the emitted 511keV gamma photons. The signal amplifier amplified the signals. The amplified signals were carried to the multi-channel analyser attached to a computer, which recorded the reading. For each measurement, about 600000 counts were collected in the annihilation photo peak by the high purity germanium detector. At each incidence energy E, the line shape parameters S and W were computed using a FORTRAN 77 programme.

2.2 Analysis

The variation of the S and W parameters with the energy of the incident positron beam was carried out from the experimental result.

The positron implantation profile can approximately be described as (Eichler et el; 1997)

$$p(E,z) = \frac{mz^{m-1}}{z_0^m}\exp\left[-\left(\frac{z}{z_0}\right)^m\right] \qquad (1)$$

where m = 2, z_0 is related to the mean implantation depth through the expression

$$z_0 = \frac{\bar{z}}{\sqrt{\left(\frac{1}{m+1}\right)}} \qquad (2)$$

is gamma function. The mean positron depth, is correlated with the incident positron energy E by the power law (Mills and Wilson, 1982)

$$\bar{z} = \frac{AE^n}{\rho} \qquad (3)$$

where ρ is the density of the material, E is the energy of the incident positrons, E and A are depth dependent parameters that were found empirically.

According to Ghosh (1995), the back scattered fraction for most materials display a weak energy dependence, which can be fitted with the functional form

$$B(E) = b_1 - b_2 \exp(-b_3 E) \qquad (4)$$

where b_1, b_2 and b_3 are material and model dependent.

In this work, the values of A, n, b_1, b_2, and b_3 used are the ones obtained by Ghosh (1995) in his Monte Carlo calculation of positron profile in elemental and multilayer systems. In the energy range of 1 to 25keV, for aluminium of density 2.701gcm^{-3}, A = 283.8, n = 1.727, b_1 = 0.1535, b_2 = 7.162x10-2 and b_3 = 0.3619. These parameters were used to calculate the mean positron depth, the implantation profile and the positron scattered back fraction according to equations (3), (1), and (4) respectively.

3. Results and Discussion.

The variation of the S and W parameters of the annihilation line-shape parameter as a function of the incident positron energy are presented in Fig.1. The behaviour of the S and W parameters can be divided into two regions: (i) surface and near surface regions and (ii) bulk. As shown in the figure, the S parameter decreased from a value of 0.315 to 0.29 in the incident positron energy range of 0.2keV to 2.0keV. This positron energy range represents the surface and near surface region of the aluminium disc. The positron states in the surface and near surface region of the aluminium are a little mobile as revealed by the steepness of the S parameter between 0.2 and 2.0keV. At low incident energies, (at about 0.2keV) the penetration depths of the positrons in the material is low, consequently, the positrons can diffuse back to the surface. This causes a reduction of the electron density at the surface resulting in a narrower annihilation line, which is observed as a higher S parameter. At about 2keV, the S parameter has its lowest value. This is because at this energy range, the positrons are annihilating in the bulk of the aluminium material. In the bulk of the material, the positron wavefunction is delocalized. The annihilation from the bulk gives most broadened momentum distribution, which can be seen, from the high W parameter and low S parameter for 2keV in Fig.1. The relatively small increase and high values of the S parameters for E 6keV may be due to the presence of vacancies in the bulk of the material.

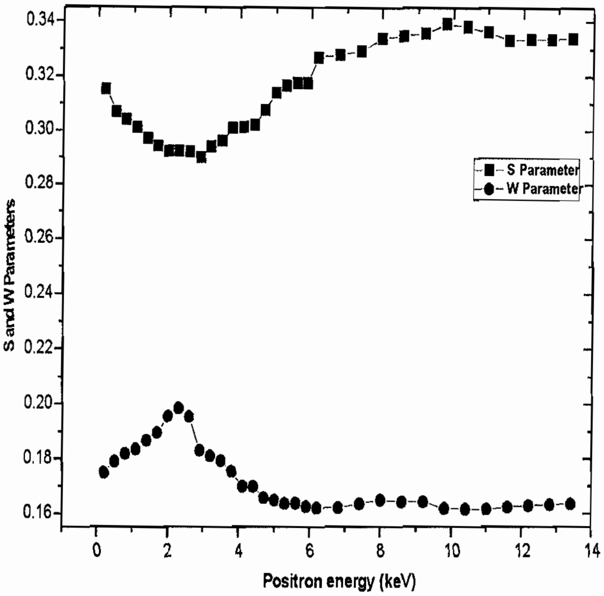

Fig. 1: Variation of S parameter and W parameter with incident positron energy for aluminum metal.

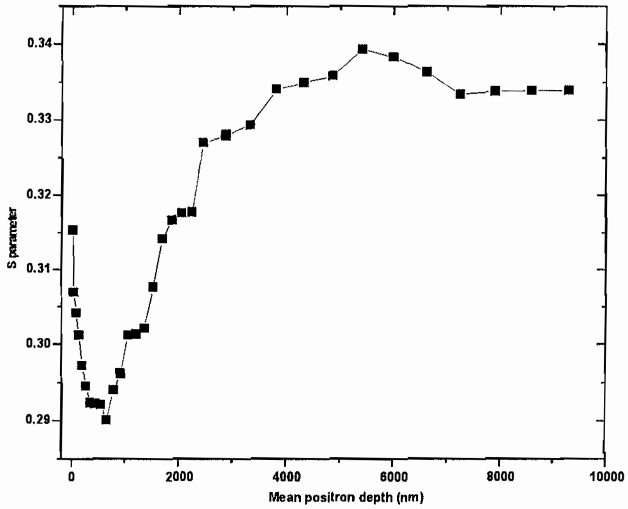

Fig.2: S parameter depth profile for aluminum metal

The S parameter depth profile is shown in fig.2. As revealed by the figure, the S parameter decreased to about 70nm and then increased to a depth of 6000nm and starts to decrease to a depth of 7500nm and remained fairly constant to a depth of 9750nm. This reveals that the S parameter changes in a material as the positrons annihilation within the surface and near surface region and in the bulk. The decrease of the S parameter to a depth of 70nm represents annihilation of positrons in the surface and near surface regions while the increase of the S parameter to a depth of 750nm represents annihilation of positrons in the bulk of the material.

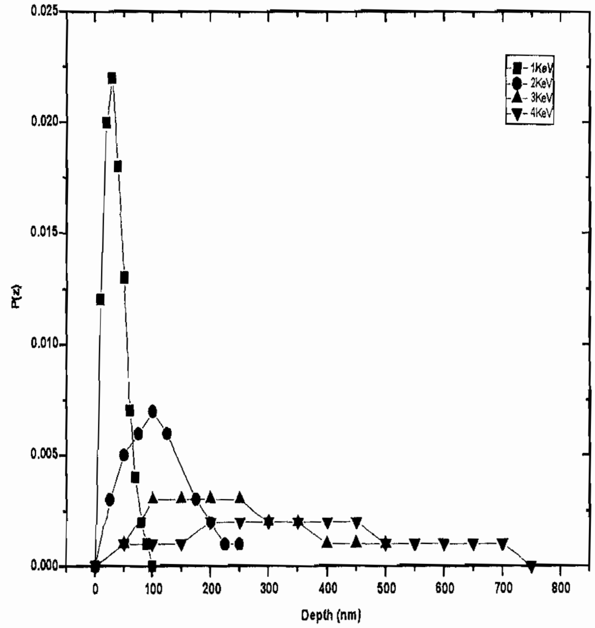

Fig.3: Simulated positron implantation profile in aluminium metal for different energies.

Fig. 3 reveals the variation of the positron implantation profile with depth. The figure shows that the implantation profile is highest for low energies. As the energy increases, the positron implantation profile decreases, but the depth that the positrons get to increases. The increase in the depth that the positron implantation profile gets to in the metal is as a result of the energy dependence of the depth penetration of the positrons. More energetic positrons penetrate to greater depth in materials. Fig. 4 revealed that the positron back scattered fraction increases with an increase in the incident positron energy.

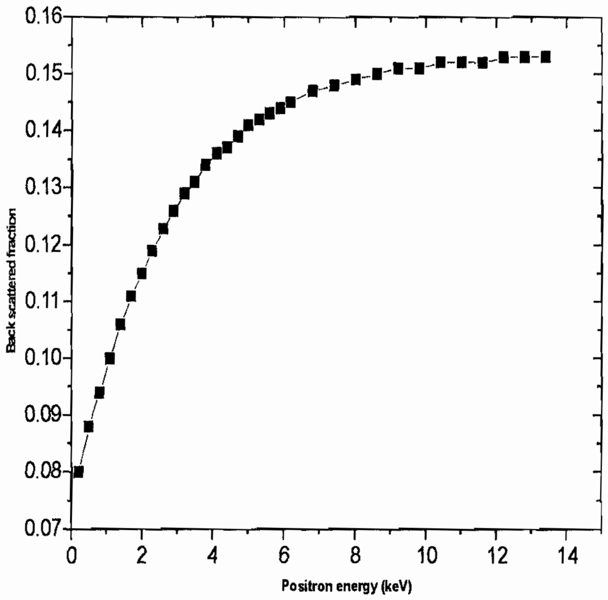

Fig. 4: Variation of calculated positron back scattered fraction with energy for aluminum metal.

This may be due to the fact that as the energy of the incident positrons is increased, more of the positrons get to the sample, but not all the positrons that get to the sample annihilated in the sample. Some of the positrons are back scattered whose number increases with an increase in the energy of the incident positrons.

4. Conclusion

Depth profiling of aluminium metal was successfully carried out using Doppler broadening slow positron beam technique. The aluminium sample has a thin surface and near surface region with vacancies in the bulk. The depth penetration of the positrons and the implantation profiles depth depends linearly on the energy of the incident positrons. The implantation profile decreased with an increase in the energy of the incident positron beam while the positron back scattered fraction increases with an increase in the energy of the incident positrons.

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