Implantation profile for low energy positrons in diamond

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Abstract:

In this paper, Implantation profile I(z,E) and the penetration depths has been evaluated by employing a distribution function of Valkealahti-Nieminen for Diamond of differentthicknesses:0.2,0.4,0.6,0.8,1.2,1.4,1.6 μm. The obtained results reveals that the Makhov's profile decreased with increase the energy of the incident positron, and the implantation profile depths increased with an increase the energy of the incident positron.

Keywords:
Implantation profile, distribution function of Valkealahti-Nieminen ,positron absorption coefficient , Diamond, penetration depth

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Math. Sub. classifications:54 H 11, 54 H 15, 22 F 05

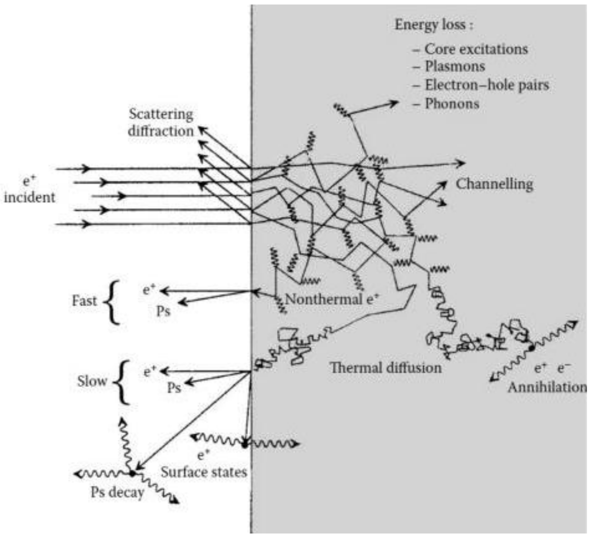
1.Introduction:

The positron has an intrinsic spin of one half and is thus a fermion. According to the CPT theorem, which states that the fundamental laws of physics are invariant under the combined actions of charge conjugation(C), parity (P) and time reversal (T), its mass, lifetime and gyromagnetic ratio are equal to those of the electron, and it has the same magnitude of electric charge, though of opposite sign[1].The magnitudes of the charges of the electron and the positron have been found by Hughes and Deutch [2] to be equal to 4 parts in 10^8 in an analysis of the measured charge-to-mass ratios and the values of the Rydberg constant derived from the energy spectra of hydrogen and positronium. Current theories of particle physics predict that, in a vacuum, the positron is a stable particle, and laboratory evidence in support of this comes from experiments in which a single positron has been trapped for periods of the order of three months[3] . If the CPT theorem is invoked then the intrinsic positron lifetime must be $\geq 4 \times 10^{23}$ yr, the experimental limit on the stability of electron [4]. When a positron encounters normal matter it eventually annihilates with an electron after a lifetime which is inversely proportional to the local electron density. In condensed matter lifetimes are typically less than 500 ps, whilst in gases this figure can be considered as a lower limit, found either at very high gas densities or when the positron forms a bound state or long-lived resonance with an atom or molecule. Annihilation of a positron with an electron may proceed by a number of mechanisms. The positron can also annihilate with an inner shell electron in a radiationless process, the consequent energy release giving rise to nuclear excitation [5].The importance of implantation profile lies in obtaining the defect depth profile from the measured variation of annihilation parameters as a function of the incident positron energy, knowledge of the positron implantation profile is required [7-12].

The aim of this work is studying the positron implantation profile and pentration depths (stopping depths) for daimond with the aid distribution function of Valkealahti and Nieminen and otherapproximated equations .

2- Calculations:

The interactions of positrons entering condensed matter can be divided into three stages: implantation, thermalization, diffusion and finally annihilation with a random electron. On closer inspection, definite boundaries between them cannot be strictly determined.



Fig(1):Interactions of positron with solid surface[21].

A backscattering process due to elastic scattering at atomic nuclei accompanies the direct injection of a positron [13]. This does not allow the positron penetrate deeply into the matter. Emission of secondary electrons from the surface also accompanies the entering process [14]. Physics of positrons is an important discipline for science, industry and medicine ,the positron annihilation spectroscopies have found use as probes of local electronic or defect densities in condensed matter and materials science (see e.g.[15,16,17]).For positrons , the absorption coefficient α in a material is defined by [1]

$$\alpha(cm^{-1}) = 17\frac{\rho}{E_{max.}^{1.43}} \text{...........(1)}$$

Where ρ (g/cm^3) is the material density and E_{max} (MeV) is the maximal energy of the emitted positrons. The probability to the incident positron with energy E_{max} to stop (thermalize) inside the region between z and $z + dz$ can be described by an exponential function[18]

$$P(z,E) = \alpha e^{-\alpha z} \text{..........(2)}$$

For mono-energetic positrons obtained from variable energy positron systems with energies up to several MeV. The positron implantation profile of a positron with energy E, as simulated by the distribution function of Valkealahti and Nieminen [19,20]obeys the relationship:

$$I(z,E) = -\frac{d}{dz}[P(\alpha,E)] = -\frac{d}{dz}[e^{-(z/z_0)^m}] = \frac{m z^{m-1}}{z_0^m} e^{-(z/z_0)^m} \text{........(3)}$$

Where $m=2$ is a parameter and z_0 is related to the average stopping depth $\bar{Z}$, by[19]

$$z_0 = \frac{\bar{z}}{\Gamma(1+1/m)} \text{..........(4)}$$

Where Γ is the gamma function , after substation the gamma function value , the eq.(4)becomes

$$\bar{z} = 0.886\, z_0 ....(6)$$

Since $\bar{Z}$ is defined as

$$\bar{z} = \frac{AE^n}{\rho} ....(7)$$

Where n and A are empirical parameters. The more commonly used values for these parameters, which are considered to give a better description of the material behavior, are [19].

$$A = 4\mu g.keV^{-n}.cm^{-2}.$$
$$m = 2 \qquad ....(8)$$
$$n = 1.6$$

After substation the values of equation 8 in 7 and the resultant equation in 6, we obtain

$$z_0(\mu m) = \frac{4.515E^{1.6}}{\rho} = 1.2842E^{1.6}(\mu m/keV^{1.6})..........(9)$$

The average positron stopping depth varies from the nanometer scale up to a few micrometers when its energy is up to ~30 keV. This position selectivity along the average stopping depth allows the monoenergetic positrons the possibility of depth investigation from the surface until the bulk material. Using a variable energy positron system, it is then possible to obtain the depth profile of defects close to the surface region and to perform the analysis of interfaces of thin film and multilayer systems[21].

3-Diamond Physical properties :

Owing to the large band gap, most diamonds are insulators at room temperature, and so electronic transport is extrinsically determined and therefore strongly dependent on the impurity content. Natural (type IIb) and synthetic semiconducting diamonds are always p-type. The electron mobility can be derived only from photoconductivity experiments[22].

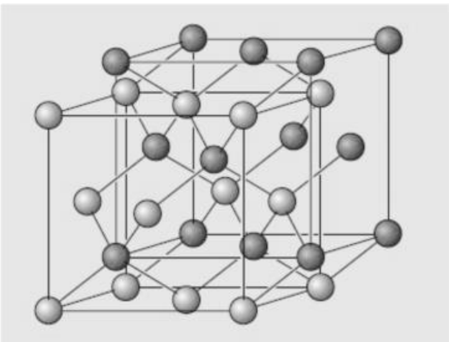


Fig.2 The diamond lattice. The elementary cubes of the two face-centered cubic lattices are shown. In the diamond lattice all the atoms in the two elementary cubes are identical, they are atoms from the same chemical element. Each atom in this lattice is surrounded tetrahedral by four nearest neighbor atoms[22].

Table (1):Summarize some physical properties of Diamond [22].

Physical property	Value
Crystal structure	fcc
Density	3.5157g/cm^3
Melting point	4100K
Expansion coefficient	0.000001(K^{-1})
Lattice parameter	0.356685
Refractive index	3.5

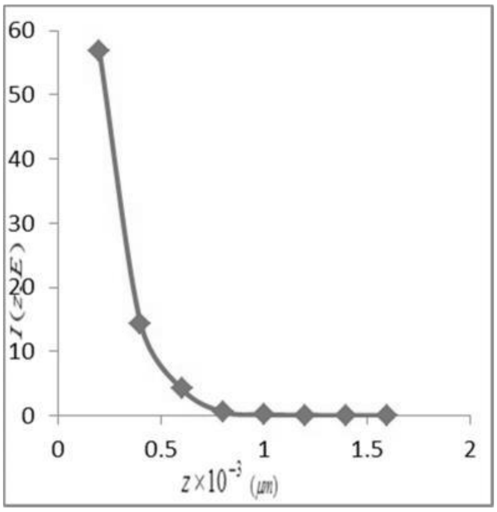
3-Results and discussion

After the positrons have been implanted , they are likely to diffuse at thermal energies and can still propagates some distance randomly through the sample before they are annihilated freely in the lattice or at the surface ((in this situation ,the positrons are attracted by both the negatively charged and neutral defects))to be trapped prior to annihilation .

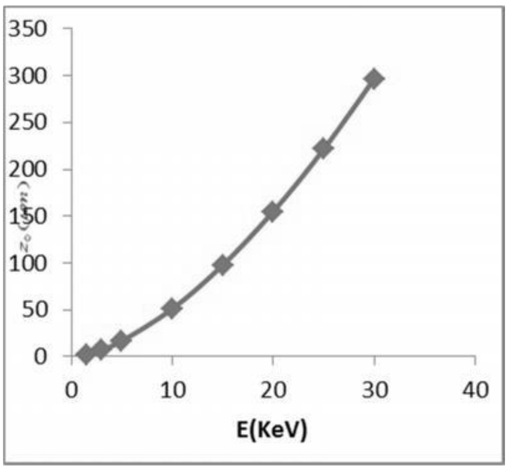
In order to explain the results of table 2 and fig. 3 ,we concur with the conclusions of Spanel et al. [23] that the shape of the implantation profile reflects the shape of the energy spectrum of the positrons. We have found that the implantation profile for monoenergetic positrons implanted randomly into the diamond exhibits an almost perfect Gaussian shape. At low thicknesses ,(at about 0.2 – 0.8micrometer)the implantation profile is greatest and penetration depths of the positrons in diamond is low, consequently the positron can diffuse back to the surface .This causes a reduction of electron density at the surface which in turn , resulting in a narrower annihilation line , that is observed as a higher values of I(z,E) parameter as in figure 3 and table 2 .At about 30keV has its lowest value ,this is because at this energy , the positrons are annihilating in the bulk of diamond material where the positron wavefunction is delocalized. This means , more energetic positron more penetration into material ,this behavior gets as a result of the energy dependence of the depth penetration of positrons.

Table (2):Germanium Implantation profile as a functions of both Z of target material and positron incident energy E .

E(keV)	$z(\mu m)$	$z_0(\mu m)$	I(dimensionless)
1.5	0.2	2.4568	0.065812
3	0.4	7.4477	0.014380
5	0.6	16.86533	0.0042146
10	0.8	51.125	0.00061185
15	1	97.8112	0.0002089
20	1.2	154.985	0.00009989
25	1.4	221.486	0.00005707
30	1.6	296.508	0.000036388



Fig(3):The calculated positron implantation profile as a function of z (μm) for positron with various energy in diamond .



Fig(4):The calculated mean penetration depth z_0 (μm) as a function of positron energy E for diamond .

4-Conclusions

A fraction of the positron particles striking a material are back scattered, the size of the fraction being dependent upon the atomic number of the target and the thickness of the material (up to a certain saturation value) .The depths penetration z of the positrons and the implantation profile depends linearly with the energy of the incident positrons .That is the implantation profile I(E,z) decreases with an increase in the energy of the incident positrons beam and vice versa for z. The variation of the positron energy allows the detection of defects as a function of the penetration profile of mono-energetic positrons having the energy E .

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منحني الاستنبات للبوزترونات واطئة الطاقة في عنصر الماس

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الخلاصة:

في هذا البحث تم دراسة منحني الاستنبات I(z,E) واعماق الاختراق للبوزترونات واطئة الطاقة لعنصر الماس باستخدام دالة توزيع فلكلهتي ونيمنين ولا سماك مختلفة 0.2, 0.4,0.6,0.8,1,1.2,1.4,1.6 مايكرومتر وقد اظهرت النتائج المستحصلة ان منحني مايكوف يتناقص مع زيادة طاقة البوزترونات الساقطة الا ان عمق المنحني يزداد مع زيادة طاقة البوزترونات الساقطة.

الكلمات المفتاحية:
منحني الاستنبات , دالة توزيع فلكلهتي ـنيمنين , معاملات الامتصاص للبوزترونات , الماس , عمق الاختراق.