Verification Makhov's profile for slow positron in Germanium

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Abstract:
In this paper the mean penetration depths z_0 and Makhov (Implantation) profile I(z,E) were evaluated for low energies positrons(1.5-30/keV)by using a distribution function of Valkealahti - Nieminen for Germanium for different thicknesses:0.2, 0.4,0.8,1.2,1.4,1.6 μm. The obtained results reveals that the values of Makhov's profile decreased exponentialy with increasing the positron energy and profile depths increasing linearly with increasing the incident energy. The shape of the Makhov's profile reflects the shape of the energy spectrum of the positrons, which indicates the annihilation of positrons inside the material where its wavefunction is delocalized.

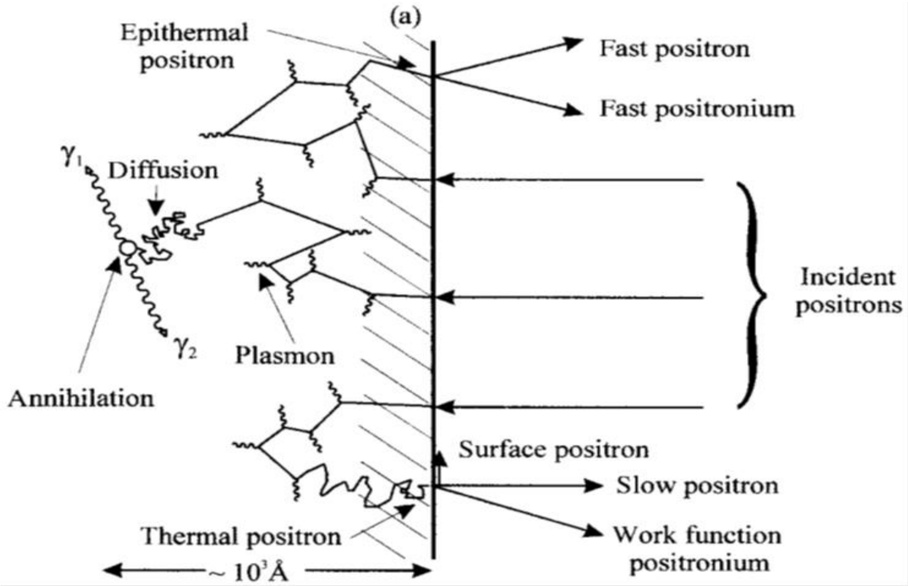
Keywords: Makhov's profile (Implantation), distribution function of Valkealahti-Nieminen ,positron absorption coefficient ,germanium .

Introduction
The transport of an energetic positron into matter is a complex phenomenan and the interactions of positrons which 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. A backscattering process due to elastic scattering at atomic nuclei accompanies the direct injection of a positron [1]. This does not allow the positron penetrate deeply into the matter. Emission of secondary electrons from the surface also accompanies the entering process [2]. At the initial stage of implantation, the channeling of a positron along the crystalline planes is also possible [3].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.[4,5,6]). For example, In order to obtain 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 defect profile induced by the different surface processes is an interesting topic for study and our knowledge about the so called subsurface zone (SZ) is still insufficient. This zone is important for in tribology where the wear processesmay be initialized by the defects generated on or below the damaged surface[13].Our aim is to present the results of detection of the defect depth profile and pentration depths created in the Germinium by positrons of low energies with the aid distribution function of Valkealahti-Nieminen and other approximated equations .

Theory
Positrons in Materials
Although the positron is stable in vacuum, any positron will eventually annihilate in normal matter with an electron. Thus its effective lifetime is very short ($t = 10^{-12} - 10^{-7}$ sec), however, this incredibly short period is still enough for the positron to react with matter in several ways. These physical (and sometimes even chemical) reactions alter from material to asnother providing a number of unique possibilities to study the materials .Table 1 shows the interactions of electrons and positrons with atoms[14].Fig.(1)illstrates the possible interactions of positron with matter.

Table(1):Comparison of the main features of the interactions of electrons and positrons with atoms[14]

Effect	Electron	Positron
Static interaction	Attractive	Repulsive
Polarization Interaction	Repulsive	Attractive
Exchange with Electron	yes	no
Electron-positron Annihilation	no	yes
Positronium Formation	no	yes



Fig(1):Interactions of positron with solid surface[15].

Calculations:

The absorption coefficient α in a material for positrons is defined by [16]

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

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[17]

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

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-Nieminen [18-19]obeys the relationship:

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

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

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

Where Γ is the gamma function is defined as [20]:

$$\Gamma(\frac{3}{2}) = \frac{1}{2}\sqrt{\pi} \approx 0.886 \qquad (5)$$

The eq.(4)becomes

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

And $\bar{Z}$ is defined as

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

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].

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

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

$$z_0(\mu m) = \frac{4.515E^{1.6}}{\rho} \qquad (9)$$

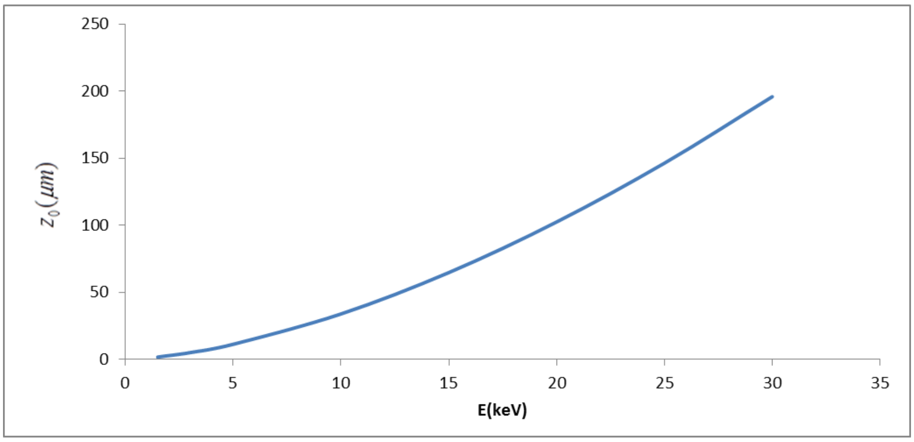
After knowing all these parameters, the calculations of implantation profile can be performed.

Results and Discussion

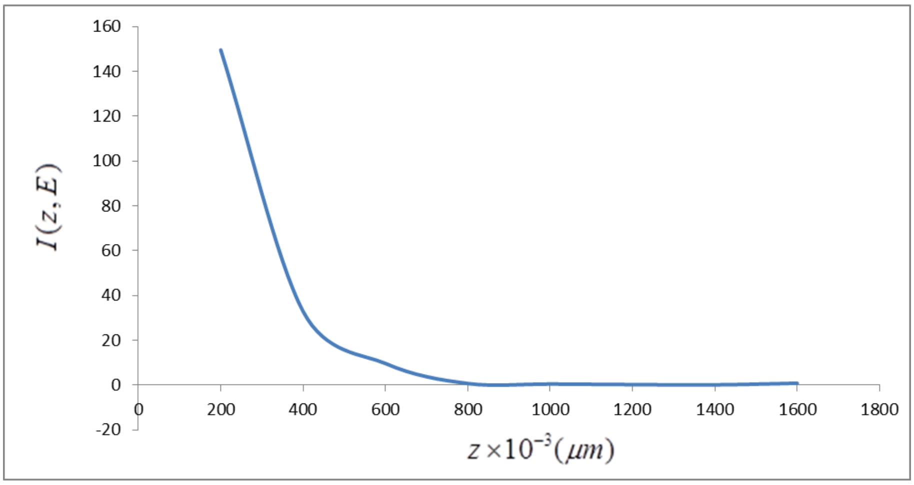
After the positrons have been implanted , they are likely to diffuse at thermal energies and can still propagates some distance randomly through the sample before they are annihilated freely in the lattice or at the surface (in this situation ,the positrons are attracted by both the nagatevily charged and neutral defects) to be trapped prior to annihilation[21-22]. The explaination of the fig. 2, is that at low incident energies, (at about 1.5keV-4keV) the mean penetration depths, of the positrons in the germanium 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 annhiliation line, that is observed as a higher parameter I(z,E) as shown in table 2. We concur with the conclusions that the shape of the implantation profile reflects the shape of the energy spectrum of the positrons. This means the Makhov profile for monoenergetic positrons implanted randomly into the germanium exhibits an almost perfect Gaussian shape ,and at about 30keV has its lowest value, this is because at this energy, the positrons are annihilating in the bulk of germanium material where the positron wavefunction is delocalized.That is, more energetic positron more mean penetration into material ,this behiviour gets as a result of the energy dependenace of the depth penetration of positrons.

Conclusions

The observed Makhov's profile an exponentially declining with the increase the mean depths(The mean depth penetration profile depends linearly on the energy of the incident positron) from the surface. For low energy positrons , the shape of the profile is much narrower than for high energies.This variation of the positron energy allows the detection of defects as a function of the penetration profile of monoenergetic positrons .



Fig(2):Show the mean penetration depth z_0 as a function of positron energy E for Germanium .



Fig(3):Shows the implantation profile I(z,E) obtained by using equation (3) as a function of z for positron with various energy in Germanium

Table (2):Show germanium Implantation profile as a functions of both mean pentration depths z_0 of target material and positron incident energy E .

E(keV)	$z(\mu m)$	$z_0(\mu m)$	I(z,E)
1.5	0.2	1.62233	0.1495
3	0.4	4.918	0.03285
5	0.6	11.136	0.0096485
10	0.8	33.759	0.0014
15	1	64.586	0.00047928
20	1.2	102.34	0.0002291
25	1.4	146.25	0.0001308
30	1.6	195.789	0.00009386

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تحقيق شكل منحني مايكوف للبوزترونات البطيئة في الجرمانيوم

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الملخص

في هذا البحث تم دراسة معدل اعماق الاختراق z_0 ومنحني مايكوف (الاستنبات) (z,E) للبوزترونات واطئة الطاقة (1.5-30/keV) باستخدام دالة توزيع فلكلهتي-نيمنين لعنصر الجرمانيوم و لسماك مختلفة 0.2, 0.4,0.8,1.2,1.4,1.6 مايكرومتر وقد اظهرت النتائج المستحصلة ان قيم منحنى مايكوف تتناقص اسيا مع زيادة طاقة البوزترونات الساقطة وزيادة عمق الاختراق خطيا مع طاقة البوزترونات الساقطة حيث ان حجم منحني الاستنبات يعكس حجم طيف طاقة البوزترونات الساقطة ويدل ذلك على فناء البوزترون داخل المادة واختفاء دالتة الموجية .

الكلمات المفتاحية: منحنى الاستنبات (مايكوف), دالة توزيع فلكلهتي -نيمنين , معاملات الامتصاص للبوزترونات ,جرمانيوم.