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# STUDY of Defects by Positron Annihilation

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**Abstract:** The development of high energy particle radiation sources like Synchrotron, Cyclotron, LINAC and neutron generators have generated considerable interest and researches in material science to study the radiation induced effects. The impact of irradiation causes changes in the micro-structure of the materials and results into several new properties of the materials which may find interesting applications. The Positron Annihilation Technique (PAT) is an important technique to study the nature and characteristics of defects in the materials. The TRIM software is most efficient software in the study of PAT.

**Key Words:** Positron annihilation spectroscopy, Homogeneous Irradiation, Defect density distribution.

## INTRODUCTION:

The radiation induced effects in the materials are used to investigate different types of information in the materials science. These effects cause changes of micro-structures of the materials. The changes in the micro-structure are investigated using different experimental techniques, some are sensitive to the surface and others are sensitive to the bulk of the material.

Defect distribution in ion-irradiated pure tungsten at different temperatures was studied by Zhexian Zhang, et. al. (1). Ion implantation and Defect Engineering in materials is of great interest in material science (2-3). The Positron Physics is concerned with the interaction of low energy positrons with matter (4). The positron technique has many advantages in the study of matter. It provides a non destructive tool, because the information is carried out of the material by the penetrating annihilation radiation.

An energetic positron moving inside the matter experiences electronic and nuclear field and hence lose its kinetic energy. Thus the positron is thereby slowed down until it becomes thermalized. After a period the annihilation is announced by the emergence of gammas whose energy, momentum and time of flight can be measured with high precision modern detector system. Figure 1 shows the schematic of positron annihilation. Positron source Na22 emits one positron followed by the emission of a gamma of energy of 1.28Mev. This gamma is also known as birth signal. This positron now moves inside the matter and annihilate with an electron and giving a pair of gammas of energy 511Kev. The pair of these gammas is also known as the death signal. The implantation range of positrons varying from 0-1000μm guarantees that the positron reaches the bulk of the material. Finally after living in thermal equilibrium, there may be several possibilities of annihilation of the positron:

a. One gamma annihilation
b. Two gamma annihilation
c. Three gamma annihilation

All above three processes are shown in the figure 2. The one gamma annihilation is possible in the presence of a third body, an electron or a nucleus which can absorb the recoil momentum. The three gamma annihilation is possible in the spin co-related state like orthopositronium (5).

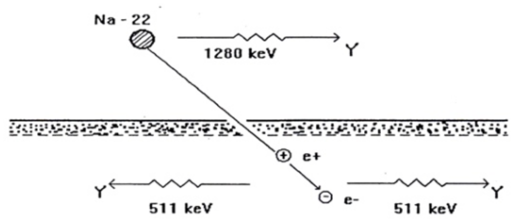


Fig. 1. The schematic of positron annihilation

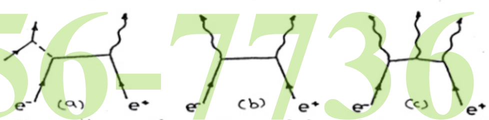


Fig. 2. Fenymann diagram of one, two and three gamma annihilation.

In such diagrams the introduction of an additional vertex multiplies the cross section for the process by a factor of the order of the fine structure constant, $\alpha$ = 1/137, the cross section for three-gamma annihilation is more than two orders of magnitude smaller than that for the twogamma process. The cross section for one gamma annihilation is still further reduced by the presence of an additional factor $\lambda_o^3\rho$ where λo is the Compton wavelength of the electron and ρ the density of additional atoms or electrons that can absorb the recoil momentum. The largest value of ρ likely to be encountered in any physical situation is such as to make this additional factor of order of α3. Thus the probability of two-gamma annihilation is considerably greater than that for one or three gamma; the ratios of the cross-sections for the respective process being $\sigma_{(3)}/\sigma_{(2)} = \alpha$, $\sigma_{(1)}/\sigma_{(2)} = \alpha^4$.

At low positron energies, the cross-section is inversely proportional to the positron velocity v:

$$\sigma_{(2)} = \pi r_o^2 \frac{c}{v}$$

Consequently, positron annihilation probability in solid or the positron decay rate is given by:

$$\lambda = \quad = \quad c\eta_e$$

where is Classical electron radius, c is velocity of light and ηe is average electron density at the site of annihilation. The positron lifetime in this case can be written as $\tau = 1/\lambda = 1/\pi r_o^2$ cηe and is independent of the positron velocity and simply proportional to the density of electrons. At defect site the electron density is less than the bulk (6). This indicates that the lifetime also will be different than the bulk (7). Figure3 shows the dynamics of the positron when a positron enters in the bulk of the material.

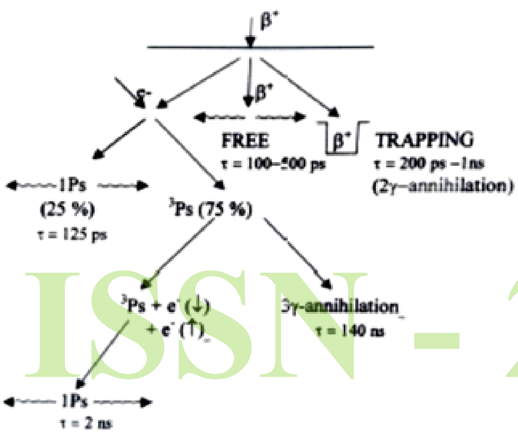


**Figure 3. Behavior of positron in materials.**

**DISCUSSION:**

The positron annihilation technique for the study of the defects is a unique field in the materials science. When a positron enters in the bulk of the sample reaches up to the maximum range and positron experiences the repulsive force from the positive lattice field. In this case the positron re-emits and thus one can say that the positron range vary from 0 to a maximum range. This means that the positron reaches everywhere in the target up to its maximum range and capable to give information from inside the target material. So to study the effect of irradiation in the bulk, homogeneous effect of irradiation should be required so that the positron gives the information about the defect site since the positron is homogeneously penetrate. We have calculated the mean and maximum range of the positron in the Cd50Te50 amorphous semiconductor for different positron sources with the concept that a positron moving inside the material can be considered equivalent to a hydrogen ion except the mass. Thus the calculated range of the positron is tabulated in the table 1.

**Table 1**: Ranges of positron in $Cd_{50}Te_{50}$ for different positron sources (using TRIM)

| Positron Source | Half life (τ) | End point energy | Mean Range ($R_o$) | Max. Range ($R_+$) |
|---|---|---|---|---|
| $Na^{22}$ | 2.6 Years | 0.543MeV | 77 µm | 177µm |
| $Co^{58}$ | 71 Days | 0.472MeV | 65µm | 150µm |
| $Cu^{64}$ | 13 Hours | 0.657MeV | 110µm | 240µm |
| $Zn^{65}$ | 245 Days | 0.324MeV | 30µm | 80µm |

TRIM software (8) is the most efficient software for the selection of projectile ion beam which also gives the electrical and nuclear energy losses and the range of the ion in the target material and helps to choose the energy range of projectile ion beam such that their projected range in the target material is of the order of the positron range. The thickness of the target is such that the positron can annihilate inside the bulk, i.e. the thickness must be greater than the range of the positron. In order to produce the homogeneous irradiation effects we use an ion beam energy moderator. In this case the TRIM software is again helpful to choose the beam chopper foil and their thickness also so that the incident ion can penetrate easily but their energy decreases as the thickness of chopper foil increases. This arrangement is shown in figure 4.

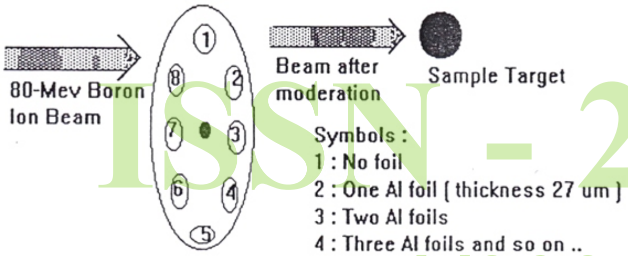


**Figure 4**. A schematic diagram of beam moderator

Using this moderator we can obtain an ion beam of energy 10-80 MeV from the initial ion beam of energy 80Mev. Thus the projectile ions of different energies produce a homogeneous distribution of the defects in the target material. Such type of irradiation effects is shown in figure 5.

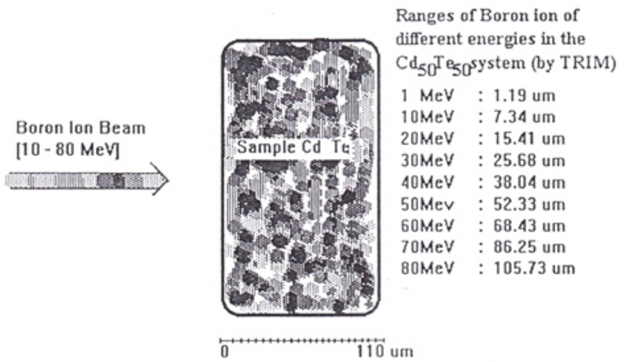


**Figure 5**. Homogeneous distribution of ion irradiation in material

The electronic and nuclear energy loss curves for the boron ion in the Cd target are pictured in figure.6 & figure 7. Figure 8. shows the boron ion beam profile in the Cd target, which verify the homogeneous distribution of the ion in the Cd target.

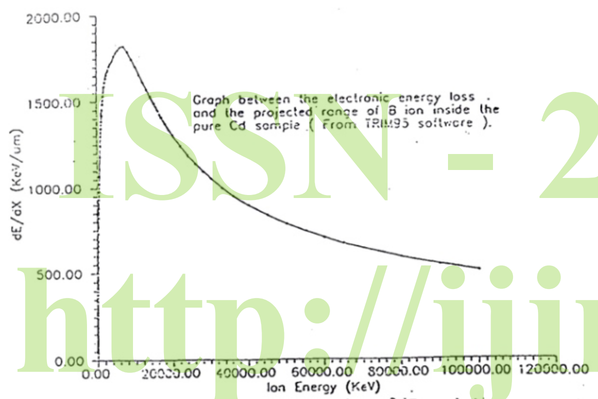


**Figure 6**. Electronic energy loss of boron ion in Cd

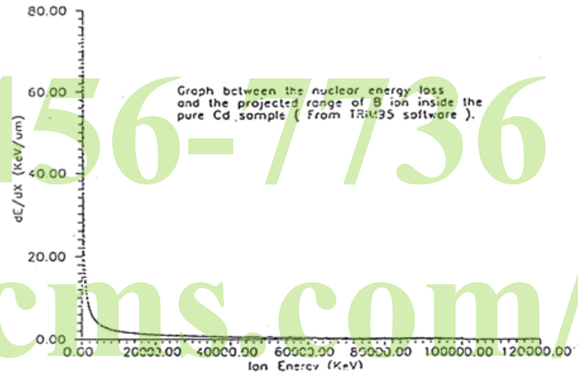


Figure 7. Nuclear energy loss of boron ion in Cd

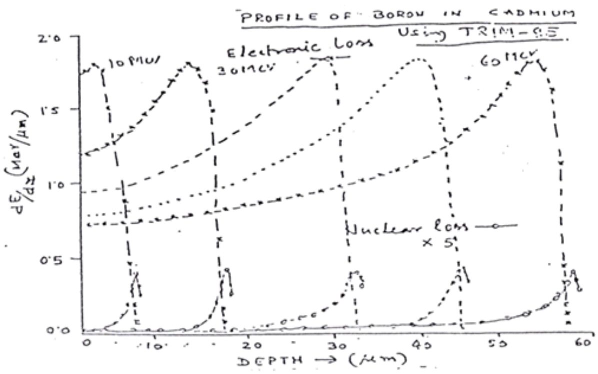


**Figure 8.** Depth profile of boron ion in Cd

**CONCLUSION:**

The positron annihilation technique for defect studies in the materials is of enormous interest in materials science Since the positron range varies from 0 to a maximum range and gets annihilated from the defect site and giving us necessary information at the site where it gets buried. The monitoring of annihilation radiation by nuclear spectroscopic methods provides valuable information on the electron positron system which can be directly related to the electronic structure of the medium. The TRIM software provides the selection of the projectile atom, their energy range and the target atom and also gives information regarding the range and energy losses of the projectile atom inside the target material. The electronic and nuclear energy losses of the projectile are the nonlinear function of energy. To find out the ion beam profile we calculated the energy losses with the concept that a ion beam of a energy does not have the constant energy loss over its range. The energy loss changes with its energy at the site, i.e. it penetrates in the sample target the energy loss changes. The beam profile of the ion for different energies suggested that the distribution of ion was homogeneous.

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