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Positron Annihilation Study of Ion-irradiated Si

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1. Introduction

Structural parts like a spaceship, satellite and solar cell are composed of metal alloy or semiconductor materials. Especially, Si is used as a primary candidate alloy. But, manned and robotic missions to the Earth`s moon and Mars are exposed to a continuous flux of Galactic Cosmic Rays (GCR) and occasional, but intense, fluxes of Solar Energetic Particles. These natural radiations impose hazards to manned exploration. Irradiation of cosmic particle induces various changes in the mechanical and physical properties of device steels. It is, therefore, important to investigate radiation damage to the component materials in semiconductor. The evolution of radiation-induced defects leads to degradation of the mechanical properties. One of them includes irradiation embrittlement, which can cause a loss of ductility and further increase the probability of a brittle fracture. It can be more dangerous in the space. Positron annihilation lifetime spectroscopy(PALS) have been applied to investigate the production of vacancy-type defects for Ion-irradiated Si wafer penetrated by H, He, O and Fe ions. Then, we carried out a comparison with an un-irradiated Si wafer.

2. Experimental and Methods

2.1 Experimental and Sample Examined

The PAL measurements were made using Digital storage Oscilloscope (DSO) system. The instrumental time resolution of the system is 270 ps of the full width at half maximum (FWHM) The source correction was made using well-annealed iron sample, which has a known positron lifetime of 106 ps. We applied the PALSfit program from the RISØ laboratory to analyze the measured spectra. In performing PALS analysis with the PALSFit package, we used two Gaussian resolution functions to extract positron lifetime information from the lifetime distributions.

We have examined Si wafer supplied by Hankook Vacuum Metallurgy Co., Korea. All the samples were encapsulated in a quartz tube and annealed in a vacuum at 1000 °C for six hours and then slowly cooled down to room temperature in a furnace over several hours. The size of the samples is 10x10 mm^2. Before ion penetration, We simulated depth by ion penetration with SRIM 2003 code. Each penetration depth results are H ion 114 um. He ion 1.96 um, O ion 2.87 um, and Fe ion 3.9 um. Remaining ion penetration depth except H ion penetration depth is less than 100 micrometer. The thermalization distance is of the order of magnitude of 100 um and is much longer than the positron diffusion length. So, We prepared Si-wafer has each different thickness considering penetration depth.

They were irradiated with ≥ 500 keV ions in the Tandem accelerator facility of KIGAM at 1.7 MV. Ion penetration conditions are listed in Table I

Table I: Ion penetration conditions

Ion	E_{max}	Flux	Hour
O	3	1 X 10^{16} ion/cm2	40 m
H	3.4	1 X 10^{15} ion/cm2	20 m
He	0.5	1 X 10^{16} ion/4inch2	50 m
Fe	8	5 X 10^{14} ion/cm2	40 m

2.2 Positron Trapping Model of a Single Type of Defect

The positron lifetime is defined as the time difference between the birth of a positron and the annihilation of positron. A thermalized positron in a perfect metal is annihilated with a constant annihilation rate $\lambda_b(=1/\tau_b$, τ_b=bulk lifetime). The positron lifetime of bulk Si is known to 207 ps. In the presence of vacancy-type defect, positrons tend to trap at their sites with a trapping rate κ_d and annihilate with a annihilation rate λ_d ($=1/\tau_d$, τ_d=defect lifetime), which is schematically shown in Fig. 1. The positron decay function can be described as

$$f(t) = I_1 \exp(-\frac{t}{\tau_1}) + I_2 \exp(-\frac{t}{\tau_2}) \qquad (1)$$

where each lifetime and intensities are defined as

$$\tau_1 = \frac{\tau_b}{1+\kappa_d \tau_b}, \tau_2 = \tau_d, \quad . \qquad (2)$$
$$I_1 = 1 - I_2, I_2 = \frac{\kappa_d}{\lambda_f - \lambda_d + \kappa_d}$$

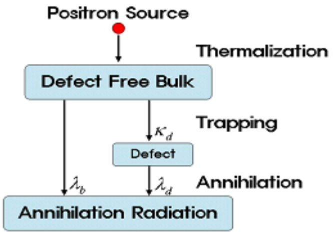

Fig. 1. A schematic of the trapping model includes only one

defect type.

3. Results and Discussion

The measured PA spectra are presented in Fig. 2. After ion penetration, the measured mean positron lifetime is slightly increased. We confirm the creation of the radiation induced point defects as a result of an ion penetration. Based on these result, we assume one defect type which we take here to be mono-vacancies.

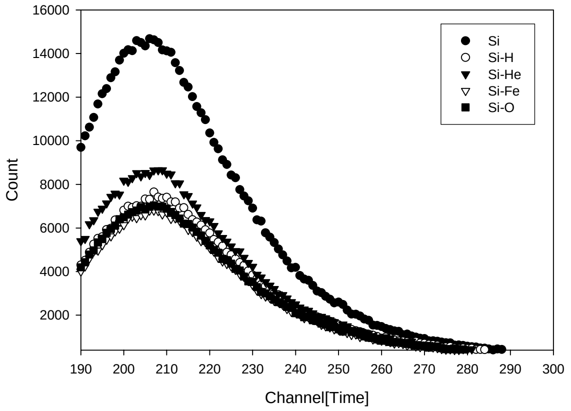

Fig. 2. The measured positron lifetime spectra of annealed Si, and Ion irradiated Si wafer.

The positron lifetime of mono-vacancy in pure Si wafer is known to almost same as 270 ps. In the analysis of PAS data, the intrinsic lifetime of ion-irradiation induced defect (mono-vacancy) are set to be 270 ps, denoted by τ_d (=τ_2). The results for positron annihilation lifetime data of the samples are listed in Table II. As shown in the Fig. 3, the single vacancy intensity (I_2) of H ion penetration Si wafer is larger than other ion penetration Si wafers.

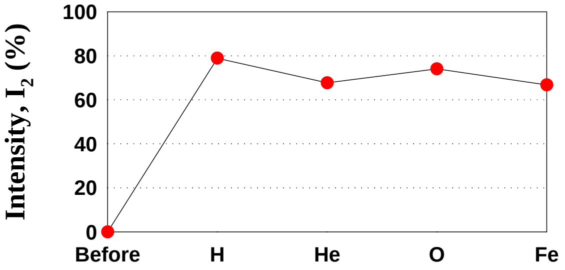

Fig. 3. Measured lifetime and intensity. After irradiation, the measured spectra were divided to two component.

Table II: Measured lifetime and intensity

Alloy	Before	after ion penetration			
	τ_b(ps)	τ_1(ps)	I_1(%)	τ_2(ps)	I_2(%)
H-Si	210±0.2	110.2±0.6	21.1±0.44	270(fix)	78.9±0.44
He-Si	210±0.2	123.8±0.6	32.3±0.53	270(fix)	67.7±0.53
O-Si	210±0.2	117.3±0.6	25.9±0.48	270(fix)	74.1±0.48
Fe-Si	210±0.2	135.9±0.6	33.2±0.53	270(fix)	66.8±0.53

4. Conclusions

We carried out a cosmic ray induced parts damage evaluation method. Through the application of the positron annihilation measurement techniques, we investigate the radiation-induced point defects in Si wafers. From the PALS, formation of mono-vacancies in the irradiated materials was confirmed. Then we employed the positron trapping model of a single type of defect. From this study, we confirmed existence of ion irradiation induced mono-defects. and, We developed a sample manufacture method considering ion penetration depth. The application PAS provided information on the radiation-induced defect production.

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