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Depth Distributions of Bi^+ Ions Implanted into Ni, Si and SiO_2, Films

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Abstract

Ni, Si and SiO_2 films were implanted by 350 keV Bi^+ ions at room temperature with fluences of 1×10^{16} and 2×10^{16} ions/cm^2. The depth distributions of implanted Bi^+ ions in Ni, Si and SiO_2 films were by investigated by Rutherford backscattering. The results show that the depth distributions of implanted Bi^+ ions into Ni, Si and SiO_2 films have obeyed nearly Gaussian distributions. The maximum difference between experimental and calculated values is less than 18 % for mean projected range. Experimental range straggling deviated significantly from calculated value. The possible reasons are discussed.

1. Introduction

When energetic ions penetrate a solid target, they dissipate their energy through interaction with the target atomic cores and electrons, become deflected from their original directions of motion and finally have stopped in target. Therefore precise knowledge of the depth profiles of ions implanted into solid is important from the technological point of view or for the better understanding of the basic interaction of ions with the solid [1-3]. A large number of papers have been published on the depth profiles which can deduce the projected range and range straggling for a variety of ion-target combination. Different groups have performed systematic studies of mean projected range and range straggling for several ionic species implanted in different kinds of substrates. An overall good agreement (～10%) is observed when these data are compared with calculations by Ziegler, Biersack and Littmark (ZBL) in the case of medium energy. But recently Grande et al. have reported that carbon and boron films were implanted with medium-heavy ions in an energy range of 10 to 300 keV, the experimental results are 20-40 % higher than the theoretical predictions by ZBL. Good agreement is achieved only when inelastic effects are included in the nuclear stopping regime [4].

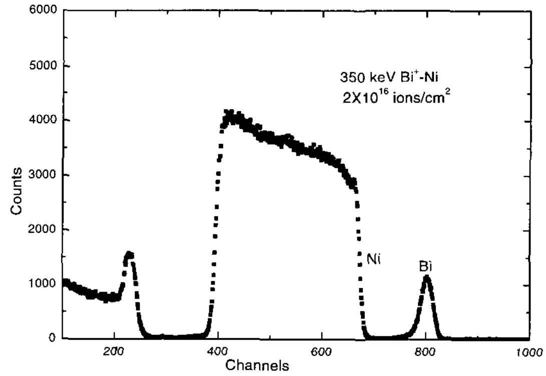

Fig. 1. Rutherford backscattering spectrum of 2.1 MeV He ions for Ni film implanted by 350 keV Bi^+ with 2×10^{16} ions/cm^2.

Due to the high polarizability of bismuth, it has been proposed that materials containing bismuth, such as glass, can be candidate materials for nonlinear optical devices.

In the present work, we have reported the measurements of mean projected range and range straggling of 350 keV Bi^+ ions implanted into Ni, Si and SiO_2 films by Rutherford backscattering and compared with TRIM (transport of ions in matter) code [5].

2. Experimental

The Ni, Si and SiO_2 films were formed by deposition technique. All thicknesses of Ni, Si and SiO_2 films exceed the expected range of Bi^+ ions in corresponding films. The films were implanted with. Beam current density less than 1.0 $\mu A/cm^2$ to avoid excessive heating of the target. The fluences varied from 1×10^{16} to 2×10^{16} ions/cm^2, respectively. Ion energy was kept at 350 keV for all cases. The ion implantation was done at room temperature.

Depth distributions of 350 keV Bi+ ions into Ni, Si and SiO_2 films with different fluences were measured by Rutherford backscattering using 2.1 MeV He ions. The backscattered particles were detected by Si surface barrier detector placed at 165° with respect to the beam direction.

The ion implantation was carried at the 400-kV implanter at Beijing Normal University. Rutherford backscattering was measured at the 1.7 MV tandem accelerator of Shandong University.

3. Results and Discussion

Fig. 1 shows a Rutherford backscattering spectrum of 2.1 MeV He ions for 350 keV Bi^+ implanted into Ni film with a fluence of 2×10^{16} ions/cm^2. It is found that the depth distributions of implanted Bi^+ are nearly Gaussian. From energy to depth transformation, we have used the surface energy approximation and the stopping-cross section by Chu *et al.*[6]. Fig. 2 indicates the comparison of depth distribution for 350 keV Bi^+ implanted into Ni film with TRIM (transport of ions in matter) in the case of 2×10^{16} ions/cm^2. The depth distribution of implanted Bi^+ into Ni film was investigated by Rutherford backscattering. Squares represent the experimental data of implanted Bi ions into Ni film. The histograms indicate the TRIM prediction. The results show that the depth distributions of implanted Bi^+ into Ni film have obeyed regular ones

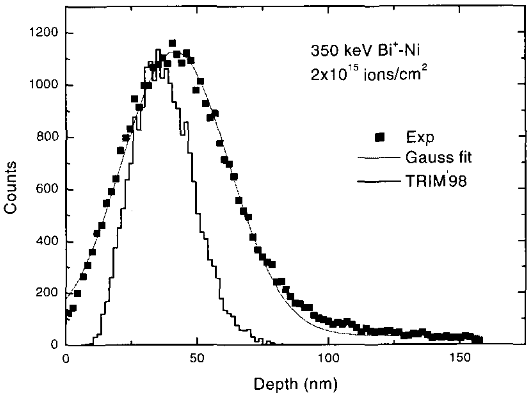

Fig. 2. Comparison of experimental depth distributions of 350 keV Bi^+ ions implanted Ni film with TRIM'98 prediction. Squares are experimental data. The histogramms represent TRIM'98 prediction.

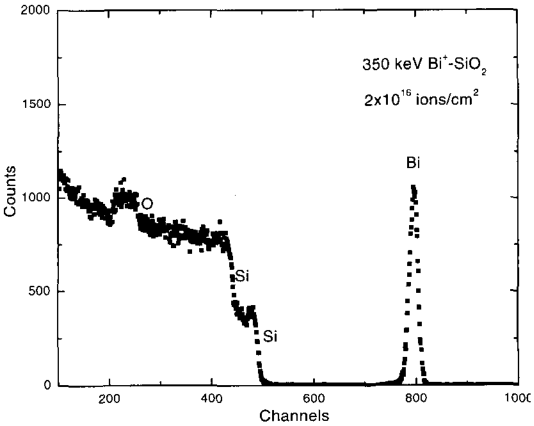

Fig. 3. Rutherford backscattering spectrum for 350 keV Bi^+ ions implanted into SiO_2 film, with a fluence of 2×10^{16} ions/cm^2.

with lower fluence (less than 2×10^{16} ions/cm^2). Experimental mean projected range R_p is 41.5 nm. The range straggling ΔR_p has been obtained from the FWHM (full width at half maximum) of Gaussian distribution via formula: ΔR_p =FWHMc /2.355N[ε] where N is atomic density of the film and [ε] is stopping cross section factor. FWHM$_c$ can be obtained after deconvolution considering the system resolution and probing He-particle straggling. Experimental range straggling ΔR_p obtained is 19.6 nm. The mean projected range R_p and range straggling ΔR_p calculated by TRIM are 36.0 nm and 11.5 nm, respectively. The experimental mean projected range is higher than calculated value by TRIM'98 around 15%. But experimental range straggling significantly deviated from TRIM'98 prediction.

Fig.3 shows a Rutherford backscattering spectrum of 2.1 MeV He ions for 350 keV Bi$^+$ implanted into SiO_2 film with a fluence of 2×10^{16} ions/cm^2. Again, similar behavior is found to the case of Ni film, the depth distributions of implanted Bi+ displays Gaussian one. SiO_2 is two elemental compounds. In the present work, it is assumed that Bragg's rule is valid. We can use simple summation of stopping power data for constituent elements, weighted by the proportion of each element in the compound. Fig. 4 shows the comparison of depth distribution for 350 keV Bi$^+$ implanted into SiO_2 film with TRIM in the case of 2×10^{16} ions/cm^2. Squares represent the experimental data of implanted Bi$^+$ ions into SiO_2 film. The histograms indicate the TRIM prediction. The solid line represents Gaussian fit. It is observed that the peak position of the depth distribution of implanted 350 keV Bi in SiO_2 is deeper than the one predicated by TRIM. The mean projected range R_p and range straggling ΔR_p calculated by TRIM are 109.0 nm and 21.4 nm, respectively. The experimental mean projected range and range straggling are 122.1 nm and 33.5 nm, respectively. The experimental mean projected range is higher than calculated value by TRIM'98 around 12%, again experimental range straggling significantly deviated from TRIM'98 prediction. Table 1 lists the comparison of experimental R_p and ΔR_p with calculated values obtained by TRIM'98 for 350 keV Bi$^+$ implanted into Ni, Si and SiO_2 films. The maximum difference between the experimental and calculated values of R_p is less than 18 %. Experimental ΔR_p deviated significantly from calculated value. The possible reason is that the present TRIM code does not contain any correlation between the nuclear and electronic stopping powers. If such a correlation is included in ZBL calculation, the agreement between the measured and calculated values of R_p and ΔR_p when heavy ions are implanted into lighter targets. Another reason probably is due to sputtering to cause the widen FWHM during ion implantation.

Table 1 Comparison of experimental R_p and ΔR_p with calculated values obtained by TRIM'98 for 350 keV Bi$^+$ implanted into Ni, Si and SiO_2 films with fluences of 2×10^{16} ions/cm^2

Target	Experimental		TRIM'98	
	R_p (nm)	ΔR_p (nm)	R_p (nm)	ΔR_p (nm)
Ni	41.5	19.6	36.0	11.5
Si	128.2	34.0	108.6	24.0
SiO_2	122.1	33.5	109.0	21.4

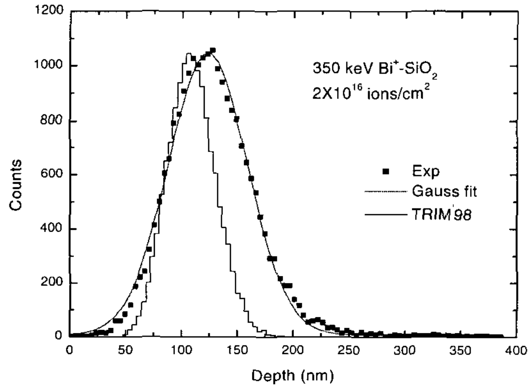

Fig. 4. Comparison of experimental depth distributions of 350 keV Bi$^+$ ions implanted SiO_2 film with TRIM'98 prediction. Squares are experimental data. The histograms represent TRIM'98 prediction.

4. Summary

The depth distributions of 350 keV Bi^+ ions implanted into Ni, Si and SiO_2 films were investigated by Rutherford backscattering of 2.1 MeV He ions. The results show that the depth distributions of implanted Bi^+ into Ni, Si and SiO_2 films have obeyed regular ones with lower fluence of 1×10^{16} and 2×10^{16} ions/cm^2. The maximum difference between the experimental and calculated values of R_p is less than 18 % for all cases. Experimental ΔR_p deviated significantly from calculated value. The possible reason is that the present TRIM code does not contain any correlation between the nuclear and electronic stopping powers. If such a correlation is included in ZBL calculation, the agreement between the measured and calculated values of R_p and ΔR_p when heavy ions are implanted into lighter targets. Another reason for range straggling is due to the sputtering and thermal diffusion during ion implantation.

Acknowledgement

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