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DEPTH PROFILING OF ^{1}H AND/OR ^{4}He IN SOLIDS. BY ERD WITH ^{19}F IONS

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ABSTRACT

^{1}H or ^{4}He depth profiling in ^{1}H or ^{4}He implanted silicon samples was performed by elastic recoil detection (ERD) with multicharged ^{19}F ions at a small accelerator. Optimization of the experimental parameters such as incident ions energy and scattering geometry were calculated by computer simulation. Depth resolution of about 20-30nm at depth of 400nm for ^{1}H and at depth of 300nm for ^{4}He can be obtained, respectively.

Key words: Elastic recoil detection Depth profiling

I . INTRODUCTION

The quantitative detection and the profiling of ^{1}H or ^{4}He in solids is interesting and important for many applications. But it is quite difficult. The nuclear reaction analysis (NRA) for ^{1}H detection provides good depth resolution (about 20nm) in the near surface region and a sensitivity of about 0.1 at %[1], but it is a relatively time consumed method. The detection of ^{4}He by nuclear reaction is somewhat impractical. L'Ecuyer et al[2] have developed a recoil detection for light element analysis by ion beams of 30-40MeV. This paper present ^{1}H or ^{4}He detection and depth profiling obtained by ERD at a small MV accelerator.

II . PRINCIPLE AND EXPERIMENT

The elastic recoil detection (ERD) is based on the elastic scattering process of Coulomb interaction. A beam ions of mass M_1 and energy E_0 is incident on a solid target at an angle α with respect to sample surface. It will be collided with a target atom M_2 at a depth x. The energy loss of the incident beam before the collision along its trajectory is equal to $(dE/dx)_{in}(x/\sin\alpha)$.The energy transfer to the recoile at outgoing path is $(dE/dx)_{out}[x/\sin(\theta-\alpha)]$. Then recoil particle energy E_3 will be

$$E_3 = KE_0 - [S]x \tag{1}$$

where

$$K = [4M_1M_2/(M_1+M_2)^2]\cos^2\theta$$

$$[S] = K(dE/dx)_{in}(1/\sin\alpha) + (dE/dx)_{out}[1/\sin(\theta - \alpha)]$$

The background of elastically scattered incident ions and heavy target particle are eliminated by a stopping foil of appropriate thickness in front of the detector. The energy loss of light ions is $\delta E_0(E_3)$. Detected energy of recoil ions will be

$$E_f = E_3(x) - \delta E_d(E_3) \tag{2}$$

It can be seen from Eq.(2), recoil spectrum have a depth distribution information.

If the energy spread can be neglect, the ideal energy spectrum $n(E)$ of detected recoils ions is given by

$$n(E_f)dE_f = I\Omega\, \sigma(E_1)C(x)dx \tag{3}$$

where, I: number of incident particles; Ω: solid angle of detector; δ (x): elastic scattering cross section; $C(x)$: concentration profile of recoil ions.

Then the concentration profile of detected ions from Eq.(3) can be obtained.

The experiment was performed at a 2× 1.7 MV tandem accelerator. The experimental set-up is shown in Fig.1. Multicharged ^{19}F ion beams with energy of 6-8 MeV, impact a solid target at an angle α with respect to the target surface. The recoil particles were detected at an angle θ with respect to the incident beam direction. Elastically scattered F ions and recoil ions heavier than ^1H and ^4He have been absorbed by a Mylar foil of 4.8 μ m thick in front of the detector. A 2 mm diaphragm in front of the detector was used to limited the detection angle divergence and to improve the depth resolution. A negative voltage of 300V was applied to the electrode in front of the target holder to suppress secondary electrons. The silicon sample was implanted by ^1H ions of 25 keV and He ions of 15 keV with the implantation dose of 5×10^{16} atoms/cm^2 and 1×10^{17} atoms/cm^2, respectively.

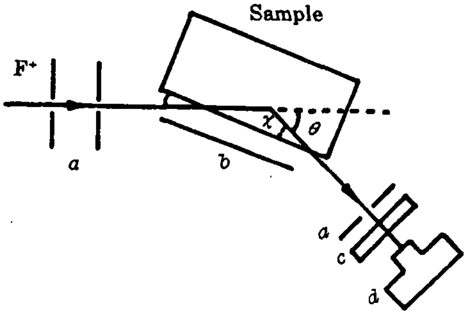

Fig.1 Experiment set up for H or He profiling by ERD

a: diaphragm *b*: suppressing electrode *c*: Mylar foil *d*: Si(Al) detector α : incident angle θ : recoil angle

III. RESULTS AND DISCUSSION

The energy spectra of recoils at different incident beam energies and different incident angles α have been collected and analyzed by a ND – 683 computerized multichannel analyzer. The typical energy spectra of hydrogen recoils are shown in Fig.2. The peak at high energy end of the spectrum comes from hydrogen atoms associated with surface contaminations. The next broad peak at lower energy comes from implanted ^{1}H atoms. The ^{4}He recoil spectrum of a He implanted silicon sample is shown in Fig.3. The broad peak at the high energy end of the spectrum shows the ^{4}He profiling. The next sharp peak represents the hydrogen atoms from surface contamination. The ^{1}H depth profiling was obtained by computer fitting of the spectrum. The H profiling obtained here by ERD agreed well with the profiling by ^{1}H (^{19}F, α γ)^{16}O resonance nuclear reaction analysis of the same samples[3]. The depth resolution of ^{1}H and ^{4}He profiling by ERD depends on the stopping power and the energy straggling of the incident and the recoil particle in the sample and the absorber, the scattering geometry and the energy resolution (detector resolution, energy stability etc.). The various factors limiting the depth resolution of the method have been considered. An accurate calculation shows that a depth resolution of about 20nm – 30nm at depth of 400nm for ^{1}H and about 20nm – 30nm at depth of 300nm for ^{4}He can be obtained by ERD respectively. The estimated sensitivity for case is about 0.1 this at %.

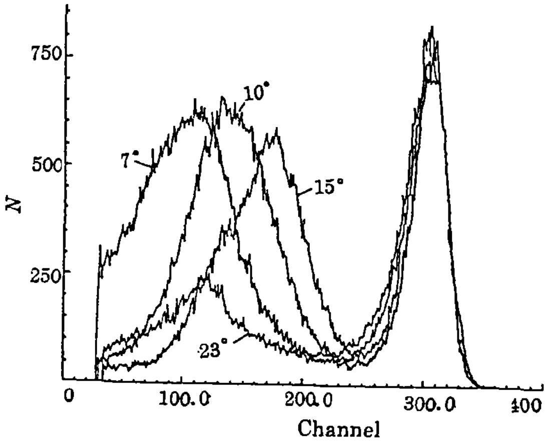

Fig.2 Energy spectra of recoil proton for different tilt angles α = 7°,10°,15°,23° and θ = 30° at 7.5 MeV of F ions

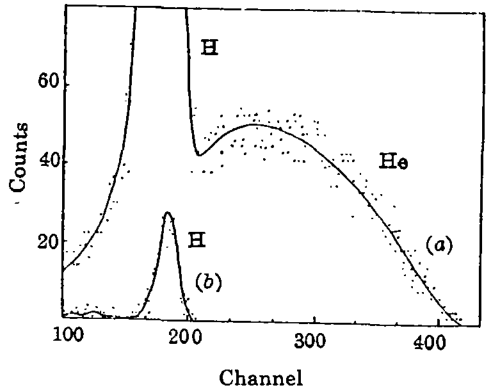

Fig.3 He recoil energy spectra

θ = 30°, α = 20°, E = 7.5 MeV

(a) He implanted silicon target

(b) amorphous silicon

The recoil energy spectra detected at different parameters of *E*, α , θ and *Z* are different[1]. The optimization of the experimental parameters for the ERD method is very critical. The data in Fig.4 and Fig.5 are calculated by a computer program ERD. The energy loss used in the calculations was obtained by TRIM – 85[5]. The principal conclusions are as follows:

1. The depth resolution δ x and the probing depth X_{max} depend strongly on the experimental parameters (E, α, θ, Z).
2. The δ x improves as an angle α decreases, but with losses of the X_{max} values. Compromised values of δ x and X_{max} can be obtained at the angle α between $\theta/2$ and $2\theta/3$.
3. The X_{max} increases as the energy increases, but with losses of the depth resolution δ x.
4. The ^{4}He recoil peak from ERD spectra by MV ^{19}F ion beams are often overlapped with the ^{1}H peak of surface contaminations. So an accurate selection of experimental parameters is necessary.

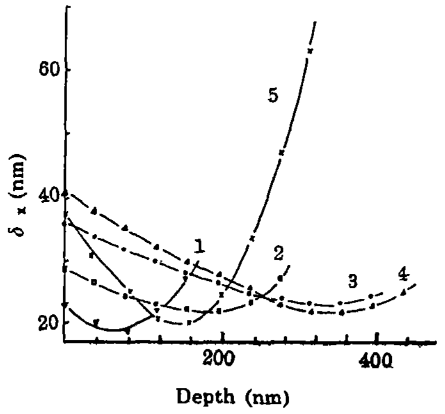

Fig.4 Calculated depth resolution δ x vs. tilt angle α for H depth profiling

$\theta = 30°$, $\alpha = 1(5°)$, $2(10°)$.$3(15°)$, $4(20°)$, $5(25°)$, and $E_0 = 7$MeV F ions

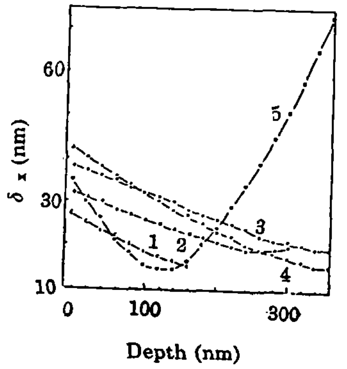

Fig.5 Calculated depth resolution δ x vs. tilt angle α for H depth profiling

$\theta = 30°$, $\alpha = 1(5°)$, $2(10°)$.$3(15°)$, $4(20°)$, $5(25°)$, and $E_0 = 7.5$MeV

The depth resolution of ^{1}H depth profiling by ERD with ^{19}F ions is better than that with He or D ion beams. The difficult He profiling can be performed by ERD with quite good depth resolution also.

The depth resolution and the sensitivity are almost the same as in the resonance nuclear reaction analysis by ^{19}F ions. The data collection time is much shorter than that of NRA. ^{1}H or ^{4}He profiling by ERD with ^{19}F ions is a sensitive and fast method with low radiation damage of samples.

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