HEAVY ION RECOIL SPECTROMETRY OF Si_xGe_{1-x} THIN FILMS

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ABSTRACT

Mass and energy dispersive recoil spectrometry employing 77 MeV ^{127}I ions from ANTARES (FN Tandem) facility at Lucas Heights has been used to examine the isotopic composition of samples of Si_xGe_{1-x} grown at the Australian National University by Electron Beam Evaporation (EBE). The recoiling target nuclei were analysed by a Time Of Flight and Energy (TOF-E) detector telescope composed of two timing pickoff detectors and a surface barrier (energy) detector. From the time of flight and energy, the ion mass can be determined and individual depth distributions for each element can be obtained. Recoil spectrometry has shown the presence of oxygen in the Si_xGe_{1-x} layer and has enabled the separate determination of energy spectra for individual elements.

INTRODUCTION

Over the past few decades Rutherford Backscattering Spectrometry (RBS) has been used extensively to study the composition of semiconductor device materials. However, RBS is not easily applied to situations involving light element impurities in heavier elements. The determination of light element concentration and distribution, whether dopant or impurity, is an important problem in many semiconductor compounds. Mass and energy dispersive Recoil Spectrometry (RS) has recently found application in such situations where RBS is inapplicable, e.g. [1]. The technique involves the use of a high energy heavy ion beam and employs a Time of Flight and Energy (TOF-E) detector to extract mass and depth information from the recoiling target nuclei. Amorphous layers of

Figure 1. Recoil Spectrometry data for $Si_{0.2}Ge_{0.8}$ projected onto a histogram with axes E and M.

Si_xGe_{1-x} were grown for potential optoelectronic device applications by Electron Beam Evaporation (EBE) at the Australian National University. It was suspected that oxygen was present as an impurity in significant quantities in these layers. Recoil Spectrometry has enabled the separation of the oxygen, silicon and
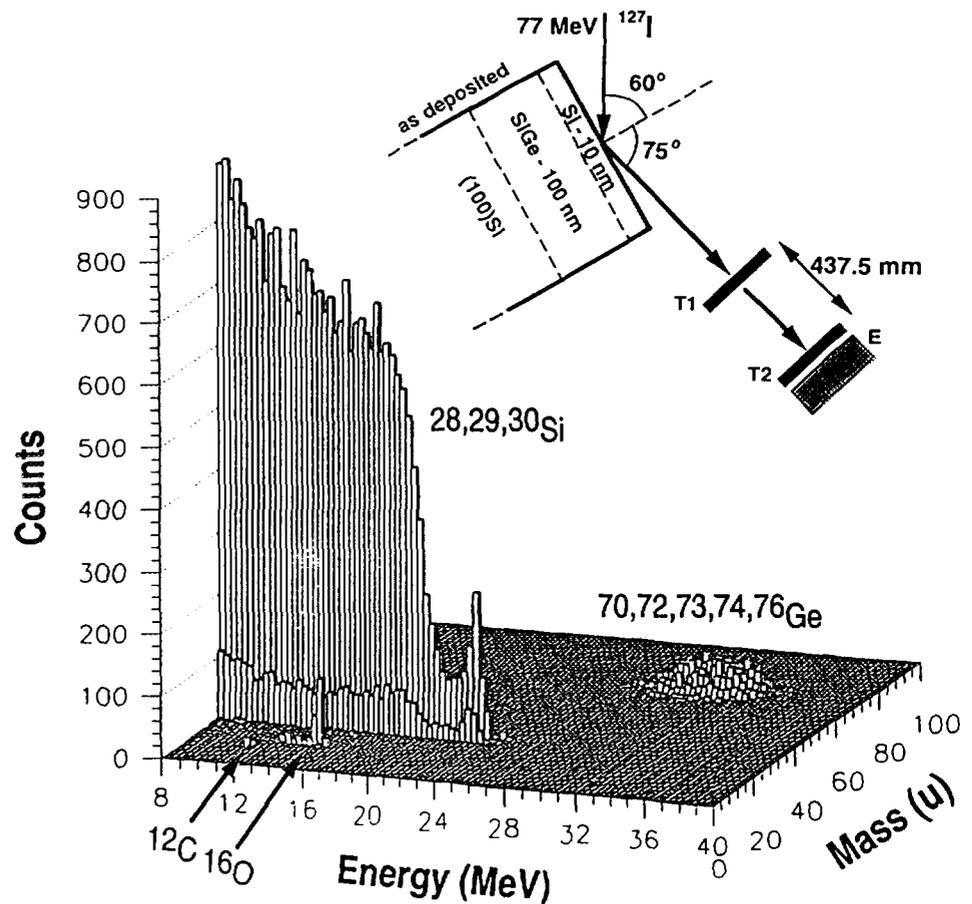
germanium signals and can provide individual energy spectra for Ge, Si and O in these structures, thus revealing the depth distribution of these elements.

EXPERIMENTAL

Seven samples of the structure 10 nm Si/100 nm $Si_xGe_{1-x}/$ (100) Si were analysed with x ranging from 0.2 to 0.9.

The Recoil Spectrometry experiments were performed at Lucas Heights using the ANTARES Tandem Accelerator. 77 MeV $^{127}I^{10+}$ ions impinged on the sample at an angle of 60° relative to the target surface normal and recoiling ions from the sample were detected, with a Time of Flight and Energy (TOF-E) detector subtending a solid angle of 0.10 msr, at 45° to the incident beam (Fig. 1). The spectrometer consisted of two time pickoff detectors separated by a flight length of 437.5 mm and a 100 mm^2 ion implanted Si detector[2-4]. The time detectors functioned by the detection of electron emission from the passage of recoil ions through a thin carbon foil (≈ 3 $\mu g/cm^2$) and employed a mirror electrode configuration to provide isochronous electron trajectories in order to minimise the electron path effect on time resolution[2,4]. The experiments used a conventional electronic instrumentation arrangement, as used in previous experiments [3,4], however the instrumentation included a second Time-to-Amplitude Converter (TAC), to examine the time resolution of the energy detector.

DATA ANALYSIS

The data from the experiment were examined and manipulated using the CERN data analysis package, PAW (Physics Analysis Workstation) [5].

For non-relativistic particles of mass m,

$$m = \frac{2E}{L^2} t^2$$ where t is the time taken to travel the flight length, L, and the kinetic energy of the detected ion, T, can be related to the pulse height from the Si detector, E.

Experimentally the signals from recoiling ions of differing mass are separated using the transformation:

$$M = CE(t - t_0)^2$$

Where t is the output from the first TAC and t_0 represents the delay imposed on the time pickoff nearest the target [6]. Data for one measurement projected onto a histogram in the (E, M) plane is shown in Fig. 1.

M is not linearly related to m due to inevitable small electronic offsets and variations in the Si detector response

Figure 2. Energy not causing ionisation versus Ion energy for ^{238}U, ^{127}I, ^{81}Br, ^{28}Si and ^{12}C

with recoil mass. Simulations with TRIM 91[8] using full damage cascades can be used to predict the fraction of the incident ion energy converted into ionisation (Fig. 2). It is the ionisation created in the Si detector that determines the pulse height.
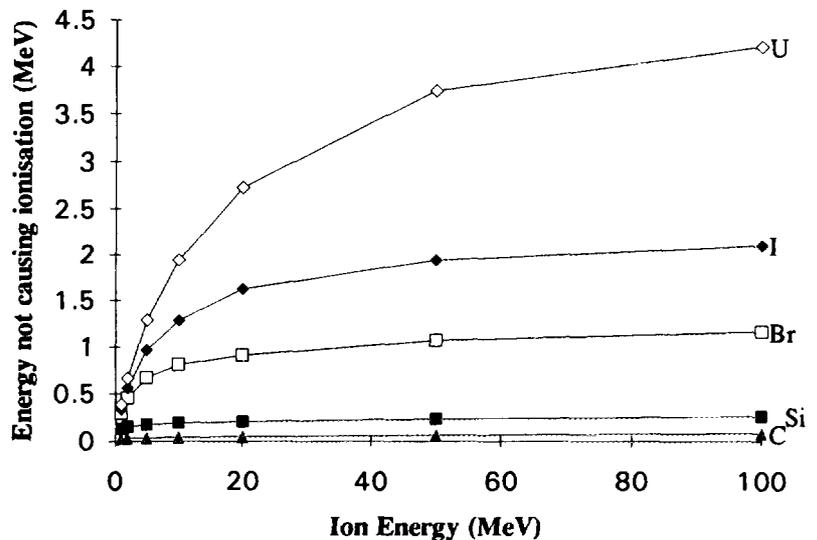
The data for each separate element can be selected according to mass and projected onto the E axis. The data were quantitatively analysed using a variant of the RMIT software for Nuclear Reactions Analysis (NRA) [9]. Recoil Spectrometry can be considered to be a special case of NRA where the reaction is $X(^{127}I, X)^{127}I$ and the Q-value is 0. The spectrum is simulated for each isotope and fitted to the raw data using a non-linear least squares routine. Fig. 3 shows an energy spectrum and corresponding simulation for oxygen.

RESULTS

The Mass versus Energy spectrum (Fig. 1) displayed features consistent with the known structure of the sample investigated. The Si signal contains a surface peak associated with the 10 nm Si layer, the decrease associated with the $Si_{0.2}Ge_{0.8}$ layer and the signal from the substrate. The Ge signal displays a broad peak from the 100 nm buried $Si_{0.2}Ge_{0.8}$ layer. The spectrum also displays a peak associated with surface carbon. The O spectrum (Fig. 3) exhibits two main features, a definite peak due to contamination at the surface and the bulk impurity signal from O contained in the Si_xGe_{1-x} layer.

The analysis software was used to fit simulations to the elemental energy spectra and quantify the atomic fractions. The seven Si_xGe_{1-x} samples analysed ranged in x from 0.2 to 0.9. The bulk oxygen content of the Si_xGe_{1-x} layers ranged from 2.6 to 5.0 at. %. O content increased with increasing x (decreasing Ge content).

CONCLUSIONS

Recoil Spectrometry is a technique with significant potential in the study of light elements incorporated in heavier element compounds. Recoil spectrometry has demonstrated that O is the contaminant in the Si_xGe_{1-x} layers studied in this work and has allowed the quantification of O levels. Recoil Spectrometry allows the determination of not only bulk concentration levels but provides significant depth information, with good discrimination of surface contamination. It enables the determination of separate elemental depth distributions in multi element materials.
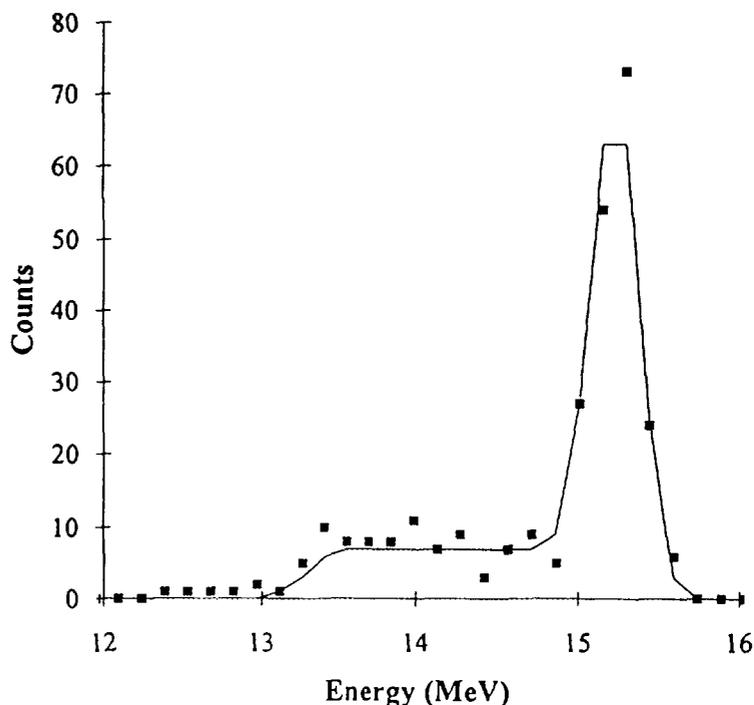

Figure 3. Simulation fit for oxygen spectra in $Si_{0.2}Ge_{0.8}$ sample from quantitative analysis

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