COMPLEMENTARY SCATTERED AND RECOILED ION DATA FROM TOF-E HEAVY ION ELASTIC RECOIL DETECTION ANALYSIS

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The advantage of Time of Flight and Energy (ToF-E) Heavy Ion Elastic Recoil Detection Analysis (HIERDA) over Rutherford Backscattering (RBS) analysis is its mass and energy dispersive capabilities. The mass resolution of ToF-E HIERDA deteriorates for very heavy elements. The limitation is related to the poor energy resolution of Si detectors for heavy ions. While the energy spectra from ToF-E HIERDA data are normally used to extract depth profiles, this work discusses the benefits of using the time spectra of both the recoiled and the scattered ions for depth profiling.

1. Introduction

HIERDA using either the mass dispersive ToF-E or the nuclear charge dispersive ΔE-E (Energy Loss and Energy) detection systems, has been extensively studied during the last few years by groups in Sweden [1], Germany [2], Canada [3], France [4], Finland [5] and Australia [6] using (0.2-2 A MeV) heavy ions. The exceptional and unambiguous multi-elemental depth profiling capabilities of HIERDA are due mainly to its dispersive multi-elemental detection characteristics. Despite the effort devoted to optimising HIERDA, the ability to extract depth profiles is limited due to: (i) the poor understanding of the transport of heavy ions, and (ii) the poor energy resolution and stability of Si detectors for heavy ions [7].
Limitations of HIERDA are not a result of physical principles but are mainly related to the mass or nuclear charge separation performance of the detection system. In the case of the ToF-E detection telescope, this limitation is due to the energy resolution of the Si detector. In a previous study, the mass resolution of ToF-E HIERDA [8] was determined, showing an improvement with increasing energy and lighter recoils due to the energy response of the Si detector. For ToF-E detection systems, several data processing methodologies have been developed and used to simulate (ToF, E) data [9] or extract elemental energy spectra [10] to determine depth profiles. Time spectra have been largely ignored. Also the forward scattered spectrum is not used even though it contains valuable information.
This work demonstrates that: (i) instead of the ToF detector, the Si detector should be used as the dispersive instrument. The time spectra provide better depth profiling information, improving the depth resolution of HIERDA, and (ii) some difficulties in extracting elemental energy spectra of the overlapping signals from heavy recoils (Pt-Bi) can be overcome by using the complementary time spectra of the recoiled and forward scattered ions.

2. Advantages of Time spectra

In IBA studies, energy spectra are usually measured and used for depth profiling. The ToF detector in HIERDA is normally only used for mass dispersion as it depends on the flight length (L). Despite modelling of the ion-matter interactions being defined in terms of energy, there is no need to reformulate the models of ion-matter interactions in terms of the ToF parameter. Experimental time spectra can be directly used for depth profiling. The depth profiles are extracted using a simulation where each isotopic contribution is calculated independently and then summed. This is advantageous for HIERDA as the depth resolution is

improved and ion damage induced changes in the Si detector pulse height do not affect the analysis. On the contrary, the time resolution can be well approximated by a constant.

Fig. 1 shows the gain in depth resolution when using time spectra for a ferroelectric sample. The energy resolution of the Si detector is so poor that it is difficult to distinguish the high energy edges of the different elements. On the contrary, the shape of the time spectrum shows well defined high energy edges, demonstrating superior resolution of the ToF detector. Fig. 2 shows a comparison between the energy resolutions of the Si and ToF. The energy resolution of the Si detector is estimated using Amsel's formula [13] fitted to the available experimental data for elements up to Br [14]. Amsel's empirical formula is:

$$\Delta E_{Si} = a + b\, E^{1/3} \qquad (1)$$

where a and b are constants for a given atomic mass number. The energy E is expressed in keV. From Hinrichsen's compilation [14] the mass dependence of the parameters a and b is estimated to be:

$$\Delta E_{Si} = (108.08\text{-}3.38\, M) + (0.51\, M\text{-}5.85)\, E^{1/3} \qquad (2)$$

where M is the atomic mass of the detected ion.

This expression fits experimental data ranging from ^{12}C to ^{81}Br ions with energies below 25 MeV and has been extrapolated for ^{127}I ions. A measurement of the energy resolution for 58 MeV ^{127}I ions gives 3200 keV including geometrical factors suggesting that the expression (2) is an underestimate. The energy resolution derived from the ToF detector is:

$$\Delta E_{ToF} = 2\, E\, \Delta t/t \qquad (3)$$

where t is the time of flight of the ion. Δt is the total time resolution of the ToF detector including the intrinsic time resolution, electronic noise, geometrical contributions and sample roughness. Δt is 400 ps for scattered ^{127}I ions in this work.

The energy resolution of the ToF detector for ^{127}I ions (Fig.2b) is lower than the energy resolution of the Si detector and is at least a factor of 2 better at high energies and a factor of 10 better below 20 MeV for L of 0.5 metres and can be improved by a longer L at the expense of the solid angle.

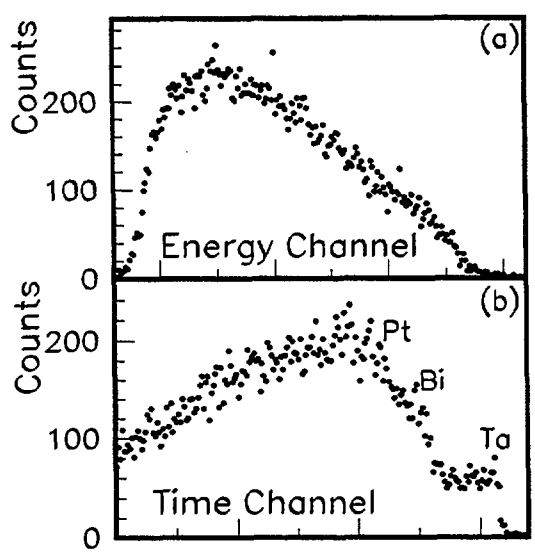

Figure 1: (a) Energy spectrum of the overlapped Ta, Pt and Bi recoils detected at 45° from 97.5 MeV ^{127}I incident ions, and (b) projected time spectrum of the same recoils. Details of the measurements on the sample of nominal structure $SrBi_2Ta_2O_9/Pt/TiO_2/Si$ are given in ref.[6].

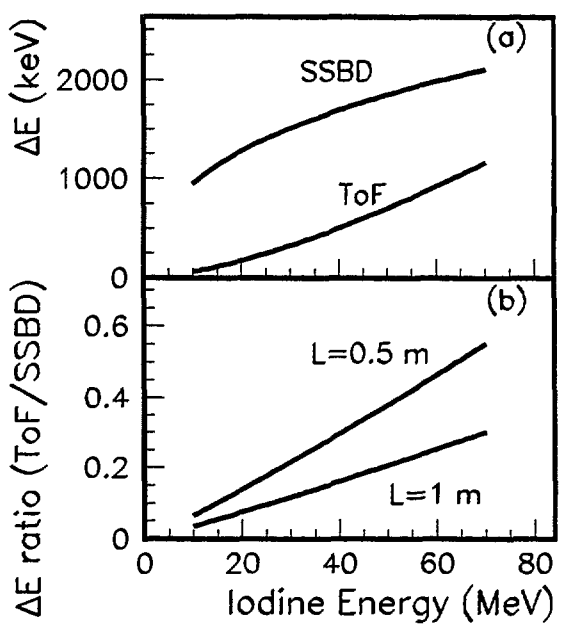

Figure 2: (a) Energy resolutions for both ToF and Si detectors of ^{127}I ions. (b) The ratio of energy resolutions of Si detector and ToF detector for ^{127}I ion for L of 0.5 and 1 m.

3. Complementary spectra of scattered and recoiled ions

It is proposed to use the time spectra of both the forward scattered and the recoiled ions as they contain valuable complementary information. The kinematics governing the scattering process mean that the mass dependencies of the energy transfer to the recoil and the scattering energies follow opposite trends when the incident ion is lighter than the analysed ion. This means that the overlapping isotopic contributions from the recoiled ions are completely different for scattering signals (Fig.3). The simulation of both the scattered and recoiled data from heavy ions adds extra information for the depth profile extraction.

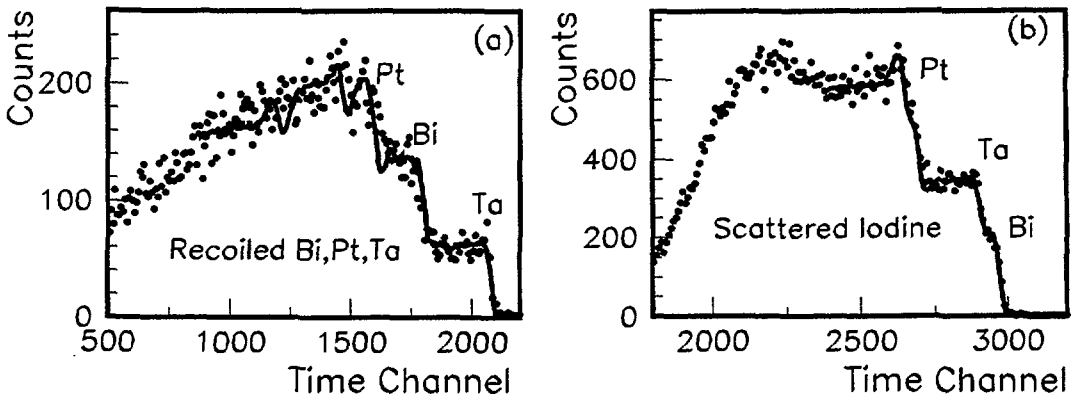

Figure 3: Superposition of experimental and simulated time spectra for (a) overlapped Ta, Pt and Bi recoils (b) forward scattered ^{127}I from Ta, Pt and Bi.

4. Conclusions

We have demonstrated for HIERDA using a ToF-E telescope that the high stability of the ToF signal which is independent of the mass, atomic number and energy of the detected ions has significant advantages over the use of the energy signal from Si detectors. The simulation of the complementary scattered and recoiled ion time spectra improves depth profiling and reduces current limitations when dealing with very heavy ions.

Acknowledgments

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