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The stopping cross-section of aluminum for He ions

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Abstract

The stopping cross-section of Aluminum for He ions has been determined from experimental Rutherford Backscattering (RBS) spectra of bulk and thick film samples by using a Bayesian inference data analysis method. This method allows for the extraction of continuous stopping curves together with a consistent estimate of the errors. The valid energy range of the present parameterization is 0.3–3.0 MeV. The contribution of the plural scattering on the RBS yield at low energy has been measured on thick film samples and it has been observed that a double scattering (DS) calculation is not sufficient to reproduce the low energy background. Nevertheless, the low energy yield of the bulk spectra could be used to reject a class of unphysical simulations, where the calculated low energy yield is significantly larger than the experimental data.

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Keywords: Stopping power; Stopping force; Rutherford backscattering spectrometry; Bayesian inference analysis

1. Introduction

Rutherford Back-scattering Spectrometry (RBS) is a mature analytical technique, routinely used to determine the atomic composition depth profile of a sample. From the experimental point of view a precise methodology concerning, for example, the charge integration or the solid angle calibration has been defined [1] and total uncertainties as low as 1–2% can be achieved. The interpretation of RBS spectra and the consequent extraction of the compositional profiles mostly rely on the accuracy of the measured stopping and scattering cross-section data available in the literature. The reference database for stopping of ions in matter is the software package SRIM [2]. The

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overall accuracy of the SRIM calculation for H and He ions with the stopping data (all energies and all elements) is about 4%. For 150 common compounds corrections are applied to the Bragg's rule in order to reach a claimed accuracy of 2% at the peak of the stopping curve. However, in spite of this satisfactory state-of-the-art, the uncertainty of the available stopping data is still larger than the experimental one, in particular for energies lower than the maximum of the stopping curve and this energy range is relevant in the conventional RBS routine measurements. For this reason a set of evaluated and recommended stopping data for the most important materials could be beneficial for practical applications. It is instructive to note that a precise stopping cross-section for He in Silicon, the material with the highest technological impact of the last decades, has been published by Konac et al. (KKKNS) in 1998 only [3]. Since then, this curve has been subject of various evaluations and it has been substantially confirmed at 2% level [4–9], whereas a similar effort has been undertaken to produce recommended stopping data for He in SiO_2 [9,10].

Some of these experiments showed that a reliable stopping curve can be extracted in a straightforward way by the RBS spectra of bulk samples collected at few different energies, eliminating the problems connected with the measurement of the thin film thickness. This method is so well consolidated that it can be found even in the RBS textbook [11] but it has been seldom used in the past. Nowadays, following the practical indications of [1], it is possible to perform demonstrably good absolute measurements and, at the same time, Bi implanted Si standards having an accuracy as low as 0.6% are available [8]. Moreover, the stopping cross-section of Si is now sufficiently accurate to use the RBS surface yield of an amorphized Si sample as a standard [5].

For this reason we suggest this method as the first choice for practical stopping measurements. In this paper, we applied it in the case of He on bulk aluminum. A Bayesian inference (BI) analysis using Markov chain Monte Carlo integration, including a consistent estimate of the errors [6] was used to extract continuous stopping curves from the experimental spectra. We also measured thin film samples to quantify the plural scattering contribution to the spectrum tail and we will show that this effect prevents the correct extraction of the stopping curve at low energy. For heavy targets such effect is so strong that this method cannot be applied, at least until codes able to quantitatively describe the plural scattering at high backward angles with very high accuracy are available. In this case, different measurements [3,12–14] could overcome these problems at expenses of a more complex experimental procedure.

2. Experimental

Commercial 99.999% Al and 99% Be samples 0.5 mm thick were lapped with abrasive paper 10 μm SiC grit size and subsequently with 3 μm diamond particles dispersed on a soft cloth. Specimens were finally cleaned ultrasonically in isopropanol. To quantify the plural scattering contribution to the low energy yield of the bulk Al spectra, a 530 nm Al film was evaporated onto the Be sample. Moreover a 3 nm Au film was evaporated on a 32 nm SiO_2/Si sample to test the energy distribution of the analyzing beam.

The RBS measurements were performed with the 1.7 MV Tandetron accelerator of IMM in Bologna. 1.0, 1.5, 2.0, 2.5 and 3.034 MeV He beams with a 1×1 mm^2 cross-section were used. The samples were mounted on a motorized 3-axes goniometer installed in an electrically insulated scattering chamber acting as a Faraday cup. Backscattered ions were collected by a ORTEC Ion-Implanted Si detector BU-013-025-300 having a dead-layer equivalent thickness of 250×10^{15} Si/cm^2. The detector was placed in IBM geometry at $170.0 \pm 0.2°$ scattering angle with a measured acceptance of 1.950 ± 0.016 msr. Details of the experimental set-up can be found in [7]. Since all parameters affecting the spectrum yield were measured, no calibration standards were used in this experiment. The standard uncertainty connected with this absolute measurement was evaluated to be 2% [5]. In the last years the surface yield of an amorphized Si sample has been occasionally measured during RBS experiments to test the charge-solid angle product of the system (see