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Development of a versatile user-friendly IBA experimental chamber

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ABSTRACT

Reliable performance of the Ion Beam Analysis (IBA) techniques is based on the accurate geometry of the experimental setup, employment of the reliable nuclear data and implementation of dedicated analysis software for each of the IBA techniques. It has already been shown that geometrical imperfections lead to significant uncertainties in quantifications of IBA measurements. To minimize these uncertainties, a user-friendly experimental chamber with a heuristic sample positioning system for IBA analysis was recently developed in the Van de Graaff laboratory in Tehran. This system enhances IBA capabilities and in particular Nuclear Reaction Analysis (NRA) and Elastic Recoil Detection Analysis (ERDA) techniques. The newly developed sample manipulator provides the possibility of both controlling the tilt angle of the sample and analyzing samples with different thicknesses. Moreover, a reasonable number of samples can be loaded in the sample wheel. A comparison of the measured cross section data of the $^{16}O(d,p_1)^{17}O$ reaction with the data reported in the literature confirms the performance and capability of the newly developed experimental chamber.

1. Introduction

Most light elements appear as hydrides, borides, carbides, nitrides and oxides in the near-surface region of engineered bulk materials and thin films. The composition and distribution of these light element compounds determine to a great extent the mechanical, optical, electrical and chemical properties of the bulk material's surface [1]. Improving the performance of the above-mentioned materials requires reliable quantification of these light elements and enhancing the quality of the manufacturing process.

NRA and ERDA are the two key accelerator-based nuclear techniques for sensitive and selective tracing of light elements. In order to achieve reliable information with these IBA analysis techniques, in addition to appropriate nuclear data and dedicated analysis software [2], an accurately controllable and stable experimental setup is required.

In most commercially available IBA experimental chambers, 3-axis goniometers (x, y and z motions) are generally used for manipulation of the sample, while only a few samples could be loaded in the sample holder [3,4]. For these 3D bellows type positioning systems, it is difficult to adjust the elevation of sample surface from sample holder to keep the beam spot on the same sample point when the tilt is changed. To overcome the drawbacks of commercially available IBA reaction chambers, a versatile user-friendly multi-purpose experimental chamber with a number of distinct features leading to reproducible, accurate and more reliable measurements was developed and will be presented in this work. In fact, to facilitate the experimental handling in different IBA experiments and increase the accuracy of the measurements, various possibilities of adjusting the sample position and orientation together with the multi-sample arrangement on a wheel are foreseen.

2. Motivation

Geometrical parameters in ion beam analysis experiments are of great importance and have to be very well defined. Especially, if one or more of the angles are not consistent, significant errors can occur and misleading data can be collected. Since the direction of incident beam is generally very well defined and the position of the detector is mostly predetermined, the sample surface is the only parameter which can be changed from one sample to the other. Therefore, if samples of different thicknesses are analyzed, one has to adopt proper measure to adjust the elevation of the sample surface from the sample holder. The uncertainty originated from geometrical imperfections has already been observed and reported for different IBA techniques. For example, in PIXE analysis, uncertainty due to 1 mm sample thickness variation in a conventional IBA setup leads to a considerable change in the quantification of light elements [5]. Moreover, the geometric deviations in hydrogen depth profiling by ERDA are comprehensively

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addressed. In fact, variation of incident and recoil beam path lengths as well as kinematic shift can be originated from geometrical deviations [6,7]. A numerical example shows the experimental error due to a typical geometrical imperfection on the analysis results. Based on the equations derived by Verda et al. [6], kinematic energy shift of the recoiled H atoms due to 2 mm deviation in target position for a typical ERDA experiment with 1.8 MeV $^4He^+$ ions, is derived to be 30 keV (incidence angle of 70°, $\theta = 25°$, target to detector distance of 100 mm). Obviously, this energy shift is a considerable error in H depth profiling and cannot be neglected.

In the present work, by development of a versatile experimental chamber, efforts are made to facilitate precise and reliable IBA measurements. Using this experimental chamber, IBA capabilities and in particular NRA and ERDA techniques are enhanced. Moreover, RBS measurement can be carried out at grazing beam incidence and/or exit. Obviously, in such an optimized geometry, it would be possible to achieve excellent depth resolution and to determine film parameters including thickness, uniformity and stoichiometry more accurately [8]. In addition, by employment of the developed setup, one particular sample can be analyzed at different angles.

3. Design

3.1. Experimental chamber

The experimental chamber is composed of three main components: cylindrical wall, fixed bottom plate and hinged cover plate as schematically shown in Fig. 1a. The thick cylindrical wall made of an aluminum alloy with an inner diameter of 350 mm and height of 300 mm is designed thick enough to machine a number of facets on the outer surface to be used for the connecting ports. While the bottom plate is fixed and vacuum-sealed to the cylindrical wall, the hinged cover plate can be handled for loading the samples. The small side ports at the scattering angles of 0°, 30°, 60° and 180° are dedicated for beam entrance, beam exit and installation of viewing window, vacuum gauges and vacuum feedthroughs. On the other hand, large side ports at the scattering angles of 90° and 135° are dedicated for mounting HPGe and Si(Li) detectors in the chamber, respectively (Fig. 1b).

The chamber is evacuated using the combination of a backing pump and a turbo-molecular pump. The typical vacuum under operational conditions is better than 2×10^{-6} torr and it takes less than 3 min to reach this vacuum after changing the samples.

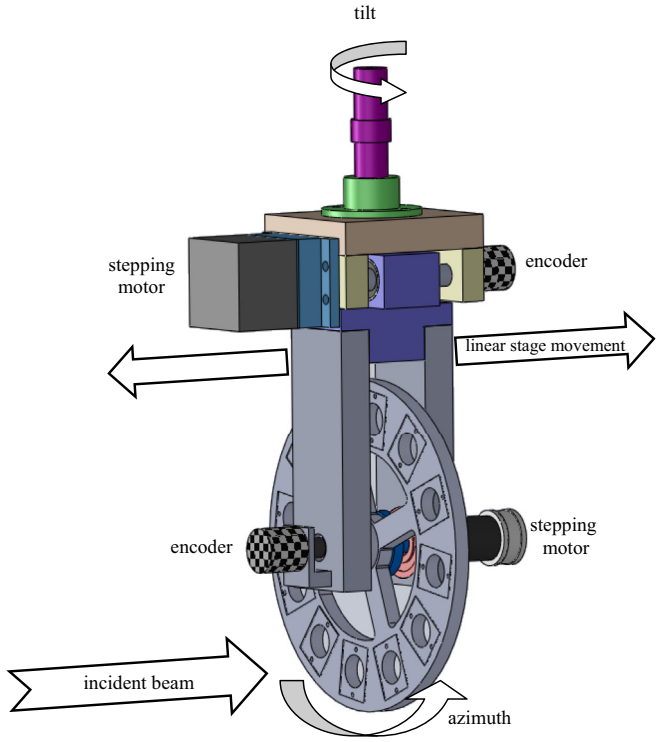

Fig. 2. Modeled sample positioning system: tilt (0–180° ± 0.1°) and azimuthal (0–360° ± 1°) rotations as well as linear (10 mm ± 0.1 mm) movement are driven by stepping motors.

Charge measurement can be performed either directly by connecting the charge integrator to the Faraday cup (and the isolated sample wheel) or indirectly, using the simultaneous RBS analysis. In the latter case, the total accumulated charge of the particular experiment can be obtained by simulation of RBS spectrum on well-calibrated RBS experimental setup for a certain sample.

3.2. Sample manipulator

In the design of the sample manipulator, the following technical requirements have been taken into account:

- Placing the sample in the desired tilt angle.

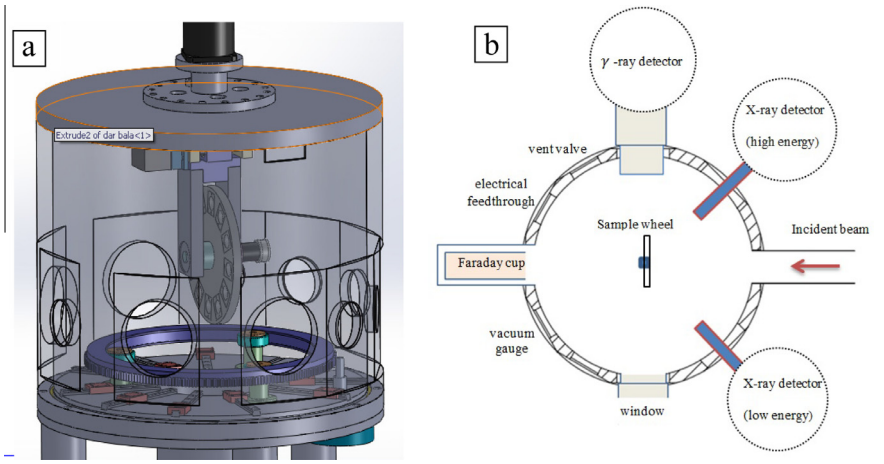

Fig. 1. (a) Modeled experimental chamber including cylindrical wall, fixed bottom plate and hinged cover plate, (b) a schematic top view of the chamber indicating the relative position of beam and detector ports.