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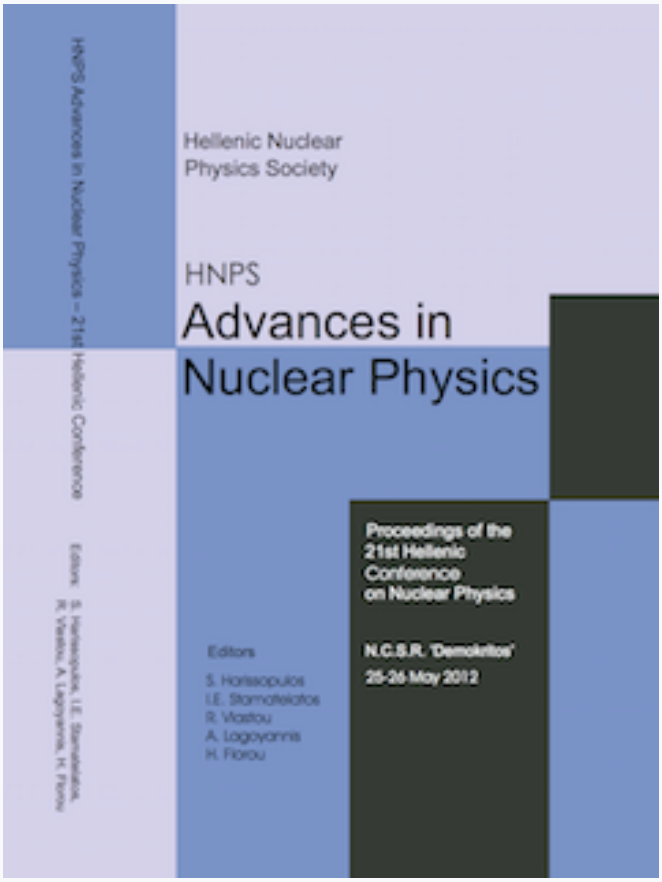
HNPS Advances in Nuclear Physics

Vol 20 (2012)

HNPS2012



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doi: 10.12681/hnps.2502

To cite this article:

Kanellakopoulos, A., Lagaki, V., Mertzimekis, T. J., & Paneta, V. (2012). Characterization of Nuclear Targets and Thin Films Using Ion-Beam Techniques. *HNPS Advances in Nuclear Physics*, *20*, 160–163. https://doi.org/10.12681/hnps.2502

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Characterization of Nuclear Targets and Thin Films Using Ion-Beam Techniques

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Abstract

We report on the characterization of nuclear targets and thin films using standard ion-beam techniques at the Tandem Accelerator Laboratory (TAL) of INPP, NCSR "Demokritos". The characterization was carried out with the application of Rutherford Backscattering and standard Nuclear Reaction Analysis using both large and small goniometric chambers available at TAL. Results from the measurements and simulations are presented.

Keywords: Targets Characterization, Ion Beams

1. Introduction

Why Ion-Beam Spectroscopy? Ion-beam spectroscopy is our way of seeing the fine structure of matter at atomic and subatomic level. The ion-beam spectroscopy is, in fact, a collection of techniques that were developed at the dawn of nuclear science and are rather well understood. These techniques are based on the interactions between ion beams and matter, which can lead to various particles' emission. The properties of the emitted radiation may reveal important information on the examined material that we can further combine to alternative types of investigation, such as geochemical, material, chemical or health studies.

Due to the high demand for applications of nuclear physics in several disciplines, such as nuclear technology, materials science, biology and geosciences, ion beams are now routinely used. In the present work, ion beams were used to characterize natural carbon foils and thin films. The former were manufactured for multipurpose use, including their use as ion-stripping foils for the TANDEM accelerator beam production, and as targets in future spectroscopy experiments. The latter were foils of unknown properties made prior to the present work.

Elastic Rutherford backscattering (RBS) and Nuclear Reaction Analysis (NRA) were applied to measure thicknesses, layers composition and stoichiometry of the targets and foils.

2. Experimental Methods

Natural carbon thin foil targets were manufactured at the accelerator's chemistry lab using the physical evaporation deposition technique. These targets, along with a bunch of earlier made targets provided by other labs, of various elemental compositions with unknown thickness, layers structure and stoichiometry (NiO, ZnO, Ti, LiF, CaF_2, Al - see also Table 3) were subjected to characterization using RBS and NRA spectroscopy techniques.

Measurements were performed at the large and small scattering chambers of the Tandem accelerator lab of NCSR "Demokritos". Proton and deuteron ion beams were used with energies ranging between 1500 and 2300 keV. Radiation was detected by silicon surface-barrier detectors (SSB) (of 8 mm diameter and $\simeq 100$ nm thick), positioned at detection angles of 150° and 170° with respect to the incident beam and 20 cm away from our samples. An additional SSB was used at 160° in the large goniometer setup. The whole setup was monitored by a in-vacuum camera. The targets were irradiated with beam currents $I \simeq 5$ nA and for a total time of $t \simeq 20$ min.

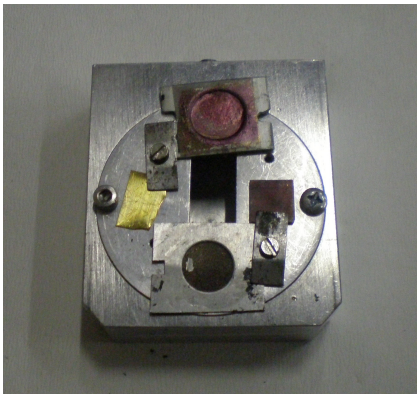

Figure 1: A sample holder with mounted LiF and ^{nat}C targets. A gold foil (left) was used as current calibration.

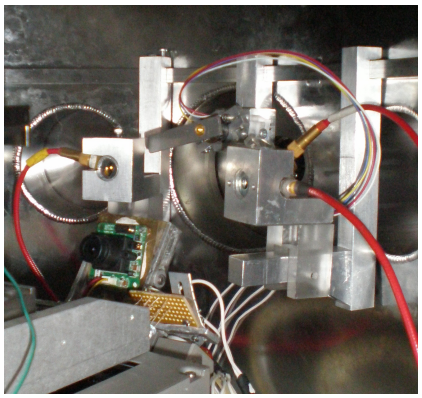

Figure 2: The interior of the RBS chamber. Two SSB detectors, the camera and the chopper are clearly visible.

3. Analysis and Results

Using the spectroscopy techniques mentioned above several spectra were collected over a period of a week. Spectra analysis and simulations were carried out using SIMNRA [2], a specialized software suitable to simulate IBA & NRA spectra.

For charge calibration, we used a specially designed instrument, called *chopper*, which is made of a think gold film attached to the end of an aluminum bar capable of pivoting between two preset positions (angles). The chopper can be positioned so that it may interrupt the beam path. At one position it lets

the beam particles enter the scattering chamber unobstructed and irradiate the target, while at the other one it interrupts the beam causing its particles to scatter on its gold foil. Those scattered particles are collected by a dedicated SSB detector positioned exactly behind the aluminum bar. We can manage its timing manually, so that in our experiment it was set up for 5 *sec* out of the way of the beam and 1 *sec* interrupting it. The total number of scattered particles divided by the irradiation time gives us the current of the beam.

RBS cross sections have been calculated by SIMNRA for any combination of beam particle-target at any given geometry using the analytical formula. In addition, SIMNRA contains an extensive database of cross sections for nuclear reactions unlike RBS. These data cross sections can be downloaded from online sources, such as the most common one, IBANDL, which is provided by IAEA [3]. In case a nuclear reaction is not measured for specific beams, target, energy and detector angle combinations, IBANDL provides the evaluated algorithm SigmaCalc to interpolate the data.

Some typical spectra are illustrated in Figure 3. After several attempts to optimize spectra simulation, foil thicknesses were deduced. There results are presented in Table 3.

Target	**Beam**	**Energy** $[keV]$	**Thickness** $[\mu gr/cm^2]$	**Comments**
LiF	d	1550	218	Contains various layers such as Li, F, B, Be, C, Au
^{nat}C	d	1550	50	Noise at low energies at 170°
ZnO	p	1500	142	Contaminated with SiO_2
NiO	p	1500	187	Contaminated with SiO_2
^{nat}Ti	p	1500	877	Contaminated with ^{17}F
^{27}Al	p	1500	∼1 mm	Contaminated with B, O, Na
^{27}Al	p	1600	0.5	Various resonance energies
CaF_2	p	1540	∼8 mm	^{17}F resonance
CaF_2	p	1600	∼8 mm	^{17}F resonance
CaF_2	d	1900	∼8 mm	Low statistics on (d,p) reactions
CaF_2	d	2300	∼8 mm	Low statistics on (d,p) reactions

Table 1: An aggregated list of the samples measured with IBA and NRA. Thickness is in $\mu gr/cm^2$ unless noted otherwise.

Target thicknesses are shown in units of $\mu gr/cm^2$ except when samples are too thick for the beam to pass through. These thicknesses are given in mm and have been measured with a caliber. There were no available data in IBANDL for the ^{19}F (d,p) & (d,a) reactions at 160° or 170°.

In LiF, traces of Ba and Be were found as byproducts of the manufacturing process. In addition, a layer of F in the Ti spectrum is present, originating from the standard natural metals composition.

The contamination of SiO_2 at ZnO and NiO spectra comes from the fact that the evaporated material was deposited on a glass frame known to consist

of Si compounds. Any traces of ^{nat}C that was present in our spectra are due to sample contamination with organic residues coming from human activity with the target or as a residue from the evaporation chamber. Noise at low energies at 170° for the carbon spectrum did not allow for seeing clearly the RBS peaks.

In addition, for the case of CaF_2 samples the current at every detector differs, as the geometry of the scattering chamber provided limited space for positioning them at the same distance form the target without causing obstruction to the beam at the entrance of the chamber.

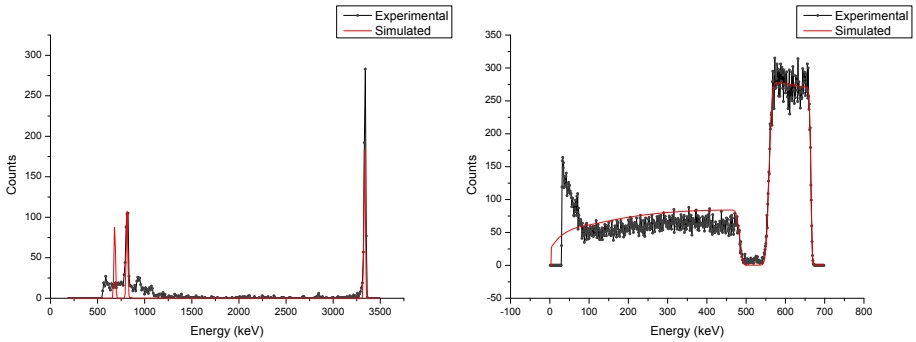

Figure 3: *Left*: A typical spectrum of a thin ^{nat}C bombarded with deuterons of $E_d = 1550$ keV acquired at an angle of 150° *Right*: A typical spectrum of a ^{nat}Ti thin film irradiated with a proton beam of $E_p = 1500$ keV at 150°

4. Conclusion

A number of various targets were characterized at the Tandem Accelerator of NSCR "Demokritos". Using RBS and NRA spectroscopies, the thickness, layers structure and stoichiometry of these samples were measured.

Acknowledgments

We would like to thank the staff of the Institute of Nuclear and Particle Physics of NSCR "Demokritos" for the pleasant atmosphere they created at the lab and their help with our questions and spectra analysis.

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