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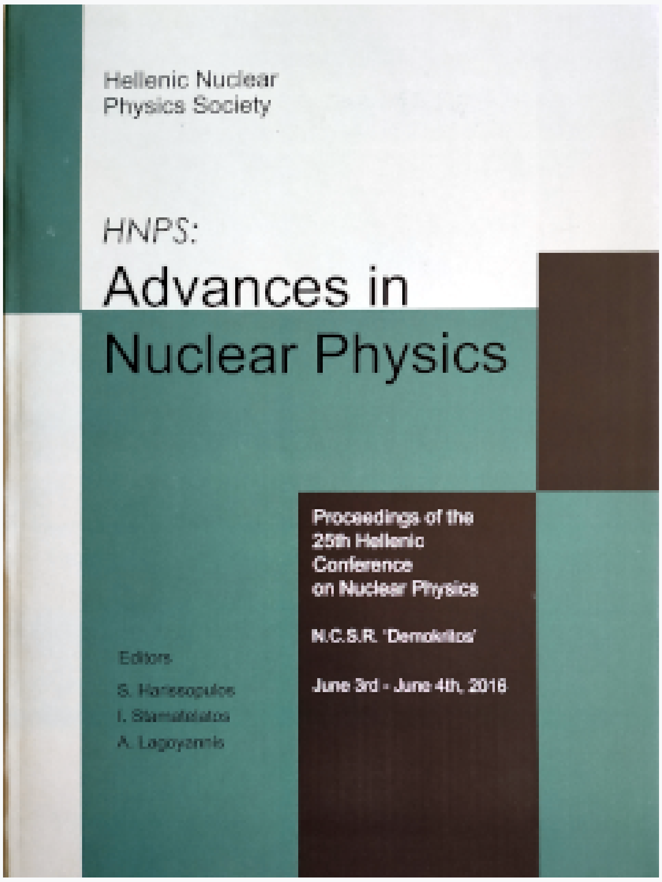

Construction and Ion-Beam Characterization of Nuclear Targets

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Construction and Ion-Beam Characterization of Nuclear Targets

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Abstract We report on the construction and ion-beam characterization of nuclear targets and thin films as part of the ongoing NuSTRAP group research program at the University of Athens. Two different techniques were used for the preparation of new targets, depending on the desired material and thickness. Self-supported, natural silver targets were manufactured by Physical Evaporation Deposition (PVD) through electrical resistance heating, using the evaporation apparatus at the INPP (NCSR "Demokritos"). Thick iron targets were constructed using the rolling technique at the INRASTES (NCSR "Demokritos") facilities. The Rutherford Backscattering Spectrometry (RBS) was employed to characterize the newly manufactured and existing targets using proton and deuteron beams accelerated by the Tandem Van de Graff Accelerator (at INPP) at several energies. The results from the analysis of experimental spectra and corresponding simulations carried out with the simNRA software package are presented.

Keywords target, cold rolling, PVD, RBS, stopping power

INTRODUCTION

In recent years, the NuSTRAP group at University of Athens have invested significant time in research activities using light and heavy ions impinging nuclear targets. In such studies, the nuclear target characteristics need to be selected carefully to optimize the experimental output.

In nuclear structure experiments involving magnetic-moment measurements with the Transient Field Technique (TF) very strong magnetic fields (~20'000 Tesla) are produced as an ion trespasses a ferromagnetic layer, vastly exceeding those produced by any type of electromagnet or superconducting magnet. Common ferromagnetic hosts are iron or gadolinium foils, the latter requiring cooling at LN_2 temperatures (77 K). Despite Fe foils present lower saturation magnetization than Gd ones they can be used in room temperature and are the first choice for TF experiments. In nuclear astrophysics studies, isotopic materials are highly desirable as nuclear targets. Thin layers can be manufactured by thermal evaporation of the material of interest subsequently deposited on a substrate (PVD).

In the present work, two techniques have been employed in manufacturing nuclear targets for future experiments: *thermal evaporation* and *cold rolling*. The former was used to produce self-supported thin films made of natural silver (abundance: 51.8% ^{107}Ag, 48.2% ^{109}Ag), while thick iron foils were manufactured with the latter. These foils and some existing ones (^{112}Cd, ^{106}Pd) have been characterized using ion-beam analysis (RBS) at the Tandem Accelerator Laboratory (INPP, NCSR "Demokritos"). A part of this work is presented here.

CONSTRUCTION OF TARGETS

Physical Vapor Deposition (PVD)

A small amount of ^{nat}Ag material (≈2g) was placed in a specially formed refractory tantalum container (boat). High electric currents were released through the boat causing melting of the silver due to extreme heat. The material evaporates onto glass plates placed at

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a small distance from the boat (about 15 cm above). The whole setup is inside a chamber remaining under high vacuum throughout the procedure (Fig. 1). Once the evaporation stops, the plates are immersed in a bath (floating method) and thin layers are carefully removed and adhered to metal frames (Fig. 2).

Fig. 1 The material before (left) and after (right) evaporation in the chamber.

Fig. 2 The floating method (left) and the target holders (right)

Cold Rolling

Due to difficulties in evaporating ^{56}Fe [3], a different method was applied. Thick iron foils were manufactured with a rolling device at the facilities of INRASTES (NCSR "Demokritos"). The rolling technique is commonly used in metalworking and it constitutes in passing a thick piece of metal through two manually-rotating metal cylinders repeatedly in order to reduce its thickness (Fig. 3) [4]. In the present work, a 99.99% pure iron disk of initial thickness of 0.1 mm was rolled to reach a final thickness of 12 μm (Fig. 4). Impurities deposited on the surface of the iron disk before rolling were removed by placing the sample in an ultrasonic cleaner (Fig. 5).

Fig. 3 The Rolling Machine

Fig. 4 The prepared Iron foil

Fig. 5 The Ultrasonic Cleaner

ION-BEAM CHARACTERIZATION

Theoretical Background

Backscattering spectrometry (RBS) using low-mass ion-beams with energies in the MeV range has been used extensively for accurate determination of stoichiometry, elemental areal density, and impurity distribution in thin films. Measurement of the number and energy distribution of ions backscattered by atoms in the near-surface region of solid materials allows the identification of the atomic masses and the determination of distribution of the target elements as a function of depth below the surface [1].

Rutherford Backscattering is an elastic collision between a high kinetic energy particle from the incident beam (the *projectile*) and a stationary particle located in the sample (the *target*). Considering the kinematics of the collision (i.e. the conservation of momentum and kinetic energy), the energy E_2 of the scattered projectile is deduced from the initial energy E_1:

$$E_2 = E_1 \cdot \left\{ \frac{\sqrt{m_2^2 - m_1^2 \sin^2\theta} + m_1 \cos\theta}{m_1 + m_2} \right\}^2$$

where particle 1 is the projectile, particle 2 is the scattered projectile, and θ is the scattering angle of the projectile. The *differential cross section of the reaction* is given by

$$\sigma(\mathrm{E}_1, \theta) = \frac{d\theta}{d\Omega} = \left(\frac{\mathrm{Z}_1 \mathrm{Z}_2 e^2}{4E_1} \right)^2 \frac{4\left[\sqrt{m_2^2 - m_1^2 \sin^2\theta + m_2 \cos\theta} \right]^2}{m_2 \sin^4\theta \sqrt{m_2^2 - m_1^2 \sin^2\theta}}$$

EXPERIMENTAL SETUP

Deuteron beams were accelerated by the Tandem Van de Graaff Accelerator of the INPP, NCSR "Demokritos" at 1500 keV and impinged on thin silver foils. Backscattered particles were detected by a Si detector (SSB) placed at 170^{o} with respect to the beam axis. Thick Au foils were used to calibrate the spectra and obtain information on the total charge deposited on the foils. After simulating the collected spectra with the simNRA program [2], target thicknesses were calculated.

RESULTS

<u>*^{nat}Ag spectrum*</u>

The RBS spectrum of ^{nat}Ag is shown in Fig. 6. The main energy peak is appeared at E_{Ag}=1354 keV. A step is formed at energy E=984 keV due to ^{28}Si contained in glass plates. Two additional energy peaks are identified. The first one, at E=806 keV, belongs to ^{16}O and the second one, at E=654 keV, belongs to ^{12}C. Cross sections for deuterons on the indicated elements are nearly Rutherford. Table 1 shows the areal densities of target elements.

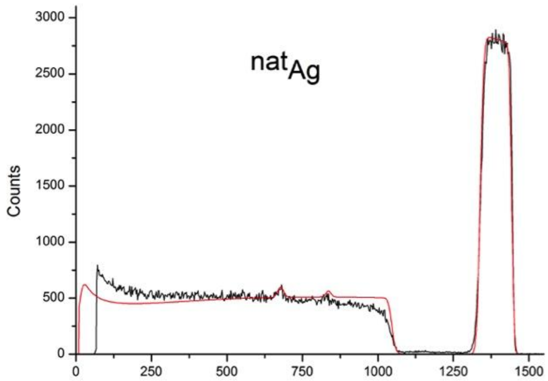

Fig. 6 The RBS spectrum of ^{2}D beams on ^{nat}Ag target.

Table 1 ^{nat}Ag target composition

Layer No	*1*	2	3	4
Layer composition	^{nat}Ag	^{16}O	^{nat}C	^{28}Si
Thickness (mg/cm^2)	0.4	0.009	0.2493	1.7

<u>*^{112}Cd spectrum*</u>

The higher energy part of ^{112}Cd spectrum is shown in Fig. 7. Two energy peaks are identified. The main one, refers to ^{112}Cd at energy E=1427 keV and to ^{209}Bi at energy E=1384 keV. The backscattering peaks overlap. Cross sections for deuterons are purely Rutherford.

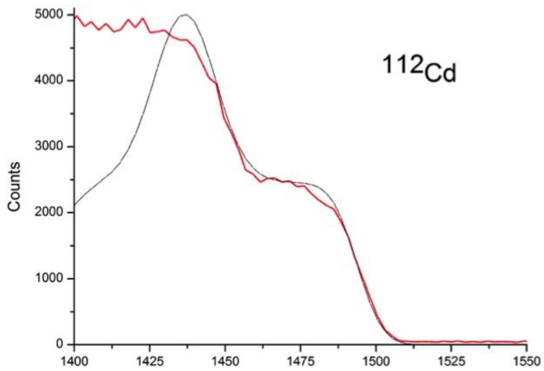

Fig. 7 The RBS spectrum of ^{2}D beams on ^{112}Cd target

A comparison between initial and final thickness is shown in Table 2. The large value difference is due to foil degradation after irradiation and has to be taken into account.

Table 2 ^{112}Cd target layer thickness

	^{112}Cd
Initial Thickness (mg/cm^2)	1.2
Final Thickness (mg/cm^2)	0.448

STOPPING POWER CALCULATIONS

Prior to ion-beam analysis, a study was undertaken to select the optimal conditions for beam energies depending on the estimated thickness of the rolled iron foils. The range of an incident beam of protons with varying energies, in a Fe target of 12 μm, was calculated with SRIM (v.2013) [5]. SRIM uses the Monte Carlo method to calculate the backscattered ions, the transmitted ions and the beam stopping power due to the interaction with the target particles. The number of events during simulation was in the range of 100’000 events (see Fig. 8).

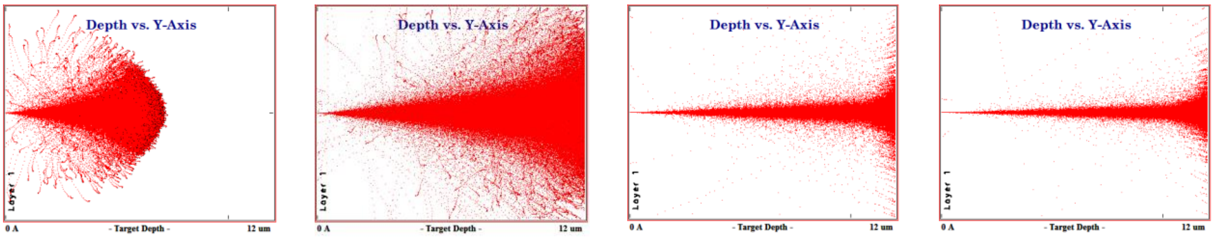

Fig. 8 SRIM2013 simulations of proton beams impinging a 9.4 mg/cm^2 thick ^{nat}Fe target at various energies

CONCLUSIONS

Two different target preparation techniques were used to produce self-supported foils to be used as nuclear targets in future experiments. The foils were simulated and characterized with ion beams with respect to the thickness, composition and beam stopping powers. The results show that the foils fall within the specification range required by the experimental techniques.

Acknowledgments

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