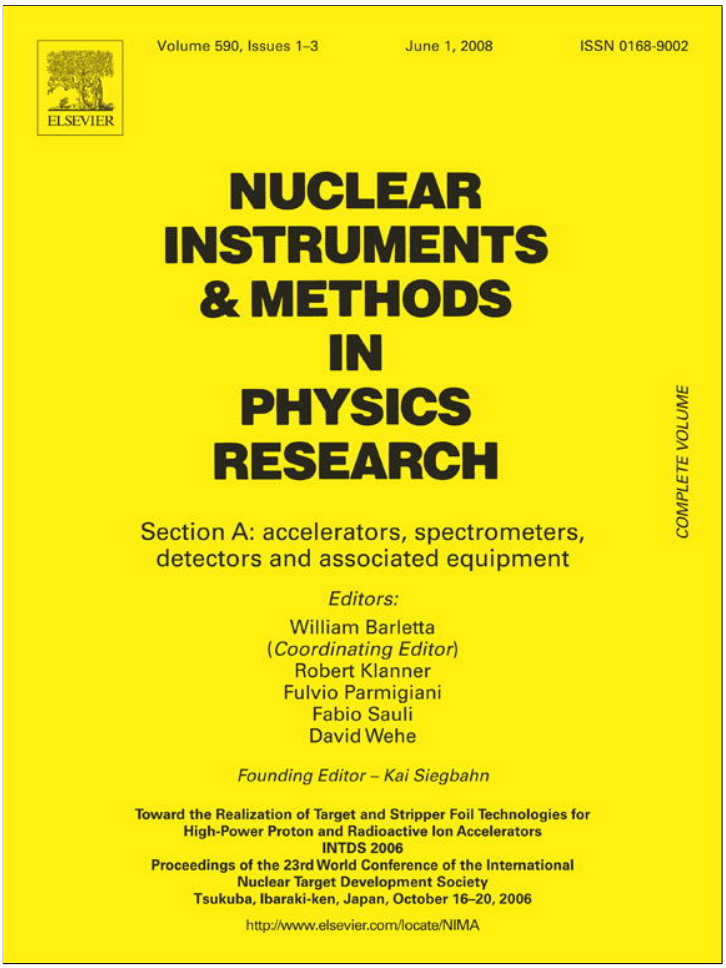

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Boron foils for RDDS experiment

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Abstract

Application of the deposition method based on the vibrational motion of micro particles in an electrostatic field [I. Sugai, Nucl. Instr. and Meth. A 397 (1997) 81] is described for the production of isotopic ^{11}B foils. The method proved suitable for target production of this typically brittle material when a very flat target surface was required. The goal to produce ^{11}B targets of 160–350 μg/cm^2 was achieved by depositing the boron on a thin foil substrate, such as Nb and Sn. The coated foil was stretched flat before it was mounted on a frame.

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1. Introduction

The recoil-distance Doppler-shift (RDDS) method is one of the most powerful and precise experimental techniques for the determination of excited nuclear-state lifetimes. With this technique, nuclear lifetimes in the range of hundreds of picoseconds to tenths of a picosecond can be measured [2]. In the last couple of decades, with the invention of feedback plunger devices [3] and the introduction of the differential decay method [4,5] for analyzing RDDS data, most of the inherent problems [2] of the RDDS method have been solved. RDDS measurements are now often considered as decisive and final with respect to the physics questions they are addressing. However, there are two interconnected limitations which prevent a wider use of the RDDS method. These are, namely, the type of reactions necessary to produce the nuclei of interest and the requirement for flatness of the stopper and the target foil [2].

Most of the RDDS results for medium- and high-spin states in nuclei have been obtained in fusion–evaporation reactions. However, the number of these reactions that lead to neutron rich residual nuclei around the line of stability is severely limited. The available reactions of this type, particularly in the mass $A = 100$ and 130 regions, usually involve light-ion beams (^{7}Li, ^{9}Be, ^{11}B, ^{12,13}C). As a result, the recoil velocity of the residual nuclei is smaller than 1% of the speed of light. This makes impossible the use of RDDS method for lifetimes on the order of 1 ps or less because the time of flight between the target and the stopper becomes too large. Apparently, one possibility to overcome this problem is to use fusion–evaporation reactions in inverse kinematics. For instance, the ordinary kinematics reaction ^{96}Zr(^{11}B,3n)^{104}Rh at 40 MeV beam energy provides a recoil velocity of 0.9% of the speed of light, while the analogous inverse kinematics reaction ^{11}B(^{96}Zr,3n)^{104}Rh at 350 MeV beam energy provides a recoil velocity 7.9% of the speed of light. Consequently, the sensitive distances in ordinary kinematics are about 2–3 μm/ps, which are extremely difficult if not impossible to achieve and maintain during the experiment. On the other hand, in inverse kinematics the sensitive distances are about 23–24 μm for lifetimes of 1 ps, which are not a problem for contemporary plunger devices [3]. RDDS measurements in inverse kinematics also require some changes in the plunger arrangement—it is much more beneficial to use a degrader foil instead of the classical

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stopper. Such a configuration has been used in plunger measurements in inverse kinematics [6] and its potential for radioactive-ion beams is apparent.

Heavy-ion beams are available at big LINAC accelerators, like ATLAS at Argonne National Laboratory or ALPI in Legnaro, Italy. However, ensuring the flatness of the target and the stopper/degrader foil still remains a problem. Sufficiently, flat foils that remain flat under beam bombardment can be made by using the technique described in Ref. [7]. This technique requires use of sufficiently rigid, stretchable foils (Cu, Ni, Nb, Sn, Ta or Au). Below we report on a method that produced a stretchable ^{11}B-on-^{93}Nb target for RDDS measurements with inverse kinematics reactions. The method is completely generic for the experiment and we think can be applied to other materials, such as Be or C.

2. Procedures

2.1. Experimental setup

The simple, capacitor-like setup used followed the basic principles of the deposition method described by Sugai [1], later named high-energy vibrational powder plating (HIVIPP) [8]. It consisted of two parallel, metallic flat-plate electrodes separated by a glass cylinder (Fig. 1). During the deposition, negative high-voltage potential (through a high-value, current-limiting resistor) was maintained on the upper plate. The lower plate was at ground potential. The glass cylinders in Fig. 1 (10, 15 and 20 mm diameter and 10–25 mm height) can be interchanged depending on the required size of the target (Fig. 1). Prior to the deposition, the assembly with ^{11}B powder inside was placed in a vacuum chamber and connected to a regulated DC power supply via copper leads and a high-voltage feedthrough. The vacuum chamber was then evacuated and no special attention was paid to the quality of vacuum inside the glass cylinder.

2.2. Target materials

The target-backing foils were Niobium and Tin rolled to 4 mg/cm^2 and cut into circles with the diameter corresponding to the outside diameter of the glass cylinder. For each run, foils of the same element were held by the glass cylinder in contact with the upper and lower electrode plates. Inside the assembly was 50 mgs of enriched isotopic ^{11}B powder ground by hand in a mortar and pestle. The grinding was required because available powder had significantly larger grain/particle size than suggested by Sugai.

2.3. Boron deposition

With a pressure of $\sim 10^{-3}$ Pa in the surrounding vacuum chamber, an initial potential difference of about 2 kV was applied between the electrodes. This was increased gradually in increments of 1 kV. At about 8 kV, one could clearly observe powder movement inside the glass cylinder. That, and other values of 8, 10, 12, 14 and 16 kV were held until the current draw indicated little powder was vibrating between the electrodes. In all cases, the current observed was less than 0.1 mA. The deposition time was different and as much as 15 h for each applied voltage. Above 17 kV, a violent discharge inside the glass cylinder was observed; hence, all depositions were below this value. Our observations also agreed with Sugai's results that higher voltages and longer exposure times of B powder to the electrostatic field resulted in thicker deposits on both the upper and lower substrates [1]. Because the boron grain size for each run was unknown, we did not attempt to look for systematic effects that might indicate a correlation between the deposition time required and the electrical potential

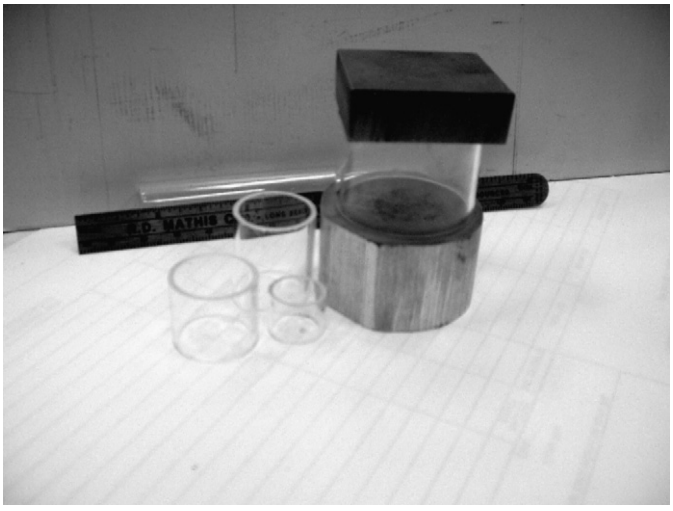

Fig. 1. Glass cylinders used in several boron depositions. The tube between the metallic plates/electrodes placed in vacuum creates a deposition capacitor.

Fig. 2. Frames with foil ready for a stretching test on a conical-shaped Al base.

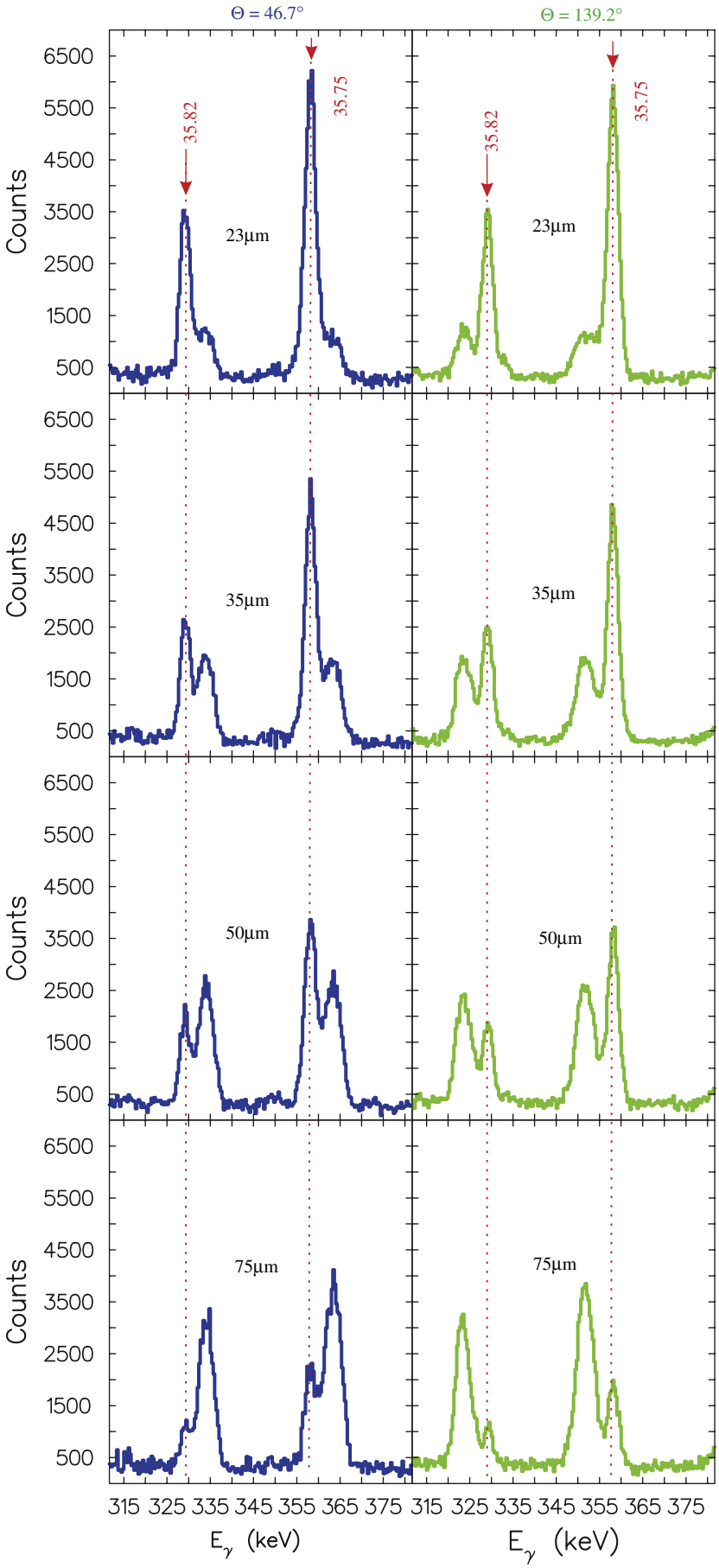

Fig. 3. Sample γ-ray spectra gated on the 158.0 keV ($9^- \rightarrow 8^-$) transition in ^{104}Rh [7] at four target-to-degrader distances. The spectra are Doppler corrected with respect to the recoil velocity after the degrader. The positions of the 357.5 keV ($10^- \rightarrow 9^-$) and the 328.5 keV ($11^- \rightarrow 10^-$) transitions in ^{104}Rh [7] are indicated.

applied to the electrodes. To increase the thickness of the deposit beyond that achieved with −16 kV, the procedure was repeated with a new load of ground boron powder.

2.4. Target properties

Several targets were made with ^{11}B deposits ranging 160–350 μg/cm^2 in areal density. All displayed uniform surfaces when examined with 50 times magnification. Stretching the foils (Fig. 2) failed to produce visible cracks in the thinnest or thickest boron layer until the backing foil tore. The stretched targets presented a uniform, flat surface to the accelerated particle beams. This allowed the distance between target and stopper to be within a few microns, the plunger device limitation.

3. Target performance

The inverse kinematics reaction ^{11}B(^{96}Zr,3n)^{104}Rh for which the targets were made had as the primary goal to measure the lifetimes of states in the chiral bands of ^{104}Rh [9]. A stretched ^{11}B target, as described in the previous section, was used with a ^{96}Z beam of 320 MeV delivered by the ATLAS accelerator at Argonne National Laboratory. The emitted γ-rays were detected with the Gammasphere array, used in this experiment in conjugation with the Cologne plunger device [2]. The target chosen consisted of a 270 μg/cm^2 ^{11}B deposit on a backing of 4 mg/cm^2 ^{93}Nb. The Boron layer faced the beam. The degrader was 3.5 mg/cm^2 ^{93}Nb foil.

Electrical contact between the stretched target and the degrader in vacuum occurred at a separation distance of 4 μm. Data were taken at seven relative distances in the following order: 15, 100, 8, 35, 23, 50 and 75 μm. The target was able to sustain beam intensities between 0.6 pnA at 8 μm to 2.5 pnA at 100 μm. At higher intensities, the temperature vibrations become intolerable.

In this arrangement, ^{104}Rh ions leave the target with recoil velocity of 5.7% of the speed of light. After the degrader, their velocity decreases to 3.19% of the speed of light. As a result some γ-ray transitions in ^{104}Rh are split into two components, corresponding to the Doppler shifts for the speeds before and after the degrader. The data were Doppler corrected with respect to the lower speed and sorted in RDDS matrices which contain γ–γ coincidences observed between the detectors in the forward hemisphere (Gammasphere rings 2, 3, 4 and 5; $\theta_{aver} = 46.7^\circ$) or between the detectors in the backward hemisphere (Gammasphere rings 13, 14, 15, 16 and 17; $\theta_{aver} = 139.2^\circ$). Examples of spectra taken at four different distances for two transitions in ^{104}Rh are shown in Fig. 3.

4. Conclusion

We believe the boron deposits are in the form of tightly packed powder, with density depending on the voltage applied to the electrodes during target production. They are also sufficiently flexible (not brittle) to withstand stresses created during stretching, and strongly adhere to the substrate material, preventing peeling during and after exposure to a ^{96}Z incident beam of 2.5 pnA.

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