Encapsulated Sulfur targets for light ion beam experiments

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Abstract. A new method was developed to produce enriched Sulfur targets with minimum loss of material. This was made possible by inserting Sulfur in-between two 0.5 µm Mylar foils ($C_{10}H_8O_4$). The initial aim was to ensure that the Sulfur targets reduce by no more than 50% of the initial thickness within 24 hours under the equivalent of 10 J/cm^2 of integrated energy deposition by an energetic (E_b > 50 MeV) proton beam. There is no loss of enriched material while making the target, as all the material is deposited within the surface area to be exposed to the beam. During beam irradiation, the targets were frequently swivelled in order to expose each part of the target to the beam and achieve homogeneous irradiation. Targets of 0.4 mg/cm^2 thickness were produced and characterised using ion beam analysis technique with a 3 MeV proton beam.

1 Introduction

Sulfur targets for energetic light ion beam experiments using direct reaction measurements pose certain challenges. Elemental Sulfur targets cannot be produced as self-supporting and this element sublimes rapidly in vacuum when subjected to energy deposition during beam bombardment. When less abundant Sulphur isotopes ($^{33,\ 34,\ 36}$S) are required financial implications may limit the amount of material that is available. For instance, with only 0.01% natural abundance ^{36}S material is on the higher end of the price list of enriched materials especially if very high purity is required. Previously Sulfur targets were made available in compounds namely Cadmium, Silver, Mercury and Antimony Sulfide [1]. These types of targets were successfully used for neutron-rich nuclei studies in the N=20 region [2-5]. For direct reaction experiments such as (d,p) transfer reactions heavy contaminants are highly undesirable as they lead to many states from the substrate being populated making it difficult to distinguish the states of interest from the contaminants. Furthermore, the cross sections for scattering of the projectile are high which is also detrimental to charged particles detectors. To this respect, a method developed by Hogenbirk *et al.* [6] consisted of sandwiching evaporated Sulfur between evaporated layers and encapsulated between carbon foils. In this paper an alternative method to Sulfur evaporation was investigated to make the best use of enriched Sulfur material using direct powder deposition between Mylar foils. This development was undertaken to perform a nuclear physics measurement using the ^{36}S(p,d) reaction at El_{ab} = 66 MeV with a high resolution magnetic spectrometer at iThemba LABS [7].

2 Experimental Techniques and Equipment

2.1. Production of targets

The targets were produced by inserting Sulfur in between two thin Mylar ($C_{10}H_8O_4$) foils. The interesting part of this method is that while making the target there is no loss of material as it is all deposited within the surface area to be exposed to the beam. Two Mylar foils of 80 µg/cm^2, corresponding to 5.5×10^{18} atoms/cm^2, were "welded" together. This was done by applying heat on the Mylar using a temperature controlled copper cylinder. The temperature was adjusted so that the Mylar foils stick together and encapsulate 1 mg of Sulfur material with a surface area of approximately 1 cm^2 (1.9×10^{19} atoms/cm^2). The target frame consisted of two identical rings to support the Mylar foils as displayed in Figure 1 for examples of target before (left) and after

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(right) irradiation. The rings offer attachments for the swivelling system displayed in Figure 2.

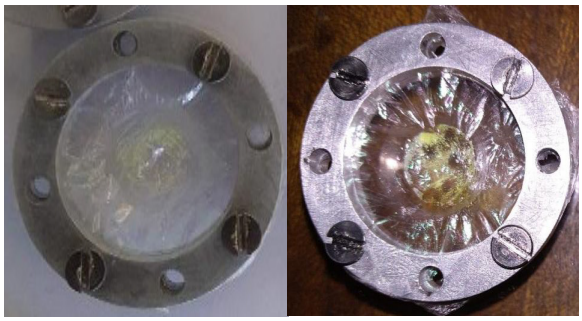

Fig. 1. 1 mg of Natural Sulfur deposited over a disk of 1 cm diameter. Left: target before irradiation, Right: target after 2 continuous days of irradiation with E lab = 3 MeV, I_b = 6 nA proton beam.

Mylar is a good material for encapsulating foils as the contaminants peaks observed are solely from C and O in the Mylar which are well accounted for and therefore do not interfere with our measurement. This was verified during EBS (Elastic Back Scattering) measurements where no discernible structure was observed between the proton energy corresponding to the oxygen elastic peak and the beam energy.

2.2 Elastic Back Scattering characterization

Elastic Back Scattering was performed at the iThemba LABS Material Research Department's (MRD) Tandetron facility. A 3 MeV proton beam was incident on a target made of natural S. A single silicon barrier detector was placed at Θ_{lab} = 135° relative to the beam axis. The natural S target was connected to two independent motors and suspended using springs. The motor and gearbox were mounted within the chamber with connecting rods pulling the target frame with a direction forming a 90° angle with respect to each other. The target is held by one or multiple springs pulling opposite to the motors as shown in Figure 2.

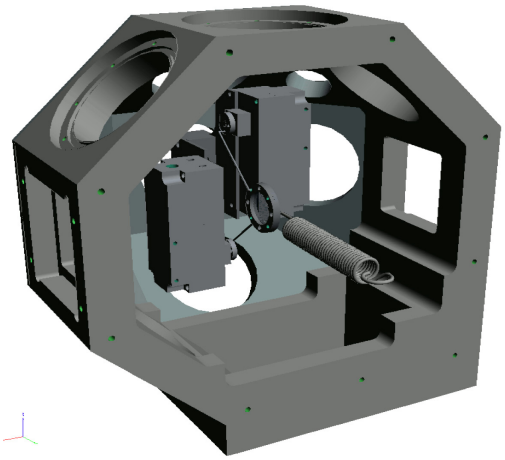

Fig. 2. Two-axis swivelling system to uniformly expose the target to the beam and hence energy deposition. The beam traverses the chamber from left to right. The sides and blanking flanges of the vacuum chambers are deleted from the 3D drawing for viewing purposes.

The target was moved regularly in sequences of 15 minutes in a swivelling motion to expose each part of the target to the beam and achieved homogeneous irradiation while Sulfur is continuously evaporated and sublimated within the space between the Mylar foils. The aim of the test was to evaluate the lifetime of how long the targets last when exposed to a 3 MeV proton beam and with the knowledge that less energy is deposited at a proton energy of 66 MeV allows for an estimating for the target lifetime for 66 MeV protons.

3 Results

The main drawback of this method is the varying target thickness (due to uneven distribution of material in the target), that can be detrimental using low energy beams. This can have implications in the overall energy resolution and can also be detrimental when performing cross section measurements. However, this method allows to employ extremely small amounts of some of the most expensive enriched materials.

Figure 3 displays the EBS spectrum recorded with a fresh target and after the equivalent of 12 hours of irradiation on the area containing natural Sulfur material. A SIMNRA analysis [8] indicates a very high roughness of the encapsulated layer. As the powder is deposited, the thickness varies substantially from areas with no material at all to areas with clusters or large grains. The overall thickness is measured as 450 μg/cm^2 from the fresh target. A relatively large roughness is needed to reproduce the Sulfur tail, and the single C and O peaks otherwise two distinct peaks for C and O would be visible with no roughness. This also produces the low-energy tail on the Sulfur elastic peak.

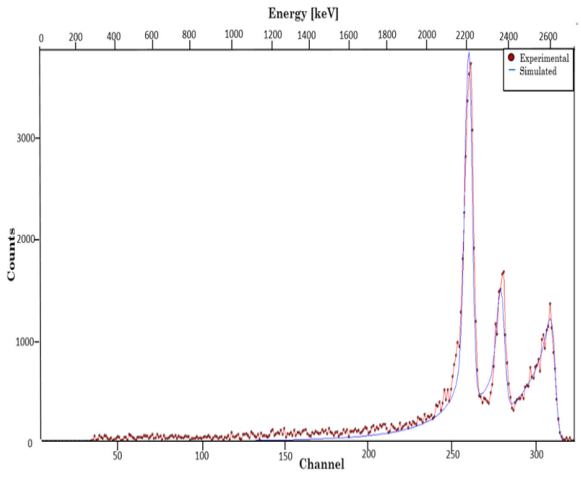

Fig. 3. EBS spectra obtained using the SIMNRA simulations comparing with experimental data.

Assuming a Gaussian distribution of the thickness, the FWHM roughness is 2 mg/cm^2. Considering the final application to this specific target using a 66 MeV proton beam, the resulting degradation of the energy resolution is expected to be δE = 15 keV through 2 mg/cm^2 of Sulfur material which is considered acceptable. It is not clear why half of the areal density is measured using EBS technique as compared to the expected 1 mg/cm^2

from the initial weighted material. It is conceivable that some material is lost during the "welding" process as heat is employed to 300º C for a short period of time. Some of the target material may also not be accounted for because of the large roughness and the possible related errors in the simulations. The targets lasted for approximately 48 hours of continuous irradiation with the 3 MeV proton beam.

Figure 4 shows the scalar spectrum obtained by integrating the Rutherford Back Scattering peak on Sulfur. The beam current was kept constant within +/- 10%. The Sulfur content decreased by 25% over the irradiation period. Considering only the heat deposition, it follows that the energy deposited as per SRIM [9] calculations by 3 MeV protons in 0.4 mg/cm^2 of natural Sulfur is 33.5 keV while that of the 66 MeV protons is 3.2 keV. The time it takes to lose 50 % of the target material is then given as follows:

$$Days = (dE(3MeV)\times 6)/(dE(66\ MeV)\times 10) \quad (1)$$

Where:
• dE(3MeV) - energy loss for 1 proton at 3 MeV in 0.4mg/cm^2 of S

• dE(66 MeV) - energy loss for 1 proton at 66 MeV in 0.4mg/cm^2 of S

Therefore assuming that only energy deposition is responsible for loss of material, it is possible to run for 6 days before losing 50 % of the target.

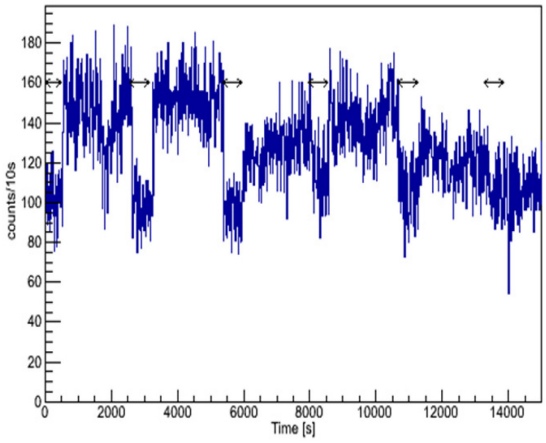

Fig. 4. Arrows indicate when the target is swiveling within region comprising Mylar-Sulfur and Mylar only areas. Target positions are selected when high Sulfur spots are found. The scaler plot is obtained for protons measured with energy E_p between 2.45-2.65 MeV. The accumulated time is 4 hours at I_b = 6 nA, E_b = 3 MeV.

4 Conclusion

The method of encapsulating Sulfur between two Mylar foils is an effective way to produce targets with an extremely small amount of material (0.5-1 mg/cm^2). Good tenure to heat deposition is observed using thin Mylar foils, but the main drawback is the relatively large roughness (FWHM = 2 mg/cm^2) which makes it unsuitable for nuclear reactions with heavy beams or low energy projectiles. Some of the material is not accounted for using EBS analysis. It is theorized to be lost during the welding process or missed because of the large roughness. Further improvements to reduce the roughness are envisaged by applying heat to the Sulfur during the encapsulation, however caution should be taken to avoid loss of Sulfur material.

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