Optimization of Evaporation Parameters and Fabrication of Natural Si target for in-beam Gamma ray Spectroscopy

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Introduction

The natural Si is hard, brittle crystalline solid with a blue-gray metallic luster. It is composed of three stable isotopes ^{28}Si, ^{29}Si and ^{30}Si having abundance 92.2%, 4.7% and 3.1%, respectively. The primary goal of our experiment is to perform gamma-ray spectroscopy in the mass region A$\sim$40, which is astrophysical important towards the endpoint of nova nucleosynthesis. For this, ^{12}C beam is going to be used on ^{28}Si target to populate nuclei by fusion evaporation reaction. As per reaction's optimized yield calculations, ^{28}Si target of thickness $\sim$400–900 μg/cm^2 on Gold (Au) backing of thickness 6-7 mg/cm^2 has been proposed. As natural Si is cost-effective hence can be used for target fabrication trials to optimize evaporation parameters. Also, because of higher abundance of ^{28}Si in Si, later can be used as back-up target. The Si targets were prepared successfully using rolling machine and electron beam coating unit with high vacuum environment and the final experiment will be carried out with Indian National Gamma Array (INGA) [1] and Charge Particle Detector Array (CPDA) setup at IUAC, New Delhi.

Experimental Technique

Backing preparation

As the temperature of the metal had to be kept below its recrystallization temperature, cold rolling of Au was carried out to obtain uniform and desired thickness in the range of 6-7 mg/cm^2 using a rolling machine setup at IUAC, New Delhi (Fig. 1). The stainless steel packs were used to insert the Au sheet for rolling; and a dust-free and the smooth environment was provided to avoid any pinholes and destruction in the foils.

FIG. 1: The Rolling machine at IUAC, New Delhi.

High vacuum Evaporation technique

As Si has a very high melting point, i.e., 1414°C, the electron beam evaporation technique becomes more pertinent in the deposition of Si on Au Backing. In this process, an electron beam imparts thermal energy to the source material, which increases the temperature. The process is followed by the condensation of vapourised source materials onto the substrate, i.e., Au backing.

For fabricating natural Si on Au backing, a high vacuum e-beam facility of IUAC, New Delhi, was used (Fig. 2). The evaporation unit

FIG. 2: The high vacuum e-beam set-up at IUAC, New Delhi.

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consists of a turbo molecular pump backed with a scroll pump to achieve a high vacuum of the order of 10^{-6} mbar. It consists of multi-pocket electron gun with a 6 kW power supply. A piezoelectric quartz crystal monitor was used to monitor the deposition and thickness of the source material onto the substrate. For verification of thickness by surface profilometer ultrasonically cleaned glass slides were placed above Au foil holder.
When the total quantity of source material was more than 1 gram, Si was deposited on Au foils by placing the source material directly in contact with a copper hearth. The two Si targets were fabricated successfully using this practice. As availability of ^{28}Si material is 100mg only, hence optimization needs to be done with 100mg natural Si. But deposition became challenging when 100 mg of natural Silicon was placed in the in-built copper hearth due to the heat drainage issue. To resolve this issue, a thick sheet (∼6 mm) of Graphite was used. Two Si targets were fabricated using this technique.

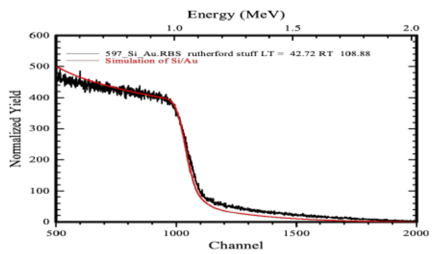

FIG. 3: The RBS spectrum and simulation using XRUMP.

Characterization

Initially, Si thickness was measured over Au foil with a stylus surface profilometer at IUAC, New Delhi. Using that, the thickness of targets calculated as ∼597 μg/cm^2, ∼622 μg/cm^2, ∼900 μg/cm^2 and ∼1.17 mg/cm^2. To confirm the thickness more precisely, RBS (Rutherford backscattering spectrometry) ion beam analysis was also performed on first two targets. The RBS was carried out with a 1.7 MV Tandem accelerator (model 5SDH-2, National Electrostatics Corporation) at IUAC [2] in a backscattered configuration using a Si surface barrier detector at 166° with respect to the beam direction. A 2.0 MeV He^+ beam was bombarded through Si films, and simulation was carried out using XRUMP [3]. The thickness for one of target used in the experiment measured from RBS measurement was 384±12 μg/cm^2 and for second target was 410±10 μg/cm^2. The RBS spectrum of first natural Si target is shown in figure 3.

Conclusion

The fabrication of natural silicon targets with a wide range of thicknesses is described. One of the fabricated targets was used in a gamma ray spectroscopy experiment for INGA + CPDA testing at IUAC, New Delhi. The parameters of fabrication i.e., distance between source and substrate, voltage and current values of e-gun set up, and quantity of source material required are optimized and will be used to fabricate the isotopic ^{28}Si. The discrepancy between the stylus profilometer and RBS measurement will be carried out with more thickness characterization techniques.

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