Thickness Measurement of Nuclear Targets Using X-Ray Fluorescence Technique

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Introduction

Studies of nuclear reactions relevant to astrophysical scenario, often require measurement of cross-section in pico-barn to nano-barn range (1 barn = 10^{-24} cm^2). So we need isotopically pure targets and the thickness of the target should be known accurately. In nuclear structure experiment also, target thickness information is very important to estimate the reaction rate as well as the level lifetimes. Mostly, based on the calibration values, the thickness of the target was estimated during its preparation. But sometimes it shows large uncertainty on their estimated values. So, one should verify the estimated thickness of the target using some direct techniques like, Rutherford Back scattering Spectroscopy (RBS), Nuclear Resonance Reaction, etc. However, these techniques are not easily available for us. Recently, we have procured an X-Ray Fluorescence (XRF) instrument for quantitative and qualitative elemental analysis. In the present work, we have utilized the X-ray Fluorescence technique to measure the target thickness. We have used the concept of attenuation of fluorescence X-ray of the backing material.

Theory

If I_0*(λ_i) is the intensity of the X-ray coming out from the X-ray source (**Fig. 1**), then while reaching to the backing through the target it will be attenuated and will generate fluorescence X-ray of intensity I^f as given by [1, 2],

$$I^f_{backing} = \left(\frac{K \times I_0^*(\lambda_i) \times (\mu^{\lambda_i}_{Backing}) \times cosec\,\psi_1}{\mu^{\lambda_i}_{Backing} \times cosec\,\psi_1 + \mu^{\lambda_{Backing}}_{Backing} * cosec\,\psi_2} \right). \quad (1)$$

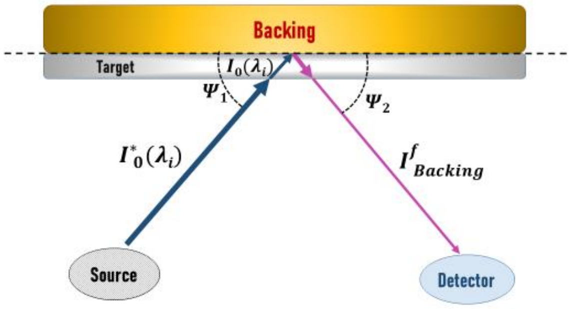

Fig. 1 Schematic diagram of experimental set-up. The blue arrow represents the incident X-ray whereas the violet one is the fluorescent X-ray. Difference in thickness of the lines stand for different intensity.

Where, K is the geometrical constant of the detection system, $\mu^{\lambda_i}_{Backing}$, $\mu^{\lambda_{Backing}}_{Backing}$ are the mass attenuation coefficients of the backing at the incident wavelength and at the characteristics line wavelength, respectively. Ψ_1 and Ψ_2 are the angles between the backing and the incident and fluorescent X-ray, respectively (**Fig. 1**). In our set-up both the angles are 45°. The fluorescence X-rays are then attenuated while passing through the target. Finally, the attenuated X-rays are detected by the detector. The detected intensity of the fluorescent X-rays is [1, 2] given by,

$$ln\left(I^f_{Backing}\right) = ln\left(\frac{K \times I_0^*(\lambda_i) \times (\mu^{\lambda_i}_{Backing}) \times cosec\,\psi_1}{\mu^{\lambda_i}_{Backing} \times cosec\,\psi_1 + \mu^{\lambda_{Backing}}_{Backing} \times cosec\,\psi_2} \right) - \left(\mu^{\lambda_i}_{Target} \times cosec\,\psi_1 + \mu^{\lambda_{Backing}}_{Target} \times cosec\,\psi_2\right)\rho x \quad (2)$$

Here, ρ and x is the density and thickness of the target, respectively. $\mu^{\lambda_{Backing}}_{Target}$ is the mass attenuation coefficient of the target at the characteristic wave length of the backing.

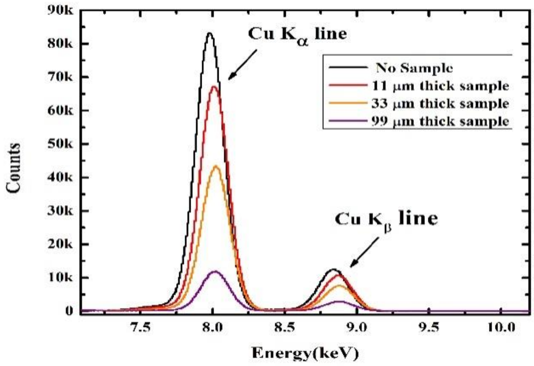

Fig. 2 Variation of fluorescence intensity of backing (Cu) for different thickness of target (Al).

Thus, for known values of K (geometrical constant), X-ray intensity of the source (I_0), mass attenuation coefficients (μ), density of the target material (ρ), and the attenuated fluorescence intensity of the backing (I^f), one can estimate the thickness of the target (x) using Eq. **(1)** and **(2).**

In **Fig. 2** we have shown how the fluorescence intensity decreases with the thickness of the Al foils. The shift of the K X-rays towards higher energy with target (compared to no target) may be for the variation of mass attenuation coefficients with energy.

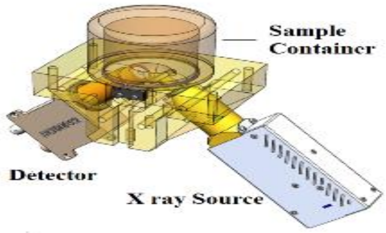

Fig. 3 Schematic diagram of Source and Detection System.

Experimental set-up

Our experimental set up consists of a 4 W MAGNUM X ray source, a Si-pin diode detector and a digital pulse processor (DPP) [3] for data processing. A schematic representation of our set up is shown in **Fig. 3**. In the present work, Al foil was used as target and we have measured the thickness of the Al foil for two different backing materials Cu, and Ti. Pure Cu and Ag samples have been used to calibrate the system. The attenuated fluorescence X-rays have been analyzed using the INGASORT [4] software.

Results & Discussion

Since, the geometrical constant (K) of the present set up and the intensity of X-ray (I_0) coming out from the source are not known, one has to use a few reference targets (target + backing) of known thickness to estimate the slope and intercept of Eq. **(2).** It must be noted that the geometrical constant (K) also depends on the targets materials. Therefore, the materials of the reference targets (target + backing) should be the same as our original target of interest. This is not easy to get same kind of targets of known thickness for such measurement. Therefore, we have followed a semi theoretical approach to measure the thickness of the target. The advantage of this approach is that we do not require any target of known thickness [1, 2]. In this approach, we have first calculated the slope of the Eq. **(2)** using available data of mass attenuation coefficient [5] and density (ρ). In order to get the value of intercept of Eq. 2, we have measured the X-ray intensity of the backing (I^f) without target material i.e. x = 0. Because, at x =0, the L.H.S of Eq. **(2)** gives us the intercept value. Therefore, instead of several reference targets of known thickness, we need only the backing for this measurement. Using this intercept and calculated slope, we have measured the thickness of the Al foil (target) for two different backing Cu and Ti. The results are shown in **Table 1**. The measured thickness of the Al foil with Cu and Ti backing are in good agreement with the reported value.

Table 1: Measured Thickness of Al foil**.**

Backing Material	**Obtained Thickness (μm)**	**Reported Thickness* (μm)**
Cu	11.15±0.04	11.00
Ti	12.41±0.10	

*Provided by makers.

Acknowledgement

One of the authors A.G acknowledges DST- INSPIRE (IF 160297) for financial support.

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[5]https://physics.nist.gov/cgi-bin/Xcom/xcom2