Vacuum 158 (2018) 42–47

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Energy loss straggling of α-particles in Tb, Ta and Au metallic foils

Sunil Kumar[a], Vishal Sharma[b,**], P.K. Diwan[a,*]

[a] Department of Applied Science, UIET, Kurukshetra University, Kurukshetra, 136 119, India
[b] Institute of Forensic Science & Criminology, Panjab University, Chandigarh, 160 014, India

ARTICLE INFO

Keywords:
Energy loss straggling
α-particles
Metallic foils

ABSTRACT

The energy loss straggling of 5.486 MeV α-particles in Tb, Ta and Au metallic foils (varying thicknesses ~4.20–16.00 mg/cm^2) is measured, in the fractional energy loss limits (ΔE/E %) ~20–85, using transmission technique. These measured straggling values are compared with the predicted values based on Bohr, Lindhard and Scharff, Bethe and Livingston, Yang et al. and Titeica analytical straggling formulas. The present comparison reveals that the prediction of Titeica straggling formula shows better agreement with the measured values as compared to other considered straggling formulas. Here, Titeica formula based predicted values show generally ~0.60–1.30 times deviation with the presently measured straggling values.

1. Introduction

In material science, ion beam based techniques viz. Rutherford Backscattering (RBS) and Elastic Recoil Detection Analysis (ERDA) are widely used for quantitative analysis of elemental compositions, defect analysis, thickness of thin layer film and in depth profiling of individual elements in the target materials [1–3]. The success of these techniques depends upon the exact knowledge of energy loss straggling of energetic ions, as a function of energy in the considered target material. This is due to the reason that the energy loss straggling is one of the major factors limiting the depth resolution in the ion beam based experiments.

Energy loss straggling is an associated parameter of energy loss and represents the broadening in energy loss distribution around its average value (average energy loss). Over the past decades, the average energy loss has been extensively studied both theoretically as well as experimentally [4–10]. However, as far energy loss straggling is concerned; very inadequate work has been done so far. This may be due to the involvement of various complexities in energy loss straggling measurements/calculations [11–19]. For theoretical calculations, very limited analytical formulas viz. Bohr [20], Lindhard and Scharff [21], Bethe and Livingston [22], Yang et al. [23] and Titeica [24] are available. Further, most of these formulas are developed when very limited energy loss straggling measurements were performed. Therefore, there is a need to check the authenticity of these formulas through comparison with the systematically measured values before using the prediction of these formulas as an input in ion beam based technique.

In the present study, the measurement of the energy loss straggling of 5.486 MeVα-particles after passing through the varying thicknesses of Tb, Ta and Au, metallic foils is carried out. These measured energy loss straggling values are used to check the authenticity of Bohr, Lindhard and Scharff, Bethe and Livingston, Yang et al. and Titeica formulas, through comparison with the predicted values. Finally, the behaviour of presently measured energy loss straggling values as a function of energy loss of α-particles in considered metallic foils are observed.

2. Experimental details

For present measurements, Tb (Thickness: 250 μm; Purity: 3N), Ta (Thickness: 500 μm; Purity: 3N5) and Au (Thickness: 250 μm; Purity: 3N) metallic foils are procured from STREM Chemical, USA. In order to obtain desired thicknesses of these metallic foils, the procured metallic foils are rolled through hardened roller machine at slow rate, with uniform pressure, for different time duration. Thicknesses of these rolled foils are measured through Gravimetric method and the uncertainty in thickness measurement is observed to be less than 3%.

These rolled foils of considered metals are then mounted one by one on the collimator, which is lying in between Am^{241} source and Silicon Surface Barrier Detector (SSBD) [25–28]. Here, α-particles emitted from the Am^{241}radioactive source are allowed to pass through the metallic foils and energy spectra are recorded.

While analyzing, the recorded energy spectra of α-particles, with and without metallic foils are found to be tailed towards the lower

* Corresponding author.
** Corresponding author.
E-mail address: diwanpk74@gmail.com (P.K. Diwan).

https://doi.org/10.1016/j.vacuum.2018.09.035
Received 31 July 2018; Received in revised form 14 September 2018; Accepted 16 September 2018
Available online 17 September 2018

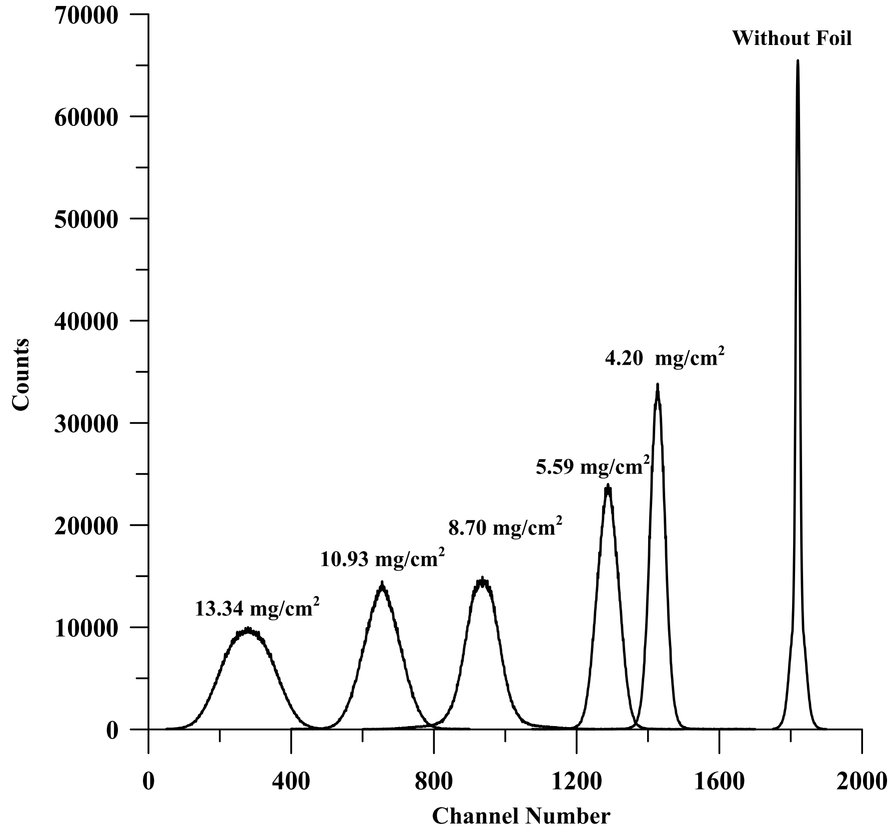

Fig. 1. Energy spectra of 5.486 MeV α-particles after passing through varying thicknesses of Tb metallic foils.

Table 1
Measured energy loss straggling of 5.486 MeV α-particles in Tb, Ta and Au metallic foils.

Metal	Thickness (mg/cm^2)	ΔE/E %	$\delta E_{Measured}$ (keV)
Tb	4.20 ± 0.08	22	141 ± 6
	5.59 ± 0.11	29	207 ± 7
	8.70 ± 0.17	48	319 ± 9
	10.93 ± 0.22	64	364 ± 11
	13.34 ± 0.27	85	517 ± 16
Ta	4.75 ± 0.10	22	185 ± 7
	5.63 ± 0.11	26	234 ± 8
	7.50 ± 0.15	36	283 ± 9
	11.60 ± 0.24	60	416 ± 9
	13.40 ± 0.27	72	494 ± 12
Au	4.65 ± 0.09	21	202 ± 6
	5.93 ± 0.12	27	300 ± 9
	8.30 ± 0.17	40	358 ± 10
	10.72 ± 0.21	52	416 ± 11
	14.25 ± 0.29	74	529 ± 12
	16.01 ± 0.32	87	616 ± 19

energy side. This may be due to the mixing of lower energy α-particles emitted from Am^{241} source [29]. In order to eliminate this mixing, the energy loss spectra are regenerated by taking the replica of the right portion of each spectrum to the left portion, about the average value. Fig. 1 shows one of such spectra for 5.486 MeV α-particles as a function of thicknesses in Tb metal. Now, using ORIGIN software Full Width at Half Maxima (FHWHM) of regenerated spectra is noted.

Finally, utilizing the FWHMs of regenerated energy spectra with (δE_{with}) and without ($\delta E_{without}$) metallic foils, the energy loss straggling ($\delta E_{Measured}$) is determined through the following relation:

$$\delta E_{Measured} = \sqrt{\delta E_{with}^2 - \delta E_{without}^2} \quad (1)$$

The experimental error in the present straggling measurements is about 10%, estimated through repeated measurements and the propagation of error adopting standard methods [30].

These straggling measurements are also corrected by eliminating the contribution of non-uniformity of the foils, adopting Besenbacher et al. correction [31].

3. Energy loss straggling theories

The basic energy loss straggling theory was introduced by Bohr based on classical concepts [20]. With the passage of time, various researchers refined the Bohr's theory by including different appropriate corrections. Such well recognized energy loss straggling theories were given by Lindhard and Scharff [21], Bethe and Livingston [22], Yang et al. [23] and Titeica [24]. The brief descriptions of these theories are given as follow:

3.1. Bohr's Theory

According to Bohr [20], in high energy limit, for fully stripped incident ions, energy loss straggling (in terms of standard deviation (Ω)) is calculated through the following formula

$$\Omega_{Bohr}^2 = 4\pi Z_1^2 e^4 Z_2 N x \quad (2)$$

Where Z_1 is the atomic number of incident ion, e is the electronic charge, N, x and Z_2 are the atomic density, thickness and atomic number of the target material, respectively.