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Simulation analysis of the aluminum thin film thickness measurement by using low energy electron beam

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ABSTRACT

This paper indicates a simulation analysis for estimating the aluminum (Al) thin film thickness measurements by using the low energy electron beam. In order to calculate the Al thickness estimation, the energy of the incident electron beams was varied from 10 to 30 keV, while the thickness of the Al film was varied between 6 and 14 μm. From the simulation results it was found that electron transmittance fraction in 14 μm sample is about nine orders of magnitude more than 6 μm sample at the same incident electron beam energy. Simulation results show that maximum transmitted electrons versus Al layer thickness has a parabolic relation and by using the obtained equation, it is possible to estimate unknown thickness of the thin film Al layer. All calculations here were done by CASINO numerical simulation package.

1. Introduction

The study of the physical properties of thin films is important due to its multiple technological applications such as, modern optoelectronic devices, sensors, micro and nano electronic devices [1–4]. Aluminum thin films and Al binary and ternary alloys are widely used for electronic and optoelectronic device applications and comprise the majority of the interconnections used in the electronic chipsets [5–7]. The physical properties of the Al thin films depend strongly on their microstructure, which can be characterized using different techniques [1,8].

After having fulfilled the growing of the film, one of the following tasks is to determine its thickness. Scanning electron microscopy (SEM) is one of the most popularly used tools for thin films characterizing such as thickness measurement, and grain boundary studies. Recently, SEM and related instrument such as energy dispersive X-ray spectrometer (EDS) and Electron Spectroscopy for Chemical Analysis (ESCA) have attracted a lot of interests to research and application in material science and provide increased information from bulk, thin film and coating samples [9–11]. But above mentioned techniques cannot be used in general labs and also, for a large area coated thin films, these techniques are too expensive. Most of today's available techniques are restricted to certain type of films and many have difficulties in performing the measurement in situ [7,12]. Measurement and estimation of the thin films thickness by using the simple and inexpensive techniques is too important parameter in both industrial and scientific aspects. In this paper, a simulation analysis presented for estimating the Al thin film thickness measurements by using the low energy electron beam. We used CASINO simulation software which developed by Raynald Gauvin et al. at Université de Sherbrooke, Québec, Canada [13–15]. This program is a Monte Carlo simulation of electron trajectories in solids, specially designed to simulate the interaction of low energy electron beams with bulk samples and thin foils. This paper indicates a numerical analysis method to estimation of thin film layers which by using the presented experimental set up (see Fig. 1), it is possible to low-cost and in situ thin film thickness measurement. The computation used tabulated Mott elastic scattering cross sections of Czyzewski and stopping powers model from Joy and Luo [14].

2. Physical model

CASINO program is a single scattering Monte CArlo SImulation of electroN trajectory in sOlid specially designed for low-beam interaction in a bulk and thin foil [13]. In this section we describe the main routine that use in this software. Firstly, a Gaussian distribution of the electron from the origin of the beam is used. The next step

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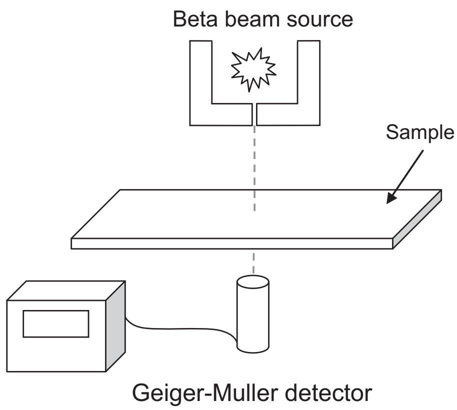

Fig. 1. Proposed experimental setup.

is to determine which atom is responsible for the elastic scattering. To achieve this, Eq. (1) is used [14]:

$$\text{Random} > \sum_{i=1}^{n} \frac{\sigma_i F_i}{\sum_{j=1}^{n} \sigma_i F_i}, \tag{1}$$

where "Random" is a random number uniformly distributed between 0 and 1, σ_i is the total cross section of element i, F_i is the atomic fraction of element i, and n is the number of elements in the region.

When Eq. (1) is true, the element responsible for the collision is i. The polar angle of collision θ is determined with the value of the partial cross section of the element i. This routine computes the polar angle of collision by solving:

$$R = \frac{\int_0^{\theta} \frac{d\sigma}{d\theta} \sin(\theta) d\theta}{\int_0^{\pi} \frac{d\sigma}{d\theta} \sin(\theta) d\theta}, \tag{2}$$

where $\frac{d\sigma}{d\theta}$ is the partial cross section and R is a random number. The azimuthal angle φ is uniformly distributed from 0 to 2π and is given by Eq. (3):

$$\varphi = R \times 2\pi, \tag{3}$$

where R is another random number. The φ and θ angles are defined as the angle formed by the last and new directions of the electrons, so we must recalculate the direction relative to a fixed axis.

CASINO computes the direction $\cos(R_x, R_y, R_z)$ with the old value (R_{x0}, R_{y0}, R_{z0}). R_{x0}, R_{y0}, R_{z0} directions can be present by Eqs. (4)–(6), respectively [16].

$$R_x = \frac{R_{z0} \sin\theta \cos\varphi}{\sqrt{R_{x0}^2 \times R_{z0}^2}} + \frac{R_{x0} \times R_{y0} \sin\theta \sin\varphi}{\sqrt{R_{x0}^2 \times R_{y0}^2 + (R_{x0}^2 \times R_{z0}^2) \times (R_{x0}^2 \times R_{z0}^2) + R_{y0}^2 \times R_{z0}^2}} + R_{x0} \cos\theta, \tag{4}$$

$$R_y = \frac{-R_{x0}^2 \times R_{z0}^2 \sin\theta \sin\varphi}{\sqrt{R_{x0}^2 \times R_{y0}^2 + (R_{x0}^2 \times R_{z0}^2) \times (R_{x0}^2 \times R_{z0}^2) + R_{y0}^2 \times R_{z0}^2}} + R_{y0} \cos\theta, \tag{5}$$

$$R_z = \frac{-R_{x0} \sin\theta \cos\varphi}{\sqrt{R_{x0}^2 \times R_{z0}^2}} + \frac{R_{z0} \times R_{y0} \sin\theta \sin\varphi}{\sqrt{R_{x0}^2 \times R_{y0}^2 + (R_{x0}^2 \times R_{z0}^2) \times (R_{x0}^2 \times R_{z0}^2) + R_{y0}^2 \times R_{z0}^2}} + R_{z0} \cos\theta, \tag{6}$$

We have noticed that their equation does not always satisfy the simple sum rule of cosine:

$$R_x^2 + R_y^2 + R_z^2 = 1, \tag{7}$$

This equation must always be true to compute consistent direction. To determine the distance (L) between two collisions, Eq. (8) is used:

$$L = \lambda \log(RLPM), \tag{8}$$

where $RLPM$ is a random number and λ is the electron mean free path. CASINO computes the electron mean free path using this equation:

$$\lambda = \frac{1 \times 10^{21} \sum_{i=1}^{n} (C_i A_i / \rho)}{N_0 \sum_{i=1}^{n} F_i \sigma_i} \text{ (nm)}, \tag{9}$$

where C_i is the weight fraction, F_i is the atomic fraction, A_i is the atomic mass, and σ_i is the total cross section of element i. ρ is the density of the region and N_0 is the Avogadro number. If σ_i is given in nm^2, the value of λ will be in nm as expected by the program.

The energy lost during a travel distance L is a constant value, since a continuous slowing down approximation is used in this program. The energy at position i is computed by the following equation:

$$E_i = E_{i-1} + \frac{dE}{dS} L, \tag{10}$$

where E_{i-1} and E_i are the respective energy at previous and current collision and dE/dS is the rate of energy loss. Before carrying out the next collision, the program will check whether the electron had escaped the region or the specimen.

3. Results and discussion

The energy of the incident electron beams was varied from 10 to 30 keV, while the thickness of the Al film was varied between 6 and 14 μm. CASINO calculates the amount and the energy of the transmitted electrons, while the incident energy and the film thickness were varied. Many cases while changing the incident electron energy and the Al film thickness were simulated.

As the experimental aspects, it is easy to propose a simple experimental set up to investigate above-mentioned circumstance. The proposed experimental set up shown in Fig. 1.

As it is shown in Fig. 1, by using a high energy electron source, such as nuclear beta-ray sources, and a Geiger–Muller detector, it is possible to count the amount and the energy of the transmitted electrons. In different thickness samples, because of the differences between received electrons to Geiger–Muller detector due to the sample thickness, it is possible to count transmitted versus incident electrons fraction.

Fig. 2 shows the fraction of the transmitted/incident electrons of the 10 μm Al sample at 25, 28 and 30 keV. In this figure, it is shown that by increasing the incident electron beam energy, fraction of the transmitted electrons increases and delay to this fact that at higher energy beams, large part of the incident electron can be transmit the Al sample. Also, it is shown that in 25 keV, 94% of the incident electrons absorbed and only 6% can be transmit Al sample, but at 30 keV, about 13% of the incident electrons transmit through the sample, which it is two orders of magnitude more than 25 keV incident electron beam.