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Backscattered electron emission after proton impact on carbon and gold films: Experiments and simulations

F. Hespeels [a], A.C. Heuskin [a], E. Scifoni [b,c], M. Kraemer [c], S. Lucas [a,*]

[a] University of Namur, PMR, 61 rue de Bruxelles, B-5000 Namur, Belgium
[b] TIFPA-INFN, Trento Institute for Fundamental Physics and Applications, Via Sommarive 14, I-38123 Trento, Italy
[c] GSI-Helmholtzzentrum für Schwerionenforschung, Biophysik, Max Planck-Strasse 1, D-64291 Darmstadt, Germany

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ABSTRACT

This work aims at measuring the proton induced secondary electron energy spectra from nanometer thin films. Backscattered electron energy spectra were measured within an energy range from 0 to 600 eV using a Retarding Field Analyser (RFA). This paper presents energy spectra obtained for proton (0.5 MeV; 1 MeV; 1.5 MeV; 2 MeV) irradiation of thin carbon films (50 and 100 nm thick) and thin gold film (200 nm). These experimental spectra were compared with Monte Carlo simulations based on TRAX code and Geant4 simulation toolkit. Good agreement between experimental, TRAX and Geant4 results were observed for the carbon target. For the gold target, we report major differences between both Monte Carlo environments. Limitation of Geant4 models for low energy electron emission was highlighted. On the contrary, TRAX simulations present encouraging results for the modeling of low-energy electron emission from gold target.

1. Introduction

The interactions of charged particle with a solid gives rise to electrons emission from the solid target. This phenomenon has been described by Sternglass as a succession of three steps [1]: First, the emission of an electron after collision between the incident projectile and the electron. Secondly, the transport of the excited electron through the solid which could lead to other electron excitation. Finally the transmission of the electron through the surface barrier. Most measurements and theoretical calculations focused on the electron emission yield γ (the average number of emitted electron per incident particle) [2–8]. γ is considered to be proportional to the electronic stopping power S_e:

$$\gamma = \Lambda * S_e \quad (1)$$

where Λ is the so-called material parameter which depends on the target material. It has been shown that, for proton incidence on carbon films, Λ is constant in an energy range from 0.02 to 10 MeV [9].

Electron emission energy spectra from thin films provide valuable information which can be used to validate or update Monte Carlo codes database. Reproducing the interaction between thin target and proton beam by Monte Carlo simulation requires cross section data which are still incomplete, especially for low energy ionization for which no experimental data are available yet. In order to understand the physical mechanisms involved, experimental studies are needed.

This work aims at measuring experimentally the proton induced secondary electron energy spectra from nanometer thick film. Backscattered electron energy spectra are measured using a Retarding Field Analyser (RFA). Experiments presented in this paper focused on energy spectra obtained for proton irradiation of thin carbon films and thin gold film. These experimental spectra were compared with Monte Carlo simulations based on TRAX code and Geant4 simulation toolkit [10,11].

The next section presents the experimental setup installed at the University of Namur, from the proton beam production, to the secondary electron detection. It also describes both Monte Carlo codes used. Section 3 presents electron energy spectra gathered after proton irradiation of 50 nm or 100 nm thick carbon films and 200 nm thick gold film. Each spectrum is compared with the corresponding simulation from TRAX and Geant4. Moreover, we study the dependence of secondary electron yield on primary proton beam energy. Finally, we discuss differences observed between TRAX and Geant4 simulations.

* Corresponding author.
E-mail address: stephane.lucas@unamur.be (S. Lucas).

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2. Materials and methods

2.1. Experimental part

In the present work, detection of electron is based on the use of a RFA detector. Backscattered electron energy spectra were measured for different samples:

- Auto supported Carbon thin film: 50 nm and 100 nm thick. These films were purchased from ACF Metals [12].
- Auto supported Gold thin film: 200 nm thick.

Each sample was irradiated with a proton beam of energy 0.5, 1, 1.5 or 2 MeV to highlight the impact of decreasing linear energy transfer (LET) in electron emission yield.

2.1.1. Experimental setup

A schematic representation of the experimental setup is given in Fig. 1.

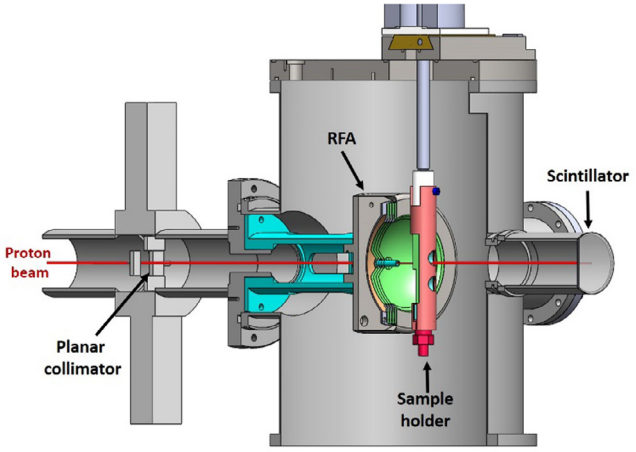

Fig. 1. Experimental setup.

The incident proton beam was generated with the ALTAIS accelerator, a 2 MV Tandem accelerator [13]. The beam homogeneity and size were monitored with an electrostatic lens coupled with 4 planar collimators placed along the beam line. The proton beam diameter was set to 1 mm. Beam intensity was measured continuously with a Faraday cup connected to a current digitizer. For each irradiation, a current beam of 5 nA was used.

2.1.2. Sample preparation

In order to remove pollutant material at the sample surface, we developed an in-situ sputtering method with Argon gas. The sample was set to a negative potential of 500 V to ignite an Argon plasma. A grounded shell placed around the sample holder allowed the discharge to be sustained only at the sample surface. Surface pollution impact on electron spectrum is discussed in Section 3.2.

2.1.3. XPS analysis

X-ray photoelectron spectroscopy (XPS) was used to determine the species present on the samples surfaces [14]. XPS analyses were performed on a ThermoFisher K-alpha spectrometer [15]. This spectrometer used a monochromatic Al K_α X-ray source (1486.6 eV). Sputtering of the sample was carried out by a 2 keV Ar^+ ion beam to clean the sample surface.

Angle resolved XPS (ARXPS) was used for the measurement of thin surface layer thickness. Considering a thin layer A of material A′ placed above an infinite substrate B of material B'. We can calculate the thickness d of this layer A using Beer-Lambert law. Indeed, we can express the ratio of the intensity of photoelectron emitted from layer A I_A and the intensity of photoelectron emitted from substrate B I_B as:

$$\frac{I_A}{I_B} = R^\infty \left[e^{\left(\frac{d}{\lambda_{B,A}\cos\theta}\right)} - e^{\left(\frac{d}{\cos\theta}\left[\frac{1}{\lambda_{B,A}} - \frac{1}{\lambda_{A,A}}\right]\right)} \right], \quad (2)$$

where R^∞ is the ratio of the intensities from thick samples of the materials A′ and B′. $\lambda_{A,A}$ is the attenuation length in layer A for photoelectrons emitted from the surface layer A. $\lambda_{B,A}$ is the attenuation length in layer A for photoelectron electrons emitted from the substrate B. θ is the emission angle measured from the surface normal. As Eq. (2) cannot be linearized, collected data for different angles θ has to be plotted and fitted to determine the thickness d. ARXPS was used in order to quantify the carbon pollution film present in the surface of gold sample. For each sample data were gathered for 20 angles over a range from 0° to 80° with respect to the surface normal.

2.1.4. Secondary electron detection

During irradiation, backscattered electrons are collected within an angle of 102° by a Retarding Field Analyser (RFA). The sample was placed at 19.5 mm in front of the detector exit. The RFA detector is based on the principle of a high-pass energy filter and is illustrated in Fig. 2:

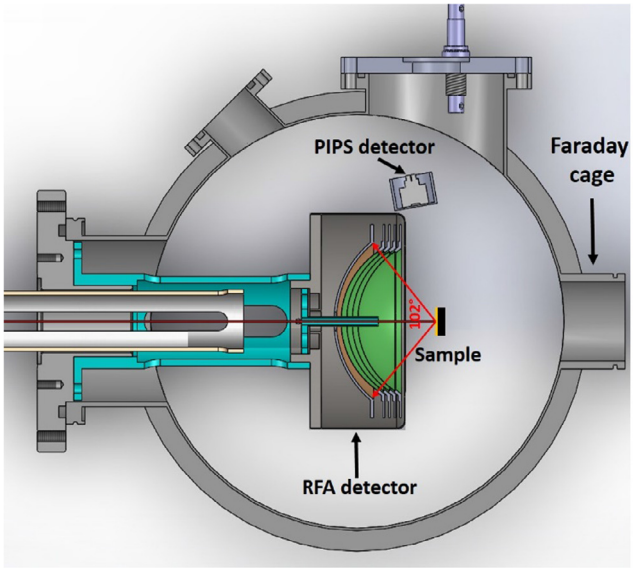

Fig. 2. Schematic view of the Retarding Field Analyzer (RFA).

It consists of four equally spaced grids placed in front of a hemispherical collector. The collector screen was set to a positive potential of +66 V. The first and last grids were grounded. A retarding potential, created by a TDK-Lambda power supply (ripple and noise (p-p, 20 MHz) 300 mV and ripple rms (5 Hz–1 MHz) 60 mV), was applied to the internal grids. Only electrons that have an energy higher than the applied retarding grid potential can reach the collector screen. The current of secondary electrons reaching the screen was measured by a programmable electrometer with a resolution up to 100 aA for 2 pA range. By measuring the collector current as a function of the grid potential one can obtain