Nuclear Instruments and Methods in Physics Research B 328 (2014) 65–69

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

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

On the effective sputter yield during magnetron sputter deposition

D. Depla *

Department of Solid State Sciences, Ghent University, Krijgslaan 281(S1), 9000 Gent, Belgium

ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form 28 February 2014
Accepted 3 March 2014
Available online 28 March 2014

Keywords:
Sputter yield
Magnetron
Modelling

ABSTRACT

The effective sputter yield during magnetron sputtering of elemental targets was measured by weighing the target before and after sputtering at constant discharge voltage. During the experiment, the pressure and discharge current were logged. The effective sputter yield is compared with a set of published semi-empirical equations to calculate the sputter yield for ion/solid interactions. The differences between both yields are discussed based on different contributions which affect the effective sputter yield such as redeposition, the target roughness and the contribution of high energetic neutrals.

1. Introduction

The sputter yield is a key parameter during sputter deposition as it drives the deposition rate. In this context is not surprising that, besides the fundamental papers with the objective to explain the observed experimental trends in sputter yields (e.g. [1,2]), several papers have been published to calculate the sputter yields based on (semi)-experimental formulas (e.g. [3–5]) and simulation codes (e.g. [6,7]). Nevertheless, to calculate the deposition rate, the outcome of these models is not sufficient because the effective sputter yield is needed. Several factors play a role in the effective number of atoms leaving the magnetron target per incoming ion. As shown before [8,9] the target roughness defines the impact angle of the ions and the atoms recapture on the target. At higher pressure backscattering of the sputtered atoms towards the target will reduce the effective number of leaving atoms. This process is also known as redeposition [10–13]. Further the measured discharge voltage V_d defines the ion energy, but the ion energy is not equal to eV_d (with e the electronic charge) but rather on average 75% of eV_d [14–16]. Finally as indicated to Burmakinskii et al. [16] and Bultinck et al. [17] not only ions bombard the target but also high energy neutrals. These neutrals originate from resonant charge exchange between the ions and the thermal argon atoms.

This paper measures the effective sputter yield by a weighing the target mass before and after sputtering while the discharge current is logged. This method was also used by Burmakinskii et al. [16]. In presented paper a wider range in discharge voltage is studied (between 200 and 600 V) as compared to that work (between 260 and 375 V). Further a larger number of yield-voltage pairs is studied, 61 as compared to 14, is studied which allows to generalize some conclusions.

2. Experimental

Two inch targets were mounted on a magnetron powered by a DC power supply (Hüttinger 1500DC). The magnetron is installed in a stainless vacuum chamber pumped by a combination of the turbomolecular and rotary pump. The base pressure was equal or lower than 4×10^{-4} Pa, measured with Penning gauge. The initial argon pressure was set at 0.5 Pa, measured with Baratron capacitance gauge. The argon flow was controlled by a MKS mass flow controller. During the sputtering process the discharge voltage was fixed. Due to the target erosion, the magnetic field at the target surface increases. As the discharge voltage is fixed, this results in an increase of the discharge current. To avoid target overheating, a feedback loop is programmed which automatically decreases the initial argon pressure to decrease the discharge current. An example of the discharge current behaviour is shown in Fig. 1. To measure the effective sputter yield at higher discharge voltages, thin (0.5 mm) copper disks were inserted between the target and the cathode. This results in a decrease of the magnetic field at the target surface, and at fixed discharge current to a higher discharge voltage. The relationship with the target thickness, discharge voltage and magnetic field have been published before [18].

3. Results

Several target materials were sputtered at constant voltage while the discharge current and pressure were continuously

* Tel.: +32 9 264 43 42; fax: +3292644996.
E-mail address: Diederik.Depla@ugent.be

http://dx.doi.org/10.1016/j.nimb.2014.03.001
0168-583X/

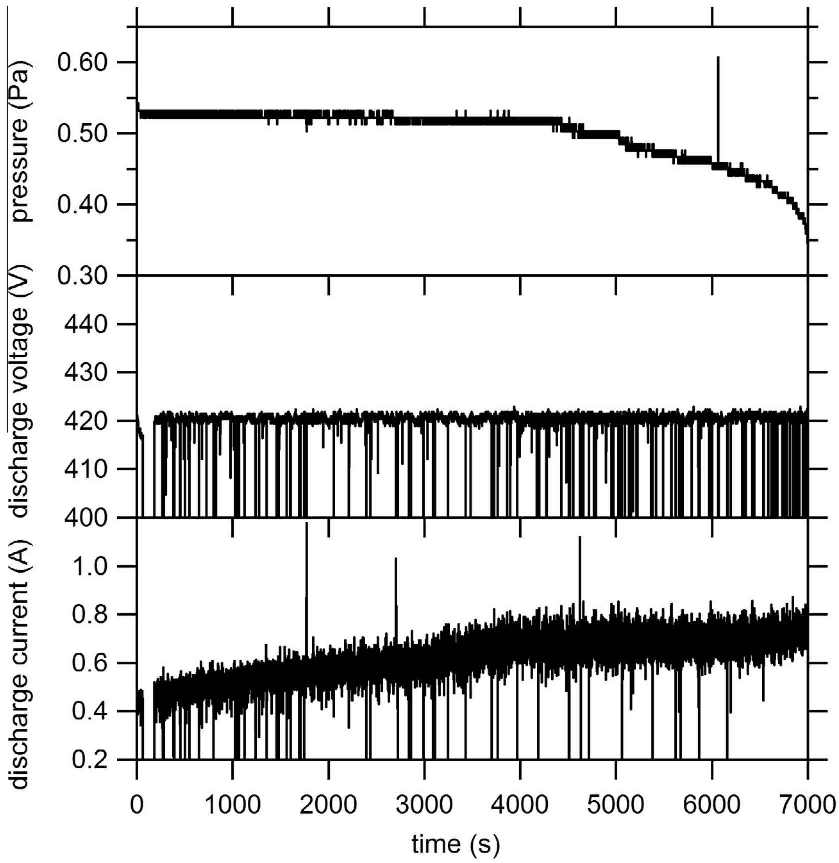

Fig. 1. Argon pressure (top), discharge voltage (middle) and discharge current (bottom) as a function of the sputter time for an aluminium target. The spikes in both discharge current and voltage are due to micro arcs which were detected by the power supply. The mass difference after sputtering the target was equal to 0.75 g.

registered. Before and after sputtering the target was weighted, and the mass difference was used to calculate the effective sputter yield using the following equation:

$$Y_{\mathrm{eff}} = \frac{(\Delta m/\mathrm{MM})\mathrm{N_a}}{I/(e(1+\gamma_{\mathrm{ISEE}}))\Delta t} \quad (1)$$

which is the ratio of the number of atoms leaving the target and the number of impinging ions. The number of atoms leaving the target is calculated from the mass difference Δm, the molar mass MM and Avogadro's number $\mathrm{N_a}$. The number of impinging ions is calculated from the discharge current I and the electron charge e, and the duration of the experiment Δt. The ion current is related to the discharge current by the ion induced secondary electron emission yield,

$$I = I_{\mathrm{ion}} + I_{\mathrm{electron}} = I_{\mathrm{ion}}(1+\gamma_{\mathrm{ISEE}}) \quad (2)$$

with I_{ion} and I_{electron}, respectively the ion and electron current. The electron yields were taken from [19].

The effective sputter yields for the studied materials as a function of the discharge voltage are shown in Fig. 2, together with the measurements published by Burmakinskii et al. [16].

4. Discussion

A comparison between the effective yields presented in this paper and the data provided by Burmakinskii et al. [16], shows that the latter effective yields are systematically lower. Based on the experimental conditions, contamination is probably the main reason. The current density (A/cm^2) in both papers is similar, but in this paper the base pressure was approximately 30 times lower as compared to the paper of Burmakinskii et al. where a value of 1.3×10^{-2} Pa is reported. Based on the ion current density it is possible to calculate that approximately 150 monolayers are removed per second for a material with an effective sputter yield of 0.5. At a base pressure of the order of 4×10^{-4} approximately 1 monolayer of contaminants will reach the target, which is negligible compared to the removal rate. However, at the high base pressure as reported by Burmakinskii et al. approximately 35 monolayers of contaminants will reach the target, which will influence the measurements. As the sputter yield of compounds [20] and/or chemisorbed species [21] is typically quite low, this could explain the difference between both sets of measurements.

The comparison between both data sets is further impeded by the lower accuracy of the measurements and the used electron yields in the report by Burmakinskii et al. Therefore, this data will not be further used in this paper, but the main idea reported by Burmakinskii et al. i.e. the influence of high energy neutral on the sputter yield will be further investigated.

In Fig. 3 the effective sputter yield Y_{eff} is plotted as a function of the sputter yield Y_{ion} calculated with the semi-empirical model published by Seah [5]. As discussed in the introduction, the average ion energy is a fraction of the maximum possible energy which is defined by the discharge voltage. The ratio f_{ion} between the ion energy and eV_{d}, the maximum possible ion energy is typically a value between 0.6 and 0.8. In Fig. 3 a value of 0.75 is used to calculate the sputter yield. The effective sputter yield is on average 28.5% larger as compared to the calculated sputter yield. Even, when the fraction is increased to 1 (see striped lines in Fig. 3), the effective sputter yield is 3% too large.

A first possible error in the analysis is that we should account for the ion energy distribution to calculate the average sputter yield. In the paper by Goeckner et al. [15], a typical ion energy