

# Ion sputtering yield coefficients from In thin films bombarded by different energy Ar<sup>+</sup> ions

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**Abstract.** Noble gas ion sputtering combined with Auger analysis has been applied extensively to determine the elemental composition as a function of sputtering depth. Data from such depth profiles have been used widely to determine the sputtering yield coefficients ( $S$ ) of many elements. Sputtering yield coefficients ( $S$ ) are important in many fields such as sample preparation particularly where ion sputtering is applied for surface cleaning (the surface is usually cleaned by cyclic ion bombardment and annealing), depth profiling and manufacturing. Many published data on the Auger-ion (Ar<sup>+</sup>) sputtering of indium (In) focused on In compounds like indium nitride (InN), indium phosphide (InP) etc. In this study, the focus is on metal In films that were grown by electron beam evaporation on silica substrates. Auger peak to peak heights (APPHs) were measured while the In films were subjected to Ar<sup>+</sup> ion sputtering at different energies. The Ar<sup>+</sup> ion energy was varied from 0.5 to 4.0 keV. The sputter yield coefficients ( $S$ ) of the In films were determined as 2.2, 3.2, 4.1, 5.3 and 5.7 atoms/ion for the Ar<sup>+</sup> ions with energies 0.5, 1.0, 2.0, 3.0 and 4.0 keV respectively.

## 1. Introduction

Noble gas ion sputtering combined with Auger analysis has been applied extensively to determine the elemental composition as a function of sputtering depth. Ion sputtering is an important technique for analysis and has also become an important fabrication technique for the semiconductors industry. A thin film magnetic head for instance is fabricated by utilizing ion milling (sputtering) [1]. Knowledge of the number of atoms removed for each sputtering ion is therefore important to accurately determine the sputtering depth during fabrication and sample analysis. The sputtering yield depends on the chemical state of the material that is sputtered, the ion current density, the energy of incoming ions, the type of the noble gas ions, the incidence angle of the sputtering ions and the temperature of the sample to name a few factors that influence the sputtering yield.

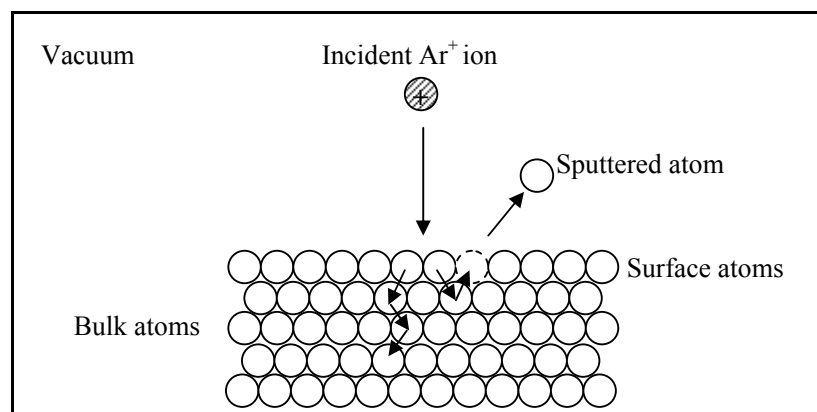
During the ion sputtering process, the incidental ion hitting the target loses its energy through a series of inelastic collisions with target atoms (collision cascade).

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The penetration depth of a collision cascade depends on the energy of the incoming ion and is normally only a few mono-layers. Recoils originating from the outermost layer and having enough energy to overcome the surface binding energy barrier will contribute to the sputtered flux [2] (see figure 1).

Published data on the Auger-ion ( $\text{Ar}^+$ ) sputtering of indium (In) focused mainly on In compounds used by the semiconductor industry [3,4,5]. The sputtering yield of In is therefore still unknown. In this study, the focus is on determining the sputtering yield of metallic In from electron evaporated thin films.



**Figure 1.** Schematic diagram of the sputtering process.

## 2. Experimental details

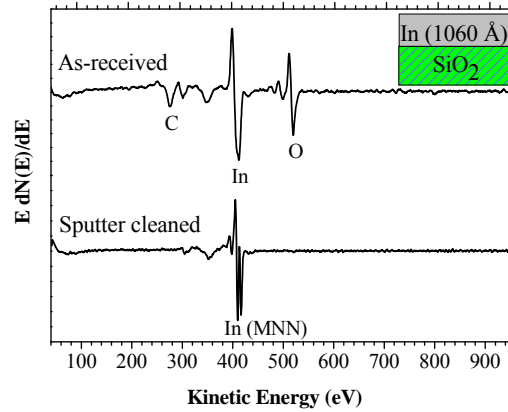
$\text{SiO}_2$  substrates were prepared by wet oxidation at 1000 °C for 1 hour. The In films (1060 Å) were evaporated onto  $\text{SiO}_2$  substrates by means of electron beam evaporation as shown in figure 2 (the insert). During the evaporation of the films the base pressure in the vacuum chamber was  $2.5 \times 10^{-5}$  Torr. The films thicknesses were monitored during the evaporation with an Inficon Leybold Heraeus XTC thin film monitor.

The In thin films were subjected to ion ( $\text{Ar}^+$ ) sputtering and during sputtering the surface composition was monitored with Auger Electron Spectroscopy (AES). Auger peak to peak heights (APPHs) were recorded as a function of the sputtering time for In (301-440 eV), O (450-530 eV), Si (60-105 eV) and C (230-300 eV). The Auger measurements were performed on a PHI 600 Scanning Auger system using a cylindrical mirror analyzer (CMA) with a co-axial electron gun. During spectrum acquisition the base pressure in the main chamber was  $9.0 \times 10^{-8}$  Torr and the ion gun was operated at an argon pressure of  $3.4 \times 10^{-5}$  Torr in the ionization chamber. A 10.0 keV primary electron beam with a current of  $4.8 \mu\text{A}$  was used for the AES measurements. The ion gun was operated at beam voltages that range from 0.5-4.0 keV and the beam was rastered over a  $2 \text{ mm} \times 2 \text{ mm}$  area. The sample was tilted with the normal of the film surface at a  $30^\circ$  with respect to the direction of the incident electron beam and  $50^\circ$  with respect to the direction of the incident ion beam. A Faraday cup with a hole diameter of  $300 \mu\text{m}$  was used to determine the ion current densities of 0.5, 1.0, 2.0, 3.0 and 4.0 keV  $\text{Ar}^+$  ion beams as 3.7, 7.6, 14.8, 31.4 and  $51.5 \mu\text{A}/\text{cm}^2$  respectively. The ion current was measured with a Keithley's picoammeter (6485).

## 3. Results and Discussion

Auger spectra for In film for as-received and sputter cleaned are shown in figure 2. The Auger spectrum for as-received sample shows some surface contamination (C and O) on the sample surface

(most likely due to sample handling in air). The contamination layer was sputter cleaned with a 2.0 keV Ar<sup>+</sup> ion beam and Auger spectrum of the clean In film is presented in figure 2. From the Auger spectrum of the sputtered cleaned In film it was clear there were no detectable contaminants in the thin film. The only Auger peaks that were seen were those of In with the most prominent peaks at 405 and 412 eV corresponding to the MNN Auger transitions of In. The line shapes of the peaks were also the same as those of a metallic In given in standard Auger electron spectroscopy (AES) handbook [6] indication also that the films were pure In.



**Figure 2.** Auger spectra for as-received and sputter cleaned In film with Ar<sup>+</sup> ions.

Figure 3(a)-(e) shows the depth profiles obtained from the In (1060 Å) films sputtered with Ar<sup>+</sup> ion energies 0.5, 1.0, 2.0, 3.0 and 4.0 keV respectively. The APPHs measured as function of sputtering time for In (MNN), O (KLL), Si (LMM) and C (KLL) were converted to fractional concentration using Palmberg equation (shown in Ref. [7]) with the correction factors as discussed by Seah *et al.* [7]. The correction factors includes the backscattering factor, inelastic mean free path (IMFP) (determines the analyzed depth) of Auger electrons (calculated with the TPP-2M formula [8]), the atomic density and elastic scattering factor. The sensitivity factors used were determined from pure elemental standards under the same conditions used for the depth profiles.

For each depth profile in figure 3, the sputter time was converted to Ar<sup>+</sup> ion dose using the relation:

$$Ion\ dose = \frac{j_b t}{e} \quad (1)$$

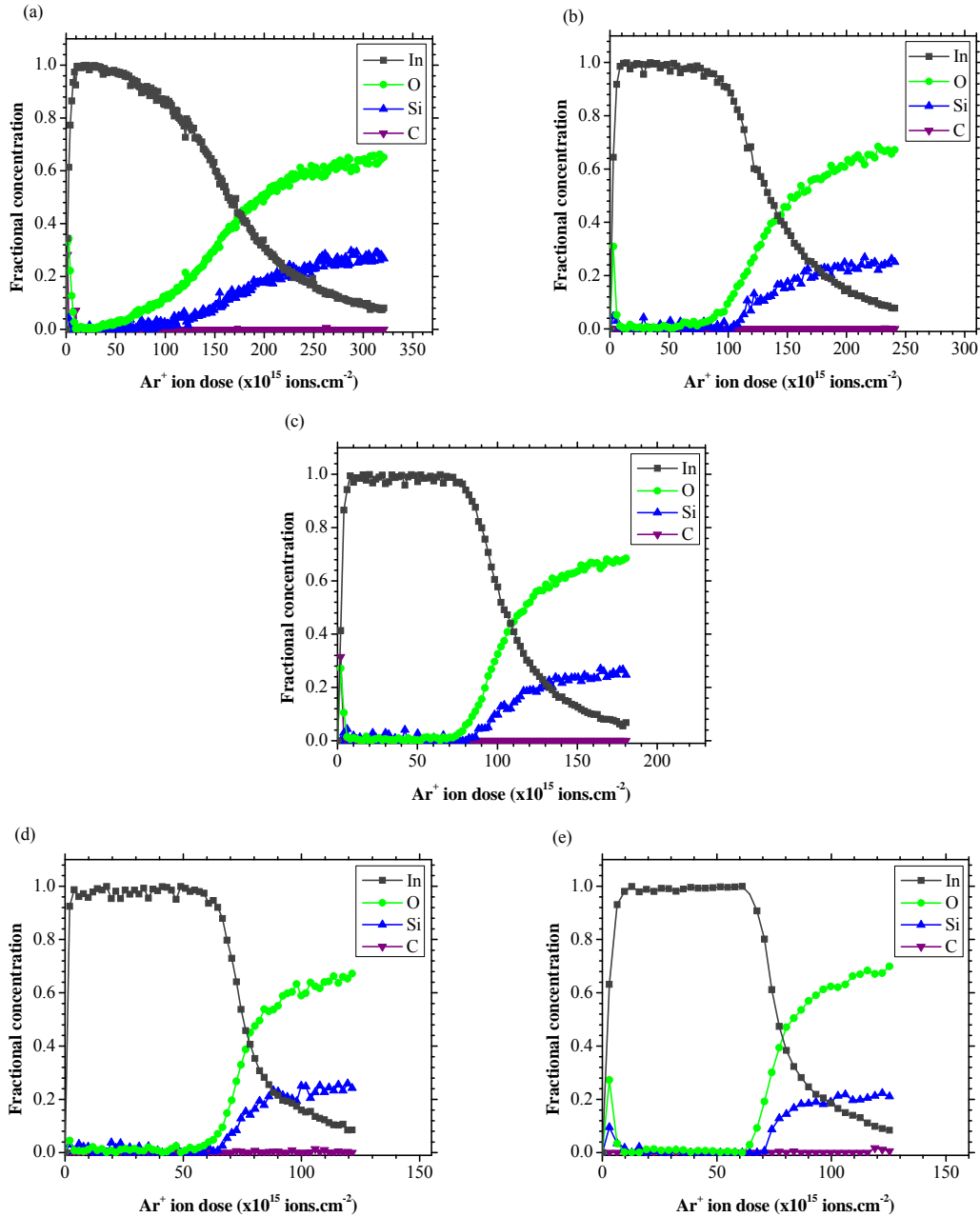
where  $j_p$  is primary ion current density,  $e$  is the charge on the ion and  $t$  is sputter time.

From the depth profiles (Figure 3), the Ar<sup>+</sup> ion dose ( $D_z$ ) required to etch the In film of a known thickness ( $z$ ) was determined from the full width at half maximum (FWHM) of In profiles for each ion beam energy. According to Hofmann [9] the sputter yield coefficient ( $S$ ) can be calculated with

$$S = \frac{z \rho N_A}{D_z M} \quad (2)$$

where  $\rho$  is density,  $N_A$  is Avogadro's number and  $M$  is atomic mass number.

Using the Ar<sup>+</sup> ion dose ( $D_z$ ) values required to etch the In films (1060 Å) and equation (2), the sputter yield coefficients ( $S$ ) from In films for each Ar<sup>+</sup> ion beam energy were obtained and tabulated in table 1.



**Figure 3.** Depth profiles obtained from the In (1060 Å) films with Ar<sup>+</sup> ion energies (a) 0.5, (b) 1.0, (c) 2.0, (d) 3.0 and (e) 4.0 keV.

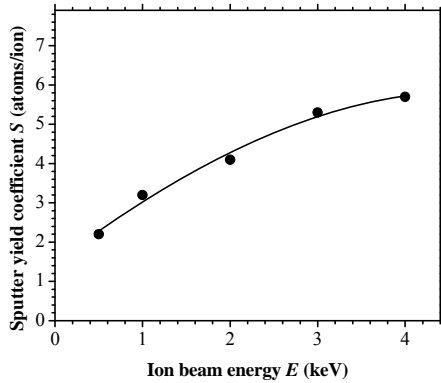
From equation (1) it is clear that the ion current density have to be determined accurately. Since the largest error in determining sputter yield coefficients values are in the ion current density measurements. Therefore, ion beam stability was monitored by measuring ion current with a faraday cup for each ion beam before depth profiling and immediately after depth profiling. In addition to this, the depth profiles measurements were repeated for all ion beam energies. The sputter yield coefficients values given in table 1 are the average values for the corresponding ion beam energies.

**Table 1.** Ion sputtering yield coefficients from In thin films bombarded at different Ar<sup>+</sup> ions energy.

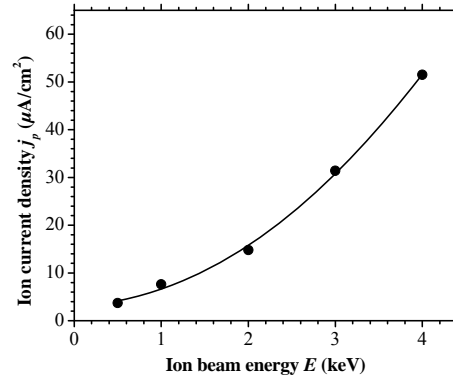
Ar <sup>+</sup> ion beam energy $E$ (keV)	Sputter yield coefficient $S$ (atoms/ion)
0.5	$2.2 \pm 0.3$
1.0	$3.2 \pm 0.4$
2.0	$4.1 \pm 0.4$
3.0	$5.3 \pm 0.2$
4.0	$5.7 \pm 0.5$

The ion beam energy and sputtering yield coefficients values shown in table 1 are plotted in figure 4. From figure 4, it can be seen that as the ion beam energy increased from 0.5 to 4.0 keV the sputtering yield coefficient increased from 2.2 to 5.7 atoms/ion. It is also eminent that the rate at which the sputtering yield coefficient increased (with beam energy) decreased at higher beam energies. At higher beam energies the ion beam interacts less with the surface atoms since the ions penetrate deeper into the material.

Figure 5 shows the ion current density as a function of the Ar<sup>+</sup> ion beam energy.



**Figure 4.** Ion sputtering yield coefficients for In as a function of Ar<sup>+</sup> ion beam energy.



**Figure 5.** Ion current density as function of Ar<sup>+</sup> ion beam energy.

#### 4. Conclusion

The diameter of the primary electron beam ( $1.3 \mu\text{m}$ ) used for the AES measurements is small compared to the ion beam rastered area of  $2 \text{ mm} \times 2 \text{ mm}$ . Therefore, the ion dose over an analysed area was uniform. The ion sputtering yield coefficients from In bombarded with Ar<sup>+</sup> ions were obtained for different ion beam energies ranging from 0.5 to 4.0 keV and the sputter yield coefficients ( $S$ ) were 2.2, 3.2, 4.1, 5.3 and 5.7 atoms/ion for Ar<sup>+</sup> ion with energies 0.5, 1.0, 2.0, 3.0 and 4.0 keV respectively. No data was found from literature for comparison.

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