ADDENDUM

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To cite this article: Henry Holland-Moritz et al 2017 Semicond. Sci. Technol. 32 109401

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Addendum

Ion beam irradiation of nanostructures: sputtering, dopant incorporation, and dynamic annealing

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Received 3 August 2017
Accepted for publication 29 August 2017
Published 8 September 2017

We presented an approach to obtain sputter yields of ion irradiated nanoparticles using high resolution scanning electron microscopy (SEM) [1, 2]. The approach compared the cross sectional areas of unirradiated (A0) and irradiated (Ai) nanoparticles derived from the respective SEM images. The sputter yield SY was then calculated from the volume ratio using

\[ SY = \frac{4 \rho_a}{3 \pi \rho_a} \cdot \left( A_0^{1/2} - A_i^{1/2} \right), \]

where \( \rho_a \) is the atomic density of the target material and \( \phi \) the ion fluence.

This formula is correct in first approximation. However, it does not account for the decrease of the projection area (A0) during irradiation which becomes significant if the ion fluence and, with this, the difference between initial cross sectional area and cross sectional area of the irradiated nanoparticle is large. More accurately, the number of ions per differential time has to be calculated. If a time interval \( dt \) is assumed, the number of sputtered atoms \( dN_{sp} \) is given by

\[ dN_{sp} = \rho_{at} \cdot dV = 4\pi \rho_{at} \cdot r^2 dr, \]

where \( r \) is the nanoparticle radius. The number of ions is given by

\[ N_i = \phi \cdot A = \phi \cdot \pi r^2, \]

where \( A \) the cross sectional area of the nanoparticle. The sputter yield results in

\[ SY = \frac{N_{sp}}{N_i}, \]

and therefore

\[ \frac{dSY}{dr} = \frac{1}{N_i} \cdot \frac{dN_{sp}}{dr} = \frac{4 \rho_{at}}{\phi}. \]

This results in

\[ SY = \frac{4 \rho_{at}}{\phi} \int_{r_1}^{r_0} dr = \frac{4 \rho_{at}}{\phi} (r_0 - r_1) = \frac{4 \rho_{at}}{\sqrt{\pi} \phi} (\sqrt{A_0} - \sqrt{A_i}). \]

The differences between this and the former formalism is shown in figure 1(a). The difference in the sputter yields is negligible for a difference in the cross sectional area up to 10%, while they significantly differ for a relative cross sectional difference larger than 20%. A comparison of the data presented in [1, 2] and the differential approach derived in this addendum is shown in figure 1(b). It is noticeable that the differences between both calculations are minor and essentially in the range of the error bars, because the differences between the cross sectional areas of unirradiated and irradiated nanoparticles are small.

Therefore, all results and conclusions presented in [1, 2] remain valid. However, the more detailed calculation has to be considered, if the relative difference in cross sectional areas of the pristine and irradiated nanoparticles exceeds a value of ~10%.
Figure 1. (a) Sputter yields of the original (red) and differential calculation (blue) (left axis) and relative change in sputter yield (right axis, dashed curve) as a function of the relative difference of the cross sectional areas before and after irradiation for a nanoparticle with a diameter of 50 nm. (b) Sputter yield as a function of ion energy. The results by iradina [3] are shown as blue data points. The red data points show the results presented in [1, 2], while the green data points show the sputter yields calculated with the differential approach presented in this addendum.

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**References**

