Re-deposition characteristics of FIB milling for nanofabrication

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When a sample is structured for nano-fabrication using a 30 kV Ga^+ focused ion beam (FIB), substrate particles will be sputtered away due to multiple scattering and momentum transfer of the primary ion beam. Because a FIB is used to induce local sputtering at the nm to μm range, there is a very local source of particles leaving the sample. These particles follow their own trajectories and they will either hit residual gas molecules, parts of the vacuum chamber or return to the sample at another location. This last phenomenon is known as re-deposition, and it sets a basic limit to the size and shape of structures that can be created. An example of this effect using patterned FIB milling is shown in Fig. 1. In addition, re-deposition has a negative influence of the milling yield.

Using the SRIM simulation software[1], it is possible to study the outgoing particles using their individual energy and direction, and in this way determine the spectral and angular distribution. For a Si sample with a perpendicular ion beam the angular distribution has been calculated using angular class-groups of 10 degrees. From literature it is suggested that the distribution follows a $\cos^n$ relationship ($n = 1 – 2$)[2,3]. The calculations however, show a distribution below a $\cos^2$ relation, see Fig. 2.
Quantitative measurement of re-deposition is not straightforward, due to the low amount of material and the two different species (atoms and substrate ions). In previous experiments[3] more than 40 hours of milling on a gold target have been applied and the transmission through half a quartz tube centered at the impact area, is measured as a value for the local re-deposition. This method is time consuming, ignores field generation due to charging of the quartz tube and does not account for a possible gold texture and subsequent ion channeling. In this paper a new method is presented to quantitatively determine the re-deposition of material at the inside of a FIB created hole in a thin, FIB created, lamella in doped silicon. The principle is shown in Fig. 3. Once the lamella and hole test structure are created (in ~ 30 min), the ion beam is used for top down milling to penetrate perpendicularly into the 500 nm diameter hole. The re-deposition is performed in 10's of seconds and results in a decrease of the diameter of the hole, due to mass build-up by the sputtered species. By recording images before and after milling and generating an overlay as shown in Fig. 4, the angular distribution can directly be measured.

The measured data are plotted in Fig. 2 as well and match quite nicely with the values calculated with SRIM. The new experimental method is relatively fast and simple, using a FIB created micro- structure at the corner of homogeneous sample.

References

[1] *SRIM simulation software* available at www.srim.org
[2] GBerhish, R., Wittmaack, K., *Topics in Applied Physics Vol 64, Sputtering, Chapter 2,* Springer (1991)
[3] K.P. Muller, H.C. Petzold, *SPIE Vol 1263 (1990), 12-20*

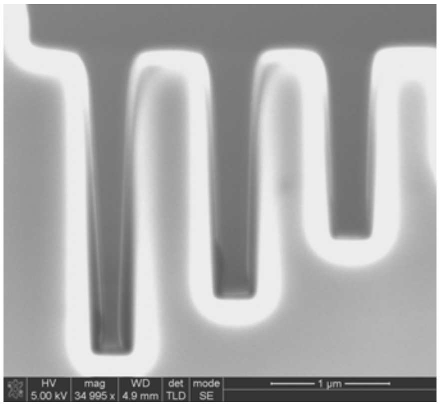

Fig. 1: FIB creation of trenches at different aspect ratios. The re-deposited material is shown as a darker, thin film in the trench. For a high aspect ratio, the effect of re-deposition is substantial.

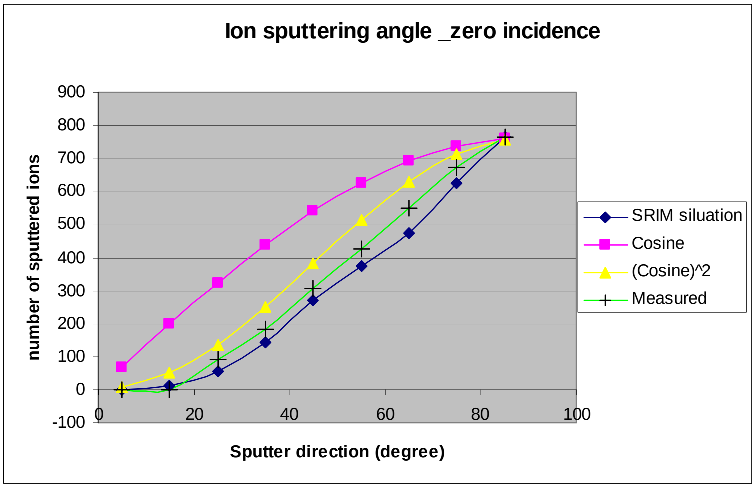

Fig. 2: Angular distribution of sputtered particles at zero incidence ion beam. Distributions according literature limits (purple, yellow), calculated (blue) and measured data points (green).

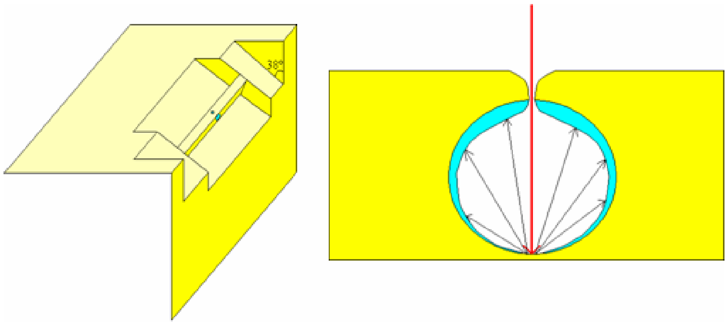

Fig. 3: A schematic view of the lamella created by multiple-angle FIB milling including sample rotation, (left). SEM view of the hole in the thin lamella after re-deposition (blue) induced by the primary beam (red) (right).

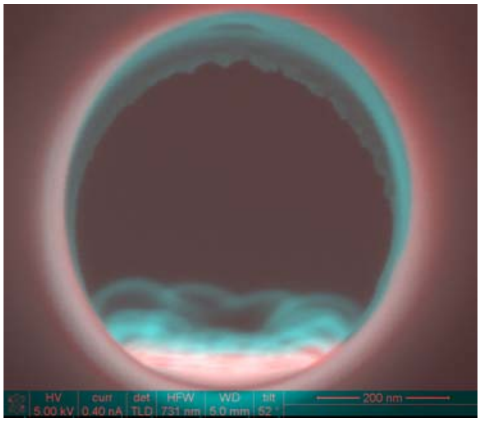

Fig. 4: Red/blue color coded side-view overlay images of the hole. Red refers to the pre-milling and blue to the post-milling condition. The dark-blue area around the hole is the re-deposited material. The lower structure is far behind the hole is an image background and has no relevance.