Ion-Induced Secondary Electron Yields and Simulation of Ion Imaging

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For decades, the Focused Ion Beam (FIB) has been an essential tool for micro- and nano-fabrication. As imaging device, however, its use has always been limited by the fact that the impinging ions transfer to the target a momentum that, being far greater than the one carried by electrons of the same energy, cause considerable and irreversible damage, removing atoms (sputtering) and causing atomic rearrangement (redeposition, amorphisation). Only recently, the development of ion sources with small virtual source size and high brightness, employing lighter ions such as He^+, renewed the interest in using FIBs for Scanning Ion Microscopy (SIM). [1–3] When imaging with ions, the effect of the ion beam on the target can not be neglected, for it affects, and often limits, the imaging performance of the microscope, in a way that is not easily quantified. [4] To obtain a better understanding of the scanning ion imaging process and its effect on the target, a "SIM Simulator" has been developed, whose flow chart is shown in fig. 1.

The first step is the definition of the ion beam, i. e. the ion current distribution. The sample is then defined as a "multilayer" matrix: one layer contains the morphological structure, other layers account for the different materials present in the target, in terms of Secondary Electron (SE) Yield (materials_δ), Sputter Yield (materials_Y), density (materials_ρ) and molecular mass (materials_MM). At each cycle, the beam stands on a given position on the sample, for a given amount of time ("dwell time"). During this time the number of produced SEs is calculated taking into account the morphology of the sample, the ion current distribution, the angular dependence of the SE Yield and the effect of the detector; this number represents the pixel value of the final image in the current beam position. In the same time, the way the sample surface is modified by the incident beam is calculated on the basis of the Sputter Yield angular dependence, the characteristics of the sample and the ion current distribution. When the beam is then moved to the next position, the area of the sample in which the beam overlaps with the previous dwelled area will have been modified by the previously calculated sputtering effect. When the cycle is repeated for each position of the beam on the sample, the final image is complete. As it appears from fig. 1, the whole simulation process relies on the availability of the curves showing the angular dependence of SE Yield and Sputter Yield for atom/ion pairs and beam energies of interest. For the Sputter Yields, values as obtained from the Monte Carlo simulation code TRIM [5] are used, while the SE Yields are experimentally determined for He^+ and Ga^+ beams at 25 keV and 30keV (fig. 2).

[1] B. Ward, J.A. Notte, and N.P. Economou. *J. Vac. Sci. Technol. B*, 24(6):2871–2874, 2006.
[2] T. Ishitani et al. *J. Electron Microsc.*, 51(4):207–213, 2002.
[3] R. Ramachandra, B. Griffin, and D. Joy. *Ultramicroscopy*, 109(6):748–757, 2009.
[4] V. Castaldo et al. *J. Vac. Sci. Technol. B*, 26(6):2107–2115, 2008.
[5] SRIM/TRIM reference website: `http://www.srim.org/`

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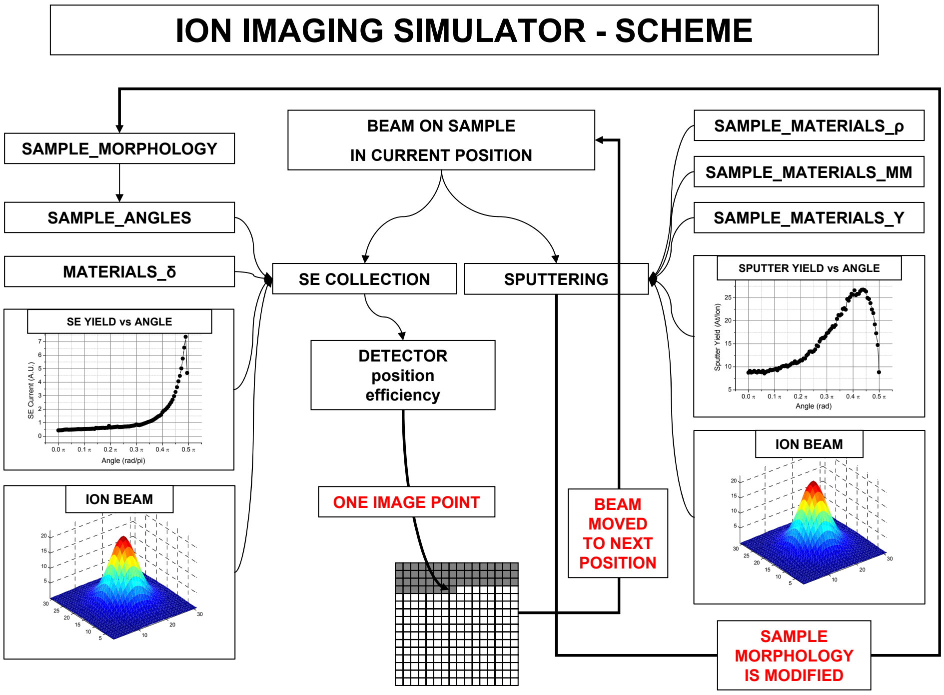

FIG. 1: A scheme of the cycle used for obtaining the SIM image starting from a given sample and a given ion current distribution; the cycle is repeated for each pixel of the final image; and at each position of the beam the morphology of the sample is modified according to the sputtering effect. The Sputter Yield curve is simulated, while the SE Yield curve is obtained experimentally.

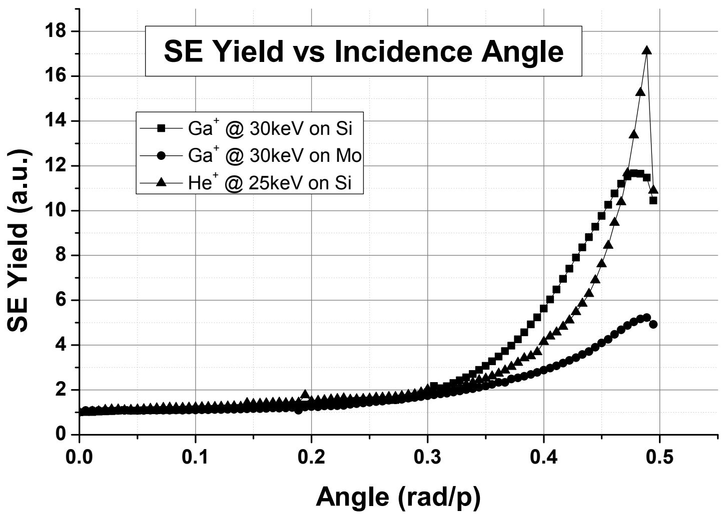

FIG. 2: Measured angular dependence of the ion-induced SE Yield for 3 different pairs ion/atom; the curves have been normalised for visual comparision; the vertical axis needs to be calibrated with real SE emission current values.