Towards secondary ion mass spectrometry on the helium ion microscope

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The ORION Helium Ion Microscope (HIM) has become a well-established tool for high-resolution microscopy [1]. It is based on the atomic-sized ALIS gas field ion source, which has a brightness of \(4 \times 10^9\) A cm\(^{-2}\) sr\(^{-1}\). This leads to probe sizes of less than 0.5 nm. The source can operate with helium and, after special prototype modifications, with neon [2]. While secondary electrons are used for high-resolution high-contrast imaging, detection of backscattered atoms can provide only limited specimen composition information.

By contrast, Secondary Ion Mass Spectrometry (SIMS) is an extremely powerful technique for analyzing surfaces due to its excellent sensitivity, high dynamic range, very high mass resolution and ability to differentiate between isotopes (see Figure 1). In order to get chemical information with a higher sensitivity and a high lateral resolution, we have investigated the feasibility of performing SIMS on the Helium Ion Microscope.

To reach these objectives, the secondary ion formation process under \(\text{He}^+\) and \(\text{Ne}^+\) bombardment has to be investigated and optimized along with the experimental beam parameters such as spot size and dwell time. High secondary ion yields are crucial when using a small low current analytical probe. To investigate secondary ion formation an experimental study was performed, to investigate sputtering effects on resolution a simulation approach was taken.

First, secondary ion yields for different elements sputtered from different materials exposed to helium and neon ion beams were experimentally determined on a test set-up. The basic yields were, as expected due to the use of noble gas primary ions, lower than those of conventional SIMS. However, yields may be increased by using reactive gas flooding during analysis, eg. oxygen flooding for positive secondary ions [3] and cesium flooding for negative secondary ions [4]. Figure 2 shows the measured useful yield enhancement (up to three orders of magnitude) with \(\text{O}_2\) flooding for different analyzed materials. Detection limits have been calculated taking into account the experimentally obtained useful yields. Figure 3 shows the detection limit for \(\text{Ne}^+\) bombardment on silicon with oxygen flooding in secondary positive mode. Depending on the dwell time, ppm sensitivity can be obtained.

Second, a detailed study of the sputtering phenomena was carried out in order to determine the effect of the collision cascade on the lateral resolution. \(\text{He}^+\) and \(\text{Ne}^+\) bombardment of different materials was studied using TRIM simulations [5]. In particular, the effects of the different beam and target parameters were investigated in order to estimate the best achievable lateral resolution, taking into account the competition between sputtering and imaging. The diameter (FW\(50\)) of the area from which sputtered atoms originate has been calculated for 10 keV \(\text{He}^+\) and \(\text{Ne}^+\) bombardment of different materials. The simulations show that a lateral resolution smaller than 10 nm can be obtained and that the mass and density of the target material are important parameters in determining the achievable resolution.

The results obtained are very encouraging and the prospects of performing SIMS on the ORION are very interesting. The combination of high-resolution microscopy and high-sensitivity chemical mapping on a single instrument will lead to a new level of correlative microscopy. This paper will present an overview of our experimental and simulation results and will discuss the prospects of SIMS on the Helium Ion Microscope in terms of detection limits and lateral resolutions.

References

**Figure 1.** Schematic of Secondary Ion Mass Spectrometry and its main applications.

**Figure 2.** Enhancement factor of the positive ionization probability with O₂ flooding.

**Figure 3.** Detection limits obtained for Si with a 10 pA Ne⁺ beam and oxygen flooding in the positive secondary ion mode.