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# Contrast Mechanisms in Transmission Microscopy Using keV Helium Ions

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Microscopy using transmitted ions and neutrals can reveal crystallographic and sub-surface details which are not captured by conventional secondary electron (SE) imaging. Scanning Transmission Ion Microscopy (STIM) has been available since several decades, but the majority of the facilities use MeV ions which require large infrastructure and therefore are not widely available. Furthermore, the typical probe sizes available in MeV STIM are relatively large (~μm) and hence do not resolve nanometric scale features. In this context, the high-brightness Gas Field Ion Source used in Helium Ion Microscopy (HIM) helps to reach sub-nm probe size and hence offers superior lateral resolution for SE imaging. Hence, the use of HIM for STIM applications has the potential to go beyond the state-of-the-art STIM imaging. While the typical energy of the $He^+$ ions used in HIM is relatively low (< 40 keV), the large range of $He^+$ ions in materials (e.g., 25 keV $He^+$ can penetrate > 200 nm thick Si) makes it feasible to perform STIM using keV $He^+$. While STIM is similar to (Scanning) Transmission Electron Microscopy (S/TEM), STIM offers some advantages in comparison to S/TEM. For example, contrast related to the charge exchange between the primary particles and the sample is not available in TEM as the electrons are either transmitted or simply absorbed within the material. Another example is the investigation of the sites of dopant atoms (substitutional vs interstitial) is straightforward when using ion channelling contrast whereas such investigations are difficult in an S/TEM.

We developed two prototype microscopes namely GALILEO and npSCOPE to explore the potential to perform STIM using keV $He^+$ ions. The main goals were to understand the contrast mechanisms and ion energy loss characteristics and to develop and demonstrate advanced imaging modalities using transmitted keV $He^+$ ions and He neutrals. The specific instrumental details of GALILEO and npSCOPE prototypes are described elsewhere [1-3]. Briefly, GALILEO is an in-house built imaging testbench equipped with a duoplasmatron ion source, a Wien filter, transfer and projection optics and a microchannel plate delay-line (MCP-DL) detector for the detection of transmitted ions and neutrals. It is also equipped with a pulsing unit to pulse the primary ion beam to enable time-of-flight (TOF) measurements. npSCOPE has a commercial Zeiss HIM column mounted on a custom-built instrument with enlarged sample chamber and is equipped with various detectors in addition to the conventional SE detector, notably a 2D MCP-DL detector for STIM and a focal plane MCP-DL detector for Secondary Ion Mass Spectrometry besides offering the possibility to perform experiments even at cryo-temperatures.

The recent upgrades of the two prototypes focusing on the STIM imaging capabilities including TOF-STIM will be discussed. Application examples will be presented to demonstrate the contrast mechanisms and imaging modes (on-axis, off-axis imaging) that are possible using keV $He^+$ STIM. For instance, ion channelling contrast due to variations in crystal orientation in a polycrystalline gold membrane was investigated [4]. An example of a STIM image obtained using 25 keV $He^+$ ions in the npSCOPE prototype from a polycrystalline gold membrane is shown in Fig. 1 below. The membrane contains several twin bands which appear as dark stripes in bright grains or vice versa depending on the local channelling conditions. Some twin bands were invisible in the STIM images. STIM imaging in the npSCOPE prototype showed a lateral resolution close to 30 nm, for the specific experimental conditions used. The 4D datasets (for each pixel on the sample a 2D detector image is recorded) allowed us to quantitatively probe channelling even within nanometre scale features, which was previously not possible [5].

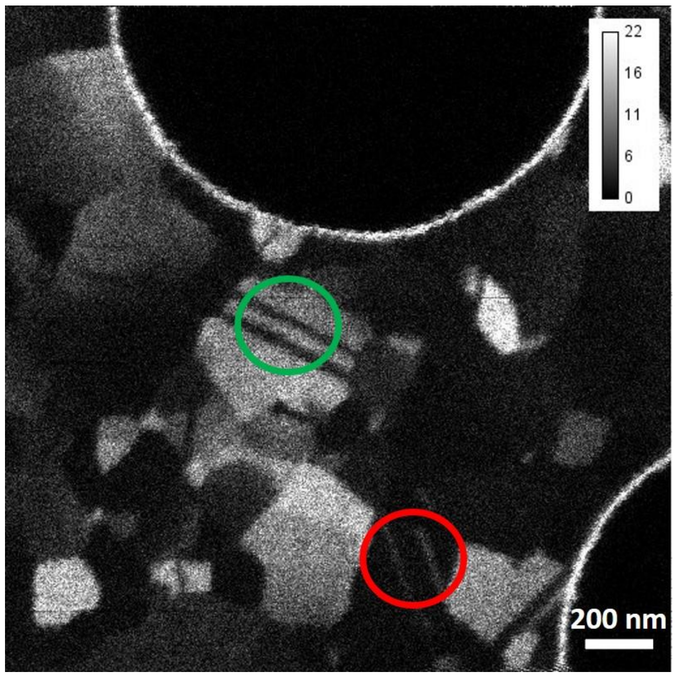


**Figure 1.** An example STIM image of 50 nm thick gold membrane obtained using 25 keV $He^+$ ion beam. Dark twin bands in a bright grain (green circle) and bright twin bands in a dark grain (red circle) are highlighted. Variations in the extent of ion channelling from one pixel to the next results in an image contrast. Such datasets allow analysing transmitted ion channelling within nanometric scale features.

References:
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