The advance of scanning neutral helium microscopes, SHeM: from the first images with neutral atoms to the fundamentals of imaging with state-of-the-art scanning neutral helium microscopes

S. D. Eder[1], M. G. Barr[2], A. Fahy[2], P.C. Dastoor[2] and B. Holst[1]

[1]*Department of Physics and Technology, University of Bergen, Allégaten 55, 5007 Bergen, Norway*,
[2]*Centre for Organic Electronics, University of Newcastle, Callaghan, NSW, Australia,*

Corresponding author: sabrina.eder@uib.no

At the SCANDEM meeting in 2012 we presented our concept and idea for the design of new microscope based on imaging with neutral He atoms after the first ever recorded images with neutral helium atoms were presented in 2008 [1]. Back then, some people were a little surprised that we were talking about this new imaging technique they have never heard about. Since then, multiple experimental systems capable of generating spatially resolved scans of a sample surface via neutral helium atoms have come online, representing a significant advance to the pursuit of routine atom imaging [2-4] and generating a small but eager community of neutral helium microscopists.

Neutral helium microscopy is of particular interest for working with delicate materials that may suffer degradation and even damage under other microscopies utilising charged particles or light [5].

As with all other microscopy techniques, the specifics of image formation within the instrument are crucial to gaining a full understanding of the produced micrographs. Questions around the sources of the observed contrast further complicate the issue. From the many decades of work on Helium Atom Scattering (HAS), it has been theorised that contrast in neutral helium microscopy will arise not only from the surface topography, but also its composition [6,7]. However, the development of a complete understanding of the different contrast channels and their respective contributions to a collected micrograph is still an active topic of investigation and one of great importance to the field. With the nature of image formation and the contrast mechanisms being intricately related, teasing them apart is key to pushing our understanding of the technique further.

Here we present a short history on the development of neutral helium microscopy as well as more recent work detailing contrast and image formation as explored in the Scanning Helium Microscope (SHeM). We will talk about the basics of the projection distortion that arises due to the instrument scattering geometry; *supra*- and *sub*-resolution contrast formation; the effects of multiple scattering on the produced image; and the exciting possibility of chemical contrast.

With the 'soft' nature of the He probe, the SHeM presents the possibility for completely damage free imaging, making it a uniquely suited instrument for a variety of delicate sample systems. We will show how the SHeM can be used for surface quality investigations in the nanoscale regime; how it is possible to record images of OPV (organic photovoltaic) materials without any surface coatings or damage to the polymer layers; as well as the application of SHeM to the field of taxonomy, utilising a stereophotogrammetry approach to draw qualitative taxonomical information from biological samples.

[1] "Imaging with neutral atoms - a new matter-wave microscope", M. Koch et al, Journal of Microscopy **229**, 1-5 (2008).

[2] “Unlocking new contrast in scanning helium microscopy”, M. Barr et al, Nature Communications **7:10189** (2016).
[3] “0-Order Filter for Diffractive Focusing of de Broglie Matter Waves”, Eder et al, Phys. Rev. A **95**, 023618 (2017)
[4] “A ray tracing method for predicting contrast in neutral atom beam imaging”, Lambrick et al, Micron **113**, 61-68 (2018)
[5] “Taxonomy through the lens of neutral helium microscopy”, Myles & Eder et al, Sci. Rep. **9**, 2148 (2019)
[6] “Atomic beam diffraction from solid surfaces“, Farías & Rieder et al, Rep. Prog. Phys. **61**, 1575-1664 (1998)
[7] “Probing Surfaces with Thermal He Atoms: Scattering and Microscopy with a Soft Touch”, B. Holst & G. Bracco, in: Surface Science Techniques. Springer Series in Surface Sciences, vol **51**, 333-365, Springer, Berlin, Heidelberg (2013)