

Is Microanalysis Possible in He⁺ Ion Microscopes?

David C Joy^{*,**} and Brendan Griffin^{**,***}

* University of Tennessee, Electron Microscopy Facility, Knoxville, TN 37996 -1840

** Center for NanoPhase Materials Science, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6496

*** Center for Microscopy, Characterization and Analysis (M010), University of Western Australia, Crawley, WA, Australia 6009

Helium ion microscopy (HIM) has established itself as being capable of meeting and beating the imaging performance of conventional scanning electron microscopes (SEM). However, chemical microanalysis, which is now an essential adjunct to microscopy, poses problems for the HIM. Low energy ion beams cannot generate fluorescent X-ray emission because the key initial step of ionization is dependent on particle velocity not particle energy and ions are much heavier, and therefore slower than, electrons of the same energy. Ions can, however, be backscattered from the surface of the specimen and images recorded from this signal show a significant contrast variation with the atomic number of the target area (figure 1). While this provides valuable chemical information in image mode it is not possible to perform elemental analysis in this way because, although there is a general upward trend in signal with atomic number, shell filling effects modulate the yield and make a unique correlation between the signal level and the atomic number unobtainable. Some additional information is therefore needed to identify the element(s) concerned. This can be obtained by energy dispersive spectroscopy of the backscattered ions because there is a direct relationship between the atomic weight of the surface atom struck by the ion, the angle through which the ion is deflected, and its energy. Figure (2) shows how the ratio of the energy of the scattered He⁺ ion (E_{scatter}) to the incident ion (E_{incident}) varies with target atom type assuming a scattering angle of 180 degrees. Other take-off angles (90 – 180 degrees) show generally similar behavior.

While this idea is promising there are still practical difficulties to overcome. The elements between He ($Z=2$) and Ca ($Z=20$) have scattered energies which fall into the range extending up to about 60% of the incident energy, thus leaving the 80 or so elements that comprise the rest of the periodic table to occupy the remaining 40% of the energy window. So for operation at 40keV, while peaks associated with successive elements in the periodic table up to Calcium would be separated by ~ 1keV, the corresponding spacing for heavier elements would be ~ 200eV or less. Heavier ion beams (e.g. Ga⁺) produce a more equitable distribution of scattered energies with atomic weight, but at the expense of sample damage. For anything other than the simplest chemistries therefore there will be significant overlaps between peaks unless the energy resolution of the detector is of the order of tens of eV

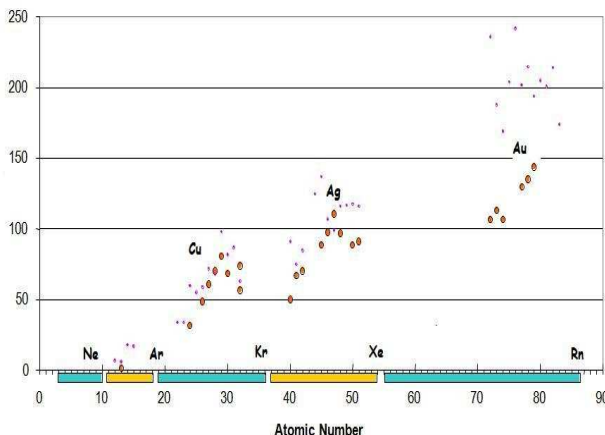


Figure 1. Measured RBI yield (arb. units) for He⁺ ions at 40keV, and Monte Carlo computed values

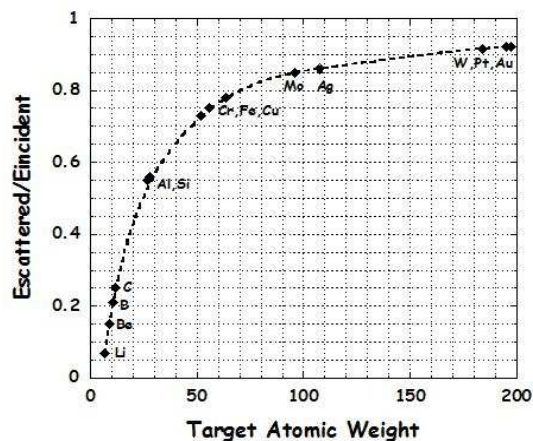


Figure 2. Energy of He⁺ RBI vs atomic weight for 180° take-off

The energy resolution of the detector is therefore critically important and, unfortunately, measuring energy with a diode detector of the type used for energy dispersive X-ray analysis is not satisfactory. X-rays (photons) deposit all their energy in a single event so, provided only that the diode is thick enough to stop all X-rays of interest, the number of electron-hole pairs produced per event will vary linearly with the energy of the photon. In contrast ions, like electrons, give up their energy continuously as they travel but, unlike electrons, the rate of energy transfer is highest at impact and falls thereafter. In an “EDX” diode the region immediately below the entrance surface is often (unhelpfully) called the ‘dead layer’ because here the competition between carrier drift and diffusion greatly reduces electron-hole pair collection efficiency. This layer typically extends for 0.2 - 0.3 micrometers into the active region of the diode and so is exactly where many of the He⁺ ions, because of their limited range, would deposit a majority of their energy resulting in fewer electron-hole pairs for collection and analysis. Although higher energy ions will travel into the active region they will already have lost an indeterminate fraction of their energy along their trajectory so further degrading the energy resolution. In an attempt to overcome these problems a detector specially optimized for the energy dispersive analysis of ions has been designed, based on detailed Monte Carlo simulations of ion and electron transport, and will be described. The computed performance of this device shows some promise but significant limitations remain.

Energy dispersive analysis of the ions, by a ‘time of flight’ method is feasible but difficult to implement without a major redesign of the microscope. Secondary Ion Mass Spectrometry (SIMS) is also possible with He⁺ ions but would suffer from the low sputter yields available especially at higher (>50keV) beam energies^[1].

References

[1]. The authors are grateful to Dr. John Notte, Zeiss SMT for valuable discussions, experimental assistance, and the data shown in figure 1. David Joy is grateful to the GRC, program manager Dr. Dan Herr, for partial support for this work.