

Secondary, Backscattered and Low Energy Loss electrons in the SEM: Quantification for nano analysis

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The scanning electron microscope (SEM) has been an important instrument that underpinned many of the advances made in science and engineering over the last 50 years or so. This instrument continues to play the same crucial role today in many disciplines thanks to several advantageous properties of this instrument, in comparison to others, which include: ease of sample preparation, simple instrument operation, moderately high spatial resolution approaching 1 nm, offered by a number of manufacturers of modern SEMs. The latter property has been mainly due to recent advances made in the electron optics of SEM cathodes and detectors. These properties have placed the SEM at the heart of semiconductor fabrications; as an aide in research and development, and as a metrology tool on fabrication lines.

The continuous challenge to conform to the Moore's law which means ever shrinking dimensions on electronic devices, places additional demands on the instrument capabilities and its use in this environment. In addition, the assessment of nano-structures and nano-materials is another field that requires the use of the SEM. Metrology, in the wider sense of scale and composition, remains to be the challenge to SEMs, however, fortunately, the basic physics of electron-solid interaction that takes place in the SEM is quite advanced and well understood. It is time to revisit the electron-solid interaction in the SEM and to see if new detectors and procedures should now be adopted to maximise the benefits gained in inspecting a solid sample.

Monte Carlo (MC) techniques have been extensively used in the analysis and interpretation of signals generated by electron-solid interaction as well as an aide in designing electron detectors [1-2]. While a detailed trace of incident electrons in solids still remains time consuming, recent MC models [3-5] are both quite accurate and efficient in describing this interaction, particularly at incident electron energies >5 keV. However, at lower energies (<5 keV) these models show variations which need to be taken into account in data analysis [6]. For example, [3 and 4] show lower backscattered electron coefficients (η) than experimental values, while [5] reveal a "bump" in η between 1 keV and 2 keV (see Fig. 1 showing the results for Ge as an example). Further, none of the freely available programs simulate the secondary electron coefficient (δ).

We have recently developed a three dimensional MC suite of programs (Mc3D) to simulate electron solid interactions, where various signals can be generated, η , δ , low energy loss electrons and x-rays. The program, which is written in C++, is object oriented making use of well known "design patterns". It has been extensively updated and revised since its first inception [7]. The electrons can travel through materials which are formed into various 3D shapes (e.g. spheres, cylinders, boxes). In order to determine when an electron moves from one shape into another, vector algorithms were used which originate from the field of computer graphics [8].

The Mc3D program has been used to estimate η and δ in the energy range 250eV to 5 keV and the results are compared with experimental measurement collected at York under ultra high vacuum conditions of “as inserted” and argon ion bombarded surfaces as well as data published by [9]. Using the Mc3D program, it was possible to detect residual surface contaminants of carbon and oxygen. These contaminants were included in the program and better agreement of simulated and measured data was obtained.

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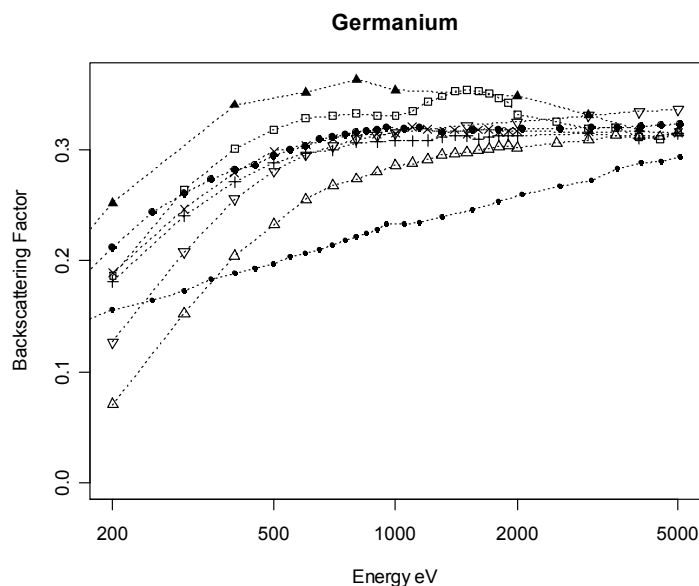


FIG 1. The backscattering factors for Ge. The solid symbols represent measured values: small \bullet = η for as inserted samples, large \bullet = η for cleaned samples, \blacktriangle = η as measured by [9]. The open symbols represent MC calculations from public domain programs: \square = η according to [5], Δ = η according to [4], ∇ = η according to [3]. The crosses represent our MC calculations: \times = η using the Continuous Slowing Down Approximation (CSDA) of [10], $+$ = η using the CSDA of [11].