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# Improved Electron Microscopy with Monte Carlo Simulations

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This tutorial will review the principles of Monte Carlo simulations to perform x-ray microanalysis in the scanning electron microscope (SEM) and in the transmission electron microscope (TEM) as well as to simulate electrons backscattered images in the SEM. Emphasis will be given on two Monte Carlo free commercial software, Casino [1] and Win X-Ray [2] that can be used to perform quantitative x-ray microanalysis as well as to find optimum conditions to analyse and image various types of materials. The utility of Monte Carlo simulations to characterize non homogeneous materials in the SEM will also be covered. Finally, Monte Carlo simulations for the effect of the skirt on X-Ray microanalysis in the environmental scanning electron microscope (ESEM) or the variable pressure scanning electron microscope (VP-SEM) will be discussed. Casino simulates electron scattering for homogeneous and heterogeneous materials consisting of horizontal or vertical layers and x-ray emission for characteristic lines only. Win X-Ray computes the full X-ray spectrum emitted from a homogeneous bulk specimen and measured with an energy dispersive spectrometer (EDS) x-ray detector in a SEM. These two Monte Carlo programs can be downloaded at http://www.montecarlomodeling.mcgill.ca/ .

As an example, CASINO was used to simulate the variation of the BSE coefficient, $\eta$, and of the boron $K_\alpha$ line on a line scan for a Fe specimen having a 10 nm layer of boron for various electron beam energy ($E_0$) with a beam diameter of 10 nm and with 5000 electron trajectories simulated. Figure [1] shows the variation of $\eta$ with the beam position. Clearly, the boron layer should be visible at all $E_0$. Figure [2] shows the computed contrast as a function of $E_0$ using the line scans of figure [1]. The contrast decreases with $E_0$ owing to the increase of the interaction volume. Figure [3] shows the variation of the intensity of the boron $K_\alpha$ line with the beam position. Figure [4] shows the variation of the intensity of the boron $K_\alpha$ line when the beam is located at the center of the boron layer as a function of $E_0$ for two cases, same beam current and the real situation of the brightness proportional to $E_0$. In this later real case, 20 keV would be the condition that would maximize the B $K_\alpha$ line count rate.

## References

1. P. Hovington, D. Drouin and R. Gauvin (1997), “Casino: A New Era of Monte Carlo Code in C Language for Electron Beam Interaction, Part I: Description of the Program”, Scanning, Vol.19, pp. 1-14.
2. R. Gauvin, E. Lifshin, H. Demers, P. Horny and H. Campbell (2003), “Win X-ray, a new Monte Carlo Program that Computes X-ray Spectrum for X-ray Microanalysis in the Scanning Electron Microscope”, Submitted to Microscopy & Microanalysis.

**Figure [1] Variation of the BSE coefficient with the beam position. 10 nm B vertical layer in Fe.**

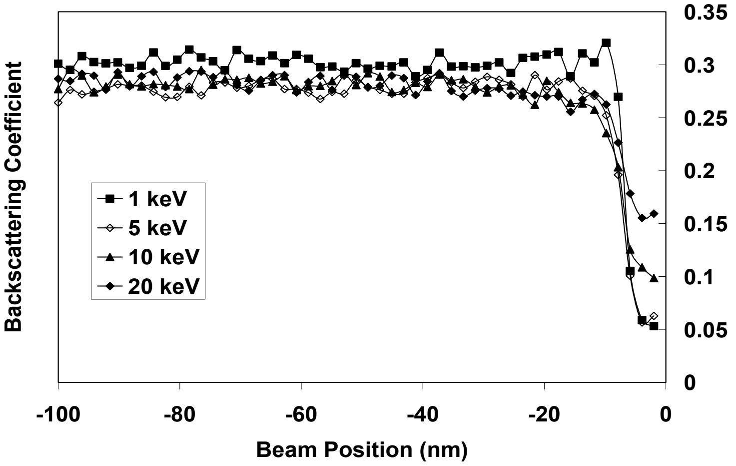

**Figure [2] Variation of the contrast versus $E_0$ computed from the data of figure [1].**

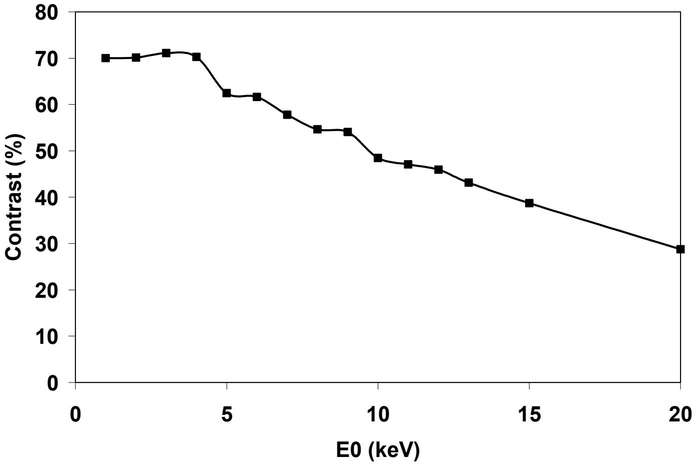

**Figure [3] Variation of the B $K_\alpha$ line with the beam position. 10 nm B vertical layer in Fe.**

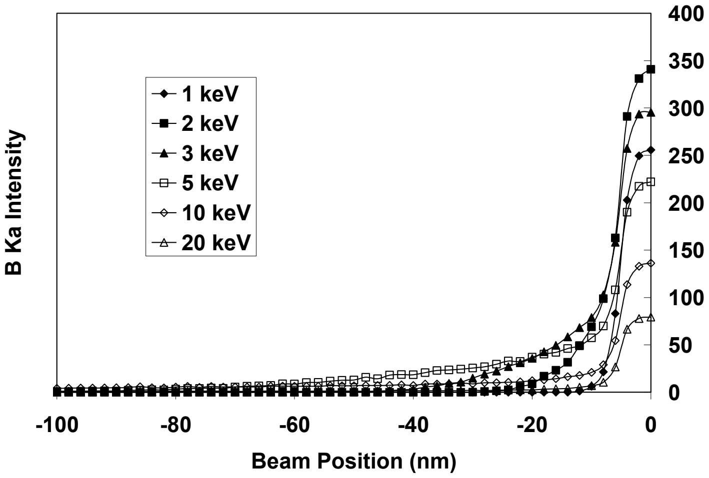

**Figure [4] variation of the intensity of the B $K_\alpha$ line when the beam is located at the center of the layer as a function of $E_0$.**