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Spatial Resolution of X-Ray Images

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Current SDD detectors can now deliver 200 000 to 1 000 000 of counts per seconds and the count rates is now limited by the maximum probe current available in the electron microscope for a given probe diameter. The question of imaging materials with x-ray in the SEM needs to be investigated; especially the relation between the spatial resolution and the number of x-ray counts in the x-ray image. This paper will demonstrate how Monte Carlo simulations can be used to determine this relationship using a new Monte Carlo program, MC X-Ray [1].

This new program computes the complete x-ray spectra from the simulation of electron scattering in solids with various types of geometries. MC X-Ray allows for more than 100 different regions in materials with shape of spheres, cylinders and combinations of horizontal and vertical planes. All these regions can have a different composition. MC X-Ray includes the Bremstrallung cross-sections of Ding – Statham to compute the emitted background x-ray intensity in order to generate a synthetic X-Ray spectrum. Then, a true EDS spectrum detected by a SDD detector can be simulated using the absorption of photons and the subsequent diffusion of the photo-electrons in the x-ray detector using the synthetic spectra. MC X-Ray simulates the true noise of EDS spectra without using Gaussian noise techniques, as classically done in others softwares. As a result, complete EDS maps can be simulated for a given number of emitted photons per pixel.

In this work, EDS images were simulated for embedded spheres of Cu in C of diameter of 50, 20, 10 and 5 nm at 10 keV for various number of emitted photons per pixels in 128 X 128 images having a size of 140 X 140 nm. Figure [1] shows such simulated X-Ray images for the C $K\alpha$ and the Cu $K\alpha$ and $L\alpha$ lines with 1000 and 100 000 emitted photons per pixel. At 1000 emitted photons per pixel, all the Cu spheres are visible for the C $K\alpha$ and the Cu $L\alpha$ lines while for the Cu $K\alpha$ line, the 5 nm is not visible and the 10 nm sphere is barely visible. Since at 10 keV, the overvoltage is low for the Cu $K\alpha$ line, even if the x-rays that are coming closer to the surface should give a better spatial resolution in that case, the low ionisation cross-section gives few emitted photons and with a total of 1000 emitted photons per pixels, the small spheres do not emit sufficient photons to be visible. This is not the case with 100 000 emitted photons per pixels with all the maps showing the Cu spheres. In order to quantify the spatial resolution, the Smart routine [2] is used with the simulated x-ray images. Figure [2] shows the resolution of these x-ray images as a function of the total number of emitted photons per pixel. Clearly, the resolution improves with an increase of photon number, especially for the Cu $K\alpha$ line which has a terrible resolution below 10 000 counts. It is interesting to note that images with the C $K\alpha$ line seem to have the best resolution owing to its stronger absorption.

References

1. P. Michaud and R. Gauvin (2009), "MC X-Ray, a New Monte Carlo Program for Quantitative X-Ray Microanalysis of Real Materials", Microscopy and Microanalysis, 15 (Supp.2), p. 488-489.
2. D. C. Joy. The Smart routine is available at http://web.utk.edu/~srcutk/

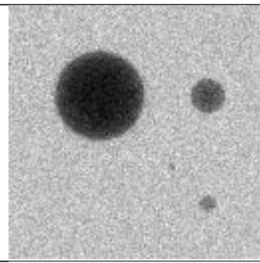
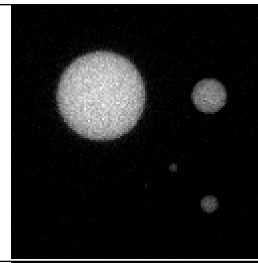
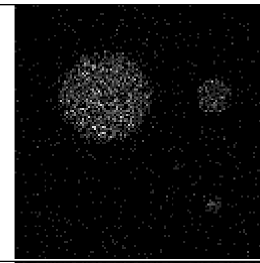
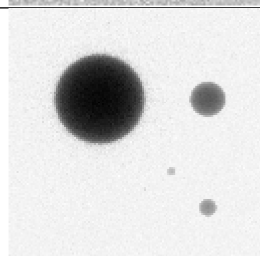
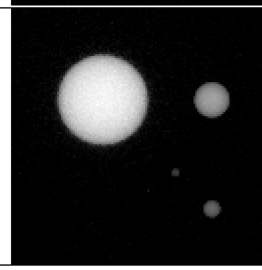
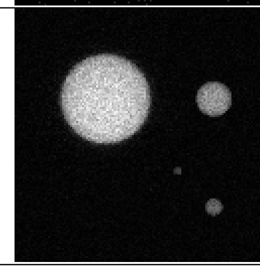
Total number of emitted photons per pixel	C K_α	Cu L_α	Cu K_α
1000			
100000			

Figure [1] Simulated X-Ray images of embedded spheres of Cu in C having diameter of 50, 20, 10 and 5 nm at 10 keV for the C K_α and the Cu K_α and L_α lines with 1000 and 100000 emitted photons per pixel. The images have 128 X 128 pixels and a size of 140 X 140 nm.

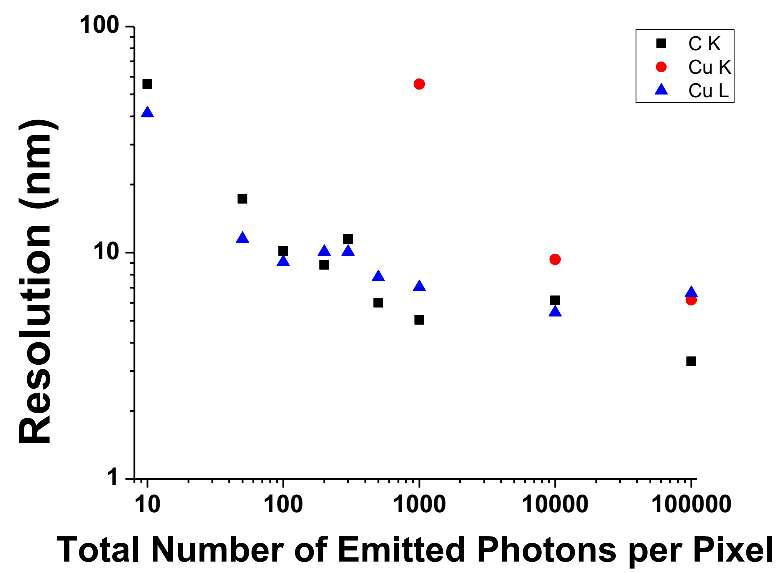


Figure [2] Resolution of the x-ray images as a function of the total number of emitted photons per pixel.

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