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The energy dispersion characteristics of a magnetic beam separator

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Abstract

This paper presents an energy spectrometer design for scanning electron microscopy, where the spectrum of secondary, Auger and backscattered electrons can be captured at the same time. The spectrometer is based upon the use of a magnetic sector beam separator that deflects the primary beam while dispersing the scattered electrons. A series of retarding field magnetic sector post-deflectors is used to focus the scattered electrons on to a multi-channel detector plane. Initial simulation results predict that pre-focusing the scattered electrons into the beam separator via a transfer lens will significantly reduce the effect of angular dispersion and improve the beam separator spectrometer's energy resolution.

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Keywords: Electron energy loss spectroscopy; Energy dispersion; Magnetic separator

1. Introduction

Recently, a "Spectroscopic SEM" proposal made by Khursheed et al [1,2] describes the possibility of redesigning the SEM so that it can capture the entire energy range of scattered electrons that leave the specimen. The new design, depicted in Fig. 1, is based upon the use of a magnetic sector deflector as a beam separator which bends the primary beam through a large angle, typically 90 degrees. The primary beam then enters a mixed field electric/magnetic immersion lens. The scattered electrons travel back through the objective lens, and are focused into the beam separator by a transfer lens. The beam separator now acts as the first stage of an energy spectrometer. Subsequent first-order focusing on to multi-channel detectors can be achieved through the use of additional magnetic sector/retarding field units. In the present paper, the energy dispersive characteristics of the beam separator are analyzed for a spectrometer designed to acquire the energy spectrum of secondary, Auger and backscattered electrons in parallel.

The beam separator consists of circular magnetic sector plates, which is able to both deflect the primary electron beam and act like a round lens, a feature known as "stigmatic focusing". The primary beam aberrations of the beam separator have been analyzed in detail, and they are predicted to lie in the sub-nanometer range for SEM

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applications [3]. These predictions have recently been verified by experiment, and they are the subject of another paper presented at CPO-7 [4].

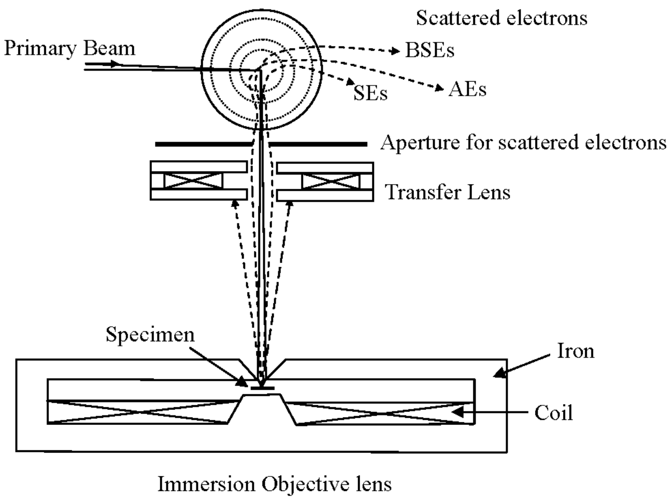

Fig. 1. *Schematic layout of beam separator energy dispersion action. BSEs, AEs and SEs denote backscattered, Auger and secondary electrons respectively.*

2. Field distribution simulations

Simulation of the spectrometer's characteristics requires accurate ray tracing of electron trajectory paths through curved magnetic sector plates. Since magnetic sector field distributions are inherently three-dimensional in nature, and in this case involve curved boundaries, direct ray tracing of electrons through them is a non-trivial task. Numerical field solving techniques such as the finite element method do not in general provide enough accuracy to extract aberration coefficients from the trajectory paths of focused beams in three dimensions. This is because numerical meshes in three dimensions that model complex shaped boundaries typically need over a million free nodes, requiring prohibitively large amounts of computer memory and unmanageably long program run times. The situation is made even more difficult for retarding sector units where an electric field is overlaid onto the deflecting magnetic field in order to slow down electrons to very low energies (a few eV). Another disadvantage of using a fully finite element approach is that high-order interpolation methods are needed to extract accurate field information from nodal potentials. While not impossible to carry out, this is quite a challenging task in 3D where the mesh density is relatively low. For all for these reasons, mesh-less methods are preferred. In the following work, a semi-analytical approach is taken, one which uses a modified two-dimensional finite element solution in combination with a Fourier-series expansion. This approach avoids the direct use of a fully three-dimensional finite element solution, and has the desirable feature of not requiring a mesh in the region where electron trajectories are to be plotted.

Fig. 2 shows schematic layouts of sector plates having odd and even symmetry planes. The scalar potential $\Psi(x,y,z)$ represents magnetic fields in the case of odd symmetry and electric fields in the case of even symmetry. Consider a box with dimensions a ,b, L and in the x, y and z directions. A finite element solution in the plane of the plates, $\Psi(x,y,L)=g(x,y)$, is used as the potential distribution on top of the box region. In the case of magnetic deflectors, where z = 0 represents the odd-symmetry plane and the other sides have zero magnetic potential, as shown in Fig. 2a, the magnetic potential inside the box can be expressed as a double Fourier-series: