On the Influence of Backscattered Electrons on the Lateral Resolution in Scanning Auger Microscopy

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Abstract. A definition of edge resolution is proposed, which is adapted to the peculiarities of scanning Auger microscopy. Based on recent Monte-Carlo computer simulations for scanning electron microscopy, the influence of backscattered electrons on the edge resolution is estimated for low-Z (Al) and high-Z materials (Au). The resolution is found to be of the order of 100 nm and to be nearly independent of the atomic number of the sample.

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Though Auger Electron Spectroscopy (AES) is a highly surface-sensitive technique, the information contained in Auger intensity maps is not restricted to the first few monolayers only. It has been demonstrated earlier [1] that particles of a high-Z material lying within a low-Z material far below the surface do show up indirectly in Auger micrographs. This effect is due to backscattered electrons from the high-Z material which indicate its presence by enhancement of the surface signals, though no traces of the heavy element are detected in the Auger spectrum. The results of high resolution Scanning Auger Microscopy (SAM) revealed, that the surface topography also may have major influence on the intensity distribution in Auger micrographs: At least in the conventional modes of image formation it is a still not completely resolved task to distinguish between structural effects and true surface composition variations [2]. In both cases the production of Auger electrons by the primary beam as well as by backscattered and secondary electrons has to be taken into account in order to extract the wanted surface information out of Auger images.

In this note, we consider the influence of backscattered electrons on the lateral resolution in scanning Auger microscopy. Based on recent computer-simulations [3] we estimate the edge resolution for low-Z (Al) and high-Z (Au) materials.

First, we have to specify what is meant with resolution. We do not have in mind to detect a small isolated particle or to determine the minimum gap size between two extended particles. In these cases the sharpness of the variation of the Auger signal upon scanning across the edge of a sample is mainly determined by the primary beam diameter, backscattering effects being almost negligible. Therefore, the resolution is dictated experimentally by the compromise between a useful signal-to-noise ratio and beam size. Values of about 30 nm have been reported [4, 5].

As AES is capable of detecting very thin surface layers, we find it natural to adopt a definition of resolution, as illustrated in Fig. 1.: A thick smooth sample of material \( Z_1 \) is covered by a thin layer of material \( Z_2 \), having an infinitely sharp edge at the position \( x = 0 \). The layer thickness is assumed to be of the order of the typical mean free path of Auger electrons, i.e. several atomic layers. The question is: How sharply does the Auger signal from layer \( Z_2 \) increase upon scanning an infinitely fine electron beam under normal incidence from minus infinity across the edge to plus infinity? From the rise of the Auger intensity around \( x = 0 \) we then determine the edge resolution by applying a suitable definition.

Within the layer \( Z_2 \) the spreading of the primary beam is negligible as the total elastic and inelastic scattering cross section \( \sigma_r \) for high energy electrons is very small compared to the mesh size of the unit cell (e.g. \( \sigma_r \approx 10^{-17} \text{ cm}^2 \) for 20 keV electrons in Al [6]) and, in addition, is mainly due to forward scattering. There is, however, a relatively large flux of secondary electrons from below, the spatial distribution of which
is more or less extended, depending on the material $Z_1$. If the energy of these electrons is sufficient to ionize $Z_2$-atoms, an additional Auger current results which smears out the step-like rise of intensity due to the primary beam. The term secondary electrons is not very well defined in electron microscopy, all electrons with $E < 50$ eV being called true secondary electrons, those with $E > 50$ eV being called backscattered electrons. This distinction is arbitrary as the spectra of both types of secondary electrons extend from zero up to the primary energy. The backscattered electrons are, however, well distinguishable from the true secondaries, as the energy of the former is referred to the cathode potential of the electron gun, whereas that of the latter ones is referred to the Fermi level of the sample [7]. The only justification for a limit at 50 eV stems from the fact that the majority of true secondaries has energies below 50 eV, whereas the energy loss spectrum has small intensity at low energies. At typical excitation thresholds for Auger electrons (about 100 eV to 2 KeV) the total energy spectrum may contain a considerable amount of true secondaries. In computer simulations of scattering and energy loss of primary electrons the high energy secondaries are neglected, which may lead to underestimating the enhancement of low energy Auger electrons.

The enhancement of an Auger line due to all secondary electrons, irrespective of their nature, relative to the intensity due to the primary beam alone, is described by a factor $r$ which is somewhat misleading called "backscattering factor" ("enhancement factor" would be a better name).

For a given sample material and primary energy, $r$ is a function of the excitation threshold of the Auger line in question [1]. The backscattering factor $r$ is therefore not directly related to the backscatter coefficient $\eta$, which gives the ratio of the number of electrons leaving the sample with energy $E > 50$ eV to the primary electron intensity. The relative contributions of true secondaries and backscattered electrons to the backscattering factor also depend on the choice of the Auger line. It is known from computer simulations [8] that the majority of the low energy true secondaries is centered around the impact point of the primary beam within a few nm's. Very little is known about the spatial distribution of the high energy secondaries, but it seems reasonable to expect a radially more extended distribution. In view of this lack of knowledge we restrict our considerations to Auger energies around 500 eV or more (e.g. oxygen KLL), where the contribution from true secondary electrons is expected to be sufficiently small. With this limitation in mind, computer simulations of electron scattering in semi-infinite targets [3,9,10] can serve as a guide in estimating the edge resolution within the model described above (normal incidence, primary energy $E_0 = 20$ KeV). The basic assumptions of the Monte-Carlo calculations are a screened Rutherford scattering cross section which was modified to take the enhanced backscattering from heavy elements into account (Mott scattering [11]) and a continuous Bethe-type energy loss law.

The energy distribution $\Delta n/\Delta E$ of the backscattered electrons, normalized to the primary intensity, is given in Fig. 2 (dashed lines) as a histogram with $\Delta E = 1$ KeV step width for Au and Al [9]. As we wish to know the