An Improved Backscattering Correction Equation for Wide Analytical Conditions on Quantitative Auger Analysis

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We have described the electron backscattering correction for Auger analysis. Ichimura-Shimizu equation has been frequently used for this correction, but has limitations for incident electron energies and angles. Then, we have proposed an improved correction for the backscattering correction that could be applied to the wide analytical conditions based on the Ichimura-Shimizu equation.

1. Introduction

The backscattering correction for Auger electron spectroscopy (AES) is important for quantitative analysis and for the understanding of spatial resolution of Auger image.

The Ichimura-Shimizu equation [2] has been frequently used for the correction [3]. However, this equation has several limitations for the incident electron energy range (3 – 10 keV) and electron incident angles (0, 30, 45 from the surface normal). Nowadays, high electron incident energy such as 25 and 30 keV are frequently used for nano-area analysis[4]. Then, we have improved the backscattering correction equation of Ichimura-Shimizu in which can be used for wide analytical conditions. The details of this paper was already published in *J. Surf.Anal.*[1]

2. Calculations

The energy and electron incident angle dependence of backscattering coefficient for 10 elemental solids (Be, B, C, Al, Si, Cu, Zr, Ag, La, Au) were investigated using Monte Carlo (MC) simulations.

The backscattering coefficient η was calculated by

$$\eta = \int_{0.1}^{1} \left(\frac{dn}{d\left(E/E_0\right)} \right) d\left(E/E_0\right) / n_0 = n / n_0 \qquad (1)$$

where E_0 is the incident electron energy, E is backscattered electron energy, n_0 is the number of input electrons and n is the number of backscattered electrons. The $dn / d\left(E/E_0\right)$ is normalized energy distribution of backscattered electrons.

The backscattering correction factor R can be calculated from

$$R = 1 + \frac{I_B}{I_P} = 1 + \frac{\Sigma Q(U_i) \sec\theta_i}{n_0 Q(U) \sec\alpha} \qquad (2)$$

where I is the intensity of Auger signals, θ is the escape angle and α is the electron incident angle from the surface normal. The Grezinsky equation was used for the calculation of ionization cross section Q.

3. Results and Discussion

The calculated η at 10, 20 and 30 keV were shown in Figures 1-3 as functions of electron incident angle. The backscattering coefficient η_α at incident angle α can be described as [5]

$$\eta_\alpha = A(\eta_0 / A)^{\cos\alpha} \qquad (3)$$

The resulting A values with curve fits were shown in Figure 4. Form this figure, we found that the A could be expressed by

$$A = 0.01\eta_0^{-1.1} + 0.84 \qquad (4)$$

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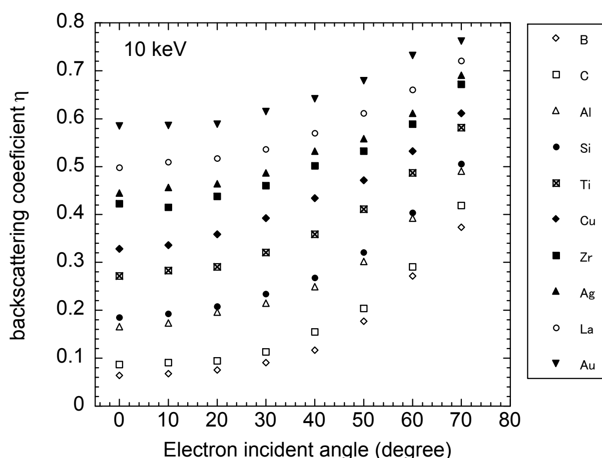

Fig. 1 Electron backscattering coefficient η at 10 keV electrons for 10 elemental solids (B, C, Al, Si, Ti, Cu, Zr, Ag, La, Au) as functions of electron incident angle.

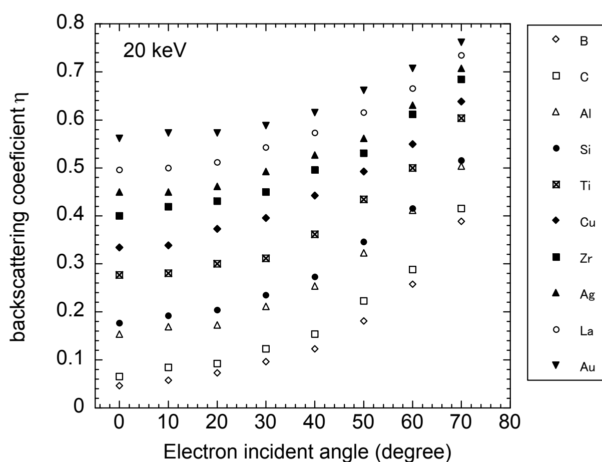

Fig. 2 Electron backscattering coefficient η at 20 keV electrons for 10 elemental solids as functions of electron incident angle. See caption to Figure 1.

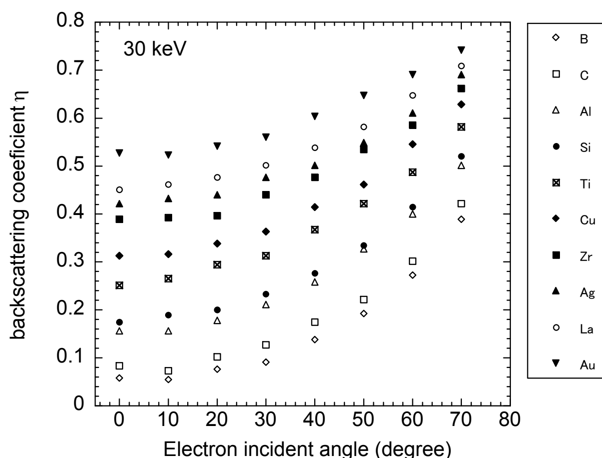

Fig. 3 Electron backscattering coefficient h at 30 keV electrons for 10 elemental solids as functions of electron incident angle. See caption to Figure 1.

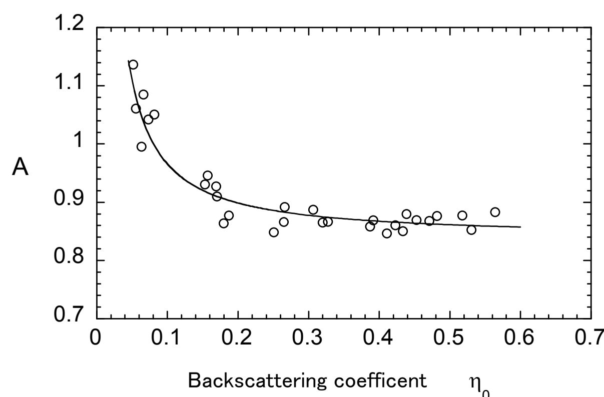

Fig. 4 Curve fit results of A values in equation (3) from the data in Figures 1 - 3 as a function of backscattering coefficient η_0.

From this results, we found that the backscattering coefficient η_α at incident angle α can be described as

$$\eta_\alpha = (0.01\eta_0^{-1.1} + 0.84)\left[\eta_0 / (0.01\eta_0^{-1.1} + 0.84)\right]^{\cos\alpha} \tag{5}$$

where η_0 is the backscattering coefficient at incident angle 0°. The Love-Scott equation [6] for η_0 was superior to the others in wide incident energy range. Using these backscattering coefficient equations, we have developed an improved equation for backscattering correction in Auger electron spectroscopy as shown below, which can be used for wide incident energy range (3 - 30 keV) and incident angles ($0° - 60°$).

$$R = 1 + \frac{\eta_\alpha}{1+\eta_\alpha}\cos\alpha\left[a + b\ln(1+1.27\eta_\alpha)\right] \tag{6}$$

$$a = 2.727 - 6.028(1/U) + 2.606(1/U)^2 \tag{6a}$$

$$b = 2.933 - 1.816\ln(1/U) - 2.688\ln(1/U)^2 - 1.007\ln(1/U)^3 - 0.109\ln(1/U)^4 \tag{6b}$$

$$\eta_0 = \eta_{20}\left[1 + \frac{G(Z)}{\eta_{20}}\ln(E_0/20)\right] \tag{6c}$$

$$\eta_{20} = (-52.3791 + 150.48371Z - 1.67373Z^2 + 0.00716Z^3) \times 10^{-4} \tag{6d}$$

$$G(Z)/\eta_{20} = (-1112.8 + 30.289Z - 0.15498Z^2)\times 10^{-4} \quad (6e)$$

$$U = \frac{E_b}{E_0}$$

where U is the over-voltage ratio, E_0 is the incident electron energy, E_b is the binding energy, and Z is the atomic number of the target. The constants in a and b equation were determined from the curve fit to the backscattering factors at normal incident angle in the 3, 5, 7.5 and 10 keV electron incident energy calculated by Ichimura-Shizimu [7] with MC method. The curve fit results were shown in Figure 5. The root mean square (RMS) differences for backscattering factors for 10 elemental solids calculated by Monte Carlo method using continuous slowing down approximation and those from proposed equation were less 3% in the 10 - 30 keV (over-voltage ratio U = 0.1 -100 and incident angle $\alpha = 0 - 60^{\circ}$).

In the 3 - 10 keV energy range, we have also compared the proposed equation to the calculated values at incident angle 30° and 45° by Ichimura-Shimizu with MC method. The results were shown in Figures 6 and 7. We found that they coincide well each other. Then, the proposed equations for backscattering correction could be applied to the quantitative Auger analysis in wide analytical conditions.

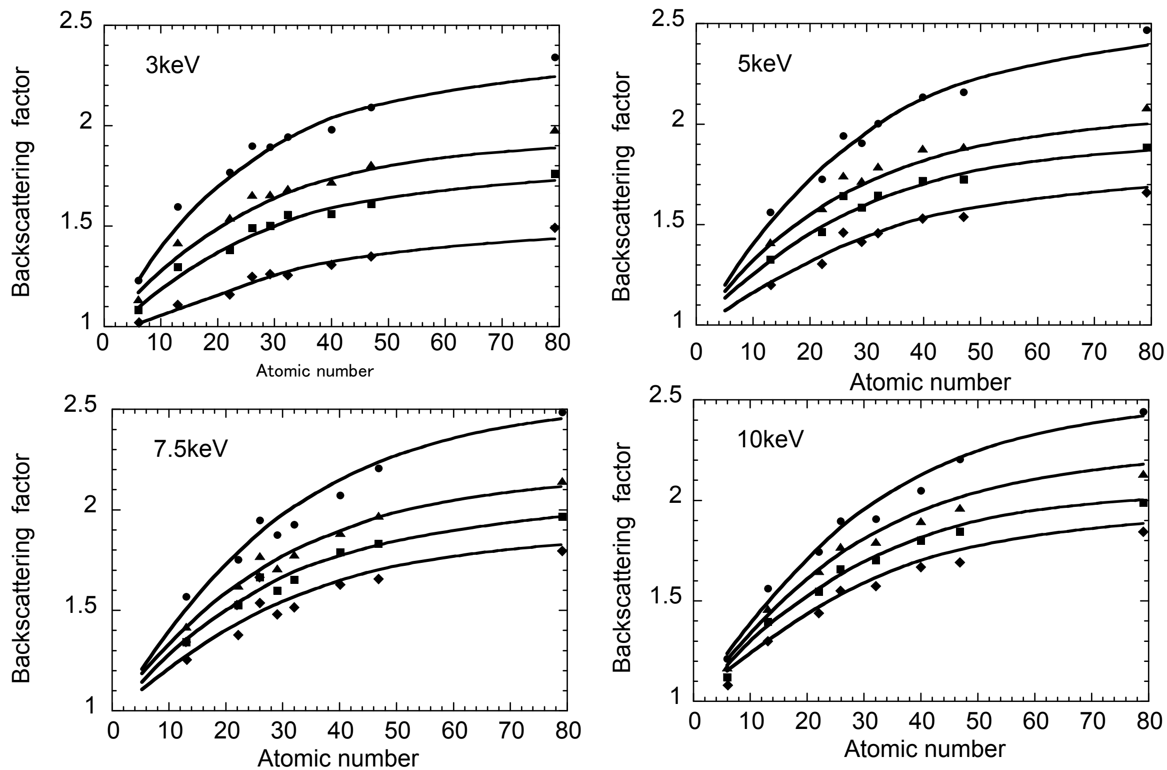

Fig. 5 Curve fit results . The parameter a and b are described by

$$a(U_0) = 2.727 - 6.028(1/U_0) + 2.606(1/U_0)^2,$$

$$b(U_0) = 2.933 - 1.816\ln(1/U_0) - 2.688\ln[(1/U_0)]^2 - 1.007[\ln(1/U_0)]^3 - 0.109[\ln(1/U_0)]^4$$

where U is the over-voltage ratio. The constants in the above equations were determined from the curve fits. The solid line shows the curve fit results. Solid marks were cited from Ichimura-Shimizu[7]; ●: E_b = 0.1 keV [7], ▲: E_b = 0.5 keV, ■: E_b = 1.0 keV, ◆: E_b = 2.0 keV.

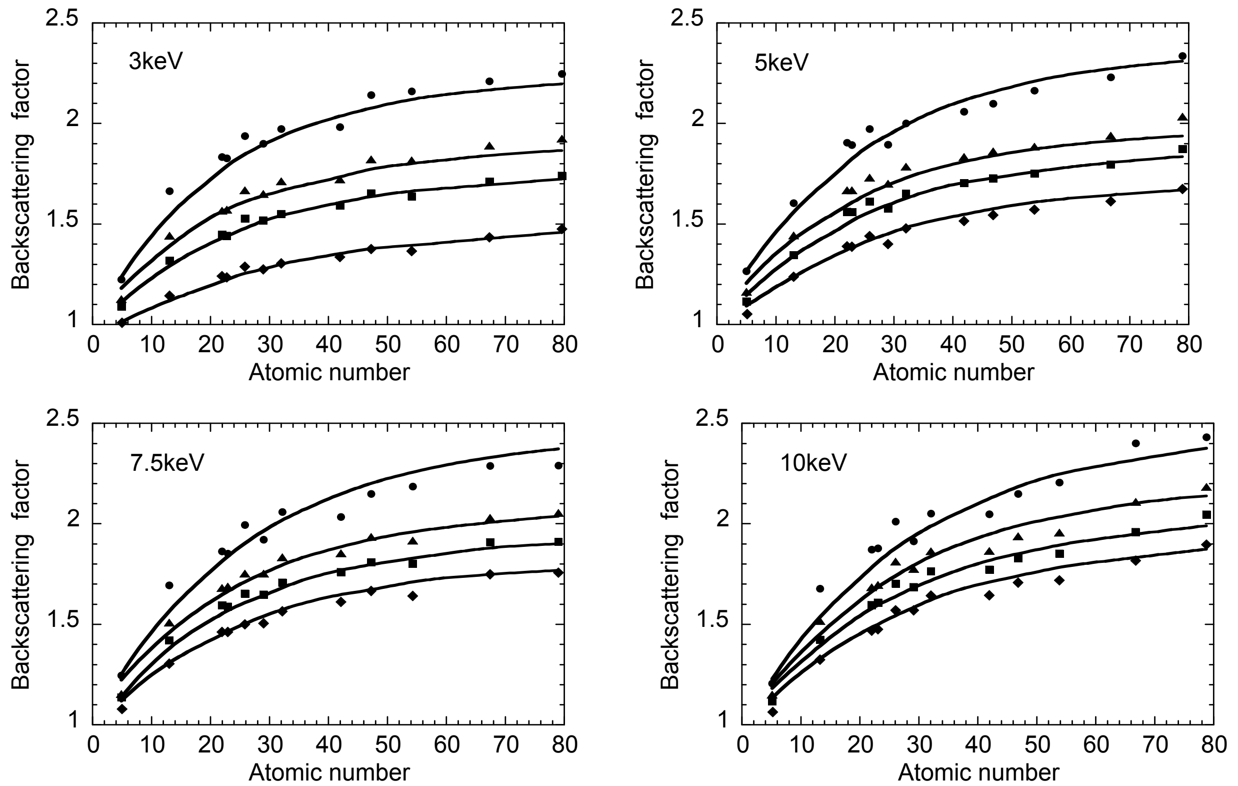

Fig. 6 Comparison of calculated backscattering factors at 30° incident angle with MC method by Ichimura-Shimizu [2] and those from the proposed equations for R (6). The data of ●: E_b = 0.1 keV [7], ▲: E_b = 0.5 keV, ■: E_b = 1.0 keV, and ◆: E_b = 2.0 keV are cited from Ichimura-Shimizu.

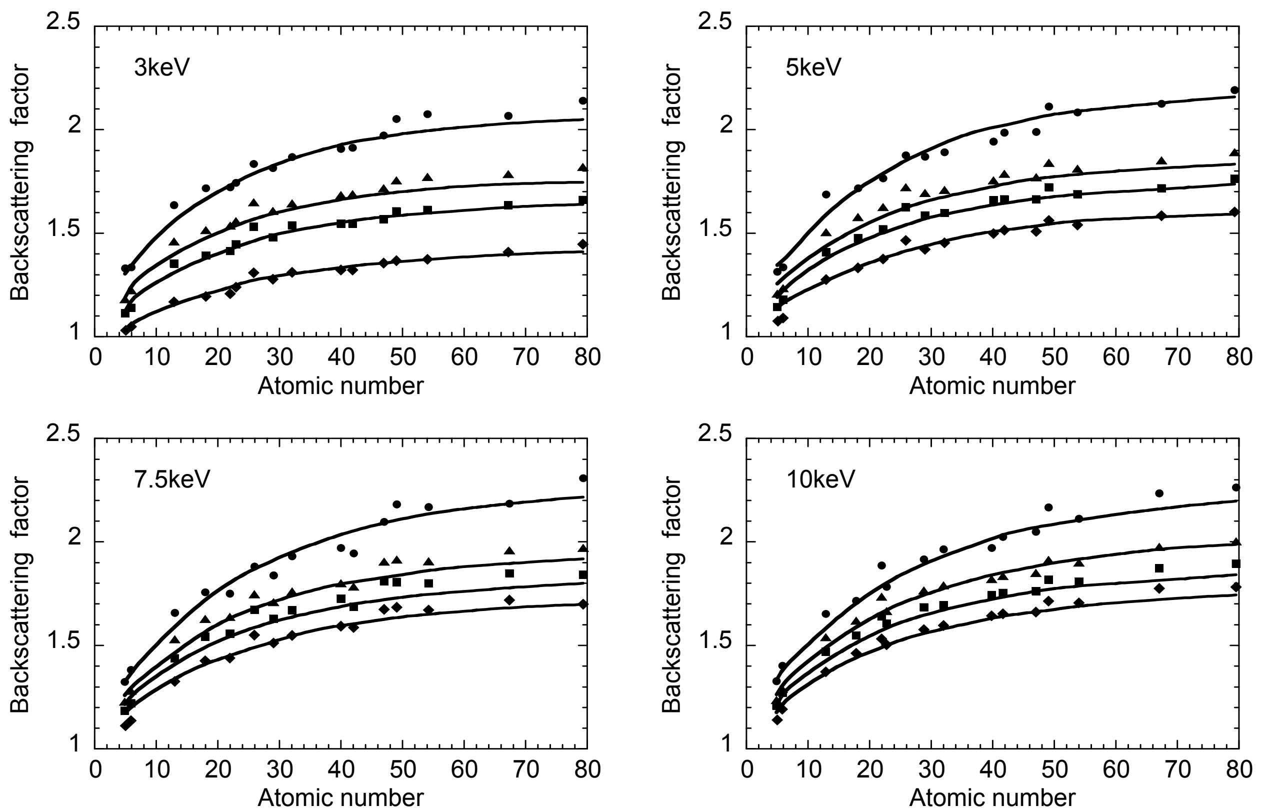

Fig. 7 Comparison of calculated backscattering factors at 45° incident angle. See caption of Fig.6.

4. Summary

The backscattering correction for quantitative Auger analysis was investigated. We have analyzed the incident angle dependence of electron backscattering coefficient (EBC) using median and mean energy of backscattered electrons using Monte Carlo method for Be, B, C, Al, Si, Cu, Zr, Ag, La, and Au. We found that the backscattering coefficient η_α at incident angle α can be described as

$$\eta_\alpha = (0.01\eta_0^{-1.1} + 0.84)\left[\eta_0 / (0.01\eta_0^{-1.1} + 0.84)\right]^{\cos\alpha}$$

where η_0 is the backscattering coefficient at incident angle 0°. The Love-Scott equation [6] for η_0 was superior to the others in wide incident energy range. Using these backscattering coefficient equations, we have developed an improved equation for backscattering correction in Auger electron spectroscopy, which can be used for wide incident energy range (3 - 30 keV) and incident angles ($0^\circ - 60^\circ$). We found that the resulting back scattering correction factor calculated by the proposed equation were in good agreement with those of MC results at at incident angle 30° and 45° in the 3 - 10 keV energy range by Ichimura-Shimizu. Then, the proposed equations for backscattering correction could be applied to the quantitative Auger analysis in wide analytical conditions.

5. References

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