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Low-Voltage Dark-Field STEM imaging with optimum detection angle

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Recently, a low-voltage SEM has been applied for STEM observation as well as SEM observation. A ultra-high resolution SEM (Hitachi S-5500) has a bright field (BF) and/or dark-field (DF) Duo-STEM detector (in option)[1], which allows both simultaneous display of BF and DF STEM images with variation in DF detection angle. The DF detction angle-range is extended from 50 to 700mrad to obtain Z-contrast image which reflects mean atomic number difference with lower operating voltages such as 10 to 30kV.

To optimize detection angle for low voltage DF STEM imaging, a few different detection angle ranges are examined for DF STEM imaging with the specimen of 0.1μm-thick Si device prepared by FIB (FB-2100). Figures 1 (a) and (b) show 30kV BF and DF images, respectively. The later DF image obtained at low detection angle-range of 50 to 150mrad, however, has similar contrast to the BF image. Due to the extension of DF detection angle, the image contrast is reversing as shown in Figures 1 (c) and (d), and the latter figure 1(d) at a high detection angle-range of 350 to 700mrad shows ordinary Z-contrast, i.e., a complementary image contrast with the BF STEM image .

To verify the variation of DF STEM image contrast with the detecting angle-range, the scattered and transmitted elecron trajectories are simulated using the Monte Carlo (MC) method based on a single scattering model, in which the sample is amorphous and composed of single element. The modified screened Rutherford scattering cross-section [2] was employed for the elastic collisions. A fraction of electrons transmitted at the DF detection angle θ per unit detection angle and unit incident electron is calculated as a function of θ under specified incident beam energies E and samples with some thickness. Figure 2 is the calculated curves at E of 30keV for 0.1μm-thick specimens of SiO_2, Cu, and Ta. The SiO_2 sample is treated in the calculation as a single-element sample with the average in atomic number and atomic mass. The DF STEM image contrast corresponds to the integral area ((1)-(3) in Fig. 2) within the detection angle range. The MC results predict that the relative intensities of SiO_2, Cu and Ta for the DF detection ranges of (b) 50 – 100mrad, (c) 150 – 300mrad, and (d) 350 – 700mrad are SiO_2 > Cu > Ta, Cu > Ta > SiO_2, and Ta > Cu > SiO_2, respectively. The MC results follow well with the experimental ones shown in Figs. 1 (b) to (d)). The MC simulations of DF STEM imaging is useful for confirming the ordinary Z-contrast images with the Duo-STEM detector.

References
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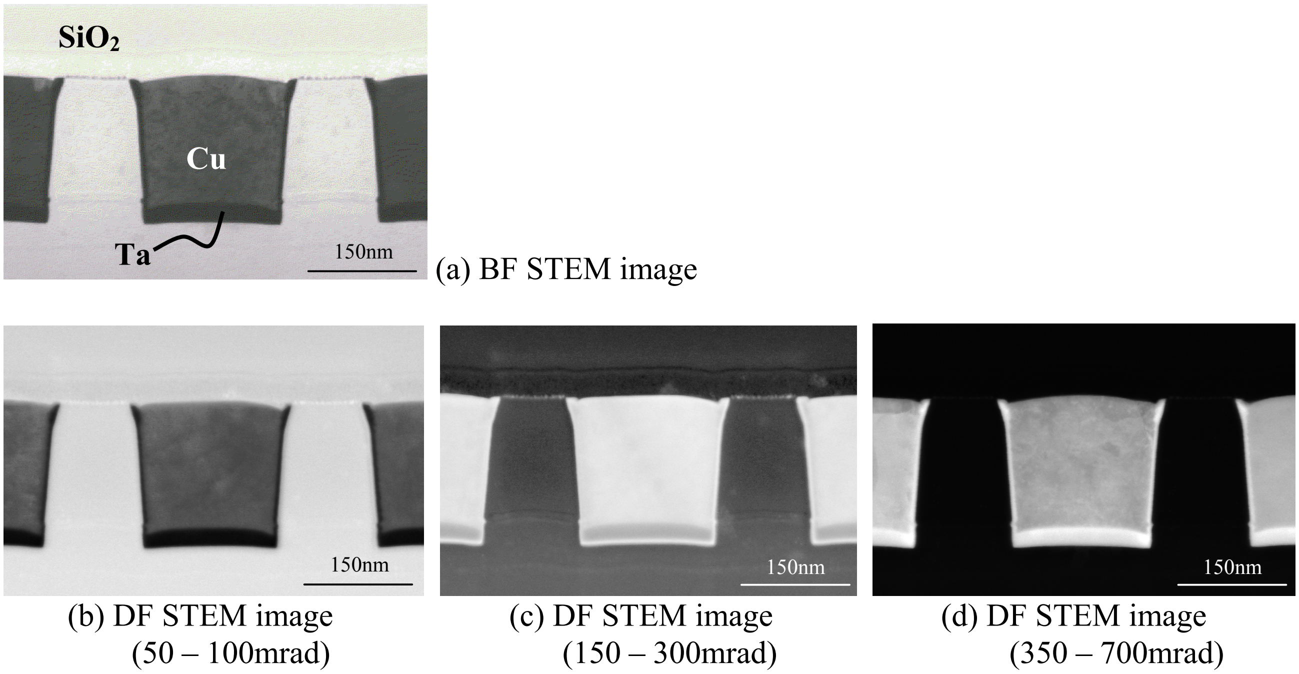

Fig.1 Typical 30kV BF and DF images (at three DF-detection angle-ranges) of a 100nm-thick Si device

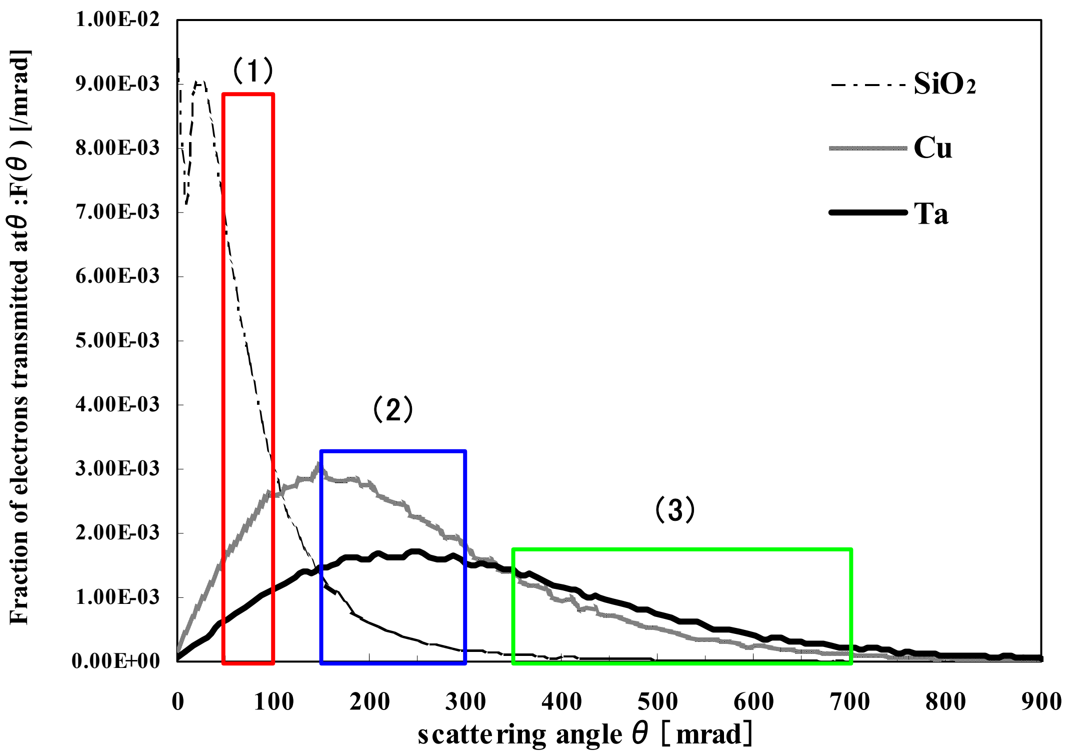

Fig. 2 Fraction of electrons transmitted at θ (MC results)

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