

determining a measured peak voltage of said specimen electrode based on output from said means for detecting; means for obtaining a specimen electrode voltage corrected for type I local field effect error
5 using said measured peak voltage and a type I calibration curve, said type I calibration curve representing peak voltage versus specimen electrode voltage; and means for correcting for type II local field effect error in output of said means for
10 obtaining based on a type II calibration curve, said type II calibration curve representing a shift in specimen electrode peak voltage versus adjacent electrode voltage.

These and other related objectives of the present
15 invention will become more readily apparent from the detailed description given hereafter. It should, however, be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of
20 illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

25 The present invention will become more fully understood from the detailed description here-in-below and the accompanying drawings which are given by way of illustration only, and thus do not limit the present invention.

30 Figures 1-4(c) are flow charts illustrative of the method according to the present invention;

Figure 5 is a block diagram of the measurement apparatus according to the present invention;

Figure 6 is a schematic diagram of the energy
35 analyzer according to the present invention;

lock-in amplifier 20 a voltage representing the detected secondary electrons. The lock-in amplifier 20 also receives the small a.c. signal from the function generator 24 as a reference signal. The lock-in
5 amplifier 20 differentiates the curve representing the output of detector 18 versus the retarding grid voltage V_r . The output of the lock-in amplifier 20 corresponds to the energy distribution of secondary electron emissions. The shift in the peak of the secondary
10 electron energy distribution provides information on the voltage of the electrodes. The retarding grid voltage V_r where the output of the lock-in amplifier 20 is maximum indicates the peak of the secondary electron distribution. The lock-in amplifier 20 may be a
15 commercially available lock-in amplifier such as the SR-530 Lock-in Amplifier from Stanford Research Systems.

The PC 10 receives the output of the lock-in amplifier 20, and measures the quantitative voltage
20 contrast based thereon. The output of the lock-in amplifier 20 can also be monitored using oscilloscope 22.

The quantitative voltage contrast measurement performed by the measurement apparatus of Figure 5 will
25 now be described with reference to the flow charts of Figures ^{I-4-C}~~I-4(c)~~.

The flow chart of Figure 1 shows the method for making quantitative voltage contrast measurements. In step S2 a Type I calibration curve is obtained. The
30 Type I calibration curve, which is a plot of peak voltage versus specimen electrode voltage, will be used in later steps for correcting Type I local field effect errors.

Figure 2 is a flow chart showing the method for
35 obtaining the Type I calibration curve. The description of the flow chart shown in Figure 2 will be made in association with an example of a Type I

scheme for Type II local field effects, elaborated in the flow chart of Figures ~~4(a)-4(c)~~^{4-a-4-c}, includes two iterative processes.

In the first iterative process, the voltages of the adjacent electrodes for each of the N electrodes are examined, and the shift in the peak voltage due to the voltages of the adjacent electrodes are determined for each of the N electrodes using the Type II calibration curve. The PC 10 then determines a corrected peak voltage for each of the N electrodes using the determined shifts in the peak voltage, and determines the actual N specimen electrode voltages therefrom. If the largest peak voltage correction amount falls below a predetermined tolerance (i.e. achieves a desired measurement accuracy), then the quantitative voltage contrast measurement process ends; otherwise, the PC 10 begins a second iterative process.

The second iterative process differs from the first iterative process in that the peak voltage correction amounts of the adjacent electrodes are used, instead of the voltages of the adjacent electrodes, to determine the shifts in the peak voltage for each of the N electrodes. The remainder of the quantitative voltage contrast measurement process continues as in the first iterative process. If, however, the largest peak voltage correction amount of the second iterative process exceeds the predetermined tolerance, the second iterative process is repeated, and will only terminate upon reaching the desired measurement accuracy. Each successive iteration of the second iterative process uses the peak voltage correction amounts of the previous iteration of the second iterative process.

The first and second iterative process will now be described in detail with respect to Figures ~~4(a)-4(c)~~^{4-a-4-c}. At the beginning of step S16, since this is the beginning of the first iterative process, iterative process counter K is set to one in step S42. Then, in

N electrodes determined in step S64 are determined as the quantitative voltage contrast measurements.

If the answer in step S76 is no, then the second iterative process begins with incrementing the
5 iterative process counter K in step S78, setting the measurement electrode counter to one in step S82, setting the specimen electrode voltage for electrode i+1 equal to the correction amount $V_{corr(i+1)}$ for electrode i+1 in step S86, and setting the specimen electrode
10 voltage for electrode i-1 equal to the correction amount $V_{corr(i-1)}$ for the electrode i-1 also in step S86.

After step S86 the second iterative process beings measurement processing at step S48.

If the answer in step S70 is no, then in step S72
15 it is determined if the iterative process counter K is greater than one. If the answer to step S72 is yes, then second iterative processing continues beginning at step S86. If the answer to step S72 is no, then first iterative processing continues beginning at step S46.

20 Figure 9 is a graph of the error in the measured specimen electrode voltage, as to Type I local field effects only, versus the actual specimen voltage V_s with the adjacent electrode voltages set to zero. Figure 9 provides a comparison between the conventional feedback
25 technique and three methods (A, B, and C) according to the present invention.

Method A is the method just described above with respect to Figures ^{1-4-C}~~1-4(c)~~ (i.e., Neumann boundary conditions are used). Method B is the same as method
30 A except that in step S50, V_{i-1} is set to zero and in step S54, V_{i+1} is set to zero (i.e., Dirichlet boundary conditions). Method C is also the same as method B except that step S86 is omitted. As seen from Figure 9, the present invention provides for greatly increased
35 accuracy in measuring quantitative voltage contrast.

Figure 10 is a scatter plot showing the error in the measured electrode voltage, when both Type I and

ABSTRACT OF THE DISCLOSURE

In a method and apparatus for measuring quantitative voltage contrast, an electron beam of the scanning electron microscope is located on a specimen electrode, and a grid voltage of an energy analyzer of the scanning electron microscope is varied. A detector detects secondary electron emission from the specimen electrode. A measured peak voltage of the specimen electrode is determined based on output from the detector. A specimen electrode voltage corrected for type I local field effect error is then obtained using the measured peak voltage and a type I calibration curve. The type I calibration curve represents peak voltage versus specimen electrode voltage. Type II local field effect error in the specimen electrode voltage is then corrected based on a type II calibration curve. The type II calibration curve represents a shift in specimen electrode peak voltage versus adjacent electrode voltage.

ABSTRACT

A method and apparatus for measuring quantitative voltage contrast are described in which an electron beam of the scanning electron microscope is located on a specimen electrode, and a grid voltage of an energy analyzer of the scanning electron microscope is varied. A detector detects secondary electron emission from the specimen electrode. A measured peak voltage of the specimen electrode is determined based on output from the detector. A specimen electrode voltage corrected for type I local field effect error is then obtained using the measured peak voltage and a type I calibration curve. The type I calibration curve represents peak

voltage versus specimen electrode voltage. Type II local field effect error in the specimen electrode voltage is then corrected based on a type II calibration curve. The type II calibration curve represents a shift in specimen electrode peak voltage versus adjacent electrode voltage. (Fig. 1)