azimuth discrimination errors being introduced by the high magnetic field of the objective lens.

[0026] In one embodiment, the emittance analyzer assembly 120 includes a set of deflection optics 124. In one embodiment, the set of deflection optics are positioned prior to, or upstream of, one or more additional components of the emittance analyzer assembly 120. The set of deflection optics are configured to align the image beam including backscattered electrons 114 and/or secondary electrons 116 with one or more components of the emittance analyzer assembly 120. For example, the deflection optics 124 may serve to de-scan the image beam and align the image beam 114, 116 to be coaxial with respect to one or more of the additional components of the emittance analyzer assembly 120. It is further noted that the lateral velocity components imparted to the backscattered electrons 114 and/or the secondary electrons 116 from the primary beam scan elements may be cancelled with the set of deflection optics 124.

[0027] The set of deflection optics may include one or more sets of deflection elements. For example, the set of deflection optics 124 may include, but is not limited to, one or more quadrupole elements, one or more octupole elements or one or more higher order electron-optical deflection elements. In one embodiment, the set of deflection optics 124 include one or more electrostatic deflectors. In another embodiment, the set of deflection optics 124 include one or more magnetic deflectors. For example, the one or more electrostatic or magnetic deflectors may be disposed within a high potential, acceleration liner and floated at the liner potential.

[0028] In another embodiment, the emittance analyzer assembly 120 includes a first electron-optic lens 126 (or lenses). In one embodiment, the first electron-optic lens 126 is disposed downstream from the set of deflection optics 124. For example, the first electron-optic lens 126 may be disposed proximate to the set of deflection optics 124. In one instance, the first electron-optic lens 126 may serve

aperture 146 allows for the transmission of secondary electrons 116 through the detector 128, while high angle backscattered electrons 114 are collected by the quadrant detecting portions Q1, Q2, Q3 and Q4.

[0044] FIG. 1E illustrates a schematic view of a high density array electron detector suitable for use as the first electron detector 128, in accordance with one or more embodiments of the present disclosure. As shown in FIG. 1E, the high density array electron detector includes a high density array 144 for collecting and resolving the position of electrons. The high density array detector 128 includes aperture 146, which again allows for the transmission of secondary electrons 116 through the detector 128, while high angle backscattered electrons 114 are collected by the array 144.

[0045] It is noted that the detector configurations depicted in FIGS. 1D-1E may also be implemented in the case of detector 142, although an aperture 146 would be unnecessary for the detector 142. In the case where the detector 142 is a segmented detector (e.g., segmented solid state detector) or is a high density array detector, bright-field and/or dark-field images may be formed by the assembly 120.

[0046] FIG. 1F illustrates an emittance analyzer 150, in accordance with an alternative embodiment of the present disclosure. In this embodiment, the emittance analyzer 150 eliminates the first detector, thereby sacrificing simultaneous detection of backscattered electrons. In another embodiment, the emittance analyzer 150 includes an aperture plate 158. The aperture plate 158 serves to block backscattered electrons from reaching the detector 142. In this regard, the detector 142 will only detect secondary electrons or near paraxial backscattered electrons.

[0047] FIG. 1G illustrates the emittance analyzer assembly 120 configured in BSE-HAR imaging mode, in accordance with one embodiment of the present disclosure. As noted previously herein, the system 100 may be switched from

[0052] FIG. 1H illustrates the emittance analyzer assembly 120 configured in BSE-only mode, in accordance with one embodiment of the present disclosure. As noted previously herein, the system 100 may be switched from the BSE-HAR configuration of FIG. 1G to the BSE-only configuration of FIG. 1H.

[0053] In one embodiment, the set of deflection elements 124 may center the backscattered electron cone 114 onto the aperture 146 of the first electron detector 128. In another embodiment, the first electron-optic lens 126 is used to focus the backscattered electrons 114 to form a conjugate point in the backscattered electron beam path in the plane of the first detector 128. In this regard, all or a significant portion of the backscattered electrons 114 are passed through the first detector 128.

[0054] In another embodiment, the energy filter 128 is set (e.g., set by controller 121) to reject secondary electrons 116. As such, the second electron detector 142 may be used to produce simultaneous bright-field and dark-field backscattered electron images. In another embodiment, energy filter 128 is set (e.g., set by controller 121) to pass high energy backscattered electrons (i.e., backscattered electrons above a selected threshold) to the second electron detector 142 in order to enhance image resolution. In another embodiment, the second electron-optic lens 140 is used to select the polar angle discrimination ratio of electrons. The drift region 135 of the emittance analyzer assembly may align the backscattered electron polar angles as efficiently as it aligns secondary electron polar angles. It is noted, however, that backscattered electrons have a larger initial polar angle error than the secondary electrons as result of transport from the sample 110 to the assembly 120.

[0055] In another embodiment, the first electron detector 128 is used to produce partial bright-field secondary electron images.

[0056] It is again noted that the emittance analyzer assembly 120 may be rapidly switched between SE-BSE, BSE-HAR and BSE-only modes, which are

depicted in FIGS. 1C, 1G and 1H. In some embodiments, one or more controllers 121 may be used to adjust the various components of the system 100 to transition between the SE-BSE, BSE-HAR and BSE-only modes. In this regard, set points for the each of the modes may be pre-calibrated and stored in memory (e.g., memory of the controller 121). Further, the set points may be recalled by the controller 121, which then uses the set points to establish the preferred mode.

[0057] FIG. 2 illustrates a block diagram view of a system 200 that implements two emittance analyzer assemblies 120a, 120b to form a bandpass energy filter with simultaneous acquisition of highpass and bandpass images, in accordance with one or more embodiments of the present disclosure. In one embodiment, the system 200 includes a first emittance analyzer 120a and a second emittance analyzer 120b. In another embodiment, the system 200 includes a splitter element 202 (e.g., Wien filter).

[0058] It is noted herein that the system 200 may be implemented to analyze secondary electrons and/or backscattered electrons. While the following description focuses on the implementation of system 200 in the context of secondary electrons, this is not a limitation on the present disclosure. It is noted that system 200 and the embodiments and components described below may be extended to a backscattered electron context.

[0059] In one embodiment, the emittance analyzer assembly 120a deflection is used to remove lateral momentum vectors imparted on the image beam by the illumination scanning optics. In another embodiment, the deflection of the first emittance analyzer assembly 120a is used to center the secondary electron cone to be paraxial with the optical image path. In another embodiment, the first electron-optics lens 126a of the first emittance analyzer assembly 120a forms a point conjugate to the secondary electron emission point on the sample (not shown) in the secondary electron beam path in the plane of the detector 128 at the entrance to the deceleration region to block backscattered electrons and

[0066] In another embodiment, the deflection optics 124b of the second emittance analyzer assembly 120b center the secondary electron beam cone on the second emittance analyzer assembly 120b aperture plate at the entrance of the deceleration region.

[0067] In another embodiment, the second electron-optic lens 126b of the second emittance analyzer assembly 120b forms a conjugate point in the plane of and centered on the aperture plate at the entrance of the deceleration region.

[0068] In another embodiment, the energy filter 138b of the second emittance analyzer assembly 120b acts to pass only the highest energy secondary electrons rejected from the first emittance analyzer assembly 120a.

[0069] In another embodiment, the second electron-optic lens 126b of the second emittance analyzer assembly 120b sets the secondary electron polar angle discrimination threshold.

[0070] In another embodiment, the system 200 simultaneously produces the following: secondary high-pass, brightfield and darkfield images using secondary electrons with energies greater than the energy filter setting of the first emittance analyzer assembly 120a; bandpass, brightfield and darkfield secondary electron images using energies between the energy filter setting of the first emittance analyzer assembly 120a and the energy filter setting of the second emittance analyzer assembly 120b; and brightfield and darkfield backscattered electron images.

[0071] FIG. 3 illustrates a block diagram view of a system 300 that implements three emittance analyzer assemblies 120a, 120b, and 120c to capture the full electron energy spectrum in low-pass, bandpass and high-pass bands, in accordance with one or more embodiments of the present disclosure.

[0072] It is noted herein that the system 300 may be implemented to analyze secondary electrons and/or backscattered electrons. While the following

description focuses on the implementation of system 300 in the context of secondary electrons, this is not a limitation on the present disclosure. It is noted that system 300 and the embodiments and components described below may be extended to a backscattered electron context.

[0073] In one embodiment, the system 300 includes a first emittance analyzer assembly 120a, a second emittance analyzer assembly 120b and a third emittance analyzer assembly 120c. In another embodiment, the system 300 includes a first splitter element 302a and a second splitter element 302b. In another embodiment, the system 300 includes a three-armed 304, 306, 308 accelerating liner.

[0074] In one embodiment, the emittance analyzer assembly 120a deflection is used to remove lateral momentum vectors imparted on the image beam by the illumination scanning optics. In another embodiment, the deflection of the first emittance analyzer assembly 120a is used to center the secondary electron cone to be paraxial with the optical image path. In another embodiment, the first electron-optics lens 126a of the first emittance analyzer assembly 120a forms a point conjugate to the secondary electron emission point on the sample (not shown) in the secondary electron beam path in the plane of the detector 128 at the entrance to the deceleration region to block backscattered electrons and coincide with an aperture opening in the plate large enough to let secondary electrons pass through.

[0075] In one embodiment, an acceleration tube 204 immerses the image path from the illumination/image beam splitter 202 to the entrance of the deceleration region in the first emittance analyzer assembly 120a in a positive high voltage. In another embodiment, the first electron-optics lens 126a of first emittance analyzer assembly 120a de-magnifies the secondary electron beam 114.

[0076] In another embodiment, the second electron-optic lens 140a of the first emittance analyzer assembly 120a selects the secondary electron polar angle discrimination threshold for dark-filed secondary electron imaging.

[0077] In another embodiment, the energy filter 138a of the first emittance analyzer assembly 120a passes only high energy secondary electrons and rejects low energy secondary electrons.

[0078] In another embodiment, the splitter element 202 separates the incoming secondary electron image beam from the secondary electrons rejected by the first emittance analyzer assembly 120a.

[0079] In another embodiment, the beam splitter element 202 includes one or more sets of magnetic deflection coils. In another embodiment, the beam splitter is a Wien filter. In another embodiment, the accelerating liner tube 204 may extend along the image path between the first emittance analyzer assembly 120a and the second emittance analyzer assembly 120b.

[0080] In another embodiment, the second emittance analyzer assembly 120b may include an aperture plate at the entrance of the deceleration region of second emittance analyzer assembly 120b. For example, the aperture plate may be a magnetic plate.

[0081] In another embodiment, the deflection optics 124b of the second emittance analyzer assembly 120b center the secondary electron beam cone on the second emittance analyzer assembly 120b aperture plate at the entrance of the deceleration region.

[0082] In another embodiment, the second electron-optic lens 126b of the second emittance analyzer assembly 120b forms a conjugate point in the plane of and centered on the aperture plate at the entrance of the deceleration region.

[0090] In another embodiment, the energy filter of the third emittance analyzer 120c passes all secondary electrons rejected from the second emittance analyzer 120b and renders simultaneous brightfield and darkfield images with secondary electrons whose energies lie between the energy filter setting of first emittance analyzer 120a and the energy filter setting of second emittance analyzer 120b.

[0091] In another embodiment, the second electron-optic lens of third emittance analyzer 120c sets the secondary electron polar angle discrimination threshold.

[0092] In another embodiment, the system 300 simultaneously produces the following: the simultaneous production of secondary electron high-pass, brightfield and darkfield images using secondary electrons with energies greater than the energy filter setting of the first emittance analyzer 120a; bandpass, brightfield and darkfield secondary electron images using energies between the energy filter setting of the first emittance analyzer 120a and the filter setting of the second emittance analyzer 120b; brightfield and darkfield images using secondary electrons with energies lower than the energy filter setting of the second emittance analyzer 120b; and brightfield and darkfield backscattered electron images.

[0093] FIGS. 4A-4H illustrate effects of wafer surface charging and beam drift during image acquisition, in accordance with one or more embodiments of the present disclosure.

[0094] It is noted that in order to operate the emittance analyzer assembly 120 of the present disclosure at full performance entitlement, the image beam position and image beam cone semi-angle must be unaffected by local charge fields and other external influences. The image beam focal plane from first electron-optic lens 124 should remain stable in the presence of a charging sample 110 and the image beam position in the plane of its crossover should be stable and coaxial with the emittance analyzer assembly 120. It is noted that a combination of high extraction field, in-situ-flood, and detector output feedback

output is received by the front end and mixing module 528. For instance, the output of each of a multi-channel segmented detector, such as detector 142, are transmitted to the front end and mixing module 528. In turn, the total detector current is transmitted from module front end and mixing module 528 to the difference module 532. Further, the front end and mixing module 528 may provide a video output. The expected average value of the detector current is transmitted from the D/A module 530 to the difference module 532. The difference module 532 then compares the detector current (e.g., sum of all channels of a segmented detector 142) to the expected average value of the detector current for a specific energy threshold. It is noted that differences between the expected value of the detector current and the actual total value of the detector current indicate that more or fewer electrons are passing the energy filter than expected. The output of the difference module 532 is then transmitted to the gating/integration module 534. The difference from the difference module 532 is then integrated by the gating/integration module 534 with a predetermined time constant. Therefore, the output tracks the surface potential of the sample.

[00122] In turn, the output of the gating/integration module 534 is transmitted to one or more signal processing elements 536 (e.g., processing circuitry, converters, drivers and the like). The processing elements 536 then feed the offset from the gating/integration module 534 to the energy filter 507 as an offset, thereby preserving the energy filter discrimination threshold. In addition, the processing elements 536 provide a sample surface potential output.

[00123] In one embodiment, the integration time constant can be set to a range of values depending on the amount of averaging desired. In another embodiment, the integrator can be gated, where its output is held at the value when gated, to ignore the detector during fly-back or to lock the control loop on only portions of the image area. In one embodiment, the gated integrator 512 locks with a signal from a pre-scan area outside the field of view and start closed loop image acquisition with that pre-scan lock value. In another embodiment, the

gated integrator 512 locks with a signal from a pre-scan area outside the image area and holds that lock value during image acquisition. In another embodiment, the gated integrator 512 uses a signal from only a portion of the image area and gates or blocks signals from other areas of the image. In another embodiment, the gated integrator 512 uses a gated signal generated during beam fly-back. In another embodiment, the system 510 saves one or more lock values of the gated integrator 512 corresponding to different image sites in a recipe and forces the gated integrator 512 to use those lock values at the start of each image acquisition during the execution of the recipe.

[00124] In another embodiment, the gated integrator 512 may transmit one or more control signals to the control circuitry 514, 516, 518, 520, 522, 524 and 526 to control various components of the electron-optical system 500 responsive to the output of the gated integrator 512.

[00125] It is noted that one disadvantage of the approach depicted in FIG. 5B is that small changes in secondary electron emission from wafer to wafer and changes in primary beam current or detector gain over time may introduce errors in the predetermined detector current causing incorrect energy filter threshold set points. This can be partially mitigated by an auto calibration procedure at the beginning of a recipe or during stage moves between image sites. In a first step, the calibration procedure may include setting the energy filter to 0 V. In a second step, the calibration procedure may include measuring the detector current. In a third step, based on prior knowledge of the secondary electron distribution, the calibration procedure may include calculating an expected detector current value for the chosen energy filter discrimination threshold.

[00126] FIG. 5C illustrates a block diagram view of the system 540 equipped with the gated integrator 512 used to establish the control loop for a multi-beam energy filter array, in accordance with one or more embodiments of the present disclosure.