images required. The time to acquire images can be relatively long, which reduces availability of the inspection tool. It would be advantageous to provide a multi-beam SEM system and method that cures the shortcomings observed in single beam SEM approaches.

## SUMMARY

**[0004]** A multi-beam scanning electron microscopy apparatus with focusing adjustment capabilities is disclosed, in accordance with one or more embodiments of the present disclosure. In one embodiment, the system includes a multi-beam scanning electron microscopy sub-system comprising: a multi-beam electron source configured to form a plurality of electron beams; a sample stage configured to secure a sample; an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron beam of the plurality of electron beams. In another embodiment, the system 100 includes a controller including one or more processor configured to execute a set of program instructions stored in memory. In another embodiment, the set of program instructions are configured to for causing the one or more processors to: receive the plurality of images from the detector assembly; identify at least one of a best focus image or a best astigmatism image of the plurality of images by analyzing one or more image quality parameters of at least some of the images of the plurality of the images; and direct the multi-beam source to adjust at least one of focus or astigmatism of one or more electron beams based on at least one of focus or astigmatism of an electron beam corresponding with at least one of the identified best focus image or the identified best astigmatism image.

**[0005]** In another embodiment, the controller directs the multi-lens array assembly to establish a focus gradient across an image field of the sample,

**[0008]** A multi-beam scanning electron microscopy apparatus with focusing adjustment capabilities is disclosed, in accordance with one or more embodiments of the present disclosure. In one embodiment, the system includes a multi-beam scanning electron microscopy sub-system comprising: a multi-beam electron beam source including an electron gun configured to generate an illumination beam and a multi-lens array assembly configured to split the illumination beam into the plurality of electron beams, wherein the multi-lens array assembly is configured for adjusting focus of one or more lenses of the lens array assembly; a sample stage configured to secure a sample; an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron beam of the plurality of electron beams. In another embodiment, the system includes a controller including one or more processors configured to execute a set of program instructions stored in memory for causing the one or more processors to: direct the multi-lens array assembly to sweep at least one of the focus or astigmatism of one or more lenses during acquisition of one or more images corresponding with the one or more lenses; receive the one or more images from the detector assembly; identify a point in the one or more images displaying at least one of best focus or best astigmatism by analyzing one or more image quality parameters across the one or more images; and direct the multi-lens array to adjust at least one of focus of one or more electron beams or astigmatism of the one or more electron beams based on at least one of the focus or astigmatism at the point in the one or more images displaying at least one of the identified best focus or the identified best astigmatism.

**[0009]** A multi-beam scanning electron microscopy apparatus for measuring and compensating for drift is disclosed, in accordance with one or more embodiments of the present disclosure. In one embodiment, the system includes a multi-beam scanning electron microscopy sub-system comprising: a multi-

beam electron beam source including an electron gun configured to generate an illumination beam and a multi-lens array assembly configured to split the illumination beam into the plurality of electron beams, wherein the multi-lens array assembly is configured for adjusting focus of one or more lenses of the lens array assembly; a sample stage configured to secure a sample; an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron beam of the plurality of electron beams. In another embodiment, a controller including one or more processors configured to execute a set of program instructions stored in memory for causing the one or more processors to: direct the multi-beam scanning electron microscopy sub-system to acquire a first image in an under-focused condition and an additional image in an over-focused condition; receive the first image acquired in the under-focused condition and the additional image acquired in the over-focused condition from the detector assembly; identify focus drift in a current image by comparing the first image and the additional image to the current image acquired at the current focus; and direct the multi-lens array to adjust a focus of one or more electron beams to compensate for the identified focus drift.

**[0010]** A multi-beam scanning electron microscopy apparatus for focus adjustment is disclosed, in accordance with one or more embodiments of the present disclosure. In one embodiment, the system includes a multi-beam microscopy sub-system to perform a line scan of a plurality of electron beams comprising: a multi-beam electron source configured to form the plurality of electron beams; a sample stage configured to secure a sample; an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron

FIG. 5 is conceptual view of an SEM image that was swept in focus during image acquisition, in accordance with one embodiment of the present disclosure.

FIG. 6 is conceptual view of a set of SEM images used to analyze focus drift in a multi-beam SEM system, in accordance with one embodiment of the present disclosure.

FIG. 7 is conceptual view of a set electron beam lines scans used for rapid focus adjustment of a multi-beam electron beam system, in accordance with one embodiment of the present disclosure.

FIG. 8 is a process flow diagram illustrating a method for rapid focus adjustment in a multi-beam SEM system, in accordance with one or more embodiments of the present disclosure.

FIG. 9 is a process flow diagram illustrating a method for rapid focus adjustment in a multi-beam SEM system, in accordance with one or more embodiments of the present disclosure.

FIG. 10 is a process flow diagram illustrating a method for rapid focus adjustment in a multi-beam SEM system, in accordance with one or more embodiments of the present disclosure.

FIG. 11 is a process flow diagram illustrating a method for rapid focus adjustment in a multi-beam SEM system, in accordance with one or more embodiments of the present disclosure.

FIG. 12 is a process flow diagram illustrating a method for rapid focus adjustment in a multi-beam SEM system using a set of electron beam line scans, in accordance with one or more embodiments of the present disclosure.

## DETAILED DESCRIPTION OF THE INVENTION

**[0012]** Reference will now be made in detail to the subject matter disclosed, which is illustrated in the accompanying drawings. Referring generally to FIGS. 1 through 12, a system and method for rapid focus adjustments in a multi-beam scanning electron microscopy (SEM) imaging system is described in accordance with the present disclosure.

more embodiments of the present disclosure. FIG. 4A depicts a nominal configuration 400, whereby the multi-lens array assembly 109 does not impart a focus and/or astigmatism gradient to the electron beams 105.

**[0037]** In one embodiment, as shown in view 410 of FIG. 4B, the multi-lens assembly 109 may vary the focus across an image field by varying the voltages across the set of lenses 111 of the multi-lens assembly 109 in one or more directions. It is noted that by varying the voltages of the various lenses 111 across the multi-lens assembly 109 the strength of each lens may be varied in a corresponding fashion. In this regard, a focus gradient may be established across the multi-lens assembly 109, as shown in FIG. 4B.

**[0038]** In another embodiment, as shown in view 420 of FIG. 4C, the multi-lens assembly 109 may vary the focus across an image field by mechanically varying the gaps in the plates of the lenses 111 across the multi-lens array 109. It is noted that by varying the plate gap in the various lenses 111 across the multi-lens assembly 109 the strength of each lens may be varied in a corresponding fashion. In this regard, a focus gradient may be established across the multi-lens assembly 109, as shown in FIG. 4C.

**[0039]** In another embodiment, as shown in view 430 of FIG. 4D, the multi-lens assembly 109 may vary the focus across an image field by mechanically tilting the multi-lens array 109. It is noted that by varying tilt of the multi-lens assembly 109 the focus of each beam 105 may be varied in a corresponding fashion. In this regard, a focus gradient may be established across the multi-lens assembly 109, as shown in FIG. 4D.

**[0040]** In one embodiment, the change in voltage, lens gap, and tilt is temporary. In this regard, the changes may be imparted temporarily in order for the detector assembly 108 to acquire multiple SEM images at different focus and transmit the image results to controller 110. Then, once the controller 110 has identified the best focus condition, the controller 110 may then direct the multi-

controller 110 identifies focus drift, the controller 110 may direct the multi-lens assembly 109 to adjust the focus of one of more of the beams 105 to compensate for the identified drift.

**[0047]** Referring again to FIG. 1A, in another embodiment, the program instructions are configured to cause the one or more processors to average one or more images to identify best focus and/or settings to minimize astigmatism.

**[0048]** In one embodiment, the controller 110 may utilize information from multiple sub-images or repeat sub-images to allow focusing on images that are otherwise too noisy for conventional focus algorithms. In one embodiment, the controller 110 may utilize information from multiple sub-images or repeat sub-images to allow focusing on images that have fewer pixels than would normally be required for good focusing.

**[0049]** It is noted that in the case of the multi-beam SEM sub-system 101 the set of focus images can be acquired at a much higher frame rate than that of a single beam SEM. In some cases, this may result in noisier images that are more difficult to focus. However, by averaging focus results across all sub-images (or a sub-set of sub-images) an accurate result can still be obtained. In another embodiment, image frames may be acquired with few number of pixels (per sub-image). In this case, the use of multiple channels of the multi-beam SEM sub-system 101 provides for enough pixels and image data for accurate focus determination.

**[0050]** In one embodiment, the SEM sub-system 101 may acquire two or more "repeat" image for each channel defined by the primary beams105 and signal beams 117. Further, the controller 110 may combine (e.g., average) the multiple repeat images for each channel of the SEM sub-system 101 to form an aggregated image for each of the multiple channels of the SEM sub-system 101. For example, rather than take one slow image that takes 1 second to acquire, 10 fast images, each 1/10 of a second in duration, are acquired and averaged to

create a single high-quality image. Based on this averaged image a focus determination may be made.

**[0051]** While much of the present disclosure has focused on focus adjustments of the multi-beam SEM sub-system 101 using multiple images with the multiple beams 105, this should not be interpreted as a limitation on the scope of the present disclosure. Rather, it is contemplated herein that the system 100 may be extended to achieve rapid focus adjustments in a multi-beam sub-system 101 in a variety of ways.

**[0052]** In one embodiment, the system 100 may carry out focus adjustments on the multiple beams 105 of the multi-beam SEM sub-system 101 using one or more line scans. It is noted herein that the various embodiments and components described previously herein with respect to image-based focusing may be extended to any of the embodiments of the present disclosure related to line scanning based focusing.

**[0053]** In one embodiment, the multi-beam SEM sub-system 101 may cause two or more of the electron beams 105 to scan a selected pattern across the sample. Then, the detector assembly 108 may acquire line scan information from each of the corresponding signal beams 117. Based on the signal beams 117 measured by the detector assembly 108, the controller 110 may determine the best focus condition (utilizing any mechanism described previously herein)

**[0054]** The one or more focus targets used to analyze the focus quality of the line scans may be found through any suitable process. In one embodiment, the one or more focus targets are locating using information from a CAD database associated with the sample 107. In another embodiment, the one or more focus targets are located using prior information associated with the stage location during recipe setup. In another embodiment, the one or more focus targets are locating using prior associated information received from an additional tool or system (e.g., additional inspection tool).

stage. For example, the sample stage 106 may include, but is not limited to, one or more translational stages suitable for selectably translating the sample 107 along one or more linear directions (e.g., x-direction, y-direction and/or z-direction). By way of another example, the sample stage 106 may include, but is not limited to, one or more rotational stages suitable for selectively rotating the sample 107 along a rotational direction. By way of another example, the sample stage 106 may include, but is not limited to, a rotational stage and a translational stage suitable for selectably translating the sample along a linear direction and/or rotating the sample 107 along a rotational direction. It is noted herein that the system 100 may operate in any scanning mode known in the art.

**[0062]** The detector assembly 108 of the multi-beam SEM sub-system 101 may include any detector assembly known in the art suitable for detecting multiple electron signals from the surface of the sample 107. In one embodiment, the detector assembly 108 includes an electron detector array. In this regard, the detector assembly 108 may include an array of electron-detecting portions. Further, each electron-detecting portion of the detector array of the detector assembly 108 may be positioned so as to detect an electron signal from sample 107 associated with one of the incident electron beams 105. In this regard, each channel of the detector assembly 108 corresponds to a particular electron beam of the multiple electron beams 105.

**[0063]** It is noted that the detector assembly 108 may be, but is not limited to, a secondary electron detector or a backscattered electron detector. The detector assembly 108 may include any type of electron detector known in the art. For example, the detector assembly 108 may include a micro-channel plate (MCP), a PIN or p-n junction detector array, such as, but not limited to, a diode array or avalanche photo diodes (APDs). By way of another example, the detector assembly 108 may include a high speed scintillator/PMT detector.

**[0064]** The electron-optical assembly 104 may include any electron-optical assembly known in the art suitable for illuminating a sample with multiple electron

beams and acquiring multiple images associated with the multiple electron beams. In one embodiment, the electron optical assembly 104 includes a set of electron-optical elements for directing the multiple electron beams 105 onto the surface of the sample 107. The set of electron-optical elements may form an electron-optical column. The set of electron-optical elements of the column may direct at least a portion of the electron beams 105 onto multiple portions of the sample 107. The set of electron-optical elements may include any electron-optical elements known in the art suitable for focusing and/or directing the primary electron beams 105 onto the various areas of the sample 107. In one embodiment, the set of electron-optical elements includes one or more electron-optical lenses. For example, the one or more electron-optical lenses may include, but are not limited to, one or more condenser lenses (e.g., magnetic condenser lens) for collecting electrons from the multi-beam source 103. By way of another example, the electron-optical lenses may include, but are not limited to, one or more objective lenses 114 (e.g., magnetic objective lens) for focusing the primary electron beams 105 onto the various areas of the sample 107.

**[0065]** In another embodiment, the electron optical assembly 104 includes a set of electron-optical elements for collecting electrons (e.g., secondary electrons and/or backscattered electrons) emanating from the sample 107 in response to the multiple primary electron beams 105 and directing and/or focusing those electrons to the detector assembly 108. For example, the electron optical assembly 104 may include, but is not limited to, one or more projection lenses 115 for focusing the multiple electron signal beams 117 to form multiple images of the various portions of the sample 107 at the detector assembly 108.

**[0066]** It is noted that the electron optical assembly 104 of system 100 is not limited to the electron-optical elements depicted in FIG. 1A, which are provided merely for illustrative purposes. It is further noted that the system 100 may include any number and type of electron-optical elements necessary to direct/focus the multiple beams 105 onto the sample 107 and, in response,

non-transitory memory medium. The memory medium 118 may include, but is not limited to, a read-only memory, a random access memory, a magnetic or optical memory device (e.g., disk), a magnetic tape, a solid state drive and the like. It is noted herein that the memory medium 118 may be configured to store one or more results from the detector assembly 108 and/or the output of one or more of the various steps described herein. It is further noted that memory medium 118 may be housed in a common controller housing with the one or more processors 116. In an alternative embodiment, the memory medium 118 may be located remotely with respect to the physical location of the one or more processors 116. For instance, the one or more processors 116 may access a remote memory (e.g., server), accessible through a network (e.g., internet, intranet and the like).

**[0071]** The embodiments of the system 100 illustrated in FIG. 1 may be further configured as described herein. In addition, the system 100 may be configured to perform any other step(s) of any of the method embodiment(s) described herein.

**[0072]** FIG. 8 is a flow diagram illustrating steps performed in a method 800 of performing a focus adjustment of a multi-beam SEM system, in accordance with one or more embodiments of the present disclosure. It is noted herein that the steps of method 800 may be implemented all or in part by the system 100. It is further recognized, however, that the method 800 is not limited to the system 100 in that additional or alternative system-level embodiments may carry out all or part of the steps of method 800. In step 802, a set of images of a surface of a sample are simultaneously acquired with a multi-lens array. In step 804, a best focus (or best astigmatism) image of the set of images is identified. In step 806, the multi-lens array is directed to adjust a focus condition (or astigmatism condition) of one or more electron beams based on the focus settings of an electron beam corresponding with the identified best focus (or best astigmatism) image.

18. The apparatus of claim 1, wherein the detector assembly comprises:

one or more secondary electron detectors.

19. The apparatus of claim 1, wherein the detector assembly comprises:

one or more backscattered electron detectors.

20. A multi-beam scanning electron microscopy apparatus comprising:

a multi-beam scanning electron microscopy sub-system comprising:

a multi-beam electron beam source including an electron gun configured to generate an illumination beam and a multi-lens array assembly configured to split the illumination beam into the plurality of electron beams, wherein the multi-lens array assembly is configured for adjusting focus of one or more lenses of the lens array assembly;

a sample stage configured to secure a sample;

an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and

a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron beam of the plurality of electron beams;

a controller including one or more processors configured to execute a set of program instructions stored in memory for causing the one or more processors to:

direct the multi-lens array assembly to establish a focus gradient across an image field of the sample, wherein two or more lenses of the multi-lens array focus two or more electron beams of the plurality of electron beams to different foci;

receive the plurality of images from the detector assembly, wherein at least some of the images have a different focus;

identify a best focus configuration based on the received plurality of images; and

28. The apparatus of claim 20, wherein the set of electron-optical elements comprise:

at least one of a condenser lens or objective lens.

29. The apparatus of claim 20, wherein the detector assembly comprises:

a detector array.

30. The apparatus of claim 20, wherein the detector assembly comprises:

one or more secondary electron detectors.

31. The apparatus of claim 20, wherein the detector assembly comprises:

one or more backscattered electron detectors.

32. A multi-beam scanning electron microscopy apparatus comprising:

a multi-beam scanning electron microscopy sub-system comprising:

a multi-beam electron beam source including an electron gun configured to generate an illumination beam and a multi-lens array assembly configured to split the illumination beam into the plurality of electron beams, wherein the multi-lens array assembly is configured for adjusting astigmatism of one or more lenses of the lens array assembly;

a sample stage configured to secure a sample;

an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and

a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron beam of the plurality of electron beams;

a controller including one or more processors configured to execute a set of program instructions stored in memory for causing the one or more processors to:

direct the multi-lens array assembly to establish an astigmatism gradient across an image field of the sample, wherein two or more lenses of the multi-lens array focus two or more electron beams of the plurality of electron beams to so as to display different amounts of astigmatism;

receive the plurality of images from the detector assembly, wherein at least some of the images have different amounts of astigmatism;

identify a best astigmatism configuration based on the received plurality of images; and

direct the multi-lens array assembly to adjust astigmatism of one or more electron beams based on a lens condition of an electron beam corresponding with the identified best astigmatism image.

33. A multi-beam scanning electron microscopy apparatus comprising:

a multi-beam scanning electron microscopy sub-system comprising:

a multi-beam electron beam source including an electron gun configured to generate an illumination beam and a multi-lens array assembly configured to split the illumination beam into the plurality of electron beams, wherein the multi-lens array assembly is configured for adjusting focus of one or more lenses of the lens array assembly;

a sample stage configured to secure a sample;

an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and

a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron beam of the plurality of electron beams;

a controller including one or more processors configured to execute a set of program instructions stored in memory for causing the one or more processors to:

direct the multi-lens array assembly to sweep at least one of the focus or astigmatim of one or more lenses during acquisition of one or more images corresponding with the one or more lenses;

receive the one or more images from the detector assembly;

identify a point in the one or more images displaying at least one of best focus or best astigmatism by analyzing one or more image quality parameters across the one or more images; and

direct the multi-lens array to adjust at least one of focus of one or more electron beams or astigmatism of the one or more electron beams based on at least one of the focus or astigmatism at the point in the one or more images displaying at least one of the identified best focus or the identified best astigmatism.

34. A multi-beam scanning electron microscopy apparatus comprising:

a multi-beam scanning electron microscopy sub-system comprising:

a multi-beam electron beam source including an electron gun configured to generate an illumination beam and a multi-lens array assembly configured to split the illumination beam into the plurality of electron beams, wherein the multi-lens array assembly is configured for adjusting focus of one or more lenses of the lens array assembly;

a sample stage configured to secure a sample;

an electron-optical assembly including a set of electron-optical elements configured to direct at least a portion of the plurality of electron beams onto a portion of the sample; and

a detector assembly configured to simultaneously acquire a plurality of images of the surface of the sample, each image associated with an electron beam of the plurality of electron beams;