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Simple spherical aberration corrector for SEM

Abstract

Compact correctors for correcting spherical aberrations of a particle-optical lens in a charged particle microscope system, according to the present disclosure a strong hexapole configured to generate a strong hexapole field when a voltage is applied to it, and a weak hexapole positioned between the strong hexapole and a sample. The strong hexapole is positioned such that the crossover of a charged particle beam of the charged particle system does not pass through the center of the strong hexapole, such that the strong hexapole field applies at least an A2 aberration and a D4 aberration to the charged particle beam. The weak hexapole is further positioned or otherwise configured such that, when a voltage is applied to the weak hexapole it generates a weak hexapole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam of the charged particle microscopy system.

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Background/Summary

BACKGROUND OF THE INVENTION

(1) Particle-optical microscopes utilize round lenses to direct electron/charged particle beams to irradiate a specimen. However, round lenses generate positive spherical aberration coefficient (Cs) that restrict higher opening angles and inhibit resolution and probe current. Over the years, many Cs-corrector systems have been developed to address spherical aberration in microscope systems, such as transmission electron microscopes

(TEMs) and scanning transmission electron microscopes (STEMs).

(2) However, Cs-correctors have been difficult to successfully implement in scanning electron microscope (SEM) columns due to their difficulty to manufacture such correctors, and their exorbitant manufacturing costs. This is because, present Cs-corrector designs used in S(T)EM systems require many additional component elements which can be difficult hence expensive to manufacture. These many additional elements and excitations are usually needed to nullify the parasitic aberrations which are caused by mechanical errors inherent to the ordinary component fabrication techniques. This makes, the costs of such techniques exceed the budgets of most SEM users. Because these factors have resulted in the costs for many current Cs-correctors for SEM systems exceeding the cost of the SEM columns themselves, it is desired to find a simpler and more compact Cs-corrector systems (e.g., with fewer pieces that are easier to manufacture) which are capable of correcting for spherical aberrations in a SEM optical column. Moreover, additional cost reduction can be perceived if one also uses very accurate fabrication techniques such as MEMS technology.

SUMMARY OF THE INVENTION

(3) Compact corrector for correcting spherical aberration of a particle-optical lens in a charged particle microscope system, according to the present disclosure a first multipole element (e.g., a 6-pole element, an 8-pole element, a 12-pole element, etc.) configured to generate a strong hexapole field when a first voltage is applied to it, and a second multipole element configured to generate a weak hexapole field that is positioned between the first multipole element and a sample when the corrector module is used in the charged particle microscopy system. According to the present invention, the strong hexapole is positioned such that the crossover of a charged particle beam of the charged particle system does not pass through the center of the first multipole element (i.e., the strong hexapole), such that the first multipole element field applies at least an A2 aberration and a D4 aberration to the charged particle beam. The second multipole element is further positioned or otherwise configured such that, when a second voltage is applied to the second multipole element the weak hexapole field it generates applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam of the charged particle microscopy system. In this way, the net combination of the aberrations applied to the charged particle beam by the weak and strong hexapole fields result in the beam having a desired A2, C3, and D4 aberrations at or near the sample plane.

(4) Additionally, charged particle systems including compact correctors according to the present disclosure include a sample holder configured to hold a sample, a charged particle source configured to emit a charged particle beam towards the sample, an optical column configured to direct the charged particle beam such that it is incident on the sample, and a detector system configured to detect emissions resultant from the sample being irradiated by the charged particle beam. The optical column includes the compact corrector module which comprises a first multipole (i.e., strong hexapole) configured to generate a strong hexapole field when a first voltage is applied to it, and a second multipole (i.e., weak hexapole) positioned between the strong hexapole and the sample. The strong hexapole is positioned such that the crossover of the charged particle beam does not pass through the center of the strong hexapole causing the strong hexapole field to apply at least an A2 aberration and a D4 aberration to a charged particle when a second voltage is applied to the weak hexapole it generates a weak hexapole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam;

(5) Moreover, optical corrector modules for charged particle columns which comprise split multipoles, according to the present invention include at least one split multipole composed of two multipoles (e.g., wafer multipoles, magnetic multipole, electrostatic multipole, etc.) separated by a distance less than any of 100 mm, 10 mm, 1 mm, 100 μ m, and 10 μ m. Each of the individual multipoles comprise at least two electrodes positioned to partially define a beam path through the multipole. According to the present invention, each of the electrodes comprises: a first surface that faces upstream of a charged particle beam when used in the charged particle column; and a second surface that faces downstream of the charged particle beam when used in the charged particle column, wherein the thickness between the first surface and the second surface for each of the electrodes is less than 3 mm. Within the scope of the disclosure, the split multipoles may be electrostatic and may correspond to hexapoles.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identify the figure in which the reference number first appears. The same reference numbers in different figures indicates similar or identical items.

(2) FIG. 1 illustrates example compact correctors for correcting the A2, C3, and/or D4 aberrations at or near the sample plane, according to the present invention.

(3) FIG. 2 illustrates an example charged particle microscope system(s) for inspection of a component of a sample whose optical column includes a compact correctors for correcting the A2, C3, and/or D4 aberrations at or near the sample plane, according to the present invention.

(4) FIG. 3 illustrates an alternate embodiment example compact correctors for correcting the A2, C3, and/or D4 aberrations at or near the sample plane, according to the present invention.

(5) FIG. 4 illustrates an example Crewe corrector comprising a single split multipole, according to the present disclosure.

(6) FIG. 5 illustrates an example corrector as described in association with FIGS. 1-3, where the strong hexapole corresponds to a split composed of two hexapoles.

(7) FIGS. 6 and 7 illustrate a prior art Crewe type corrector and a Crewe type corrector according to the present disclosure in which one or more of the hexapoles are split hexapoles, respectively.

(8) FIG. 8 illustrates a Rose type corrector that comprises at least one split hexapole.

(9) FIG. 9 is a diagram that illustrates the optical behavior of Rose type corrector that comprises two split hexapoles according to the present disclosure.

(10) Like reference numerals refer to corresponding parts throughout the several views of the drawings. Generally, in the figures, elements that are likely to be included in a given example are illustrated in solid lines, while elements that are optional to a given example are illustrated in broken lines. However, elements that are illustrated in solid lines are not essential to all examples of the present disclosure, and an element shown in solid lines may be omitted from a particular example without departing from the scope of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

(11) Compact corrector system for correcting the spherical aberration of a particle-optical lens in charged particle microscope systems, including but not limited to SEM, STEM, TEM, and FIB, are disclosed herein. Specifically, the systems disclosed herein uses multipoles (such as, but not limited to electromagnetic multipoles, the electrostatic multipoles, split multipoles, etc.) to correct for A2, C3, and/or D4 aberrations. An example corrector system according to the present disclosure includes a strong hexapole that is positioned such that its center is misaligned with the crossover of the beam (e.g., either the strong hexapole is positioned within the system, the beam is manipulated, or a combination thereof, such that the center of the strong hexapole is positioned 0.1-2 mm from a location of a crossover of the beam), and a weak hexapole (e.g., 10×, 50×, 100×, etc. smaller than the strong hexapole) is positioned downstream of the strong hexapole. According to the present invention, the misalignment of the strong hexapole is in the direction of the weak hexapole. Because of this displacement, when a first voltage is applied to the strong hexapole it generates a strong hexapole field when a first voltage is applied to it, and a weak hexapole positioned between the strong hexapole and a sample when the corrector module is used in the charged particle microscopy system.

(12) According to the present invention, the strong hexapole is positioned such that the crossover of a charged particle beam of the charged particle system does not pass through the center point of the strong hexapole (i.e., does not pass within 0.1, 0.2, 0.5, 1 mm, 1.2 mm, 1.5 mm, or 2 mm distance of the center of the strong hexapole), such that the strong hexapole field applies at least an A2 aberration and a D4 aberration to the charged particle beam. A second voltage may then be applied to the weak hexapole such that it generates a weak hexapole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam of the charged particle microscopy system. In some embodiments, the weak and strong hexapoles may be positioned, charged, or otherwise configured such that the two hexapole fields further apply combination C3 aberrations to the beam. In this way, the net combination of the aberrations applied to the charged particle beam by the weak and strong hexapole fields can be adjusted so that the charged particle beam has a desired A2, C3, and/or D4 aberrations at or near the sample plane. By doing so, compact corrector according to the present disclosure are able to improve the resolution of charged particle microscopes. For example, the compact correctors according to the present disclosure are able to improve the resolution of 30 kV beam SEM optical columns by a factor of at least 2.5×.

(13) The present disclosure further describes various types of corrector systems disclosed that include split multipoles. Split multipoles are comprised of two hexapoles separated by a distance (e.g., less than 20 mm), where the multipoles are each composed of two or more electrodes having a thickness of less than 10 mm, 5 mm, 3 mm, or 1 mm. For example, where the multiples are wafer multipoles, such wafer multipoles are each composed of two or more electrodes having a thickness between 1 and 100 μm. In some embodiments, such wafer hexapoles may correspond to and/or be constructed using the systems and methods disclosed in U.S.

patent Ser. No. **17/883,495** titled CHARGED PARTICLE OPTICS COMPONENTS AND THEIR FABRICATION and filed on Aug. 8, 2022, which is hereby incorporated by reference in its entirety. Split multipoles are configured to generate a strong multipole field when a voltage (e.g., 100 V-300 kV) is applied to each of the wafer multipoles. By applying a same voltage to each of the multipoles, the combined electromagnetic fields generated by the two multipoles combine to provide the effect of a strong multipole. Because split multipoles are composed of multipoles, the split multipole can be used to correct aberrations in charged particle beams having energies of more than 10 KeV.

(14) FIG. 1 is an illustration of example compact correctors **100** for correcting the A2, C3, and/or D4 aberrations at or near the sample plane, according to the present invention. Example compact multipole correctors **100** include a strong hexapole **102** (e.g., a first 6-pole, 8-pole, or 12-pole element) having an effective length L which is configured to generate a strong hexapole field when a first voltage is applied to it, and a weak hexapole **104** (e.g., a second 6-pole, 8-pole, or 12-pole element) positioned downstream of the strong hexapole **102** when used in a charged particle system that is configured to generate a weak hexapole field when a second voltage is applied to it. The strength and/or orientation of the strong hexapole and the weak hexapole can be adjusted to allow for a desired value of contribution of their generated fields to A2, C3, and/or D4. In various embodiments, the strong hexapole **102** may be an electrostatic multipole having a length within the range of 0.01-10 mm (e.g., at least and the first voltage may be between 0.1 kV and 30 kV. Moreover, the weak hexapole **104** is at least 30×, 50×, or 100× weaker than the strong hexapole **102**. As shown in FIG. 9, in some embodiments the strong hexapole **102** may be a split hexapole comprised of two hexapoles separated by a distance less than any of 100 mm, 10 mm, 1 mm, 100 μm, and 10 μm. Such multipoles are composed of two or more electrodes having a thickness of less than 10 mm, 3 mm, or 1 mm.

(15) During operation of the charged particle system comprising the compact corrector **100**, a charged particle beam **106** is directed along a central axis **108** toward a first end **110** of the compact corrector. According to the present invention, the weak hexapole **104** is positioned, excited, and/or otherwise configured such that the weak hexapole field combines with the strong hexapole field to create a combination aberration that applies one or more of a A2, C3, and/or D4 aberration effect to the charged particle beam as it passes through the corrector **100**. According to the present invention, the contributions of the strong hexapole field to one or more of the A2, C3, and/or D4 aberrations and this combination aberration effect generated by the combination of the strong hexapole field and the weak hexapole field may be such that the net result of the contributions of the strong hexapole field and the combination aberration effect with regard to one or more of the A2, C3, and/or D4 aberrations are such that the value of one or more of the A2, C3, and/or D4 aberrations in the charged particle **106** at or near the sample plane have a desired value. In some embodiments, this may result in the charged particle beam **106** having zero or near zero A2, C3, and/or D4 aberrations when it leaves the corrector **100**. Alternatively, or in addition, the corrector may cause the charged particle beam **106** to have desired A2, C3, and/or D4 aberrations values when it leaves the corrector **100** which combine with other aberration effects of the other optical elements downstream of the corrector **100** within a charged particle system such that a desired value of the A2, C3, and/or D4 aberrations is present in the charged particle beam **106** at the sample plane.

(16) In prior art correctors, the component multipoles are positioned at crossovers of charged particle beams so as to prevent an aberration. However, in the example compact correctors **100**, the strong hexapole **102** is positioned, or the charged particle beam **106** is adjusted, or a combination thereof, such that a displacement ε exists between the center **112** of the strong hexapole and a crossover **114** of the charged particle beam. Because the strong hexapole **102** is misaligned with the charged particle beam crossover **114** in this way, the contribution of the strong hexapole field to the charged particle beam **106** A2, C3, and D4 aberrations. Specifically, contributions of the strong hexapole field contributes to each of A2, C3, and D4 aberrations to the charged particle beam **106** are each a function of displacement ε. For example, in a model compact corrector **100** where the hexapoles are magnetic hexapoles, using the Hamilton equations the back extrapolated contribution to each of the A2, C3, and D4 aberrations by the corrector at position **114** can be shown as:

$$(17) \quad A2 = \frac{1}{4}kL^3 + kL^3 \quad (1) \quad C3 = \frac{-1}{336}k^2L^7 - \frac{1}{24}k^2L^6 - \frac{2}{3}k^2L^4 - \frac{1}{3}k^2L^3 - 2k^2L^2 \quad (2)$$

$$D4 = \frac{k^3L^{10}}{8064} + \left(\frac{kL^3}{8} + \frac{k^3L^9}{1008}\right) + \frac{1}{672}k^3L^8 + \left(\frac{kL}{2} + \frac{55k^3L^7}{1008}\right)^3 + \frac{1}{18}k^3L^6 + \frac{7}{15}k^3L^5 + \frac{1}{3}k^3L^4 + k^3L^3 \quad (3)$$

Moreover, in a second example, in a model compact corrector **100** where the hexapole **102** is electrostatic, the back extrapolated contribution to each of the A2, C3, and D4 aberrations by the corrector at position **114** can be shown as:

$$(18) \quad A2 = \frac{1}{4}kL^3 + kL^3 \quad (4) \quad C3 = \frac{-1}{336}k^2L^7 - \frac{1}{24}k^2L^6 - \frac{2}{3}k^2L^4 - \frac{1}{3}k^2L^3 - 2k^2L^2 \quad (5)$$

$$D4 = \frac{k^3 L^{10}}{8064} + \left(\frac{kL^3}{6} + \frac{k^3 L^9}{1008} \right) + \frac{1}{672} k^3 L^8 + \left(\frac{2kL}{3} + \frac{55k^3 L^7}{1008} \right)^3 + \frac{1}{18} k^3 L^6 + \frac{7}{15} k^3 L^5 + \frac{1}{3} k^3 L^4 + k^3 L^3 \quad (6)$$

A person having skill in the art would understand from (1)-(6) how the characteristics of the strong hexapole **102** (i.e., the first voltage, L, k, etc.) and the value of displacement ϵ in such an example system may affect or otherwise induce A2, C3, and D4 aberrations in a **106** charged particle beam as it passes through the strong hexapole **102**. Persons having skill in the art would understand how a subsequent lens **118** and/or the weak hexapole **104** can be designed, positioned, or otherwise tuned such that the resultant values of the A2, C3, and/or D4 aberrations of the charged particle beam **106** may have a desired value in the sample plane.

(19) For example, the displacement ϵ may be adjusted such that each of the A2, C3, and/or D4 aberrations can have desired non-zero or zero values at the sample plane. In another example, the dimensions, positions, and excitations of the subsequent lens **118** and the weak hexapole **104** may be selected so that their contributions to the A2, C3, and D4 aberrations in the charged particle beam **106** combine with the corresponding contributions of the strong hexapole **102** to the charged particle beam such that A2 and D4 are nearly zero. In such embodiments, the characteristics of the strong hexapole **102**, weak hexapole **104**, and/or the lens **118** may be tuned such that the slight negative spherical aberration present in the charged particle beam **106** after passing through the corrector **100** compensates for contribution of the objective lens **116** to the spherical aberration of the charged particle beam. In the equations above, k is the strength of the strong hexapole and L is the effective length of the hexapole.

(20) FIG. **1** illustrates the weak hexapole as being proximate to an objective lens **116** of the charged particle system. In some embodiments, the weak hexapole **104** may be positioned within the field of the objective lens **116** of the charged particle system, and/or within the objective lens **116** of the charged particle system itself. However, a person having skill in the art would understand that according to the present invention the weak hexapole **104** may be placed at any location between the strong hexapole **102** and a sample under investigation so long as (1) it is able to affect the beam **106** striking the sample, and (2) the voltages applied to the weak hexapole **104** and/or the strong hexapole **102** are adjusted such that the A2, C3, and/or D4 contributions by each of their corresponding hexapole fields combine to result in a desired net A2, C3, and/or D4 contribution to the beam **106**.

(21) Moreover, while not pictured in FIG. **1**, the weak hexapole **104** may be positioned either upstream or downstream of a microscope beam scanning system (e.g., AC scan unit). For example, in an embodiment the weak hexapole **104** may be positioned downstream of the microscope scanning unit and configured to dynamically adjust the hexapole field it creates based on the path of the beam through the weak hexapole **104**. Additionally, in some embodiment of the present invention the weak hexapole **104** may be able to be dynamically tuned based on one or more components of the microscope system in which it is used. For example, the weak hexapole **104** may be tunable to compensate for a beam rotation created by a lens in such a microscope system.

(22) FIG. **1** further illustrates the compact corrector **100** as including optional transfer lens(es) **118** positioned between the strong hexapole **102** and the weak hexapole **104** and downstream of the weak hexapole. However, embodiments of the corrector system **100** may include only one of these transfer lenses, additional transfer lenses, or no such transfer lens. For example, in embodiments of the present invention the corrector **100** may include a round lens **118** positioned between the strong hexapole and the weak hexapole which is positioned, charged, or otherwise configured to apply a lensing effect to the charged particle beam such that the magnitude of the D4 aberration in the charged particle beam **106** is influenced to allow the charged particle beam to have a desired value of the D4 aberration in the sample plane. In FIG. **1**, multipole corrector **100** is illustrated as being a box comprising a plurality of optical components (i.e., multipoles and lenses). In various embodiments, these optical components may be encased or partially encased by a protective and/or supporting structure. Additionally, in embodiments including such a structure, one or more of the optical components may be not within such a structure

(23) FIG. **2** is an illustration of example charged particle microscope system(s) **200** for inspection/imaging of a component of a sample **202** whose optical column includes a compact correctors **100** for correcting the A2, C3, and/or D4 aberrations at or near the sample plane, according to the present invention. The example charged particle microscope system(s) **200** may include electron microscope (EM) setups or electron lithography setups that are configured to irradiate and/or otherwise impinge the sample **202** with a beam of electrically charged particles **204** (usually an electron beam or an ion beam). In various embodiments the charged particle microscope system **200** may be or include one or more different types of EM and/or charged particle microscopes, such as, but not limited to, a scanning electron microscope (SEM), a scanning transmission electron microscope (STEM), a transmission electron microscope (TEM), a charged particle microscope

(CPM), dual beam microscopy system, etc. Additionally, in some embodiments a TEM is capable of operating as a STEM as well. FIG. 2 shows the example charged particle microscope system(s) **200** as being a SEM system **206**. However, as the compact correctors **100** according to the present invention may be composed of electrostatic hexapoles that are able to accept a wide range of excitations (e.g., including but not limited to 50 kV and 300 kV), the compact correctors are capable for correcting the A2, C3, and/or D4 in TEM and STEM systems.

(24) The example charged particle microscope system(s) **200** includes a charged particle source **208** (e.g., a thermal electron source, Schottky-emission source, field emission source, a liquid metal ion source, a plasma ion source, etc.) that emits the charged particle beam **204** along an emission axis **210** and towards an accelerator lens **212**. The emission axis **210** is a central axis that runs along the length of the example charged particle microscope system(s) **200** from the charged particle source **208** and through the sample **202**.

(25) The accelerator lens **212** accelerates/decelerates, focuses, and/or directs the charged particle beam **204** towards a focusing column **214**. The focusing column **214** focuses the charged particle beam **204** so that it is incident on sample **202**. Additionally, the focusing column **214** corrects and/or tunes aberrations (e.g., geometric aberrations, chromatic aberrations) of the charged particle beam **204**.

(26) In FIG. 2, the focusing column **214** is illustrated as including compact correctors **100** for correcting the A2, C3, and/or D4 aberrations at or near the sample plane according to the present invention. That is, FIG. 2 illustrates charged particle microscope system(s) **200** that include a SEM multipole corrector system **100** that comprises a strong hexapole **102** and a weak hexapole **104**, where the center of the strong hexapole **102** is displaced from an axial crossover **114** of a charged particle beam by a displacement E. The strong hexapole **102** may be configured to generate a strong hexapole field when a first voltage is applied to it, and the weak hexapole **104** may be configured to generate a weak hexapole field when a second voltage is applied to it. In some embodiments, the strong hexapole **102** may be a split hexapole comprised of two wafer hexapoles separated by a distance less than any of 100 mm, 10 mm, 1 mm, 100 μ m, and 10 μ m. A person having skill in the art would understand how, the weak hexapole **104** may be positioned, excited, and/or otherwise configured such that the weak hexapole field makes a contribution to one or more of the A2, C3, and/or D4 aberrations in the charged particle beam **204** that are combination to the strong hexapole field's contributions to one or more of the A2, C3, and/or D4 aberrations in the charged particle beam **204**. In this way, by adjusting the positioning and excitation of the weak hexapole **104**, the contributions of the weak hexapole field to one or more of the A2, C3, and/or D4 aberrations may be such that they combine with the contributions of the strong hexapole field to cause the charged particle beam **204** to have a desired A2, C3, and/or D4 aberrations at or near the sample plane.

(27) The objective lens **216** is an optical element that focuses the charged particle beam **204** to a point on the sample **202**. The objective lens **216** may comprise a single-polepiece lens, a magnetic electrostatic compound lens, electrostatic detector objective lens, or another type of objective lens. An additional benefit of the compact correctors **100** according to the present invention is that they allow for an increased opening angle of the charged particle beam. For example, an example compact correctors **100** can allow for the opening angle of the charged particle beam to be greater than 20 mrad.

(28) FIG. 2 further illustrates the example charged particle microscope system(s) **200** as including a sample holder **218** that holds the sample **202**. The example charged particle microscope system(s) **300** is also shown as including detector systems(s) **220** that are configured to detect emissions from the sample **202** resultant from the charged particle beam **204** being incident on the sample **202**. In addition, while not shown in FIG. 2 the example charged particle microscope system(s) **200** may include astigmatism correction and/or scan coils for causing the charged particle beam **204** to scan the surface of the sample **202**. For example, by operating scan coils, the direction of the charged particle beam **204** may be shifted so that it strikes a different location of the sample **202**. A person having skill in the art would understand that in TEM or (S)TEM systems, the detector system **220** may also include and/or consist of one or more detectors positions below the sample.

(29) FIG. 2 further shows example charged particle microscope system(s) **200** as optionally including a computing device(s) **230**. Those skilled in the art will appreciate that the computing devices **230** depicted in FIG. 2 are merely illustrative and are not intended to limit the scope of the present disclosure. The computing system and devices may include any combination of hardware or software that can perform the indicated functions, including computers, network devices, internet appliances, PDAs, wireless phones, controllers, oscilloscopes, amplifiers, etc. The computing devices **230** may also be connected to other devices that are not illustrated, or instead may operate as a stand-alone system.

(30) FIG. 3 is an illustration of an alternate embodiment of example compact correctors **300** for correcting the A2, C3, and/or D4 aberrations at or near the sample plane, according to the present invention. Example

compact multipole correctors **300** include a strong hexapole **102** having an effective length L that is configured to generate a strong hexapole field when a first voltage is applied to it, and a weak hexapole **104** downstream of the strong hexapole **102** when used in a charged particle system that is configured to generate a weak hexapole field when a second voltage is applied to it. During operation of the charged particle system comprising the compact corrector **300**, a charged particle beam **302** is directed along a central axis **304** toward a first end **306** of the compact corrector **300**.

(31) FIG. **3** further illustrates the compact corrector **300** as including optional transfer lens(es) **118** positioned on each side of the strong hexapole **102**, and downstream of the weak hexapole **104**. While in some embodiments an AC scan unit may be placed upstream of the weak hexapole **104**, FIG. **3** illustrates an embodiment where an AC scanning unit **308** is positioned between the compact corrector **300** and an objective lens **310** of the microscope system.

(32) FIG. **4** shows an example Crewe corrector **400** comprising a single split multipole, according to the present disclosure. Specifically, FIG. **4** depicts a Crewe style Hexapoles Cs-corrector. As discussed above, in some embodiments a strong multipole may correspond to a split multipole **402** be comprised of two wafer hexapoles **404** having a thickness d and which are separated by a distance (e.g., less than 20 mm). According to the present invention, no optical components (lenses, multipoles, etc.) are positioned between the component wafer multipoles **404** for the split multipole. Where the split multipole **402** has a length of L , the separation can thus be written as $L-2d$. The wafer multipoles are composed of two or more electrodes having a thickness of less than 10 mm, 5 mm, 3 mm, or 1 mm.

(33) FIG. **4** illustrates the Crewe corrector **400** as further comprising a first transfer lens **406** and a second transfer lens **408**, where the first transfer lens **406** applies a focusing effect to a charged particle beam **410** passing through the corrector **400** that causes a crossover of the charged particle beam between the component two wafer multipoles **404** of the split multipole **402**. While FIG. **4** shows the crossover as being equidistant to each component wafer multipole, in other embodiments (such as the embodiment depicted in FIG. **5**) the first transfer lens **406** may be configured to apply a focusing effect that causes the crossover of the charged particle beam **410** to not be equidistant to each component wafer multipole **404**.

(34) FIG. **5** shows an example corrector **500** as described in association with FIGS. **1-3**, where the strong hexapole **502** corresponds to a split hexapole **504** composed of two wafer hexapoles **506**. FIG. **5** shows the corrector **500** as including three transfer lenses **508** and a weak hexapole **510**. As discussed above, the initial transfer lens **512** applies a focusing effect to the charged particle beam **514** passing through the corrector **500** that causes a crossover that is not equidistant between the two wafer multipoles **506** of the split multipole **504**. As discussed above, the weak hexapole **510** may be positioned, excited, and/or otherwise configured such that the weak hexapole field it generates makes a contribution to one or more of the A2, C3, and/or D4 aberrations in the charged particle beam **514** that are combination to the strong hexapole field's contributions to one or more of the A2, C3, and/or D4 aberrations in the charged particle beam **514**. In this way, by adjusting the positioning and excitation of the weak hexapole **510**, the contributions of the weak hexapole field to one or more of the A2, C3, and/or D4 aberrations may be such that they combine with the contributions of the strong hexapole field to cause the charged particle beam **514** to have a desired A2, C3, and/or D4 aberrations at or near a sample plane.

(35) FIGS. **6** and **7** illustrate a Crewe type corrector **600** and a Crewe type corrector **700** according to the present disclosure in which one or more of the hexapoles are split hexapoles. Specifically, FIG. **6** shows a corrector that comprises two strong hexapoles **602** with a single transfer lens **604** positioned at an axial crossover of the charged particle beam **606** which is equidistant from the two hexapoles **602**. However, as shown in FIG. **7**, according to the present invention such Crewe type correctors can also be made with one or more split hexapoles. For example, FIG. **7** illustrates a Crewe type corrector **700** according to the present invention in which both strong hexapoles **702** are split hexapoles **704**. However, a person having skill in the art would understand that in some embodiments only one of the strong hexapoles **702** may be split hexapoles **704**. FIG. **7** also shows the corrector **700** as including a single transfer lens **706** positioned at an axial crossover of the charged particle beam **708** which is equidistant from the two split hexapoles **704**.

(36) FIG. **8** illustrates a Rose type corrector **800** that comprises at least one split hexapole. Specifically, FIG. **8** illustrates a Rose type corrector where one of the two strong hexapoles **802** corresponds to a split hexapole **804** composed of two wafer multipoles **806**. However, a person having skill in the art would understand how corrector **800** could be constructed with both strong hexapoles **802** corresponding to split hexapoles **804**. Corrector **800** is shown as having two transfer lenses **808** positioned between the split hexapoles **804**.

(37) FIG. **9** is a diagram **900** that illustrates the optical behavior of Rose type corrector **000** that comprises two split hexapoles according to the present disclosure. Specifically, diagram **900** illustrates the optical behavior for

aberrations present in a Rose type corrector **800** comprising two split hexapoles. FIG. **9** shows the behavior of an axial ray **902** passing through an example Rose type corrector **800** in which the two hexapoles are electrostatic split hexapoles **904** according to the present invention. Specifically, FIG. **9** shows the split hexapoles **904** as having a length L and being composed of two wafer hexapoles having a thickness of d , where a same charge is applied to each of the wafer hexapoles. For example, where the thickness of the wafer hexapoles is 2 mm, the length of the split hexapole may be 12 mm, and the voltage applied to each wafer hexapoles may be $\pm 170\text{V}$. In various embodiments, the split hexapoles **904** may be configured to generate small dipole and/or quadrupole fields in addition to hexapole fields. While not limiting to the present disclosure, a person having skill in the art would understand the corrector strength of the Rose type corrector **800** as corresponding to

$$(38) \quad C_{3s} = 4k^2 d^2 (L - \frac{2}{3}d), \text{ with } k = \frac{3}{2U_r} \frac{V_{\text{hex}}}{R^3}. \quad (6)$$

FIG. **9** further shows a condenser lens **906** positioned upstream of the Rose type corrector **800**, and an objective lens **908** configured to focus the charged particle beam onto a sample **910**. The axial ray **902** is illustrated as exiting the Rose type corrector **800** as being parallel to the optical axis **912** and being positioned x.sub.exit distance from the optical axis **912**.

(39) While FIGS. **4-9** show split multipoles being included within a number of example corrector systems, a person having skill in the art would understand how the split multipole technology described herein may be included in other corrector systems as a replacement for a any general multipole element where the produced secondary effect of the hexapole field is important.

(40) Examples of inventive subject matter according to the present disclosure are described in the following enumerated paragraphs.

(41) A1. A compact corrector module for a charged particle microscopy system, the corrector module comprising: a strong hexapole configured to generate a strong hexapole field when a first voltage is applied to it, wherein the strong hexapole is positioned such that the crossover of a charged particle beam of the charged particle system does not pass through the center of the strong hexapole causing the strong hexapole field to apply at least an A2 aberration and a D4 aberration to a charged particle beam of the charged particle microscopy system; and a weak hexapole positioned between the strong hexapole and a sample when the corrector module is used in the charged particle microscopy system, wherein when a second voltage is applied to the weak hexapole it generates a weak hexapole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam of the charged particle microscopy system.

(42) A1.1. The compact corrector module of paragraph A1, wherein the combined application of the A2 aberration and the combination A2 aberration to the charged particle beam results in the A2 aberration of the charged particle beam being at or near zero at or near the sample plane.

(43) A1.2. The compact corrector module of any of paragraphs A1-A1.1, wherein the combined application of the D4 aberration and the combination D4 aberration to the charged particle beam results in the D4 aberration of the charged particle beam being at or near zero at or near the sample plane.

(44) A1.3. The compact corrector module of any of paragraphs A1-A1.2, wherein the strong hexapole field further applies a C3 aberration to the charged particle beam of the charged particle microscopy system, and the weak hexapole field further applies a combination C3 aberration to the charged particle beam of the charged particle microscopy system.

(45) A1.3.1. The compact corrector module of paragraph A1.3, wherein the combined application of the C3 aberration and the combination C3 aberration to the charged particle beam results in the C3 aberration of the charged particle beam being at or near zero at or near the sample plane.

(46) A2. The compact corrector module of any of paragraphs A1-A1.3.1, wherein the second voltage is determined selected based on the distance between the crossover of the charged particle beam and the center of the strong hexapole.

(47) A2.1. The compact corrector module of paragraph A2, wherein the second voltage is determined selected based on the distance between the crossover of the charged particle beam and the center of the strong hexapole such that one or more of the A2, C3, and D4 aberrations caused by the weak multipole field are combination to the A2, C3, and D4 aberrations caused by the strong multipole field.

(48) A3. The compact corrector of any of paragraphs A1-A2.1, wherein the weak hexapole is at least 50 or 100 times weaker than the strong hexapole.

(49) A4. The compact corrector of any of paragraphs A1-A3, wherein the weak hexapole is positioned within the objective lens when used in the charged particle system.

(50) A5. The compact corrector of any of paragraphs A1-A4, wherein the weak hexapole is positioned within

the field of the objective lens.

(51) A6. The compact corrector of any of paragraphs A1-A5, wherein the charged particle microscope is one of a scanning electron microscope (SEM), a scanning transmission electron microscope (STEM), and a transmission electron microscope (TEM).

(52) A7. The compact corrector of any of paragraphs A1-A6, wherein the strong hexapole is an electrostatic hexapole or an electromagnetic hexapole.

(53) A7.1. The compact corrector of paragraph A7, wherein the strong hexapole has a (effective) length of at least 5 mm.

(54) A8. The compact corrector of any of paragraphs A1-A7.1, wherein the corrector module is a probe corrector.

(55) A9. The compact corrector of any of paragraphs A1-A8, further including a transfer lens positioned between the strong hexapole and the weak hexapole.

(56) A9.1. The compact corrector of paragraph A9, further including an additional transfer lens positioned downstream of the weak hexapole.

(57) A10. The compact corrector of any of paragraphs A1-A9, wherein the first voltage applied to the strong hexapole is between 50 and 300 kV.

(58) A11. The compact corrector of any of paragraphs A1-A10, wherein the compact corrector module is configured to allow the opening angle of the charged particle beam of the charged particle microscopy to be greater than 20mrads.

(59) A12. The compact corrector of any of paragraphs A1-A11, further including a condenser lens positioned upstream of the strong hexapole when used in the charged particle system.

(60) A13. The compact corrector of any of paragraphs A1-A12, wherein the compact corrector comprises only one strong hexapole.

(61) B1. A charged particle system comprising: a sample holder configured to hold a sample; a charged particle source configured to emit a charged particle beam towards the sample; an optical column configured to direct the charged particle beam such that it is incident on the sample, the optical column including a compact corrector module that comprises: a strong hexapole configured to generate a strong hexapole field when a first voltage is applied to it, wherein the strong hexapole is positioned such that the crossover of the charged particle beam does not pass through the center of the strong hexapole causing the strong hexapole field to apply at least an A2 aberration and a D4 aberration to a charged particle beam; and a weak hexapole positioned between the strong hexapole and the sample, wherein when a second voltage is applied to the weak hexapole it generates a weak hexapole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam; and a detector system configured to detect emissions resultant from the sample being irradiated by the charged particle beam.

(62) B1.1. The compact corrector module of paragraph B1, wherein the combined application of the A2 aberration and the combination A2 aberration to the charged particle beam results in the A2 aberration of the charged particle beam being at or near zero at or near the sample plane.

(63) B1.2. The compact corrector module of any of paragraphs B1-B1.1, wherein the combined application of the D4 aberration and the combination D4 aberration to the charged particle beam results in the D4 aberration of the charged particle beam being at or near zero at or near the sample plane.

(64) B1.3. The compact corrector module of any of paragraphs B1-B1.2, wherein the strong hexapole field further applies a C3 aberration to the charged particle beam of the charged particle microscopy system, and the weak hexapole field further applies a combination C3 aberration to the charged particle beam of the charged particle microscopy system.

(65) B1.3.1. The compact corrector module of paragraph B1.3, wherein the combined application of the C3 aberration and the combination C3 aberration to the charged particle beam results in the C3 aberration of the charged particle beam being at or near zero at or near the sample plane.

(66) B2. The compact corrector module of any of paragraphs B1-B1.3.1, wherein the second voltage is determined selected based on the distance between the crossover of the charged particle beam and the center of the strong hexapole.

(67) B2.1. The compact corrector module of paragraph B2, wherein the second voltage is determined selected based on the distance between the crossover of the charged particle beam and the center of the strong hexapole such that one or more of the A2, C3, and D4 aberrations caused by the weak multipole field are combination to the A2, C3, and D4 aberrations caused by the strong multipole field.

(68) B3. The compact corrector of any of paragraphs B1-B2.1, wherein the weak hexapole is at least 50 or 100 times weaker than the strong hexapole.

- (69) B4. The compact corrector of any of paragraphs B1-B3, wherein the weak hexapole is positioned within the objective lens when used in the charged particle system.
- (70) B5. The compact corrector of any of paragraphs B1-B4, wherein the weak hexapole is positioned within the field of the objective lens.
- (71) B6. The compact corrector of any of paragraphs B1-B5, wherein the charged particle microscope is one of a scanning electron microscope (SEM), a scanning transmission electron microscope (STEM), and a transmission electron microscope (TEM).
- (72) B7. The compact corrector of any of paragraphs B1-B6, wherein the strong hexapole is an electrostatic hexapole or an electromagnetic hexapole.
- (73) B7.1. The compact corrector of paragraph B7, wherein the strong hexapole has a length of at least 5 mm.
- (74) B8. The compact corrector of any of paragraphs B1-B7.1, wherein the corrector module is a probe corrector.
- (75) B9. The compact corrector of any of paragraphs B1-B8, further including a transfer lens positioned between the strong hexapole and the weak hexapole.
- (76) B9.1. The compact corrector of paragraph B9, further including an additional transfer lens positioned downstream of the weak hexapole.
- (77) B10. The compact corrector of any of paragraphs B1-B9, wherein the first voltage applied to the strong hexapole is between 50 and 300 kV.
- (78) B11. The compact corrector of any of paragraphs B1-B10, wherein the compact corrector module is configured to allow the opening angle of the charged particle beam of the charged particle microscopy to be greater than 20 mrad.
- (79) B12. The compact corrector of any of paragraphs B1-B11, further including a condenser lens positioned upstream of the strong hexapole when used in the charged particle system.
- (80) B13. The compact corrector of any of paragraphs B1-B12, wherein the compact corrector comprises only one strong hexapole.
- (81) C1. An optical corrector module for a charged particle column, the optical corrector module comprising: a split multipole composed of two wafer multipoles separated by a distance less than 100 mm, the individual wafer multipoles comprising: at least two electrodes positioned to partially define a beam path through the wafer multipole, wherein each of the electrodes comprises: a first surface that faces upstream of a charged particle beam when used in the charged particle column; and a second surface that faces downstream of the charged particle beam when used in the charged particle column, wherein the thickness between the first surface and the second surface for each of the electrodes is less than 3 mm.
- (82) C1.1. The optical corrector module of paragraph C1, wherein the split multipole is configured to generate a strong multipole field when a first voltage is applied to each of the wafer multipoles.
- (83) C1.1.1 The optical corrector module of paragraph C1.1, wherein the two wafer multipoles of the split multiple are separated by a distance of any one of 10 mm, 1 mm, 100 μm , and 10 μm .
- (84) C1.2. The optical corrector module of any of paragraphs C1-C1.1.1, wherein the thickness between the first surface and the second surface for each of the electrodes is less than 100 μm .
- (85) C1.2.1. The optical corrector module of paragraph C1.2, wherein the thickness between the first surface and the second surface for each of the electrodes is between 1 and 100 μm .
- (86) C1.2.2. The optical corrector module of any of paragraphs C1.2 or C1.2.1, wherein the thickness between the first surface and the second surface for each of the electrodes is less than any of 10 mm, 1 mm, 100 μm , and 10 μm .
- (87) C1.3. The optical corrector module of any of paragraphs C1-C1.2.2, wherein the distance between the wafer multipoles in the split multipole is less than 20 mm.
- (88) C1.4. The optical corrector module of any of paragraphs C1-C1.3, wherein a third surface of each of the electrodes which faces the charged particle beam as it passes through the wafer multipole has a maximum surface roughness of Ra 0.05 μm .
- (89) C1.5. The optical corrector module of any of paragraphs C1-C1.4, wherein the individual wafer multipoles are configured to be used with a charged particle beam energy of more than 10 KeV.
- (90) C1.6. The optical corrector module of any of paragraphs C1-C1.4, wherein the voltages applied to the wafer hexapoles at between 100 V and 300 kV.
- (91) C1.7. The optical corrector module of any of paragraphs C1-C1.6, wherein the voltages applied to each of the wafer hexapoles are the same.
- (92) C1.8. The optical corrector module of any of paragraphs C1-C1.7, wherein no optical component is positioned between the two wafer multipoles along the charged particle beam path.

- (93) C1.9. The optical corrector module of any of paragraphs C1-C1.8, wherein the split multipole is a split hexapole configured to generate a strong hexapole field when a first voltage is applied to each of the wafer multipoles.
- (94) C1.9.1. The optical corrector module of paragraph C1.9, wherein each of the wafer multipoles are wafer hexapoles configured to generate a hexapole field when a voltage is applied to each of the wafer hexapoles.
- (95) C1.10. The optical corrector module of any of paragraphs C1-C1.9.1, comprising a first transfer lens and a second transfer lens, wherein the first transfer lens is the optical element that is immediately upstream of the split multipole and the second transfer lens is the optical element that is immediately downstream of the split multipole.
- (96) C1.10.1. The optical corrector module of paragraph C1.10, wherein the first axial ray applies a focusing effect that causes a crossover of the charged particle beam between the component two wafer multipoles of the split multipole.
- (97) C1.10.1.1. The optical corrector module of paragraph C1.10.1, wherein the crossover of the charged particle beam is equidistant to each component wafer multipole.
- (98) C1.10.1.2. The optical corrector module of paragraph C1.10.1, wherein the crossover of the charged particle beam is not equidistant to each component wafer multipole.
- (99) C2. The optical corrector module of any of paragraphs C1-C1.10, wherein the split multipole is a strong hexapole.
- (100) C2.0.1. The optical corrector module of paragraph C2, wherein the optical corrector module is a Crewe style Hexapoles Cs-corrector.
- (101) C2.0.2. The optical corrector module of any of paragraphs C2-C2.0.1, wherein and the corrector further comprises a weak hexapole positioned between the strong hexapole and a sample when used in the charged particle column.
- (102) C2.1. The optical corrector module of paragraph C2, wherein the split hexapole is positioned such that the crossover of the charged particle beam does not pass through the center of the split hexapole causing the split hexapole field to apply at least an A2 aberration and a D4 aberration to the charged particle beam when used in a charged particle column.
- (103) C2.1.1. The optical corrector module of paragraph C2.1, wherein when a second voltage is applied to the weak hexapole it generates a weak hexapole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam.
- (104) C2.1.1.1. The optical corrector module of paragraph C2.1.1, wherein the combined application of the A2 aberration and the combination A2 aberration to the charged particle beam results in the A2 aberration of the charged particle beam being at or near zero at or near the sample plane.
- (105) C2.1.1.2. The optical corrector module of any of paragraphs C2.1.1-C2.1.1.1, wherein the combined application of the D4 aberration and the combination D4 aberration to the charged particle beam results in the D4 aberration of the charged particle beam being at or near zero at or near the sample plane.
- (106) C2.1.3. The optical corrector module of any of paragraphs C2-C2.1.1.2, wherein the strong hexapole field further applies a C3 aberration to the charged particle beam of the charged particle microscopy system, and the weak hexapole field further applies a combination C3 aberration to the charged particle beam of the charged particle microscopy system.
- (107) C2.1.3.1. The optical corrector module of paragraph C2.1.3, wherein the combined application of the C3 aberration and the combination C3 aberration to the charged particle beam results in the C3 aberration of the charged particle beam being at or near zero at or near the sample plane.
- (108) C2.2. The optical corrector module of any of paragraphs CA2.1.1-C2.1.3.1, wherein the second voltage is determined selected based on the distance between the crossover of the charged particle beam and the center of the split hexapole.
- (109) C2.2.1. The optical corrector module of paragraph C2.2, wherein the second voltage is determined selected based on the distance between the crossover of the charged particle beam and the center of the strong hexapole such that one or more of the A2, C3, and D4 aberrations caused by the weak multipole field are combination to the A2, C3, and D4 aberrations caused by the strong multipole field.
- (110) C2.2.2. The optical corrector module of any of paragraphs C2.2-C2.2.1, wherein the weak hexapole is at least 50 or 100 times weaker than the strong hexapole.
- (111) C2.3. The optical corrector module of any of paragraphs C2-C2.2.2, wherein the weak hexapole is positioned within the objective lens when used in the charged particle system.
- (112) C2.4. The optical corrector module of any of paragraphs C2-C2.3, wherein the weak hexapole is positioned within the field of the objective lens.

- (113) C2.5. The optical corrector module of any of paragraphs C2-C2.4, wherein the strong hexapole is an electrostatic hexapole.
- (114) C2.6. The optical corrector module of paragraph C2.5, wherein the strong hexapole has a (effective) length of at least 5 mm.
- (115) C2.8. The optical corrector module of any of paragraphs C2-C2.7, further including a transfer lens positioned between the strong hexapole and the weak hexapole.
- (116) C2.8.1. The optical corrector module of paragraph C2.8, further including an additional transfer lens positioned downstream of the weak hexapole.
- (117) C2.9. The optical corrector module of any of paragraphs C2-C9, wherein the first voltage applied to the strong hexapole is between 50 and 300 kV.
- (118) C2.10. The optical corrector module of any of paragraphs C2-C2.9, wherein the optical corrector module is configured to allow the opening angle of the charged particle beam of the charged particle microscopy to be greater than 20 mrad.
- (119) C2.11. The optical corrector module of any of paragraphs C2-C2.10, further including a condenser lens positioned upstream of the strong hexapole when used in the charged particle system.
- (120) C3. The optical corrector module of any of paragraphs C1-C2.11, wherein the corrector further comprises an additional multipole.
- (121) C3.1. The optical corrector module of paragraph C3, wherein the additional multipole is a split multipole.
- (122) C3.1.1. The optical corrector module of paragraph C3.1, wherein the additional multipole composed of two additional wafer multipoles separated by a distance less than 10 mm, the individual additional wafer multipoles comprising:
- (123) at least two additional electrodes positioned to partially define a beam path through the additional wafer multipole, wherein each of the additional electrodes comprises:
- (124) a first surface that faces upstream of a charged particle beam when used in the charged particle column; and
- (125) a second surface that faces downstream of the charged particle beam when used in the charged particle column,
- (126) C3.1.2. The optical corrector module of any of paragraphs C3.1-C3.1.1, wherein the thickness between the first surface and the second surface for each of the additional electrodes is less than 3 mm.
- (127) C3.1.3. The optical corrector module of any of paragraphs C3.1-C3.1.1, wherein the thickness between the first surface and the second surface for each of the additional electrodes is less than 100 μm .
- (128) C3.2. The optical corrector module of any of paragraphs C3-C3.1.3, wherein the additional multipole is positioned downstream of the split multipole when used in a charged particle system.
- (129) C3.3. The optical corrector module of any of paragraphs C3-C3.1, wherein the additional multipole is positioned upstream of the split multipole when used in a charged particle system.
- (130) C3.4. The optical corrector module of any of paragraphs C3-C3.3, wherein the additional multipole is positioned downstream of the split multipole when used in a charged particle system.
- (131) C3.5. The optical corrector module of any of paragraphs C3-C3.4, wherein there are no multipoles positioned between the split multipole and the additional multipole.
- (132) C3.6. The optical corrector module of any of paragraphs C3-C3.5, comprising a transfer lens positioned between the split multipole and the additional multipole.
- (133) C3.6.1. The optical corrector module of paragraph C3.6, wherein the transfer lens is positioned at an axial crossover of the charged particle beam.
- (134) C3.6.2. The optical corrector module of any of paragraphs C3.6-C3.6.1, wherein the axial crossover of the charged particle beam is equidistant to each of the split multipole and the additional multipole.
- (135) C3.6.3. The optical corrector module of any of paragraphs C3.6-C3.6.2, wherein the charged particle beam is not a parallel beam when passing through the split multipole when the optical corrector module is used in a charged particle system.
- (136) C3.7. The optical corrector module of any of paragraphs C3-C3.5, comprising a first transfer lens and a second transfer lens positioned between the split multipole and the additional multipole.
- (137) C3.7.1. The optical corrector module of paragraph C3.7, wherein the first transfer lens is positioned upstream of an axial crossover of the charged particle beam, and the second transfer lens is positioned downstream of an axial crossover of the charged particle beam.
- (138) C3.7.2. The optical corrector module of any of paragraphs C3.7-C3.7.1, wherein the axial crossover of the charged particle beam is equidistant to each of the split multipole and the additional multipole.
- (139) C3.7.3. The optical corrector module of any of paragraphs C3.7-C3.7.2, wherein the axial crossover of

- the charged particle beam is equidistant to each of the first transfer lens and the second transfer lens.
- (140) C3.7.4. The optical corrector module of any of paragraphs C3.7-C3.7.3, wherein the charged particle beam is a parallel beam when passing through the split multipole when the optical corrector module is used in a charged particle system.
- (141) C3.7.5. The optical corrector module of any of paragraphs C3.7-C3.7.3, wherein the charged particle beam is substantially a parallel beam when passing through the split multipole when the optical corrector module is used in a charged particle system.
- (142) C3.8. The optical corrector module of any of paragraphs C3-C3.7.5, wherein the split multipole and the additional multipole are both electrostatic multipoles.
- (143) C3.9. The optical corrector module of any of paragraphs C3-C3.8, wherein the split multipole and the additional multipole are both hexapoles.
- (144) C4. The optical corrector module of any of paragraphs C2-C2.6, wherein the optical corrector module is a probe corrector.
- (145) C5. The optical corrector module of any of paragraphs C1-C4, wherein the corrector strength for the optical corrector module corresponds to the relationship:
- (146) $C_{3s} = 4k^2 d^2 (L - \frac{2}{3}d)$, with $k = \frac{3}{2U_r} \frac{V_{hex}}{R^3}$.
- (147) D1. A charged particle system comprising: a sample holder configured to hold a sample; a charged particle source configured to emit a charged particle beam towards the sample; an optical column configured to direct the charged particle beam such that it is incident on the sample, the optical column including an optical corrector module of any of paragraphs C1-C5; and a detector system configured to detect emissions resultant from the sample being irradiated by the charged particle beam.
- (148) E1. Use of the corrector module of any of paragraphs A1-A13 and C1-C5.
- (149) F1. Use of the charged particle system of any of paragraphs B1-B13 and D1.

Claims

1. A charged particle microscopy system comprising: a sample holder configured to hold a sample; a charged particle source configured to emit a charged particle beam towards the sample; an optical column configured to direct the charged particle beam such that it is incident on the sample, the optical column including a compact corrector module that comprises: a strong multipole configured to generate a strong multipole field when a first voltage is applied to it, wherein the strong multipole is positioned such that a crossover of the charged particle beam does not pass through the center of the strong multipole causing the strong multipole field to apply at least an A2 aberration and a D4 aberration to the charged particle beam; and a weak multipole positioned between the strong multipole and a sample plane, wherein the weak multipole is configured such that when a second voltage is applied to the weak multipole it generates a weak multipole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam; and a detector system configured to detect emissions resultant from the sample being irradiated by the charged particle beam, wherein the number of strong multipoles in the compact corrector module is only one, wherein the compact corrector module comprises no multipoles other than the strong multipole that are stronger than the weak multipole, wherein the combination of the application of the A2 aberration and the combination A2 aberration to the charged particle beam results in the charged particle beam having a desired A2 aberration at the sample plane, and wherein the combination of the application of the D4 aberration and the combination D4 aberration to the charged particle beam results in the charged particle beam having a desired D4 aberration at the sample plane.
2. The charged particle microscopy system of claim 1, wherein: the strong multipole field further applies a C3 aberration to the charged particle beam of the charged particle microscopy system; the weak multipole field further applies a combination C3 aberration to the charged particle beam of the charged particle microscopy system; and the combination of the application of the C3 aberration and the combination C3 aberration to the charged particle beam results in the charged particle beam having a desired C3 aberration at the sample plane.
3. The charged particle microscopy system of claim 2, wherein the charged particle microscopy system is configured to apply the second voltage, the second voltage being based on the distance between the crossover of the charged particle beam and the center of the strong multipole such that one or more of the combination A2 aberration, the combination C3 aberration, and the combination D4 aberration caused by the weak multipole field are combination to the A2, C3, and D4 aberrations caused by the strong multipole field.
4. The charged particle microscopy system of claim 1, wherein the charged particle microscopy system is

configured to apply the first voltage and the second voltage such that the weak multipole is at least 50 times weaker than the strong multipole.

5. The charged particle microscopy system of claim 1, wherein the weak multipole is positioned within an objective lens of the optical column of the charged particle microscopy system.

6. The charged particle microscopy system of claim 1, wherein the weak multipole is positioned within a field of an objective lens of the optical column of the charged particle microscopy system.

7. The charged particle microscopy system of claim 1, further comprising a round lens positioned between the strong multipole and the weak multipole, wherein the round lens is positioned, charged, or otherwise configured such that a lensing effect of the round lens causes the magnitude of the D4 aberration to be adjusted such that it combines with the combination D4 aberration to result in the charged particle beam having a desired D4 aberration at the sample plane.

8. The charged particle microscopy system of claim 1, wherein the strong multipole is an electrostatic multipole.

9. The charged particle microscopy system of claim 8, wherein the strong multipole has a length of at least 5 mm.

10. The charged particle microscopy system of claim 1, wherein the strong multipole is a strong hexapole, and the weak multipole is a weak hexapole.

11. The charged particle microscopy system of claim 1, wherein the charged particle microscopy system is configured to apply the first voltage to the strong multipole such that the first voltage is between 0.1 and 30 kV.

12. The charged particle microscopy system of claim 1, wherein the compact corrector module is configured to allow the opening angle of the charged particle beam of the charged particle microscopy system to be greater than 20mrad.

13. The charged particle microscopy system of claim 1, wherein the charged particle microscopy system is configured to apply the first voltage to the strong multipole such that the first voltage is between 50 and 300 kV, and wherein the weak multipole is at least 50 or 100 times weaker than the strong multipole.

14. A compact corrector module for a charged particle microscopy system, the compact corrector module comprising: a strong multipole configured to generate a strong multipole field when a first voltage is applied to it, wherein the strong multipole is positioned such that a crossover of a charged particle beam of the charged particle microscopy system does not pass through the center of the strong multipole causing the strong multipole field to apply at least an A2 aberration and a D4 aberration to the charged particle beam; and a weak multipole positioned between the strong multipole and a sample plane when the compact corrector module is used in the charged particle microscopy system, wherein the weak multipole is configured such that when a second voltage is applied to the weak multipole it generates a weak multipole field that applies at least a combination A2 aberration and a combination D4 aberration to the charged particle beam, wherein the strong multipole is the only multipole of the compact corrector module that is stronger than the weak multipole.

15. The compact corrector module of claim 14, wherein the combination of the application of the A2 aberration and the combination A2 aberration to the charged particle beam results in the charged particle beam having a desired A2 aberration at the sample plane, and wherein the combination of the application of the D4 aberration and the combination D4 aberration to the charged particle beam results in the charged particle beam having a desired D4 aberration at the sample plane.

16. The compact corrector module of claim 14, wherein: the strong multipole field further applies a C3 aberration to the charged particle beam of the charged particle microscopy system; the weak multipole field further applies a combination C3 aberration to the charged particle beam of the charged particle microscopy system; and the combination of the application of the C3 aberration and the combination C3 aberration to the charged particle beam results in the charged particle beam having a desired C3 aberration at the sample plane.

17. The compact corrector module of claim 16, wherein the compact corrector module is configured to operate such that one or more of the combination A2 aberration, the combination C3 aberration, and the combination D4 aberration caused by the weak multipole field are combination to the A2, C3, and D4 aberrations caused by the strong multipole field.

18. The compact corrector module of claim 14, further comprising a round lens positioned between the strong multipole and the weak multipole, wherein the round lens is positioned, charged, or otherwise configured such that a lensing effect of the round lens causes the magnitude of the D4 aberration to be adjusted such that it combines with the combination D4 aberration to result in the charged particle beam having a desired D4 aberration at the sample plane.

19. The compact corrector module of claim 14, wherein the strong multipole is an electrostatic multipole.

20. The compact corrector module of claim 14, wherein the strong multipole is a strong hexapole, and wherein the weak multipole is a weak hexapole.
