

US Patent & Trademark Office

Patent Public Search | Text View

United States Patent	12394589
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Mangnus; Albertus Victor Gerardus et al.

Charged particle device, detector, and methods

Abstract

A detector for use in a charged particle device for an assessment tool to detect signal particles from a sample, the detector including a substrate, the substrate including: a semiconductor element configured to detect signal particles above a first energy threshold; and a charge-based element configured to detect signal particles below a second energy threshold.

Inventors: Mangnus; Albertus Victor Gerardus (Eindhoven, NL), Slot; Erwin (Zoetermeer, NL)

Applicant: ASML NETHERLANDS B.V. (Veldhoven, NL)

Family ID: 1000008764257

Assignee: ASML NETHERLANDS B.V. (Veldhoven, NL)

Appl. No.: 17/856722

Filed: July 01, 2022

Prior Publication Data

Document Identifier	Publication Date
US 20230005706 A1	Jan. 05, 2023

Foreign Application Priority Data

EP	21183811	Jul. 05, 2021
----	----------	---------------

Publication Classification

Int. Cl.: H01J37/244 (20060101); H01J37/145 (20060101); H01J37/28 (20060101)

U.S. Cl.:

CPC **H01J37/244** (20130101); **H01J37/145** (20130101); **H01J37/28** (20130101);
H01J2237/2446 (20130101); H01J2237/24475 (20130101); H01J2237/2448 (20130101)

Field of Classification Search

CPC: H01J (37/244); H01J (37/145); H01J (37/28); H01J (2237/2446); H01J (2237/24475);
H01J (2237/2448); H01J (2237/2441); H01J (2237/24465); H01J (2237/2804); H01J
(2237/2806)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
2738431	12/1955	Herzog	250/386	H01J 47/08
4785186	12/1987	Street	257/E31.089	G01T 1/242
5973323	12/1998	Adler	250/307	H01J 37/285
6204087	12/2000	Parker	257/E27.129	H01L 31/0352
7714300	12/2009	McCord	250/397	H01J 37/244
10466212	12/2018	Brown et al.	N/A	N/A
11054753	12/2020	Kaplan et al.	N/A	N/A
11222766	12/2021	Wang	N/A	H01J 37/28
11821859	12/2022	Wieland et al.	N/A	N/A
2005/0224707	12/2004	Guedj	257/E27.141	H01L 31/103
2006/0151711	12/2005	Frosien	250/396ML	H01J 37/28
2010/0276606	12/2009	Baars et al.	N/A	N/A
2012/0175527	12/2011	De Boer	250/492.1	H01J 37/185
2012/0298864	12/2011	Morishita	250/310	H01J 37/244
2014/0361168	12/2013	Ogawa et al.	N/A	N/A
2016/0203947	12/2015	Aoki et al.	N/A	N/A
2019/0259564	12/2018	Kruit et al.	N/A	N/A
2019/0259570	12/2018	Kruit et al.	N/A	N/A
2019/0378682	12/2018	Wang	N/A	H01L 31/085
2020/0118784	12/2019	Jiang et al.	N/A	N/A
2020/0203116	12/2019	Winkler et al.	N/A	N/A
2020/0227229	12/2019	Wang	N/A	H01L 27/14609
2020/0273664	12/2019	Wang et al.	N/A	N/A
2021/0116398	12/2020	Ren	N/A	H01J 37/244
2021/0134557	12/2020	Wang et al.	N/A	N/A
2021/0319977	12/2020	Liu	N/A	H01J 37/244
2022/0196581	12/2021	Wieland	N/A	G01N 23/2251
2022/0415611	12/2021	Steenbrink	N/A	H01J 37/141
2023/0005706	12/2022	Mangnus	N/A	H01J 37/145
2023/0137186	12/2022	Ren	250/306	H01J 37/244
2023/0324318	12/2022	Ren	250/252.1	G01N 23/2251
2024/0128043	12/2023	Van Soest	N/A	H01J 37/12
2024/0128045	12/2023	Slot	N/A	H01J 37/28

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
0872873	12/1997	EP	N/A
3863040	12/2020	EP	N/A
3937205	12/2021	EP	N/A
4002421	12/2021	EP	N/A
4020516	12/2021	EP	N/A
4020518	12/2021	EP	N/A
4020565	12/2021	EP	N/A
201633357	12/2015	TW	N/A
201942940	12/2018	TW	N/A
202101515	12/2020	TW	N/A
2004081910	12/2003	WO	N/A
2010125526	12/2009	WO	N/A
2012148267	12/2011	WO	N/A
2012165955	12/2011	WO	N/A
2016077047	12/2015	WO	N/A
2020135963	12/2019	WO	N/A
2021204740	12/2020	WO	N/A
2022008462	12/2021	WO	N/A
2022/136064	12/2021	WO	N/A

OTHER PUBLICATIONS

Office Action issued in the corresponding Taiwanese Patent Application No. 111124693, dated Apr. 13, 2023. cited by applicant

International Search Report dated Nov. 29, 2022, issued in the corresponding International Application No. PCT/EP2022/067788, pp. 1-2. cited by applicant

Primary Examiner: Vanore; David A

Attorney, Agent or Firm: Pillsbury Winthrop Shaw Pittman, LLP

Background/Summary

- (1) This application claims the benefit of priority to European patent application no. 21183811.5, filed Jul. 5, 2021, which is incorporated herein in its entirety by reference.
- FIELD
- (2) The disclosure herein generally relates to charged-particle devices, detectors, and methods.
- BACKGROUND
- (3) When manufacturing semiconductor integrated circuit (IC) chips, undesired pattern defects, as a consequence of, for example, optical effects and incidental particles, inevitably occur on a substrate (i.e. wafer) or a mask during the fabrication processes, thereby reducing the yield. Monitoring the extent of the undesired pattern defects is therefore an important process in the manufacture of IC chips. More generally, the inspection and/or measurement of a surface of a substrate, or other object/material, is an important process during and/or after its manufacture.
- (4) Pattern inspection tools with a charged particle beam have been used to inspect objects, for

example to detect pattern defects. These tools typically use electron microscopy techniques, such as a scanning electron microscope (SEM). In a SEM, a primary electron beam of electrons at a relatively high energy is targeted with a final deceleration step in order to land on a sample at a relatively low landing energy. The beam of electrons is focused as a probing spot on the sample. The interactions between the material structure at the probing spot and the landing electrons from the beam of electrons cause electrons to be emitted from the surface, such as secondary electrons, backscattered electrons or Auger electrons. The generated secondary electrons may be emitted from the material structure of the sample. By scanning the primary electron beam as the probing spot over the sample surface, secondary electrons can be emitted across the surface of the sample. By collecting these emitted secondary electrons from the sample surface, a pattern inspection tool may obtain data representing characteristics of the material structure of the surface of the sample. The data may be referred to as an image and may be rendered into an image.

SUMMARY

(5) Although the data obtained in this way can be useful, there are limitations in the information obtained about the sample from such known electron microscopy techniques. In general, there is a need to obtain additional or alternative information, for example, relating to structures below the surface of the sample and relating to overlay targets.

(6) It is an object of the present disclosure to provide, for example, embodiments that support obtaining information from a sample using charged particles, for example, using backscattered and/or secondary signal particles.

(7) According to an aspect, there is provided a detector for use in a charged particle device for an assessment tool, the charged particle device configured to project a beam of charged particles to a sample and the detector to detect resulting signal particles from the sample, the detector comprising a substrate, the substrate comprising: a semiconductor element configured to detect signal particles above a first energy threshold; and a charge-based element configured to detect signal particles below a second energy threshold, the charge-based element being configured to electrically connect the charge-based element for applying a biasing voltage, wherein the charge-based element and the semiconductor element are each at least part of layers that are substantially co-planar with major surfaces of the detector and the layers are comprised in a stacked structure comprised in the detector stacked in a thickness direction of the detector.

(8) According to an aspect, there is provided a detector for use in a charged particle device for an assessment tool, the charged particle device configured to project a beam of charged particles to a sample and the detector to detect resulting signal particles from the sample, the detector comprising a substrate, the substrate comprising: a semiconductor element configured to detect signal particles above a first energy threshold; a charge-based element configured to detect signal particles below a second energy threshold, the charge-based element being configured to electrically connect the charge-based element; and an electrically insulated via configured to connect the charge-based element to detector circuitry wherein the electrically insulated via extends through at least part of the semiconductor element.

(9) According to an aspect, there is provided a method of projecting a beam of charged particles onto a sample so as to detect resulting signal particles emitted from the sample, the method comprising: projecting the beam along a primary beam path onto a surface of the sample; and detecting the resulting signal particles emitted from the sample at a detector, the detector being proximate the sample and comprising a semiconductor element, the detecting comprising simultaneous detection of signal particles above a first energy threshold at a first detector element and signal particles below a second energy threshold at a second detector element.

(10) According to an aspect, there is provided a detector for use in a charged particle device for an assessment tool to detect signal particles from a sample, the detector comprising a substrate, the substrate comprising: a semiconductor element configured to detect signal particles above a first energy threshold; and a charge-based element configured to detect signal particles below a second

energy threshold.

(11) According to an aspect, there is provided a detector array comprising a plurality of detectors described in an aspect above, wherein the detectors are comprised in a common substrate, each detector corresponding to a respective sub-beam.

(12) According to an aspect, there is provided a detector array for use in a multi-beam charged particle device for an assessment tool to detect signal particles from a sample, the detector array comprising at least one substrate in which is defined a plurality of apertures for the passage therethrough of the plurality of sub-beams of charged particle beams towards a sample, the substrate comprising: a plurality of semiconductor elements configured to detect signal particles above a first energy threshold; and a plurality of charge-based elements configured to detect signal particles below a second energy threshold, wherein each semiconductor element is associated with a corresponding one of the charge-based elements.

(13) According to an aspect, there is provided charged particle device for an assessment tool to detect signal particles from a sample, the device comprising: an objective lens configured to project a beam of charged particles onto a sample; and a detector described in an aspect above.

(14) According to an aspect, there is provided a charged particle device for an assessment tool to detect signal particles from a sample, the device comprising: an objective lens array configured to project a plurality of sub-beams of charged particles onto a sample in a multi-beam array, and in which an aperture is defined for each sub-beam; and a detector system comprising at least one detector array described in an aspect above, wherein the apertures of the at least one detector array are aligned with the apertures defined in the objective lens array.

(15) According to an aspect, there is provided charged particle device for an assessment tool to detect charged particles from a sample, the device comprising: an objective lens configured to project a beam of charged particles onto a sample, and in which an aperture is defined for the beam; and a detector proximate the sample and defining an aperture aligned with the aperture of the objective lens, the detector comprising a first detector element configured to detect signal particles above a first energy threshold and a second detector element configured to detect signal particles below a second energy threshold simultaneously, wherein the detector comprises a semiconductor element.

(16) According to an aspect, there is provided a method of projecting a beam of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: projecting the beam along a primary beam path onto a surface of the sample; and detecting the signal particles emitted from the sample simultaneously at a semiconductor element and at a charge-based element.

(17) According to an aspect, there is provided method of projecting a beam of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: projecting the beam along a primary beam path onto a surface of the sample; and detecting the signal particles emitted from the sample at a detector, the detector being proximate the sample and comprising a semiconductor element, the detecting comprising simultaneous detection of signal particles above a first energy threshold at a first detector element and signal particles below a second energy threshold at a second detector element.

(18) According to an aspect, there is provided a method of projecting a plurality of sub-beams of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: projecting the sub-beams along primary sub-beam paths onto a surface of the sample; and detecting the signal particles emitted from the sample at a detector array, the detector array being proximate the sample and comprising a detector comprising a semiconductor element corresponding to each sub-beam, the detector comprising a first detector element and a second detector element, the detecting comprising simultaneous detection by each detector of signal particles above a first energy threshold at the corresponding first detector element and signal particles below a second energy threshold at the second detector element.

(19) According to an aspect, there is provided a method of projecting a beam of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: providing a device according to an aspect above; projecting a beam of charged particles to the sample using the objective lens; and detecting the resulting signal particles simultaneously using the semiconductor element and the charge-based element.

Description

BRIEF DESCRIPTION OF FIGURES

- (1) The above and other aspects of the present disclosure will become more apparent from the description of exemplary embodiments, taken in conjunction with the accompanying drawings.
- (2) FIG. 1 is a schematic diagram illustrating an exemplary charged particle beam inspection apparatus.
- (3) FIG. 2 is a schematic diagram illustrating an exemplary multi-beam apparatus that is part of the exemplary charged particle beam inspection apparatus of FIG. 1.
- (4) FIG. 3 is a schematic diagram of an exemplary multi-beam apparatus according to an embodiment.
- (5) FIG. 4 is a schematic cross-sectional view of an objective lens according to an embodiment.
- (6) FIG. 5 is a schematic diagram of an exemplary charged particle optical device according to an embodiment.
- (7) FIG. 6A and FIG. 6B show a bottom view of variations of a detector.
- (8) FIG. 7 is a schematic cross-sectional view of an objective lens comprising detectors located in various positions along a beam path.
- (9) FIG. 8 is a schematic diagram of an exemplary charged particle-optical system comprising a macro collimator and macro scan deflector.
- (10) FIG. 9 is a schematic diagram of an exemplary single beam apparatus according to an embodiment.
- (11) FIGS. 10A, 10B and 10C are schematic representations of a detector array and an associated cell array according to an embodiment, a schematic representation of a cell of the cell array, and a cell of the cell array according to an embodiment.
- (12) FIG. 11 is a circuit diagram of another exemplary amplification circuit according to an embodiment.
- (13) FIG. 12 is a circuit diagram of another exemplary amplification circuit according to an embodiment.
- (14) FIG. 13 is a schematic representation of a cross-section wiring route showing circuit wires and a shielding arrangement according to an embodiment.
- (15) FIG. 14 is a cross-section of a detector according to an embodiment.
- (16) FIG. 15 is a cross-section of a detector according to an embodiment.
- (17) FIG. 16 is a cross-section of a detector according to an embodiment.
- (18) FIG. 17 is a cross-section of a detector array according to an embodiment.
- (19) FIG. 18 is a cross-section of a detector array according to a variation of FIG. 17.
- (20) The figures are schematic. The schematic diagrams and views show the components described below. However, the components depicted in the figures are not to scale. Relative dimensions of components in drawings are exaggerated for clarity. Within the following description of drawings the same or like reference numbers refer to the same or like components or entities, and only the differences with respect to the individual embodiments are described.

DETAILED DESCRIPTION

- (21) Reference will now be made in detail to exemplary embodiments, examples of which are illustrated in the accompanying drawings. The following description refers to the accompanying

drawings in which the same numbers in different drawings represent the same or similar elements unless otherwise represented. The implementations set forth in the following description of exemplary embodiments do not represent all implementations consistent with the invention. Instead, they are merely examples of apparatuses and methods consistent with aspects related to the invention as recited in the appended claims.

(22) The enhanced computing power of electronic devices, which reduces the physical size of the devices, can be accomplished by significantly increasing the packing density of circuit components such as transistors, capacitors, diodes, etc. on an IC chip. This has been enabled by increased resolution enabling yet smaller structures to be made. For example, an IC chip of a smart phone, which is the size of a thumbnail and available in, or earlier than, 2019, may include over 2 billion transistors, the size of each transistor being less than 1/1000th of a human hair. Thus, it is not surprising that semiconductor IC manufacturing is a complex and time-consuming process, with hundreds of individual steps. Errors in even one step have the potential to dramatically affect the functioning of the final product. Just one “killer defect” can cause device failure. The goal of the manufacturing process is to improve the overall yield of the process. For example, to obtain a 75% yield for a 50-step process (where a step can indicate the number of layers formed on a wafer), each individual step must have a yield greater than 99.4%. If each individual step had a yield of 95%, the overall process yield would be as low as 7%.

(23) While high process yield is desirable in an IC chip manufacturing facility, maintaining a high substrate (i.e. wafer) throughput, defined as the number of substrates processed per hour, is also essential. High process yield and high substrate throughput can be impacted by the presence of a defect. This is especially true if operator intervention is required for reviewing the defects. Thus, high throughput detection and identification of micro and nano-scale defects by inspection tools (such as a Scanning Electron Microscope (SEM)) is essential for maintaining high yield and low cost.

(24) A SEM comprises a scanning device and a detector apparatus. The scanning device comprises an illumination apparatus that comprises an electron source, for generating primary electrons, and a projection apparatus for scanning a sample, such as a substrate, with one or more focused beams of primary electrons. Together at least the illumination apparatus, or illumination system, and the projection apparatus, or projection system, may be referred to together as the electron-optical system or apparatus. The primary electrons interact with the sample and generate secondary electrons. The detection apparatus captures the secondary electrons from the sample as the sample is scanned so that the SEM can create an image of the scanned area of the sample. For high throughput inspection, some of the inspection apparatuses use multiple focused primary beams, i.e. a multi-beam, of primary electrons. The component beams of the multi-beam may be referred to as sub-beams or beamlets or an array of primary beams. A multi-beam can scan different parts of a sample simultaneously. A multi-beam inspection apparatus can therefore inspect a sample at a much higher speed than a single-beam inspection apparatus. An implementation of a known multi-beam inspection apparatus is described below.

(25) Reference is now made to FIG. 1, which is a schematic diagram illustrating an exemplary charged particle beam inspection apparatus **100**. The charged particle beam inspection apparatus **100** of FIG. 1 includes a main chamber **10**, a load lock chamber **20**, a charged particle beam tool **40** (which may otherwise be referred to as an electron beam tool), an equipment front end module (EFEM) **30** and a controller **50**. The charged particle beam tool **40** is located within the main chamber **10**.

(26) The EFEM **30** includes a first loading port **30a** and a second loading port **30b**. The EFEM **30** may include additional loading port(s). The first loading port **30a** and the second loading port **30b** may, for example, receive substrate front opening unified pods (FOUPs) that contain substrates (e.g., semiconductor substrates or substrates made of other material(s)) or samples to be inspected (substrates, wafers and samples are collectively referred to as “samples” hereafter). One or more

robot arms (not shown) in the EFEM **30** transport the samples to the load lock chamber **20**.

(27) The load lock chamber **20** is used to remove the gas around a sample. This creates a vacuum that is a local gas pressure lower than the pressure in the surrounding environment. The load lock chamber **20** may be connected to a load lock vacuum pump system (not shown), which removes gas particles in the load lock chamber **20**. The operation of the load lock vacuum pump system enables the load lock chamber to reach a first pressure below the atmospheric pressure. After reaching the first pressure, one or more robot arms (not shown) transport the sample from the load lock chamber **20** to the main chamber **10**. The main chamber **10** is connected to a main chamber vacuum pump system (not shown). The main chamber vacuum pump system removes gas particles in the main chamber **10** so that the pressure in around the sample reaches a second pressure lower than the first pressure. After reaching the second pressure, the sample is transported to the charged particle beam tool **40** by which it may be inspected. A charged particle beam tool **40** may comprise a multi-beam charged particle-optical apparatus.

(28) The controller **50** is electronically connected to the charged particle beam tool **40**. The controller **50** may be a processor (such as a computer) configured to control the charged particle beam inspection apparatus **100**. The controller **50** may also include a processing circuitry configured to execute various signal and image processing functions. While the controller **50** is shown in FIG. **1** as being outside of the structure that includes the main chamber **10**, the load lock chamber **20**, and the EFEM **30**, it is appreciated that the controller **50** may be part of the structure. The controller **50** may be located in one of the component elements of the charged particle beam inspection apparatus or it can be distributed over at least two of the component elements. While the present disclosure provides examples of the main chamber **10** housing a charged particle beam inspection tool, it should be noted that aspects of the disclosure in their broadest sense are not limited to a chamber housing a charged particle beam inspection tool. Rather, it is appreciated that the foregoing principles may also be applied to other tools and other arrangements of apparatus that operate under the second pressure.

(29) Reference is now made to FIG. **2**, which is a schematic diagram illustrating an exemplary charged particle beam tool **40** including a multi-beam inspection tool that is part of the exemplary charged particle beam inspection apparatus **100** of FIG. **1**. The multi-beam charged particle beam tool **40** (also referred to herein as apparatus **40**) comprises a charged particle source **201**, a projection apparatus **230**, a motorized stage **209** (or an actuated stage), and a sample holder **207**. The charged particle source **201** and projection apparatus **230** may together be referred to as an illumination apparatus. The sample holder **207** is supported by motorized stage **209** so as to hold a sample **208** (e.g., a substrate or a mask) for inspection. The multi-beam charged particle beam tool **40** further comprises a detector array **240** (e.g. an electron detection device).

(30) The controller **50** may be connected to various parts of the charged particle beam inspection apparatus **100** of FIG. **1**. The controller **50** may be connected to various parts of the charged particle beam tool **40** of FIG. **2**, such as the charged particle source **201**, the detector array **240**, the projection apparatus **230**, and the motorized stage **209**. The controller **50** may perform various data, image and/or signal processing functions. The controller **50** may also generate various control signals to govern operations of the charged particle beam inspection apparatus **100**, including the charged particle multi-beam apparatus. The controller **50** may control the motorized stage **209** to move sample **208** during inspection of the sample **208**. The controller **50** may enable the motorized stage **209** to move the sample **208** in a direction, preferably continuously, for example at a constant speed, at least during sample inspection. The controller **50** may control movement of the motorized stage **209** so that it changes the speed of the movement of the sample **208** dependent on various parameters. For example, the controller **50** may control the stage speed (including its direction) depending on the characteristics of the inspection steps of scanning process.

(31) The charged particle source **201** may comprise a cathode (not shown) and an extractor or anode (not shown). During operation, the charged particle source **201** is configured to emit charged

particles (e.g. electrons) as primary charged particles from the cathode. The primary charged particles are extracted or accelerated by the extractor and/or the anode to form a primary charged particle beam **202**. The charged particle source **201** may comprise multiple sources, such as described in European patent application publication no. EP3937205, which is incorporated herein in its entirety by reference and at least with respect to the multiple sources and how they relate to multiple columns and their associated charged particle-optics.

(32) The projection apparatus **230** is configured to convert the primary charged particle beam **202** into a plurality of sub-beams **211**, **212**, **213** and to direct each sub-beam onto the sample **208**. Although three sub-beams are illustrated for simplicity, there may be many tens, many hundreds or many thousands of sub-beams. The sub-beams may be referred to as beamlets. Furthermore, although the present description and figures relate to a multi-beam system, a single beam system may be used instead in which the primary charged particle beam **202** is not converted into multiple sub-beams. This is described further below in relation to FIG. **9**, but it will be noted that the sub-beams may be interchangeable with a single primary charged particle beam **202**.

(33) The projection apparatus **230** may be configured to focus sub-beams **211**, **212**, and **213** onto a sample **208** for inspection and may form three probe spots **221**, **222**, and **223** on the surface of sample **208**. The projection apparatus **230** may be configured to deflect the primary sub-beams **211**, **212**, and **213** to scan the probe spots **221**, **222**, and **223** across individual scanning areas in a section of the surface of the sample **208**. In response to incidence of the primary sub-beams **211**, **212**, and **213** on the probe spots **221**, **222**, and **223** on the sample **208**, signal charged particles (e.g. electrons) are generated (i.e. emitted) from the sample **208** which include secondary signal particles and backscatter signal particles. The signal particles emitted from the sample, e.g. secondary electrons and backscatter electrons, may otherwise be referred to as charged particles, e.g. secondary charged particles and backscatter charged particles. Signal beams are formed of signal particles emitted from the sample. It will generally be understood that any signal beams emitted from the sample **208** will travel in a direction with at least a component substantially opposite to the charged particle beams (i.e. the primary beams), or will have at least a component of direction which is opposite to the direction of the primary beams. Signal particles, which are emitted by the sample **208** may also pass through the electrodes of the objective lens and would also be affected by the field.

(34) The secondary signal particles typically have charged particle energy 50 eV. Actual secondary signal particles can have an energy of less than 5 eV, but anything beneath 50 eV is generally treated as a secondary signal particle. Backscatter signal particles typically have energy between 0 eV and the landing energy of the primary sub-beams **211**, **212**, and **213**. As signal particles detected with an energy of less than 50 eV are generally treated as a secondary signal particles, a proportion of the actual backscatter signal particles will be counted as secondary signal particles. The secondary signal particles may more specifically be referred to, and are interchangeable with, secondary electrons. The backscatter signal particles may more specifically be referred to, and are interchangeable with, backscatter electrons. The skilled person would understand that the backscatter signal particles may more generally be described as secondary signal particles. However, for the purposes of the present disclosure, the backscatter signal particles are considered to be different from the secondary signal particles, e.g. having higher energies. In other words, the secondary signal particles will be understood to be particles having kinetic energy ≤ 50 eV when emitted from the sample and the backscatter signal particles will be understood to be particles having kinetic energy higher than 50 eV when emitted from the sample. In practice, the signal particles may be accelerated before being detected and thus, the energy range associated with the signal particles may be slightly higher. For example, the secondary signal particles will be understood to be particles having kinetic energy 200 eV when detected at a detector and the backscatter signal particles will be understood to be particles having kinetic energy higher than 200 eV when detected at a detector. It is noted that the 200 eV value may vary depending on the extent

of acceleration of the particles, and may for example be approximately 100 eV or 300 eV. Secondary signal particles having such values are still considered to have sufficient energy different with respect to the backscatter signal particles.

(35) The detector array **240** is configured to detect (i.e. capture) signal particles emitted from the sample **208**. The detector array **240** is configured to generate corresponding signals which are sent to a signal processing system **280**, e.g. to construct images of the corresponding scanned areas of sample **208**. The detector array **240** may be incorporated into the projection apparatus **230**. The detector array may otherwise be referred to as a sensor array, and the terms “detector” and “sensor” and “sensor unit” are used interchangeably throughout the application.

(36) The signal processing system **280** may comprise a circuit (not shown) configured to process signals from the detector array **240** so as to form an image. The signal processing system **280** could otherwise be referred to as an image processing system or a data processing system. The signal processing system may be incorporated into a component of the multi-beam charged particle beam tool **40** such as the detector array **240** (as shown in FIG. 2). However, the signal processing system **280** may be incorporated into any components of the inspection apparatus **100** or multi-beam charged particle beam tool **40**, such as, as part of the projection apparatus **230** or the controller **50**. The signal processing system **280** could be located outside of the structure that includes the main chamber which is shown in FIG. 1. The signal processing system **280** may include an image acquirer (not shown) and a storage device (not shown). For example, the signal processing system may comprise a processor, computer, server, mainframe host, terminals, personal computer, any kind of mobile computing devices, and the like, or a combination thereof. The image acquirer may comprise at least part of the processing function of the controller. Thus the image acquirer may comprise at least one or more processors. The image acquirer may be communicatively coupled to the detector array **240** permitting signal communication, such as an electrical conductor, optical fiber cable, portable storage media, IR, Bluetooth, internet, wireless network, wireless radio, among others, or a combination thereof. The image acquirer may receive a signal from the detector array **240**, may process the data comprised in the signal and may construct an image therefrom. The image acquirer may thus acquire images of the sample **208**. The image acquirer may also perform various post-processing functions, such as generating contours, superimposing indicators on an acquired image, and the like. The image acquirer may be configured to perform adjustments of brightness and contrast, etc. of acquired images. The storage may be a storage medium such as a hard disk, flash drive, cloud storage, random access memory (RAM), other types of computer readable memory, and the like. The storage may be coupled with the image acquirer and may be used for saving scanned raw image data as original images, and post-processed images.

(37) The signal processing system **280** may include measurement circuitry (e.g., analog-to-digital converters) to obtain a distribution of the detected secondary signal particles. The electron distribution data, collected during a detection time window, can be used in combination with corresponding scan path data of each of primary sub-beams **211**, **212**, and **213** incident on the sample surface, to reconstruct images of the sample structures under inspection. The reconstructed images can be used to reveal various features of the internal or external structures of the sample **208**. The reconstructed images can thereby be used to reveal any defects that may exist in the sample.

(38) Known multi-beam systems, such as the charged particle beam tool **40** and charged particle beam inspection apparatus **100** described above, are disclosed in U.S. patent application publication nos. US 2020/118784, US 2020/0203116, US 2019/0259570 and US2019/0259564 which are incorporated herein in their entireties by reference.

(39) In known single-beam systems, different signals (e.g. from secondary signal particles and/or backscatter signal particles) might theoretically be detected. Multi-beam systems are known and are beneficial as the throughput can be much higher than when using single-beam systems, e.g. the throughput of a multi-beam inspection system may be 100 times higher than the throughput in a

single-beam inspection system.

(40) In known multi-beam systems, an array of primary sub-beams of charged particles at a relatively high energy are targeted with a final deceleration step in order to land on a sample at a relatively low landing energy for detection of secondary signal particles as mentioned above. However, in practice, it has not generally been possible to use multi beam inspection in combination with backscatter detection, or at least by direct backscatter detection, i.e. presently known multi-beam systems rely primarily on detection of secondary signal particles. However, there are limitations in the information which can be obtained solely from secondary signal particles. Backscatter signal particles provide information about structures below the surface, such as buried defects. Additionally, backscatter signals can be used to measure overlay targets.

(41) As described above, backscatter signal particles have a large range of energies, typically between 0 eV and the landing energy. The backscatter signal particles have a large range in energy (for example up to the landing energy of the primary beam) and wide angle of emitted backscatter signal particles. Secondary signal particles typically have a more restricted energy range and tend to be distributed around an energy value. The large energy range and wide angle of emitted backscatter signal particles results in crosstalk in a multi-beam system. Crosstalk occurs when backscatter signal particles resulting from one primary sub-beam are detected at a detector assigned to a different sub-beam. Crosstalk generally occurs very close to the sample **208**, i.e. proximate the sample onto which the primary beam is projected. Due to the crosstalk, previously known multi-beam assessment tools have not been able to effectively image backscatter signals. As a consequence, it has not been possible to increase the throughput for backscattered detection by using multi-beam systems.

(42) Components of an assessment tool **40** which may be used in an embodiment of the present invention are described below in relation to FIG. **3** which is a schematic diagram of an assessment tool **40**. The charged particle assessment tool **40** of FIG. **3** may correspond to the multi-beam charged particle beam tool (also referred to herein as apparatus **40**).

(43) The charged particle source **201** directs charged particles (e.g. electrons) toward an array of condenser lenses **231** (otherwise referred to as a condenser lens array) forming part of the projection system **230**. The charged particle source **201** is desirably a high brightness thermal field emitter with a good compromise between brightness and total emission current. There may be many tens, many hundreds or many thousands of condenser lenses **231**. The condenser lenses **231** may comprise multi-electrode lenses and have a construction based on European patent application publication no. EP1602121, which is incorporated herein in its entirety by reference and at least with respect to the disclosure of a lens array to split an e-beam into a plurality of sub-beams, with the array providing a lens for each sub-beam. The array of condenser lenses **231** may take the form of at least two plates, acting as electrodes, with an aperture in each plate aligned with each other and corresponding to the location of a sub-beam. At least two of the plates are maintained during operation at different potentials to achieve the desired lensing effect.

(44) In an arrangement the array of condenser lenses **231** is formed of three plate arrays in which charged particles have the same energy as they enter and leave each lens, which arrangement may be referred to as an Einzel lens. Thus, dispersion only occurs within the Einzel lens itself (between entry and exit electrodes of the lens), thereby limiting off-axis chromatic aberrations. When the thickness of the condenser lenses is low, e.g. a few mm, such aberrations have a small or negligible effect. More generally, the condenser lens array **231** may have two or more plate electrodes each with an array of apertures that are aligned. Each plate electrode array is mechanically connected to, and electrically isolated from, an adjacent plate electrode array by an isolating element, such as a spacer which may comprise ceramic or glass. The condenser lens array may be connected and/or spaced apart from an adjacent charged particle-optical element, preferably an electrostatic charged particle-optical element, by an isolating element such as a spacer as described elsewhere herein.

(45) The condenser lenses may be separated from a module containing the objective lenses (such as

an objective lens array assembly as discussed elsewhere herein). In a case where the potential applied on a bottom surface of the condenser lenses is different than the potential applied on the top surface of the module containing the objective lenses an isolating element (e.g. a spacer) is used to space apart the condenser lenses and the module containing the objective lenses. In a case where the potential is equal then a conductive element can be used to space apart the condenser lenses and the module containing the objective lenses.

(46) Each condenser lens **231** in the array directs a primary beam of charged particles into a respective sub-beam **211**, **212**, **213** which is focused at a respective intermediate focus down beam of the condenser lens array. The respective sub-beams are projected along respective sub-beam paths **220**. The sub-beams diverge with respect to each other. The sub-beam paths **220** diverge down beam of the condenser lenses **231**. In an embodiment, deflectors **235** are provided at the intermediate focuses. The deflectors **235** are positioned in the sub-beam paths at, or at least around, the position of the corresponding intermediate focusses **233** or focus points (i.e. points of focus). The deflectors are positioned in or close to the sub-beam paths at the intermediate image plane of the associated sub-beam. The deflectors **235** are configured to operate on the respective sub-beams **211**, **212**, **213**. The deflectors **235** are configured to bend a respective sub-beam **211**, **212**, **213** by an amount effective to ensure that the principal ray (which may also be referred to as the beam axis) is incident on the sample **208** substantially normally (i.e. at substantially 90° to the nominal surface of the sample). The deflectors **235** may also be referred to as collimators or collimator deflectors. The deflectors **235** in effect collimate the paths of the sub-beams so that before the deflectors, the sub-beam paths with respect to each other are diverging. Down beam of the deflectors the sub-beam paths are substantially parallel with respect to each other, i.e. substantially collimated. Suitable collimators are deflectors disclosed in European patent application publication no. EP3863040, which is incorporated herein in its entirety by reference and at least with respect to the application of the deflectors to a multi-beam array. The collimator may comprise a macro collimator **270**, instead of, or in addition to the deflectors **235**. Thus, the macro-collimator **270** described below in relation to FIG. **8** may be provided with the features of FIG. **3** or FIG. **4**. This is generally less preferred than providing the collimator array as deflectors **235**.

(47) Below (i.e. down beam or further from source **201**) the deflectors **235** there is a control lens array **250**. The sub-beams **211**, **212**, **213** having passed through the deflectors **235** are substantially parallel on entry to the control lens array **250**. The control lenses pre-focus the sub-beams (e.g. apply a focusing action to the sub-beams prior to the sub-beams reaching the objective lens array **241**). The pre-focusing may reduce divergence of the sub-beams or increase a rate of convergence of the sub-beams. The control lens array **250** and the objective lens array **241** operate together to provide a combined focal length. Combined operation without an intermediate focus may reduce the risk of aberrations.

(48) In further detail, it is desirable to use the control lens array **250** to determine the landing energy. However, it is possible to use in addition the objective lens array **240** to control the landing energy. In such a case, a potential difference over the objective lens is changed when a different landing energy is selected. One example of a situation where it is desirable to partly change the landing energy by changing the potential difference over the objective lens is to prevent the focus of the sub-beams getting too close to the objective lenses. In such a situation there is a risk of components of the objective lens array **241** having to be too thin to be manufacturable. The same may be said about a detector at this location, for example in, on or otherwise associated with the objective lens. This situation can for example occur in case the landing energy is lowered. This is because the focal length of the objective lens roughly scales with the landing energy used. By lowering the potential difference over the objective lens, and thereby lowering the electric field inside the objective lens, the focal length of the objective lens is made larger again, resulting in a focus position further below the objective lens. Note that use of just an objective lens would limit control of magnification. Such an arrangement could not control demagnification and/or opening

angle. Further, using the objective lens to control the landing energy could mean that the objective lens would be operating away from its optimal field strength. That is unless mechanical parameters of the objective lens (such as the spacing between its electrodes) could be adjusted, for example by exchanging the objective lens.

(49) The control lens array **250** comprises a plurality of control lenses. Each control lens comprises at least two electrodes (e.g. two or three electrodes) connected to respective potential sources. The control lens array **250** may comprise two or more (e.g. three) plate electrode arrays connected to respective potential sources. The control lens array electrodes may be spaced a few millimeters (e.g. 3 mm) apart. The control lens array **250** is associated with the objective lens array **241** (e.g. the two arrays are positioned close to each other and/or mechanically connected to each other and/or controlled together as a unit). Each control lens may be associated with a respective objective lens. The control lens array **250** is positioned up-beam of the objective lens array **241**. Up-beam may be defined as being closer to the source **201**. Up-beam may otherwise be defined as further from the sample **208**. The control lens array **250** may be in the same module as an objective lens array **241**, i.e. forming an objective lens array assembly or objective lens arrangement, or it may be in a separate module. In this case, the arrangement may be described as four or more lens electrodes that are plates. In the plates are defined apertures, for example as aperture arrays, which are aligned with a number of sub-beams in a corresponding beam array. The electrodes may be grouped into two or more electrodes, for example to provide a control electrode group, and an objective electrode group. In an arrangement the objective electrode group has at least three electrodes and the control electrode group has at least two electrodes. Alternatively, if the control lens array **250** and the objective lens array **240** are separate, the spacing between the control lens array **241** and the objective lens array **250** (i.e. the gap between lower electrode of the control lens array **250** and the upper electrode of the objective lens **241**) can be selected from a wide range, e.g. from 2 mm to 200 mm or more. A small separation makes alignment easier whereas a larger separation allows a weaker lens to be used, reducing aberrations.

(50) Each plate electrode of the control lens array **250** is preferably mechanically connected to, and electrically separated from, an adjacent plate electrode array by an isolating element, such as a spacer which may comprise ceramic or glass. Each plate electrode of the objective lens array is preferably mechanically connected to, and electrically separated from, an adjacent plate electrode array by an isolating element, such as a spacer which may comprise ceramic or glass. The isolating element may otherwise be referred to as an insulating structure, and may be provided to separate any adjacent electrodes provided, such as in the objective lens array **240**, the condenser lens array (as depicted in FIG. 3) and/or the control lens array **250**. If more than two electrodes are provided, multiple isolating elements (i.e. insulating structures) may be provided. For example, there may be a sequence of insulating structures.

(51) The control lens array **250** comprises a control lens for each sub-beam **211**, **212**, **213**. A control lens adds optical degrees of freedom to the function of the associated objective lens. A control lens may comprise of one or more electrode or plates. The addition of each electrode may provide a further degree of freedom of the control of the charged particle-optical function of the associated objective lens. In an arrangement the function of the control lens array **250** is to optimize the beam opening angle with respect to the demagnification of the beam and/or to control the beam energy delivered to the objective lenses **234**, each of which directs a respective sub-beam **211**, **212**, **213** onto the sample **208**. The objective lenses may be positioned at or near the base of the charged particle-optical system. More specifically, the objective lens array may be positioned at or near the base of the projection system **230**. The control lens array **250** is optional, but is preferred for optimizing a sub-beam upbeam of the objective lens array.

(52) For ease of illustration, lens arrays are depicted schematically herein by arrays of oval shapes (as shown in FIG. 3). Each oval shape represents one of the lenses in the lens array. The oval shape is used by convention to represent a lens, by analogy to the biconvex form often adopted in optical

lenses. In the context of charged-particle arrangements such as those discussed herein, it will be understood however that lens arrays will typically operate electrostatically and so may not require any physical elements adopting a biconvex shape. Lens arrays may instead comprise multiple plates with apertures.

(53) Optionally, an array of scan deflectors **260** is provided between the control lens array **250** and the array of objective lenses **234**. The array of scan deflectors **260** comprises a scan deflector for each sub-beam **211**, **212**, **213**. Each scan deflector is configured to deflect a respective sub-beam **211**, **212**, **213** in one or two directions so as to scan the sub beam across the sample **208** in one or two directions.

(54) The objective lens array **241** may comprise at least two electrodes in which are defined aperture arrays. In other words, the objective lens array comprises at least two electrodes with a plurality of holes or apertures. Adjacent electrodes of the objective lens array **241** are spaced apart from each other along the sub-beam paths. The distance between adjacent electrodes along the beam path, in which an insulating structure might be positioned as described below, is smaller than the size of an objective lens (along the beam path, i.e. between the most upbeam and most down beam electrode of the objective lens array). FIG. 4 shows electrodes **242**, **243** which are part of an exemplary objective lens array **241** having respective aperture arrays **245**, **246**. The position of each aperture in an electrode corresponds to the position of a corresponding aperture in another electrode. The corresponding apertures operate in use on the same beam, sub-beam or group of sub-beams in the multi-beam. In other words, corresponding apertures in the at least two electrodes are aligned with and arranged along a sub-beam path, i.e. one of the sub-beam paths **220**. Thus, the electrodes are each provided with apertures through which the respective sub-beam **211**, **212**, **213** propagates.

(55) The aperture arrays **245**, **246** of the objective lens array **241** may consist of a plurality of apertures, preferably with substantially uniform diameters, d . However there may be some variation for optimizing aberration correction as described in European patent application publication no. EP4002421, which is incorporated herein in its entirety by reference and at least with respect to corrections achieved by varying aperture diameter. The diameter, d , of the apertures in at least one electrode may be less than approximately 400 μm . Preferably, the diameter, d , of the apertures in at least one electrode is between approximately 30 to 300 μm . Smaller aperture diameters may provide larger detectors of the detector array **240** for a given aperture pitch, improving the chance of capturing backscatter signal particles. Thus the signal for the backscatter signal particles may improve. However, having apertures that are too small risk inducing aberrations in the primary sub-beams. The plurality of apertures in an electrode may be spaced apart from each other by a pitch, P . The pitch, P , is defined as the distance from the middle of one aperture to the middle of an adjacent aperture. The pitch between adjacent apertures in at least one electrode may be less than approximately 600 μm . Preferably, the pitch between adjacent apertures in at least one electrode is between approximately 50 μm and 500 μm . Preferably, the pitch between adjacent apertures on each electrode is substantially uniform. The values for the diameter and/or pitch described above can be provided in at least one electrode, multiple electrodes, or all electrodes in an objective lens array. Preferably, the dimensions referred to and described apply to all electrodes provided in an array of objective lenses.

(56) The objective lens array **241** may comprise two or three electrodes or may have more electrodes (not shown). An objective lens array **241** having only two electrodes can have fewer aberrations, e.g. a lower aberration risk and/or impact, than an objective lens array **241** having more electrodes. A three-electrode objective lens can have greater potential differences between the electrodes and so enable a stronger lens. Additional electrodes (i.e. more than two electrodes) provide additional degrees of freedom for controlling the charged particle trajectories, e.g. to focus secondary signal particles as well as the incident beam. A benefit of two electrode lens over an Einzel lens is that the energy of an in-coming beam is not necessarily the same as an out-going

beam. Beneficially the potential differences on such a two electrode lens array enables it to function as either an accelerating or a decelerating lens array. The objective lens array **241** can be configured to demagnify the charged particle beam by a factor greater than 10, desirably in the range of 50 to 100 or more. Each element in the objective lens array **240** may be a micro-lens operating a different sub-beam or group of sub-beams in the multi-beam.

(57) Preferably, each of the electrodes provided in the objective lens array **241** is a plate. The electrode may otherwise be described as a flat sheet. Preferably, each of the electrodes is planar. In other words, each of the electrodes will preferably be provided as a thin, flat plate, in the form of a plane. Of course, the electrodes are not required to be planar. For example, the electrode may bow due to the force due to the high electrostatic field. It is preferable to provide a planar electrode because this makes manufacturing of the electrodes easier as known fabrication methods can be used. Planar electrodes may also be preferable as they may provide more accurate alignment of apertures between different electrodes.

(58) FIG. 5 is an enlarged schematic view of multiple objective lenses of the objective lens array **241** and multiple control lenses of the control lens array **250**. As described in further detail below, the lens arrays can be provided by electrodes with a selected potential applied to the electrode by a voltage source, i.e. electrodes of the arrays are connected to respective potential sources. In FIG. 5, multiple lenses of each of the control lens array **250**, the objective lens array **241** and the detector array **240** are depicted, for example, with any of sub-beams **211**, **212**, **213** passing through the lenses as shown. Although FIG. 5 depicts five lenses, any appropriate number may be provided; for example, in the plane of the lenses, there may be 100, 1000 or of the order of 10,000 lenses.

Features that are the same as those described above are given the same reference numerals. For conciseness, the description of these features provided above applies to the features shown in FIG. 5. The charged particle optical device may comprise one, some or all of the components shown in FIG. 5. Note that this figure is schematic and may not be to scale. For example, in a non-limited list: the sub-beams may be narrower at the controller array **250** than at the objective lens array **241**; the detector array **240** may be closer to the electrodes of the objective lens array **241** than the electrodes of the objective lens array **241** are to each other; and a focus point of each sub-beam between the controller lens array **250** may be closer to the objective lens array **241** than depicted. Spacing between electrodes of the control lens array **250** may be larger than spacing between electrodes of the objective lens array **241** as shown in FIG. 5, but this is not a necessity.

(59) As shown in FIG. 5, the sub-beams may be parallel on entry into the control lens array **250**, as shown in FIG. 3. However, the same components of FIG. 5 may be used in a configuration as shown in FIG. 8, in which case, the sub-beams may be separated (or generated) from a beam from a source further down beam. For example, the sub-beams may be defined by a beam limiting aperture array which may be part of a lens arrangement such as an objective lens array, a control lens array, or any other lens element that may be associated with an objective lens array for example that is part of an objective lens array assembly. As depicted in FIG. 8, the sub-beams may be separated from the beam from the source by a beam limiting aperture array that may be part of the control lens array **250** as a most up beam electrode of the control lens array **250**.

(60) Voltage sources V3 and V2 (which may be provided by individual electric power sources, or may all be supplied by electric power source **290**) are configured to apply potentials to the upper and lower electrodes of the objective lens array **241** respectively. The upper and lower electrodes may be referred to as an up-beam electrode **242** and a down-beam electrode **243** respectively.

Voltage sources V5, V6, V7 (which may be provided by individual electric power sources, or may all be supplied by electric power source **290**) are configured to apply potentials to the first, second and third electrodes of the control lens array **250** respectively. A further voltage source V4 is connected to the sample to apply a sample potential. A further voltage source V8 is connected to the detector array to apply a detector array potential. Although the control lens array **250** is shown with three electrodes, the control lens array **250** may be provided with two electrodes (or more than

three electrodes). Although the objective lens array **240** is shown with two electrodes, the objective lens array **240** may be provided with three electrodes (or more than three electrodes). For example, a middle electrode may be provided in the objective lens array **241** between the electrodes shown in FIG. 5 with a corresponding voltage source, **V1** (not shown).

(61) Desirably, the potential **V5** of the uppermost electrode of the control lens array **250** is maintained the same as the potential of the next charged particle-optic element up-beam of the control lens (e.g. deflectors **235**). The potential **V7** applied to the lower electrode of the control lens array **250** can be varied to determine the beam energy. The potential **V6** applied to the middle electrode of the control lens array **250** can be varied to determine the lens strength of the control lens and hence control the opening angle and demagnification of the beam. It should be noted that even if the landing energy does not need to be changed, or is changed by other means, the control lens can be used to control the beam opening angle. The position of the focus of a sub-beam is determined by the combination of the actions of the respective control lens array **250** and the respective objective lens **240**.

(62) The detector array **240** (which may otherwise be referred to as an array of detectors) comprises a plurality of detectors. Each detector is associated with a corresponding sub-beam (which may otherwise be referred to as a beam or primary beam). In other words, the arrays of detectors (i.e. the detector array **240**) and sub-beams correspond. Each detector may be assigned to a sub-beam. The array of detectors may correspond with the array of objective lenses. In other words, the array of detectors may be associated with the corresponding array of objective lenses. A detector array **240** is described below. However, any reference to detector array **240** could be replaced with a single detector (i.e. at least one detector) or multiple detectors as appropriate. The detectors may otherwise be referred to as of detector elements **405** (e.g. sensor elements such as capture electrodes). The detectors may be any appropriate type of detector.

(63) The detector array **240** may be positioned at a position along the primary beam path at any location between an upper beam position and a lower beam position along the beam path. The upper beam position is above the objective lens array and optionally any associated lens arrays such as a control lens array (i.e. up beam of an objective lens array assembly). The lower beam position is down beam of the objective lens array. In an arrangement the detector array may be an array that is up beam of the objective lens array assembly. The detector array may be associated with any electrode of the objective lens array assembly. Reference hereafter of a detector in association with an electrode of the objective lens array may correspond to an electrode of the objective lens array assembly, except for the most down beam surface of the most down beam electrode of the objective lens array, unless stated explicitly otherwise.

(64) In an arrangement the detector array **240** may be positioned between the control lens array **250** and the sample **208**. The detector array **240** may be positioned between the objective lenses **234** and the sample **208**, as shown in FIG. 4 and FIG. 5. Although this may be preferable, the detector array **240** could be provided in additional or alternative locations, such as those depicted in FIG. 7. Multiple detector arrays may be provided in a variety of locations, e.g. as in FIG. 7. The signal particles, including backscatter signal particles may be detected directly from the surface of the sample **208**. Thus, the backscatter signal particles may be detected without having to be converted, for example, into another type of signal particle such a secondary signal particle which may be easier to detect. Thus, the backscatter signal particles may be detected by the detector array **240** without encountering, e.g. hitting, any other components or surfaces between the sample **208** and the detector array **241**.

(65) The detector array is positioned between the objective lens array **241** and the sample **208**. The detector array **240** is configured to be proximate the sample. The detector array **240** may be proximate the sample so as to detect backscatter signal particles from the sample **208**. The detector being proximate the sample enables the risk of cross-talk in detection of backscatter signal particles generated by sub-beams which correspond to another detector in the detector array to be reduced if

not avoided. In other words, the detector array **240** is very close to the sample **208**. The detector array **240** may be within a certain distance of the sample **208**, as described below. The detector array **240** may be adjacent to the sample **208**. The at least one detector may be positioned in the device so as to face the sample. That is the detector may provide a base to the device. The detector as part of the base may face a surface of the sample. This may be beneficial in positioning the at least one detector in a location in which the at least one detector is more likely to detect backscatter particles than secondary particles. For example, the at least one detector array may be provided on an output side of the objective lens array **241**. The output side of the objective lens array **241** is the side on which the sub-beams are output from the objective lens array **241**, i.e. the bottom or downbeam side of the objective lens array in the configuration shown in FIG. 3, FIG. 4 and FIG. 5. In other words, the detector array **240** may be provided downbeam of the objective lens array **241**. The detector array may be positioned on, or adjacent to, the objective lens array. The detector array **241** may be an integral component of the objective lens array **241**. The detector and objective lens may be part of the same structure. The detector may be connected to the lens by an isolating element or directly to an electrode of the objective lens. Thus, the at least one detector may be part of an objective lens assembly comprising at least the objective lens array and the detector array. If the detector array is an integral component of the objective lens array **241**, the detector array **240** may be provided at the base of the objective lens array **241**. In an arrangement the detector array **240** may be integral to the most-down-beam positioned electrode of the objective lens array **241**. (66) Ideally, the detector array is as close as possible to the sample. The detector array **240** is preferably very close to the sample **208** such that there is a proximity focus of backscatter signal particles at the detector array. As previously described, the energy and angular spread of the backscatter signal particles is generally so large that it is difficult (or impossible in known prior art systems) to keep the signals from neighboring sub-beams separated. However, the proximity focus means that backscatter signal particles can be detected at a relevant one of the detectors without cross-talk (i.e. interference from neighboring sub-beams) in the first aspect. Of course, there is a minimum distance between the sample **208** and the detector array **240**. However, it is preferable to reduce this distance as much as possible. Certain configurations may benefit from reducing the distance even more than others.

(67) Preferably, a distance 'L' as shown in FIG. 3, between the detector array **240** and the sample **208** is less than or equal to approximately 50 μm , i.e. the detector array **240** is positioned within approximately 50 μm from the sample **208**. Although it is generally preferable that the distance L is small (e.g. between around 10 to 65 microns), as this can improve detector efficiency and/or reduce crosstalk, the distance may be greater. For example, the distance L may be approximately 100 microns or less, or approximately 200 microns or less. The distance L is determined as the distance from a surface of the sample **208** facing the detector array **240** and a surface of the detector array **241** facing the sample **208**. Providing a distance of approximately 50 μm or less is beneficial in that cross-talk between backscatter signal particles can be avoided or minimized. Theoretically, there may be a lower limit of how close the sample **208** and the detector array **240** can be whilst allowing these components to move relative to each other and this may mean that the distance L might be more than approximately 5 μm or 10 μm . For example, a distance L of approximately 50 μm or less may be used whilst still allowing relatively reliable control of the device as shown as part of the tool in FIG. 3. A distance L of approximately 30 μm or less may be preferable for other configurations, such as those shown and described in relation to FIG. 8 below. A preferred range of the distance L between the detector array **240** and the sample **208** may be between approximately 5 μm to 200 μm , or preferably between approximately 5 μm to 100 μm , or preferably between approximately 5 μm to 50 μm , or preferably between approximately 10 μm to 50 μm , or preferably between approximately 30 μm to 50 μm . In an arrangement the detector array **240** may be actuatable relative to the objective lens array **241**, i.e. to vary the distance L, for example to substantially maintain a distance between the sample and the detector array L. It is noted that the

distance L described here is for a multi-beam system as shown in FIG. 3 (or FIG. 8). The same distance may be used in a single beam device, e.g. as shown in FIG. 9, although the distance L may be larger for the single beam device.

(68) The backscatter signal particles are emitted from the sample **208** with a very large energy spread, and typically with an angular spread following a cosine distribution which may take the appearance in three dimensions of a cone. The further the distance from sample **208** to the detector array **240**, the larger the cone of the emitted beam becomes. It will be understood that the backscatter signal particles can have all angles. The cone of the emitted beam is the solid angle assignable to the detector associated with a respective beam, so that this solid angle is larger with greater proximity of the sample and the detector. Because of the very large energy spread it may not be possible to image the backscatter signal particles coming from the different sub-beams onto a detector without introducing significant cross talk. The solution is to place the detector in close proximity to the substrate and choose the pitch of the sub-beams such that the backscatter signal particle signals of the neighbouring sub-beams do not overlay.

(69) Thus, the pitch size, P, as discussed above may be selected depending on the distance between the detector array **240** and the sample **208** (or vice versa). For example only, for a distance L between the sample **208** and the detector array **240** of approximately 50 microns, the sub-beam pitch p may be equal to or larger than approximately 300 microns. Such a combination may be particularly useful for detecting high energy signal particles, e.g. backscatter signal particles, with an accelerating lens. For example only, for a distance L between the sample **208** and the detector array **240** of approximately 10 microns, the sub-beam pitch p may be equal to or larger than approximately 60 microns. Providing a closer detector array allows use of a smaller sub-beam pitch p. This may be beneficial in using certain configurations in which the sub-beam pitch is beneficially smaller, such as the configuration described in relation to, and shown in, FIG. 8 below. In a different example arrangement the distance between the sample **208** and the detector array **240** is approximately 50 microns and the sub-beam pitch p is approximately 60 microns. Such a different set up is intended for different operational settings and to detect a different type of signal particle. For example, such a combination may be particularly useful for detecting low energy signal particles, e.g. secondary signal particles, with a decelerating lens. For simultaneous detection of high energy particles (e.g. backscatter signal particles) and low energy particles (e.g. secondary signal particles), the pitch p and distance L may be selected between the values described above so that the high energy particle and low energy particle signals are sufficiently large. It will be noted that there is no relation or limitation for the distance L and the pitch p for the functioning of the detector. However, due to a risk of crosstalk in neighboring detectors it might be preferable to use a larger pitch p for a larger distance L. Although, there may also be other ways to reduce the risk of crosstalk and any appropriate combination of pitch p and distance L may be used.

(70) The detector array **240** (and optionally the objective lens array **241**) may be configured to repel secondary signal particles emitted from the sample **208**. This is beneficial as it reduces the number of secondary signal particles emitted from the sample **208** which travel back towards the detector array **240**. The difference in potential between the detector array **240** and the sample **208** can be selected to repel signal particles emitted from the sample **208** away from the detector array **240**. Preferably, the detector array potential may be the same as the potential of the downbeam electrode of the objective lens array. The potential difference between the sample potential and the detector array potential is preferably relatively small so that primary sub-beams are projected through or past the detector array **240** to the sample **208** without being significantly affected. Additionally, a small potential difference will have a negligible effect on the path of a backscatter signal particle (which generally has a greater energy up to the landing energy), meaning that the backscatter signal particles can still be detected whilst reducing or avoiding detection of secondary signal particles. The potential difference between the sample potential and the detector array potential is preferably greater than a secondary signal particle threshold. The secondary signal

particle threshold may determine the minimum initial energy of secondary signal particles that can still reach the detector. Preferably, the secondary signal particle threshold is the potential difference equivalent to the likely energy of a secondary signal particle emanating from the sample **208**. That is the relatively small potential difference between the sample and detector array potentials is sufficient to repel the secondary signal particles from the detector array. For example, the potential difference between the sample potential and the detector array potential may be approximately 20 V, 50 V, 100 V, 150 V, 200 V, 250 V, or 300V.

(71) The objective lens array **241** may be configured to accelerate the primary charged particles (i.e. the sub-beams) towards the sample **208** along the sub-beam paths **220**. Accelerating the sub-beams **211**, **212**, **213** projected onto the sample **208** is beneficial in that it can be used to generate an array of sub-beams with high landing energy. The potentials of the electrodes of the objective lens array can be selected to provide acceleration through the objective lens array **241**. It is noted that an accelerating lens in the arrangement may be particularly useful for detecting ranges (e.g. different energy ranges) of backscatter signal particles. Alternatively, the objective lens array may be configured to decelerate the primary charged particles towards the sample **208** along the sub-beam paths **220**. It is noted that a decelerating lens in the arrangement may be particularly useful for detecting both secondary and backscatter signal particles. The figures described below, and particularly FIGS. **3**, **5** and **8**, show the objective lens in the accelerating mode. However, as will be understood from the description above, the objective lens may be used in the decelerating mode instead for any of the embodiments and variations described below. In other words, FIGS. **3**, **5** and **8** could be adapted to decelerate the sub-beams through the objective lenses.

(72) In an arrangement of accelerating objective lens array **241**, the low energy particles (e.g. secondary signal particles) generally cannot pass up-beam of the lower part of the accelerating objective lens. It is also increasing difficult for high energy particles (e.g. backscatter signal particles) to pass the accelerating objective lens. This is a key point for both accelerating and decelerating objective lenses. The energy difference between the low energy signal particles (e.g. secondary signal particles) and high energy signal particles (e.g. backscatter signal particles) is proportionately larger down-beam of the objective lens (in both accelerating and decelerating mode) than at any point up-beam of the objective lens. This is beneficial for detection using the detectors described below to distinguish between the different types of signal particles.

(73) The potentials and the values of the potentials defined herein are defined with respect to the source; hence the potential of a charged particle at the surface of the sample may be referred to as a landing energy because the energy of a charged particle correlates to the potential of the charged particle and the potential of the charged particle at the sample is defined with respect to the source. However, as the potentials are relative values, the potentials could be defined relative to other components, such as the sample. In this instance, the difference in potential applied to different components would preferably be as discussed below with respect to the source. The potentials are applied to the relevant components, such as the electrodes and the samples during use, i.e. when the device is being operated.

(74) For example, the device being configured to accelerate the charged particle sub-beams and repel the secondary signal particles as described above may have potentials as shown in the context of FIG. **5** with the values in Table 1 below. As mentioned above, the objective lens array as shown in FIG. **5** may comprise an additional electrode, e.g. a middle electrode. Such a middle electrode is optional and need not be included with the electrodes having the other potentials listed in Table 1. The middle electrode of the objective lens array may have the same potential (e.g. V1) as the upper electrode of the objective lens array (i.e. V3).

(75) Exemplary ranges are shown in the left hand column of Table 1 as described above. The middle and right hand columns show more specific example values for each of V1 to V8 within the example ranges. The middle column may be provided for a smaller resolution than the right hand column. If the resolution is larger (as in the right hand column), the current per sub-beam is larger

and therefore, the number of sub-beams may be lower. The advantage of using a larger resolution is that the time needed to scan a “continuous area” is shorter (which can be a practical constraint). So the overall throughput may be lower, but the time needed to scan the beam area is shorter (because the beam area is smaller).

(76) TABLE-US-00001 TABLE 1 Landing Energy >10-100 keV 30 keV 30 keV V1 (or omitted) 1-10 keV 5 keV 5 keV V2 >10-100 keV 29.95 keV 29.95 keV V3 1-10 keV 5 keV 5 keV V4 >10-100 keV 30 keV 30 keV V5 >10-100 keV 30 keV 30 keV V6 1-30 keV 4.4 keV 10 keV V7 1-10 keV 5 keV 5 keV V8 >10-100 keV 29.95 keV 29.95 keV

(77) For example, the device being configured to decelerate the charged particle sub-beams and repel the secondary signal particles as described above may have potentials as shown in the context of FIG. 5 with the values in Table 2 below. The values of the potentials provided for the accelerating lens might be swapped and adjusted to provide a deceleration. For example only, the charged particles may be decelerated from 30 kV to 2.5 kV in the objective lens. In an example, to obtain landing energies in the range of 1.5 kV to 5 kV, potentials shown in FIG. 5, such as V2, V3, V4, V5, V6 and V7, can be set as indicated in Table 2 below. V1 is optionally included if a middle objective lens electrode is included. The potentials and landing energies shown in Table 2 are examples only and other landing energies could be obtained, for example, the landing energy could be lower than 1.5 kV (e.g. approximately 0.3 kV or 0.5 kV) or higher than 5 kV. It will be seen that the beam energy at V1, V3 and V7 is the same. In embodiments the beam energy at these points may be between 10 keV and 50 keV. If a lower potential is selected, the electrode spacings may be reduced, especially in the objective lens, to limit reduction of the electric fields. The potentials in this table are given as values of beam energy in keV, which is equivalent to the electrode potential relative to the cathode of the beam source 201. It will be understood that in designing a charged particle-optical system there is considerable design freedom as to which point in the system is set to a ground potential and the operation of the system is determined by potential differences rather than absolute potentials.

(78) TABLE-US-00002 TABLE 2 Landing Energy 1.5 keV 2.5 keV 3.5 keV 5 keV V1 (or omitted) 29 keV 30 keV 31 keV 30 keV V2 1.55 keV 2.55 keV 3.55 keV 5.05 keV V3 29 keV 30 keV 31 keV 30 keV V4 1.5 keV 2.5 keV 3.5 keV 5 keV V5 30 keV 30 keV 30 keV 30 keV V6 19.3 keV 20.1 keV 20.9 keV 30 keV V7 29 keV 30 keV 31 keV 30 keV V8 1.55 keV 2.55 keV 3.55 keV 5.05 keV

(79) In order to maximize the detection efficiency it is desirable to make the surface of the detector elements 405 as large as possible, so that substantially all the area of the objective lens array 240 (excepting the apertures) is occupied by detector elements 405. Additionally or alternatively, each detector element 405 has a diameter substantially equal to the array pitch (i.e. the aperture array pitch described above in relation to the electrodes of the objective lens assembly 241). In an embodiment the outer shape of the detector element 405 is a circle, but this can be made a square or a hexagon to maximize the detection area.

(80) However a larger surface for the detector elements 405 leads to a larger parasitic capacitance, so a lower bandwidth. For this reason it may be desirable to limit the outer diameter of the detector elements 405. Especially in case a larger detector element 405 gives only a slightly larger detection efficiency, but a significantly larger capacitance. A circular (annular) detector element 405 may provide a good compromise between collection efficiency and parasitic capacitance. A larger outer diameter of the detector element 405 may also lead to a larger crosstalk (sensitivity to the signal of a neighboring hole). This can also be a reason to make the outer diameter of the detector element 405 smaller. Especially in case a larger detector element 405 gives only a slightly larger detection efficiency, but a significantly larger crosstalk.

(81) In an embodiment, the objective lens array 241 is an exchangeable module, either on its own or in combination with other elements such as the control lens array and/or detector array. The

exchangeable module may be field replaceable, i.e. the module can be swapped for a new module by a field engineer. In an embodiment, multiple exchangeable modules are contained within the tool and can be swapped between operable and non-operable positions without opening the tool.

(82) In some embodiments, one or more aberration correctors are provided that reduce one or more aberrations in the sub-beams. The one or more aberration correctors may be provided in any of the embodiments, e.g. as part of the charged particle-optical device, and/or as part of an optical lens array assembly, and/or as part of an assessment tool. In an embodiment, each of at least a subset of the aberration correctors is positioned in, or directly adjacent to, a respective one of the intermediate foci (e.g. in or adjacent to the intermediate image plane). The sub-beams have a smallest cross-sectional area in or near a focal plane such as the intermediate plane. This provides more space for aberration correctors than is available elsewhere, i.e. up beam or down beam of the intermediate plane (or than would be available in alternative arrangements that do not have an intermediate image plane).

(83) In an embodiment, aberration correctors positioned in, or directly adjacent to, the intermediate foci (or intermediate image plane) comprise deflectors to correct for the source **201** appearing to be at different positions for different sub-beams. Correctors can be used to correct macroscopic aberrations resulting from the source that prevent a good alignment between each sub-beam and a corresponding objective lens.

(84) The aberration correctors may correct aberrations that prevent a proper column alignment. Such aberrations may also lead to a misalignment between the sub-beams and the correctors. For this reason, it may be desirable to additionally or alternatively position aberration correctors at or near the condenser lenses **231** (e.g. with each such aberration corrector being integrated with, or directly adjacent to, one or more of the condenser lenses **231**). This is desirable because at or near the condenser lenses **231** aberrations will not yet have led to a shift of corresponding sub-beams because the condenser lenses are vertically close or coincident with the beam apertures. A challenge with positioning correctors at or near the condenser lenses, however, is that the sub-beams each have relatively large sectional areas and relatively small pitch at this location, relative to locations further downstream (or down-beam). The condenser lenses and correctors may be part of the same structure. For example they may be connected to each other, for example with an electrically isolating element. The aberration correctors may be CMOS based individual programmable deflectors as disclosed in European patent application publication no. EP2702595 or an array of multipole deflectors as disclosed in European patent application publication no. EP2715768, which are both incorporated herein in their entireties by reference and with respect to at least the descriptions of the sub-beam manipulators in both documents.

(85) In some embodiments, each of at least a subset of the aberration correctors is integrated with, or directly adjacent to, one or more of the objective lenses **234**. In an embodiment, these aberration correctors reduce one or more of the following: field curvature; focus error; and astigmatism. The objective lenses and/or control lenses and correctors may be part of the same structure. For example they may be connected to each other, for example with an electrically isolating element. Additionally or alternatively, one or more scanning deflectors (not shown) may be integrated with, or directly adjacent to, one or more of the objective lenses **234** for scanning the sub-beams **211**, **212**, **213** over the sample **208**. In an embodiment, the scanning deflectors described in United States patent application publication no. US 2010/0276606, which is incorporated herein in its entirety by reference, may be used.

(86) In an embodiment, a single detector element **405** surrounds each beam aperture **406**. In another embodiment, a plurality of detector elements **405** are provided around each beam aperture **406**. Thus, the detector comprises multiple portions, and more specifically, multiple detecting portions. The different portions may be referred to as different zones. Thus the detector may be described to have multiple zones or detection zones. Such a detector may be referred to as a zoned detector. The signal particles captured by the detector elements **405** surrounding one beam aperture

406 may be combined into a single signal or used to generate independent signals. The detector comprising multiple portions may be provided in any of the detector arrays described herein.

(87) The zoned detector may be associated with one of the sub-beams **211**, **212**, **213**. Thus, the multiple portions of one detector may be configured to detect signal particles emitted from the sample **208** in relation to one of the sub-beams **211**, **212**, **213**. The detector comprising multiple portions may be associated with one of the apertures in at least one of the electrodes of the objective lens assembly. More specifically, the detector **405** comprising multiple portions may be arranged around a single aperture **406** as shown in FIG. **6A** and FIG. **6B**, which provide examples of such a detector.

(88) The portions of the zoned detector may be separated in a variety of different ways, e.g. radially, annular, or any other appropriate way. Preferably the portions are of similar angular size and/or similar area and/or similar shape, for example as shown in FIG. **6B**. The separated portions may be provided as a plurality of segments, a plurality of annular portions (e.g. a plurality of concentric annuli or rings), and/or a plurality of sector portions (i.e. radial portions or sectors). The detector elements **405** may be divided radially. For example, the at least one detector **405** may be provided as annular portions comprising 2, 3, 4, or more portions. More specifically, as shown in FIG. **6A**, the detector **405** may comprise an inner annular portion **405A** surrounding aperture **406** and an outer annular portion **405B**, radially outwards of the inner annular portion **405A**.

Alternatively, the detector elements **405** may be divided angularly. For example, the detector may be provided as sector portions comprising 2, 3, 4, or more portions, for example 8, 12 etc. If the detector is provided as two sectors, each sector portion may be a semi-circle. If the detector is provided as four sectors, each sector portion may be a quadrant. This is shown in FIG. **6B** in which the **405** is divided into quadrants, i.e. four sector portions is shown in FIG. **6B**, as described below. Alternatively, the detector may be provided with at least one segment portion. The electrode elements may be separated both radially and angularly or in any other convenient manner.

(89) Each portion may have a separate signal read-out. The detector being separated into portions, e.g. annular portions or sector portions, is beneficial in that it allows more information to be obtained in relation to the signal particles detected. Thus, providing the detector **405** with multiple portions may be beneficial in obtaining additional information relating to the detected signal particles. This can be used to improve the signal to noise ratio of the detected signal particles. However, there is an additional cost in terms of the complexity of the detector.

(90) As shown in FIG. **6A**, the detector, in which an aperture **406** is defined and configured for the through passage of a charged particle beam, comprises inner detecting portion **405A** and outer detecting portion **405B**. The inner detecting portion **405A** surrounds the aperture **406** of the detector. The outer detecting portion **405B** is radially outwards of the inner detecting portion **405A**. The shape of the detector may be generally circular. Thus, the inner detecting portion and the outer detecting portion may be concentric rings. In an example, the detector may be divided into two (or more) concentric rings, for example, as depicted in FIG. **6A**.

(91) Providing multiple portions concentrically or otherwise may be beneficial because different portions of the detector may be used to detect different signal particles, which may be smaller angle signal particles and/or larger angle signal particles, or secondary signal particles and/or backscatter signal particles. Such a configuration of different signal particles may suit a concentrically zoned detector. The different angled backscatter signal particles may be beneficial in providing different information. For example, for signal particles emitted from a deep hole, small-angle backscatter signal particles are likely to come more from the hole bottom, and large-angle backscatter signal particles are likely to come more from the surface and material around the hole. In an alternative example, small-angle backscatter signal particles are likely to come more from deeper buried features, and large-angle backscatter signal particles are likely to come more from the sample surface or material above buried features.

(92) FIG. **8** is a schematic diagram of an exemplary charged particle-optical system, for example an

assessment tool, having the charged particle device as in any of the above described options or aspects. The charged particle device is configured to project a beam of charged particles onto a sample. The charged particle optical device having at least the objective lens array **241** as described in any of the aspects or embodiments above may be used in the charged particle-optical system as shown in FIG. **8**. For conciseness, features of the objective lens array **241** that have already been described above may not be repeated here.

(93) There are some considerations specific to the setup of FIG. **8**. In the present embodiment, it is preferable to keep the pitch small so as to avoid negatively impacting throughput. However, when the pitch is too small, this can lead to cross-talk. Therefore, the pitch size is a balance of effective detection of a selected signal particle such as a backscatter signal particle and throughput. Thus, the pitch is preferably approximately 300 μm in such an arrangement for detection of backscatter signal particles, which is 4-5 times larger than it might otherwise be for the embodiment of FIG. **8** when detecting secondary signal particles. When the distance between the detector and the sample **208** is reduced, the pitch size can also be reduced without negatively affecting the cross-talk. Therefore, providing the detector as close as possible to the sample (i.e. with distance L as small as possible, and preferably less than or equal to approximately 50 μm , or less than or equal to approximately 40 μm , or less than or equal to approximately 30 μm , or less than or equal to approximately 20 μm , or equal to approximately 10 μm), is beneficial in allowing the pitch to be as large as possible which improves throughput.

(94) As shown in FIG. **8**, the charged particle-optical system comprises a source **201**. The source **201** provides a beam of charged particles (e.g. electrons). The multi-beam focused on the sample **208** is derived from the beam provided by the source **201**. Sub-beams **211**, **212**, **213** may be derived from the beam, for example, using a beam limiter (which may otherwise be referred to as a beam limiting aperture array) defining an array of beam-limiting apertures. The beam may separate into the sub-beams **211**, **212**, **213** on meeting the control lens array **250**. The sub-beams **211**, **212**, **213** are substantially parallel on entry to the control lens array **250**. (In an arrangement, the control lens array **250** comprises the beam limiter.) The source **201** is desirably a high brightness thermal field emitter with a good compromise between brightness and total emission current. In the example shown, a collimator is provided up-beam of the objective lens array assembly. The collimator may comprise a macro collimator **270**. The macro collimator **270** acts on the beam from the source **201** before the beam has been split into a multi-beam. The macro collimator **270** collimates the beam from the source such that beam cross-section is substantially consistent on incidence with the beam limiter. The macro collimator **270** bends respective portions of the beam from which the sub-beams are derived by an amount effective to ensure that a beam axis of each of the sub-beams is incident on the sample **208** substantially normally (i.e. at substantially 90° to the nominal surface of the sample **208**). The macro collimator **270** applies a macroscopic collimation to the beam. The macro collimator **270** may thus act on all of the beam rather than comprising an array of collimator elements that are each configured to act on a different individual portion of the beam. The macro collimator **270** may comprise a magnetic lens or magnetic lens arrangement comprising a plurality of magnetic lens sub-units (e.g. a plurality of electromagnets forming a multi-pole arrangement). Alternatively or additionally, the macro-collimator may be at least partially implemented electrostatically. The macro-collimator may comprise an electrostatic lens or electrostatic lens arrangement comprising a plurality of electrostatic lens sub-units. The macro collimator **270** may use a combination of magnetic and electrostatic lenses.

(95) In another arrangement (not shown), the macro-collimator may be partially or wholly replaced by a collimator element array provided down-beam of the upper beam limiter. Each collimator element collimates a respective sub-beam. The collimator element array may be formed using MEMS manufacturing techniques so as to be spatially compact. The collimator element array may be the first deflecting or focusing charged particle-optical array element in the beam path down-beam of the source **201**. The collimator element array may be up beam of the control lens array

250. The collimator element array may be in the same module as the control lens array **250**.

(96) In the embodiment of FIG. **8** a macro scan deflector **265** is provided to cause sub-beams to be scanned over the sample **208**. The macro scan deflector **265** deflects respective portions of the beam to cause the sub-beams to be scanned over the sample **208**. In an embodiment, the macro scan deflector **265** comprises a macroscopic multi-pole deflector, for example with eight poles or more. The deflection is such as to cause sub-beams derived from the beam to be scanned across the sample **208** in one direction (e.g. parallel to a single axis, such as an X axis) or in two directions (e.g. relative to two non-parallel axes, such as X and Y axes). The macro scan deflector **265** acts macroscopically on all of the beam rather than comprising an array of deflector elements that are each configured to act on a different individual portion of the beam. In the embodiment shown, the macro scan deflector **265** is provided between the macro collimator **270** and the control lens array **250**.

(97) In another arrangement (not shown), the macro scan deflector **265** may be partially or wholly replaced by a scan deflector array. The scan-deflector array **260** comprises a plurality of scan deflectors. The scan-deflector array **260** may be formed using MEMS manufacturing techniques. Each scan deflector scans a respective sub-beam over the sample **208**. The scan-deflector array **260** may thus comprise a scan deflector for each sub-beam. Each scan deflector may deflect the sub-beam in one direction (e.g. parallel to a single axis, such as an X axis) or in two directions (e.g. relative to two non-parallel axes, such as X and Y axes). The deflection is such as to cause the sub-beam to be scanned across the sample **208** in the one or two directions (i.e. one dimensionally or two dimensionally). The scan deflector array may be up beam of an objective lens array **241**. The scan deflector array may be down beam of a control lens array **250**. Although reference is made to a single sub-beam associated with a scan deflector, groups of sub-beams may be associated with a scan deflector. In an embodiment, the scanning deflectors described in European patent application publication no. EP2425444, which is incorporated herein in its entirety by reference and at least specifically in relation to scan deflectors, may be used to implement the scan-deflector array. A scan-deflector array (e.g. formed using MEMS manufacturing techniques as mentioned above) may be more spatially compact than a macro scan deflector. The scan deflector array may be in the same module as the objective lens array **241**.

(98) In other embodiments both a macro scan deflector **265** and the scan-deflector array are provided. In such an arrangement, the scanning of the sub-beams over the sample surface may be achieved by controlling the macro scan deflector and the scan-deflector array **260** together, preferably in synchronization.

(99) Embodiments of the invention can be applied to various different tool architectures. For example, the charged particle beam tool **40** may be a single beam tool, or may comprise a plurality of single beam columns or may comprise a plurality of columns of multi-beams (i.e. sub-beams). The columns may comprise the charged particle optical device described in any of the above embodiments or aspects. As a plurality of columns (or a multi-column tool), the devices may be arranged in an array which may number two to one hundred columns or more. The charged particle device may take the form of an embodiment as described with respect to and depicted in FIG. **3** or as described with respect to and depicted in FIG. **8**, although preferably having an electrostatic scan deflector array and/or an electrostatic collimator array for example in the objective lens array assembly. The charged particle optical device may be a charged particle optical column. A charged particle column may optionally comprise a source.

(100) As described above, the array of detectors **240** may be provided between the objective lens array **241** and the sample **208**, as shown in FIG. **4** and FIG. **5**. The array of detectors **240** may be associated with at least one electrode of the objective lens array, preferably, the lower electrode **243**. Preferably, the down-beam array of detectors **240** faces the sample **208** in use, i.e. when the sample is present.

(101) Additional or alternative detector arrays may be provided which may be positioned in other

places. This is depicted in FIG. 7. One, some or all of the detector arrays as shown in FIG. 7 might be provided. If multiple detector arrays are provided, they may be configured to detect signal particles simultaneously. The detector array **240** positioned between the objective lens array **241** and the sample **208** is shown as a zoned detector as described in relation to FIGS. 6A and 6B. However, any appropriate type of detector may be used for this array.

(102) The charged particle-optical device may comprise an array of detectors, referred to herein as an array of mirror detectors **350**. The array of mirror detectors **350** is arranged along the primary beam paths **320** (e.g. at a common position along the primary beam path). The array of mirror detectors **350** is configured to face up-beam of the primary beam paths **320**. In other words, the array of mirror detectors **350** is configured to face along the primary beam path **320** towards a source of the primary beam (described above as source **201**). The array of mirror detectors **350** is configured to face away from the sample **208**. The array of mirror detectors **350** may otherwise be referred to as an upwards array of detectors. Preferably, the array of mirror detectors **350** is associated with the lower electrode **243**, and preferably an up-beam surface of the electrode. This may be beneficial as the signal particles may be more likely to be detected if the array of mirror detectors **350** are provided relatively close to the sample **208**, e.g. just above or on the lower electrode **343**. When the array of mirror detectors **350** is positioned within the objective lens array **241** (i.e. between electrodes of the objective lens array **241**) it may be referred to as an in-lens detector. In an arrangement of an objective lens array assembly with multiple lensing electrodes, other electrodes may feature a mirror electrode, so long as another electrode is located up beam of the mirror electrode to mirror the signal particles towards the mirror electrode.

(103) The charged particle-optical device may comprise at least one up-beam array of detectors facing towards the sample, i.e. in the direction of the sample **208**. In other words, the up-beam array of detectors may be facing in a direction along the primary beam path **320** towards the sample **208**. The charged particle-optical device may comprise upper array of detectors **370**. The upper array of detectors **370** may be associated with the down-beam surface of the upper electrode **242** of the objective lens array **241**. More generally, the upper array of detectors **370** could be associated with a down-beam surface of any appropriate electrode if more electrodes are provided in the objective lens array. The upper array of detectors **370** may be positioned between the upper electrode **342** and the lower electrode **343**, or between any other electrodes above the lowest electrode of the objective lens array. As described above, the upper array of detectors **370** is provided up-beam (in relation to the primary sub-beams **211** and **212**) of at least one electrode, which is the lower electrode **243** in relation to FIG. 7. Additionally or alternatively, the charged particle-optical device may comprise an above-lens array of detectors **380**. In other words, the up-beam array of detectors may be above the objective lens array **241**. The above-lens array of detectors **380** may be up-beam of all the electrodes forming the objective lens array **241**. The above-lens array of detectors **380** may be spaced apart from the electrode **242** so that the above-lens detector array **380** is a plate or substrate with its own mechanical support separate from the objective lens array.

(104) Any of the detector arrays may be associated with (e.g. in, on, positioned adjacent to, connected to, or integrated with) at least one electrode of the objective lens array **241** (e.g. either the upper electrode **242** or the lower electrode **243**). For example, the array of detectors may be in or on at least one electrode of the objective lens array **241**. For example, the array of detectors may be positioned adjacent to one of the electrodes. In other words, the array of detectors may be positioned in close proximity and next to one of the electrodes. For example, the array of detectors may be connected (e.g. mechanically connected) to one of the electrodes. In other words, the array of detectors may be attached to one of the electrodes, e.g. by adhesive or welding or some other attachment method. For example, the array of detectors may be integrated with the one of the electrodes. In other words, the array of mirror detectors may be formed as part of one of the electrodes.

(105) Combinations of the detector arrays may be provided. For example, the down-beam array of detectors **240** and/or the array of mirror detectors **350** and/or the upper array of detectors **370** and/or the above-lens array of detectors **380** may be provided. The device may comprise an additional array of detectors which may be provided with any combination of the down-beam array of detectors **240** and/or the array of mirror detectors **350** and/or the upper array of detectors **370** and/or the above-lens array of detectors **380**. As will be clear from the above described combinations of arrays, there could be any appropriate number of detector arrays. For example, there could be two, or three, or four, or five, or more arrays of detectors which are positioned at any appropriate place, for example, as described above in relation to the up-beam array of detectors and/or the down-beam array of detectors. Whichever detector arrays are provided may be used simultaneously. A potential of any of the detector arrays (e.g. the array of mirror detectors **350** and/or the upper array of detectors **370** and/or the above-lens array of detectors **380** and/or the down-beam array of detectors **360** and/or any additional array of detectors) relative to a potential of the sample **208** may be selected to control detection of the signal particles at least that detector array. The array of sub-beams (otherwise referred to as an array of primary beams) may correspond with any/all detector arrays provided. Thus, the array of sub-beams may correspond with the array of mirror detectors **240**, and/or the down-beam array of detectors **360**, and/or the upper array of detectors **370** and/or above-lens array of detectors **380**. Thus, any/all of the detector arrays may be aligned with the sub-beams.

(106) FIG. **9** is a schematic diagram of an exemplary single beam charged particle beam tool **40** according to an embodiment. As shown in FIG. **9**, in an embodiment the charged particle beam tool **40** comprises a sample holder **207** supported by a motorized stage **209** to hold a sample **208** to be inspected. The charged particle beam tool **40** comprises a charged particle source **201**. The charged particle beam tool **40** further comprises a gun aperture **122**, a beam limit aperture **125** (or beam limiter), a condenser lens **126**, a column aperture **135**, an objective lens assembly **132**, and a charged particle detector **144** (which may otherwise be referred to as an electron detector). The objective lens assembly **132**, in some embodiments, may be a modified swing objective retarding immersion lens (SORIL), which includes a pole piece **132a**, a control electrode **132b**, a deflector **132c**, and an exciting coil **132d**. The control electrode **132b** has an aperture formed in it for the passage of the charged particle beam. The control electrode **132b** forms the surface facing the sample **208**. Although the charged particle beam tool **40** shown in FIG. **9** is a single beam system, in an embodiment a multi-beam system is provided. Such a multi-beam system may have the same features as shown in FIG. **9**, such as the objective lens assembly **132**. Such a multi-beam system may have in addition beam limiter array, for example down-beam of the condenser lens, for generating the sub-beams. Associated with the beam limiter array, such as down beam of the beam limiter array, may be a number of charged particle array elements such a deflector array and a lens array for optimizing and adjusting the sub-beams and reducing aberrations of the sub-beams. Such a multi-beam system may have a secondary column for detecting signal charged particles. A Wien filter may be up-beam of the objective lens assembly to direct the signal particles towards a detector in the secondary column.

(107) In an imaging process, a charged particle beam emanating from the source **201** may pass through the gun aperture **122**, the beam limit aperture **125**, the condenser lens **126**, and be focused into a probe spot by the modified SORIL lens and then impinge onto the surface of sample **208**. The probe spot may be scanned across the surface of the sample **208** by the deflector **132c** or other deflectors in the SORIL lens. Signal particles emanated from the sample surface may be collected by the charged particle detector **144** to form an image of an area of interest on the sample **208**.

(108) The condenser and illumination optics of the charged particle beam tool **40** may comprise or be supplemented by electromagnetic quadrupole charged particle lenses. For example, as shown in FIG. **9** the charged particle beam tool **40** may comprise a first quadrupole lens **148** and a second quadrupole lens **158**. In an embodiment, the quadrupole lenses are used for controlling the charged

particle beam. For example, first quadrupole lens **148** can be controlled to adjust the beam current and second quadrupole lens **158** can be controlled to adjust the beam spot size and beam shape. (109) As described above, a zoned detector may have a plurality of detector portions (e.g. sensor elements) as part of a detector element **405** as described above in relation to FIGS. **6A** and **6B**. The plurality of detector portions for each detector element (or sensor unit) is provided around an aperture. The plurality of detector portions may, together, have a circular perimeter and/or a diameter. The plurality of detector portions may, together, have an area extending between the aperture and the perimeter of the plurality of detector portions. The pluralities of detector elements may be arranged in rectangular array or a hexagonal array. The signal generated from signal particles captured by detector portions surrounding one aperture may be combined into a single signal or used to generate independent signals. The surfaces of the detector elements, optionally their detector portions, may substantially fill the surface of the substrate supporting the detector elements.

(110) As shown in FIG. **10A** a surface of a detector array or detector module facing, even proximate in use to, a sample features an array of detector elements (or an array of detectors). Each detector element is associated with an aperture. Each detector element is associated with an assigned surface area of the substrate of the detector module. As the substrate is layered, for example in having a CMOS structure, each layer within the substrate is positioned with respect to the respective detector elements, preferably proximately. Commercially available CMOS structures have a usual range of layers, for example three to ten, usually about five. (For example, two functional layers may be provided for ease of description. These two layers of wiring layer and logic layer may represent as many layers as required and each layer is not restricted to wiring or logic, respectively.) The number of layers is limited by commercial availability and any number of layers is feasible. However, in view of practicality, the substrate has a limited number of layers, in order for an efficient design the available space is limited.

(111) Ideally a circuit layer of the substrate, which can be the wiring layer and/or logic layer, has a portion assigned for each detector element (or detector). The assigned portions of the different layers may be referred to as a cell **550**. The arrangement of portions in the substrate for the full multi-beam arrangement may be referred to as a cell array **552**. The cells **550** may be same shape as the surface area assigned for each detector element, such as hexagonal, or any reasonable shape that may tessellate and may all be similar in shape and/or area, such as a rectangular shape. Having a rectangular or rectilinear shape can more readily be used by placing and routing design. Such design is commonly implemented by software that is suited to define chips with a rectangular type architecture with orthogonal directions, than architecture requiring acute or obtuse angles such as in a hexagonal architecture. In FIG. **10A** the cells **550** are depicted as being hexagonal and the cell array **552** is depicted as a hexagon comprising individual cells. However, ideally each similarly located with respect to detector elements. Wiring routes **554** may connect to each cell **550**. The wiring routes **554** may be routed between other cells of the cell array **552**. Note: reference to wiring routes to be between cells of the array, it is intended that at least the wiring routes avoid the beam apertures of the array of apertures, e.g. defined through the cell array. In an arrangement circuit architecture, the cell size in at least the circuit layer may be reduced to accommodate the wiring routes, so that the wiring routes are routed between cells. Additionally or alternatively the wiring routes pass through the cells of the cell array, preferably towards the perimeter of the cells for example to reduce the interference of the wiring routes with other circuitry in the cells. Therefore reference to a wiring route between the cells encompasses: a wiring route between the circuitry of cells, a wiring route within cells, preferably towards the periphery of the cells and at least around the beam apertures through the cells and any intermediate variation. In all these arrangements, for example in a CMOS architecture, the wiring routes may be in the same die as the other circuitry which may define circuitry in the same cell as a portion of the wiring route, or circuitry in a cell around which the wiring route is routed. Thus, the cells and wiring routes may parts of a monolithic

structure. The wiring routes **554** may signally connect the cells. Thus the wiring routes signally connect the cells **550** to a controller or data processor external to the cell array or even the substrate or detector module. The circuit layer may comprise a datapath layer for the transmission of sensor signals from a cell outward of the cell array.

(112) The controller or data processor may be before circuitry within the substrate or detector module, preferably external to the cell array for example as control and I/O circuitry (not shown). The control and I/O circuitry may be in the same die as the cell array; the control and I/O circuitry may be monolithically integrated with the cell array, for example in the same CMOS chip. The control and I/O circuitry enables an efficient connection between the data from all the cells of the cell array **552**. Consider for example an arrangement of 2791 cells each having an 8 bit digital output. Such an arrangement would have 22328 signals (i.e. 8 bit output*2791 cells) to the electronics located outside the CMOS chip. The standard way of doing this is to use a SERDES circuitry (serializer/de-serializer). Such circuitry would transform a large number of low data rate signals into a few number of high data rate signals by means of time division multiplexing. It is therefore beneficial to have control and I/O circuitry monolithically with the cell array, or at least in the detector module, than external to the detector module.

(113) In embodiments the control and I/O circuitry may feature general supporting functions, such as circuitry to communicate with the electronics outside the CMOS chip to enable loading certain settings, for example for control of amplification and offset such as subtraction as described herein.

(114) The circuit layer of a cell **550** is connected to a detector element of the respective cell. The circuit layer comprises circuitry having amplification and/digitation functions, e.g. it may comprise an amplification circuit. A cell **550** may comprise a trans impedance amplifier (TIA) **556** and an analogue to digital converter (ADC) **558** as depicted in FIG. **10B**. This figure schematically depicts a cell **550** with an associated detector element such as capture electrode and a feedback resistor **562** connected to the transimpedance amplifier **556** and the analogue to digital converter **558**. The digital signal lines **559** from the analogue to digital converter **558** leave the cell **550**. Note that the detector element is represented as a detector element **560** and feedback resistor is shown associated with the detector area as a disc **562** rather than associated with the transimpedance amplifier **556**. This schematic representation is to represent each of the detector element and the feedback resistor as an area to indicate their relative size, the reason for which will become apparent when referring to FIG. **10C**.

(115) The transimpedance amplifier may comprise a feedback resistor R_f **562**. The magnitude of the feedback resistor R_f should be optimized. The larger the value of this feedback resistor, the lower the input referred current noise. Thus the better signal-to noise ratio at the output of the transimpedance amplifier. However, the larger the resistance, R_f , the lower the bandwidth. A finite bandwidth results in a finite rise and fall time of the signal, resulting in additional image blur. An optimized R_f results in a good balance between noise level and additional image blur.

(116) To implement the design the circuitry i.e. the amplification circuitry associated with each detector element should be within the layers of the associated cell **550** and fit in the limited area available of the portions of each associated layer. In the case of a sub-beam pitch of 70 microns, the available area per layer in the cell is typically only 4000 square microns. Depending on the sensed secondary and/or backscatter signal particles, for example as current to be measured by the detector element, the optimum value for the feedback resistor R_f can be as high as 30 to 300 MOhm. If such a resistor would be implemented as a poly resistor in a standard CMOS process the size of such resistor would be much larger than the area that is available in the CMOS layers of the cell **550**. For example, a resistor of 300 MOhm would consume around 500000 micron². This is about 130 times larger than the entire available area.

(117) Typically, for example in CMOS architecture, such a large resistor would be made in a single layer for example of polysilicon. Usually there is a single layer of polysilicon. In some circumstances a layer could be provided having material capable of providing high resistor values,

although with such a high aspect ratio (e.g. extreme length relative to width of the resistive structure in the layer) the reliability of the resistor remains. Even if the cell were to have multiple layers used for such a resistor, many more layers would have to be present that is readily available for example using CMOS technology. Additionally or alternatively, the meandering path through different layers would not mitigate the high aspect ratio and risk of variation in the resistance value would only be contributed by the interconnections between different layers. Such interconnects influence the variability of the resistance value of a resistor as a corner, as later described herein.

(118) Note that such dimensions are calculated assuming a 180 nm node architecture and processing. If alternatively a smaller processing node is used, it is unlikely that a factor of thousand in reducing the dimensions of the resistor structure could be gained. Further, using 180 nm node architecture is preferred to a smaller node for processing reasons. For instance interconnects in a 180 nm node are simpler to process. Post processing of a detector chip for example in etching the beam apertures **504** uses aluminum interconnects. Such post processing at a sub-180 nm node typically uses a process with Copper interconnects. Processing at 180 nm is therefore simpler than at sub-180 nm.

(119) Further if such a resistor were made, in whichever node, the reliability of the resistor specifications as well as the space available for the resistor may be challenging.

(120) In a layered structure for chip architecture, such as CMOS, the components and features are defined as structures in a layer. The specification of a component is dependent on the material of the layer and the physical properties of the layer, the dimensions of the layer, specifically its thickness and the dimensions of the structure formed in the layer. A resistor may take the form of a long narrow path, route or wire. In view of space constraints, the path may be non-linear, having corners along its path. For such a long component, the width of the path in the layer may vary such as through manufacturing tolerances. A corner may provide greater variance than a linear section of the path, limiting the accuracy with which the resistor can be made in order to have a specified resistance. With many corners and a long length, a resistor having such topology may be made with poor reliability so that the resistances for equivalent resistors in different cells of the cell array may have a large range.

(121) Such a resistive structure has a large surface area. Additionally or alternatively, a resistor with such a large surface area would additionally have a capacitance which is undesirable; such a capacitance is referred to as a parasitic capacitance. Parasitic capacitances may undesirably contribute to noise and blur, influencing the balance between noise, blur and bandwidth optimization which is elsewhere herein described

(122) The material properties of the layer can be modified chemically; however such modifications are unlikely to achieve the improvement of several orders of magnitude in size to fit into available space in the cell. Such modifications are unlikely to change the topography of the feedback resistor sufficiently so that it has the required specification and can be made with the desired reliable accuracy.

(123) Such requirements in reliability and size would enable the resistor to achieve its desired performance in terms of bandwidth, signal to noise ratio, and stability. Unfortunately, these requirements cannot be met.

(124) Alternative amplification circuitry is proposed which does not require such a large feedback resistor. Examples include a trans impedance amplifier with a pseudo resistor as a feedback element and a direct analogue to digital converter, obviating the need for a transimpedance amplifier. Two examples of a direct analogue to digital converter are: using a low duty cycled switched resistor, FIG. **11**, and using a reference capacitor, FIG. **12**. An optional arrangement is to remove the analogue to digital converter **558** from the cells **550** so that a circuit wire **570** connects the trans impedance amplifier **556** in the cell **550** with the analogue to digital converter external to the cell array **552**, FIG. **10C**. The arrangement depicted in FIG. **10C** may be applied to an amplifier circuit, e.g. as depicted in FIGS. **11** and **12**. Each option is now mentioned in turn. The example

amplifier circuits described are just some of the suitable types of amplification circuitry that can be used. Other amplifier circuits may exist which achieve similar benefits to those described herein and which use similar circuit architecture for each cell as herein described.

(125) An alternative amplification circuit is a direct analogue to digital converter for example using a switched resistor or capacitor, as depicted in FIGS. **11** and **12** that are connected directly to the output of a detector elements **503**. A suitable type of direct analogue to digital converter is a charge-balancing direct current-to-digital converter. Using a direct analogue to digital to converter avoids using a trans impedance amplifier and having the feedback resistor R_f or an exotic alternative. Removing the transimpedance amplifier removes the most power consuming component in the amplification circuit and the main source of input noise. Delta/sigma modulators provide the best realization of charge-balancing direct current-to-digital converter. The two possible solutions are depicted in FIGS. **11** and **12** are: using as a reference a low duty cycle switched resistor; and using as a reference a switched capacitor. These circuits are exemplary and other suitable circuits may exist

(126) A suitable direct current-to-digital converter with low duty cycle switched resistor, is depicted in simplified form FIG. **11**. The circuit has an integrator A to which is input the output from the detector elements **503** and the reference resistor $R_{sub.dac}$. A capacitor $C_{sub.int}$ is in a feedback loop of the integrator A. The signal output from integrator A is processed by a comparator to for the final step of converting the analogue signal to a digital signal. A bit stream bs provides a feedback from the output of the comparator to a control switch for the reference current $I_{sub.dac}$ using a charge balance loop. The design of control switch helps to ensure a long-term stable balance between the sensor current $I_{sub.in}$ and the reference current $I_{sub.dac}$. This helps ensure that the integrator will not clip its output signal and output bit stream, bs , is a digitised version of the sensor current $I_{sub.in}$

(127) In using such direct current-to-digital converter with low duty cycle switched resistor the size of a reference resistor $R_{sub.dac}$ is reduced, for example in realizing it a CMOS circuit. This is achieved by connecting the reference resistor $R_{sub.dac}$ to the input of the integrator A for a very small portion t of the clock period $T_{sub.clock}$. This results in a small duty cycle: $t/T_{sub.clock}$, e.g. 1:1000. This short connection time is sufficient to deliver the charge in reference current $I_{sub.dac}$ to balance the charge delivered in the current $I_{sub.in}$ from the detector element, i.e. the sensor current. Providing a reference current in this way to balance the sensor current helps to ensure that the reference noise is small. Yet, using such a low duty cycle enables the same effect that would otherwise be achieved by a large resistor such as the feedback resistor $R_{sub.f}$ of a standard trans impedance amplifier. So this solution applies a smaller sized resistor than would otherwise be used and using the duty cycle to boost its effective size yet minimizing the actual size of the resistor and the effective area of the circuit layer in a cell for this type of amplification circuit.

(128) A suitable direct current-to-digital converter with a reference capacitor is depicted in simplified form in FIG. **12**. The circuit has exactly the same features as the current-to-digital converter with low duty cycle switched resistor as depicted in FIG. **11**, unless otherwise specified. A capacitive digital-to-analog converter **567** arranged in a switched configuration supplies the reference current. Such a switched capacitor digital-to-analog converter contains at least one capacitor and may contains a parallel capacitor network. Individual capacitors are connected or disconnected with switches based on the input. As a capacitor based circuit, the capacitive digital-to-analog converter **567** may be represented as reference capacitor $C_{sub.dac}$. Instead of a reference resistor $R_{sub.dac}$, a reference capacitor $C_{sub.dac}$ is used. Because a capacitor is used, selection of an appropriately sized capacitor will generate a suitable reference current $I_{sub.dac}$, so that a pulse powered by a clock signal f_s to the reference circuit is not required. In restricting the use of the clock to the integrator, the effect of clock jitter is minimized. The effect of the reference current $I_{sub.dac}$ on the sensor current $I_{sub.in}$ is to quantize the signal of the sensor current. This is in effect direct digital conversion.

(129) As depicted in FIG. **10C**, a cell **550** comprises a transimpedance amplifier **556** connected to a detector element **560**. Associated with this amplification circuitry is an effective feedback resistor **568**. The output of the transimpedance amplifier is connected to an analogue to digital converter **558** (not shown) which is remote from the cell. A circuit wire **570** connects the trans impedance amplifier and the analogue to digital converter. The circuit wire **570** transmits an analogue signal. Considering that cell array **552** is densely packed, the analogue to digital to converter is external to the cell array for example one the same die as the cell array **552** and/or monolithically integrated with the cell array **552**. In an embodiment the analogue to digital converter **558** is in the substrate of the detector module. Alternatively the analogue to digital converter is remote from the substrate, for example it is part of a processor external to the substrate.

(130) The differences in components between the cells depicted in FIGS. **10B** and **10C** are that the cell of FIG. **10C** only includes a trans impedance amplifier and not an analogue to digital convert and the circuit wire **270** transmits an analogue signal rather than the digital signal transmitted by the analogue to digital converter. By removing the analogue to digital converter from the cell **550**, there is more space available in the circuit layer of the cell **550** for a feedback resistor element. This relative difference can be noted by the relative size of the feedback resistor areas **562** in FIGS. **10B** and **10C**; (but note, the relative dimensions do not necessarily apply to other features of these two figures). There is yet more space in the circuit layer of the cell **550** if the amplifier circuitry uses an alternative trans impedance amplifier circuit, for example if a trans impedance amplifier with a pseudo resistor is used as a feedback element.

(131) Although it may be easier to fit the trans impedance amplifier **556** with a pseudo resistor feedback element and analogue to digital converter in the circuit layers of the cell, in an arrangement it is more practical for space constraints for the analogue to digital converter **558** to be external to the cell array **552**. This is despite the use of a pseudo resistor in the feedback element of the trans impedance amplifier providing a gain of one to two orders of magnitude in area. One consideration to decide whether or not the analogue to digital converter **558** is external to the cell array **552** is the sub-beam pitch of the multi-beam. For example with a sub-beam pitch of 70 microns, typically only 4000 square microns is available per layer of a cell for the circuitry including the amplification circuitry.

(132) Under such space constraints, a trans impedance amplifier is located in the cell of each beam. The analogue to digital converter is located outside the array of sub-beams, i.e. outside the cell array. In an embodiment, the analogue to digital converter is present on the same die as the cell array, for example monolithically with the cell array. Such an analogue to digital converter may be located with the control and I/O circuitry which may be on the detector module or even monolithic with the cell array **552**. Locating the analogue to digital converter external to the cell array may provide an area gain of about a factor of two.

(133) The circuit wire **570** connects the trans impedance amplifier in a cell **550** with the associated analogue to digital converter **558**. The circuit wire **570** transmits an analogue signal. Unlike a digital signal, a data path transmitting an analogue signal is susceptible to interference. Signal interference can be from cross-talk with other circuit wires and from external fields such as generated by the sub-beams of the multi-beam and fields from nearby charged particle optical components such as the objective lens array **241**.

(134) The circuit wire **570** is routed through the a wiring route **554** as depicted in FIG. **10A**. The wiring route **554** is routed between cells so that the area of a cell and its layers is used for the amplification circuitry present on a cell. The wiring route **554** therefore only uses a portion of the circuit layers in which the wiring route is present, namely between adjoining cells **550** (e.g. at least around the beam apertures **504**, **406** of the adjoining cells **550**; through the adjoining cells **550** such as towards the periphery of the cells or between the circuitry in a layer assigned to the adjoining cells **550**, or any arrangement between the stated arrangements). This routing avoids architectural interference of the amplification circuitry and the architecture of the wiring routes **554**. Circuit

wires are routed along the wiring routes in the cell array in an outward direction, for example in a radially outward direction. With greater proximity to a perimeter of the cell array 552, there may be more circuit wires 570 than in a portion of the wiring route 554 remote from the perimeter. The wiring route may have a plurality of circuit wires 570, which as described, is between cells of the array. Therefore a portion of the wiring route 554 may have more than one circuit wire 570. However, having circuit wires located close to each other risks crosstalk between the circuit wires and interference of the analogue signals transmitted by the circuit wires 570.

(135) The risk of crosstalk and signal interference may be at least reduced or even prevented by having the circuit wires 570 shielded from each other within the wiring route. FIG. 13 depicts a cross-section of an exemplary arrangement of wiring route 554. Within the wiring route 554 are one or more circuit wires 470, shown extending in same direction as the wiring route 554 and a shielding arrangement. The circuit wires are shown in the same layer. Above the circuit wires 570 is an upper shielding layer 572; beneath the circuit wires 570 is a lower shielding layer 574. The upper and lower shielding layers of the shielding arrangement shield the circuit wires 570 from fields external to the wiring route 554 above and beneath the wiring route 554. The shielding arrangement has shielding elements in the same layer as the circuit wires 570. The shielding elements may be outer elements 576 at the outer edges of the layer comprising the circuit wires 570. The outer elements 576 shield the circuit wires 570 from fields external to the wiring route 554. The shielding elements may include intermediate shielding elements 578 that are present in the layer between adjoining circuit wires. The intermediate shielding elements 578 may therefore at least suppress if not prevent cross-talk between the circuit wires 570. In operation, a common potential is applied to the shielding layers 572, 574 and shielding elements 576, 578. The potential may be a reference potential for example a ground potential.

(136) Although FIG. 13 depicts a three layer arrangement, as many layers may be used in the wiring route 570 as may be desired. For example, there may be two layers of circuit wires, requiring three shielding layers which include an upper shielding layer 572, a lower shielding layer 574 and an intermediate shielding layer. The intermediate shielding layer may additionally reduce if not prevent crosstalk between the circuit wires in the different layers of the wiring route 570. Thus, there are five layers in total. Every additional layer of circuit wires involves an additional intermediate shielding layer. Whereas increasing the number of layers in the wiring route 554 reduces the proportion of a layer that wire routing requires, such a variation in design involves additional layers. In view of the limited number of layers, there is an optimum number of layers at which the width of the wiring route is reduced without exceeding the number of layers required elsewhere in the substrate of the detector module, which can be limited to five layers.

(137) A further consideration of the design of wiring route is the number of circuit wires that may need to be present in an exemplary design of detector module, for example consider the arrangement of FIG. 13 with all circuit wires 570 in a layer.

(138) For example, an array of sub-beams is arranged a hexagonal array with thirty (30) rings. The detector module therefore has a cell array of corresponding design. The number of cells is around 3000, for example 2791. Assuming such a cell array has a pitch of seventy (70) microns, the innermost cell is a ring of zeroth order, Ring #0, and has a single cell; the innermost ring, Ring #1, is around the central cell; and the outermost ring, Ring N, defines the perimeter of the cell array and consists of 6N cells. For a cell array of thirty rings, the total number of cells equals:

$$(139) N_{\text{cell}} := 1 + \sum_{n=1}^{30} 6n = 2.791 \times 10^3$$

(140) The outermost ring has the highest number of signals that need to be routed through the ring. Considering the wiring route is routed between cells of the each cell, these signals are routed through the outermost ring between the cells of the outermost ring. Because the outermost ring consists of 180 cells (e.g. thirtieth ring multiplied by six, i.e. $30 \times 6 = 6N$), the number of signals transported through the outermost ring, e.g. between the cells of the outermost ring, is:

$$(141) 1 + \sum_{n=1}^{29} \text{Math. } (6n) = 2.611 \times 10^3$$

(142) The maximum number of signals to be routed through the outer ring between adjacent cells is the total number of signals (**2611**) divided by the number of cells in the outermost ring (**180**). This is fifteen 15 (rounded up to the nearest whole number). So that the signals are well shielded, for example to limit crosstalk and the influence of external fields, the wiring route has a shielding arrangement. In a single layer of wire circuits, the layer may have outer elements **576** at the edges of the wiring route and intermediate shielding elements **578** between adjacent circuit wires **570**. With a wiring route of fifteen (15) circuit wires **570**, there are sixteen shielding elements, including fourteen (14) intermediate shielding elements and two outer shielding elements **576**. Therefore between adjacent cells **550** of the outer ring of the example, a wiring route having all circuit wires in the same layer would have thirty-one (31) elements of alternate shielding elements and circuit wires.

(143) For cell array **552** for a beam array with a pitch of 70 microns, there is enough space, or area, available in the circuit layer, for such a wiring route **554**. In a structure created using a process at the 180 nm node, the minimum half pitch of a metal layer is typically around 280 nm. In this context a half pitch is a line and a pitch is the line with an associated gap with an adjoining gap. The associated gap is typically the same width the line. The wiring route for thirty-one elements requires thirty-one pitches. However, the associated gap of one of the elements, which corresponds to the outer elements **576**, is not part of the wiring route **554**, but would separate the wiring route from adjoining circuitry. Therefore, for thirty one elements, sixty-one (61) half pitches are required, which corresponds to a width of the circuit wiring **554** of 17.1 micrometers.

(144) In a different arrangement, the beam array may be hexagonal having 108 rings and around 35000 cells, and may be considered to be a monolithic beam array. The outermost ring has around 650 cells. Around 34350 signals are required to be routed through the outermost ring. So around 54 signals need to be routed through adjoining cells in the outermost ring. A wiring route **554** having 54 circuit wires **570** has 55 shielding elements. Applying a similar calculation as for the previous example in applying this architecture to a half pitch of 280 nm, the width of the circuit wire would be under 61 micrometers. This size would fit between the cells **550** of the outermost ring. In an alternative arrangement the beam arrangement is apportioned in to two or more strips with one or more intermediate strip for routing a support structure, cooling features such as conduits, data transmission lines and the like. Such a beam array may be referred to as a stripped beam array. The wiring routes may therefore be routed through the one or more intermediate strips. This enables a larger beam array, thus cell array yet maintaining a reasonably sized wiring route. If a stripped beam array were to have the same number of sub-beams as a monolithic beam array, the wiring routes would have fewer circuit wires **570** than the monolithic cell array i.e. fewer than 54. Indeed a stripped beam array may achieve a larger number of sub-beams than a monolithic beam array because the size of the beam array, as limited by the maximum number of circuit wires that may be in the wiring route, would be larger

(145) The optimization of the noise performance for example in terms of bandwidth and noise optimization and balance between the blur and the noise can be enabled by making sure an amplification factor of the trans impedance amplifier is programmable. In a such an arrangement, the amplifier circuit of the cell, at least the trans impedance amplifier, is programmable. Such a programmable amplification circuit may comprise a variable amplifier and/or a variable analogue to digital converter for example. in terms of its sensitivity. The variable amplifier has a variable amplification range dependent on a detected beam current detected by a detector element **503**. For example, when the detected beam current is low, or for a sample with a lower than typical secondary emission coefficient, the variable amplifier can be adjusted to provide a larger amplification than normally used. When a larger beam current than normal is detected by a detector element **503**, or for a sample with a larger than typical secondary emission coefficient, the variable

amplifier can be tuned to provide a smaller amplification.

(146) This functionality is beneficial with a trans impedance amplifier with a feedback element having pseudo resistor. A pseudo resistor has different effective resistances on application of different applied voltages; unlike an ideal resistor which has a single resistance at all applied potential differences. In providing different resistance, the trans impedance amplifier associated with the pseudo resistor operates as a variable amplification. In providing an amplifier with variable functionality, an optimized balance between noise levels and image blur (referred to herein above as ‘additional blur’) may be achieved. Beneficially, the programmable amplification circuit may match the output of the trans impedance amplifier with the input of the analogue to digital converter. This may be as a programmable offset that is subtracted between the output of the trans impedance amplifier, and the input of the analogue to digital converter. The programmable offset may help reduce the required number of bits that need to be transmitted from the amplification circuit of a cell. The programmable offset may be implemented in the programmable amplifier. These measures help to ensure that the dynamic range of the trans impedance amplifier and the analogue to digital converter, and thus preferably the amplification circuit, are optimally used for different use cases. Such different use cases may include: the material properties of a sample under inspection, different assessment tool configurations for example using different beam currents. The range of applications may be enabled by the provision of a variable amplifier and a variable off set or threshold (e.g. subtraction by a programmable offset) desirable enables tuning of amplification, threshold and bandwidth As mentioned elsewhere herein, the circuitry associated with variable amplification and subtraction may be comprised in the control and I/O circuitry.

(147) It is beneficial to detect different types of signal particles in order to obtain more varied information relating to the sample. For example, in order to measure an overlay target, one might use secondary signal particles to obtain data relating to a top grating (possibly present in resist) and use backscatter signal particles to obtain data relating to a buried grating.

(148) In some systems, detectors may be provided to be used in different modes, e.g. switching between secondary signal particle detection and backscatter signal particle detection. In order to switch from secondary signal particle detection to backscatter signal particle detection, the electrostatic field between sample and detector is reversed and/or the landing energy is changed. Different sample charging conditions after changing landing energy and/or sample field can cause an overlay measurement error, because these might change the primary beam position. There is a risk the system drifts (sample position and/or beam position) while switching, resulting in an overlay measurement error. Thus, improvements can be made to a system in which detection modes are switched between backscatter detection and secondary detection. European patent application publication no. EP4020516, which is incorporated herein its entirety by reference, discloses such a system and at least the devices and methods relating to switching between different modes are hereby incorporated by reference.

(149) In alternative systems, a detector is provided with a double ring detector pad. The use of a double ring charge-based bottom detector may lead to a considerable amount of cross signals in the rings, i.e. detection of secondary signal particles in the outer ring proposed to detect backscatter signal particles, and detection of backscatter signal particles in the inner ring proposed to detect secondary signal particles. European patent application publication no. EP4020518, which is incorporated herein in its entirety by reference, discloses such a system and at least the devices and methods related to the double ring detector pad are hereby incorporated by reference.

(150) In an implementation, the detection of the two types of detectors is sought to be improved, e.g. by making use of more of, if not the complete, available detection efficiency. The separation of secondary signal particles and backscatter signal particles can be achieved by using the large energy difference between secondary signal particles and backscatter signal particles as described above. Both the secondary signal particles and the backscatter signal particles can be detected at the same time increasing the collection efficiency compared to various known detectors.

(151) In an embodiment, a detector is provided which may be used in a charged particle device for an assessment tool to detect signal particles from a sample. For example, the charged particle device is configured to project a beam of charged particles onto a sample so as to detect signal particles emitted from the sample. An exemplary version of the detector **600** is shown in FIG. **14**. The detector **600** comprises a substrate, which may otherwise be referred to as a body. The substrate comprises a semiconductor element **610** (e.g. a pin detector) configured to detect signal particles above a first energy threshold and a charge-based element **620** configured to detect signal particles below a second energy threshold. Resulting signal particles from the sample may comprise signal particles above the first energy threshold and/or signal particles below the second energy threshold. Thus, the detector **600** comprises two different types of detector element, such as a first element and a second element. As will be understood from FIG. **14**, the detector **600** may be used with a single beam device. Thus, for example, the detector could be used with the single beam device described in relation to FIG. **9** above.

(152) Each different type of detector element may be configured primarily to detect certain signal particles, e.g. those above or below a certain threshold. Signal particles with energies below the first energy threshold are shown with dashed line arrows in FIG. **14** and signal particles with energies above a second energy threshold are shown with solid line arrows in FIG. **14**. The first energy threshold may correspond to a backscatter threshold energy. Thus, the semiconductor element **610** (e.g. a first element) may be configured to detect primarily backscattered signal particles. The backscatter threshold energy may be the selected lowest energy level of backscattered signal particles that the detector is designed to detect. For example, the backscatter threshold energy may be approximately 50 eV. The second energy threshold may correspond to a secondary threshold energy. Thus, the charge-based element **620** (e.g. a second element) may be configured to detect primarily secondary signal particles. The secondary threshold energy may be the selected highest energy level of secondary signal particles that the detector is designed to detect. For example, the secondary threshold energy may be approximately 50 eV. In an arrangement the first element is configured to detect backscattered signal particles and the second element is configured to detect secondary signal particles.

(153) The first energy threshold and the second energy threshold may be substantially the same. Thus, the first energy threshold and the second energy threshold may be a single predetermined value. In this case, the charge-based element **620** may be used to detect any signal particles below the predetermined value and the semiconductor element **610** may be used to detect any signal particles above the predetermined value.

(154) As shown in FIG. **14**, the detector **600** may have an aperture **601** defined in the substrate and through which a primary beam **320** may pass to land on the sample **208**. This is beneficial in that the detecting elements of the detector **600** can surround the aperture **601** which may increase detection efficiency.

(155) The charge-based element **620** may comprise a metal layer **621**. The metal layer **621** may be a planar portion. The metal layer **621** may be a thin film. The charge-based element may have a thickness of approximately 100 nm or less, preferably approximately 10 nm to 100 nm. More specifically, the thickness of the metal layer **621** may be approximately 100 nm or less, preferably approximately 10 nm to 100 nm. Lower energy signal particles with an energy of less than 50 eV (which may correspond to the secondary signal particles described above) can be 'captured' by charge-based elements with a relatively small thickness. Higher energy signal particles have a higher penetration depth. For example, signal particles having an energy of approximately 350 eV may have a penetration depth which is greater than 10 nm to 100 nm. This means that the lower energy signal particles can be captured by the charge-based element **620** and the vast majority of higher energy signal particles will pass through the charge-based element **620**. The higher energy signal particles can be detected by the semiconductor element **610**. Therefore, such a thickness is beneficial in allowing signal particles to effectively reach the semiconductor element **610**. The

collection efficiency may be improved by applying a bias between the sample **208** and the detector **600** to attract the signal particles to the detector as described below.

(156) The semiconductor element **610** may be a PIN detector. Scintillators and PIN detectors are typically capable of detecting charged particles above a detection threshold for example typically above approximately 1 kV, although lower values for example 200 eV for PIN detectors are known. For a scintillator, the detection threshold may be varied by the selection of the thickness of a conductive coating, such as a metal layer, on the scintillator surface. The semiconductor element comprises an upper metal layer **612** and a lower metal layer **613** on either side of a p-i-n region **611**. The upper metal layer **612** may be a planar portion. The upper metal layer **612** may be a thin film. The lower metal layer **613** may be a planar portion. The lower metal layer **613** may be a thin film. The p-i-n region **611** may otherwise be referred to as a depletion layer or zone. The p-i-n region **611** may comprise a dead layer at the edge of the p-i-n region. The dead layer is an inactive zone or region at the entrance surface of the p-i-n region. The dead layer may comprise a conductive layer, a surface passivation layer and/or an anti-reflective coating. It is possible to have a p-i-n region without the dead layer, however, the dead layer is beneficial in reducing noise. Although a p-i-n region is described throughout, other semiconductor regions may be used instead of the p-i-n region. For example, the semiconductor element may comprise a diffused junction diode, surface barrier detector (e.g. Schottky diode) or an ion-implanted diode.

(157) Preferably, the charge-based element **620** and the semiconductor element **610** are each at least part of layers that are substantially co-planar with the major surfaces of the detector (i.e. the detection surface). The detection surface is the surface of the detector for passage of the signal particles to the semiconductor element **610** and/or the charge-based element **620**. It will be understood that the layers of detector elements, such as the charge-based element **620** and the semiconductor element **610** are different portions of the layered detector structure.

(158) In an embodiment, the detector elements may be provided as layers, i.e. layered portions, of a stacked structure comprised in the detector **600** stacked in a thickness direction of the detector. The stacked layers of the charge-based element **620** and the semiconductor element **610** are shown in FIG. **14**. The layers of the charge-based element **620** and the semiconductor element **610** are stacked in a direction of the primary beam **320**.

(159) Preferably, the charge-based element is closer to the detector surface than the semiconductor element. Specifically, the metal layer **621** of the charge-based element **620** is preferably closer to the detection surface than the semiconductor element, or the metal layer **621** may form the detection surface. Generally, the higher energy signal particles when hitting the detection surface, can be detected at the semiconductor element **610** through the charge-based element **610**.

(160) Providing the detector elements stacked on top of each other is beneficial because the detector elements can make use of the complete available detection efficiency by using the full detection area available for the detector **600**. In general it is important to separate the secondary signal particles (i.e. the low energy signal particles) and the backscatter signal particles (i.e. the high energy signal particles). This is because typically more secondary signal particles are produced at the sample than backscatter signal particles which causes the secondary signal particles to dominate the signal if the signal particles are not well separated. The stacked detector can separate the signal particles based on the energy difference and the difference in penetration depth. Specifically, the low energy signal particles corresponding to the secondary signal particles are captured by the charge-based element **620**. However, the high energy signal particles will penetrate the charge-based element **620** to generate electron-hole pairs in the depletion layer of the semiconductor element **610**. Thus, the higher energy signal particles can be detected in the semiconductor element **610** below the charge-based element **620**. Thus, the stacked detector allows separate detection of the lower energy signal particles at the charge-based element **620**. The stacked detector permits detection of the higher energy signal particles at the semiconductor element **610** simultaneously. These improvements in function are beneficial for improving detection efficiency.

(161) The charge-based element **620** may form the detection surface of the detector. In other words, the charge-based element **620** may be an outermost layer of the detector **600**, as shown in FIG. **14**. The metal layer **621** may form the detection surface. As shown in FIG. **14**, the metal layer **621** may form substantially the whole detection surface.

(162) As shown in FIG. **14**, the charge-based element **620** may form a layer (e.g. a coating) over substantially the whole semiconductor element **610**. This means that the charge-based element **610** is provided over the whole surface of the semiconductor element **620**. In this case, the charge-based element **610** may form substantially the whole detection surface. In particular, the metal surface layer **621** of the charge-based element **620** may form substantially the whole detection surface, as shown in FIG. **14**.

(163) The semiconductor element **610** and the charge-based element **620** may be separated from each other. Specifically, the detector may comprise an electrically insulating element **630** between the charge-based element **620** and the semiconductor element **610**. The electrically insulating element **630** may be provided as a layer. The electrically insulating element **630** may be a planar portion. The electrically insulating element may be a thin film. The electrically insulating element **630** may be provided in any form or shape. The electrically insulating element **630** is configured to prevent electrical signals passing from the charge-based element **620** to the semiconductor element **610** and vice versa. The electrically insulating element **630** may extend between the charge-based element **620** and the semiconductor element **610**. The electrically insulating element **630** may be of any appropriate thickness in order to provide effective electrical insulation. Preferably, electrically insulating element **630** is not too thick to avoid that higher-energy charged particles cannot penetrate it and do not reach the active detector layer **611**.

(164) The electrically insulating element **630** may have any appropriate thickness (i.e. in the thickness direction of the detector, e.g. in a direction of the primary beam) between other components, e.g. between the metal layer **621** and the lower metal layer **613**. For example, the thickness may be between approximately 10 to 500 nm, and preferably between approximately 50 to 500 nm. It is noted that the electrically insulating element **630** is preferably thick enough to prevent voltage breakdown which depends on the voltage difference between the metal layer **621** and the lower metal layer **613** as in FIG. **14**. If the same voltage is used on lower metal layer **613** and metal layer **621** (which should be possible because for the PIN detector functioning only the voltage difference between the upper metal layer **612** and the lower metal layer **613** is important) a thickness of 10 nm could be used, otherwise thickness of 100 nm or more is preferably used. The thickness may depend on the material. The electrically insulating element may be any appropriate material. For example, the electrically insulating element may be SiO₂. In this case, the thickness of the electrically insulating element may preferably be between 10 nm to 500 nm, and preferably approximately 100 nm.

(165) The detector may comprise a circuitry layer **640** comprising the detector circuitry. More specifically, the substrate may comprise the circuitry layer **640**. The circuitry layer **640** may comprise some, if not all, of the circuitry used to process the signals from the different detector elements. Thus, the circuitry layer **640** may convert the detected signal particles into electrical signals. The circuitry layer **640** may comprise various different electrical components. The circuitry layer may be connected to the charge-based element **620** and the semiconductor element **610** as described below. The circuitry layer may comprise parallel layers of circuitry for connecting to each of the charge-based element **620** and the semiconductor element **610**. Alternatively, the circuitry layer may comprise a single layer with circuitry adjacent in cross-section for connecting to each of the charge-based element **620** and the semiconductor element **610**.

(166) Providing the circuitry layer **640** in the detector is beneficial in that the circuitry can be close to the detector elements. The detector elements are connected to circuitry to convert the detected signals into a digital signal. In general, having circuitry for converting the detected signal into a digital signal as close as possible to the relevant detector element beneficially improves the digital

detection signal. A proximate digitization circuitry reduces risks of loss or at least deterioration of or disruption to the detection signal.

(167) The detector **600** may further comprise an electrically insulated via **622** configured to connect the charge-based element **620**, and particularly the metal layer **621**, to detector circuitry. That is the electrically insulated via **622** is for the detector to detect a signal particles through connection to the charge-based element. The electrically insulated via **622** may extend through at least part of the semiconductor element **610**, as shown in FIG. **14**. Thus, the charge-based element **620** may be connected to the circuitry layer **640** by an electrical connection along the electrically insulated via **622**. This means that the charge-based element **620** may be used to form the detection surface, or at least part of the detection surface, whilst still being appropriately connected to the circuitry of the detector.

(168) The upper metal layer **612** of the semiconductor element **610** is preferably connected to detector circuitry (preferably comprised in the circuitry layer **640**). Additionally, the lower metal layer **613** may be connected to detector circuitry. The detector circuitry may be configured to apply a voltage bias **641** across the upper and lower metal layers of the semiconductor element **610**.

(169) As described in further detail below, the circuitry layer **640** may comprise or be connected to the circuit layer and/or wiring as described above in relation to FIGS. **10**, **11**, **12** and **13**. For example, the detector circuitry may comprise a transimpedance amplifier **556** and/or an analog to digital converter **558** connected to the charge-based element **620**. The detector circuitry may comprise a transimpedance amplifier **556** and/or an analog to digital converter **558** connected to the semiconductor element **620**. Such a transimpedance amplifier **556** and analog to digital converter **558** (as well as other relevant electrical components) are described above in relation to FIGS. **10A**, **10B**, **10C**, **11**, **12** and **13**. It is noted that the size available for the detector elements is relatively small. Thus, it is beneficial to provide an amplifier, such as the transimpedance amplifier. However, some amplifiers such as the transimpedance amplifier generally need a large resistance. Thus, the circuitry may be provided with wiring routed between cells as described in relation to FIG. **10A**. This allows the signal to be amplified so that the noise is small. Additionally or alternatively, a pseudo resistor may be used with the transimpedance amplifier, and/or an analog to digital converter as described in relation to FIG. **12** or **13**.

(170) Although the above describes and shows an electrically insulating element **630** between the semiconductor element **610** and the charge-based element **620**, this is not a necessity. For example, the semiconductor element **610** and the charge-based element **620** may be in direct contact with each other. Furthermore, the semiconductor element **610** and the charge-based element **620** may have at least one component in common. For example, the lower metal layer **613** of the semiconductor element **610** may be part of the charge-based element **620**. For example, the metal layer **621** forming the detection surface of the charge-based element **620** may also be the lower metal layer **613** of the semiconductor element **610**. In such a configuration, good electrical insulation is preferably provided between the circuitry of the detector for the charge-based element and the circuitry of the detector for the semiconductor element. The advantage of the metal layer **621** forming the detection surface of the charge-based element **620** and the lower metal layer **613** of the semiconductor element **610** is that the layer thickness for penetration is smaller (because the separate metal layer **621** and electrically insulating element **630** are not provided), so a greater number of particles reach the p-i-n region. This provides a lower energy threshold for **610**. However, it is noted that this configuration may make an accurate charge measurement more difficult.

(171) Although it is described above that the first energy threshold and the second energy threshold are substantially the same, they may have an offset. In other words, the first energy threshold may differ from the second energy threshold. For example, it may be noted that detection of signal particles near the threshold might result in detection of various different types of signal particle and it may be preferable to more clearly separate detection of the different signal particles. Having an

offset between the first energy threshold and the second energy threshold may reduce the signal particles detected, and may specifically reduce the amount of signal particles with borderline energy levels which may decrease noise in the detection. The first energy threshold may be more than the second energy threshold. The first energy threshold may depend on the layer thicknesses before reaching the p-i-n region. However, it can be tuned somewhat with the bias voltage between the sample and the detector (described further below as the potential different between the sample and detector). If the bias voltage is, for example, +200 V instead of +50 V, then effectively lower backscatter signal particles might gain sufficient additional kinetic energy to pass these layers, thereby lowering the effective first energy threshold. Something similar happens with the second energy threshold. Therefore, the values for the threshold can be influenced by the bias voltage, and therefore the difference between the first and second threshold could be between approximately 0 and 200 V.

(172) It will be understood from the description of the secondary and backscatter signal particles above that the threshold value (e.g. of 50 V, or 100 V, or 200 V) between the different types of signal particles is arbitrary. There is not a black and white division around (i.e. distinct separation at) this threshold. The precise selection of the threshold value is unlikely much to improve or contribute to the image contrast or quality. Thus the selection of the threshold value is unlikely to reduce the detection of signal particles with borderline energy levels. In general it is expected that the effective first and second energy thresholds may be different because of the energy loss in the layers between the charge-based detector **621** and the p-i-n region **611**. A signal particle that has just enough energy to leave the charge-based detector **621** (i.e. above the first energy threshold) might lose too much energy in the layers that are in between charge-based detector **621** and the p-i-n region **611** to reach the p-i-n region **611**; thus leading to a second energy threshold having a different value from the first energy threshold.

(173) As described above, an aperture **601** is defined in the substrate for the passage therethrough of a charged particle beam. This is beneficial in that the signal beam (e.g. primary beam **320**) may pass through the detector **600** such that signal particles can be captured by the detector **600** all the way round the primary beam. However, although this is beneficial, other configurations may also be used. For example, the detector **600** may be provided to one side of the primary beam path. This would allow the primary beam to reach the sample **208**, and the detector **600** can still detect signal particles emitted from the sample **208**. In this configuration, a Wien filter may be used in combination with the detector. In another arrangement the detector may be provided as at least two portions either side of the path of the primary beam. The two portions may be separated by a gap. The two portions may be spaced apart. The gap may take the form a slit or strip through which the path of the primary beam passes. If multiple primary beams (e.g. sub-beams) are provided, then the detector may still be provided to one or both sides, for example, with slits for paths of the multiple sub-beams of the primary multiple multi-beams. In an arrangement such a detector array may have multiple detectors on one side of the slit. Such an arrangement featuring a slit between detectors or detector portions may be easy to manufacture. However, providing the detector with an aperture formed therein may be beneficial in allowing for a larger detection surface which may thus increase the detection efficiency. Locating the detector on a lens electrode, within an electrostatic lens may be easier to achieve if such a detector has an aperture rather than a slit or the like. It is noted that the aperture of the detector an electrostatic field may cause some disturbance of the field which may affect the primary sub-beam and it is preferable if the disturbance of the sub-beam is symmetric, because it leads to less deformation by aberrations.

(174) The above embodiments and variations may be provided with a slightly different configuration of the charge-based element **620** and the semiconductor element **610**, as shown in FIG. **15** and FIG. **16**. In this case, the charge-based element **620** may not form substantially the whole detection surface. In this case, the charge-based element **620** provides at least part of the detector surface and the semiconductor element **610** provides at least part of the detector surface. In

other words, the detector surface comprises both the semiconductor element **610** and the charge-based element **620**.

(175) As would be understood from both FIG. **15** and FIG. **16**, the charge-based element **620** and the semiconductor element **610** may be positioned adjacent to each other in plan view. Thus, at least part of the charge-based element **620** may be positioned substantially next to the semiconductor element **610**, e.g. on the detection surface, in plan view. It will be noted that a small gap may be provided between the charge-based element **620** and the semiconductor element **610**, which may for example comprise electrically insulating material.

(176) FIG. **15** shows an alternative in which the semiconductor element **610** and the charge-based element **620** are stacked, as described above in relation to FIG. **14**. Specifically, the semiconductor element **610** and the charge-based element **620** are stacked in cross-section, as in FIG. **14**. However, in this embodiment, the charge-based element **620** partially covers the semiconductor element **610**. In this instance, the charge-based element **620** may be positioned on part of the semiconductor surface **610**, to form part of the detection surface as shown in FIG. **15**. In other words, the charge-based element **620** may partially overlap with the semiconductor element **610**. Thus, there may be only a partial overlap of the charge-based element over the semiconductor element **610** on the surface of the detector. In this case, the charge-based element **620** may be provided as an additional layer stacked on top of the semiconductor element **610** such that the full semiconductor element is formed beneath the charge-based element **620**. Providing the charge-based element **620** in this configuration, i.e. partially covering the semiconductor element **610**, may be beneficial for reducing capacitance which might result in a faster detector.

(177) In another instance, the charge-based element **620** may be formed adjacent to the semiconductor element **610**, to form part of the detection surface as shown in FIG. **16**. In this case, the charge-based element **620** and the semiconductor element **610** are formed adjacent to each other in cross section across the width of the detector (i.e. in a direction orthogonal to the direction of the primary beam, which may otherwise be referred to as a radial direction). In particular, the detecting surface of the charge-based element (provided by metal layer **621**) is adjacent to the detecting surface of the semiconductor element (provided by the lower metal layer **613**) in cross-section, i.e. the detecting surface of the charge-based element (provided by metal layer **621**) is radially outwards or radially inwards of the detecting surface of the semiconductor element (provided by the lower metal layer **613**) in cross-section. Thus, the charge-based element does not overlap as a layer stacked on top of the semiconductor element. Instead, the semiconductor element **610** is formed surrounding the charge-based element **620**. Specifically, there is no overlap of the charge-based element over the lower metal layer **613**. Instead, the lower metal layer **613** surrounds the metal layer **621** of the charge-based element. In other words, the lower metal layer **613** is radially outwards of the metal layer **621** in a plane. The p-i-n layer **611** may be formed through the detector and may be positioned beneath the metal layer **621** of the charge-based element. This is beneficial as the same fabrication processes or process steps may be used for the layers in both the semiconductor element and the charge-based element. As described above, the electrically insulated via **622** may connect the metal layer **621** to the detector circuitry through the p-i-n layer. The semiconductor element may be separated to provide a portion of the p-i-n layer **611a** which is associated with the charge-based element **620**. The portion of the p-i-n layer **611a** associated with the charge-based element **620** does not participate in operation of the semiconductor element **610**. The portion of the p-i-n layer **611a** associated with the charge-based element **620** may be separated from the rest of the p-i-n layer by insulating part **623**. The insulating part **623** may be an electrically insulating member and may be similar to the electrically insulating element **630** described above, albeit with a different configuration. The insulating part **623** may be positioned radially inwards of the semiconductor element **610**. The insulating part **623** may be positioned radially outwards of the charge-based element **620**.

(178) In this embodiment, the detector elements are operated in different modes. Specifically, the

semiconductor element can be used (shown in FIG. 16 as an outer ring) where the energy of higher energy signal particles (such as backscatter signal particles) is converted into electron-hole pairs in a depletion layer just below the surface of the detector. Lower energy signal particles (such as secondary signal particles) will not generally have enough kinetic energy to penetrate the top layer(s) of the detector (consisting of a lower metal layer **613** and a dead layer of the semiconductor). Thus, the lower energy signal particles will not generally be detected by the semiconductor element **620**. It is beneficial to remove the lower energy signal particles from the higher energy particle signal. This is because typically more lower energy signal particles are produced at the sample **208** causing the lower energy particles to dominate the higher energy particles if the different signal particles are not well separated. In this configuration, it is expected that the cross-talk of secondary signal particles on the semiconductor element to be very low or zero. The collector efficiency may be slightly lower than the stacked embodiment, due to the reduced overall surface area for both the detection surface of the semiconductor element and the charge-based element.

(179) The charge-based element **620** comprises the metal layer **621** (shown in FIG. 16 as an inner ring) which operates as a charge conductor. This will enable detection of secondary signal particles (and also backscatter signal particles that impact on this inner ring) by their charge. The thickness of the metal layer **621** on the charge-based element may be different than the lower metal layer **613** on the semiconductor element **610** for better charge conduction.

(180) Preferably the metal layer **621** of charge-based element **620** and at least the lower metal layer **613** of the semiconductor element are separated. Preferably the metal layer **621** of charge-based element **620** and at least the lower metal layer **613** of the semiconductor element have electrical isolation between them. There is an isolation layer between the metal layer **621** and the lower metal layer **613**. This may be beneficial in avoiding a direct interface between the two layers.

(181) It will be understood that the semiconductor element and the charge-based element could be used to form the detector surface in a number of different configurations. Thus, separation of the detecting portions in the overlapping and/or adjacent configurations described above may be similar to the description in relation to FIGS. 6A and/or 6B above.

(182) For example, the charge-based element **620** and the semiconductor element **610** may each comprise an annulus (e.g. a ring) on the detection surface. The annuli are preferably concentric and radially divided from each other. This is shown in cross section FIGS. 15 and 16. If the charge-based element and the semiconductor element each form a single annulus, it will be noted that in plan view, the detector surface may appear as shown in FIG. 6A. In this instance, the charge-based element may correspond to an inner detecting portion **405A**, and the semiconductor element may correspond to an outer detecting portion **405B**.

(183) For example, the charge-based element and the semiconductor element may each comprise at least one sector. For example, the detector surface may be formed by multiple sectors, which may be of approximately equal area. The sectors are preferably angularly divided. If the charge-based element and the semiconductor element each form two sectors and the charge-based elements and the semiconductor elements are alternating, it will be noted that in plan view, the detection surface may appear as shown in FIG. 6B. In this instance, the charge-based elements **620** may correspond to detecting portions **405C** and **405E**, and the semiconductor element **610** may correspond to detecting portions **405D** and **405F**.

(184) Although not shown, the charge-based elements and the semiconductor elements may comprise at least one sector and at least one annulus. For example, the charge-based element and the semiconductor element may form a checkerboard or dartboard pattern on the detector surface.

(185) The semiconductor element **610** may be provided with multiple annuli. The annuli may be separated, e.g. with some form of electrically insulating member, which may or may not be part of the electrically insulating element **630** and/or insulating part **623**. Each semiconductor element annuli may be separated by an insulating part **623**, e.g. as shown above in relation to FIG. 16.

Providing the semiconductor element **610** as multiple annuli may be beneficial in using an inner annulus to detect smaller angle high energy signal particles and an outer annulus to detect larger angle high energy signal particles. Thus, providing the semiconductor element as at least two annuli allows detection of higher energy signal particles to be separated into different angular ranges if desired.

(186) The detector as described in any of the above variations can work both with decelerating and accelerating objective lenses (i.e. with the device working in a decelerating or an accelerating mode). In particular, when the detector is positioned as a bottom detector (e.g. down-beam of the objective lens array **241**), the signal particle trajectories towards the detector are determined by the field between the sample and the detector, not by the decelerating or accelerating field of the objective lens. By applying negative or positive bias on the detector or detector array with respect to the sample, low energy signal particles (e.g. secondary signal particles) can either be repelled (backscatter-only mode) or attracted (combined secondary and backscatter mode). It is noted that higher landing energies are typically used with the accelerating lens. This means that the high energy signal particles (e.g. the backscatter signal particles) have higher energies on average in this case. This makes it easier for the high energy signal particles to pass through the charge-based device **620** and the electrically insulating element **630**. The high energy signal particles may thus to reach the semiconductor element **610** in such a layered detector with more ease. This detector type is even more attractive for accelerating lenses.

(187) The detector described above may be used in a single beam device, e.g. in combination with the device described in relation to FIG. **9**. Alternatively, the detector could be used in a multi-beam device, e.g. in which a primary beam is separated into sub-beams, for example as described in relation to FIGS. **3** and **8**. Thus, multiple detectors may be provided which may be suitable for use in a multi-beam charged particle device. The multiple detectors could be provided as described in any of the above variations or embodiments. The multiple detectors may form an array which may be referred to as a detector array. In this case, each detector may be configured as described above and may be positioned adjacent to other detectors in an array. Each of the detectors may have the same configuration as each other, e.g. with all the detectors having a detector element configuration as shown in FIG. **14**, or the configuration as shown in FIG. **15**, or the configuration as shown in FIG. **16**.

(188) An array of detectors is shown in FIG. **17** and a variation of the array is shown in FIG. **18**. It will be noted that the array of detectors shown in FIG. **17** and FIG. **18** correspond to the detectors described above in relation to FIG. **14**. However, the detectors could have any of the above described variations, including those described in relation to FIG. **15** or FIG. **16**.

(189) The array of detectors may be arranged in any appropriate configuration. Each detector may correspond to a respective sub-beam **320**. For example, the detectors being arranged in an array may correspond in arrangement to the array of sub-beams of the multi-beam array described above. The arrangement may be a hexagonal (see for example FIG. **10A**) or rectilinear grid. The detector array may have a plurality of apertures formed in the substrate with each aperture formed to correspond to each sub-beam in the multi-beam array. Thus, the apertures of the plurality of detectors may be for the passage therethrough of sub-beams of the multi-beam array towards the sample **208**.

(190) If an array of detectors is provided, multiple detectors may be comprised in a substrate which may be referred to as a common substrate. (Thus for an embodiment in which a single detector is present, the detector may be comprised in the substrate). The substrate may comprise a plurality of semiconductor elements **610** and a plurality of charge-based elements **620**. Each semiconductor element **610** is associated with a corresponding one of the charge-based elements **620**. The same substrate may be provided for all the detectors **600** in the array. Alternatively, multiple substrates may be provided for the detector array, with each substrate comprising a plurality of semiconductor elements **610** and a plurality of charge-based elements **620**. The number of semiconductor elements

610 may correspond to the number of charge-based elements **620**.

(191) There may be components or layers of detectors which form a common layer, i.e. which are formed in the same position in each detector **600** of the array. For example, one of the components or layers, e.g. the metal layer **621** of the charge-based element, may be formed for each of the detectors in the same position along the primary beam paths. In the case of the metal layer **621**, the metal layer **621** may be formed as a detection layer for each of the detectors forming the detector array.

(192) The semiconductor element **610** of each detector may be in a common semiconductor layer of the substrate. Thus, the substrate may comprise a semiconductor detector layer comprising the plurality of semiconductor elements **610**. The semiconductor layer may comprise a component common to multiple detectors **600**. For example, the p-i-n region **613** of the semiconductor element may be a layer formed across multiple detectors, as shown in FIG. **17**. The p-i-n region could be common to multiple, or even all of, the detectors in the detector array. Alternatively, separate p-i-n regions could be provided for each separate semiconductor element, which may for example have electrically insulating material between semiconductor elements of different detectors in the array.

(193) Additionally or alternatively, the charge-based element **620** of each detector **600** may be in a common charge-based layer of the substrate. Thus, the substrate may comprise a charged detector layer comprising the plurality of charge-based elements.

(194) Additionally or alternatively, the electrically insulating element **630** between the charge-based element and the semiconductor element of each detector may be in a common electrically insulating layer of the substrate. Thus, the substrate may further comprise an electrically insulating layer between the charge-based elements and the semiconductor elements.

(195) Additionally or alternatively, the circuitry layer **640** of each detector may be comprised in a common circuitry layer of the substrate. Thus, the substrate may comprise a circuitry layer comprising a plurality of cells comprising circuitry associated with the charge-based element and/or the semiconductor elements as for example described and depicted in FIGS. **10A**, **10B** and **10C**. The detector may comprise one or more vias for each cell, connecting the respective charge-based element **620** and/or the respective semiconductor element **610** to the circuitry of the cell. For example, each of the charge-based elements **620** may comprise an electrically insulated via **622** as described above, which is connected from a respective one of the charge-based elements **620** to the circuitry layer **640**. Each of the semiconductor elements **610** may additionally or alternatively comprise a via to connect to the detector circuitry, or the semiconductor elements may be directly connected to the detector circuitry by the upper metal layer **612**.

(196) The circuitry layer **640** may comprise a transimpedance amplifier and/or an analog-to-digital converter in each cell. Optionally, the circuitry layer may comprise a transimpedance amplifier and/or an analog-to-digital converter for each of the respective charge-based element **620** and/or the respective semiconductor element **610** of the corresponding cell. Thus, each of the charge-based element and/or the semiconductor elements may be connected to a transimpedance amplifier and/or an analog-to-digital converter associated with the respective charge-based element and/or the semiconductor elements.

(197) The detector array may comprise a shielding element **660**, as shown in FIG. **18**. The shielding element **660** may be an extra metal layer. The shielding element **660** may be positioned between the charge-based element **620** and the semiconductor element **620** to avoid (or at least reduce) crosstalk effects between the two detection elements. More specifically, the shielding element **660** may be positioned between the metal layer **621** of the charge-based element **620** and the lower metal layer **613** of the semiconductor element **610**. This would mean that signal particles need to travel through a thicker layer before reaching detector **610**, so this shielding element **660** is preferably as thin as possible. Additionally, the electrically insulating element **630** may have portions, e.g. thin portions **630A** and **630B**, either side of the shielding element. The thin portions **630A**, **630B** may be protrusions of the electrically insulating element **630**. The thin portions **630A**

and **630B** may be provided as a thin film, or layer, or planar portion. Thus, there may be an electrically insulating portion **630A** between the charge-based element **620** and the shielding element **660** and an electrically insulating portion **630B** between the semiconductor element **610** and the shielding element **660**. Preferably, the electrically insulating portions **630A**, **630B** are also as thin as possible. The thin portions **630A**, **630B** may each have a thickness as described above in relation to the electrically insulating element **630**, for example, the thickness of each portion **630A**, **630B** may be between approximately 10 to 500 nm. The thickness may depend on the material and may optionally be SiO₂ as described. The shielding element **660** could be used in any of the detectors described above, e.g. as described in relation to FIG. **14**, FIG. **15** and/or FIG. **16**.

(198) The detector array may further comprise a wiring layer. The wiring may be routed between cells. Thus, the wiring layer may include the wiring routes **554** described above. The wiring layer may connect to the circuitry of a cell (e.g. relating to a single semiconductor element and a single charge-based element) away from the apertures, e.g. defined through the cell array as described above. The wiring layer may comprise shielding between wiring connecting different cells. For example, the wiring layer may comprise a shielding arrangement as shown in and described above in relation to FIG. **13**. The cells may only be connected to each other via the wiring of the wiring layer. The wiring layer may be formed between and around the cells. The wiring layer and the circuitry layer may form a single layered portion together. (Within the layered portion, the wiring and circuitry may take up as many of the CMOS layers as the CMOS architecture permits), Alternatively the wiring layer and the circuitry layer may each have their own respective layered portion. The wiring layer may form a connection for a cell in between the cells of the cell array. The wiring layer may externally connect a cell so that the detection signal of a detector may be transmitted from a cell to an external connection towards a processor for processing detection signal. The circuits and wiring of each cell are generally isolated; that is the cells are electrically insulated from each other. The wiring layer connects the associated detector to a data path for transmitting detection signals from the detector array in a manner which reduces the risk of disruption to the detection signal. The wires for transporting the detection signal externally are isolated to prevent cross-talk. The wiring layer and/or the circuitry layer may form, for example separately or together, a monolithic layered portion in the substrate configured to connect to each of the detectors in the detector array.

(199) As described above in relation to the single detectors, the charge-based element **620** may be closer to the detection surface. Thus, the charge detector layer may be closer to the detection surface of the detector array than the corresponding semiconductor element layer. Each of the charge-based elements **620** may overlap with at least part of the corresponding semiconductor element **610**. In an embodiment, the overlap is substantially complete, as shown in FIG. **17**. Thus, the array may be provided based on the detector as shown in FIG. **14**. In another embodiment, there may only be a partial overlap. In this case, the detection surface may be provided by the charge detector layer and the semiconductor detector layer. Thus, the array may be provided based on the detector **600** as shown in FIG. **15**. In another embodiment, there may be no overlap. In this case, the detection surface may be provided by the charge detector layer and the semiconductor detector layer. Thus, the array may be provided based on the detector as shown in FIG. **16**.

(200) Any of the detectors described above may be provided as part of a charged particle device for an assessment tool to detect charged particles from a sample.

(201) The charged particle device may be a single beam device, for example as described in relation to FIG. **9**, although other configurations may be used for the provision of a single beam device. The charged particle device may comprise an objective lens (e.g. of objective lens assembly **132**) configured to project the primary beam of charged particles onto the sample **208**. The objective lens may be configured as described above. Preferably, an aperture is defined in the objective lens for the primary beam and an aperture is defined in the substrate of the detector **600** which is aligned with the aperture in the objective lens. Although as described above, the detector

600 could be provided to the side of the primary beam, such that the detector does not have an aperture formed through the detector. In this case, the detector **600** may still be aligned with the primary beam, e.g. by being positioned in the charged particle device in close proximity to the primary beam so as to detect signal particles emitted from the sample.

(202) The detector used in the charged particle device may be as described in any of the above embodiments and variations.

(203) The detector used in the charged particle device may comprise a first detector element configured to detect signal particles above the first energy threshold and a second detector element configured to detect signal particles below the second energy threshold. In this instance, the detector may be proximate the sample, and may comprise a semiconductor element. Thus, two different types of detector may be provided close to the sample, wherein the detector **600** at least comprises the semiconductor element. It is beneficial that the detector is proximate the sample, because at this location, the energy differential between the lower signal particles and the higher signal particles will be greater than further up-beam (towards the source). At this position, the energy difference may be at its greatest in magnitude. In arrangement, the ratio in energy is at its greatest. This assumes that the signal particles are substantially not accelerated towards the detector. However, there may be a potential difference applied to accelerate signal particles towards the detector, which is described further below.

(204) As described above, in general it can be expected that the effective first and second energy thresholds are different because of the energy loss in the layers between the first detector element and the second detector element.

(205) The first detector element may be the semiconductor element described in detail above. The second detector element may be the charge-based element described in detail above.

(206) The charged particle device may be a multi-beam device, for example as described in relation to FIGS. **3** and **8**, although other configurations may be used for the provision of a multi-beam device. The charged particle device may comprise an objective lens array **241** configured to project a plurality of sub-beams of charged particles onto the sample **208** in a multi-beam array. The objective lens array **241** may be configured as described above. The charged particle device may comprise a detector array as described above, or a detector system comprising a detector array as described above. Preferably, an aperture is defined in the objective lens array for each of the sub-beams and an aperture is defined in each of the detectors of the detector array. Preferably the apertures of the at least one detector array are aligned with the apertures defined in the objective lens array **241**.

(207) The detector may be associated with the objective lens array **241**. For example, the detector may be structurally connected to the objective lens array **241**. Thus, the detector may be positioned on, attached, or directly connected to the objective lens. Specifically, the detector may be associated with a major surface of an electrode plate of the objective lens array **241**. Thus, the detector may be structurally connected to an electrode of the objective lens array **241**. The detector may be positioned adjacent to, or structurally connected to the most down-beam electrode of the objective lens array **241**. The detector **600** may be positioned adjacent to, or structurally connected to, a down-beam surface of the most down-beam electrode of the objective lens array **241**. The detector could be positioned adjacent to, or structurally connected to, the most up-beam electrode of the objective lens array **241**. If the detector is part of the detector array, the detector array and or detector system may be associated with the objective lens array **241** as described herein.

(208) The detector **600** may be positioned in any appropriate location in the charged particle device. The detector may provide a surface of the device. Preferably the surface of the device is configured to face the sample. Preferably the detector is proximate the sample. Preferably the detector is adjacent the sample. Preferably the detector is directly adjacent the sample and there are no other components between the detector and the sample. It is beneficial to provide the detector proximate the sample because this improves overall detection efficiency of the lower and higher

energy signal particles simultaneously at the detector elements. The detector **600** could be provided up-beam of the objective lens array **241** along the path of the primary beam **320**. If the detector **600** is part of the detector array, the detector array and or detector system may be positioned as described herein.

(209) The device may be configured to apply a potential difference between the sample **208** and the detector array for example applied to at least part of the detector array, for example to at least a detector, for example to at least part of a detector such as a charge-based element and/or a semiconductor based element. The potential difference may be referred to as a bias voltage. For example, the potential may be relatively small. For example, the potential difference between the sample **208** and the detector array may be approximately 50 V-300 V. The detector array may be more positive than the sample. Thus, the potential difference may be used to attract signal particles to the detector array. Such an accelerating voltage (e.g. around 50 V-300 V) is small compared the difference in energy between lower energy signal particles (e.g. secondary signal particles with a maximum energy of approximately 50 eV) and higher energy signal particles (e.g. backscatter signal particles with a maximum energy up to the landing energy of keV's or more). It will be noted that a small potential difference will tend to have a greater effect on the lower energy particles, such as those corresponding to the secondary signal particles. Of course, the same potential may be applied to a single detector, e.g. when provided as part of a single beam device.

(210) Any of the configurations of detector described above may have such a potential difference applied to attract signal particles which may be beneficial as described above. It is noted that the use of this potential difference is particularly beneficial for the configuration of the detector in which the charge-based element partially covers the semiconductor element as shown in FIG. **15** or provides an inner ring as in FIG. **16**. In this case, the lower energy signal particles (e.g. secondary signal particles) may be accelerated upwards due to the resulting field between the sample and the detector. This may mean that the lower energy signal particles predominantly hit (or only hit) the charge-based element **621** formed as an inner ring of a concentric detector. Thus, it might be advantageous to only use the charge-based element on this inner ring because this reduces the creation of charge by larger energy signal particles (e.g. backscatter signal particles) in the charge-based element and reduces noise.

(211) In an arrangement of detector **600** at least one of the first and second elements is a charge-based detector or a semiconducting detector. The substrate, for example of the detector **660**, may comprises layers comprising the first and second elements in different layers. The detector further comprising an electrically insulating element between the charge-based element and the semiconductor element. The detector may comprise two charge detector elements that are configured to detect different signal particles and to detect simultaneously. Alternatively or additionally the detector may comprise a charge-based element and a semiconducting element and configured such that the semiconductor element and the charge-based element detect simultaneously.

(212) In such an arrangement of detector, an aperture is defined in the substrate for the passage therethrough of a charged particle beam. The first energy threshold may corresponds to a backscatter threshold energy. The second energy threshold may correspond to a secondary threshold energy. The first energy threshold and the second energy threshold are substantially the same or have an offset. At least one charge-based element comprises a metal layer. An electrically insulated via is configured to connect the charge-based element to detector circuitry. The vias are electrical connectors. A charge-based element may be electrically connected with an electrical connector. The semiconductor elements may be electrically connected, i.e. respectively electrically connected, with an electrical connector. The charge-based element and the semiconductor element are each at least part of layers that are substantially co-planar with the major surfaces of the detector. The charge-based element and the semiconductor element are each at least part of layers that are stacked structure along the beam path. A detector array may comprise a plurality of such

detectors; the detectors are comprised in a common substrate. Each detector may correspond to a respective sub-beam of a multi-beam array. The apertures in the plurality of detectors are for passage of the sub-beams. Such a detector and detector array may take the features of other embodiments of detector and detector array described herein.

(213) In embodiment of charged particle device which may be for a multi-beam assessment system (or assessment tool) configured to detect charged particles from a sample. The device comprises an objective lens for example as herein disclosed and a detector for example as herein disclosed. The objective lens array may be configured to project a plurality of beams of charged particles onto a sample. The detector may be proximate the sample. In the detector are defined a plurality of apertures for paths of the beams towards the sample. In an embodiment the detector comprises a first detector layer and second detector layer. The first detector layer may be a first element. The second detector layer may be a second element. The first detector layer may be configured to detect signal particles above a first energy threshold, for example above a backscatter threshold energy. The second detector layer may be configured to detect signal particles below a second energy threshold for example below a secondary threshold energy. At least one of the first and second detector layers is a charge-based detector or a semiconducting detector. The second detector layer and the first detector layer are configured to detect simultaneously.

(214) Embodiments of the present invention may also provide a method of detecting signal particles using any of the detector, detector array, or charged particle devices as described above.

(215) In an embodiment, a method is provided of projecting a beam of charged particles onto a sample **208** so as to detect signal particles emitted from the sample **208**. The method comprises projecting the beam along a primary beam path onto a surface of the sample **208**. The method comprises detecting the signal particles emitted from the sample simultaneously at a semiconductor element and at a charge-based element.

(216) In an embodiment, a method is provided of projecting a beam of charged particles onto a sample **208** so as to detect signal particles emitted from the sample **208**. The method comprises projecting the beam along a primary beam path onto a surface of the sample. The method further comprises detecting the signal particles emitted from the sample at a detector, the detector being proximate the sample and comprising a semiconductor element, the detecting comprising simultaneous detection of signal particles above a first energy threshold at a first detector element and signal particles below a second energy threshold at a second detector element.

(217) In an embodiment, a method is provided of projecting a plurality of sub-beams of charged particles onto a sample **208** so as to detect signal particles emitted from the sample **208**. The method comprises projecting the sub-beams along primary sub-beam paths onto a surface of the sample **208**. The method further comprises detecting the signal particles emitted from the sample at a detector array, the detector array being proximate the sample and comprising a detector comprising a semiconductor element corresponding to each sub-beam, the detector comprising a first detector element and a second detector element, the detecting comprising simultaneous detection by each detector of signal particles above a first energy threshold at the corresponding first detector element and signal particles below a second energy threshold at the second detector element.

(218) In an embodiment, a method is provided of projecting a beam of charged particles onto a sample so as to detect signal particles emitted from the sample **208**. The method comprises providing a device according to any of the above described embodiments or variations. The method further comprises projecting a beam of charged particles to the sample using the objective lens and detecting the resulting signal particles simultaneously using the semiconductor element **610** and the charge-based element **620**.

(219) In the present description, it will be understood that the charged particles/signal particles are generally intended to be electrons, or other negatively charged particles. However, contrary to the above, the charged particles/signal particles may be positively charged particles, e.g. ions. Thus, a

primary ion beam may be provided. With a primary ion beam, secondary ions could be emitted from the sample that could be detected by the charge-based element **620**. However, this would also generate negative charged particles, e.g. secondary electrons at the same time. So the charge accumulated with this charge-based element **620** will be a mix of positively and negatively charged particles, which would make the charged measurement unreliable. However, having either a positive or negative bias on the charge-based element **620** would make it possible to choose one of the charge polarities. Because of the much smaller range of ions than electrons in a material, backscatter ions need a much larger kinetic energy to be able to reach the semiconductor element **610**. Thus, not all backscatter ions will make it to this detector component. To improve the detection of backscatter ions, the charge-based element **620** could be made thinner. In the instance that ions are used instead of negatively charged particles, then any bias referred to above would be opposite, e.g. a positive bias should be used instead of a negative one and vice versa.

(220) The terms “sub-beam” and “beamlet” are used interchangeably herein and are both understood to encompass any radiation beam derived from a parent radiation beam by dividing or splitting the parent radiation beam. The term “manipulator” is used to encompass any element which affects the path of a sub-beam or beamlet, such as a lens or deflector. References to elements being aligned along a beam path or sub-beam path are understood to mean that the respective elements are positioned along the beam path or sub-beam path. References to optics are understood to mean electron-optics.

(221) While the description and drawings are directed to an electron-optical system, it is appreciated that the embodiments are not used to limit the present disclosure to specific charged particles. References to electrons throughout the present document may therefore be more generally be considered to be references to charged particles, with the charged particles not necessarily being electrons. The charged-particle optical device may be a negative charged particle device. The charged-particle optical device may otherwise be referred to as an electron-optical device. It will be understood that an electron is a specific charged particle and can replace all instances of charged particle referred to throughout the application as appropriate. For example, the source may specifically provide electrons. The charged particle referred to throughout the specification may be specifically a negatively charged particle.

(222) The charged particle-optical device may more specifically be defined as a charged particle-optical column. In other words, the device may be provided as a column. The column may thus comprise an objective lens array assembly as described above. The column may thus comprise a charged particle optical system as described above, for example comprising an objective lens array and optionally a detector array and/or optionally a condenser lens array.

(223) The charged particle optical device described above comprises at least the objective lens array **240**. The charged particle optical device may comprise the detector array **241**. The charged particle optical device may comprise the control lens array **250**. The charged particle optical device comprising the objective lens array and the detector array may thus be interchangeable with, and referred to as, the objective lens array assembly, which may optionally comprise the control lens array **250**. The charged particle optical device may comprise additional components described in relation to either of FIG. **3** and/or FIG. **8**. Thus, the charged particle optical device may be interchangeable with, and referred to as, a charged particle assessment tool **40** and/or a charged particle optical system if comprising the additional components in these figures.

(224) An assessment tool according to an embodiment of the invention may be a tool which makes a qualitative assessment of a sample (e.g. pass/fail), one which makes a quantitative measurement (e.g. the size of a feature) of a sample or one which generates an image or map of a sample. Examples of assessment tools are inspection tools (e.g. for identifying defects), review tools (e.g. for classifying defects) and metrology tools, or tools capable of performing any combination of assessment functionalities associated with inspection tools, review tools, or metrology tools (e.g. metro-inspection tools). The charged particle beam tool **40** (which may be a charged particle-

optical column) may be a component of an assessment tool; such as an inspection tool or a metro-inspection tool, or part of an e-beam lithography tool. Any reference to a tool herein is intended to encompass a device, apparatus or system, the tool comprising various components which may or may not be collocated, and which may even be located in separate rooms, especially for example for data processing elements.

(225) Reference to a component or system of components or elements being controllable to manipulate a charged particle beam in a certain manner includes configuring a controller or control system or control unit to control the component to manipulate the charged particle beam in the manner described, as well as optionally using other controllers or devices (e.g. voltage supplies and/or current supplies) to control the component to manipulate the charged particle beam in this manner. For example, a voltage supply may be electrically connected to one or more components to apply potentials to the components, such as in a non-limited list including the control lens array **250**, the objective lens array **241**, the condenser lens **231**, correctors, collimator element array **271**, detector array **240n** (such as one or more of the charge-based elements and/or one or more of the semiconductor elements), the stage **209** (so for example the sample **207**) and scan deflector array **260**; such voltage supply may be under the control of the controller or control system or control unit. The voltage supply may apply a potential difference such as a bias voltage to at least part of detector (or detector array such as the charge-based elements and/or semiconductor elements) for example relative to a sample **207**. Such bias voltage may be controlled for example by control system for example controller **50**. An actuatable component, such as a stage, may be controllable to actuate and thus move relative to another components such as the beam path using one or more controllers, control systems, or control units to control the actuation of the component.

(226) The embodiments herein described may take the form of a series of aperture arrays or charged particle-optical elements arranged in arrays along a beam or a multi-beam path. Such charged particle-optical elements may be electrostatic. In an embodiment all the charged particle-optical elements, for example from a beam limiting aperture array to a last charged particle-optical element in a sub-beam path before a sample, may be electrostatic and/or may be in the form of an aperture array or a plate array. In some arrangements one or more of the charged particle-optical elements are manufactured as a microelectromechanical system (MEMS) (i.e. using MEMS manufacturing techniques).

(227) The system or device of such architectures as depicted in at least FIGS. **3** and **8** and as described above may comprise components such as an upper beam limiter, a collimator element array **271**, a control lens array **250**, a scan deflector array **260**, an objective lens array **241**, a beam shaping limiter and/or a detector array **240**; one or more of these elements that are present may be connected to one more adjacent elements with an isolating element such as a ceramic or glass spacer.

(228) A computer program may comprise instructions to instruct the controller **50** to perform the following steps. The controller **50** controls the charged particle beam apparatus to project a charged particle beam towards the sample **208**. In an embodiment the controller **50** controls at least one charged particle-optical element (e.g. an array of multiple deflectors or scan deflectors **260**, **265**) to operate on the charged particle beam in the charged particle beam path. Additionally or alternatively, in an embodiment the controller **50** controls at least one charged particle-optical element (e.g. the detector array **240**) to operate on the charged particle beam emitted from the sample **208** in response to the charged particle beam.

(229) Any element or collection of elements may be replaceable or field replaceable within the charged particle beam tool **40**. The one or more charged particle-optical components in the charged particle beam tool **40**, especially those that operate on sub-beams or generate sub-beams, such as aperture arrays and manipulator arrays may comprise one or more MEMS.

(230) While the present invention has been described in connection with various embodiments, other embodiments of the invention will be apparent to those skilled in the art from consideration

of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims and clauses.

(231) There are provided the following clauses:

(232) Clause 1: A detector for use in a charged particle device for an assessment tool to detect signal particles from a sample, the detector comprising or comprised in a substrate, the substrate comprising: a semiconductor element configured to detect signal particles, e.g. from a sample, above a first energy threshold; and a charge-based element configured to detect signal particles, e.g. from the sample, below a second energy threshold, desirably the charged particle device configured to project a beam of charged particles to the sample, desirably the detector configured to detect the resulting signal particles, desirably the resulting signal particles comprising the signal particles above the first energy threshold and desirably the resulting signal particles comprising the signal particles below the second energy threshold, and desirably an electrical connector, for example a via, may be configured to electrically connect the semiconductor element and/or the charge-based element for example to so as to apply a potential difference to at least part of the detector for example the charge-based element and/or a semiconductor based element, the potential difference may be a biasing voltage

(233) Clause 2: The detector of clause 1, wherein an aperture is defined in the substrate for the passage therethrough of a charged particle beam (or of the respective charged particle sub-beams).

(234) Clause 3: The detector of clause 1 or clause 2, further comprising an electrically insulating element between the charge-based element and the semiconductor element.

(235) Clause 4: The detector of any of clauses 1 to 3, wherein the first energy threshold corresponds to a backscatter threshold energy.

(236) Clause 5: The detector of any preceding clause, wherein the second energy threshold corresponds to a secondary threshold energy.

(237) Clause 6: The detector of any preceding clause, wherein the first energy threshold and the second energy threshold are substantially the same or have an offset.

(238) Clause 7: The detector of any of the preceding clauses, wherein the charge-based element comprises a metal layer.

(239) Clause 8: The detector of any of the preceding clauses, further comprising an electrically insulated via configured to connect the charge-based element to detector circuitry, preferably the substrate comprises a circuitry layer comprising the detector circuitry.

(240) Clause 9: The detector of clause 8, wherein the electrically insulated via extends through at least part of the semiconductor element.

(241) Clause 10: The detector of any of the preceding clauses, wherein the semiconductor element comprises an upper metal layer and a lower metal layer on either side of a p-i-n region.

(242) Clause 11: The detector of clause 10, wherein the lower metal layer is also part of the charge-based element.

(243) Clause 12: The detector of clause 10 or clause 11, wherein the upper metal contact is connected to detector circuitry that is preferably comprised in a circuitry layer in the substrate.

(244) Clause 13: The detector of any of the preceding clauses, wherein the charge-based element and the semiconductor element are each at least part of layers that are substantially co-planar with the major surfaces of the detector and the layers are comprised in a stacked structure comprised in the detector stacked in a thickness direction of the detector.

(245) Clause 14: The detector of any of the preceding clauses, wherein the charge-based detector element forms a layer over substantially the whole semiconductor element.

(246) Clause 15: The detector of any of the preceding clauses, wherein the charge-based element is closer to a detector surface (or an individual detector surface) than the semiconductor element, preferably the charge-based element provides at least part of the detector surface (or the individual detector surface).

(247) Clause 16: The detector of any of clauses 1 to 12, wherein the charge-based element and the semiconductor element are positioned adjacent to each other in cross-section, preferably the charge-based element provides at least part of the detector surface (or the individual detector surface) and the semiconductor element provides at least part of the detector surface (or the individual detector surface).

(248) Clause 17: The detector of clause 16, wherein the charge-based element and the semiconductor element each comprise an annulus which are preferably concentric and radially divided from each other.

(249) Clause 18: The detector of clause 16 or 17, wherein the charge-based element and the semiconductor element each comprise sectors which are preferably angularly divided.

(250) Clause 19: The detector of any preceding clause, wherein the charge-based element has a thickness of approximately 100 nm or less, preferably approximately 10 nm to 100 nm.

(251) Clause 20: The detector of any preceding clause, wherein the charge-based element is connected to a transimpedance amplifier preferably in a circuitry layer and/or the semiconductor element is connected to a transimpedance amplifier preferably in a circuitry layer and/or further comprising a shielding layer **660** positioned between the charge-based element and the semiconductor element, preferably with electrically insulating portions between the charge-based element and the shielding layer and between the semiconductor element and the shielding layer.

(252) Clause 21: A detector for use in a charged particle device, the detector comprising a substrate, the substrate comprising: a first element configured to detect signal particles above a first energy threshold; and a second element configured to detect signal particles below a second energy threshold, wherein at least one of the first and second elements is a charge-based detector or a semiconducting detector

(253) Clause 22: The detector of clause 21, wherein the substrate comprises layers comprising the first and second elements in different layers and/or the detector further comprises an electrically insulating element between the charge-based element and the semiconductor element.

(254) Clause 23: The detector of clause 21 or 22, wherein the detector comprises two charge detector elements that are configured to detect different signal particles and to detect simultaneously

(255) Clause 24: The detector of any of clauses 21 to 23, wherein the detector comprises a charge-based element and a semiconducting element and configured such that the semiconductor element and the charge-based element detect simultaneously.

(256) Clause 25: The detector of clauses 21 to 24, wherein an aperture is defined in the substrate for the passage therethrough of a charged particle beam.

(257) Clause 26: The detector of any of clauses 21 to 25 wherein the first energy threshold corresponds to a backscatter threshold energy.

(258) Clause 27: The detector of any of clauses 21 to 26 wherein the second energy threshold corresponds to a secondary threshold energy.

(259) Clause 28: The detector of any of clauses 21 to 27, wherein the first energy threshold and the second energy threshold are substantially the same or have an offset.

(260) Clause 29: The detector of any of clauses 21 to 28, wherein at least one of the charge-based element comprises a metal layer.

(261) Clause 30: The detector of any of clauses 21 to 29, further comprising an electrically insulated via configured to connect the charge-based element to detector circuitry,

(262) Clause 31: The detector of any of clauses 21 to 30, wherein the charge-based element and the semiconductor element are each at least part of layers that are substantially co-planar with the major surfaces of the detector and are stacked structure along the beam path.

(263) Clause 32: The detector of any of clauses 21 to 31, wherein the detectors are comprised in a common substrate, each detector corresponding to a respective sub-beam of a multi-beam array, the apertures of the plurality of detectors are for passage of the sub-beams

(264) Clause 33: A detector array comprising a plurality of detectors according to any preceding clause, wherein the detectors are comprised in a common substrate, each detector corresponding to a respective sub-beam, preferably: a) the semiconductor element of each detector is in a common semiconductor layer of the substrate; b) the charge-based element of each detector is in a common charge-based layer of the substrate; c) the circuitry layer of each detector is comprised in a common circuitry layer of the substrate; d) the electrically insulating element between the charge-based element and the semiconductor element of each detector is in a common electrically insulating layer of the substrate; e) the detectors being arranged in an array corresponding in arrangement to the array of sub-beams of the multi-beam array, wherein the arrangement may be a hexagonal or rectilinear grid; and/or f) apertures of the plurality of detectors are for passage of sub-beams of a multi-beam array.

(265) Clause 34: A detector array for use in a multi-beam charged particle device for an assessment tool to detect signal particles from a sample, the detector array comprising at least one substrate in which is defined an plurality of apertures for the passage therethrough of the plurality of sub-beams of charged particle beams towards a sample, the substrate comprising: a plurality of semiconductor elements configured to detect signal particles above a first energy threshold; and a plurality of charge-based elements configured to detect signal particles below a second energy threshold, wherein each semiconductor element is associated with a corresponding one of the charge-based elements.

(266) Clause 35: The detector array of clause 34, wherein the substrate comprises a semiconductor detector layer comprising the plurality of semiconductor elements.

(267) Clause 36: The detector array of clause 34 or 35, wherein the substrate comprises a charged detector layer comprising the plurality of charge-based elements.

(268) Clause 37: The detector array of clause 36, wherein the charge-based element comprises a metal layer.

(269) Clause 38: The detector array of clause 36 or 37, wherein the charge detector layer is closer to a detection surface of the detector array than the corresponding semiconductor element, the detection surface being the surface of the detector array for passage of the signal particles to the semiconductor element or the charge-based element.

(270) Clause 39: The detector array of any of clauses 36 to 38, wherein each of the charge-based elements overlaps with at least part of the corresponding semiconductor element, preferably the overlap is substantially complete.

(271) Clause 40: The detector array of any of the clauses 36 to 38, wherein charge-based element and the semiconductor element are positioned adjacent to each other, e.g. in cross-section.

(272) Clause 41: The detector of any of the preceding clauses, the substrate further comprising an electrically insulating element between the charge-based elements and the semiconductor elements.

(273) Clause 42: The detector array of any of the preceding clauses, the substrate further comprising a circuitry layer comprising a plurality of cells comprising circuitry associated with the charge-based element and/or the semiconductor elements.

(274) Clause 43: The detector array of clause 42, further comprising one or more vias for each cell, connecting the respective charge-based element and/or the respective semiconductor element to the circuitry of the cell.

(275) Clause 44: The detector array of clause 43, wherein the circuitry layer comprises a transimpedance amplifier and/or an analog-to-digital converter in each cell, optionally for each of the respective charge-based element and/or the respective semiconductor element of the corresponding cell.

(276) Clause 45: The detector array of clause 44, further comprising a wiring layer, wherein the wiring layer comprises wiring that connects the circuitry of the cell away from the plurality of apertures

(277) Clause 46: The detector array of clause 45, wherein the wiring is routed between cells.

(278) Clause 47: The detector array of either clause 45 or 46, wherein the wiring comprises shielding between wiring connecting different cells.

(279) Clause 48: A charged particle device for a multi-beam assessment system to detect charged particles from a sample, the device comprising: an objective lens array configured to project a plurality of beams of charged particles onto a sample; and a detector proximate the sample and in which are defined a plurality of apertures for paths of the beams towards the sample, the detector comprising: a first detector layer for detecting signal particles above a first energy threshold and a second detector layer for detecting signal particles below a second energy threshold wherein at least one of the first and second detector layers is a charge-based detector or a semiconducting detector and/or the second detector layer and the first detector layer are configured to detect simultaneously

(280) Clause 49: A charged particle device for an assessment tool to detect signal particles from a sample, the device comprising: an objective lens configured to project a beam of charged particles onto a sample; and a detector of any of the clauses 1 to 32.

(281) Clause 50: The charged particle device of clause 49, wherein an aperture is defined in the objective lens for the beam and an aperture is defined in the substrate of the detector which is aligned with the aperture in the objective lens.

(282) Clause 51: A charged particle device for an assessment tool to detect signal particles from a sample, the device comprising: an objective lens array configured to project a plurality of sub-beams of charged particles onto a sample in a multi-beam array, and in which an aperture is defined for each sub-beam; and a detector system comprising at least one detector array of any of clauses 19 to 47, wherein the apertures of the at least one detector array are aligned with the apertures defined in the objective lens array.

(283) Clause 52: The charged particle device of clause 51, wherein at least one detector of the detector system is structurally connected to the objective lens.

(284) Clause 53: The charged particle device of clause 51 or 52, wherein at least one detector is associated with a major surface of an electrode plate of the objective lens.

(285) Clause 54: The charged particle device of any of clauses 49 to 53, wherein at least one detector provides a surface of the device, preferably configured to face a sample and/or such that the detector (or the at least one detector) is proximate the sample.

(286) Clause 55: The charged particle device of any of clauses 49 to 54, wherein at least one detector is provided up beam along the path of the plurality of sub-beams of the objective lens.

(287) Clause 56: A charged particle device for an assessment tool to detect charged particles from a sample, the device comprising: an objective lens configured to project a beam of charged particles onto a sample, and in which an aperture is defined for the beam; and a detector proximate the sample and defining an aperture aligned with the aperture of the objective lens, the detector comprising a first detector element configured to detect signal particles above a first energy threshold and a second detector element configured to detect signal particles below a second energy threshold simultaneously, wherein the detector comprises a semiconductor element.

(288) Clause 57: The charged particle device of clause 56, wherein the first detector element comprises the semiconductor element.

(289) Clause 58: The charged particle device of either of clauses 56 or 57, wherein the second detector element comprises a charge-based detector element.

(290) Clause 59: The charged particle device of clause 58, wherein the detector is according to any of clauses 1 to 32.

(291) Clause 60: The charged particle device of any of clauses 49 to 59, the device being configured to apply a potential difference between the sample and the detector.

(292) Clause 61: The charged particle device of clause 60, wherein the potential difference between the sample and the detector is approximately 50 V-300 V.

(293) Clause 62: The charged particle device of either of clauses 60 or 61, wherein the detector is

more positive than the sample.

(294) Clause 63: The charged particle device of any of clause 48 to 62 further comprising a voltage supply configured to be electrically connected to one or more components to apply potentials to the components, desirably further comprising a controller configured to control the voltage supply

(295) Clause 64: The charged particle device of clause 63, wherein the voltage supply is configured to apply a bias voltage to at least part of the detector (or the detector array), desirably the detector for example between the detector (or detector array) and the sample.

(296) Clause 65: A charged particle assessment tool comprising the charged particle device of any of clause 48 to 64, desirably the charged particle assessment tool is for assessing by detecting signal particles from a sample using a charged particle device for projecting a multi-beam of charged particles towards a sample

(297) Clause 66: The assessment tool of clause 65 comprising a stage configured to support a sample, desirably the stage comprising a sample holder configured to hold a sample.

(298) Clause 67: A method of projecting a beam of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: a) projecting the beam along a primary beam path onto a surface of the sample; and b) detecting the signal particles emitted from the sample simultaneously at a semiconductor element and at a charge-based element.

(299) Clause 68: A method of projecting a beam of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: a) projecting the beam along a primary beam path onto a surface of the sample; and b) detecting the signal particles emitted from the sample at a detector, the detector being proximate the sample and comprising a semiconductor element, the detecting comprising simultaneous detection of signal particles above a first energy threshold at a first detector element and signal particles below a second energy threshold at a second detector element.

(300) Clause 69: A method of projecting a plurality of sub-beams of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: a) projecting the sub-beams along primary sub-beam paths onto a surface of the sample; and b) detecting the signal particles emitted from the sample at a detector array, the detector array being proximate the sample and comprising a detector comprising a semiconductor element corresponding to each sub-beam, the detector comprising a first detector element and a second detector element, the detecting comprising simultaneous detection by each detector of signal particles above a first energy threshold at the corresponding first detector element and signal particles below a second energy threshold at the second detector element.

(301) Clause 70: A method of projecting a beam of charged particles onto a sample so as to detect signal particles emitted from the sample, the method comprising: providing a device according to any of clauses 48 to 53; projecting a beam of charged particles to the sample using the objective lens; detecting the resulting signal particles simultaneously using the semiconductor element and the charge-based element.

Claims

1. A detector for use in a charged particle device for an assessment tool, the charged particle device configured to project a beam of charged particles to a sample and the detector to detect resulting signal particles from the sample, the detector comprising a substrate, the substrate comprising: a semiconductor element configured to detect signal particles above a first energy threshold; and a charge-based element configured to detect signal particles below a second energy threshold, wherein the charge-based element and the semiconductor element are each at least part of layers that are substantially co-planar with major surfaces of the detector and the layers are comprised in a stacked structure comprised in the detector stacked in a thickness direction of the detector, and wherein the charge-based element is connected by a first electrical connection to detection circuitry

and the semiconductor element is connected by a second electrical connection to detection circuitry, the first electrical connection being separate from the second electrical connection.

2. The detector of claim 1, wherein an aperture is defined in the substrate for the passage therethrough of a charged particle beam.
3. The detector of claim 1, further comprising an electrically insulating element between the charge-based element and the semiconductor element.
4. The detector of claim 1, wherein the first energy threshold corresponds to a backscatter threshold energy.
5. The detector of claim 1, wherein the second energy threshold corresponds to a secondary threshold energy.
6. The detector of claim 1, wherein the first energy threshold and the second energy threshold are substantially the same or have an offset.
7. The detector of claim 1, wherein the charge-based element comprises a metal layer.
8. The detector of claim 1, wherein the first electrical connection comprises an electrically insulated via configured to connect the charge-based element to detector circuitry.
9. The detector of claim 8, wherein the electrically insulated via extends through at least part of the semiconductor element.
10. The detector of claim 1, wherein the semiconductor element comprises an upper metal layer and a lower metal layer on either side of a p-i-n region.
11. The detector of claim 10, wherein the lower metal layer is also part of the charge-based element, and/or wherein the upper metal layer is connected to detector circuitry.
12. The detector of claim 1, wherein the charge-based element forms a layer over substantially the whole semiconductor element.
13. The detector of claim 1, wherein the charge-based element is closer to a detector surface than the semiconductor element.
14. The detector of claim 1, wherein the charge-based element and the semiconductor element are positioned adjacent to each other in cross-section.
15. The detector of claim 14, wherein the charge-based element and the semiconductor element each comprise an annulus and radially divided from each other and/or wherein the charge-based element and the semiconductor element each comprise sectors.
16. A detector for use in a charged particle device for an assessment tool, the charged particle device configured to project a beam of charged particles to a sample and the detector to detect resulting signal particles from the sample, the detector comprising a substrate, the substrate comprising: a semiconductor element configured to detect signal particles above a first energy threshold; a charge-based element configured to detect signal particles below a second energy threshold; and an electrically insulated via configured to connect the charge-based element to detector circuitry, wherein the electrically insulated via extends through at least part of the semiconductor element.
17. The detector of claim 16, wherein the substrate comprises a circuitry layer comprising the detector circuitry.
18. The detector of claim 16, wherein the semiconductor element comprises an upper metal layer and a lower metal layer on either side of a p-i-n region.
19. The detector of claim 18, wherein the lower metal layer is also part of the charge-based element and/or wherein the upper metal layer is connected to detector circuitry.
20. A method of projecting a beam of charged particles onto a sample so as to detect resulting signal particles emitted from the sample, the method comprising: projecting the beam along a primary beam path onto a surface of the sample; and detecting the resulting signal particles emitted from the sample at a detector, the detector being proximate the sample and comprising a semiconductor element, the detecting comprising simultaneous detection of signal particles above a first energy threshold at a first detector element and signal particles below a second energy

threshold at a second detector element, wherein the first and second detector elements are comprised in a stacked structure comprised in the detector and are stacked in a thickness direction of the detector, the thickness being the smallest of the three dimensions of the detector, and wherein the first detector is connected by a first electrical connection to detection circuitry and the second detector element is connected by a second electrical connection to detection circuitry, the first electrical connection being separate from the second electrical connection.
