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(54) Title: METHOD FOR POSITIONING AN OPTICAL COMPONENT IN A LIGHT IMAGING DEVICE FOR CATHODOLUMINESCENCE INSPECTION AND APPARATUS ARRANGED FOR APPLYING SAID METHOD

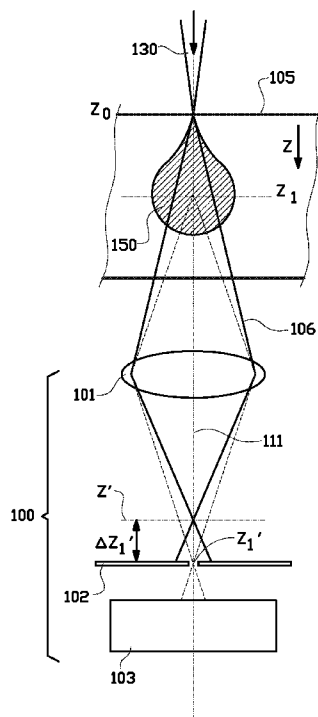


FIG. 6

(57) Abstract: The invention provides a method for positioning an optical component in a conjugate plane of a focal plane of a light imaging device, comprising the steps of: a. irradiate a substrate arranged at the focal plane by a charged particle beam having a selected energy to create light detectable by a light detector of the light imaging device; b. arranging the optical component at various positions in or around said conjugate plane and measuring an intensity of the light as a function of the position of said optical component; c. setting the optical component at a fixed position in or near the conjugate plane, said fixed position being determined using the measured dependence of the intensity of the light as a function of the position of said optical component. According to the invention, the steps are repeated using a charged particle beam with an energy lower than the selected energy.



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Method for positioning an optical component in a light
5 imaging device for cathodoluminescence inspection and
apparatus arranged for applying said method

BACKGROUND

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The invention relates to an improvement in a so-called integrated inspection apparatus, featuring the integration of a charged particle system, such as a scanning electron microscope (SEM), and light imaging device, such as
15 light microscope optics. It also relates to an improvement in a so-called cathodoluminescence inspection apparatus featuring the detection of light generated by charged particles, such as electrons, when they are irradiating a suitable sample or substrate.

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The improvement in particular relates to extension in functionality of such integrated systems, amongst others towards a new and simplified method of aligning optical components in the light detection path of such systems, in particular in such a way as to get a better signal to
25 background ratio.

In a cathodoluminescence inspection apparatus light that is generated in a specimen during or after electron beam irradiation, is detected by the light imaging device. Cathodoluminescence is thus typically studied in an
30 integrated inspection apparatus as described above. For cathodoluminescence the resolution in the sample plane (xy) is very high, but for very high resolution in three dimensions (xyz) problems may arise due to the large penetration depth (z- or axial direction) in the sample or
35 the substrate onto which the sample can be mounted. As cathodoluminescence light is generated in the entire so-called interaction volume (volume into which the charged

particles, such as electrons, penetrate and scatter), there can be a large background signal. For sample features of small detail, i.e. high-(xyz-)resolution features, the background signal from the sample body or the supporting
5 substrate can easily overwhelm the actual cathodoluminescence signal from the features of interest. In those circumstances it may be desirable to use a confocal detection scheme in which an optical component comprising a pinhole is arranged in the light path of the light imaging
10 device at a confocal position with respect to the sample plane.

Such an integrated inspection apparatus comprising an optical microscope of the confocal type is, for example, described in International Patent Application WO2014/042538.
15 In such a system a light collecting lens images the light received from the sample onto an optical component comprising a pinhole, and the light transmitted by the pinhole is directed to a light measuring device. The optical component is arranged to substantially block light beams
20 that are out of focus or laterally offset, i.e. in xy-plane, so that the maximum field of view of the light imaging device is limited.

WO2014/042538 also discloses a method of aligning the optical centres of a charged particle optical inspection
25 system and a light optical inspection system in an integrated inspection apparatus for combined and preferably simultaneous inspection of a substrate. The method comprises the steps of identifying and correlating the centre of the respective optical systems by imaging either system via a
30 substrate, and mutually correlating the optical axes of the two system in a common coordinate system. In case the light optical system is of the confocal type having a pinhole in front of the light detection element, the method may further comprise the steps of:

35 - correlating a position of the electron beam in the coordinate system of the scanning electron microscope and/or the light microscope to the observed change in

detected light signal as a consequence of the position of the pinhole,

- shifting the pinhole with respect to the charged particle and/or the light microscope to a desired position.

5 An important difference between working with light and working with charged particles is that light interacts in general much weaker with materials than charged particles. Light may penetrate deep into or even traverse transparent materials, while the penetration depth of
10 charged particles is limited to a very thin surface layer, usually less than 10 μm thick. The charged particle microscope can thus only extract information from the surface of the sample that is exposed to the beam and the region just underneath this surface. To correlate a light
15 microscope signal with the charged particle microscope signal or to detect a cathodoluminescence signal, it is therefore of importance that the light microscope is focused on the surface of the sample that is exposed to the charged particle beam, and in addition that the field of view of the
20 light optical system, as limited by the pinhole, is position at the surface of the sample that is exposed to the charged particle beam.

It is therefore an aim of the present invention is to provide a method for positioning an optical component,
25 such as an optical component comprising a pinhole, in a conjugate plane of a surface of a substrate in a light microscope by utilizing an exposure of the surface by a charged particle beam.

It should be noted that the invention also relates to positioning an optical component, such as an optical component comprising a pinhole, in a conjugate plane of a surface of a sample in a light microscope without the aim of correlated microscopy.

30 SUMMARY OF THE INVENTION

According to a first aspect, the present

invention provides a method for positioning an optical component in a conjugate plane of a focal plane of a light imaging device, wherein a substrate is arranged at the focal plane of the light imaging device, and wherein the substrate emits light when irradiated with charged particles, the method comprising the steps of:

5 a. creating a light signal detectable with a light detection system of the light imaging device by irradiating the substrate by a charged particle beam having a selected charged particle beam energy;

10 b. arranging the optical component at various positions in or around said conjugate plane and measuring an intensity of the light signal as a function of the position of said optical component;

15 c. setting the optical component at a fixed position in or near the conjugate plane, said fixed position being determined using the measured dependence of the intensity of the light signal as a function of the position of said optical component using the selected charged particle beam energy;

20 d. adjusting the charged particle beam energy to an energy lower than the selected charge particle beam energy;

25 e. moving the optical component in or around the conjugate plane of the light imaging device and measuring the intensity of the light signal as a function of the position of said optical component in the conjugate plane; and

30 f. using the measured dependence of the intensity of the light signal as a function of the position of said optical component in the conjugate plane at said lower charged particle beam energy to determine a new fixed position in the conjugate plane, and when a difference between this new fixed position and the fixed position in the conjugate plane is larger than a position threshold value, the fixed position of the optical component is adjusted to the new fixed position.

The present invention exploits the phenomenon that charged particles do not penetrate deep into a substrate. Therefore cathodoluminescence, which results from irradiating the substrate with charged particles, originates from this relatively thin surface layer and thus provides a thin, well defined, source of luminescence light. According to the present invention this thin source of luminescence light is used for positioning the optical component of the light imaging device at the conjugate plane of the surface of the substrate.

It is noted that cathodoluminescence is almost always excited in a sample or substrate when exposed to a charged particle beam. This cathodoluminescence originates from the entire interaction volume of the charged particles. The depth of the interaction volume below the surface of the sample or substrate is depended on the charged particle energy. So, in principle, with a low energy charged particle beam, the cathodoluminescence originates from near the surface of the substrate and it gives a very tight focus in the conjugate plane of the light imaging device. This is the desired position of the pinhole. However, finding this desired position can be very hard because the cathodoluminescence signal from a low energy charged particle beam can be quite low and thus the cathodoluminescence signal is hard to pick up, in particular when an optical component comprising, for example, a pinhole is misplaced.

The intensity of the cathodoluminescence signal is depended on charged particle energy and the beam current. In general for higher charged particle energy, a stronger signal originating from a larger volume is obtained, and the depth below the surface of the substrate at which cathodoluminescence intensity is at maximum is larger than for larger charged particle energy. Thus, for higher energies, it is more easy to get the optical component in a position where at least some cathodo-luminescence light is being detected, and from this point to find a position for

the optical component which provides maximum cathodoluminescence signal. However, this maximum is misplaced, i.e. not confocal with the charged particle beam focus, when using a high charged particle energy.

5 According to the invention, the method first uses a relatively high charged particle energy which yields a relatively high intensity of the luminescence light. This high light intensity is more easy to detect. However when using high charged particle energy the penetration depth of
10 the charged particles is relatively high. For example the penetration depth of an electron beam at a landing energy of 30 keV may be as large as 10 μm . Since the luminescence light originates from the whole interaction volume of the charged particle beam, the maximum intensity of the
15 luminescence light may lay well below the surface of the substrate. So positioning of the optical component at a position where the maximum intensity of the luminescence light is detected by the light detection system, will provide a misalignment with respect to the conjugate plane
20 of the surface of the substrate. By subsequently proceeding with the method at a lower charged particle energy, the luminescence intensity will be lower and more difficult to detect, but this luminescence light originates from a thinner surface layer of the substrate because the
25 penetration depth of the charged particle beam having the lower energy is less than the penetration depth of the charged particle beam having the high energy. For example the penetration depth of an electron beam at a landing energy of 2 keV may be as small as 100 nm. Accordingly the
30 optical component can be positioned more precisely at the conjugate plane of the surface of the substrate using a lower charged particle energy.

 The invention thus proposes to perform a 'coarse' alignment using a relatively high charged particle energy,
35 and subsequently performing a more precise positioning using a lower charged particle energy. When lowering the charged particle energy, the cathodoluminescence signal becomes

weaker and it shifts, but for a small change in energy, the new position for obtaining the maximum cathodoluminescence signal is close-by and thus easy to find.

In an embodiment, the steps d, e and f, are repeated until the difference between the new fixed position and the fixed position is equal to or smaller than the threshold value. According to this embodiment, the energy of the charged particles is further reduced each time the method is repeated. Each time the energy of the charged particles is reduced, the penetration dept of the charged particle is reduced and the positioning of the optical component at the conjugate plane of the surface of the substrate, converges to an optimal position. Accordingly steps d, e and f are repeated until the optical component, in particular an optical component comprising a pinhole, is placed in its desired position, using a low energy charged particle beam.

In an embodiment, the fixed position or the new fixed position of the optical component is established at the position where a maximum signal of the light intensity is measured. This embodiment is particularly suitable when using a substrate or sample which emits luminescent light when irradiated with charged particles. In this case the light emitting surface layer and the corresponding conjugate plane is at the same position where the sample will be observed with the charged particle device, such as an electron microscope.

Alternatively, in an embodiment, the position of the optical component is established by setting the fixed or new fixed position at a translation distance from the position where a maximum signal of the light intensity is measured. This embodiment may be applied for weakly luminescent substrates or samples. For such substrates the charged particle beam's energy must be high in order to obtain a detectable amount of luminescent light. As stated above, for charged particles of high energy the penetration dept is relatively large, and the position of the maximum

intensity of the emitted luminescent light lies beneath the surface of the substrate. Aligning the optical component at the position of maximum signal will result in this case that the optical component is not arranged at the conjugate plane of the surface of the substrate, but at the conjugate plane of the position of the maximum intensity of the emitted luminescent light which lies beneath the surface of the substrate, even in case the focal plane of the light imaging device is accurately aligned at the surface of the substrate. This embodiment of the invention allows to correct for the difference in the position of the maximum intensity of the emitted luminescent light and the position of the surface of the substrate, by positioning the optical component at a distance with respect to the position of maximum intensity. Thus, in case that the charged particle beam cannot be reduced because the intensity of the luminescent light would become too low to detect and/or the distance between the position of maximum intensity for a particular charged particle beam energy and the surface of the substrate is at least approximately known, a correction can be made by translating the optical component over a distance which is preferably equal to the approximate depth of the position of conjugate plane of maximum intensity below the conjugate plane of the sample surface.

According to a second aspect, the present invention provides a method for positioning an optical component in a conjugate plane of a focal plane of a light imaging device, wherein a substrate is arranged at the focal plane of the light imaging device, and wherein the substrate emits light when irradiated with charged particles, the method comprising the steps of:

a. creating a light signal detectable with a light detection system of the light imaging device by irradiating the substrate by a charged particle beam having a set charged particle beam energy;

b. arranging the optical component at various positions in or around said conjugate plane and measuring an

intensity of the light signal as a function of the position of said optical component;

5 c. setting the optical component at a fixed position in or near the conjugate plane, said fixed position being determined using the measured dependence of the intensity of the light signal as a function of the position of said optical component using the selected charged particle beam energy, wherein the fixed position is established spaced apart from the position where a maximum
10 signal of the light intensity is measured. In an embodiment, said distance is a function of the set charged particle beam energy.

As already discussed above, the positioning of the optical component of the light imaging device at the maximum
15 intensity of the luminescence light will provide a misalignment with respect to the conjugate plane of focal plane of the light imaging device. In particular, when the focal plane of the light imaging device is accurately aligned at the surface of the substrate, aligning the
20 optical component at the position of maximum signal will result in that the optical component is not arranged at the conjugate plane of the surface of the substrate, but at the conjugate plane of the position of the maximum intensity of the emitted luminescent light which lies beneath the surface
25 of the substrate when using high energy charged particles. However when the amount of misalignment is at least approximately known, the fixed position can be established at a distance to the position where a maximum signal of the light intensity is measured in order to compensate for the
30 misalignment. Preferably said distance is at least approximately equal to the amount of misalignment.

The amount of misalignment can, for example, be established using the method according the first aspect of the invention, as described above.

35 In an embodiment, the fixed position is established by translating the optical component over a translation distance in the direction along an optical axis

of the light imaging device, with respect to the position where a maximum signal of the light intensity is measured. Preferably the translation distance is at least approximately equal to the amount of misalignment.

5 The further embodiments below, may be applied to the method according to the first aspect, as well as to the method according to the second aspect.

10 In an embodiment, the direction in which the optical component is translated or the fixed position at which the optical component is positioned, is determined based on the measure intensity of the light signal as a function of the position of said optical component.

15 In an embodiment, the intensity of the light signal is measured as a function of the position of said optical component with respect to the optical axis of the light imaging device, and/or as a function of the distance to the objective lens of the light imaging device.

20 In an embodiment, the position of the optical component of the light imaging device is adjusted while monitoring the intensity of the light signal until a certain or predetermined value of the light intensity is reached and the fixed position is established at the position where said certain or predetermined value of the light intensity has been reached.

25 In an embodiment, the charged particle beam scans an area on the substrate during the measuring of the light signal, and the light signal is taken as the integrated value over the scan of the area.

30 In an embodiment, the charged particle beam is kept at a stationary position with respect to the substrate, and wherein the electron beam is substantially focused on the substrate.

35 Alternatively, in an embodiment, the charged particle beam is kept at a stationary position with respect to the substrate, and wherein the electron beam is not focused at the substrate.

 In an embodiment, at least the lower charge

particle beam energy is in a range of 0-5keV, preferably 2keV or lower.

In an embodiment, the optical component comprises a pinhole and/or a detector with a finite opening aperture.

5 According to a third aspect, the present invention provides an apparatus comprising a light imaging device and charged particle device,

wherein the charged particle device is arranged for projecting a charged particle beam to a focal plane of the light imaging device and for irradiating a substrate arranged in said focal plane,

wherein the light imaging device is arranged projecting light from the focal plane to a light detection system, wherein the light imaging device comprises an optical component arranged in or near a conjugate plane of the focal plane of the light imaging device which conjugate plane is arranged between the focal plane and the light detection system,

wherein the apparatus comprises an optical component positioning system which is arranged for moving the optical component at various positions in or around the conjugate plane, and wherein the optical component positioning system comprises a control device which comprises a computer program comprising instructions for positioning the optical component using a method as describe above, or an embodiment thereof.

In an embodiment, the light imaging device comprises an objective lens and a light detection system, wherein the objective lens is arranged for collecting light from the focal plane and for directing said collected light towards the light detection system, wherein the optical component is movably arranged between the objective lens and the light detection system, and wherein the optical component positioning system is arranged for positioning the optical component with respect to the objective lens.

According to a fourth aspect, the present invention provides a computer program comprising

instructions which, when loaded onto a computer device or control device, are adapted to perform a method as described above, or an embodiment thereof.

According to a fifth aspect, the present invention
5 provides a computer readable medium, having a computer program as described above recorded thereon.

The various aspects and features described and shown in the specification can be applied, individually, wherever possible. These individual aspects, in particular
10 the aspects and features described in the attached dependent claims, can be made subject of divisional patent applications.

BRIEF DESCRIPTION OF THE DRAWINGS

15

The invention will be elucidated on the basis of an exemplary embodiment shown in the attached drawings, in which:

Figures 1 and 2 schematically show an apparatus
20 comprising a light imaging device and charged particle device,

Figure 3 schematically indicates the interaction volume of the charged particles with a charged particle beam having a high energy,

25 Figure 4 schematically indicates the interaction volume of the charged particles with a charged particle beam having a lower energy,

Figure 5 schematically depicts the intensity of the cathodoluminescence as a function of the z position of
30 the focal plane,

Figure 6 schematically presents a more detailed view of the light imaging device according to an example of the invention, in particular in case the substrate is exposed to charged particles having a high energy,

35 Figure 7 schematically shows the example of figure 6 in case the substrate is exposed to charged particles having a lower energy,

Figure 8 schematically shows the example of figure 6 in case the optical component is arranged at or near the conjugate plane and the substrate is exposed to charged particles having a high energy,

5 Figure 9 schematically shows a flow diagram of a first example of a method according to the present invention, and

 Figure 10 schematically shows a flow diagram of a second example of a method according to the present
10 invention.

DETAILED DESCRIPTION OF THE INVENTION

 An apparatus according to the present invention
15 comprises a light imaging device 1 and charged particle device 2. The charged particle device 2 is arranged for projecting a charged particle beam 3 onto a sample 4 and/or a substrate 5 onto which the sample 4 can be mounted. The sample 4 or the substrate 5 emits light when irradiated with
20 charged particles from said charged particle beam 3. The light imaging device 1 is arranged for collecting at least a part of said emitted light 6 and for imaging said emitted light 6 from the sample 4 or the substrate 5.

 The apparatus comprises a positioning system 9
25 which is arranged for positioning a focal plane 8 of the light imaging device 1 with respect to the sample 4 and/or the substrate 5. The positioning system 9 is arranged for moving the light imaging device 1 substantially along the optical axis 11 towards and away from the sample 4 and/or
30 the substrate 5, and for positioning the focal plane 8 at a position z along the optical axis 11.

 It is noted that the light imaging device 1 can be arranged at a side of the sample 4 and/or substrate 5 which faces towards the charged particle device 2, as shown
35 schematically in figure 1. Alternatively, the light imaging device 1 can be arranged at an opposite side of the sample 4 and/or substrate 5 which faces away from the charged

particle device 2, as shown schematically in figure 2. In this latter setup as shown in figure 2, the sample 4 and the substrate 5 are preferably substantially transparent for the emitted light 6.

5 The positioning system 9 comprises a control device 10 which comprises a computer program comprising instructions for positioning the focal plane 8 of the light imaging device 1 at the surface of the sample 4 or the substrate 5 using a method as described in more detail in
10 the International Patent Application PCT/NL2015/050368 of the applicant. The method as described in the International Patent Application PCT/NL2015/050368 uses the fact that cathodoluminescence is almost always excited in a sample or sample substrate 40 when exposed to a charged particle beam
15 30, 30'. This cathodoluminescence originates from the entire interaction volume 50, 50' of the charged particles, as schematically depicted in figures 3 and 4. The depth of this interaction volume 50, 50' is depended on the energy of the charged particles of the charged particle beam 30, 30'.
20 Figure 3 schematically indicates the interaction volume 50 of the charged particles with a charged particle beam 30 having a high energy. Figure 4 schematically indicates the interaction volume 50' of the charged particles with a charged particle beam 30' having a lower energy. So, in
25 principle, with a low energy charged particle beam 30', the cathodoluminescence originates from near the surface of the sample or sample substrate 40, and focusing the light microscope on this cathodoluminescence signal then leads to the desired focal position.

30 It is noted that the cathodoluminescence signal from a low energy beam 30' can be quite low and thus hard to pick up for an out-of-focus light microscope. The intensity of the cathodoluminescence signal is depended on charged particle energy and the beam current. In general for higher
35 charged particle energy, we have a stronger signal originating from a larger volume 50, and cathodoluminescence intensity I_{30} is at maximum at a depth z_1 as indicated in

figure 5. For lower charged particle energy, we have a weaker signal originating from a smaller volume $50'$, and cathodoluminescence intensity $I_{30'}$ is at maximum at a depth z_2 as indicated in figure 5. The distance between the actual surface z_0 and z_1 is larger than the distance between the actual surface z_0 and z_2 . Thus the position z_1 of maximum cathodoluminescence intensity I is further off from the desired focal plane position at the surface z_0 .

Structures that are studied in such an integrated system are typically embedded in or supported on a holding structure, such as a sample substrate. This holding structure may also generate optical signals, which result in a background signal. If the signal from the structures to be studied is weak, it can become overwhelmed by the background signal, even if the focal plane z of the light imaging device 1 is accurately aligned at the surface of the sample or substrate, using for example the method as described in PCT/NL2015/050368. For cathodoluminescence microscopy, background is generated throughout the electron interaction volume. For high energies (say, 20-30 keV), which offer higher resolution at increased current compared to lower energies, the electron interaction volume can span several micrometers.

One way to reduce the background signal is, to use a light imaging device of the confocal type. Such a confocal light imaging device 100, as schematically depicted in figure 6, comprises an objective lens 101 which is arranged for projecting the light 106 from the sample onto a detection system 103. It is noted that figure 6 is not to scale. The objective lens 101 provides an intermediate image plane z' of the focal plane z between the objective lens 101 and the detection system 103. The intermediate image plane z' is also referred to herein as the conjugate plane z' of the focal plane z of the light imaging device 100. Preferably at this conjugate plane z' , an optical component 102 comprising a pinhole is arranged in front of the detection system 103. To optimize the filtering and thus

signal to background ratio, it is important to align the pinhole of the optical component 102 in the conjugate plane z' very accurately.

In the example as shown in figure 6, the focal
5 plane z of the light imaging device 100 is arranged at the top surface z_0 of the substrate 150. However, the interaction volume 150 of the charged particles from the charged particle beam 130 having a high energy is relatively large, and the maximum cathodoluminescence intensity is at a depth
10 z_1 as indicated in figure 6. In case the cathodoluminescence light is used for aligning the pinhole of the optical component 102 in order to obtain a maximum light signal from the light detection system 103, the pinhole of the optical component 102 will be positioned at or near the conjugate
15 plane z_1' of the maximum cathodoluminescence intensity is at a depth z_1 , instead of the conjugate plane z' of the top surface z_0 of the substrate 150.

According to the method of the present invention, a charged particle beam 130, in particular with a high
20 energy charged particle beam, is used for a 'coarse' alignment of the optical component 102 of the light imaging device 100 at or near the conjugate plane: The cathodoluminescence is monitored as a function of the position of the pinhole of the optical component 102 at least in a
25 direction along the light optical axis 111, and setting the pinhole of the optical component 102 at a fixed position in or near the conjugate plane, said fixed position being determined using the measured dependence of the intensity of the light signal as a function of the position of said
30 pinhole of the optical component 102 using the selected charged particle beam energy. Accordingly the pinhole of the optical component 102 in the example of figure 6 is arranged at a fixed position z_1' along the optical axis 111 at the conjugate plane with the maximum cathodoluminescence signal.

35 According to the present invention, the alignment is subsequently 'refined' by lowering the charged particle energy 130', as schematically shown in figure 7, and again

aligning the pinhole of the optical component 102 at or near the conjugate plane: The cathodoluminescence is monitored as a function of the position of the pinhole of the optical component 102 at least in a direction along the light optical axis 111, and determining a new fixed position for said pinhole of the optical component 102 in or near the conjugate plane, said new fixed position being determined using the measured dependence of the intensity of the light signal as a function of the position of said pinhole of the optical component 102 using the selected lowered charged particle beam energy. When the distance between this new fixed position and the fixed position in the conjugate plane is larger than a position threshold value, the fixed position of the optical component is adjusted to the new fixed position. Accordingly the pinhole of the optical component 102 in the example of figure 7, the fixed position z_1' is adjusted to the new fixed position z_2' and the pinhole of the optical component 102 is arranged at a fixed position z_2' along the optical axis 111 at the conjugate plane with the maximum cathodoluminescence signal for the lowered charged particle beam energy.

As indicated in figure 7, the z-position z_2 for maximum cathodoluminescence intensity for the lowered charged particle beam energy shifts towards the surface z_0 . Also the conjugate plane z_2' of the maximum cathodoluminescence intensity for the lowered charged particle beam energy shifts towards the conjugate plane z' of the surface z_0 of the substrate 105, and a more accurate alignment of the pinhole of the optical component 102 is obtained.

In an embodiment, the desired positioning of the pinhole of the optical component 102 at the conjugate plane z' of the focal position at the surface z_0 can be approached by an iterative procedure wherein the charged particle energy is lowered and the method described above is repeated at each iteration. The iterations are, for example, repeated until the difference between the new focal position and the focal position of the previous iteration is equal to or

smaller than a predetermined threshold value.

When a measurement is now performed at high energy, as shown in figure 8, the pinhole of the optical component 102 filters the light 106 from the substrate 105. The light (solid line) originating from the surface z_0 where the electron beam focus 130 impinges passes through the pinhole of the optical component 102, whereas the light (dashed line) originating from the interaction volume 150 below the surface z_0 is, to a substantial extend, blocked by the area of the optical component 102 that surrounds the pinhole. Hence an improved signal to background ratio is obtained.

It should be noted that this procedure also allows for alignment of the pinhole of the optical component 102 in a plane substantially perpendicular to the optical axis 111, also denoted herein as the xy plane. As the focus of the electron beam 130, 130' on the substrate 105 is translated over the surface z_0 of the substrate 105, also the cathodoluminescence focus position translates in the conjugate plane z' .

Confocal detection of cathodoluminescence has so far only been used to achieve xy-filtering, where xy denote the coordinates in the focal plane. In this case an optical component comprising a comparatively large pinhole was used and the pinhole was aligned on the light microscope signal. This is not accurate enough for smaller pinholes, i.e. better filtering. Furthermore, most cathodoluminescence detection systems do not contain all components for light microscopy (most notably, excitation paths), which brings about that these cathodoluminescence detection systems depend to a large extend to the cathodoluminescence light for aligning the optical components of the cathodoluminescence detection system.

It is further noted that this procedure can also be used to align other optical components of the light imaging device 100, such as a detector 103, in a conjugate plane.

It should be noted that for this alignment method, the electron beam 130, 130' need not be focused at the surface of the substrate 105. Charged particle interaction always starts from the surface layer exposed to the charged particle beam. In fact, it can be beneficial to use an unfocused beam, because then the charged particle beam 130, 130' need not be refocused when the charged particle energy is changed.

Also, to facilitate the method of the present invention, preferably the charged particle beam 130, 130' is scanned over part of the surface z_0 of the substrate 105. This does not influence the z-position for maximum cathodoluminescence below the surface of the substrate 105, but the increased lateral extent can make the alignment of the optical component 102 easier, as the alignment is then substantially insensitive to lateral shifts of the position of the charged particle beam 130, 130'. The size of the scan area can be stepwise decreased once the optimum position of the optical component 102 along the optical axis 111 has been found, so as to find the optimum xy-position in the conjugate plane.

In a further extension of the method of the present invention, the alignment can be performed at at least one, but preferably at three positions aside a region of interest on the surface of the substrate to determine the conjugate plane position of the region of interest.

In example of an alternative method according to the present invention, it is not necessary to make the iterations at lower energy. If the cathodoluminescence signal profile is well characterized for the material of the substrate 105 used and the distance $\Delta z_1'$ between the fixed position z_1' along the optical axis 111 at the conjugate plane with the maximum cathodoluminescence signal and the conjugate plane z' is at least approximately known, the optical component 102 comprising the pinhole is positioned at a distance to the fixed position z_1' along the optical

axis 111. Preferably the optical component 102 is directly positioned at a distance from the position of maximum cathodoluminescence, which distance is at least substantially equal to $\Delta z_1'$. By directly positioning the
5 optical component 102 at a distance to the position with maximum cathodoluminescence, a more accurate alignment of the optical element 102 is obtained.

In yet another example of a method according to
10 the present invention, it is not even needed to measure the entire intensity profile of the cathodoluminescence as a function of the position of the optical component 102 comprising said pinhole. When it is known from which direction (from the side of the objective lens 101 or from
15 the side of the detector 103) the conjugate plane z' is approached when aligning the optical component 102, or when this direction can be established from the change in the cathodoluminescence intensity signal as measured, the alignment procedure can be stopped once a specific value for
20 the cathodoluminescence intensity signal has been reached and/or once a specific change in the cathodo-luminescence intensity signal has been reached.

Figure 9 schematically shows a flow diagram of a
25 first example of a method for positioning an optical component at the conjugate plane of the focal plane of a light imaging device. At the focal plane of the light imaging device a surface of a substrate is arranged, which substrate emits light when said surface is irradiated with
30 charged particles. After starting 80 the method, the following steps are subsequently performed:

81. Creating cathodoluminescence light by irradiating the substrate with a charged particle beam having a set charged particle beam energy, wherein the
35 surface of the substrate is arranged at least substantially at the focus plane of the light imaging device;

82. The optical component of the light imaging

device is arranged at various positions in or around the conjugate plane, and an intensity of the light signal is measured as a function of the position of said optical component;

5 83. The optical component is set at a fixed position in or near the conjugate plane, wherein said fixed position is determined using the measured dependence of the intensity of the light signal as a function of the position of said optical component using the set charged particle
10 energy, preferably the fixed position is established at a position where a maximum signal of the cathodoluminescence light intensity is measured with the set charged particle energy;

 84. The charged particle beam energy is reduced to
15 a lower charged particle beam energy, while keeping the optical component at the fixed position;

 85. The optical component of the light imaging device is again moved in or around the conjugate plane of the light imaging device, and the intensity of the light
20 signal is measured as a function of the position of said optical component;

 86. The measured dependence of the intensity of the light signal as a function of the position of said optical component at said lower charged particle beam energy
25 is used to determine a new fixed position, preferably the new fixed position is established at a position where a maximum signal of the cathodoluminescence light intensity is measured with the reduced charged particle energy;

 87. Determine the difference/distance between the
30 new fixed position and the previous fixed position;

 88. Is this difference/distance larger than a threshold value?;

 89. If the answer to the question 88 is YES, adjust the fixed position to the new fixed position; and

35 90. If the answer to the question 88 is NO, the focal position is not adjusted, and the method is ended 91.

The method can also end after step 89. However, in

an embodiment, the method is continued by going back 92 to the step 84 in which the charged particle beam energy is reduced to a lower charged particle beam energy, while keeping the optical component at the adjusted fixed position.

Figure 10 schematically shows a flow diagram of a second example of a method for positioning an optical component at the conjugate plane of the focal plane of a light imaging device. At the focal plane of the light imaging device a surface of a substrate is arranged, which substrate emits light when said surface is irradiated with charged particles. After starting 95 the method, the following steps are subsequently performed:

96. Creating cathodoluminescence light by irradiating the substrate with a charged particle beam having a set charged particle beam energy, wherein the surface of the substrate is arranged at least substantially at the focus plane of the light imaging device;

97. The optical component of the light imaging device is arranged at various positions in or around the conjugate plane, and an intensity of the light signal is measured as a function of the position of said optical component;

98. The optical component is set at a fixed position in or near the conjugate plane, wherein said fixed position is determined using the measured dependence of the intensity of the light signal as a function of the position of said optical component using the set charged particle energy, wherein the fixed position is established spaced apart at a predetermined distance in the direction towards or away from the detector, with respect to the position where a maximum signal of the cathodoluminescence light intensity is measured, and the method is ended 99.

Preferably, said predetermined distance is a function of the set charged particle beam energy. The predetermined distance can, for example, be determined by

evaluating the results of the method according to the first example as shown in figure 8. When in the method according to the first example, the optical component is positioned at the position where the maximum signal of light intensity is measured with the set charged particle energy, a relation between the position of the optical component providing the maximum signal of light intensity as a function of the set charged particle beam energy can be established. This relation can then be used to establish the distance between the position of maximum signal using a relatively high set charged particle beam energy and the position of maximum signal using a low charged particle beam energy, which distance can be used as the predetermined distance mentioned above.

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The method(s) of the present invention can for example suitable be used in an apparatus which combines a scanning electron microscope SEM and a light microscope LM. Although the examples as discussed above specifically relate to the alignment of an optical component comprising a pinhole in a confocal light microscope, the method of the present invention can also be applied for positioning a detector, a diaphragm or another optical component having a finite aperture in a conjugate plane of the light microscope.

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It is to be understood that the above description is included to illustrate the operation of the preferred embodiments and is not meant to limit the scope of the invention. From the above discussion, many variations will be apparent to one skilled in the art that would yet be encompassed by the spirit and scope of the present invention.

30

C L A I M S

1. Method for positioning an optical component in a conjugate plane of a focal plane of a light imaging device, wherein a substrate is arranged at the focal plane of the light imaging device, and wherein the substrate emits
5 light when irradiated with charged particles, the method comprising the steps of:

a. creating a light signal detectable with a light detection system of the light imaging device by irradiating the substrate by a charged particle beam having a selected
10 charged particle beam energy;

b. arranging the optical component at various positions in or around said conjugate plane and measuring an intensity of the light signal as a function of the position of said optical component;

15 c. setting the optical component at a fixed position in or near the conjugate plane, said fixed position being determined using the measured dependence of the intensity of the light signal as a function of the position of said optical component using the selected charged
20 particle beam energy;

d. adjusting the charged particle beam energy to an energy lower than the selected charge particle beam energy;

25 e. moving the optical component in or around the conjugate plane of the light imaging device and measuring the intensity of the light signal as a function of the position of said optical component in the conjugate plane; and

30 f. using the measured dependence of the intensity of the light signal as a function of the position of said optical component in the conjugate plane at said lower charged particle beam energy to determine a new fixed position in the conjugate plane, and when a difference

between this new fixed position and the fixed position in the conjugate plane is larger than a position threshold value, the fixed position of the optical component is adjusted to the new fixed position.

5 2. Method according to claim 1, wherein the steps d, e and f, are repeated until the difference between the new fixed position and the fixed position is equal to or smaller than the threshold value.

10 3. Method according to claim 1 or 2, wherein the fixed position or the new fixed position of the optical component is established at the position where a maximum signal of the light intensity is measured.

15 4. Method according to claim 1, 2 or 3 wherein the position of the optical component is established by setting the fixed or new fixed position at a translation distance from the position where a maximum signal of the light intensity is measured.

20 5. Method for positioning an optical component in a conjugate plane of a focal plane of a light imaging device, wherein a substrate is arranged at the focal plane of the light imaging device, and wherein the substrate emits light when irradiated with charged particles, the method comprising the steps of:

25 a. creating a light signal detectable with a light detection system of the light imaging device by irradiating the substrate by a charged particle beam having a set charged particle beam energy;

30 b. arranging the optical component at various positions in or around said conjugate plane and measuring an intensity of the light signal as a function of the position of said optical component;

35 c. setting the optical component at a fixed position in or near the conjugate plane, said fixed position being determined using the measured dependence of the intensity of the light signal as a function of the position of said optical component using the selected charged particle beam energy, wherein the fixed position is

established spaced apart from the position where a maximum signal of the light intensity is measured.

6. Method according to claim 4 or 5, wherein the fixed position is established by translating the optical component over a translation distance in a direction along an optical axis of the light imaging device, with respect to the position where a maximum signal of the light intensity is measured.

7. Method according to claim 4, 5 or 6, wherein the direction in which the optical component is translated, is determined based on the measure intensity of the light signal as a function of the position of said optical component.

8. Method according to any one of the claims 1 - 7, wherein the intensity of the light signal is measured as a function of the position of said optical component with respect to the optical axis of the light imaging device and/or as a function of the distance to the objective lens of the light imaging device.

9. Method according to any one of the claims 1 - 8, wherein the position of the optical component of the light imaging device is adjusted while monitoring the intensity of the light signal until a predetermined value of the light intensity is reached, and the fixed position is established at the position where the predetermined value of the light intensity has been reached.

10. Method according to any one of the claims 1 - 9, wherein the charged particle beam scans an area on the substrate during the measuring of the light signal, and the light signal is taken as the integrated value over the scan of the area.

11. Method according to any one of the claims 1 - 9, wherein the charged particle beam is kept at a stationary position with respect to the substrate.

12. Method according to any one of the claims 1 - 11, wherein at least the lower charge particle beam energy is in a range of 0-5keV, preferably 2keV or lower.

13. Method according to any one of the claims 1 - 12, wherein the optical component comprises a pinhole and/or a detector with a finite opening aperture.

14. Apparatus comprising a light imaging device
5 and charged particle device,

wherein the charged particle device is arranged for projecting a charged particle beam to a focal plane of the light imaging device and for irradiating a substrate arranged in said focal plane,

10 wherein the light imaging device is arranged projecting light from the focal plane to a light detection system, wherein the light imaging device comprises an optical component arranged in or near a conjugate plane of the focal plane of the light imaging device which conjugate
15 plane is arranged between the focal plane and the light detection system,

wherein the apparatus comprises an optical component positioning system which is arranged for moving the optical component at various positions in or around the
20 conjugate plane, and wherein the optical component positioning system comprises a control device which comprises a computer program comprising instructions for positioning the optical component using a method according to any one of the claims 1 to 13.

25 15. Apparatus according to claim 14, wherein the light imaging device comprises an objective lens and a light detection system, wherein the objective lens is arranged for collecting light from the focal plane and for directing said collected light towards the light detection system, wherein
30 the optical component is movably arranged between the objective lens and the light detection system, and wherein the optical component positioning system is arranged for positioning the optical component with respect to the objective lens.

35 16. A computer program comprises instructions which, when loaded onto a computer device or control device, are adapted to perform a method according to any one of the

claims 1 to 13.

17. A computer readable medium, having a computer program according to claim 16 recorded thereon.

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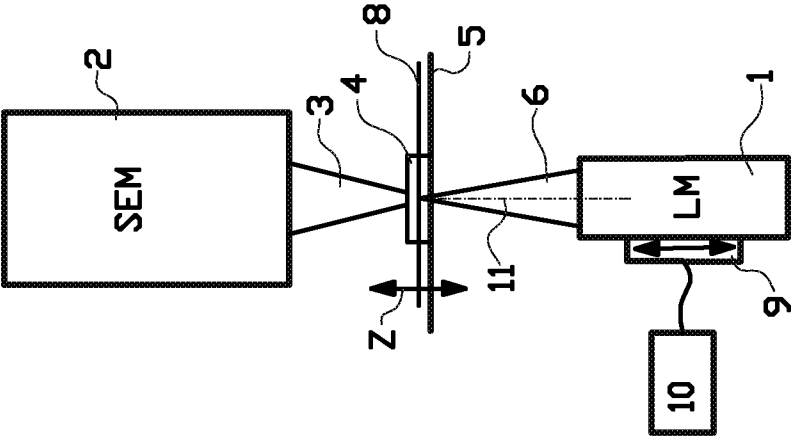


FIG. 2

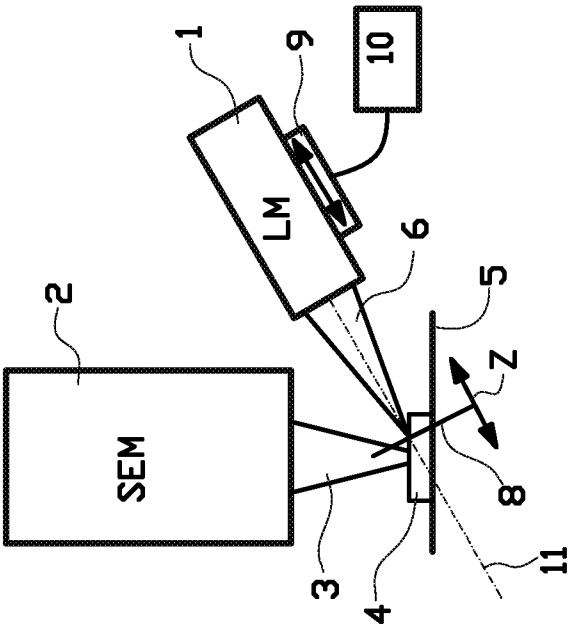


FIG. 1

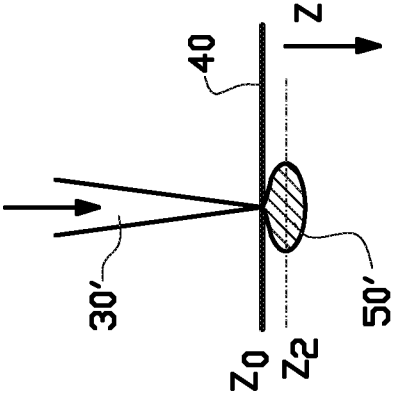


FIG. 3

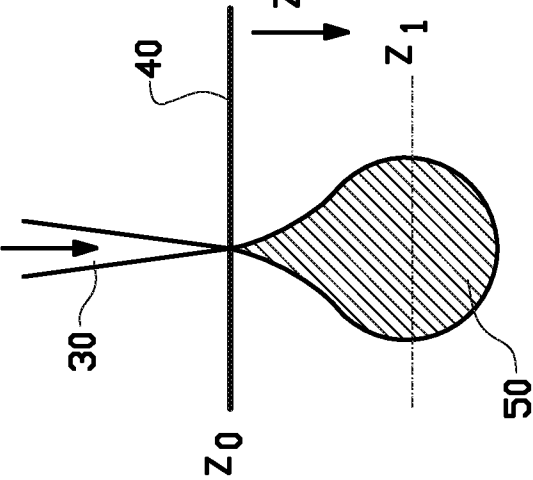


FIG. 4

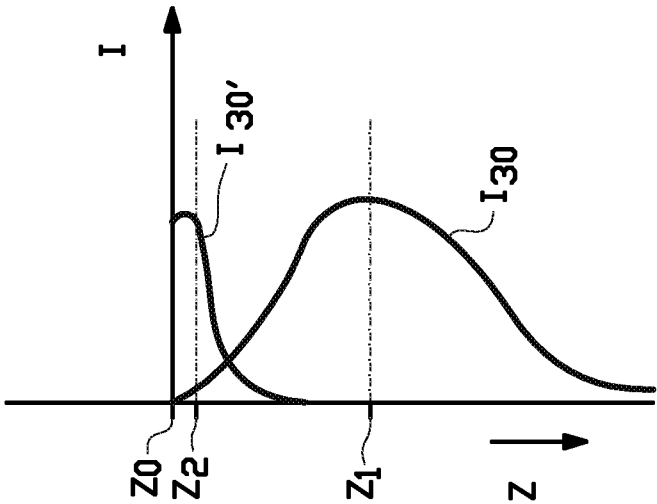


FIG. 5

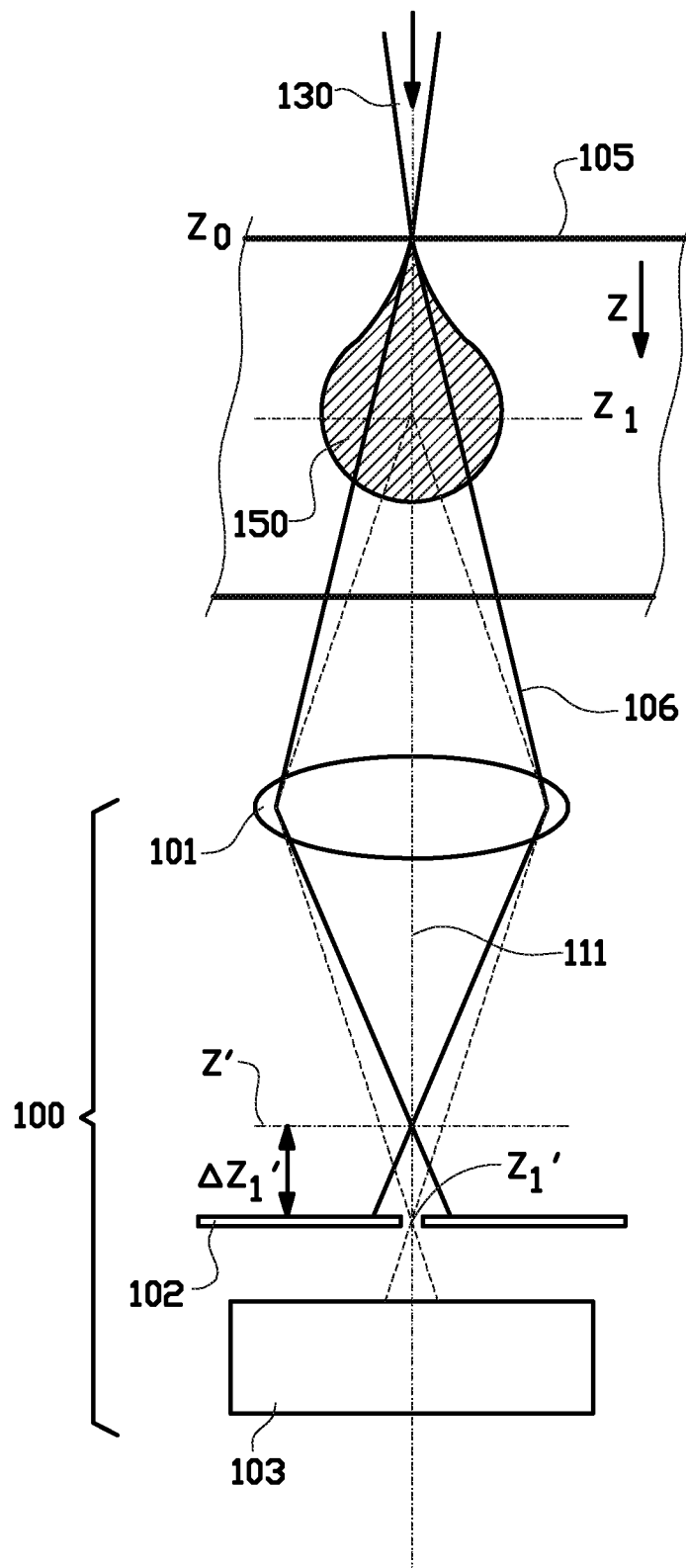
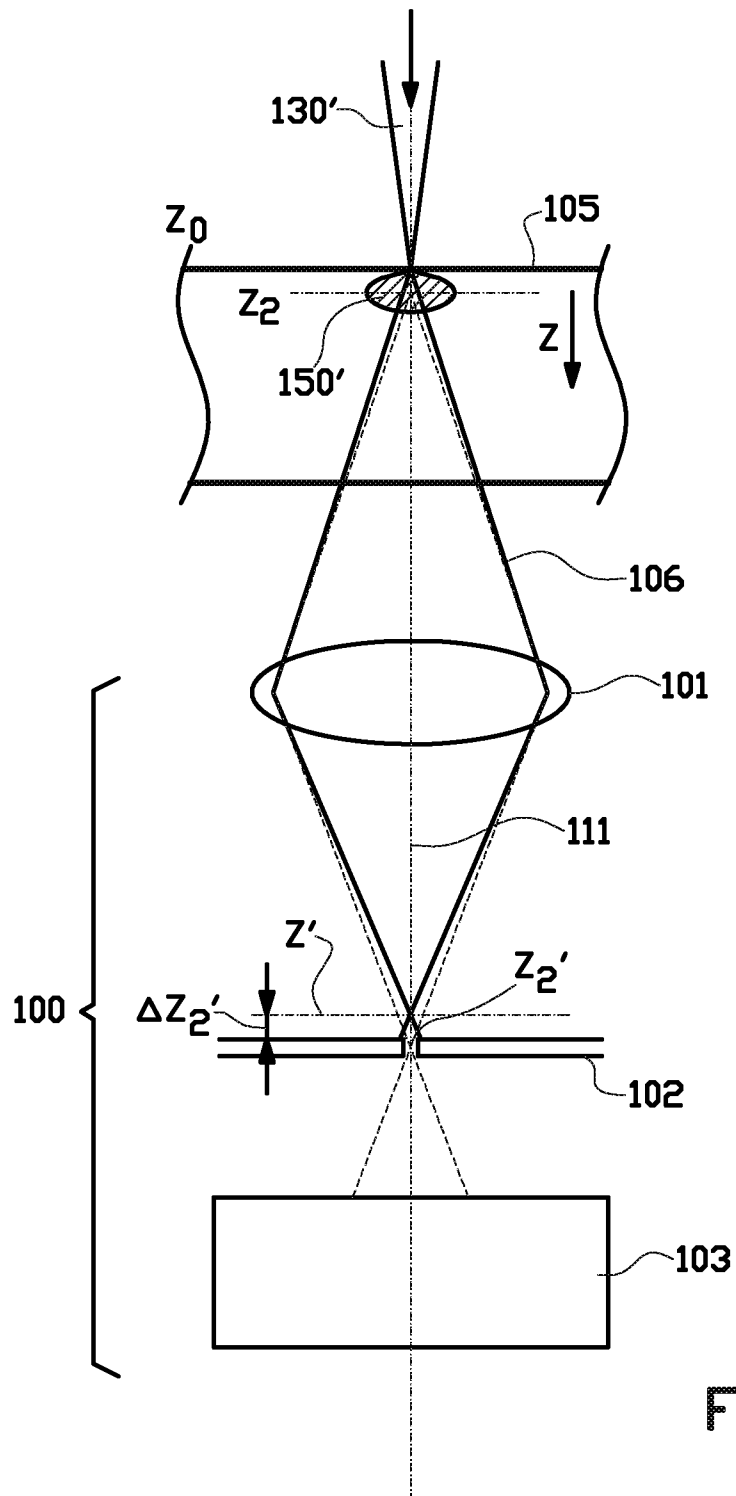


FIG. 6



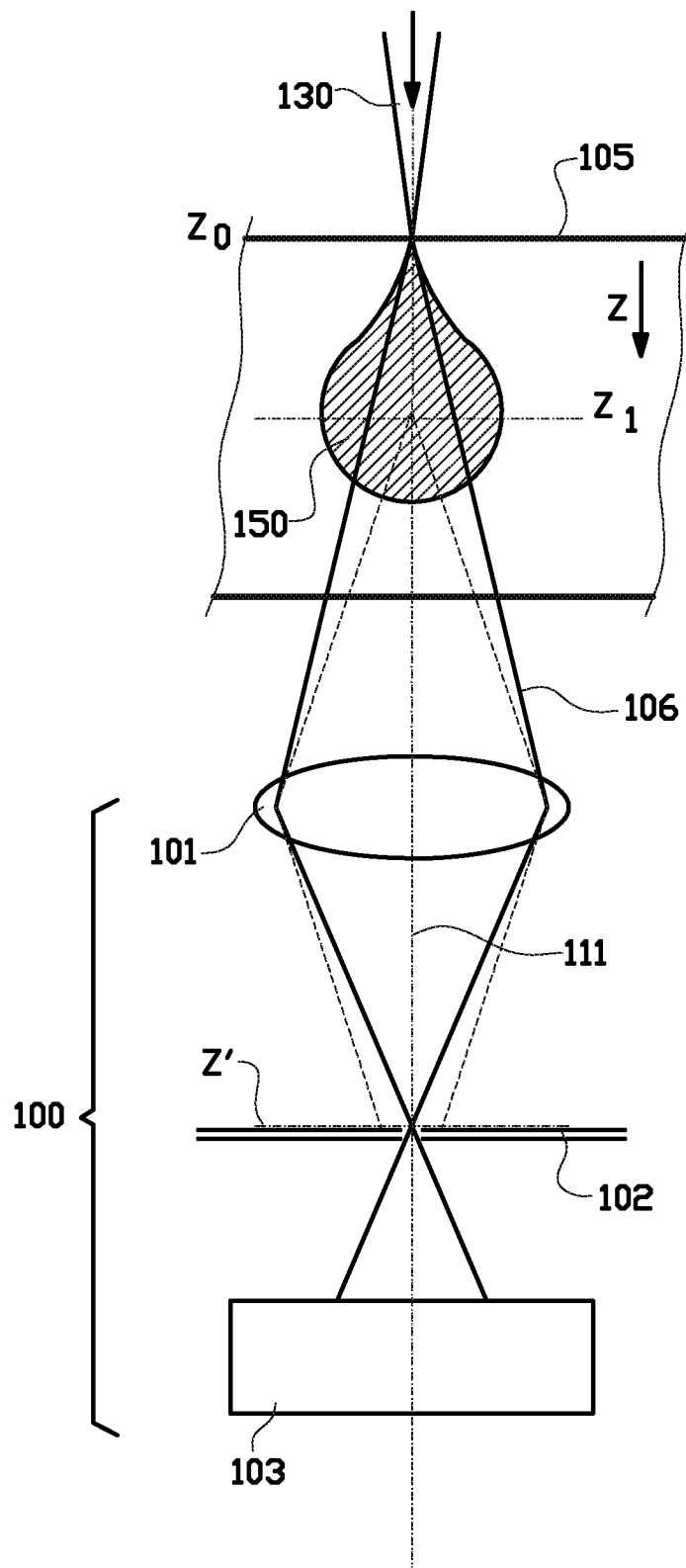


FIG. 8

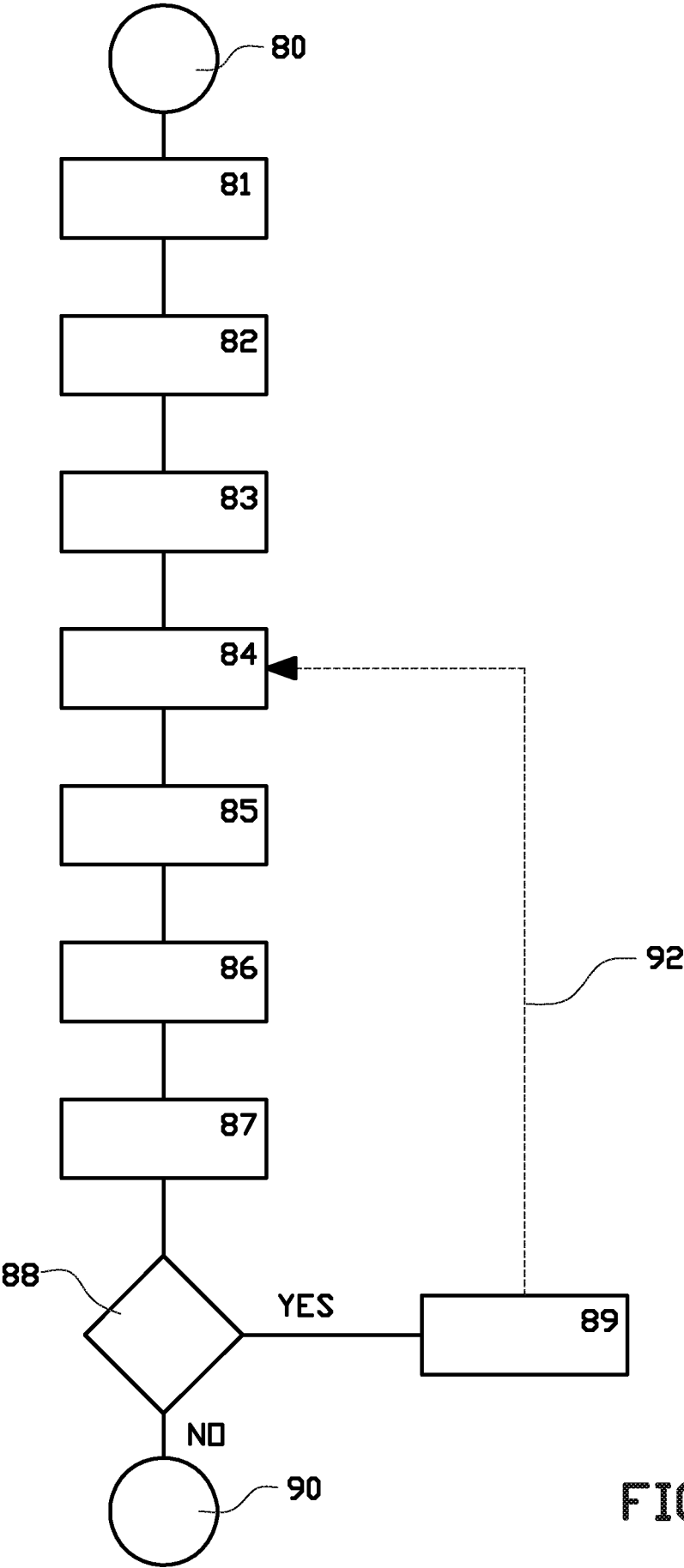


FIG. 9

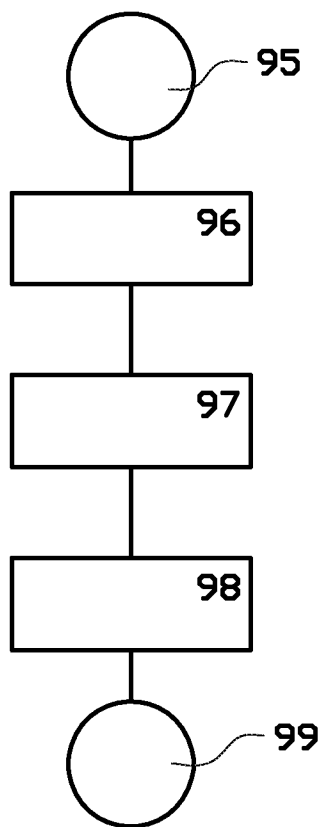


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2016/050516

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01J37/22
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/042538 A1 (DELMIC B V [NL]) 20 March 2014 (2014-03-20) page 19, lines 18,21-22,25-27; figure 9 -----	5-17
A	NARVÁEZ ANGELA C ET AL: "Confocal filtering in cathodoluminescence microscopy of nanostructures", APPLIED PHYSICS LETTERS, A I P PUBLISHING LLC, US, vol. 104, no. 25, 23 June 2014 (2014-06-23), XP012187450, ISSN: 0003-6951, DOI: 10.1063/1.4885833 [retrieved on 1901-01-01] -----	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search

5 October 2016

Date of mailing of the international search report

17/10/2016

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Authorized officer

Oestreich, Sebastian

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2016/050516

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014042538 A1	20-03-2014	EP 2896061 A1	22-07-2015
		US 2015262784 A1	17-09-2015
		WO 2014042538 A1	20-03-2014
