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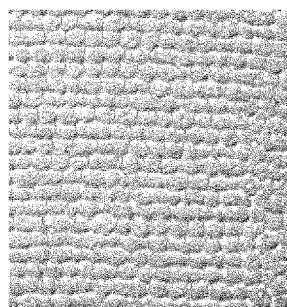
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DETECTOR AND METHOD FOR INSPECTING A LARGE AREA SUBSTRATE

Fig. 3b



(57) Abstract: A method for inspecting a substrate is described. The method includes providing the substrate being a large area substrate in a vacuum chamber, wherein the substrate has a thin-film with a grain structure deposited on the substrate; generating a primary charged particle beam with an imaging charged particle beam microscope, wherein the primary charged particle beam impinges on the substrate in the vacuum chamber; and generating one or more images from signal particles released from the substrate upon impingement of the primary charged particle beam, wherein the one or more images are topographic images.

LTPS LAYER QUALIFICATION ON DISPLAY SUBSTRATES BY INLINE SEM USING A MULTI PERSPECTIVE DETECTOR AND METHOD FOR INSPECTING A LARGE AREA SUBSTRATE

FIELD

[0001] The present disclosure relates to LTPS layer qualification and a method for inspecting a substrate. More particularly, embodiments described herein relate to a method for inspecting substrates for display manufacturing, still more particularly a large area substrate for display manufacturing.

BACKGROUND

[0002] In many applications, deposition of thin layers on a substrate, e.g. on a glass substrate is desired. Conventionally, the substrates are coated in different chambers of a coating apparatus. For some applications, the substrates are coated in a vacuum using a vapor deposition technique. Over the last few years, electronic devices and particularly opto-electronic devices have reduced significantly in price. Further, the pixel density in displays is continuously increased. For TFT displays, a high density TFT integration is desired. However, the yield is attempted to be increased and the manufacturing costs are attempted to be reduced in spite of the increased number of thin-film transistors (TFT) within a device.

[0003] One aspect to increase the pixel density is the utilization of LTPS-TFT (LTPS = Low Temperature Poly Silicon), which can be used e.g. for LCD or AMOLED displays. During manufacturing of a LTPS-TFT, the gate electrode can be used as a mask for doping of the contact area of the active layer to the source and the drain of the transistor. The quality of this self-aligned doping can determine the yield of the manufacturing process. Accordingly, it is a desire to improve and control this process. Yet, also other self-aligned doping applications, i.e. other than manufacturing of a LTPS-TFT, can benefit from an improved process.

[0004] For such processes, it is beneficial to inspect a substrate to monitor the quality of the substrate. i.e. of the deposited layer, particularly the LTPS layer. For example, glass substrates on which layers of coating material are deposited are manufactured for the

display market. Displays are often manufactured on large area substrates with continuously growing substrate sizes. Further, displays such as TFT-displays are subject to continuous improvement. For example, Low Temperature Poly Silicon (LTPS) is one development wherein low energy consumption and improved characteristics with respect to back-light can be realized.

[0005] The inspection of the substrate can, for example, be carried out by an optical system. However, the LTPS grain structure, grain sizes and topography of the grains at the grain edges are particularly difficult to review using optical systems, since the grain size may be below the optical resolution, making the grains invisible for the optical system. An inspection of small portions of substrates has also been carried out using charged particle beam devices, combined with surface etching. The surface etching may enhance the contrast of e.g. the grain boundaries but involves breaking the glass substrate, so that small pieces of the substrate are inspected instead of the substrate as a whole. Accordingly, it is impossible to continue processing the substrate, e.g. to check the impact of the grain structure on the final product, after inspection of the substrate.

[0006] Accordingly, given e.g. the increasing demands on the quality of displays on large area substrates, there is a need for an improved method for inspecting large area substrates.

SUMMARY

[0007] A method for inspecting a substrate and an apparatus utilizing the method are provided. Further aspects, benefits, and features of the present disclosure are apparent from the claims, the description, and the accompanying drawings.

[0008] According to one embodiment, a method for inspecting a substrate is provided. The method includes providing the substrate being a large area substrate in a vacuum chamber, wherein the substrate has a thin-film with a grain structure deposited on the substrate; generating a primary charged particle beam with an imaging charged particle beam microscope, wherein the primary charged particle beam impinges on the substrate in the vacuum chamber; and generating one or more images from signal particles released from the substrate upon impingement of the primary charged particle beam, wherein the one or more images are topographic images.

[0009] In some embodiments, the inventive methods described herein may be embodied in a computer readable medium. The computer readable medium has instructions stored thereon that, when executed, cause a charged particle beam microscope to perform a method for inspecting a substrate accordance with any of the methods described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] A full and enabling disclosure to one of ordinary skill in the art is set forth more particularly in the remainder of the specification including reference to the accompanying drawings wherein:

[0011] FIG. 1 shows a side view of an imaging charged particle beam microscope used for embodiments described herein;

[0012] FIG. 2 shows a detection arrangement including a segmented scintillator used for embodiments described herein;

[0013] FIG. 3A shows topographic images according to embodiments of the present disclosure;

[0014] FIG. 3B shows a combined image, which is combined of topographic images according to the present disclosure;

[0015] FIG. 4 shows an image of a prior art air SEM measurement, wherein an etched sample surface is measured;

[0016] FIG. 5 shows a flow chart illustrating a method according to embodiments described herein, particularly a method for inspecting a large area substrate; and

[0017] FIG. 6 shows a flow chart illustrating further methods according to embodiments described herein, particularly methods for calibrating and inspecting a large area substrate, e.g. for display manufacturing.

DETAILED DESCRIPTION

[0018] Reference will now be made in detail to the various exemplary embodiments, one or more examples of which are illustrated in each figure. Each example is provided by way of explanation and is not meant as a limitation. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet further embodiments. The intention is that the present disclosure includes such modifications and variations.

[0019] Within the following description of the drawings, the same reference numbers refer to the same components. Only the differences with respect to the individual embodiments are described. The structures shown in the drawings are not necessarily depicted true to scale but rather serve the better understanding of the embodiments.

[0020] The term “substrate” as used herein embraces both inflexible substrates, e.g., a glass substrate, or a glass plate, and flexible substrates, such as a web or a foil. The substrate may be a coated substrate, wherein one or more thin layers of materials are coated or deposited on the substrate, for example by a physical vapor deposition (PVD) process or a chemical vapor deposition process (CVD).

[0021] Embodiments described herein relate to large area substrates, in particular large area substrates for the display market. According to some embodiments, large area substrates or respective substrate supports may have a size of at least 1 m². The size may be from about 1.375 m² (1100 mm x 1250 mm– Gen 5) to about 9 m², more specifically from about 2 m² to about 9 m² or even up to 12 m². The substrates or substrate receiving areas, for which the structures, apparatuses, and methods according to embodiments described herein are provided, can be large area substrates as described herein. For instance, a large area substrate or carrier can be GEN 5, which corresponds to about 1.375 m² substrates (1.1 m x 1.25 m), GEN 7.5, which corresponds to about 4.39 m² substrates (1.95 m x 2.25 m), GEN 8.5, which corresponds to about 5.7m² substrates (2.2 m x 2.5 m), or even GEN 10, which corresponds to about 9 m² substrates (2.88 m × 3130 m). Even larger generations such as GEN 11 and GEN 12 and corresponding substrate areas can similarly be implemented.

[0022] Without limiting the scope of protection of the present application, in the following the charged particle beam device, e.g. a charged particle beam microscope, or components thereof will exemplarily be referred to as a charged particle beam device including the detection of secondary or backscattered particles, such as electrons. Embodiments can still be applied for apparatuses and components detecting corpuscles, such as secondary and/or backscattered charged particles in the form of electrons or ions, photons, X-rays or other signals in order to obtain a specimen image. When referring to corpuscles, the corpuscles are to be understood as light signals in which the corpuscles are photons as well as particles, in which the corpuscles are ions, atoms, electrons or other particles. As described herein, discussions and descriptions relating to the detection are exemplarily described with respect to electrons in scanning electron microscopes. Other types of charged particles, e.g. positive ions, could be utilized by the device in a variety of different instruments.

[0023] According to embodiments herein, which can be combined with other embodiments, a signal (charged particle) beam, or a signal (charged particle) beamlet is referred to as a beam of secondary and/or backscattered particles. Typically, the signal beam or secondary beam is generated by the impingement of the primary beam or primary beamlet on a specimen. A primary charged particle beam or a primary charged particle beamlet is generated by a particle beam source and is guided and deflected on a specimen to be inspected or imaged.

[0024] Fig. 1 shows a charged particle beam device or a charged particle beam microscope 100. An electron beam (not shown) may be generated by the electron beam source 112. Within the gun chamber 110, further beam shaping means like a suppressor, an extractor, and/or an anode may be provided. The beam may be aligned to a beam limiting aperture, which is dimensioned to shape the beam, i.e. blocks a portion of the beam. The electron beam source can include a TFE emitter. The gun chamber may be evacuated to a pressure of 10^{-8} mbar to 10^{-9} mbar.

[0025] In a further vacuum chamber 120 of the column of the charged particle beam microscope 100 a condenser lens can be provided. For example the condenser lens can include a pole piece 122 and the coil 124. Further electron optical elements 126 can be provided in the further vacuum chamber. The further electron optical elements 126 can be

selected from the group consisting of: a stigmator, correction elements for chromatic and/or spherical aberrations, and alignment deflectors for aligning the primary charged particle beam to an optical axis of the objective lens 140.

[0026] The primary electron beam can be focused on the substrate 10 by the objective lens 140. The substrate 10 is positioned on a substrate position on the substrate support 150. On impingement of the electron beam onto the substrate 10 signal electrons, for example, secondary and/or backscattered electrons, and/or x-rays, are released from the substrate 10, which can be detected by a detector 139.

[0027] In the exemplary embodiments described with respect to FIG. 1, a condenser lens 123 is provided. A two-stage deflection system (not shown) can be provided between the condenser lens and e.g. a beam limiting aperture, e.g. a beam shaping aperture, for alignment of the beam to the aperture. As shown in FIG. 1, the objective lens 140 has a magnetic lens component having pole pieces 142 and 146, and having a coil 144. The objective lens focuses the primary electron beam on the substrate 10. Further, an upper electrode 152 and a lower electrode 154 form an electrostatic lens component of the objective lens 140.

[0028] Further, a scanning deflector assembly 170 can be provided. The scanning deflector assembly 170 can, for example, be a magnetic, but preferably an electrostatic scanning deflector assembly, which is configured for high pixel rates. The scanning deflector assembly 170 may be a single stage assembly, as shown in FIG. 1. Alternatively, also a two-stage or even a three-stage deflector assembly can be provided for scanning. Each stage is provided at a different position along the optical axis.

[0029] The lower electrode 154 is connected to a voltage supply (not shown). The lower electrode being the deceleration electrode of the immersion lens component, i.e. a retarding field lens component, of the objective lens is typically at a potential to provide a landing energy of the charged particles on the substrate of 2 keV or below, e.g. 500 V or 1 keV. As exemplarily illustrated in fig. 1, the substrate support 150 can according to some embodiments be set to ground potential. Accordingly, the lower electrode 154 can have a positive voltage of about 200 V to 1 kV, e.g. to generate landing energy of 200 eV to 1 keV.

[0030] According to some embodiments, which can be combined with other embodiments described herein, the deceleration of the primary charged particle beam can be provided in the vicinity of the substrate 10, for example in or behind the objective lens, or a combination thereof. A deceleration can be provided by the lower electrode 154, i.e. a retarding field lens, respectively. A deceleration can e.g. be provided by an electrostatic lens component of the objective lens. For example, additionally or alternatively, a retarding bias voltage can be applied to the substrate 10 and/or the substrate support in order to provide a retarding field lens component according to embodiments described herein. The objective lens can be an electrostatic-magnetic compound lens having e.g. an axial gap or a radial gap, or the objective lens can be an electrostatic retarding field lens.

[0031] According to some embodiments, which can be combined with other embodiments, the distance between the lower portion or edge of the objective lens, for example the lower electrode 154 and the substrate, or the substrate support can be 1 mm to 3 mm, such as 1 point 5 mm. A resolution of an image measured on a large area substrate, for example a substrate having an area of 1 m² or larger, such as 1.5 m² or larger, is below 15 nm for example 3 nm to 12 nm, such as about 10 nm. The resolution is mainly delimited by the size of the substrate support for the large area substrates and vibrations and movements resulting from the size of the substrate support.

[0032] An advantage of having a landing energy of 2keV or below, particularly a landing energy of 1 keV or below, is that the primary electron beam impinging onto the substrate generates a stronger signal compared to high-energy electron beams. Since layers, e.g. LTPS layers, deposited on the substrate are thin and since high-energy electrons penetrate deeply into the substrate, i.e. below the layer, only a few electrons may generate a detector signal that contains information about the deposited layer. In contrast, low-energy electrons, such as electrons having a landing energy of 2keV or below, penetrate into a shallow region of the substrate only and thus provide more information about the deposited layer. Accordingly, an improved image of e.g. grain boundaries may be provided even when, as provided by embodiments described herein, no surface etching of the substrate is carried out. Yet further, embodiments described herein provide electron microscope images under vacuum condition on large area substrates, i.e. substrate having an area of 1 m² or larger. Providing electron microscope images under vacuum allows for having low landing energies of, for example, 2 keV or below such as 1 keV or below.

[0033] For high resolution applications it is beneficial to provide a landing energy of e.g. 2 keV or below, such as 1 keV or below, and have a high charged particle beam energy in the column, for example a beam energy of 10 keV or above, such as 30 keV or above. Embodiments may include a deceleration before the substrate 10, e.g. within the objective lens and/or between the objective lens and the substrate 10 of a factor of 5 or more, such as a factor of 10 or more. For other applications a low landing energy of 2 keV or below may also be provided without a deceleration, e.g. in the event the beam energy within the column is not above 2 keV.

[0034] According to embodiments described herein, which can be combined with other embodiments described herein, an electron microscope image of a thin film having grains is provided. For example a scanning electron microscope image of a portion of a thin film deposited on a large area substrate is provided. The image is provided under vacuum conditions allowing for low energy imaging, wherein the landing energy of an electron beam on the thin film is 2 keV or below, for example about 1 keV. Accordingly, as compared to high-energy electron beam imaging (< 7keV), for example with AIR SEM, embodiments of the present disclosure, which refer to low energy imaging, provide a non-destructive imaging. Accordingly, an electron beam review can be provided during manufacturing of an optoelectronic device, for example a display manufactured on the large area substrate.

[0035] The charged particle beam microscope 100 shown in fig. 1 includes a detector 139 in a detection vacuum area 130. The detector 139, which is also shown in fig. 2 includes a scintillator arrangement 136. The scintillator arrangement 136 has an opening 201, for example an opening in the center of the scintillator arrangement. The opening 201 serves for having the primary charged particle beam path through the detector 139.

[0036] The scintillator arrangement 136 is segmented to have two or more scintillator segments 236. According to some embodiments, which can be combined with other embodiments described herein, for scintillator segments can be provided, i.e. a Quad-detector is provided. The four segments allow for topographic images of the substrate plane in 2 dimensions x and y. Respective images are shown in FIGS. 3A.

[0037] A light guide 134 is connected to each of the scintillator segments 236. Further, a photo multiplier or another signal detection element 132 can be provided for each of the

light guides. Accordingly, some embodiments, which can be combined with other embodiments described herein include an Everhart-Thornley detector arrangement as a detector 139. Some embodiments may also utilize an avalanche photodiode as a signal detection element or a microchannel plate.

[0038] According to embodiments, which can be combined with other embodiments described herein, the scintillation arrangement can be manufactured from a low noise scintillator with a lower bandwidth, which results in a better signal-to-noise ratio, which may further be enhanced by averaging over segments of the scintillator arrangement 136. For example, the scintillator may have a decay time of 50 ns to 100 ns, e.g. about 60 ns. Measurements according to embodiments of the present disclosure may have a pixel rate of 3 MHz to 10 MHz, such as about 5 MHz.

[0039] In some embodiments, which can be combined with other embodiments described herein, the primary charged particle beam can be tilted to impinge on the substrate under a predetermined tilted beam landing angle. For example, a tilted primary charged particle beam can have a tilt angle (relative to a normal on the substrate), i.e. an angle of incidence larger than 5° such as for example 10° to 20°, such as about 15°. A non-tilted primary charged particle beam can have an angle of incidence smaller than 3°. According to embodiments described herein, an imaging charged particle beam microscope as described herein may be utilized for imaging with one or more tilted beams. Accordingly, 3D imaging, imaging of steps, and imaging of other height structures can be improved.

[0040] According to one example, a beam tilt with a tilt angle can be generated by a pre-lens deflection unit, which may include two deflection coils to deflect the beam away from the optical axis. In light of the two stages, the beam can be deflected to seemingly emerge from a point coincident with the apparent position of the charged particle beam source. The pre-lens deflection unit can be arranged between the charged particle source and the objective lens. An in-lens deflection unit can be provided inside the field of the objective lens such that the respective fields overlap. The in-lens deflection unit can be a two-stage unit comprising two deflection coils. The in-lens deflection unit can redirect the beam so that the beam crosses the center of the objective lens, i.e. the center of the focusing action, at the optical axis. The redirection is such that the charged particle beam hits the surface of the substrate from a direction, which is substantially opposite to the direction without the

beam crossing the optical axis. The combined action of the in-lens deflection unit and the objective lens directs the primary charged particle beam back to the optical axis such that the primary charged particle beam hits the sample under the predetermined tilted beam landing angle.

[0041] According to another example, a beam tilt can be generated by a deflection unit that includes two deflectors to deflect the beam away from the optical axis. In light of the two stages, the beam can be deflected to seemingly emerge from a point coincident with the apparent position of the charged particle beam source. The pre-lens deflection unit can be arranged between the charged particle source and the objective lens. Above the pre-lens deflection unit, a Wien filter can be disposed which generates crossed electric and magnetic fields. The off-axis path of the charged particle beam through the objective lens causes a first chromatic aberration. The energy dispersive effect of the Wien filter introduces a second chromatic aberration of the same kind as the first chromatic aberration. Appropriately choosing the strength of the electric field E and magnetic field B of the Wien filter, the second chromatic aberration can be adjusted to have the same magnitude but opposite direction as the first chromatic aberration. In effect, the second chromatic aberration substantially compensates the first chromatic aberration in the plane of the substrate surface. The primary charged particle beam is tilted by travelling off-axis through the objective lens and the focusing action of the objective lens.

[0042] According to yet further embodiments, which may additionally or alternatively be applied, a beam tilt may also be introduced by mechanically tilting the column, i.e. the optical axis with respect to the substrate. Tilting the charged particle beam by providing a tilted beam path within the column provides for faster switching between beam angles and reduces the introduction of vibration as compared to a mechanical movement.

[0043] According to some embodiments, an apparatus for inspecting a substrate, particularly a substrate for display manufacturing, is provided. The apparatus includes a vacuum chamber as described herein. The apparatus further includes a substrate support arranged in the vacuum chamber, as described herein. The apparatus further includes a first imaging charged particle beam microscope and optionally a second imaging charged particle beam microscope, as described herein. The second imaging charged particle beam

microscope is distanced from the first imaging charged particle beam microscope by a distance of at least 5 cm to 60 cm, such as about 25 cm to 35 cm.

[0044] The images shown in FIGS. 3A, are images of 4 segments of a detector 139 of the grain structure of low temperature polysilicon. The techniques for manufacturing TFT on the glass substrate include the amorphous silicon (a-Si) process and the low temp polysilicon (LTPS) process. The major differences between the a-Si process and the LTPS process are the electrical characteristics of the devices and the complexity of the processes. The LTPS TFT possesses higher mobility but the process for fabricating the LTPS TFT is more complicated. Although the a-Si TFT possesses lower mobility, the process for fabricating the a-Si TFT is simple. According to embodiments described herein, the LTPS TFT process can be improved and control of the process is beneficial. The LTPS TFT process is one example for which embodiments described herein can be beneficially utilized. For manufacturing of an LTPS TFT a deposited layer is locally melted due to laser radiation. For example the laser radiation can be provided in a width of about 60 cm. Thus, a distance between charged particle beam microscopes of about 30 cm may be sufficient to provide an analysis of the process in this region.

[0045] A method for inspecting a substrate is provided, the method includes generating of the primary charged particle beam within the vacuum chamber and generating one or more images from signal particles, wherein the one or more images are topographic images. As shown in FIG. 3A for example for topographic images can be provided by imaging a portion of a thin film having a grain structure with a segmented detector, for example a Quad detector having four segments. The topographic images of FIGS. 3A can be combined to a combined-perspective secondary electron image shown in FIG. 3B. According to embodiments described herein, the images described herein may be compared with optical images having two or more, e.g. four, illumination angles of a light source, wherein from the shadows of the illumination angles values of the imaged grains structure can be obtained. This is different as compared to measurements with a tilted beam, which would correspond to a stereoscopic optical image.

[0046] In FIG. 3B, an algorithm has been provided to highlight the boundaries of the grains of the LTPS thin film. The topographic images shown in FIGS. 3A or the combined image shown in FIG. 3B can be used to qualify LTPS layers, for example in the display

industry, or other layers of the thin-film with a grain structure. The electron beam reviewed according to methods as described herein is capable to image the thin films having the grain structure, for example LTPS layers with multiple perspective. Improved topographical information can be provided. This allows for more precise evaluation of the grain structure.

[0047] In comparison, a prior art measurement is shown in FIG. 4. FIG. 4 shows an image of a destructive measurement, wherein an LTPS layer has been etched and imaged with in high energy electron beam. The great of lines 42 can be provided on the image surface and peaks corresponding to dots 44 can be identified. It is apparent that the one or more images shown in FIGS. 3A or the combined image shown in FIG. 3B provides improved topographical information and make, thus, be utilized for better evaluation of the grain structure. Further, the images obtained as shown in FIGS. 3A and FIG. 3B are non-destructive. Accordingly, a thin film imaged as shown in FIGS. 3A and FIG. 3B or a corresponding substrate can be further processed according to embodiments described herein.

[0048] According to embodiments described herein, a grain structure can be described by the size of the grains, the shape of the grains, the distribution of the grains, the area of the grains, and the like. These parameters can be evaluated with statistical analysis methods with respect to one or more of the parameters. For example, a characteristic of grains of the grain structure can be determined as an arithmetic mean value, as a quadratic mean value, as a weighted mean value, and/or as a median value.

[0049] According to embodiments, which can be combined with other embodiments described herein, the topographical information can be used by an software algorithm, e.g. to detect and analyze the grain structure, for example in LTPS grain structure. A calculation of grain structure characteristics may also include a watershed algorithm. A calculation based upon one or more images, i.e. topographic images or a combined image of topographic images, can provide at least one characteristic of grains of the grain structure selected from: an area of grains of the grain structure, a circumference of grains of the grain structure, a minimum size of grains of the grain structure, maximum size of grains of the grain structure, a size of grains of the grain structure along a predetermined direction, and the height of peaks of a boundary of grains of the grain structure. For

example, a two or more channel detector, such as a four channel detector is used to image LTPS topography from two or more, e.g. four different perspectives respectively quasi illumination sources in a top down SEM image. These two or more, e.g. four perspectives give surface information to detect and evaluate the size, uniformity, local distribution and all statistics for the parameters describing the thin film with the grain structure, i.e. an LTPS layer.

[0050] According to some embodiments, which can be combined with other embodiments described herein, characteristics of the grain structure and/or statistics of the parameters of the grain structure can be used to verify process parameters of a manufacturing method of the deposited thin film. A feedback to the manufacturing process of the thin film having the grain structure can be provided. For example, an LTPS TFT process can be controlled by electron beam review (EBR) according to embodiments described herein.

[0051] According to some embodiments, which can be combined with other embodiments described herein, algorithms for identifying characteristics of the grain structure or statistics on parameters of the grain structure of the thin-film can be applied to the combined image shown in FIG. 3B. It has been found that it may be beneficial to apply these algorithms on the individual topographic images shown in FIGS. 3A and combine the values resulting from the algorithms to a combined value for evaluating the grain structure.

[0052] According to embodiments described herein, the area of grains in the grain structure, the circumference of grains in the grain structure, one or more sizes grains in the grain structure can be measured. For example the grains having a size of about 100 nm to 500 nm can be measured. According to some embodiments, which can be combined with other embodiments described herein, the field of view, which can be measured by scanning the primary electron beam over the substrate, can have a size of up to 10 μm .

[0053] The grains are typically surrounded by a boundary having peaks, which may have a height of 50 nm or below. According to embodiments, which can be combined with other embodiments described herein normal operation of the charged particle beam microscope is with a non-tilted beam, i.e. a beam with an incident angle on the substrate of 3° or below. The height of the peaks can be determined by the length of the shadow in one or more of the topographic images. The length of the shadow can be calibrated to a measured height of the peaks.

[0054] For calibration, the primary charged particle beam can be tilted to an angle of 5° or larger, for example to about 15° . A height of the height profile, i.e. a boundary of the grain, can be measured with a tilted beam image or with two or more tilted beam images. The tilted beam image or the two or more tilted beam images can be obtained on a thin film with a grain structure, for example an LTPS layer, or on a substrate with artificial calibrating features. From a measurement with a tilted beam, the height of the boundary of the grain structure or the artificial calibrating feature can be measured in absolute values. After removing the tilt and providing an incident angle of normal operation (e.g. $< 3^\circ$ tilt, such as 0° tilt) topographic images can be measured and the lengths of a shadow can be calibrated to the previously measured height.

[0055] According to some implementations, the apparatus for inspecting large area substrates for display manufacturing can be an in-line apparatus, i.e. the apparatus, potentially including a load lock for loading and unloading the substrate in the vacuum chamber for imaging with the imaging charged particle beam microscope, e.g. an SEM, can be provided in line with another, previous testing or processing procedure and in line with a yet further, subsequent testing or processing procedure. Due to the low energies of the charged particle beam of 2 keV or below on the substrate for imaging, the structures provided on the substrate are not destroyed. Accordingly, the substrate can be provided for further processing in the display manufacturing fab. As understood herein, the number of substrates to be tested can be 10% to 100% of the entire amount of substrates in the fab for display manufacturing. Accordingly, even though the apparatus for inspecting and including a imaging charged particle beam microscope can be provided as an in-line tool without necessarily testing 100% of the substrates in the production line.

[0056] The vacuum chamber may include one or more valves, which may connect the vacuum chamber to another chamber, in particular if the apparatus is an inline apparatus. After a substrate has been guided into the vacuum chamber, the one or more valves can be closed. Accordingly, the atmosphere in the vacuum chamber can be controlled by generating a technical vacuum, for example, with one or more vacuum pumps. An advantage of inspecting a substrate in a vacuum chamber, compared to e.g. atmospheric pressure, is that the vacuum conditions facilitate using a low-energy charged particle beam for inspecting the substrate. For example, low-energy charged particle beams can have a landing energy of 2 keV or below, particularly of 1 keV or below, such as 100 eV to 800

eV. Compared to high-energy beams, low energy beams do not penetrate deeply in the substrate and may therefore provide superior information about e.g. coated layers on the substrate.

[0057] Fig. 5 shows a flowchart illustrating methods of inspecting a substrate, for example for display manufacturing. As illustrated by block 502, a large area substrate is provided in the vacuum chamber, wherein the large area substrate has thin-film with a grain structure deposited on the substrate. The substrate can be measured as part of a regular manufacturing process, i.e. no sample preparation like etching is required. Further, measurement steps illustrated below are non-destructive and the substrate can be further processed after the electron beam review. A primary charged particle beam is generated as indicated by block 504 and impinges on the thin film on the large area substrate under vacuum conditions. The vacuum conditions allow for low energy landing energies on the substrate. For example, energies of 2 keV or below, such as about 1 keV, can be provided. Block 506 in fig. 5 refers to generation of one or more topographic images. According to embodiments described herein, topographic images are generated with non-tilted beam. A non-tilted beam is beneficial for ease of control of the electron beam microscope and, thus, throughput. Topographic images can be provided by a segmented detector, such that for a non-tilted beam for viewing angles can be obtained with one measurement. The topographic images can be used for determining one or more characteristics or parameters of the grain structure, for example grains in an LTPS layer.

[0058] Fig. 6 shows a flowchart illustrating yet a further method of inspecting a substrate. For a calibration of a shadow length of topographic images measured under non-tilted beam angle, the primary charged particle beam can be tilted to an angle of incidence of 5° or above, such as 10° to 20° . This is indicated in block 602. With reference 604, one or more images of an area with a tilted beam are generated. From the one or more images with a tilted beam the height of a structure or feature is measured as indicated by block 606. The same area and/or at the same structure a feature is measured with a non-tilted beam in block 608, wherein one or more topographic images, e.g. test images, are generated. From one or more topographic images the height measured in absolute values as indicated by block 606 is calibrated to a length of a shadow of the image measured in block 608. In block 608 a test image is measured with a non-tilted beam such that the length of the shadow can be calibrated to the measured heights in absolute values. This

calibration is indicated by block 610. In block 612 the calibration is used to measure the height of a peak of the grain boundary of the grain structure with the calibration and based upon a shadow length. According to embodiments described herein, the process indicated by block 612 can be repeated a plurality of times based on the calibration generated by block 602 to 610. Accordingly, the calibration can be provided once or on a regular basis at a predetermined time interval. A measurement during review of substrates in the manufacturing process can be conducted with a non-tilted beam. The calibration can be used to determine the height of boundaries of the grain structure based upon the previously done calibration. This is beneficial for increasing the measurements speed and, thus, the throughput. For example, the calibration needs to be conducted a single time, and may be checked for example once a week, or even once a month, or on even longer timescales, wherein measurements are conducted all the time.

[0059] While the foregoing is directed to some embodiments, other and further embodiments may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

CLAIMS

1. A method for inspecting a substrate, the method comprising:

providing the substrate being a large area substrate in a vacuum chamber, wherein the substrate has a thin-film with a grain structure deposited on the substrate;

generating a primary charged particle beam with an imaging charged particle beam microscope, wherein the primary charged particle beam impinges on the substrate in the vacuum chamber; and

generating one or more images from signal particles released from the substrate upon impingement of the primary charged particle beam, wherein the one or more images are topographic images.
2. The method according to claim 1, wherein a landing energy of the primary charged particle beam on impingement on the substrate is 2 keV or below.
3. The method according to any of claims 1 to 2, wherein one or more images are generated with a segmented detector, particularly a Quad detector having 4 segments.
4. The method according to claim 3, wherein one or more images are generated with a tilt angle of the primary charged particle beam of 3° or smaller.
5. The method according to any of claims 1 to 4, further comprising:

calculating from the one or more images at least one characteristic of grains of the grain structure selected from: an area of grains of the grain structure, a circumference of grains of the grain structure, a minimum size of grains of the grain structure, maximum

size of grains of the grain structure, a size of grains of the grain structure along a predetermined direction, and a height of peaks of a boundary of grains of the grain structure.

6. The method according to claim 5, wherein the at least one characteristic of grains of the grain structure is determined as an arithmetic mean value, as a quadratic mean value, as a weighted mean value, minimum value, maximum value, and/or as a median value.

7. The method according to any of claims 5 to 6, wherein the calculating uses a watershed algorithm.

8. The method according to any of claims 5 to 7, wherein two or more images of the one or more images are combined to form a combined image and the calculating is conducted utilizing the combined image.

9. The method according to any of claims 5 to 7, wherein the calculating is conducted utilizing the one or more generated images to form one or more corresponding calculated values and wherein the one or more corresponding calculated values are combined.

10. The method according to claim 5 to 9, further comprising:

verifying process parameters of a manufacturing method of the thin-film by the at least one characteristic of grains of the grain structure.

11. The method according to any of claims 1 to 10, further comprising:

tilting the primary charged particle beam to an angle of 5° or larger;

measuring a height of a height profile;

tilting the primary charged particle beam back to an angle of a normal operation;

generating one or more test images from signal particles released from the substrate upon impingement of the primary charged particle beam at an angle of normal operation, wherein the one or more images are topographic images; and

calibrating a length of a shadow of the one or more images being topographic images with the measured height.

12. The method according to any of claims 1 to 11, wherein the method of inspecting is an intermediate process of a manufacturing method of a display.

13. The method according to any of claims 1 to 12, further comprising:

generating a further primary charged particle beam with a further imaging charged particle beam microscope, wherein the further primary charged particle beam impinges on the substrate in the vacuum chamber; and

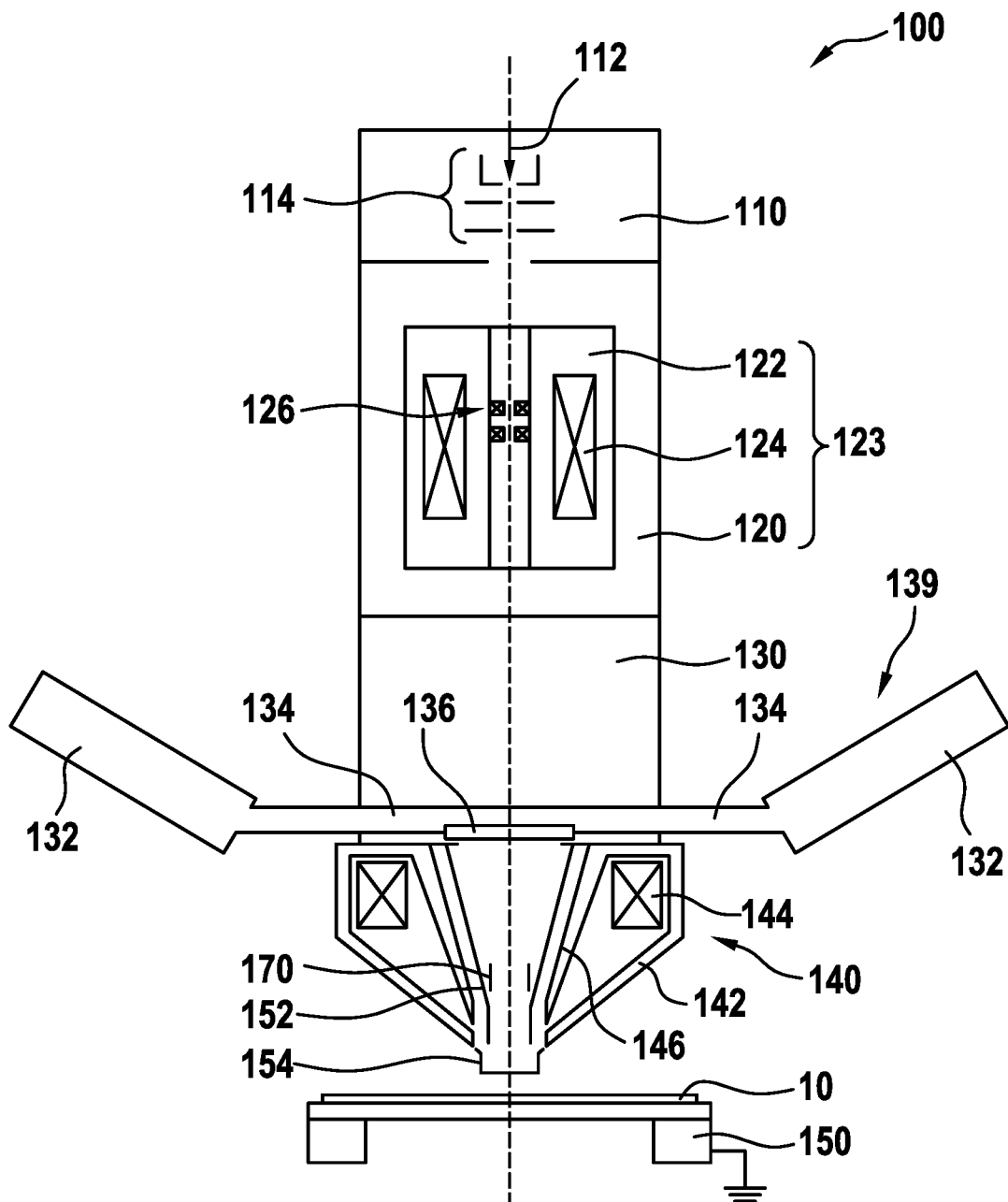
generating one or more further images from further signal particles released from the substrate upon impingement of the further primary charged particle beam, wherein the one or more further images are topographic images.

14. The method according to claim 13, wherein the primary charged particle beam and the further primary charged particle beam have a distance of 5 cm to 60 cm at the position of impingement on the substrate.

15. A computer readable medium having instructions stored thereon that, when executed, cause a charged particle beam microscope to perform a method for inspecting a substrate, the method as described in any of the preceding claims.

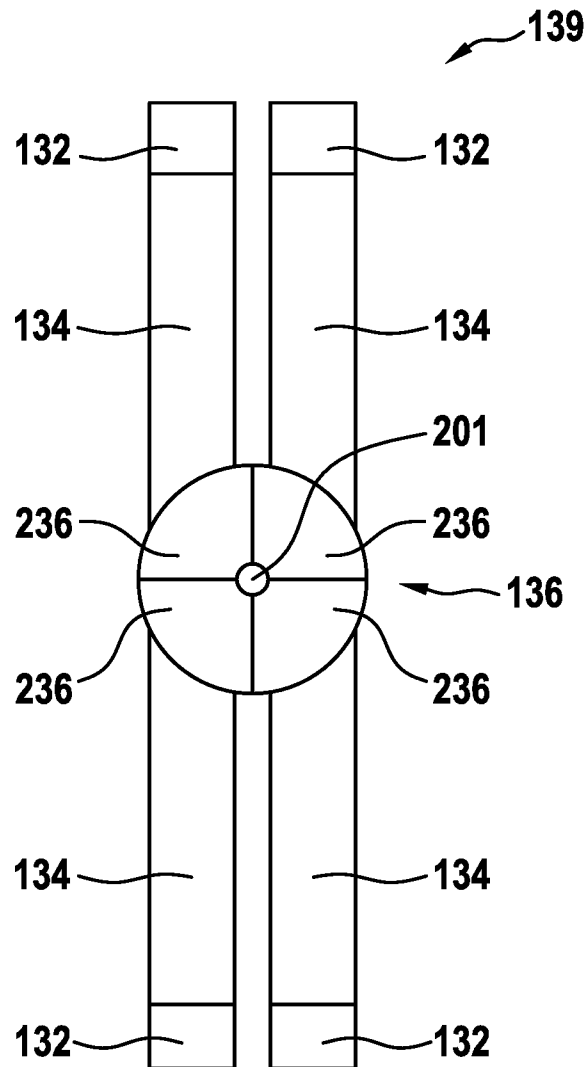
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Fig. 1



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Fig. 2



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Fig. 3b

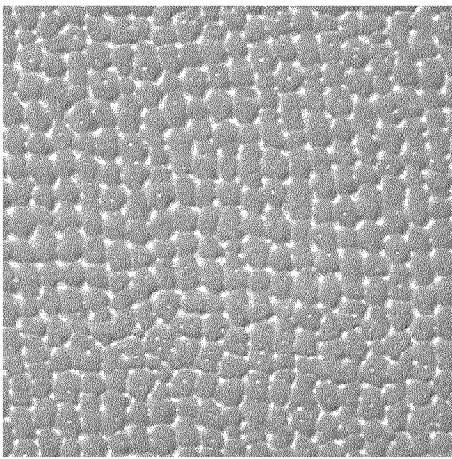
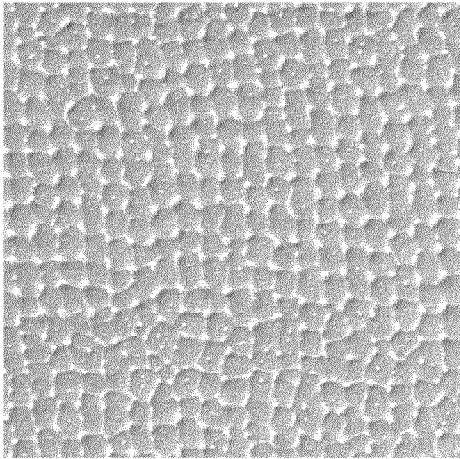
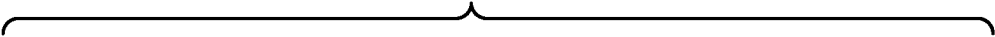
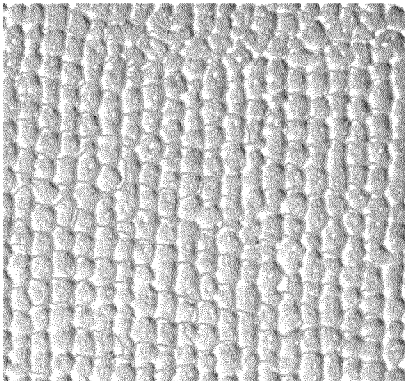
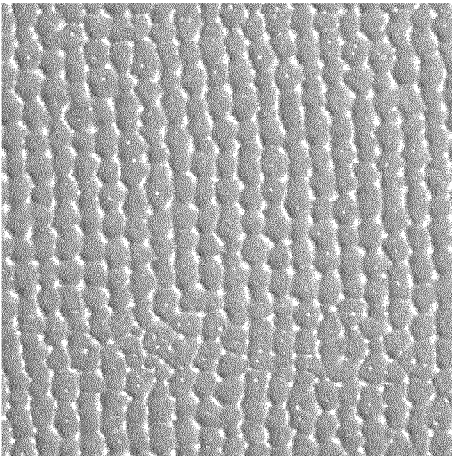
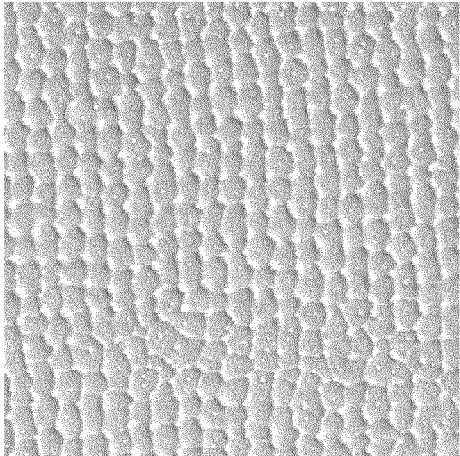


Fig. 3a



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Fig. 4

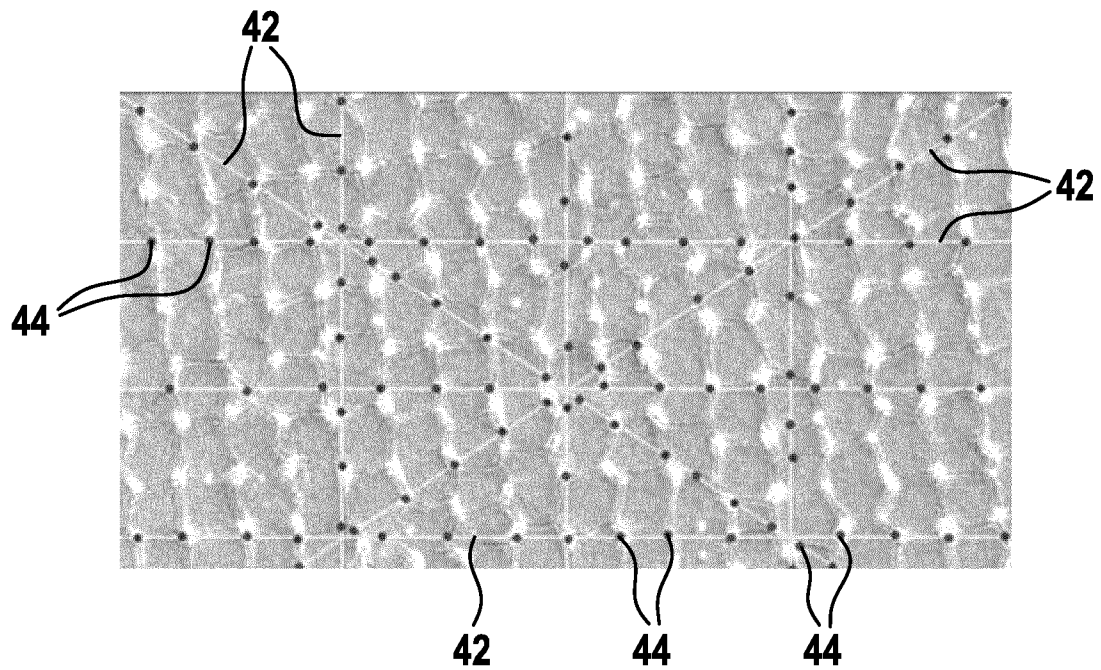
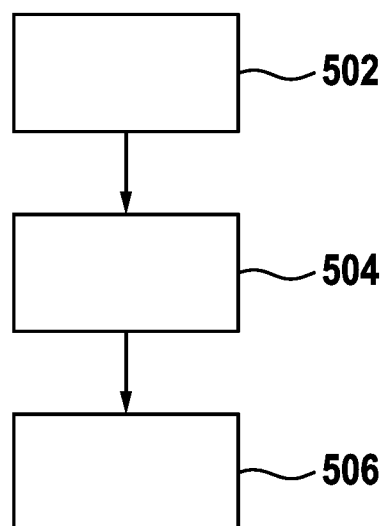
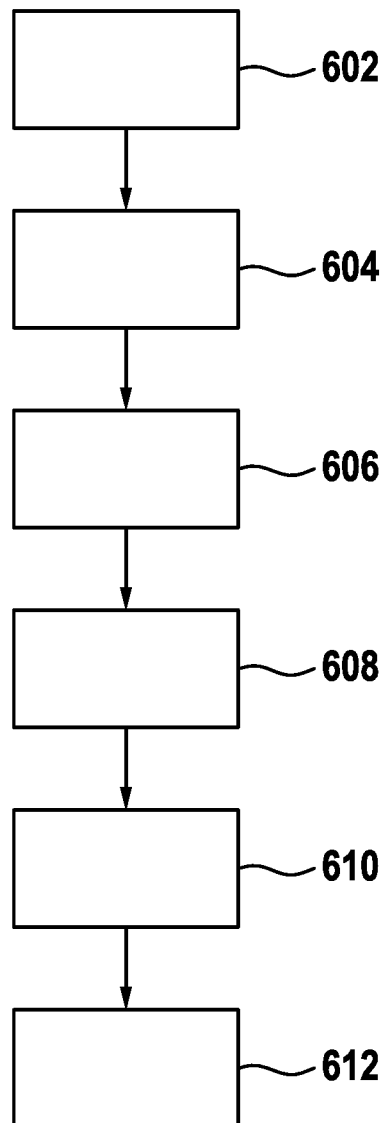


Fig. 5



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Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/080662

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01J37/28 H01J37/22 G06T7/55
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 G06T

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, WPI Data

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Y	paragraphs [0001] - [0005], [0008], [0017], [0019], [0020], [0024], [0028], [0034], [0038], [0042], [0043]; figures 1-6 paragraphs [0051], [0077] - [0081], [0084], [0088]	3, 5-9, 11
Y	----- US 2014/092230 A1 (LANGER MATTHIAS [DE] ET AL) 3 April 2014 (2014-04-03) paragraphs [0036], [0063], [0064] - [0067], [0088]; figure 1	3, 5-9
Y	----- US 2008/294236 A1 (ANAND UMANG [US] ET AL) 27 November 2008 (2008-11-27) paragraph [0065]; figure 14 ----- -/-	7



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

22 August 2017

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31/08/2017

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Chevrier, Dominique

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/080662

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