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(54) Title: MULTI-DIRECTIONAL PHASE CONTRAST X-RAY IMAGING

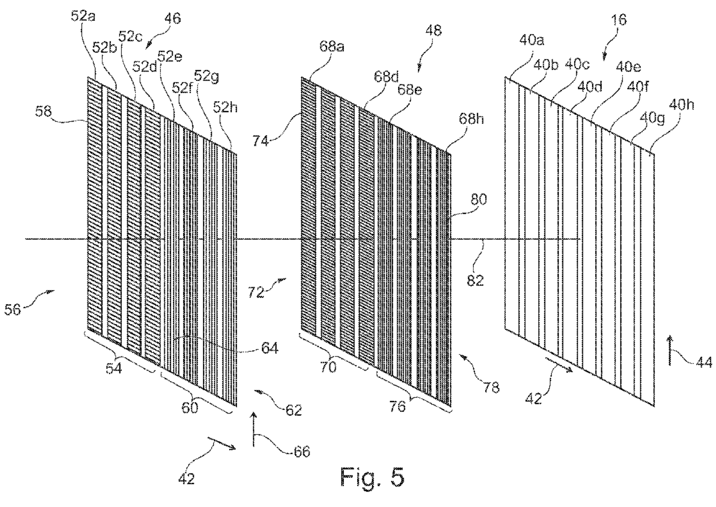

Fig. 5

(57) Abstract: The present invention relates to phase contrast X-ray imaging of an object. In order to provide phase contrast information in more than one direction, an X-ray imaging system is provided that comprises an X-ray source (12), an X-ray detector arrangement (16), and a grating arrangement (18) with a phase-grating structure (46) and an analyser-grating structure (48). The X-ray detector arrangement comprises at least eight line-detector units (40) parallel to each other in a first direction (42), the line-detector units extending linearly in a direction (44) perpendicular to the first direction. The X-ray source, the X-ray detector arrangement and the grating arrangement are adapted to perform an acquisition movement in relation to an object in a scanning direction parallel to the first direction. The phase-grating structure has a number of linear phase-gratings, each of which is arranged in fixed association with an assigned line of the at least eight line-detector units; a first part as first phase-gratings with slits in the first direction, and a second part as second phase-gratings with slits in a second direction different to the first direction. The analyser-grating structure has a number of linear analyser-gratings, each of which is arranged in fixed association with an assigned line of the at least eight line-detector units; a first part as first analyser-gratings with slits in the first direction, and a second part as second analyser-gratings with slits in the second direction. At least four adjacent lines of the line-detector units are associated with the

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first phase-gratings and the first analyser-gratings and at least four adjacent lines of the line-detector units are associated with the second phase-gratings and the second analyser-gratings. The grating arrangement may comprise a source-grating structure arranged between the X-ray source and the phase-grating structure, to provide sufficient coherence to the X-ray beam passing the source-grating structure, so that after passing the phase-grating structure, the interference can be observed at the location of the analyser-grating structure.

MULTI-DIRECTIONAL PHASE CONTRAST X-RAY IMAGING

FIELD OF THE INVENTION

The present invention relates to an X-ray imaging system for phase contrast imaging of an object, to a method for X-ray phase contrast imaging of an object, and to a computer program element as well as to a computer readable medium.

BACKGROUND OF THE INVENTION

Phase contrast X-ray imaging, i.e. differential phase contrast imaging, is used, for example, to enhance contrast of low-absorbing specimen in comparison to conventional attenuation contrast images. EP 1 731 099 A1 describes an X-ray interferometer arrangement comprising a polychromatic X-ray source, a source-grating, a phase-grating, and an analyser-grating in addition to an image detector. An object is arranged between the source-grating and the phase-grating. The gratings comprise a plurality of X-ray transparent slits between bars of absorbing material, for example gold. However, the X-ray interferometer arrangement is providing phase contrast information in only one direction.

SUMMARY OF THE INVENTION

Thus, there is a need to provide phase contrast information in more than one direction.

The object of the present invention is solved by the subject-matter of the independent claims, wherein further embodiments are incorporated in the dependent claims.

It should be noted that the following described aspects of the invention apply also for the X-ray imaging system, the method for X-ray phase contrast imaging, the computer program element and the computer readable medium.

According to a first aspect of the present invention, an X-ray imaging system for phase contrast imaging of an object is provided that comprises an X-ray source, an X-ray detector arrangement, and a grating arrangement. The X-ray detector arrangement comprises at least eight line-detector units arranged parallel to each other in a first direction, wherein the line-detector units extend linearly in a direction perpendicular to the first direction. The X-ray source, the X-ray detector arrangement and the grating arrangement are adapted to perform an acquisition movement in relation to an object in a scanning direction, wherein the scanning direction is parallel to the first direction. The grating arrangement comprises a phase-grating structure arranged between the X-ray source and the detector, and an analyser-grating structure arranged between the phase-grating structure and the detector arrangement. The phase-grating structure is having a number of linear phase-gratings, each of which is arranged in fixed association with an assigned line of the at least eight line-detector units. A first part of the phase-gratings is provided as first phase-gratings with slits in the first direction, and a second part of the phase-gratings is provided as second phase-gratings with slits in a second direction different to the first direction. The analyser-grating structure is having a number of linear analyser-gratings, each of which is arranged in fixed association with an assigned line of the at least eight line-detector units. A first part of the analyser-gratings is provided as first analyser-gratings with slits in the first direction, and a second part of the analyser-gratings is provided as second analyser-gratings with slits in the second direction. At least four adjacent lines of the line-detector units are associated with the first phase-gratings and the first analyser-gratings, and at least four adjacent lines of the line-detector units are associated with the second phase-gratings and the second analyser-gratings.

According to the present invention, the provided X-ray radiation has to show a respective transverse coherency, for example generated with an appropriately adapted source-grating. In other words, the transverse coherence of the X-rays must be large in the direction perpendicular to the scan direction relating to the first grating direction and large in the second direction different to the first direction in relation to the respective area, i.e. parts, of the phase grating with its different grating orientations. For example, in a source-grating, metal bar structures, e.g. metal-filled groove or trench structures, must be oriented parallel to the first direction in one part and parallel to the second direction in the other part. As the coherency of the X-rays in the projected areas of the intermediate regions is poorly defined, the corresponding detector line, or detector lines, may not be covered by gratings, as mentioned in one of the described examples. Of course, instead of providing a source-grating adapted to the at least two coherence directions, also a respective X-ray source providing the respective radiation with multi-coherence can be provided. In case an X-ray source is provided that is capable of applying a respective coherent X-ray radiation, wherein the direction of the coherence of different parts of the X-ray radiation is aligned or adapted to the respective grating structure parts' coherence direction, the source-grating structure can also be omitted. The latter could be achieved by a sufficiently small focal spot.

The gratings of the grating arrangement for providing phase contrast imaging are provided with a plurality of bars and gaps being arranged periodically, wherein the bars are arranged such that they change the phase and/or amplitude of an X-ray radiation and wherein the gaps are X-ray transparent. According to the present invention, the term "X-ray transparent" relates to the fact that X-ray radiation passing the grating is not changed in its phase, i.e. it is not phase-shifted, and not changed in its amplitude, both to a measurable or reasonable amount. According to the present invention, the term "changing phase" relates to shifting the phase of the X-ray radiation. The bars of the analyser-grating are X-ray absorbing such that they are changing the amplitude of X-ray radiation passing the grating. The bars of the phase-grating are changing the phase of the X-ray radiation passing the grating.

According to an exemplary embodiment of the present invention, the fixed association comprises a variation in a phase-grating to analyser-grating offset by a fraction 1/n of the pitch of the analyser-grating; wherein n is the number of lines of the line-detector units associated with one type of phase-grating.

According to an example, in relation with the adjacent lines, the "fixed association" comprises an additional offset, or additional displacement, between the grating pitch of the phase-grating and the analyser-grating, such that the actual displacement/offset position for the x^{th} analyser-grating pitch to the phase-grating pitch of the first part or the second part is d = (x-l)/n. For example, in case of n = 4 detector lines for each phase-grating direction, the grating assigned to the first of the four detector lines is provided with an offset d = (l-l)/4 = 0, the analyser-grating assigned to the second of the four detector lines is provided with an offset d = (2-l)/4 = ¼ pitch of the analyser-grating, the grating assigned to the third of the four detector lines is provided with an offset d = (3-l)/4 = ½, and the grating assigned to the fourth of the four detector lines is provided with an offset d = (4-l)/4 = ¾ pitch of the analyser-grating. Similar rules apply to the detector lines associated with the gratings in the other direction. The offset can be increasing, or decreasing. Further, it must be noted that the phase grating pitch and the analyser grating pitch can have a ratio of 2 to 1, i.e. the pitch of the analyser grating is half the size of the pitch of the phase grating. This is true for parallel geometry. In case of differing cone beam geometries, there is a magnification effect, which relates the pitch of the gratings.

According to a further example, a number of $z * n$ lines of the line-detector units associated with one type of phase-grating is provided, and a redundancy of z is provided; for example, four plus four lines in each direction, each four lines provided with an offset of 1/4 providing a redundancy of 2.

According to a further exemplary embodiment, at least twelve line-detector units are provided, wherein a further part of the phase-gratings is provided as further phase-gratings in a further direction and a further part of the analyser-gratings is provided as further analyser-gratings in the further direction, each of which is arranged in fixed association with an assigned line of the at least twelve line-detector units. The further direction is different from the first and second direction.

For example, the first direction could be parallel to the scanning direction, the second direction would be arranged in an angle 60° to the first direction and the further direction in an angle of 120°.

According to a further exemplary embodiment, for the acquisition movement, the gratings remain fixed in relation to each other and in relation to the detector arrangement. For example, for the acquisition movement, no phase stepping is provided.

According to a further exemplary embodiment, for the acquisition movement, the X-ray source, the grating arrangement, and the X-ray detector arrangement are mounted to a movement structure that is pivotable around an axis aligned to the with a focal spot of the X-ray tube.

According to a further exemplary embodiment, at least one further line-detector unit is provided as a pure attenuation measuring detector unit without an associated phase and analyser-grating structure.

According to a further exemplary embodiment, a pre-collimator is provided between the X-ray source and the analyser-grating such that an object can be arranged between the X-ray source and the analyser-grating. A post-collimator is provided between the analyser-grating and the detector.

According to a second aspect of the present invention, a method for X-ray phase contrast imaging of an object is provided, comprising the following steps:

a) acquiring phase contrast image sub-data with a detector having at least eight detector lines, wherein at least four detector lines are relating to a first phase direction of a grating structure and at least further four detector lines are relating to a second phase direction, wherein each line of the line-detector units relating to one phase direction is arranged in fixed association with the grating structure pitch;

b) moving the detector in relation to the object with an acquisition movement in a single direction;

wherein steps a) and b) are repeatedly performed at least eight times such that image information of one point is acquired by each of the detector lines;

c) computing a phase-retrieval, generating image data for each of the detector lines; and

d) providing the image data for further steps.

The fixed association comprises a variation in a phase-grating to analyser-grating offset by a fraction 1/n of the pitch of the analyser-grating; wherein *n* is the number of lines of the line-detector units associated with one type of phase-grating. For the acquisition, X-ray radiation with coherency in at least two directions, i.e. coherency in one direction for the rays passing the first set of detectors and coherency in another direction for the second set of detectors, is provided in accordance with the respective differently oriented grating structures.

According to a further exemplary embodiment, the phase-retrieval in step c) provides: i) differential phase data; ii) scatter information; and iii) attenuation data.

According to an aspect of the present invention, the gratings are provided with at least two different grating directions, thus providing phase contrast image information concerning the respective two different directions. Instead of the usually applied stepping of the gratings in order to scan different portions of the resulting interference pattern, the imaging system is moved in relation to the object to be examined. The number of four line-detector units is provided as a minimum, in order to be able, for example, to identify a sinusoidal curve in the intensities measured for the same physical rays by different detector lines corresponding to different offsets between the respective phase and analyser gratings. Of course, a higher number of so-to-speak scanning lines, each relating to different portions of the interference pattern, due to the offset from one scanning line to the next scanning line, i.e. the offset increasing or decreasing between the phase-grating and the analyser-grating, the respective image information is provided that can then be computed in a phase-retrieval step in order to arrive at the desired phase contrast image data.

According to a further aspect of the present invention, the X-ray imaging system is a mammography system, for example Philips MicroDose mammography systems, wherein the entire field of view is scanned with several linear detector units. For example, the detector units are mounted to a moving structure, which is pivotably mounted such that the focal point of the X-ray tube is the rotating point. According to the present invention, such mammography system is provided with the grating arrangement according to the present invention, as described above, such that a so-called slit scanning system can acquire phase contrast information without the need for phase stepping in the conventional sense where one of the phase or analyser gratings in the system has to be physically displaced with respect to the other. For example, making use of the twenty-one detector lines present in the Philips MicroDose system, an equivalent of the phase stepping is implemented in the system where one after the other detector lines provides samples of one and the same physical ray path through the breast. Therefore, the different line-detectors are complemented by gratings interferometers with different frozen phase states.

Two or more phase cycles are acquired with a line-detector system simultaneously by orienting phase-related grating structures at various angles with respect to the scanning direction. In one possible embodiment, the first seven line-detectors are used to acquire phase contrast in a direction parallel to the scan direction, the following seven line-detectors are used to acquire pure attenuation information, and the last seven line-detectors are used to acquire phase contrast information perpendicular to the scan direction. Instead of seven plus seven plus seven, also two groups of ten detector lines for the gradients in two different directions using a larger portion of the total X-ray flux for the phase contrast acquisition can be provided, and only one line, for example the central detector line, is not designed to acquire phase contrast, but to acquire pure attenuation information.

According to a further aspect, the present invention allows solving the symmetry breaking property of one dimensional differential phase contrast imaging, for example by providing two perpendicular scanning directions. In case of three or more, for example four, directions, for example 0°, 45°, 90° and 135° with respect to the scanning direction, improved image information, in particular for low absorbing portions of an object, such as for breast imaging, can be provided. Thus, significantly reducing the symmetry breaking as the gradient in two or more directions can be acquired, the likelihood of missing strong gradients or strongly scattering tissue components is significantly reduced.

These and other aspects of the invention will become apparent from and be elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments of the invention will be described in the following with reference to the following drawings:

Fig. 1 schematically shows an X-ray imaging system according to an exemplary embodiment of the present invention.

Fig. 2 shows a perspective view of a mammography system as an example for an X-ray imaging system for phase contrast imaging of an object according to the present invention.

Fig. 3 schematically shows a basic setup for an arrangement of an X-ray imaging system of the present invention.

Fig. 4 shows a further possible arrangement in addition to Fig. 3.

Fig. 5 shows a perspective view of a grating arrangement and an X-ray detector arrangement according to an exemplary embodiment of the present invention.

Fig. 6 shows a further perspective view of a further example of a grating arrangement and an X-ray detector arrangement according to the present invention.

Fig. 7 shows an offset between adjacent phase-gratings and analyser-gratings, respectively.

Figs. 8A and 8B show a more detailed illustration relating to the offset.

Figs. 9A and 9B show examples for at least one further coherence direction of the grating arrangement.

Fig. 10 shows an example for a source-grating according to the present invention.

Figs. 11A and 1IB shows an exemplary setup with a pre-collimator and a post-collimator in two different arrangements.

Fig. 12A and 12B show two different setups for a 2 1 lines detector arrangement.

Fig. 13 shows basic steps of a method for X-ray phase contrast imaging of an object according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows an X-ray imaging system 10 for phase contrast imaging of an object. The system 10 comprises an X-ray source 12 for radiating X-ray radiation 14 towards an X-ray detector arrangement 16. Further, a grating arrangement 18 is provided, shown in a simplified manner with a box. However, the grating arrangement 18 according to the present invention will be described also with reference to the following figures, in particular Figs. 3 and 4, and Figs. 5 to 9.

Further, an object 20 is symbolically indicated. The X-ray source 12, the X-ray detector arrangement 16, and the grating arrangement 18 are adapted to perform an acquisition movement M_A in relation to an object in a scanning direction 22, wherein the scanning direction is also referred to as first direction, i.e. the scanning direction is parallel to the first direction.

Before explaining further the X-ray detector arrangement 16 and the grating arrangement 18 according to the present invention, it is referred to Fig. 2, showing a mammography imaging system 24, in which the scanning direction 22 is indicated with a first arrow 26, and the opposite direction is indicated with a second arrow 28. In the system shown in Fig. 2, the X-ray source 12 and the X-ray detector arrangement 16 are mounted to a movement structure 30 that is pivotable around an axis 32 aligned with a focal spot 34 of the X-ray tube. Thus, for the acquisition movement, the grating arrangement 18 (not further shown in Fig. 2) remains fixed in relation to the detector arrangement 16. With relation to the mammography investigations, a lower breast support paddle 36 and an upper breast support paddle 38 are provided, which can be displaced in relation to each other in order to receive a breast to be examined as the object. For the acquisition, the breast stays in place, and rather the detector moves in relation to the breast, together with the X-ray source. By providing the axis 32 aligned with the focal spot 34 of the X-ray tube, a pivoting motion can be implemented. Of course, also other movement types, for example a translational movement of the X-ray source and the X-ray detector and the grating arrangement can be provided with a different respective mechanism.

As shown in Fig. 3, according to the present invention, the X-ray detector arrangement 16 comprises at least eight line-detector units 40 arranged parallel to each other in a first direction, indicated with a first direction arrow 42, wherein the line-detector units extend linearly in a direction, indicated with a second direction arrow 44, perpendicular to the first direction. In other words, the line-detector units are running in the direction 44, which is perpendicular to the parallel stacking order represented by the first direction 42.

The grating arrangement 18 comprises a phase-grating structure 46 arranged between the X-ray source 12 and the detector arrangement 16, and an analyser-grating structure 48 arranged between the phase-grating structure 46 and the detector arrangement 16.

It must be noted that with respect to Fig. 3, and also with respect to Fig. 1, the arrangement of the different grating structures and the object 20 can be provided in such positioning that starting from the X-ray source 12, the object is provided in front of the phase-grating structure 46, or, according to a further example, arranged following the phase-grating structure 46 and before the analyser-grating structure 48. Thus, although not shown in Fig. 3, the object 20 could also be arranged between the phase-grating structure 46 and the analyser-grating structure 48 (see also Fig. 4).

Further, the grating arrangement 18 may comprise a source-grating structure 50 arranged between the X-ray source 12 and the phase-grating structure 46. The source-grating structure 50 is also further explained with relation to Fig. 10 below. The source-grating structure is adapted to provide sufficient coherence to the X-ray beam passing the source-grating structure, so that after passing the phase-grating structure, the interference can be observed at the location of the analyser-grating structure. The source-grating structure is having a number of linear source-gratings, wherein a first part of the source-gratings is provided as first source-gratings providing coherence with relation to the first direction, and at least a second part of the source-gratings is provided as second source-gratings providing coherence with relation to the second direction. It must be noted that the radiation 14 has to be provided with at least two coherence directions, which will be explained below in relation with Figs. 5 et seq. This can be provided, according to a first example, by the source-grating structure 50 towards which polychromatic X-ray radiation is radiated and the source-grating structure 50 provides the necessary coherence. Of course, the necessary coherence can also be provided by the X-ray source itself such that the source-grating structure 50 can also be omitted, according to a further example (not further shown).

The source-grating structure 50 is having a number of linear source-gratings, wherein a first part is providing coherence with relation to the first direction, and at least a second part is providing coherence with relation to the second direction.

For example, the source-grating, or source-grating structure 50, is arranged close to the focal spot of the X-ray tube.

Fig. 4 shows a schematic setup, as mentioned above, where the object 20 is arranged between the phase-grating structure 46 and the analyser-grating structure 48.

As shown in Fig. 5, the phase-grating structure 46 is having a number of linear phase-gratings 52, each of which is arranged in fixed association with an assigned line of the at least eight line-detector units 40.

The example shows eight lines, indicated with index *A* to *H*, in addition to the reference numeral 40, i.e. lines 40_A to 40_H. Similar numbering has been applied to the phase-gratings 52_A to 52_H. A first part 54 of the phase-gratings 52, namely the phase-gratings 52_A, 52_B, 52_c, and 52_D, is provided as first phase-gratings 56 with slits 58 in the first direction 42. A second part 60 of the phase-gratings 52, namely 52_E, 52_F, 52_G, and 52_H, is provided as second phase-gratings 62 with slits 64 in a second direction 66 different to the first direction. The second direction 66 may be provided parallel to the extension direction 44.

The analyser-grating structure 48 is provided in a similar way, although with a pitch of the respective gratings which is half the size of the pitch of the phase-grating structure 46 in the case of parallel beam geometry. Theoretically, other relations between the phase pitch and the analyser pitch may be provided depending on the divergence of the beam. Since the respective grating structure principles in differential phase contrast X-ray imaging are known to a skilled person, the relation between the pitch and the distance of the gratings and the detector are also not further discussed at this point.

With reference to Fig. 5, the analyser-grating structure 48 is having a number of linear analyser-gratings 68, for example in case of eight line-detectors as eight linear analyser-gratings 68_A to 68_H. Each of the analyser-gratings 68 is arranged in fixed association with an assigned line of the at least eight line-detector units 40. A first part 70 of the analyser-gratings 68 is provided as first analyser-gratings 72 with slits 74 in the first direction 42. A second part 76 of the analyser-gratings 68 is provided as second analyser-gratings 78 with slits 80 in the second direction 66. Thus, the first part 70 comprises the analyser-gratings 68_A to 68_D, and the second part 76 comprises the analyser-gratings 68_E to 68_H.

As can be seen from Fig. 5, the respective first and second parts of the phase-grating structure and the analyser-grating structure are arranged with an aligned orientation of the respective grating structures with regard to the overlapping arrangement in a successive arrangement of the radiation path, indicated with central radiation line 82.

At least four adjacent lines of the line-detector units 40 are associated with the first phase-gratings 56, for example the lines 40_A to 40_D associated with the phase-gratings

52_A to 52_D. The four adjacent lines of the line-detector units are also associated with the first analyser-gratings 72, for example the analyser-gratings 68A to 68D- Further, at least four adjacent lines of the line-detector units 40 are associated with the second phase-gratings 62 and the second analyser-gratings 78. For example, the lines 40E to 40H are associated with the phase-gratings 52_E to 52_H, and the analyser-gratings 68_E to 68_H.

The term "fixed association" shall be further explained in relation with Fig. 6, showing a schematic arrangement of the detector arrangement 16 in the bottom part, on top of which the analyser-grating structure 48 is shown, followed by the phase-grating structure 46. Of course, the drawing is not to scale and does not show any particular relations with respect to distance or aspect ratio. The detector arrangement 16 is shown with nine detector lines 40. It must be noted that the arrangement and order of the respective lines 40A to 40H is shown in a rotated orientation compared to the previous figures, i.e. starting with *A* on the right side and ending with *H* on the left side, thus having the first gratings 56, 72 also on the right half and the second gratings 62, 78 on the left half.

In addition to the above-described eight detector lines 40_A to 40_H, a further detector line 84 is provided as a pure attenuation measuring detector unit without any associated phase and analyser-grating structures. It must be noted that with respect to the aspect of the offset described in the following, the further line-detector unit 84 can also be omitted, or be replaced by a larger number of attenuation measuring detector lines.

The phase-gratings 52 of the phase-grating structure 46 are shown with the slits 58 for the first part 54 running in one direction and with the slits 64 for a second part 60 running in the second direction. Similar is the case of the analyser-gratings 68 shown also with the slits 74 running parallel to the slits 58 for the first part 70 (not further indicated) and the slits 80 for the second part.

Further, the detector lines 40 are shown with a respective distance to the adjacent line unit, which distance may be provided due to manufacturing aspects of the line-detectors. However, the distance is not a condition and can also be omitted in case the respective detector technology provides a seamless arrangement of line-detector units. Similar applies to the shown structure of the gratings, where the gratings are also shown with a distance to each other for an improved readability of the drawings. Of course, the gratings can also be provided abutting each other, or also with a larger distance. The different grating structures can be provided in an integrated grating body structure.

Dash-dotted lines 86 indicate so-to-speak a grating structure axis. For example, the first of the phase-gratings 52, when starting from the left in Fig. 6, is having a distance 88 from the grating structure axis 86 to the starting point of the first bar of the respective grating structure. This distance is provided as the same distance for all of the phase-gratings 52. However, with respect to the analyser-gratings 68, also these are provided with a distance 90 between the grating structure axis 86, or so-to-speak system axis, and the starting of the first bar of the analyser-grating structure. The fixed association comprises a variation in a phase-grating to analyser-grating offset by a fraction 1/n of the pitch of the analyser-grating, wherein *n* is the number of lines of the line-detector units associated with one type of phase-grating. In other words, the distance 90 increases from one analyser-grating 68 to the next, which is indicated with an index 90;, 90 ;; and 90 $_{iii}$. Since the phase-gratings 52 are provided with the same distance 88, an increasing offset is thus provided with respect to the arrangement of the phase-gratings 52 to the analyser-gratings 68. Similar also applies to the other part of the gratings, i.e. the first part 54 of the phase-gratings 52 in relation to the first part 70 of the analyser-gratings 68.

This is shown in Fig. 7, where for illustration purpose only the analyser-gratings 68 are shown in a planar view in viewing direction of the X-ray radiation 14. As can be seen, the second part 76, in form of the analyser-gratings 68_E to 68_H, is provided with the respective offset 90. In the right half, the first part 70 in form of the analyser-gratings 68A to 68D is shown, wherein the starting of the grating structure is shown in relation to a further system axis 92, indicated with a further dash-dotted line. The analyser-grating 68D starts with the first bar with a distance 94, which distance 94 is provided with a similar offset by a fraction 1/n as the above described distance 90 in relation with the second part 76. Therefore, the same index *i* to *Hi* is also used.

This can also be seen from Fig. 8A, showing a further example for the offset of the second part 76 of the analyser-gratings 68H starting at the top and 68E at the bottom. As can be seen, the upper analyser-grating starts with the bar structure directly at the system axis 86, wherein the one below is provided with a first offset 96. The one further below, i.e. the analyser-grating 68_F is provided with a further increased offset 98, and the one below that, i.e. analyser-grating 68_E is provided with a still further increased offset 100.

Similar applies to the first part 70 of the analyser-gratings 68 shown in Fig. 8B, where from top to bottom the analyser-gratings 68D to 68A are shown. The grating starts at the second system axis 92 at the upper analyser-grating 68D, and the grating of the analyser-grating 68c below is provided with an offset 102. The next analyser-grating, i.e. analyser-grating 68_B, starts with a further increased offset 104, which is also the case for the below analyser-grating 68_A, provided with a still further increased offset 106.

It must be noted in general that according to an alternative example (not shown), all analyser gratings are aligned to the structure axis and offsets are implemented at the phase gratings.

According to a further exemplary embodiment, at least twelve line-detector units are provided. A further part of the phase-gratings is provided as further phase-gratings in a further direction and a further part of the analyser-gratings is provided as further analyser-gratings in the further direction, each of which is arranged in fixed association with an assigned line of the at least twelve line-detector units. For example, a first part of the gratings is provided in an angle of +60° to the scanning direction, a second part of the gratings is provided parallel to the scanning direction and a third part of the gratings is provided in an angle of -60° to the scanning direction. This is illustrated in Fig. 9A showing the arrangement of the directions and not the particular grating layer. As can be seen, a middle portion is provided with a grating structure in the first direction 42, and on both sides a respective angle of 60° is applied to achieve the other two directions, as mentioned above (see also graph with the three directions on the right side of the direction scheme). The detector lines, which are arranged in the radiation direction behind the gratings, are also not shown in Fig. 9A.

Of course, also more than three directions can be provided for more than three parts. As an example, Fig. 9B shows four directions, wherein the first direction 42 and the second direction 66 are supplemented by two further directions in two different variations of a 45° angle. Thus, a first direction of 0°, a second direction of approximately 45°, a third direction of approximately 90°, and a fourth direction of approximately 135° with respect to the scanning direction is provided (see also graph with the four directions on the right side of the direction scheme). Of course, in such case, at least sixteen line-detector units are provided in order to be able to have at least four lines for each grating orientation, or coherence direction. It is noted that similar to Fig. 9A, also Fig. 9B shows the directions only, and not a particular grating; the detector lines are also not shown.

With respect to Fig. 10, as already indicated above, the source-grating structure 50 is adapted to provide sufficient coherence to the X-ray beam passing the source-grating structure so that after passing the phase-grating structure, interference can be observed at the location of the analyser-grating structure. Therefore, the source-grating structure 50 is having a number of linear source-gratings 108, wherein the first part 110 provides coherence with relation to the first direction, and wherein at last a second part 112 provides coherence with relation to the second direction.

The source-grating 50 is provided with a source-grating pitch, wherein the ratio of the source-grating pitch to the analyser-grating pitch is equal to the ratio of the distance between the source-grating and the phase-grating to the distance between the phase-grating and the analyser-grating.

In case of further gratings in a further direction, the further part of the source-grating provides coherence with relation to the further direction (not shown).

According to the example shown in Figs. 11A and 1IB, a pre-collimator 114 is provided between the X-ray source 12 and the analyser-grating 48 such that an object can be arranged between the X-ray source 12 and the analyser-grating 48. The post-collimator 116 is provided between the analyser-grating 48 and the detector 16.

For example, as indicated in Fig. 11A, when starting from the source, the following arrangement is provided: the pre-collimator 114, the phase-grating structure 46, the space to receive an object 20, the analyser-grating structure 48, the post-collimator 116, and the detector arrangement 16.

As shown in Fig. 1IB, when starting from the source 12, the following arrangement is provided: the pre-collimator 114, the space to receive the object 20, the phase-grating structure 46, the analyser-grating structure 48, the post-collimator 116, and the detector arrangement 16.

The pre-collimator 114 is thus provided between the X-ray source 12 and the phase-grating 46 such that an object 20 can be arranged between the X-ray source 12 and the phase-grating 46, wherein the post-collimator 116 is provided between the object and the detector 16, for example, before or after the analyser-grating 48.

According to a further example, not shown, the phase-grating structure 46 is mounted to the pre-collimator 114, and the analyser-grating structure 48 is mounted to the post-collimator 116. The object can be arranged between the phase-grating structure 46 and the analyser-grating structure 48 in a way that the object is arranged closer to the phase-grating structure 46.

The collimators provide the possibility to reduce the X-ray dose applied to the object in such a way that all of the applied dose is used for obtaining image data. Since the line detectors may be provided in a distance to each other, the collimators can preferably be adapted to the line structure. Thus, only small slices of a patient are radiated at a given time.

Due to the movement, the slices can be provided in a sequence such that each point in the region of interest is radiated only once with respect to each grating structure considering the offset, i.e. for example only eight times, each time with a further offset of the analyser grating to the phase grating, namely four times for one direction and four time for the second direction. Of course the sum of eight would be higher in case of one or more further direction(s).

According to the present invention, the system 10 is adapted to acquire at least eight sub-images for phase-retrieval, namely at least four sub-images in relation with one coherence direction, and at least four sub-images for the second coherence direction. For example, as shown in Fig. 12A, the detector arrangement comprises 21 line-detector units 118, wherein seven adjacent line-detector units 120 are associated with first phase and analyser-gratings each. Further seven adjacent line-detector units 122 are associated with second phase and analyser-gratings. Still further seven adjacent line-detector units 124 are provided as pure attenuation measuring detector unit. For example, the attenuation measuring detector unit is provided between the first and second group of seven lines. However, it must be noted that when providing one or more attenuation detector lines, these can also be provided in a different order, namely the group of the first detector lines followed by the second group relating to the second coherence direction, and then followed by the attenuation line or lines. Further, instead of having seven lines, also another number of lines can be provided as attenuation lines.

With respect to the source-grating, according an example (not shown) the source-grating is designed in such a way here that no attenuation takes place by the source-gratings for detector lines that require no coherency at all, for example the central lines in Figs 12. In other words, the source grating may comprise a free section, where no coherence effect to the respective X-ray beam portion is provided for parts of the X-ray beam radiated to pure attenuation measuring detector units.

As shown in Fig. 12B, the detector arrangement comprises 21 line-detector units 118, wherein ten adjacent line-detector units 126 are associated with first phase and analyser-gratings, and further ten adjacent line-detector units 128 are associated with second phase and analyser-gratings. One line-detector unit 130 is provided as a pure attenuation measuring detector unit. For example, the pure attenuation measuring detector unit is provided between the first and the second group of line-detector units.

Fig. 13 shows a method 200 for X-ray phase contrast imaging of an object, comprising the following steps. In a first step 210, phase contrast image sub-data is acquired with a detector having at least eight detector lines, wherein at least four detector lines are relating to a first phase direction of a grating structure, and at least further four detector lines are relating to a second phase direction. Each line of the line-detector units relating to one phase direction is arranged in fixed association with the grating structure pitch. In a second step 212, the detector is moved in relation to the object with an acquisition movement in a single direction. According to the present invention, the first step 210 and the second step 212 are repeatedly performed at least eight times, such that image information of one point is acquired by each of the detector lines. This is indicated with an arrow 214 from the second step 212 back to the first step 210. The provision and repeating of the first and second steps 210 and 212 is also indicated by a surrounding frame 216 in a dotted line. In a third step 218, a phase-retrieval is computed, generating image data for each of the detector lines. In a fourth step 220, the image data is provided for further steps.

The third step may include a gain correction in case different gains on different lines occur.

The first step 210 is also referred to as step a), the second step 212 as step b), the third step 218 as step c), and the fourth step 220 as step d).

According to a further example, not shown, the X-ray source, the grating arrangement, and the X-ray detector arrangement are mounted to a movement structure that is pivotable around an axis aligned with a focal spot of the X-ray tube. In the second step 212, the X-ray detector is pivoted together with the X-ray source in relation to the object for the acquisition movement.

The phase-retrieval in step c) provides differential phase data, scatter information, and attenuation data.

In another exemplary embodiment of the present invention, a computer program or a computer program element is provided that is characterized by being adapted to execute the method steps of the method according to one of the preceding embodiments, on an appropriate system.

The computer program element might therefore be stored on a computer unit, which might also be part of an embodiment of the present invention. This computing unit may be adapted to perform or induce a performing of the steps of the method described above. Moreover, it may be adapted to operate the components of the above described apparatus.

The computing unit can be adapted to operate automatically and/or to execute the orders of a user. A computer program may be loaded into a working memory of a data processor. The data processor may thus be equipped to carry out the method of the invention.

This exemplary embodiment of the invention covers both, a computer program that right from the beginning uses the invention and a computer program that by means of an up-date turns an existing program into a program that uses the invention.

Further on, the computer program element might be able to provide all necessary steps to fulfil the procedure of an exemplary embodiment of the method as described above.

According to a further exemplary embodiment of the present invention, a computer readable medium, such as a CD-ROM, is presented wherein the computer readable medium has a computer program element stored on it which computer program element is described by the preceding section.

A computer program may be stored and/or distributed on a suitable medium, such as an optical storage medium or a solid state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

However, the computer program may also be presented over a network like the World Wide Web and can be downloaded into the working memory of a data processor from such a network. According to a further exemplary embodiment of the present invention, a medium for making a computer program element available for downloading is provided, which computer program element is arranged to perform a method according to one of the previously described embodiments of the invention.

It has to be noted that embodiments of the invention are described with reference to different subject matters. In particular, some embodiments are described with reference to method type claims whereas other embodiments are described with reference to the device type claims. However, a person skilled in the art will gather from the above and the following description that, unless otherwise notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters is considered to be disclosed with this application. However, all features can be combined providing synergetic effects that are more than the simple summation of the features.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive. The invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing a claimed invention, from a study of the drawings, the disclosure, and the dependent claims.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items re-cited in the claims. The mere fact that certain measures are re-cited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. An X-ray imaging system (10) for phase contrast imaging of an object, comprising:

- an X-ray source (12);
- an X-ray detector arrangement (16); and
- a grating arrangement (18);

wherein the X-ray detector arrangement comprises at least eight line-detector units (40) arranged parallel to each other in a first direction (42); wherein the line-detector units extend linearly in a direction (44) perpendicular to the first direction;

wherein the X-ray source, the X-ray detector arrangement and the grating arrangement are adapted to perform an acquisition movement (M_A) in relation to an object in a scanning direction (22), wherein the scanning direction is parallel to the first direction;

wherein the grating arrangement comprises a phase-grating structure (46) arranged between the X-ray source and the detector, and an analyser-grating structure (48) arranged between the phase-grating structure and the detector arrangement;

wherein the phase-grating structure is having a number of linear phase-gratings (52), each of which is arranged in fixed association with an assigned line of the at least eight line-detector units;

wherein a first part (54) of the phase-gratings is provided as first phase-gratings (56) with slits (58) in the first direction; and a second part (60) of the phase-gratings is provided as second phase-gratings (62) with slits (64) in a second direction (66) different to the first direction; and

wherein the analyser-grating structure is having a number of linear analyser-gratings (68), each of which is arranged in fixed association with an assigned line of the at least eight line-detector units;

wherein a first part (70) of the analyser-gratings is provided as first analyser-gratings (72) with slits (74) in the first direction; and a second part (76) of the analyser-gratings is provided as second analyser-gratings (78) with slits (80) in the second direction; and wherein at least four adjacent lines of the line-detector units are associated with the first phase-gratings and the first analyser-gratings and wherein at least four adjacent lines of the line-detector units are associated with the second phase-gratings and the second analyser-gratings.

2. X-ray imaging system according to claim 1, wherein the fixed association comprises a variation in a phase-grating to analyser-grating offset by a fraction 1/n of the pitch of the analyser-grating; wherein *n* is the number of lines of the line-detector units associated with one type of phase-grating.

3. X-ray imaging system according to claim 1 or 2, wherein at least twelve line-detector units are provided;

wherein a further part of the phase-gratings is provided as further phase-gratings in a further direction and a further part of the analyser-gratings is provided as further analyser-gratings in the further direction, each of which is arranged in fixed association with an assigned line of the at least twelve line-detector units; and wherein the further direction is different from the first and second direction.

4. X-ray imaging system according to claim 1, 2 or 3, wherein for the acquisition movement, the gratings remain fixed in relation to each other and in relation to the detector arrangement.

5. X-ray imaging system according to one of the preceding claims, wherein for the acquisition movement, the X-ray source, the grating arrangement and the X-ray detector arrangement are mounted to a movement structure (30) that is pivotable around an axis (32) aligned with a focal spot (34) of the X-ray tube.

6. X-ray imaging system according to one of the preceding claims, wherein the system is adapted to acquire at least eight sub-images for phase-retrieval.

7. X-ray imaging system according to one of the preceding claims, wherein at least one further line-detector unit (84) is provided as a pure attenuation measuring detector unit without any associated phase and analyser-grating structure.

8. X-ray imaging system according to one of the preceding claims, wherein the grating arrangement comprises a source-grating structure (50) arranged between the X-ray source and the phase-grating structure;

wherein the source-grating structure is adapted to provide sufficient coherence to the X-ray beam passing the source-grating structure, so that after passing the phase-grating structure, interference can be observed at the location of the analyser-grating structure; and

wherein the source-grating structure is having a number of linear source-gratings (108); wherein a first part (110) provides coherence with relation to the first direction; and wherein at last a second part (112) provides coherence with relation to the second direction.

9. X-ray imaging system according to claim 8, wherein the source grating comprises a free section, where no coherence effect to the respective X-ray beam portion is provided for parts of the X-ray beam radiated to pure attenuation measuring detector units.

10. X-ray imaging system according to one of the preceding claims, wherein a pre-collimator (114) is provided between the X-ray source and the analyser-grating such that an object can be arranged between the X-ray source and the analyser-grating; and

wherein a post-collimator (116) is provided between the analyser-grating and the detector.

11. A method (200) for X-ray phase contrast imaging of an object, comprising the following steps:

a) acquiring (210) phase contrast image sub-data with a detector having at least eight detector lines;

wherein at least four detector lines are relating to a first phase direction of a grating structure and at least further four detector lines are relating to a second phase direction; and wherein each line of the line-detector units relating to one phase direction is arranged in fixed association with the grating structure pitch;

b) moving (212) the detector in relation to the object with an acquisition movement in a single direction;

wherein a) and b) are repeatedly performed at least eight times such that image information of one point is acquired by each of the detector lines;

c) computing (218) a phase-retrieval, generating image data for each of the detector lines; and

d) providing (220) the image data for further steps.

12. Method according to claim 11, wherein the X-ray detector and an X-ray source are mounted to a movement structure that is pivotable around an axis aligned with a focal spot of the X-ray tube; and wherein in step b) the X-ray detector is pivoted together with the X-ray source in relation to the object.

13. Method according to claim 11 or 12, wherein the phase-retrieval in step c) provides:

i) differential phase data;

ii) scatter information; and

iii) attenuation data.

14. A computer program element for controlling an apparatus according to one of the claims 1 to 10, which, when being executed by a processing unit, is adapted to perform the method of claims 11 to 13.

15. A computer readable medium having stored the program element of claim 14.

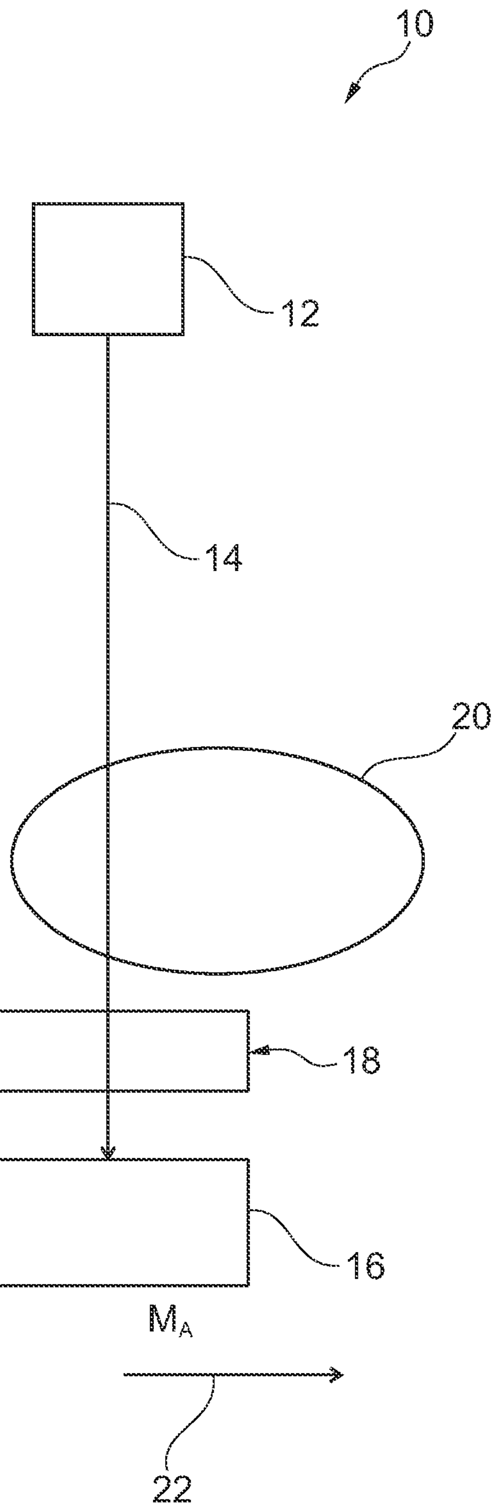


Fig. 1

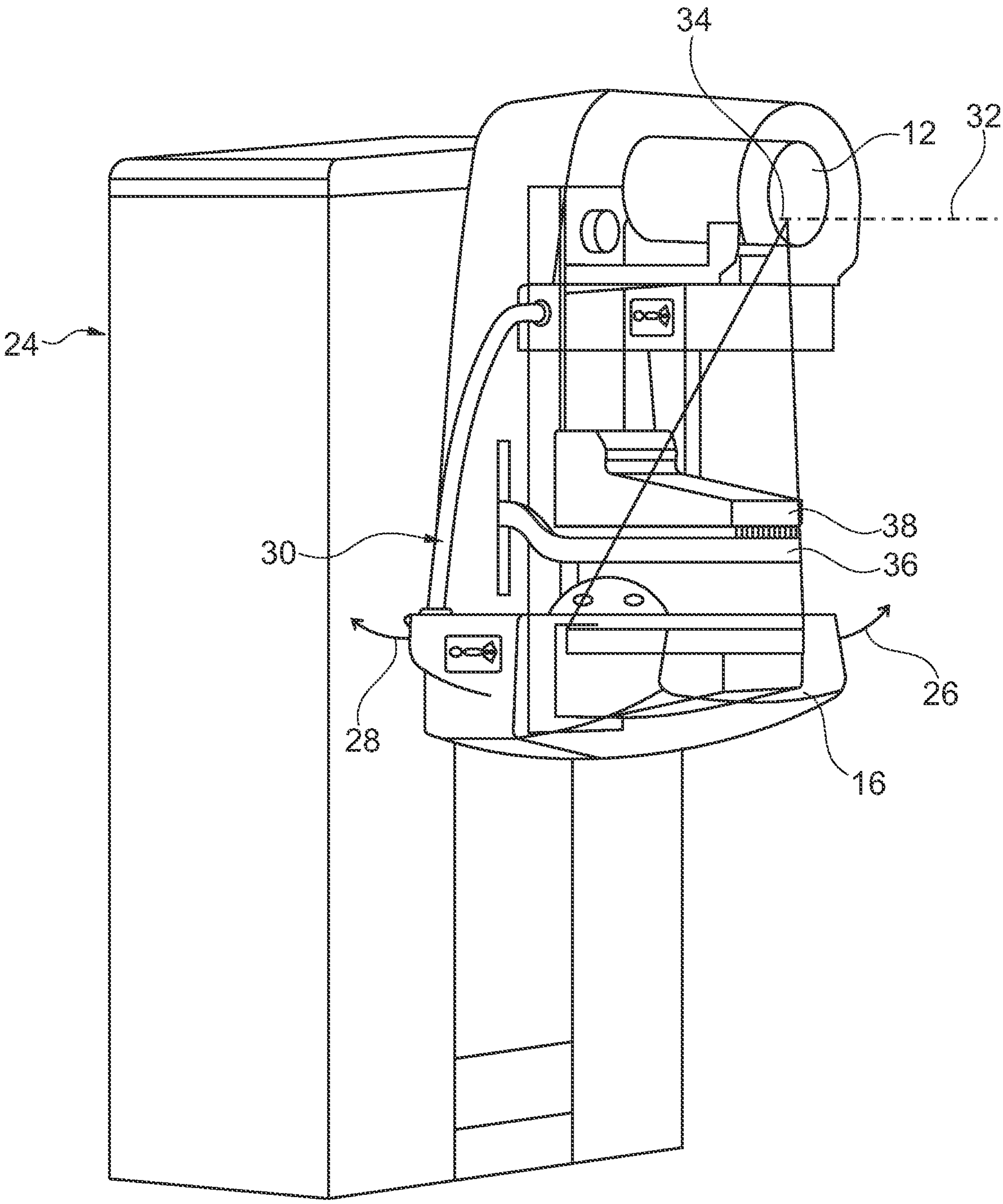


Fig. 2

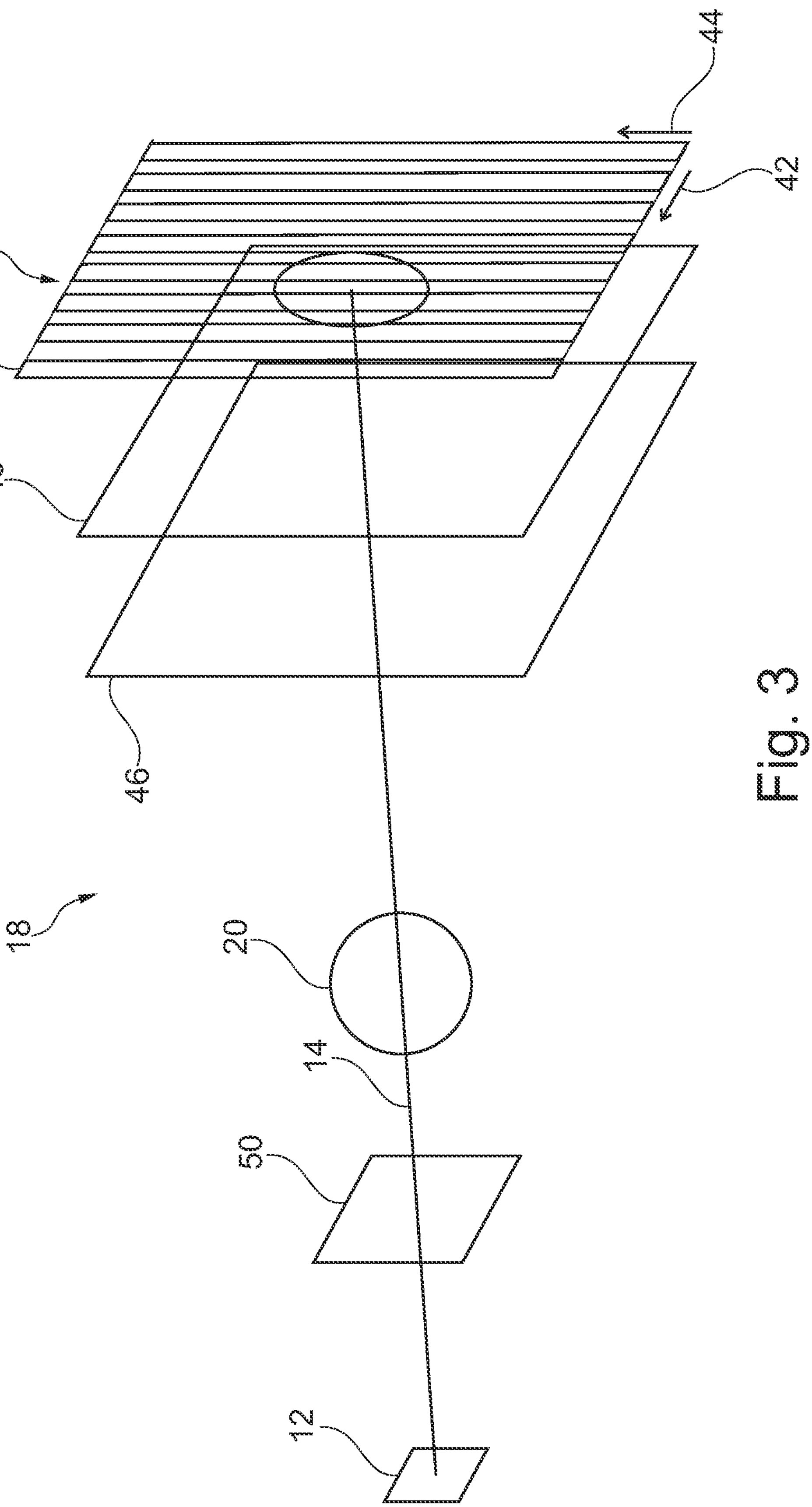


Fig. 3

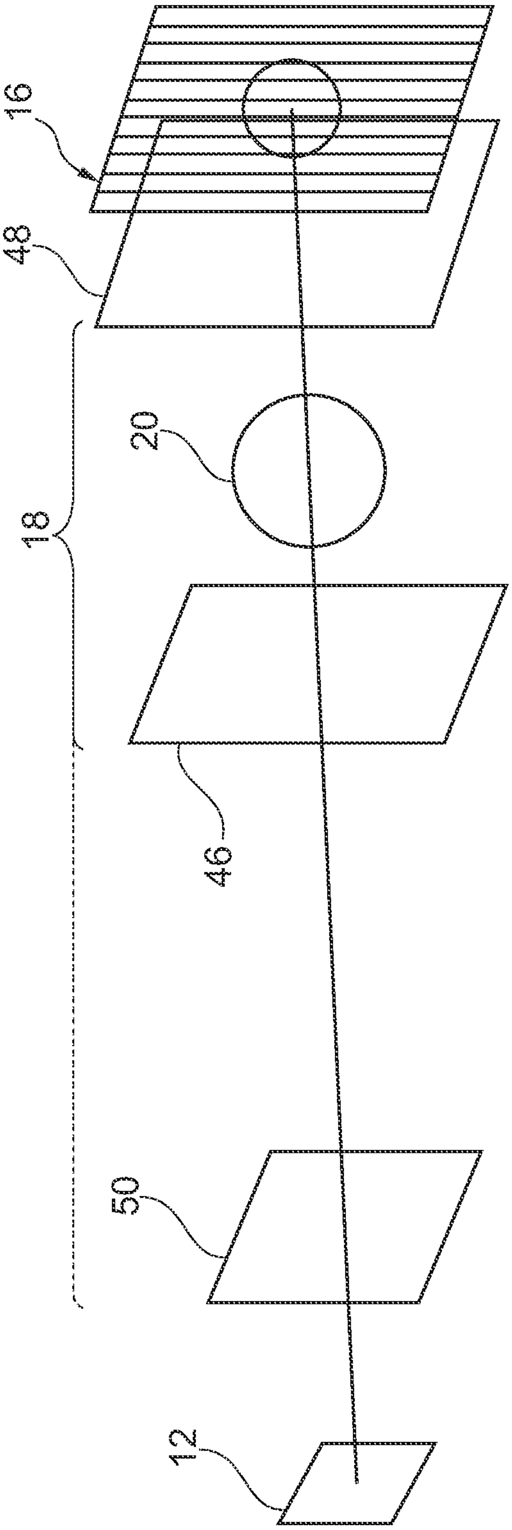
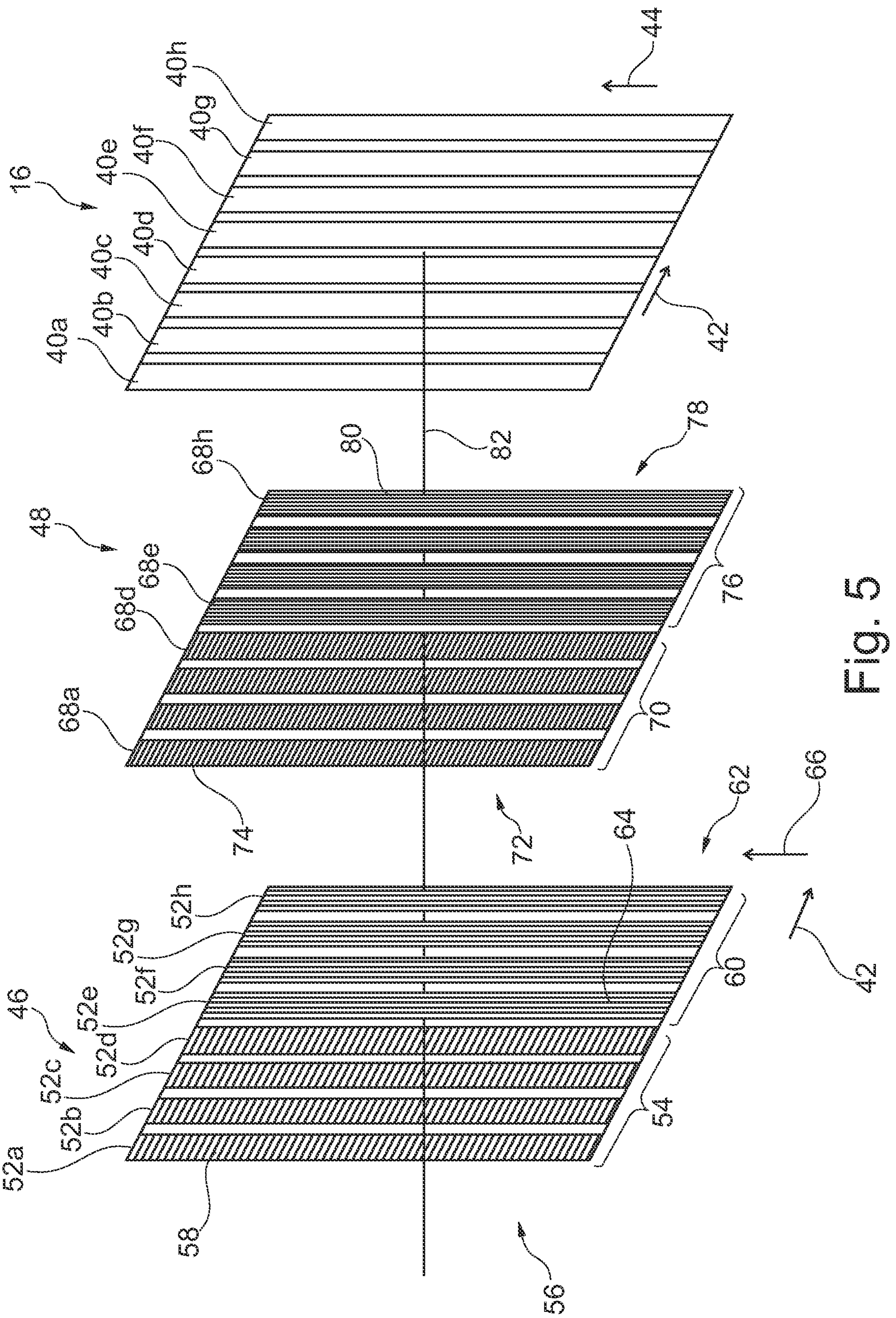


Fig. 4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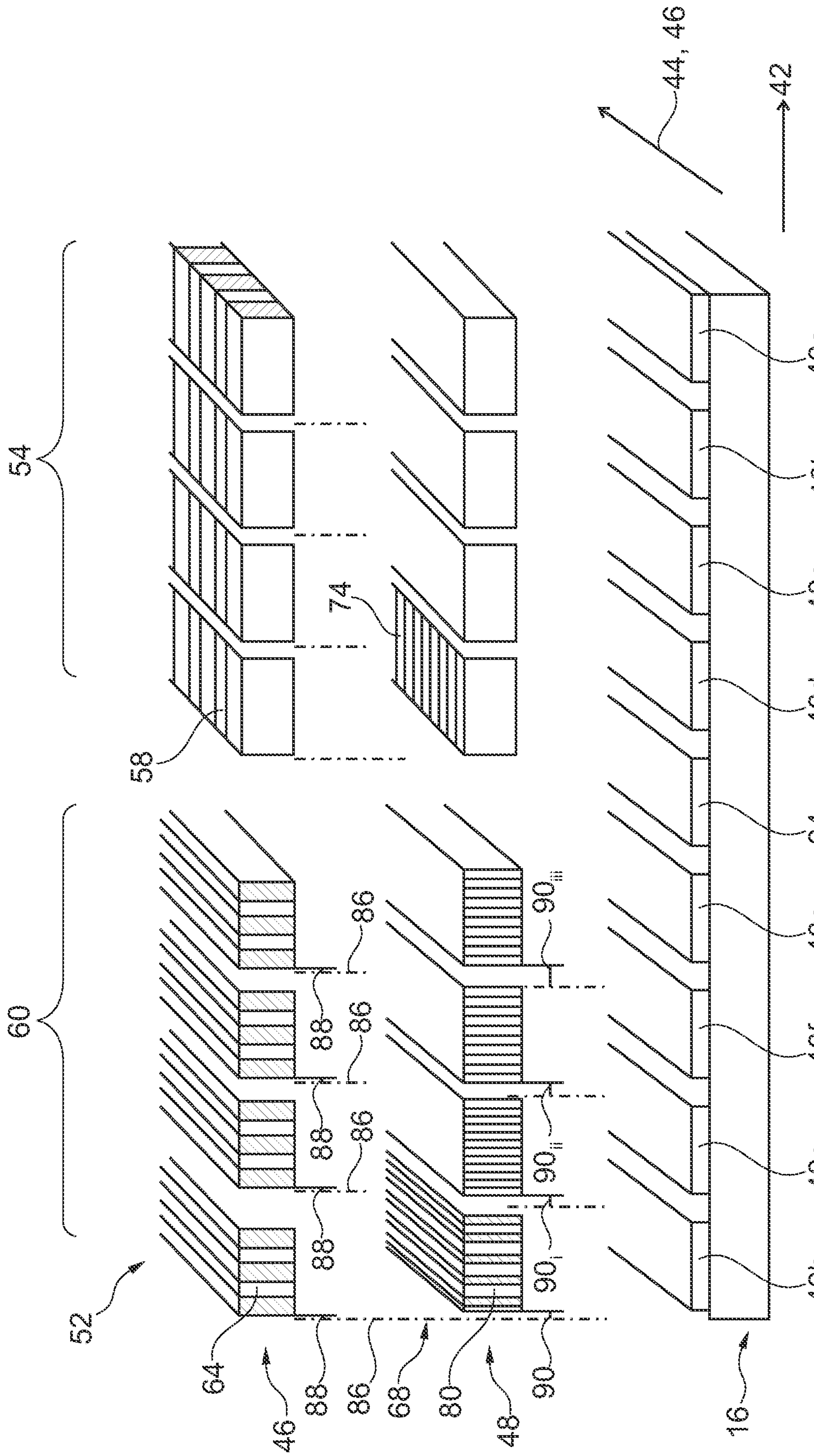
56

Fig. 5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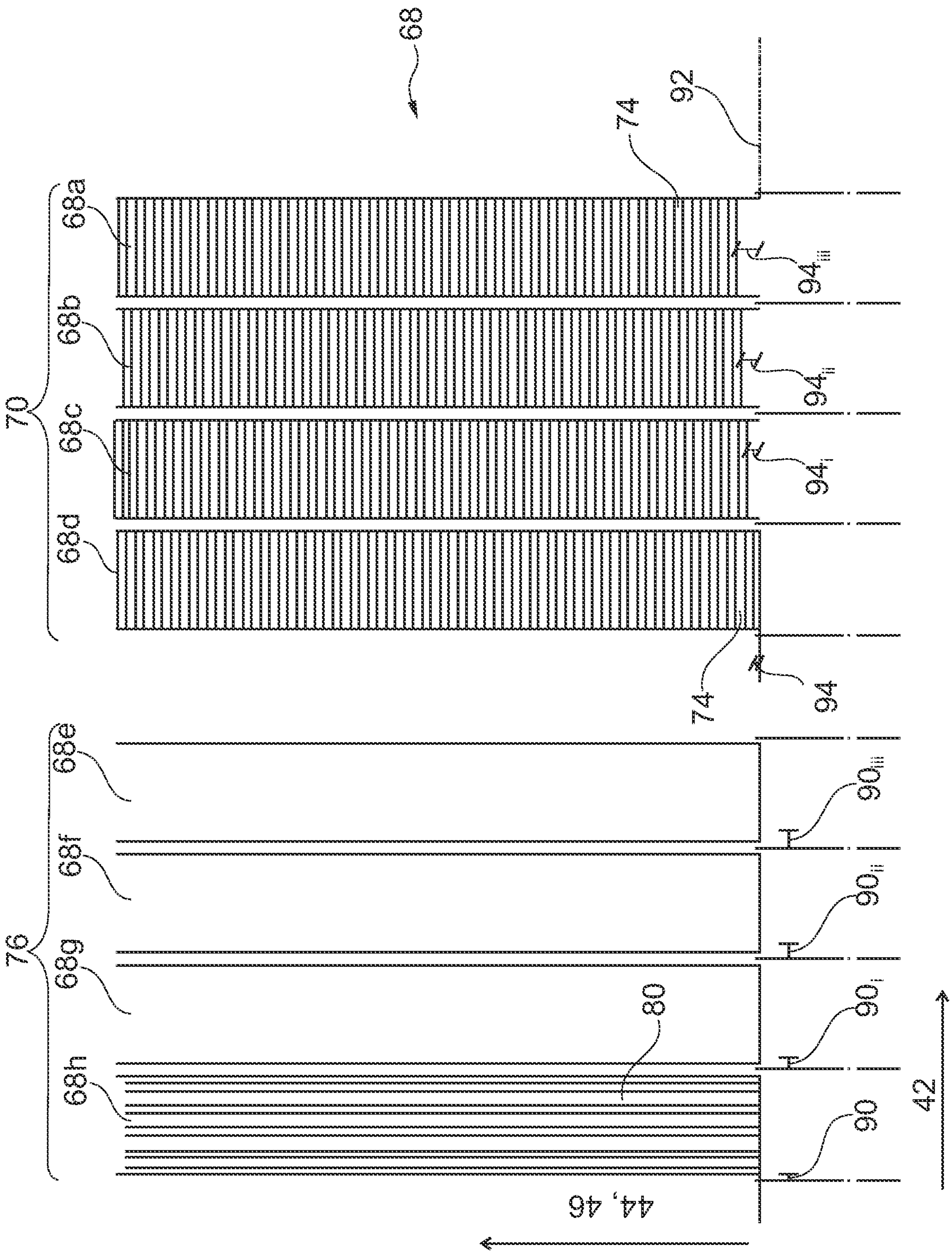
16

Fig. 6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44, 46

Fig. 7

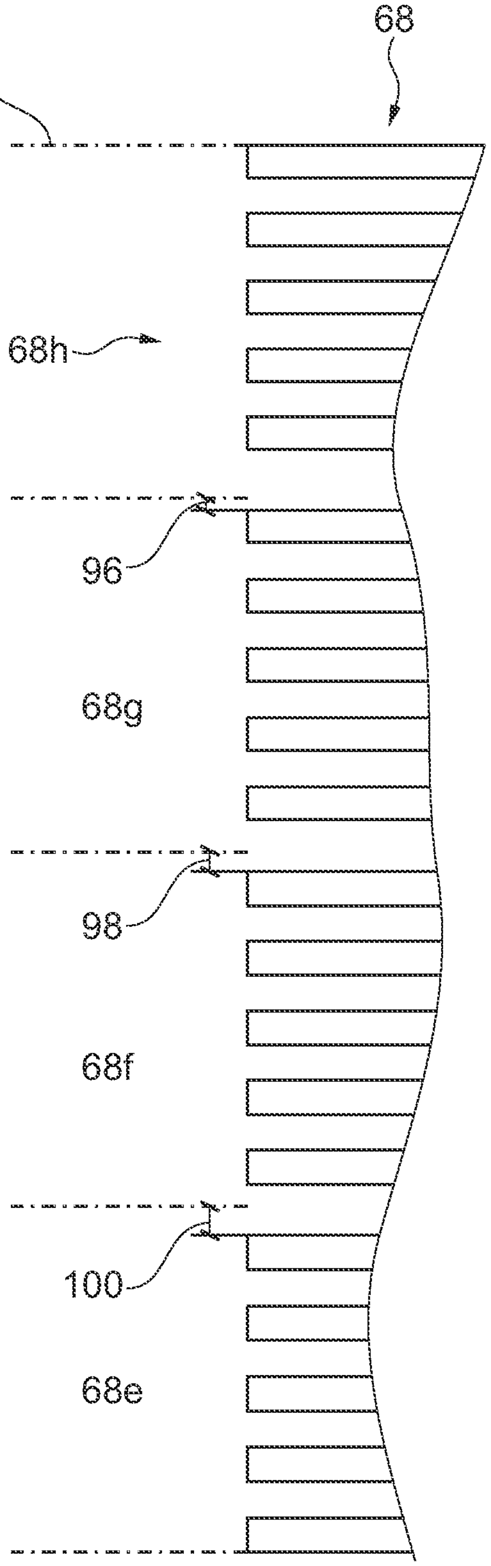

Fig. 8a

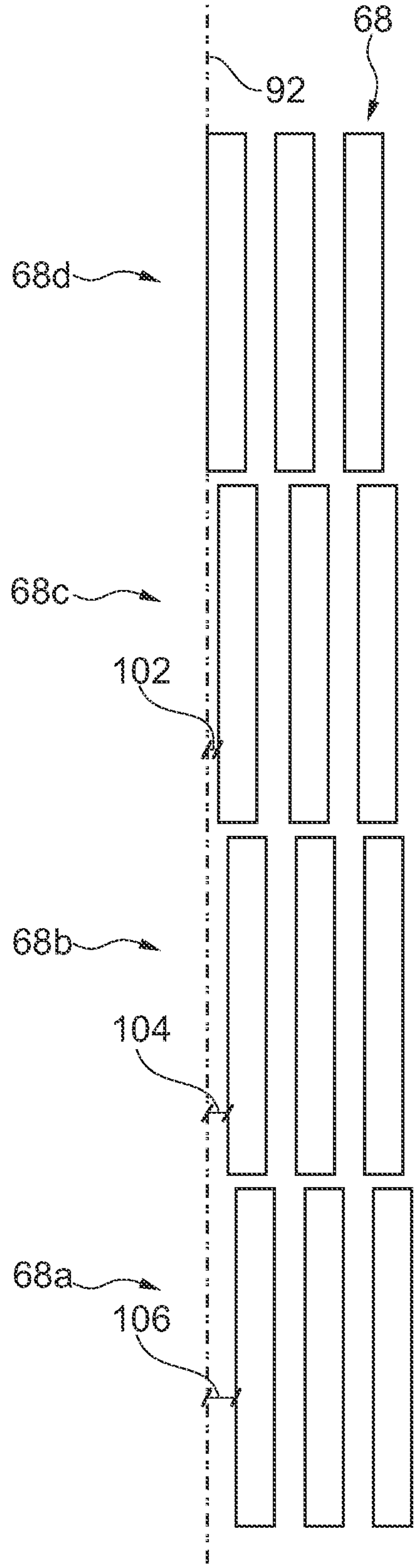

Fig. 8b

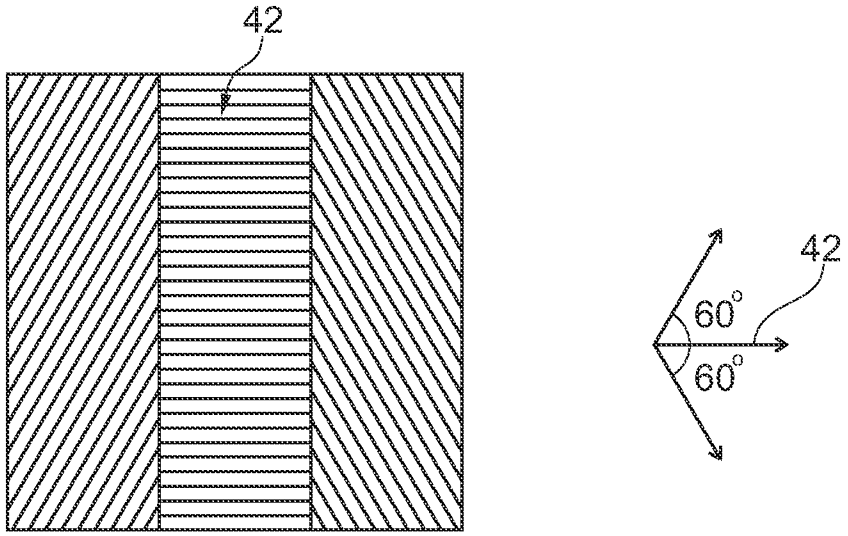

Fig. 9a

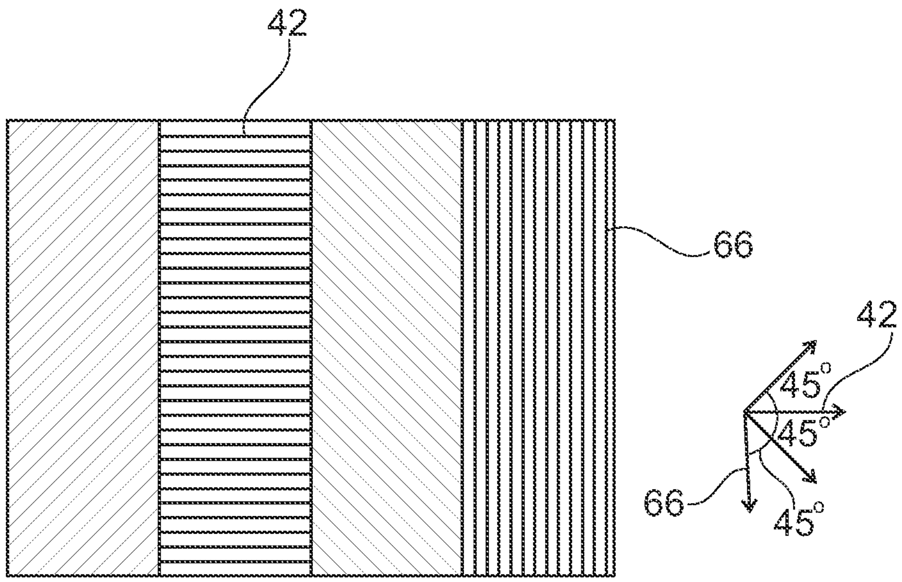

Fig. 9b

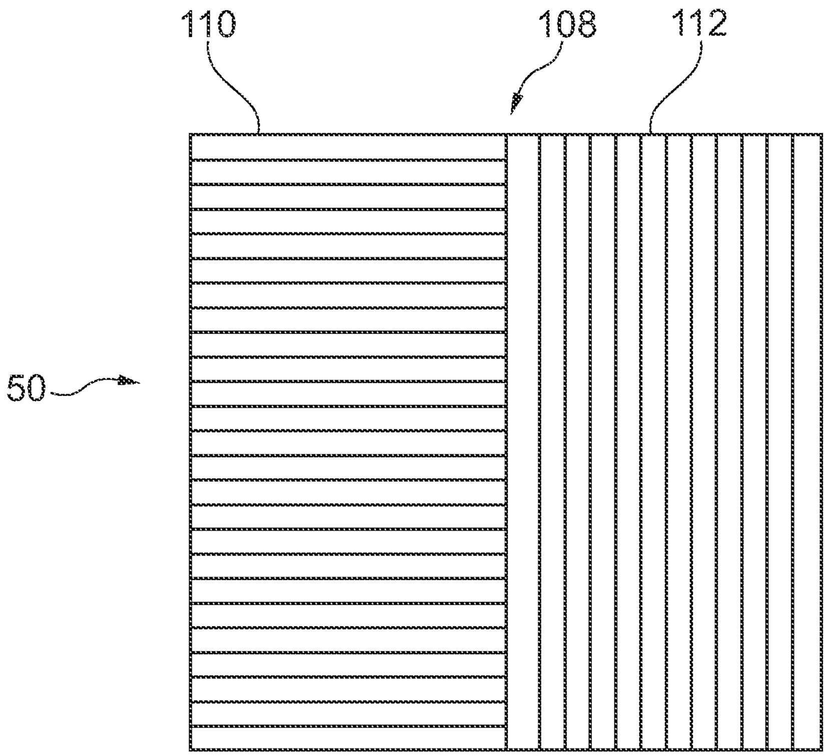

Fig. 10

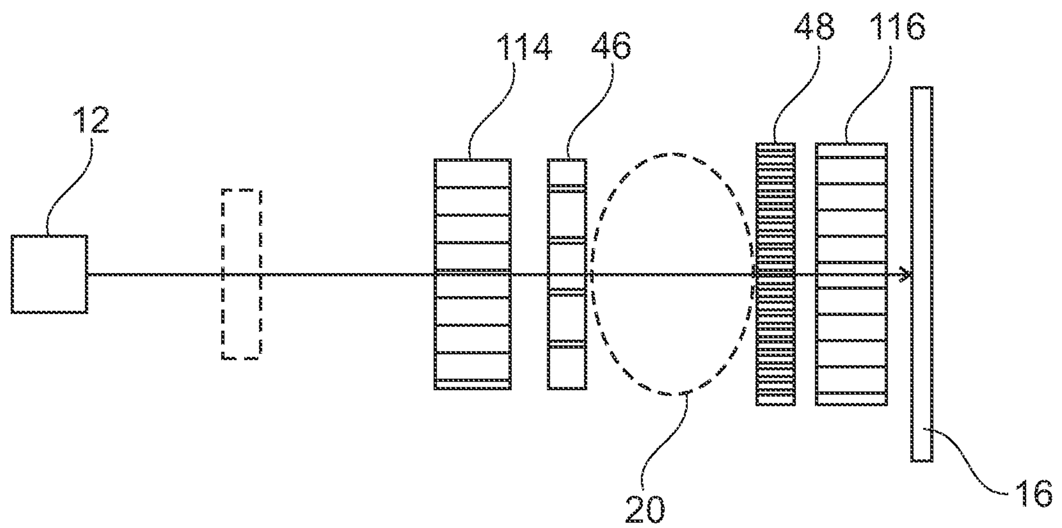

Fig. 11a

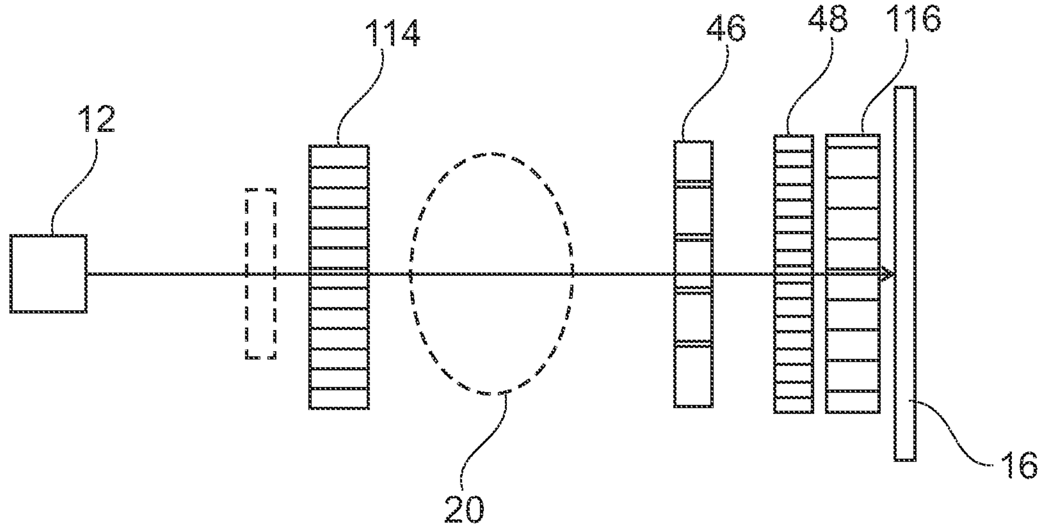

Fig. 11b

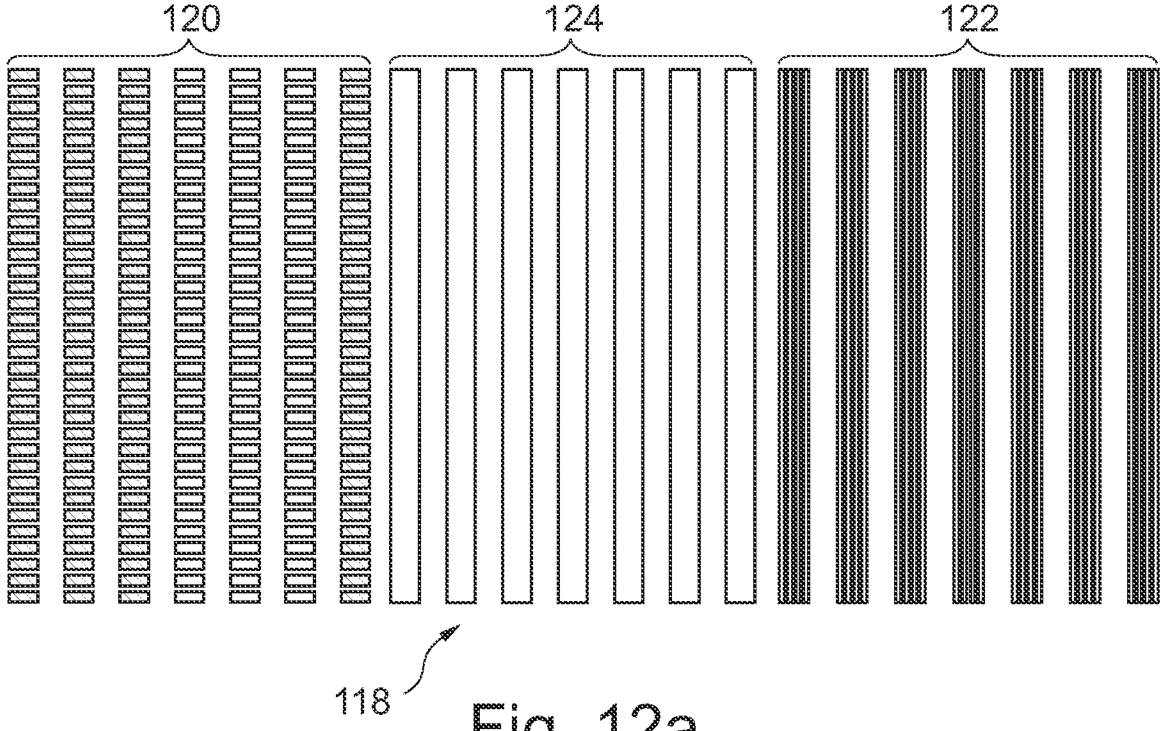

Fig. 12a

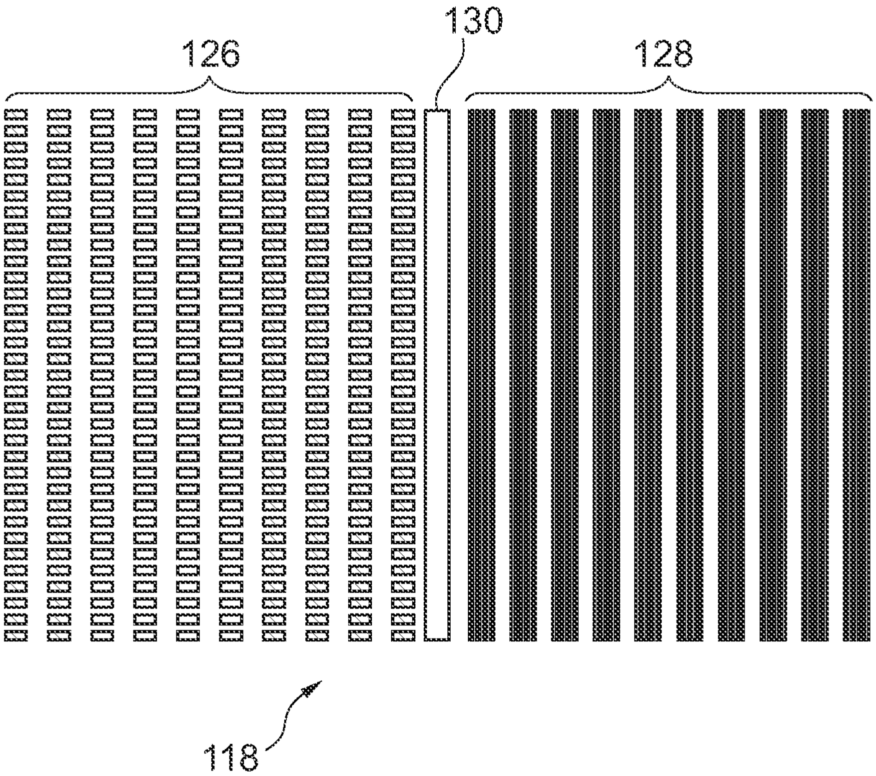

Fig. 12b

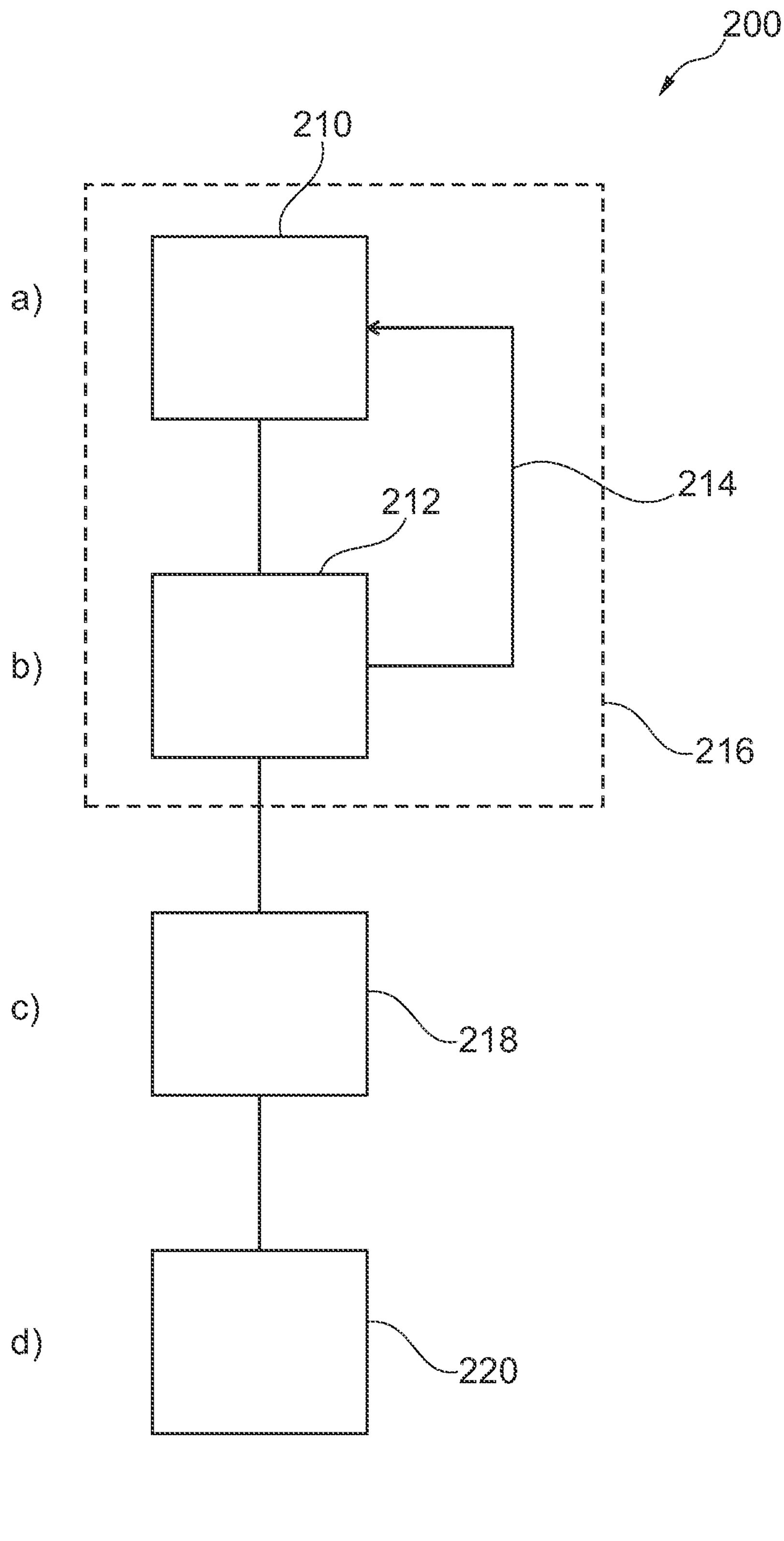

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/05Q542

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/Q0
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)
A61B

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.
A	WO 2012/000694 AI (SCHERRER INST PAUL [CH] ; DAVID CHRISTIAN [DE] ; STAMPANONI MARCO [CH]) 5 January 2012 (2012-01-05) figure 3 -----	1-15
A	W0 2011/070489 AI (K0NINKL PHILIPS ELECTRONICS NV [NL] ; PHILIPS INTELLECTUAL PROPERTY [DE) 16 June 2011 (2011-06-16) page 10, line 19 -----	1-15
A	W0 2009/101569 A2 (K0NINKL PHILIPS ELECTRONICS NV [NL] ; PHILIPS INTELLECTUAL PROPERTY [DE) 20 August 2009 (2009-08-20) Page 9, 2nd paragraph ; figure 1 ----- -/- -	1-15

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) orwhich is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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