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(71) Applicants: **UNIVERSITEIT ANTWERPEN** [BE/BE]; Prinsstraat 13, 2000 Antwerpen (BE). **IMEC VZW** [BE/BE]; Kapeldreef 75, 3001 Leuven (BE).

(72) Inventors: **DE BEENHOUWER, Jan**; c/o RIVA, Valorisation office, Middelheimlaan 1, 2020 Antwerpen (BE). **SIJBERS, Jan**; c/o RIVA, Valorisation office, Middelheimlaan 1, 2020 Antwerpen (BE). **VANTHIENEN, Pieter-Jan**; c/o RIVA, Valorisation office, Middelheimlaan 1, 2020 Antwerpen (BE).

(74) Agent: **DE CLERCQ & PARTNERS**; Edgard Gevaertdreef 10a, 9830 Sint-Martens-Latem (BE).

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(54) **Title:** MASK ASSEMBLY FOR EDGE ILLUMINATION PHASE CONTRAST RADIATION IMAGING

(57) **Abstract:** In general, the technology disclosed herein relates object inspection utilizing radiation imaging, more specifically, edge illumination phase contrast X-ray imaging. The apparatus and methods described in the present disclosure can be applied for inspection of various objects in different industrial settings, such as manufacturing, food, agriculture, aerospace, automotive, electronics, healthcare, transport, logistics, security, and others. An aspect of the present invention relates to a mask assembly for radiation phase contrast imaging apparatus, comprising a first mask comprising a plurality of X-ray absorbing element and apertures arranged in a manner that gradually diverges from one portion to an opposite portion of the body, resulting in a variable pitch perpendicular to the optical axis direction; and a mask alignment mechanism configured to adjust a position and/or orientation of the first mask to align the variable pitch of the first mask for phase contrast imaging.

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MASK ASSEMBLY FOR EDGE ILLUMINATION PHASE CONTRAST RADIATION IMAGING

FIELD OF THE INVENTION

The present invention is situated in the technological domain of object inspection utilizing radiation imaging, more specifically, edge illumination phase contrast X-ray imaging. The apparatus and methods described in the present disclosure can be applied for inspection of various objects in different industrial settings, such as manufacturing, food, agriculture, aerospace, automotive, electronics, healthcare, transport, logistics, security, and others.

BACKGROUND

Edge illumination (EI) phase-contrast X-ray imaging offers a non-destructive testing and characterization method across various industrial sectors. When ionizing radiation, such as X-rays, passes through an object, it primarily exhibits two effects: absorption and phase shift. While certain objects or regions with the objects may have similar attenuation properties, small differences in thickness and composition can significantly affect the phase of X-ray radiation, thereby enabling better visualization of inner features.

However, directly measuring the phase of X-ray waves presents a significant challenge. In order to capture phase information, the broad, cone-shaped radiation typically emitted by an X-ray source—such as an X-ray tube—must first be divided into multiple narrower beamlets. This enables measurement of the attenuation and refraction of each beamlet as it interacts with the object under inspection. One way to achieve this is by placing a mask or grating between the X-ray source and the object, allowing the beamlets to pass through the object and generate image signals from which phase information can be extracted.

Despite its potential, phase-contrast imaging is limited by a lack of geometric flexibility, owing to the rigid configurations of existing X-ray imaging systems. Optimal contrast is typically achieved when the object is positioned as close as possible to the mask. However, conventional methods for improving resolution—such as moving the object closer to the X-ray source—are often impractical. Even small changes in magnification can lead to misalignment between beamlets and detector pixels, due to the fixed pitch of the mask. This lack of flexibility impedes the system's ability to adapt to different imaging geometries and prevents the achievement of the varying resolution levels required for detailed region-of-interest scans or multi-resolution imaging. Although the use of exchangeable masks has been proposed, this solution introduces significant delays and still restricts the imaging system to a limited number of predefined magnification settings, which may not be optimal for the specific object or region under inspection.

US 2014/112440 A1 discloses an X-ray arrangement that includes an X-ray source; two or more gratings; a position-sensitive detector with spatially modulated detection sensitivity; a recorder for recording the images; an evaluator for evaluating the intensities for each pixel to identify the characteristic of the object for each individual pixel as an absorption and/or a differential phase contrast and/or an x-ray scattering dominated pixel. The grating structures extend along the X-ray path which determines the phase shift.

US 2013/272501 A1 discloses another X-ray arrangement that includes an X-ray source, a grating that divides diverging X-rays irradiated from the X-ray source, and a detector that detects X-rays which are divided by the grating and pass through a sample. The grating includes a plurality of transparent objects which pass the diverging X-rays and a plurality of opaque objects that shield the diverging X-rays.

However, the above referenced diverging gratings still only allow for a single, fixed rate of divergence, as determined by the X-ray system’s magnification and cone angle. These X-ray arrangements thus fail to address the fundamental limitations associated with performing multi-resolution phase-contrast imaging, where flexibility in beamlet configuration is required.

Therefore, there is a clear need for a solution that addresses the limitations of current phase contrast X-ray imaging systems, particularly related to multi-resolution phase-contrast imaging. Specifically, overcoming the challenges associated with achieving optimal inspection parameters within the rigid setups of these imaging systems across varying imaging conditions is necessary.

SUMMARY OF THE INVENTION

In general, the technology disclosed herein relates to item inspection utilizing radiation imaging, more specifically, X-ray imaging. The (computer-implemented) methods and systems described herein can be applied for inspection control of various produced items in different industrial settings, such as manufacturing, aerospace, automotive, electronics, healthcare, and others. Therefore, the methods and systems described herein find direct application in defect detection or metrology, but other applications may be considered as well, such as screening or non-destructive testing of produced items.

It is an objective of the present invention to address the limitations of the current state of the art for multi-resolution phase contrast tomography, enabling the inspection of objects at different imaging magnification, thereby improving imaging efficiency of specific region-of-interest and multi-resolution scans. The present invention provides for a mask assembly comprising a mask having a variable effective period thus facilitating multi-resolution acquisitions for multiple pixel rows. The present invention aims to improve phase contrast imaging by enhancing flexibility and enabling higher-resolution imaging or improved field of view (FOV) across various applications.

The below summary is provided to introduce a selection of key embodiments of the invention in a simplified form. These embodiments are described in further detail in the detailed description of the disclosure below. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

An aspect of the present invention relates to a mask assembly for a radiation phase contrast imaging apparatus, the mask assembly comprising:

- a first mask comprising a plurality of X-ray absorbing element and apertures arranged in a manner that gradually diverges from one portion to an opposite portion of the body, resulting in a variable pitch perpendicular to an optical axis direction; and,

- a mask alignment mechanism configured to adjust a position and/or orientation of the first mask to align the variable pitch of the first mask for phase contrast imaging.

Another aspect of the present invention relates to a radiation imaging apparatus for phase-contrast imaging of an object, the apparatus comprising:

- an image signal generation system comprising at least one X-ray source configured to generate an X-ray beam and at least one image signal detector comprising a plurality of pixels configured for detecting an image signal generated by the radiation irradiated from the X-ray source;

- a mask assembly comprising at least a first mask configured to split the X-ray beam into a plurality of X-ray beamlets;

- an object stage extending in an optical axis direction of the X-rays, the object stage being configured to adjust a position of the object to correspond with a predetermined imaging magnification;

- wherein the first mask comprises a body with a plurality of X-ray absorbing elements and apertures arranged in a manner that gradually diverges from one portion to an opposite portion of the body, resulting in a variable pitch perpendicular to the optical axis direction; and

- wherein the mask assembly further comprises a mask alignment mechanism configured to adjust a position of the first mask along the optical axis direction to match the predetermined imaging magnification; and, further adjust a position and/or an orientation of the first mask to align the variable pitch of the first mask for phase contrast imaging, thereby adjusting the separation between the X-ray beamlets to match the dimensions of the pixels of the image signal detector.

In some embodiments the body of the first mask comprises a plurality of elongated bars arranged in a trapezoidal configuration, whereby the bars diverge linearly from one portion to the opposite portion of the first mask.

In some embodiments the rate of divergence of the first mask is between 0.005 m/m and 0.0001 m/m; defined as the difference between a highest and a lowest period of the first mask, divided by a height of the first mask.

In some embodiments the variable pitch of the first mask ranges from at least 30 at the one portion to at most 120 at the opposite portion of the first mask.

In some embodiments the mask assembly further comprises a second mask arranged between the first mask and the image signal detector, wherein the second mask comprises a body with a periodically spaced arrangement of X-ray absorbing elements and apertures resulting in a fixed pitch; and wherein the mask alignment mechanism is further configured to align the variable pitch of the first mask with the fixed pitch of the second mask.

In some embodiments the mask alignment mechanism is configured to adjust the position and/or orientation of the first mask responsive to the image signal, such that each X-ray beamlet irradiates a set of pixels of the image signal detector; preferably wherein a central pixel of each set of pixels corresponds to a maximum intensity of the respective X-ray beamlet, thereby resulting in a substantially Gaussian profile for the image signal.

In some embodiments the mask alignment mechanism is configured for tilting the first mask to adjust a field of view; wherein the tilt angle is between at least 1° to at most 50°.

In some embodiments the mask alignment mechanism is configured for tilting the signal detector signal detector and/or the second mask to adjust a field of view; wherein the tilt angle is between at least 1° to at most 50°.

In some embodiments the first mask may be a grating comprising a plurality of lines, bars, grooves or other functionally equivalent mechanical structures that form or are part of the X-ray absorbing elements.

In some embodiments the mask alignment mechanism is configured to adjust a position of the source and/or signal detector along the optical axis direction to match the predetermined imaging magnification.

In some embodiments the mask alignment mechanism comprises a moving mechanism driven by a drive unit; preferably wherein the moving mechanism comprises a platform or a suspension.

In some embodiments the mask alignment mechanism is moveably coupled on the object stage such that the positional adjustment of the object can be synchronized with the positional adjustment of the first mask.

In some embodiments the object stage and the mask are operatively coupled to an integrated moving mechanism, wherein the integrated moving mechanism is configured for simultaneously moving the object and the first mask along the optical axis direction.

In some embodiments the object is a produced item, food product, medical device, pharmaceutical, electronic device, fiber-containing polymers, tissues, and/or luggage.

Another aspect of the present invention relates to a method of phase-contrast imaging of an object with a radiation phase contrast imaging apparatus, comprising the steps of:

- providing the object;

- adjusting a position of the object along an optical axis direction to correspond with a predetermined imaging magnification;
- adjusting a position of a first mask along the optical axis direction to match the predetermined imaging magnification;
- further adjusting the position and/or orientation of the first mask to align the variable pitch of the first mask, thereby adjusting the separation between the X-ray beamlets split by the first mask to match the dimensions of the pixels of an image signal detector; and
- acquiring a plurality of images by emitting radiation from an X-ray source, directed through the first mask, and detecting an image signal based on the emitted radiation on the image signal detector for phase contrast imaging.

Another aspect of the present invention relates to a radiation imaging apparatus for phase-contrast imaging of an object, the apparatus comprising:
- an image signal generation system comprising at least one X-ray source configured to generate an X-ray beam and at least one image signal detector comprising a plurality of pixels configured for detecting an image signal generated by the radiation irradiated from the X-ray source;
- a mask assembly comprising at least a first mask to which the X-rays from the X-ray source are irradiated, thereby splitting the X-ray beam into a plurality of X-ray beamlets; and a second mask arranged between the first mask and the image signal detector;
- an object stage extending in an optical axis direction of the X-rays, the object stage being configured to adjust a position of the object to correspond with a predetermined imaging magnification;
- wherein the first mask comprises a body with a plurality of X-ray absorbing elements and apertures arranged in a manner that gradually diverges from one portion to an opposite portion of the body, resulting in a variable pitch perpendicular to the optical axis direction;
- wherein the second mask comprises a body with a periodically spaced arrangement of X-ray absorbing elements and apertures resulting in a fixed pitch; and,
- wherein the mask assembly further comprises a mask alignment mechanism configured to adjust a position of the first mask along the optical axis direction to match the predetermined imaging magnification; and, further adjust a position and/or an orientation of the first mask to align the variable pitch of the first mask with the fixed pitch of the second mask for phase contrast imaging.

DESCRIPTION OF THE FIGURES

The following description of the figures relate to specific embodiments of the disclosure which are merely exemplary in nature and not intended to limit the present teachings, their application or uses.

Throughout the drawings, the corresponding reference numerals indicate the following parts and features: object 5; radiation imaging apparatus 100; radiation source 10; image signal detector 20; radiation beam 11; radiation beamlets 12; first mask 30; x-ray absorbing element 31; aperture 32; mask alignment mechanism 40; mask stage 41; object stage 42; second mask 50.

FIG. 1 shows a top view of an embodiment of a radiation imaging apparatus 100 according to some aspects of the present disclosure.

FIG. 2 shows a top view of another embodiment of a radiation imaging apparatus 100 according to some aspects of the present disclosure.

FIG. 3 shows a front view of an embodiment of a first mask 20 of a mask assembly according to some aspects of the present disclosure.

FIG. 4 shows a front view of another embodiment of a first mask 20 of a mask assembly according to some aspects of the present disclosure.

FIG. 5 shows a top view of the radiation imaging apparatus 100 used in Example 1, whereby the mask assembly is aligned to increase imaging resolution.

FIG. 6 shows a top view of the radiation imaging apparatus 100 used in Example 1, whereby the mask assembly is aligned for an increased FOV.

FIG. 7 shows a phase-contrast image obtained at a lowest magnification using the simulation setup discussed in Example 1.

FIG. 8 shows a phase-contrast image obtained at a higher magnification using the simulation setup discussed in Example 1.

FIG. 9 shows a phase-contrast image obtained at the highest magnification using the simulation setup discussed in Example 1.

FIG. 10 shows a top view of the radiation imaging apparatus 100 used in Example 2, with a non-tilted first mask, viewed along the vertical (y) direction.

FIG. 11 shows a front view of the radiation imaging apparatus 100 used in Example 2, with a non-tilted first mask, viewed along the optical axis (z) direction.

FIG. 12 shows a side view of the radiation imaging apparatus 100 used in Example 2, with a non-tilted first mask, viewed along the transverse (x) direction.

FIG. 13 schematically shows the spatial relationships of the components calculate in a radiation imaging apparatus 100 setup for calculating an appropriate tilt angle θ to achieve optimal alignment of the first mask 30.

FIG. 14 shows a phase-contrast image obtained at a lower magnification for a tilted first mask using the simulation setup discussed in Example 2.

FIG. 15 shows a phase-contrast image obtained at a higher magnification for a tilted first mask using the simulation setup discussed in Example 2.

FIG. 16 shows a top view of the radiation imaging apparatus 100 used in Example 2, with a tilted first mask, viewed along the vertical (y) direction.

FIG. 17 shows a front view of the radiation imaging apparatus 100 used in Example 2, with a tilted first mask, viewed along the optical axis (z) direction.

FIG. 18 shows a side view of the radiation imaging apparatus 100 used in Example 2, with a tilted first mask, viewed along the transverse (x) direction.

FIG. 19 shows an experimental setup of a radiation imaging apparatus 100 according to some aspects of the present disclosure.

FIG. 20 shows a perspective view of an embodiment of a radiation imaging apparatus 100 according to aspects of the present disclosure.

FIG. 21 schematically illustrates the spatial relationships between components in the radiation imaging apparatus 100, used to calculate an appropriate tilt angle θ for optimal alignment of the first mask 30 in Example 3.

FIG. 22 shows the design of the trapezoidal mask and its associated parameters used for calculating the tilt angle θ in Example 3.

FIG. 23 shows a top view of the radiation imaging apparatus 100 used in Example 2, with a tilted detector, viewed along the vertical (y) direction.

FIG. 24 shows a front view of the radiation imaging apparatus 100 used in Example 2, with a tilted detector, viewed along the optical axis (z) direction.

FIG. 25 shows a side view of the radiation imaging apparatus 100 used in Example 2, with a tilted detector, viewed along the transverse (x) direction.

FIG. 26 shows a top view of the radiation imaging apparatus 100 as configured for Example 4.

FIG. 27 presents differential phase contrast radiographs at five magnification levels (panels A–E) for Example 4.

FIG. 28 shows a top view of the radiation imaging apparatus 100 as configured for Example 5.

FIG. 29 shows a top view of the radiation imaging apparatus 100 as configured for Example 6.

FIG. 30 presents phase contrast reconstructions at eleven magnification levels (M = 1.12 to M = 3.0) for Example 5.

FIG. 31 presents phase contrast reconstructions at four magnification levels (panels A–D) for Example 6.

DETAILED DESCRIPTION

An overview of various aspects of the technology of the present disclosure is given hereinbelow, after which specific embodiments will be described in more detail. This description is meant to aid the reader in understanding the technological concepts more quickly, but it is not meant to identify the most important or essential features thereof, nor is it meant to limit the scope of the present disclosure, which is limited only by the claims. Hence, present the description is to be regarded as illustrative in nature, and not as restrictive.

In the present disclosure, technology is described that relates to inspection of objects utilizing radiation imaging, more specifically, edge illumination phase contrast X-ray imaging. In particular, the technology described herein seeks to address the limitations of the current phase contrast imaging apparatuses regarding optimization of the imaging resolution and field of view by providing a mask assembly that is adjustable to the position and orientation the object or region under inspection. The assembly described in the present disclosure can be implemented for inspection of various objects in different industrial settings, such as manufacturing, food, agriculture, aerospace, automotive, electronics, healthcare, transport, logistics, security, and others.

Although certain embodiments and examples are disclosed below, it will be understood by those in the art that the present disclosure extends beyond the specifically disclosed embodiments and/or uses of the present disclosure and obvious modifications and equivalents thereof. Thus, it is intended that the scope of the present disclosure disclosed should not be limited by the particular disclosed embodiments described below.

As defined herein, Edge Illumination (EI) phase contrast imaging refers to a method of radiation imaging designed to detect phase shifts in an X-ray beam as it passes through an object under inspection. A typical EI phase contrast imaging apparatus may consist of a conventional computed tomography (CT) setup with the addition of at least one mask positioned between the X-ray source and the object, featuring a pattern of X-ray absorbing elements and apertures. This mask divides the incoming X-ray beam into discrete beamlets, which then pass through the object and onto an image signal detector. As the beamlets travel through the object, phase shifts caused by variations in thickness and composition lead to changes in the beamlets' intensity. These intensity variations can be detected by the pixels of an image signal detector, enabling phase-contrast imaging. Optionally, a secondary mask can be included to create insensitive regions between signal detector pixels to improve image quality.

As defined herein, a “radiation imaging apparatus” refers to a system for capturing and processing images derived from the interaction of ionizing radiation, particularly X-rays, with an object or material. It typically comprises several key components, including a monochromatic or polychromatic radiation source, such as an X-ray tube or other suitable X-ray devices, which generates a cone shaped radiation beam directed toward the object to be imaged, and an image signal detector, which captures the radiation after it has passed through the object and converts it into electrical signals that can be processed into images. The signal detector often consists of an array of pixels or other sensitive elements designed to detect changes in intensity, phase, or other characteristics of the radiation.

To maintain a high-level understanding, this disclosure avoids detailed descriptions of the radiation imaging apparatus. However, it is understood by those skilled in the art that a radiation imaging apparatus typically includes additional components to ensure proper and safe operation. For example, these may include a housing that encloses and protects internal components, as well as electronic and mechanical elements like circuit boards, cooling systems, actuators, and power supplies to provide the necessary electrical power to the system. Additionally, safety features such as interlocks and radiation shielding help ensure safe operation. Interfaces for controlling and handling the object within the apparatus might also be included.

The radiation imaging system may also comprise at least one processing unit that includes memory for storing image signal data received from the image signal generation system. The processing unit typically contains a processor that communicates with the memory, allowing it to perform various data processing tasks required for generating and analyzing radiation images. Additional software-based features could encompass computer-implemented data processing steps and algorithms designed for efficient generation and analysis of radiation images. For example, in some configurations, automatic alignment systems, calibration tools, and advanced software for data processing and analysis are utilized. These implementations are generally known in the art and are briefly mentioned here for completeness without excessive detail.

In the context of the present disclosure, an "object" refers to any physical item or material intended for inspection using the edge illumination phase contrast X-ray imaging described herein. Objects can encompass a wide range of forms and compositions, for example, mechanical parts, electronic components, consumer products, agricultural produce, medical devices, biological specimens, and so on. The objects can vary in size, shape, density, and internal structure, necessitating flexible imaging techniques to effectively visualize their inner details. The technology discussed in this disclosure is versatile, allowing for the inspection of different types of objects without being restricted by specific properties, dimensions, shapes, or materials. Instead, it is applicable to any item suitable for inspection with radiation imaging technology.

As defined herein, an "imaging space" refers to the three-dimensional (3D) area within the radiation imaging apparatus where the interaction between the radiation source, the object being imaged, and the image signal detector occurs. This space encompasses the pathway along which the radiation, specifically X-rays, travels from its source, through the object, ultimately reaching the signal detector. The size, shape, and configuration of the imaging space are influenced by the design of the apparatus, the orientation of the source and signal detector, and the positioning of the object.

As defined herein, the term “optical axis direction” refers to the direction in which the radiation beam propagates through the imaging space, typically extending from the radiation source, through the object stage, and toward the image signal detector. Adjusting the positions of the object and any interacting components such as masks along the optical axis direction, relative to the source and signal detector, defines the imaging magnification at which the imaging system captures and displays the features of an object being imaged. Imaging magnification—alternatively referred to as imaging factor or zoom level—thus determines the resolution at which the system captures and displays the features of the object under inspection.

As defined herein, the term “substantially perpendicular to the optical axis direction” refers to a direction that intersects the optical axis at or near 90 degrees—preferably exactly 90 degrees—while allowing for acceptable tolerances inherent in design or manufacturing. With the context of the first mask as described herein, this expression describes the orientation of features such as the variable pitch to extends in a direction that is substantially perpendicular to the optical axis. This means that the spacing between the X-ray absorbing elements and apertures of the mask varies laterally with respect to the radiation beam path, rather than along it.

As used herein, the term "first direction" refers to a direction that is substantially perpendicular to the optical axis direction, which corresponds to the path along which the radiation beam propagates from the X-ray source to the image signal detector. In various embodiments, the position and/or orientation of the first mask may be adjusted substantially along the first direction to align the variable pitch of the mask with the pixel structure of the image signal detector. The first direction may, for example, lie within a detector plane or object plane that is orthogonal to the optical axis.

Specific embodiments in accordance with various aspects of the technology of the present disclosure will be described in more detail below. When describing embodiments, reference is made to the accompanying drawings, which are provided solely to aid in the understanding of the described embodiment. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

Figure 1 schematically illustrates a top view of a radiation imaging apparatus 100 configured for phase-contrast imaging of an object 5 using a mask assembly, in accordance with an embodiment of the present invention. The apparatus 100 includes an image signal generation system comprising at least one source 10 that generates an X-ray beam, and at least one image signal detector 20, positioned opposite the source 10, that detects the signal produced by the radiation emitted from the source 10. The signal detector 20 is depicted as a row of squares, representing the individual pixels of the image signal detector.

In an embodiment, the X-ray source may be a standard monochromatic or polychromatic X-ray source, adaptable to the imaging requirements. The image signal detector can be any position-sensitive signal detector converting the radiation into electrical signals that can be processed into images. Signal detectors often consist of an array of pixels or other sensitive elements designed to detect changes in the intensity, phase, or other characteristics of the radiation. Depending on the imaging requirement, the image signal detector can be a 1D signal detector (single row of pixels) or a 2D signal detector (multiple rows of pixels). Those skilled in the art understand how the quality of phase-contrast and amplitude-contrast images depends on the accurate determination of phase and amplitude at each pixel, making high-quality signal detectors critical for enhanced imaging results.

The radiation source 10 and the signal detector 20 define the imaging space within the radiation imaging apparatus 100. The optical axis direction, labelled as ‘z’, indicates the primary path along which the X-ray radiation travels from the source 10 to the signal detector 20, passing through the object 5 being imaged. This direction serves as a reference for aligning the below discussed components of the apparatus 100 to ensure precise imaging performance and accuracy. Specifically, the directions labelled as ‘x’ and ‘y’ are understood to be substantially perpendicular to the optical axis direction z.

The object 5 can be provided on an object stage designed to support and position the object within the apparatus for imaging. In one embodiment, the object stage may comprise a platform or holder extending in the optical axis direction z of the X-rays, providing a stable base for placement of the object. The object holder may feature mechanisms for automated adjustment of the object's position. Alternatively, the object may be arranged in a suspended manner, for example using wires, enabling a clear imaging pathway without obstructions from a traditional support structure. In a particular embodiment, the object stage may comprise a robotic arm or a manipulator controlled by a robotic arm.

A first mask 30, part of the mask assembly, is positioned between the source 10 and the object 5 being imaged. The first mask 30 may consists of a body comprising a plurality of X-ray-absorbing elements separated by apertures. These elements and apertures can be arranged in a pattern that gradually diverges from one portion to an opposite portion of the body, resulting in a variable pitch that can be adjusted using the mask alignment mechanism 40 discussed below. In a particular embodiment the first mask may be a grating, defined as a specific type of mask with periodic or repeating patterns formed by a plurality of lines, bars, and/or grooves.

Within the context of the present disclosure, a "pitch" refers to the distance between adjacent elements of the first mask, typically measured from the center of one element to the center of the next, or from one side of one element to the corresponding side of the next. This distance determines the regular interval at which the mask's pattern repeats. Alternatively, the term "period" can be used to indicate the same concept.

As the incoming X-ray beam 11 reaches the first mask 30, it is divided into a plurality of X-ray beamlets, which then individually pass through the object. The first mask is described as having a variable pitch because its pitch can be adjusted by adjusting the position and/or orientation of the first mask 30 relative to the other components of the imaging apparatus 100. Specific embodiment of the first mask will be discussed further below, with reference to figures illustrating different views for easier understanding.

In phase-contrast imaging, the pattern of the X-ray beamlets split by the first mask is aligned with the sensor's detection capabilities. Specifically, if the pitch of the first mask is not correctly aligned with the signal detector's pixel structure, the beamlets may not hit the signal detector as desired, potentially leading to blurred or misaligned images or image artifacts. Thus, matching the pitch ensures that each beamlet is captured in a way that provides optimal resolution and contrast in the resulting images, allowing for accurate phase-contrast analysis.

Advantageously, the X-ray beamlets generated by the first mask are spaced sufficiently to ensure that when they reach the signal detector, their ‘footprint’ on the signal detector’s pixels can be distinguished. This allows each beamlet to be distributed across multiple pixels to create an approximately Gaussian profile on the signal detector. For example, a footprint of three pixels can be defined, with each beamlet's peak ideally centered on the middle pixel of this three-pixel footprint. However, this configuration can be adjusted based on the application, with other numbers, such as a five-pixel footprint, also possible. The mask alignment mechanism can then align the mask with the signal detector to ensure accurate beamlet targeting, as described below.

In a preferred embodiment, the mask alignment mechanism may be operatively connected to the image signal generation system in such a way that it adjusts the position and/or orientation of the first mask in response to the generated image signal. This adjustment advantageously ensures that each X-ray beamlet irradiates a set of pixels on the signal detector, preferably with the central pixel of each set corresponding to the point of maximum intensity for the respective X-ray beamlet. This arrangement advantageously results in a substantially Gaussian profile for the image signal. The adjustment may be controlled through a control system configured to generate a control signal to the mask alignment mechanism. This control unit may receive signal data from the signal detector and uses it to fine-tune the position and/or orientation of the first mask, ensuring optimal alignment and imaging performance. Optionally, the control unit can be part of the signal generation system.

To ensure proper alignment with the object, the mask alignment mechanism can mechanically adjust the position and/or orientation of the first mask to align the variable pitch with the signal detector’s configuration, specifically to ensure the alignment of the X-ray beamlets with the corresponding pixels of the signal detector. However, it is appreciated that there are various ways the mask alignment mechanism can adjust the position and/or orientation of the first mask, depending on the configuration of the first mask and the object stage described above.

In an embodiment, the first mask can be arranged on a mask stage designed to support and position the mask within the apparatus for imaging. The mask stage may comprise a platform or a suspension driven by a drive unit, similar to the previously described object stage. For example, the mask stage may include a PI hexapod. Alternative devices may include rotational and translational stages with high precision, such as stepper motors, BLDC motors, torque-quantum motors, controlled AC motors, and similar mechanisms. In a further embodiment, the mask stage can be moveably coupled to the object stage such that positional adjustment of the object can be synchronized with positional adjustment of the first mask.

Alternatively or in combination, the mask stage may be configured to tilt the first mask 30 to adjust the field of view. The first mask can be tilted in various directions of rotation, for example, along the optical axis direction or along a direction perpendicular to the optical axis. **Figures 16 to 18** illustrate examples of how rotating the first mask about different axes results in distinct configurations of the radiation imaging apparatus, thereby impacting the FOV and magnification of the acquired images. In some embodiments, the tilt angle can range from at least 1° to at most 50°, with intermediate examples including 10°, 20°, 30°, or 40°.**Figure 2** schematically illustrates a top view of another embodiment of the radiation imaging apparatus 100. This embodiment comprises the same components as discussed earlier for Figure 1, with the addition of a second mask 50, part of the mask assembly, positioned between the object 5 being imaged and the signal detector signal 20. The second mask 50 may consist of a body comprising a plurality of X-ray-absorbing elements separated by apertures. These elements and apertures can be arranged in a periodic pattern, resulting in a fixed or predetermined pitch.

The provision of the second mask 50 adjacent to the signal detector 20 may serve to block or reduce the detection of certain parts of the X-ray beamlets, effectively creating "dead zones" or regions where the signal detector is less sensitive or not sensitive at all to incoming X-rays between adjacent signal detector pixels. By creating these insensitive regions, the overall quality of the imaging system can be improved by focusing on critical portions of the signal, thereby producing clearer and more structured images. This targeted detection can be beneficial for phase-contrast imaging, where specific patterns and their analysis are crucial.

In a further embodiment, the mask alignment mechanism can be configured to align the variable pitch of the first mask with the fixed pitch of the second mask. This alignment can be performed after aligning the variable pitch of the first mask to the signal detector pixels, as previously described, or as an alternative approach. This feature promotes proper synchronization between the components, ensuring optimal phase-contrast imaging performance.

Alternatively or in combination, the mask stage may be configured to tilt the signal detector 20 and/or the second mask 50 to adjust the field of view. The signal detector 20 and/or the second mask 50 can be tilted in various directions of rotation, for example, along the optical axis direction or along a direction perpendicular to the optical axis. **Figures 23 to 25** illustrate examples of how rotating the signal detector 20 and the second mask 50 about different axes results in distinct configurations of the radiation imaging apparatus, thereby impacting the FOV and magnification of the acquired images. In some embodiments, the tilt angle can range from at least 1° to at most 50°, with intermediate examples including 10°, 20°, 30°, or 40°.

Figure 20 provides a perspective view of another embodiment of the radiation imaging apparatus 100. While comprising the same components described in Figure 2, this three-dimensional illustration serves to better highlight the variable pitch of the first mask 30.

The coordinate system in Figure 20 defines the z-axis as the optical axis, corresponding to the path of X-ray radiation from the source 10 to the signal detector 20 through the first mask 30. The x- and y-axes are oriented in directions substantially perpendicular to this optical axis. In the illustrated embodiment, the variable pitch of the first mask 30 extends along the x-direction, indicating a pitch variation transverse to the beam path. By adjusting the position of the first mask 30 along the y-direction, the projected pitch along the z-axis can be controllably adjusted, enabling multi-resolution imaging.

Figure 19 shows an image of an experimental radiation imaging apparatus 100 set up for phase-contrast imaging of an object 5 using a mask assembly, in accordance with an embodiment of the present invention—specifically, the embodiment described above with reference to Figure 2.

The mask assembly includes a first mask 30, mounted on a mask stage 41 configured for adjusting the position of the first mask 30 relative to the object 5 (depicted as an apple in this image). For example, the mask stage 41 can increase or decrease the distance between the first mask 30 and the object 5 along the optical axis. Additionally, both the first mask 30 (via the mask stage 41) and the object 5 are positioned on an object stage 42 configured to simultaneously adjust their positions relative to other components—specifically, the source 10, the signal detector 20, and the second mask 50. For example, the object stage 42 can move the first mask 30 and the object 5 closer to the source 10, thereby increasing the distance from the signal detector 20, or vice versa. In this embodiment, the mask stage 41 and the object stage 42 jointly form part of the mask alignment mechanism 40. Optionally, the mask stage 41 and/or object stage 42 can comprise a stop mechanism configured to prevent a collision between the object 5 and the first mask 30 and/or the second mask 50 during any positional and/or orientational adjustments.

The mask stage 41 and the object stage 42 can be equipped with motors or actuators configured to move the first mask and the object. These motors or actuators can operate in tandem to control the positioning along the optical axis. In an alternative arrangement, separate motors or actuators can be used for each stage, providing independent control of the mask stage 41 and the object stage 42. Additionally, more motors or actuators may be incorporated to enable further movements, such as tilting the first mask or the object in one or more rotational directions.

Figure 3 shows a preferred embodiment of the first mask 30 from a front view, i.e., along the optical axis direction z. In this embodiment, the body of the first mask consists of a plurality of elongated bars 31 configured as x-ray absorbing elements. The elongated bars 31 are arranged in a trapezoidal configuration, with the bars 31 diverging linearly from one portion to the opposite portion of the body, resulting in a continuously variable pitch that is defined by the apertures 32 formed between adjacent bars 31. Specifically, the pitch of the present embodiment changes gradually and without distinct steps or discrete intervals. This approach allows for precise control over the changing pitch across a range without abrupt transitions or fixed intervals.

The trapezoidal configuration of the shown first mask can be achieved by varying the distance between the opposite portions of the body and keeping the width of the elongated bars fixed. In the present embodiment these portions are discussed as the top and bottom portions, respectively. However, the skilled person appreciates that the body can be tilted sideways or flipped and still obtain a similar technical result given appropriate adjustment of the alignment mechanism. Accordingly, the top portion of the first mask, denoted by a total length m (measured from the edges of opposite portions of the bars), is shorter in length than the bottom portion of the first mask, denoted by a total length n (measured in an analogous manner), such that m < n. Consequently, the pitch at the top portion of the first mask, indicated by p_m (measured as the distance between the central point of adjacent bars), is lower than the pitch at the opposite bottom portion of the first mask, denoted by p_n (measured in a similar manner between corresponding adjacent bars), such that $p_m < p_n$. Lastly, h is the height of the first mask.

In the shown embodiment, the number of diverging bars is limited to 6 for clarity, but those skilled in the art understand that in applications, the number of bars can be adapted to any number depending on the imaging requirements. It is also understood that the mask typically includes additional elements, such as a frame and possible connections to a mask stage described herein, which are not illustrated in the present drawing. In a particular embodiment the first mask may be a grating formed by the plurality of diverging bars.

In some embodiments the rate of divergence of the first mask can be between 0.005 m/m and 0.0001 m/m, wherein the rate of divergence is defined as the difference between a highest period and a lowest period, preferably at opposite portions of the mask, wherein said difference is divided by a height of the mask. For example, the rate of divergence can be 0.001 m/m or 0.0005 m/m.

In some embodiments, the pitch at the one portion of the first mask is at least twice the pitch at the opposite portion; preferably at least three times the pitch at the opposite portion, or more. Advantageously, the aperture-pitch ratio remains the same from the one portion to the opposite portion.

In some embodiments, the pitch of the first mask ranges from at least 30 at one portion to at most 120 at the opposite portion. The variable pitch can include any value within this range, such as 40, 50, 60, 70, 80, 90, 100, and 110. It is also understood that any subranges falling within this range are part of the present invention.

In some embodiments a rate of linear divergence of the first mask is defined by a divergence angle formed between the direction of the bars at one end of the mask and the direction of the bars at the opposite end, measured relative to a reference line perpendicular to a longitudinal direction of the mask; wherein the divergence angle is between at least 1° to at most 10°. For example, the divergence angle can be 5° or 7°.

In some embodiments the elements of the first mask, preferably including the elongated bars, can have a length ranging from 100 to 500 millimeters measured along a longitudinal direction (labelled as y in **Figure 3**). For example, the height can be 200, 300 or 400 millimeters.

In some embodiments the elements of the first mask, preferably including the elongated bars, can have a width ranging from 100 to 500 millimeters measured along a transverse direction (labelled as x in **Figure 3**). For example, the width can be 200, 300 or 400 millimeters.

In some embodiments the elements of the first mask, preferably including the elongated bars, can have a depth ranging from 100 to 250 micrometers measured along the optical axis direction (labelled as z in **Figure 3**). For example, the depth can be 150 or 200 micrometers.

Figure 4 shows another preferred embodiment of the first mask 30 from a front view, along the optical axis direction z. In this embodiment, the body of the first mask consists of a solid plate 31 configured as x-ray absorbing element, provided with a plurality of circular apertures 32 arranged in a trapezoidal configuration. These apertures 32 are circular with a predetermined diameter and are spaced at specific intervals, thereby defining the pitch at various points along the height of the body of the shown first mask 30. The spacing distance between each circular aperture can be varied, allowing the pitch to change at distinct points from one portion to the opposite portion of the body, resulting in a discretely variable pitch. Specifically, the pitch in this embodiment changes in distinct, separate steps or intervals, creating discrete variations in the distance between adjacent elements, rather than varying smoothly or continuously. This approach can be beneficial when the apparatus can be operated at set levels or predefined configurations, allowing for repeatable and consistent positioning.

Additionally, the circular apertures can be replaced by other geometrical shapes, depending on the application and desired characteristics of the pitch. Alternative shapes may include oval apertures, rectangular bars, L-shaped bars, triangular prisms, or even more complex geometries like star or hexagon-shaped structures. The choice of shape can impact the distribution and patterning of the X-ray beamlets, as well as the performance of the discretely variable pitch. This flexibility allows for adaptation to a wide range of imaging requirements and design configurations.

Based on the described embodiment, it is clear that the mask assembly as defined herein can be readily incorporated into a radiation imaging apparatus, offering enhanced versatility in phase-contrast X-ray imaging systems. By integrating this mask assembly, existing imaging devices can achieve improved functionality and versatility.

To further clarify the operational methodology, the following steps outline the method of operating the mask assembly in a radiation imaging apparatus:

- providing the object for imaging, preferably by positioning the object on an object stage;
- adjusting a position of the object along an optical axis direction to correspond with a predetermined imaging magnification, preferably by moving the object stage or specific components thereof;
-adjusting a position of a first mask along the optical axis direction to match the predetermined imaging magnification, preferably by moving a mask stage or an appropriate part of the mask alignment mechanism;
- further adjusting the position and/or orientation of the first mask to align the variable pitch of the first mask with the image signal detector for phase-contrast imaging, preferably by adjusting the separation between the radiation beamlets split by the first mask to match the dimensions of the pixels of the image signal detector; and
- optionally, acquiring one or more images by emitting radiation from a radiation source, directed through the first mask, and detecting an image signal based on the emitted radiation on the image signal detector for phase contrast imaging.

In an alternative embodiment, where the mask assembly further comprises a second mask with a fixed pitch as defined herein, the method may include the step of adjusting the position and/or orientation of the first mask to align its variable pitch with the fixed pitch of the second mask. This step can be carried out in addition to, or as an alternative to, the step of aligning the variable pitch of the first mask with the image signal detector, ideally with the pixels of the image signal detector, as discussed above.

For completeness, it is clarified that the approach to phase-contrast imaging can vary depending on the configuration of the mask assembly described herein. Specifically, in an embodiment that includes only a first mask (without a second mask placed before the image signal detector), it is possible to acquire a single radiation image; however, this may lead to reduced resolution. In this case, the image captured by a group of pixels on the signal detector may show a curve, which can be used to derive different contrasts.

Alternatively, in an embodiment with both a first mask (positioned before the object) and a second mask (positioned before the image signal detector), at least two radiation images should be acquired at different phase shifts of the masks to effectively separate attenuation and phase-contrast information. However, to further enhance the separation of attenuation, phase, and dark-field images, acquiring at least three radiation images at different phase shifts is recommended.

Therefore, it is understood that the term "phase-contrast image," as used herein, does not refer to an image that directly captures phase contrast, even though the technique is commonly called "phase-contrast imaging." Instead, it involves indirectly measuring phase contrast through specific processing techniques. Nonetheless, the skilled person is familiar with the appropriate methodologies to extract and generate phase-contrast images from the acquired radiation images.

Reference throughout this specification to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present disclosure. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment.

As used herein, the terms “comprising”, “comprises” and “comprised of” as used herein are synonymous with “including”, “includes” or “containing”, “contains”, and are inclusive or open-ended and do not exclude additional, non-recited members, elements, or method steps. The terms “comprising”, “comprises” and “comprised of” when referring to recited members, elements or method steps also include embodiments which “consist of” said recited members, elements or method steps. The singular forms “a”, “an”, and “the” include both singular and plural referents unless the context clearly dictates otherwise.

As used herein, relative terms, such as “left,” “right,” “front,” “back,” “top,” “bottom,” “over,” “under,” etc., are used for descriptive purposes and not necessarily for describing permanent relative positions. It is to be understood that such terms are interchangeable under appropriate circumstances and that the embodiment as described herein are capable of operation in other orientations than those illustrated or described herein unless the context clearly dictates otherwise.

Objects described herein as being “adjacent” to each other reflect a functional relationship between the described objects, that is, the term indicates the described objects must be adjacent in a way to perform a designated function which may be a direct (*i.e.* physical) or indirect (*i.e.* close to or near) contact, as appropriate for the context in which the phrase is used.

Objects described herein as being “connected” or “coupled” reflect a functional relationship between the described objects, that is, the terms indicate the described objects must be connected in a way to perform a designated function which may be a direct or indirect connection in an electrical or nonelectrical (*i.e.* physical) manner, as appropriate for the context in which the term is used.

As used herein, the term “substantially” refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result. For example, an object that is “substantially” enclosed would mean that the object is either completely enclosed or nearly completely enclosed. The exact allowable degree of deviation from absolute completeness may in some cases depend on the specific context. However, generally speaking the nearness of completion will be so as to have the same overall result as if absolute and total completion were obtained. The use of “substantially” is equally applicable when used in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result.

As used herein, the term “about” is used to provide flexibility to a numerical value or range endpoint by providing that a given value may be “a little above” or “a little below” said value or endpoint, depending on the specific context. Unless otherwise stated, use of the term “about” in accordance with a specific number or numerical range should also be understood to provide support for such numerical terms or range without the term “about”. For example, the recitation of “about 30” should be construed as not only providing support for values a little above and a little below 30, but also for the actual numerical value of 30 as well.

The recitation of numerical ranges by endpoints includes all numbers and fractions subsumed within the respective ranges, as well as the recited endpoints. Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order, unless specified. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the disclosure described herein are capable of operation in other sequences than described or illustrated herein.

Reference in this specification may be made to devices, structures, systems, or methods that provide “improved” performance (*e.g.* increased or decreased results, depending on the context). It is to be understood that unless otherwise stated, such “improvement” is a measure of a benefit obtained based on a comparison to devices, structures, systems or methods in the prior art. Furthermore, it is to be understood that the degree of improved performance may vary between disclosed embodiments and that no equality or consistency in the amount, degree, or realization of improved performance is to be assumed as universally applicable.

In addition, embodiments of the present disclosure may include hardware, software, and electronic components or modules that, for purposes of discussion, may be illustrated and described as if the majority of the components were implemented solely in hardware. However, one of ordinary skill in the art, and based on a reading of this detailed description, would recognize that, in at least one embodiment, the electronic based aspects of the present disclosure may be implemented in software (*e.g.*, instructions stored on non-transitory computer-readable medium) executable by one or more processing units, such as a microprocessor and/or application specific integrated circuits. As such, it should be noted that a plurality of hardware and software-based devices, as well as a plurality of different structural components may be utilized to implement the technology of the present disclosure. For example, “servers” and “computing devices” described in the specification can include one or more processing units, one or more computer-readable medium modules, one or more input/output interfaces, and various connections connecting the components.

EXAMPLE

The following examples illustrate various implementations of the technology according to aspects of the present invention. The inclusion of these examples is intended to aid the reader in understanding the technological concepts more easily, but they are not intended to identify the most important or essential features, nor are they meant to limit the scope of the present disclosure. It is understood that the embodiments presented in these examples form preferred embodiments of the invention described herein.

Example 1

The present example demonstrates how positional adjustments to the mask assembly described herein affect imaging quality through Monte Carlo (MC) simulation performed on an object at different magnifications. The simulation setup is performed using the MC software GATE (Geant4 Application for Tomographic Emission).

Figures 5 and 6 illustrate different configurations of the simulation setup, featuring a source 10, an object 5, a signal detector 20, a first mask 30 positioned between the source 10 and the object 5, and a second mask 50 positioned between the object 5 and the signal detector 20. The object 5 used in the simulations is a glass ellipsoid containing aluminum cylinders of varying diameters, which increase in size along in a transverse direction—i.e., in a direction perpendicular to the optical axis direction along the axis, labelled as ‘x’.

The first mask 30 used in the simulation corresponds to the embodiment previously discussed with reference to Figure 3, featuring a trapezoidal configuration with bars that diverge linearly from the top to the bottom. The body of the first mask is made of gold, an aperture size ranging from 5 µm to 25 µm, a period ranging from 5 µm to 125 µm, and a thickness of 200 µm. The second mask 50 has a fixed pitch and is not moved throughout the simulation. The body of the second mask is made of gold, an aperture size of 30 µm, a period ranging of 148 µm, and a thickness of 200 µm.

Throughout the experiments, a constant distance of 1800 mm is maintained between the source 10, the second mask 50, and the signal detector 20. The source is a cone-beam monochromatic source with an energy range of 1 keV to 60 keV. The signal detector 20 is a 1D signal detector consisting of a single row of 150µm-sized pixels, enabling 2D imaging with a 66x66 pixel array.

Images at different magnifications are obtained by translating the object 5 and the first mask 30 along the optical axis direction 'x'. Subsequently, by translating the first mask 30 vertically—i.e., perpendicular to the optical axis direction x, along the axis labelled as ‘y’— variable pitch of the mask changes, compensating for the pitch mismatch following the former translation.

Figure 5 shows an example of the radiation imaging apparatus configured for increased resolution by positioning the mask 30 and the object 5 closer to the source 10 and farther from the signal detector 20. Conversely, **Figure 6** depicts an apparatus configuration configured for increased FOV by positioning the mask 30 and the object 5 farther from the source 10 and closer to the signal detector 20. By translating the first mask 30 along the optical axis direction z, coupled with compensation for pitch mismatch, the apparatus enables imaging of sections of the phantom at varying resolutions and/or FOV, providing a continuous range between high-resolution imaging, as shown in the configuration of Figure 5, and/or wide-field imaging , as shown in the configuration of Figure 6.

As an alternative, the resolution and FOV can also be modulated by adjusting the positions of the source 10 and/or the signal detector 20 along the optical axis. Specifically, in Figure 5 the resolution can be increased by positioning the source 10 closer to the mask 30 and/or positioning the signal detector 20 closer to the object 5. Conversely, in Figure 6 the FOV can be increased by positioning the source 10 farther away from the mask 30 and/or positioning the signal detector 20 farther away from the object 5. By translating the source 10 and/or the signal detector 20 along the optical axis direction z, coupled with compensation for pitch mismatch, the apparatus similarly enables continuous tuning of imaging conditions across a range of resolution and FOV settings.

The phase contrast results of the experiments are shown in the subsequent figures. In **Figure 7**, which has the lowest magnification, the entire ellipsoid is visible, but the aluminum cylinders cannot be distinctly observed in the phase contrast image. In **Figure 8**, with increased magnification, the edges of the ellipsoid are cut off, but the largest cylinders are distinguishable. **Figure 9** presents the highest magnification, focusing on the center of the ellipsoid, where each cylinder can be individually identified.

In conclusion, these results demonstrate that magnification can be reliably increased by adjusting the position of the first mask relative to the object, resulting in clear and distinguishable features in the 2D images acquired by a signal detector consisting of single row of signal detector pixels.

Example 2

The present example demonstrates how orientational adjustments to the mask assembly described herein affect imaging quality using the same MC simulation setup as discussed above for Example 1. Specifically, the orientation of the first mask 30, positioned between the source 10 and the object 5, is adjusted through tilting the first mask in various directions within the imaging space along the optical axis direction x.

In a first part of this example, the signal detector 20 is a 1D signal detector consisting of a single row of pixels, enabling 2D imaging with a 66x66 pixel array. Images with varying FOV are obtained by adjusting the position and orientation of the first mask 30 through tilting along the optical axis. During these adjustments, the remaining components of the apparatus 100, along with the object 5 being imaged, are fixed in position.

To achieve optimal results, both the position and the tilt angle of the first mask must be carefully selected. Tilting the mask compensates for mismatches in magnification that can occur when pixel rows above and below the focused row are not perfectly aligned. The optimal tilt angle is dependent on certain design parameters that also dictate the possible FOV and resolution range for this setup.

Figure 13 illustrates the spatial relationships in the simulation setup. In this configuration, the first mask having is perfectly aligned at point B. To find the appropriate angle θ that aligns the first mask at point F, two expressions for the period in point F are applied.

The first expression (pp_1) defines the required period at point F to account for the change in magnification when tilting the first mask. This first expression is given by $pp_1(\theta) = p\frac{|AF|}{|AD|}$, where pixel size p and $|AD|$ are fixed setup parameters, while $|AF|$ depends on the tilt angle θ.

The second expression (pp_2) defines the period at point F. Tilting the first mask changes the intersection between AD and BF, resulting in a different period along the optical axis direction. The second expression is given by $pp_2(\theta) = \text{period}_B + |BF| \cdot g_s$, where pperiod_B is again a fixed setup parameter, while $|BF|$ depends on the tilt angle θ. Additionally, g_s is a design factor of the first mask that essentially defines its broadening; the value of g for a trapezoidal configuration of the present example is given by $g = \frac{p_n - p_m}{h}$, where p_m is the pitch at the top portion, p_n the pitch at the bottom portion, and h is the height.

The appropriate angle to align the first mask can then be determined by solving the equation $pp_1 = pp_2$, or through $\frac{p(h_d + 2 z_{sd}\tan(\theta))}{2z_{sd}(h_d - z_{sd}\tan(\theta))}\sqrt{\frac{(h_d^2 + 4 z_{sd}^2)}{h_d^2 + z_{sd}^2}} = \frac{p}{z_{sd}} - \frac{2 g_s h_d}{(h_d - 2 z_{sd}\tan(\theta))\cos\theta}$, where h_d is the signal detector height, z_{sd} is the distance between source and signal detector, p the pixel size, and θ the tilt angle.

Examples of an aligned setup after tilting of the first mask 31 (dotted pattern fill) along a first axis of rotation are shown in the subsequent figures from different perspectives. Specifically, **Figure 10** shows the apparatus 100 when viewed from the top along the vertical direction 'y'. **Figure 11** shows the same from along the optical axis, more clearly illustrating the tilted mask 30. Lastly, **Figure 12** shows the apparatus 100 from the side along the horizontal direction 'x', emphasizing the 1D signal detector layout.

The described configuration was tested using a raytracing simulation of an Edge Illumination (EI) setup with a first mask having a trapezoidal configuration. **Figure 14** shows a 2D phase-contrast image produced by the simulation produced, obtained at varying resolutions using the same trapezoidal mask configuration. **Figure 15** offers a higher magnification image, focusing on a region of interest centered within Figure 14. The FOV consists of 66x66 pixels, with a rotation angle of 43.71°.

In conclusion, the appropriate tilt angle θ for the mask assembly can be calculated based on known setup parameters. This calculation also allows for the determination of design parameters that optimize the FOV and resolution range. Current phase contrast imaging setups typically have a fixed resolution determined by the first mask. In contrast, the results from the herein described mask assembly demonstrate that it enables phase contrast imaging across a continuous range of resolutions. These results indicate that the first mask design allows for imaging an entire object at a lower resolution and selectively focusing on a region of interest at a higher resolution.

In a second part of the present example, the signal detector 20 is a 2D signal detector consisting of multiple rows of pixels. Examples of an aligned setup after tilting of the first mask 31 (dotted pattern fill) along a second axis of rotation are shown in the subsequent figures from different perspectives. Specifically, **Figure 16** shows the apparatus 100 when viewed from the top along the vertical direction 'y'. **Figure 17** shows the same from along the optical axis. Lastly, **Figure 18** shows the apparatus 100 from the side along the horizontal direction 'x', more clearly illustrating the tilted mask 30. The described configuration was tested using a raytracing simulation of an EI setup with a trapezoidal mask configuration, showing similar results.

In a third part of the present example, an alternative setup is shown after tilting of the signal detector 20 and the second mask 50 in the subsequent figures from different perspectives. Specifically, **Figure 23** shows the apparatus 100 when viewed from the top along the vertical direction 'y'. **Figure 24** shows the same from along the optical axis. Lastly, **Figure 25** shows the apparatus 100 from the side along the horizontal direction 'x', more clearly illustrating the signal detector 20 and the second mask 50.

Example 3

The present example demonstrates how orientational adjustments to the mask assembly described herein affect imaging quality using the same MC simulation setup as discussed above for Example 2. Specifically, the orientation of the first mask 30, positioned between the source 10 and the object 5, is adjusted through tilting the first mask in various directions within the imaging space along the optical axis direction x.

To enable imaging on a two-dimensional detector grid, a trapezoidal mask 30 may be tilted about the mask-stepping axis. This configuration is illustrated in Figs. 16 to 18, which provide a three-view representation of the system incorporating a tilted mask. Specifically, Figure 16 shows a top view of the radiation imaging apparatus 100 along the vertical (y) axis; Figure 17 shows a front view along the optical axis (z); and Figure 18 shows a side view along the transverse (x) direction.

As shown, tilting the gratings allows to align the sample mask for the pixel rows above and underneath the focused row. The tilting angle is thus dependent on the design parameters of the setup, which also determine the FOV and resolution range.

Figure 21 shows the spatial relationships of the setup. Specifically, point A represents the source, points C & D the boundaries of the detector onto which the mask is aligned. Line segments [AD] and [AC] correspond to the outer beamlets. The trapezoidal mask is aligned in point B, and point E represents the intersection between a non-tilted mask, and the most outward beamlet [AD]. When the mask is rotated over an angle θ, point F corresponds the intersection of the tilted mask and the most outward beamlet.

The trapezoidal mask is perfectly aligned in point B. To find the angle θ that aligns the tilted mask in point F, the intersection between the mask (BF) and the outer beamlet (AD), as shown in Figure 21, two expressions are constructed for the mask aperture period in this point F.

The first expression $p_{F1}(\theta)$ defines the mask period required in point F, to comply with the changing magnification when tilting the mask. Point A represents the source, points C & D the boundaries of the detector onto which the mask is aligned. Line segment [AD] correspond to the outer beamlet and [AF] to the line segment between the source point (A) and the point of alignment (F) , as shown in Figure 21. The pixel size p and |AD| are fixed setup parameters.

$$p_{F1}(\theta) = p \cdot \frac{|AF|}{|AD|}$$

The second expression $p_{F2}(\theta)$ is the mask period of the trapezoidal mask that is obtained in point F. By rotating the mask, the intersection point F shifts along AD and BF, resulting in a different period in F on the trapezoidal mask. [BF] corresponds to the line segment between the original aligned point (B) and the point to be aligned by tilting (F), as shown in Figure 21.

$$p_{F2}(\theta) = p_B + |BF| \cdot g.$$

Figure 22 shows the trapezoidal mask and its design parameters. The period in B (p_B) is again determined by the setup and g is a design factor of the trapezoidal mask which defines the diverging of the trapezoidal mask bars. This parameter g is defined as $\frac{p_M - p_m}{h_g}$, with p_M the largest period on the mask, p_m the smallest period on the mask, and h_g the height of the mask, as shown in Figure 22.

The distance |AD| is defined using Pythagoras theorem in the triangle formed by A, D and the center of the segment [DC]. The distance between A and the segment [DC] is the distance between source and detector z, and the length of the segment [DC] is the detector height h.

$$|AD| = \sqrt{z^2 + (h/2)^2}.$$

For the distances |AF| and |BF| we define the coordinates of the point F as the intersection of lines AF and BF in a cartesian system with origin. Point F can be defined as follows:

$$x_F = \frac{z_{ss}h}{2z} \frac{\cot\theta + \frac{h}{2z}}{\cot\theta - \frac{h}{2z}}.$$

$$y_F = z_{ss} \frac{\cot\theta + \frac{h}{2z}}{\cot\theta - \frac{h}{2z}}.$$

With z_{ss} the distance between source and sample mask, or the distance between point A and the line segment [EB].

The distance |AF| is defined as follows:

$$|AF| = \sqrt{x_F^2 + y_F^2}$$

$$= \sqrt{\left(z_{ss}\frac{\cot\theta + \frac{h}{2z}}{\cot\theta - \frac{h}{2z}}\right)^2 + \left(\frac{z_{ss}h}{2z}\frac{\cot\theta + \frac{h}{2z}}{\cot\theta - \frac{h}{2z}}\right)^2}$$

$$= \frac{z_{ss}}{2z\cot\theta - h}\sqrt{(2z\cot\theta + h)^2 + \frac{h^2}{z^2}(2z\cot\theta + h)^2}$$

$$= \frac{z_{ss}}{z}\frac{2z\cot\theta + h}{2z\cot\theta - h}\sqrt{\left(\frac{h}{2}\right)^2 + z^2}.$$

To calculate the distance |BF|, point B is define as follows:

$$x_B = z_{ss}.$$

$$y_B = \frac{hz_{ss}}{2z}.$$

The distance |BF| is defined as follows:

$$|BF| = \sqrt{(x_F - x_B)^2 + (y_B - y_F)^2}$$

$$= \sqrt{\frac{\left(\cot\theta\ z_{ss} + \frac{h\,z_{ss}}{2\,z}\right)^2}{\left(\cot\theta - \frac{h}{2\,z}\right)^2} + \frac{h^2\left(\cot\theta\ z_{ss} + \frac{h\,z_{ss}}{2\,z}\right)^2}{4\,z^2\left(\cot\theta - \frac{h}{2\,z}\right)^2}}$$

$$= \sqrt{\left(\frac{\cot\theta\ z_{ss} + \frac{h\,z_{ss}}{2\,z}}{\cot\theta - \frac{h}{2\,z}}\right)^2}\sqrt{\frac{4z^2 + h^2}{h^2}}$$

$$= \frac{z_{ss}}{h}\frac{2z\cot\theta + h}{2z\cot\theta - h}\sqrt{4z^2 + h^2}.$$

To complete the expression, p_B is defined as follows: $p_B = \frac{pz_{ss}}{z}$.

The appropriate angle to align the mask can then be computed by solving the equation $p_{F1}(\theta) = p_{F2}(\theta)$.

$$p_{F1}(\theta) = p_{F2}(\theta)$$

$$\Rightarrow p \cdot \frac{|AD|}{|AF|} = p_B - |BF| \cdot g$$

$$\Rightarrow p \cdot \frac{\frac{z_{ss}}{z}\frac{2z\cot\theta + h}{2z\cot\theta - h}\sqrt{\left(\frac{h}{2}\right)^2 + z^2}}{\sqrt{z^2 + (h/2)^2}} = \frac{pz_{ss}}{z} - \frac{z_{ss}}{h}\frac{2z\cot\theta + h}{2z\cot\theta - h}\sqrt{4z^2 + h^2} \cdot g$$

$$\Rightarrow \frac{p}{z}\frac{2z\cot\theta + h}{2z\cot\theta - h} = \frac{p}{z} - \frac{g}{h}\frac{2z\cot\theta + h}{2z\cot\theta - h}\sqrt{4z^2 + h^2}$$

$$\Rightarrow \frac{p}{z}(2z\cot\theta + h) = \frac{p}{z}(2z\cot\theta - h) - \frac{g}{h}(2z\cot\theta + h)\sqrt{4z^2 + h^2}$$

$$\Rightarrow \frac{2ph}{z} = -\frac{g}{h}(2z\cot\theta + h)\sqrt{4z^2 + h^2}$$

$$\Rightarrow 2z\cot\theta + h = -\frac{2ph^2}{gz\sqrt{4z^2+h^2}}$$

$$\Rightarrow \theta = \cot^{-1}\left(-\frac{\frac{2ph^2}{gz\sqrt{4z^2+h^2}}+h}{2z}\right) = \cot^{-1}\left(-\frac{2ph^2+hgz\sqrt{4z^2+h^2}}{2gz^{2\sqrt{4z^2+h^2}}}\right)$$

With z the perpendicular distance between source and detector and h the detector height, |DC| in Figure 21. The previous equation allows to calculate tilt angle leading to the geometry depicted in Figures 16-18, based on setup parameters g, h, p and z_{sd}.

Example 4

An EI radiograph of a test phantom was simulated using the GATE simulation framework.

Figure 26 schematically shows the simulation setup, including the phantom geometry and imaging configuration. The test phantom consisted of an ellipsoidal volume containing triplets of cylinders with diameters ranging from 10 µm to 50 µm.

To capture radiographs at multiple magnification levels, the grating was positioned at different locations along the optical axis. At each position, the grating was vertically translated and tilted to match the FOV with a 66 × 66 pixel detector grid.

Figure 27 presents the resulting differential phase contrast radiographs at five magnification levels, shown in panels A to E. The grey level of each pixel corresponds to the measured differential phase contrast, ranging from -2.4×10^{-6} (black) to 2.3×10^{-6} (white). As the magnification increases from panel A to panel E, finer details within the phantom become more visible, demonstrating the system's capacity for multi-resolution imaging.

Example 5

An edge-illumination X-ray computed tomography (EIXCT) simulation was performed using a trapezoidal grating. Unlike previous Examples 1-4, this simulation was conducted using the CAD-ASTRA toolbox. As only a single axial slice was simulated, the trapezoidal grating was not tilted.

Figure 28 schematically illustrates the simulation setup, including the phantom geometry and imaging configuration. The test phantom consisted of groups of five cylinders with diameters ranging from 8 µm to 80 µm.

The detector was modeled as a single row of 50 pixels, resulting in a FOV varying from 6.7 mm × 6.7 mm at the lowest magnification (M = 1.12) to 2.5 mm × 2.5 mm at the highest magnification (M = 3).

For each magnification level, 150 projection angles were simulated. The resulting differential phase contrast projections were integrated and reconstructed using filtered back-projection with the iradon function in MATLAB. Given the low noise level in the CAD-ASTRA framework, a Ram-Lak filter with linear interpolation was applied.

Figure 30 shows the reconstructed phase contrast images of the cylinder phantom at eleven magnification levels, ranging from M = 1.12 up to M = 3.0. Each image corresponds to a distinct magnification setting. Pixel gray values represent phase contrast, varying from -1.0×10^{-4} (black) to 2.5×10^{-4} (white). Arrows indicate equivalent groups of cylinders across the different magnifications to guide the eye. The smallest cylinders are only resolved at higher magnifications, while lower magnifications offer a larger FOV. These results illustrate how the proposed imaging approach enables multi-resolution imaging, allowing the user to select the optimal trade-off between FOV and spatial resolution.

Example 6

An EIXCT simulation was performed using a trapezoidal grating, employing a simulation setup using the CAD-ASTRA toolbox identical to that described in Example 5.

Figure 29 schematically shows the simulation setup, including the phantom geometry and imaging configuration The test phantom consisted of a metal screw.

Figure 31 shows the resulting phase contrast reconstructions of the screw at four different magnification levels (panels A–D). The FOV ranges from 6.7 mm × 6.7 mm at the lowest magnification (panel A) to 2.5 mm × 2.5 mm at the highest magnification (panel D). The grey level of each pixel corresponds to the phase contrast, varying between -1.3×10^{-4} (black) and 3.2×10^{-4} (white). A visible background pattern results from the limited number of sampling rays used in the CAD-ASTRA simulation.

At the lowest magnification (M = 1.28), the entire screw is captured within the FOV, but screw threads are not resolved due to limited spatial resolution. As the magnification increases from panel A to panel D, the screw threads become progressively more visible and sharply defined, demonstrating the system's capability to resolve fine structural features. These results demonstrate the system's capacity for multi-resolution imaging.

CLAIMS

1. A radiation imaging apparatus (100) for phase-contrast imaging of an object (5), the apparatus comprising:
- an image signal generation system comprising at least one X-ray source (10) configured to generate a radiation beam (11) and at least one image signal detector (20) comprising a plurality of pixels configured for detecting an image signal generated by the radiation irradiated from the X-ray source;
- a mask assembly comprising at least a first mask (30) configured to split the radiation beam (11) into a plurality of radiation beamlets (12);
- an object stage (42) extending in an optical axis direction of the radiation beam (11), the object stage being configured to adjust a position of the object to correspond to a predetermined imaging magnification;

characterized in that
- the first mask (30) comprises a body with a plurality of X-ray absorbing elements (31) and apertures (32) arranged in a manner that gradually diverges from one portion to an opposite portion of the body, resulting in a variable pitch in a first direction substantially perpendicular to the optical axis direction; and,
- the mask assembly further comprises a mask alignment mechanism (40) configured to adjust a position of the first mask (30) along the optical axis direction to match the predetermined imaging magnification, and to further adjust a position and/or orientation of the first mask (30) substantially along the first direction, so as to align the variable pitch of the first mask (30) with the image signal detector (20) for phase-contrast imaging.

2. The apparatus (100) according to claim 1, wherein the body of the first mask (30) comprises a plurality of elongated bars arranged in a trapezoidal configuration, whereby the bars diverge linearly from one portion to the opposite portion of the first mask.
3. The apparatus (100) according to any one of the preceding claims, wherein a rate of divergence of the first mask (30) is between 0.005 m/m and 0.0001 m/m; defined as the difference between a highest and a lowest period, divided by the height.
4. The apparatus (100) according to any one of the preceding claims, wherein the variable pitch of the first mask (30) ranges from at least 30 µm at one portion to at most 120 µm at the opposite portion of the first mask.
5. The apparatus (100) according to any one of the preceding claims, wherein the mask assembly further comprises a second mask (50) arranged between the first mask (30) and the image signal

detector (20), wherein the second mask (50) comprises a body with a periodically spaced arrangement of X-ray absorbing elements and apertures resulting in a fixed pitch; and

optionally, wherein the mask alignment mechanism (40) is further configured to adjust the first mask (30) to align the variable pitch of the first mask (30) with the fixed pitch of the second mask (50).

6. The apparatus (100) according to any one of the preceding claims, wherein the mask alignment mechanism (40) is configured to adjust the first mask (30) responsive to the image signal, preferably by adjusting the separation between the radiation beamlets (12) split by the first mask (30) to match the dimensions of the pixels of the image signal detector (20), such that each radiation beamlet (12) irradiates a predetermined set of pixels, resulting in a substantially Gaussian profile for the image signal.
7. The apparatus (100) according to any one of the preceding claims, wherein the mask alignment mechanism (40) is configured for rotating and/or tilting the first mask (30) to adjust a field of view; wherein the rotation angle is between at least 1 and at most 50 degrees.
8. The apparatus (100) according to any one of the preceding claims, wherein the mask alignment mechanism (40) comprises a mask stage (41) moveably driven by a drive unit, preferably wherein the mask stage (41) comprises a moveably arranged platform or a suspension for the first mask (30).
9. The apparatus (100) according to any one of the preceding claims, wherein the mask alignment mechanism (40) is moveably coupled to the object stage (42), allowing the positional adjustment of the object (5) to be synchronized with the positional adjustment of the first mask (30).
10. The apparatus (100) according to any one of the preceding claims, wherein the object stage (52) and the first mask (30) are operatively coupled to an integrated moving mechanism, wherein the integrated moving mechanism is configured for simultaneously moving the object and the first mask along the optical axis direction.
11. A method of phase-contrast imaging for examining an object (5) with the radiation imaging apparatus (100) according to any one of the preceding claims, comprising the steps of:

- providing the object (5);
- adjusting a position of the object (5) along an optical axis direction to correspond with a predetermined imaging magnification;
- adjusting a position of a first mask (30) along the optical axis direction to match the predetermined imaging magnification;
- further adjusting the position and/or orientation of the first mask (30) along a first direction substantially perpendicular to an optical axis direction, so as to align the variable pitch of the first mask (30) with the image signal detector (20) for phase-contrast imaging, preferably by adjusting

the separation between the radiation beamlets (12) split by the first mask (30) to match the dimensions of the pixels of the image signal detector (20); and

- acquiring one or more images by emitting radiation from a radiation source (10), directed through the first mask (30), and detecting an image signal based on the emitted radiation on the image signal detector (20) for phase contrast imaging.

12. The method of claim 12, wherein the object (5) is a produced item, food product, medical device, pharmaceutical, electronic device, fiber-containing polymers, tissues, and/or luggage.

13. A mask assembly for a radiation phase-contrast imaging apparatus (100), comprising:

- a first mask (30) comprising a plurality of X-ray absorbing elements (31) and apertures arranged in a manner that gradually diverges from one portion to an opposite portion of the body, resulting in a variable pitch in a first direction substantially perpendicular to an optical axis direction of the radiation phase-contrast imaging apparatus (100); and,
- a mask alignment mechanism (40) configured to adjust the position of the first mask (30) along the optical axis direction of the radiation phase-contrast imaging apparatus (100) to match a predetermined imaging magnification, and to further adjust a position and/or orientation of the first mask (30) along the first direction, so as to align the variable pitch of the first mask (30) for phase-contrast imaging.

14. The mask assembly according to claim 13, wherein the body of the first mask (30) comprises a plurality of elongated bars arranged in a trapezoidal configuration, whereby the bars diverge linearly from one portion to the opposite portion of the first mask.

15. The mask assembly according to any one of claims 13 or 14, further comprising a second mask (50) comprising a body with a periodically spaced arrangement of X-ray absorbing elements and apertures resulting in a fixed pitch, wherein the mask alignment mechanism (40) is further configured to adjust the first mask (30) to align the variable pitch of the first mask (30) with the fixed pitch of the second mask (50).

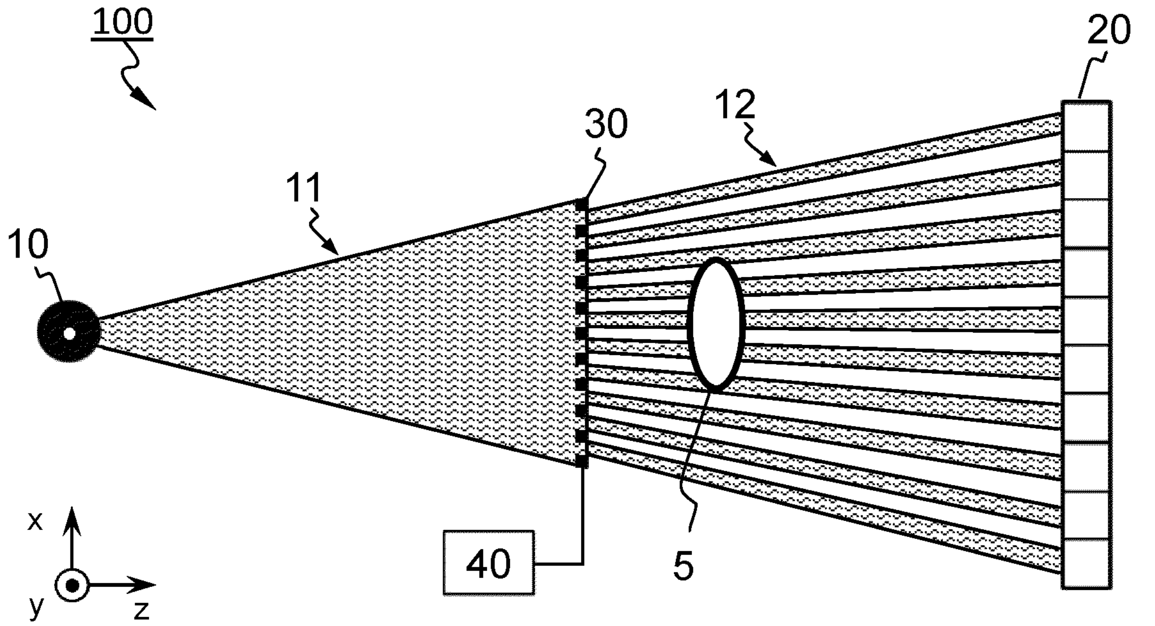

FIG. 1

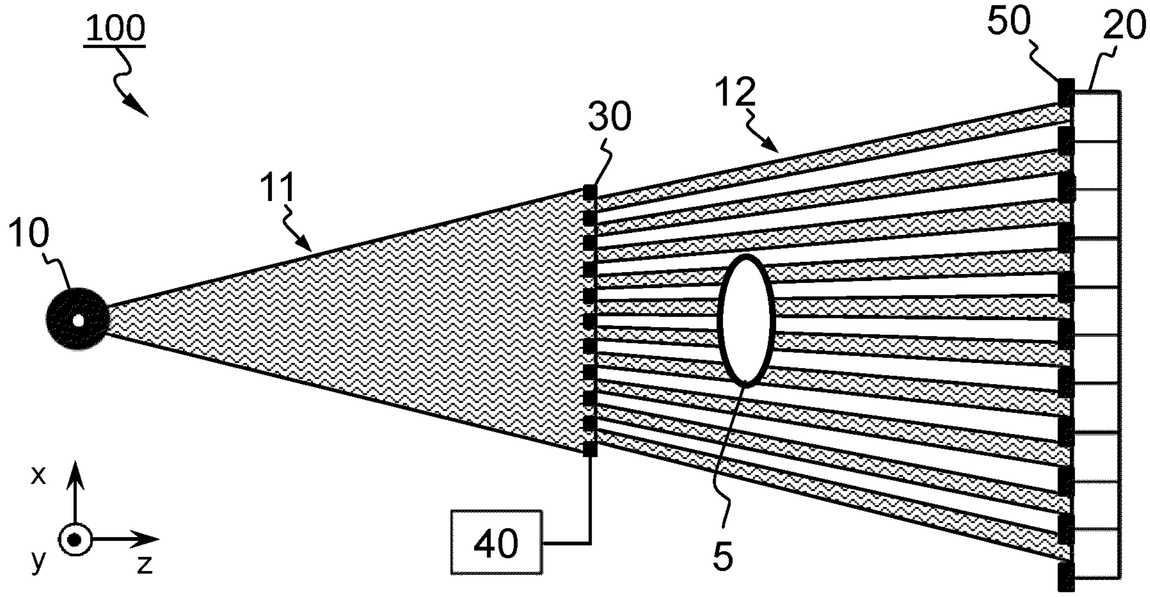

FIG. 2

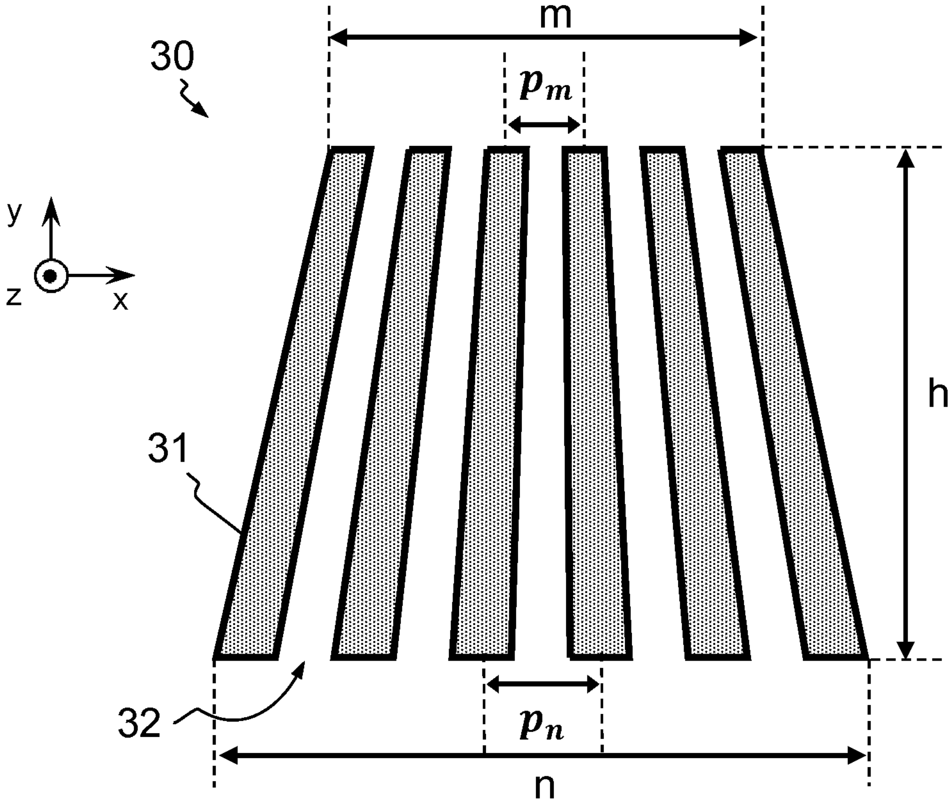

FIG. 3

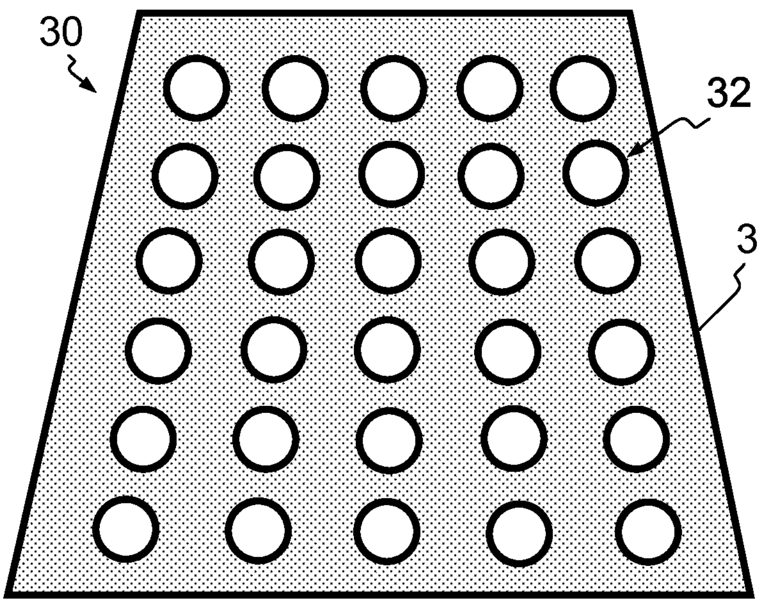

FIG. 4

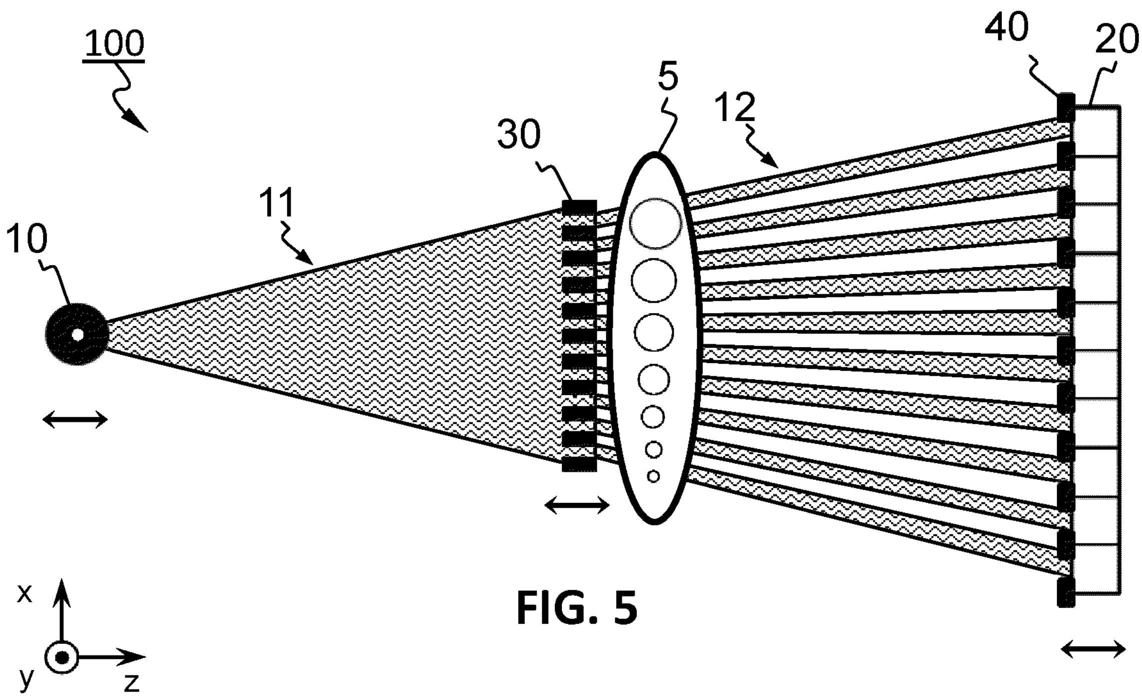

FIG. 5

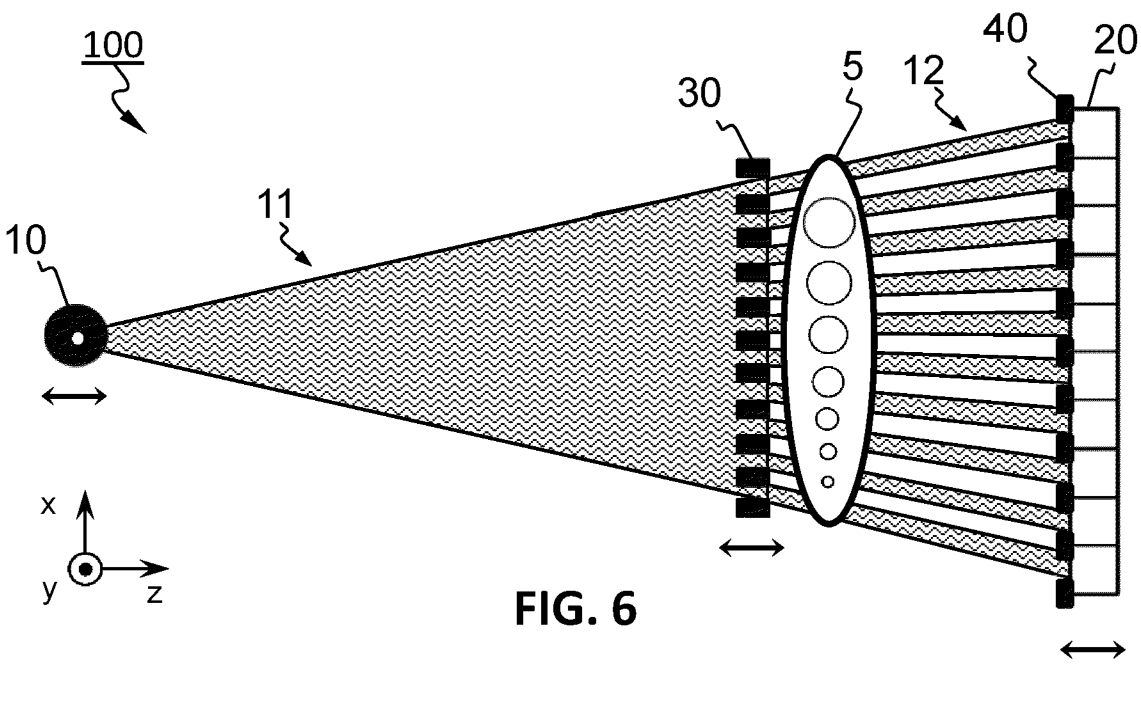

FIG. 6

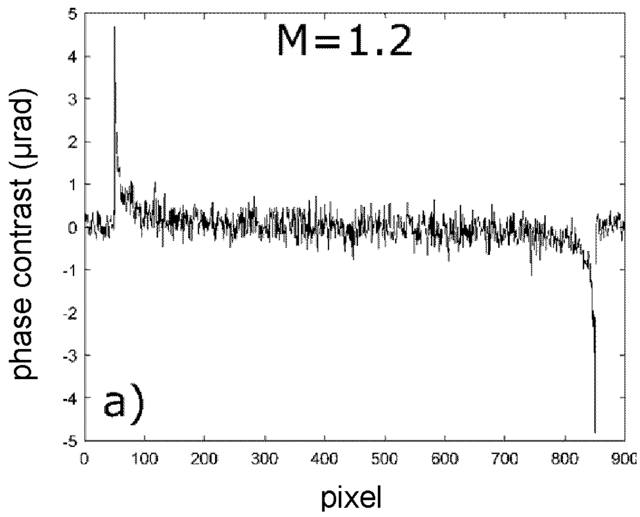

FIG. 7

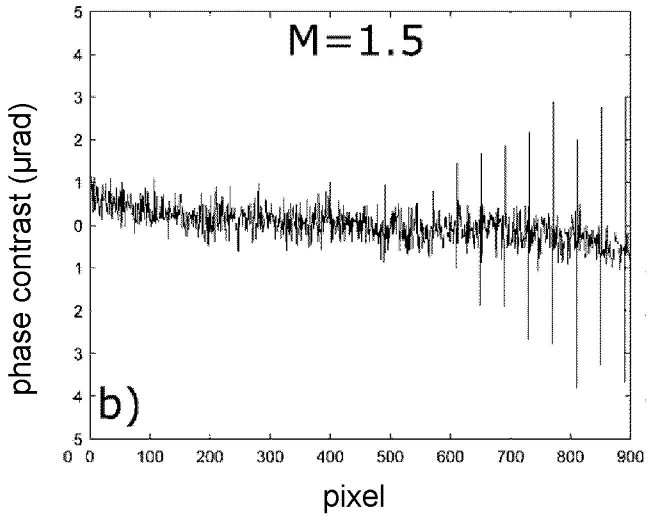

FIG. 8

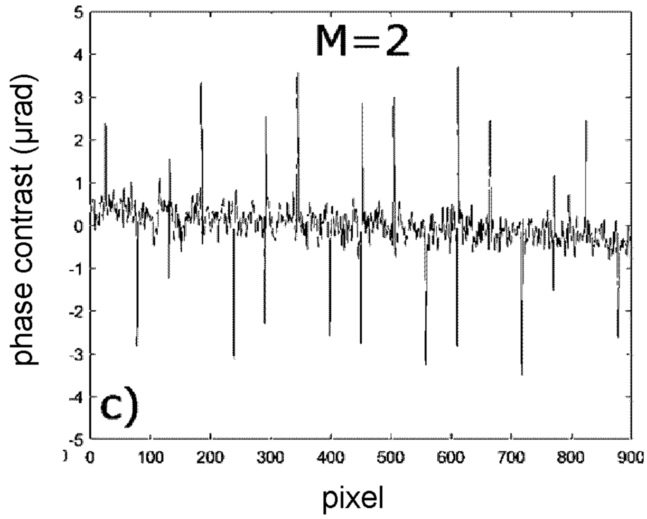

FIG. 9

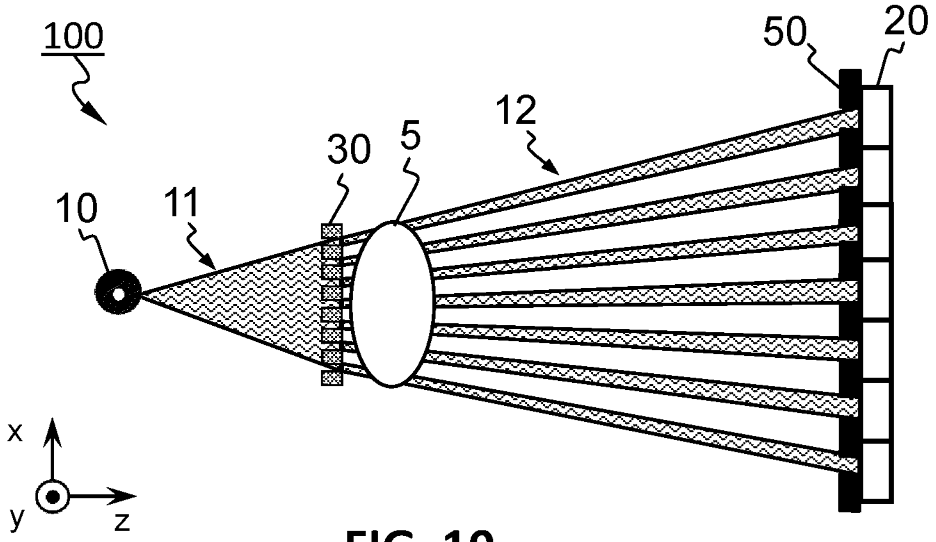

FIG. 10

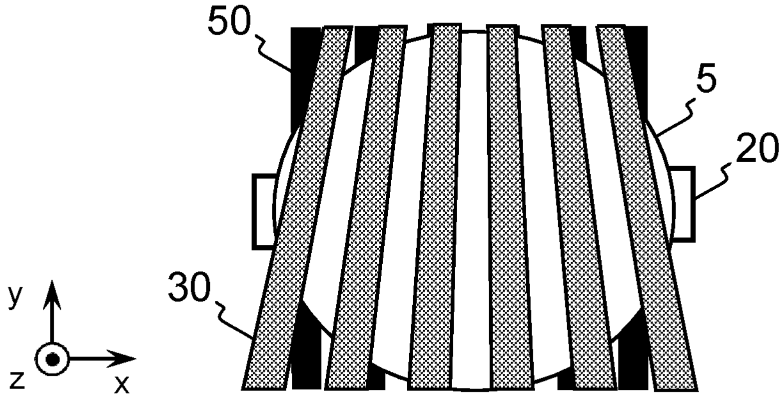

FIG. 11

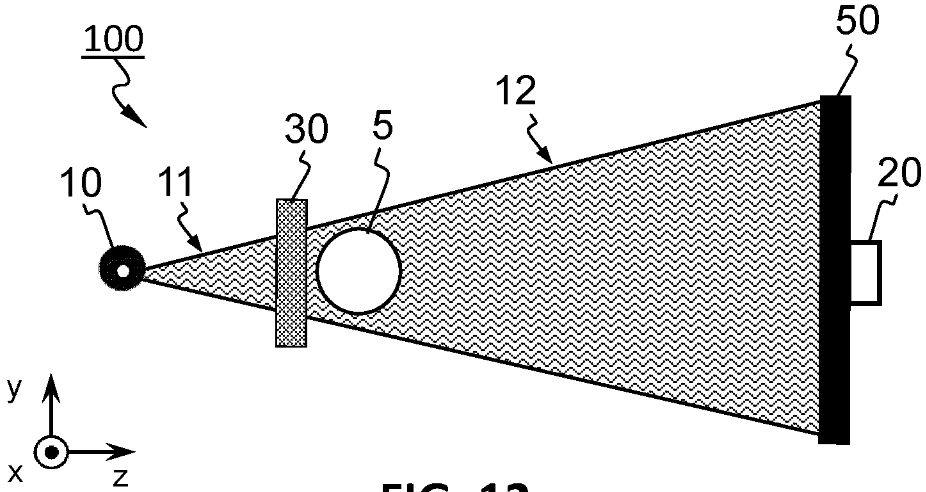

FIG. 12

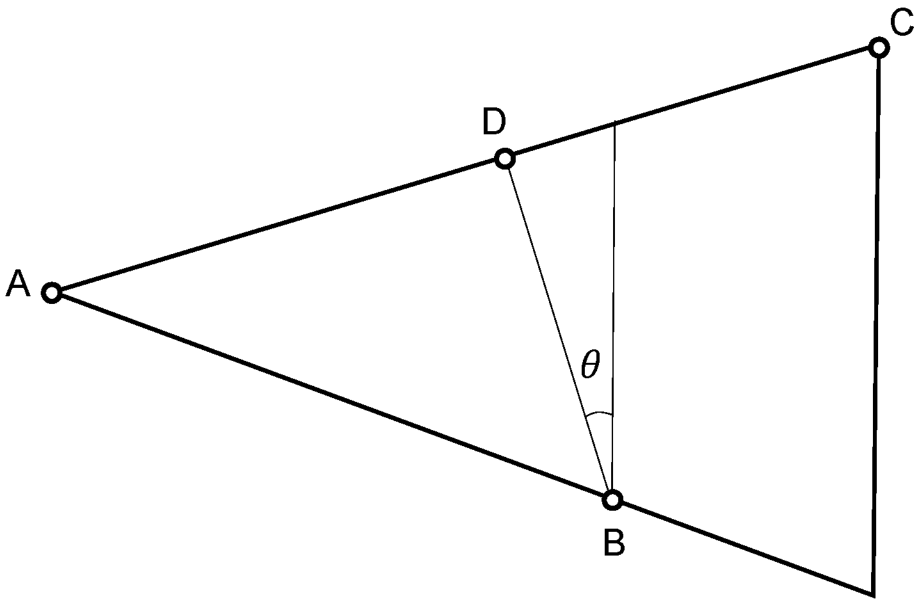

FIG. 13

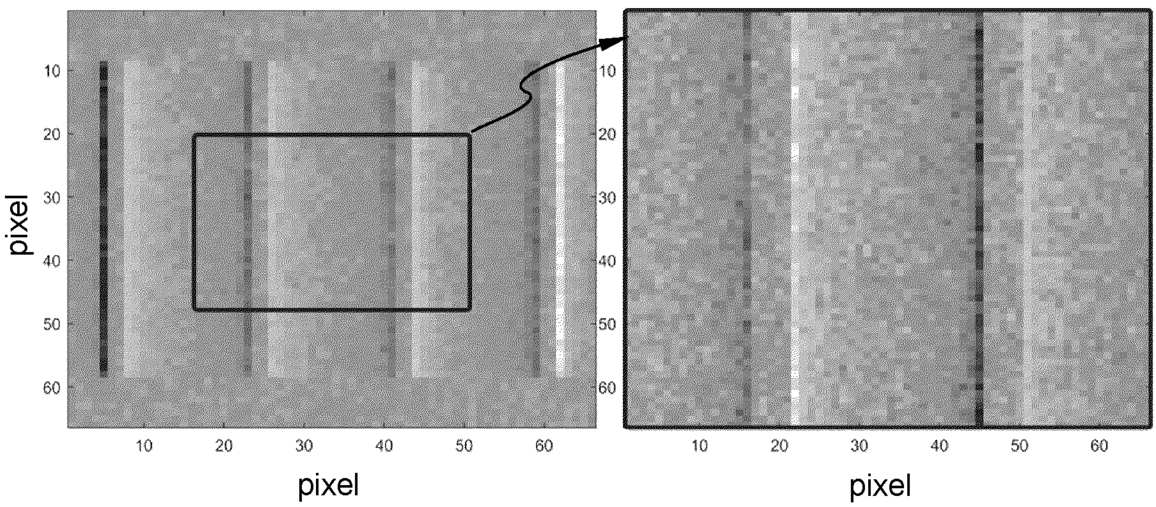

FIG. 14

FIG. 15

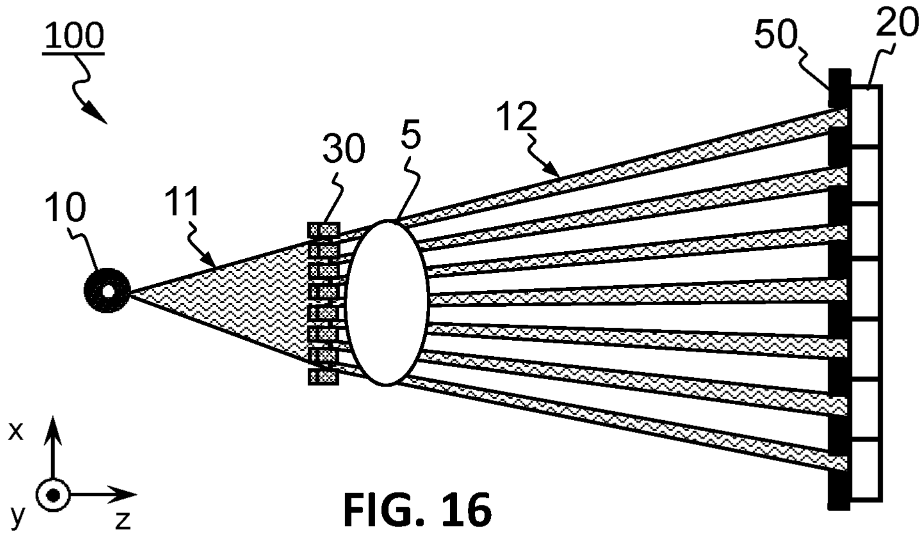

FIG. 16

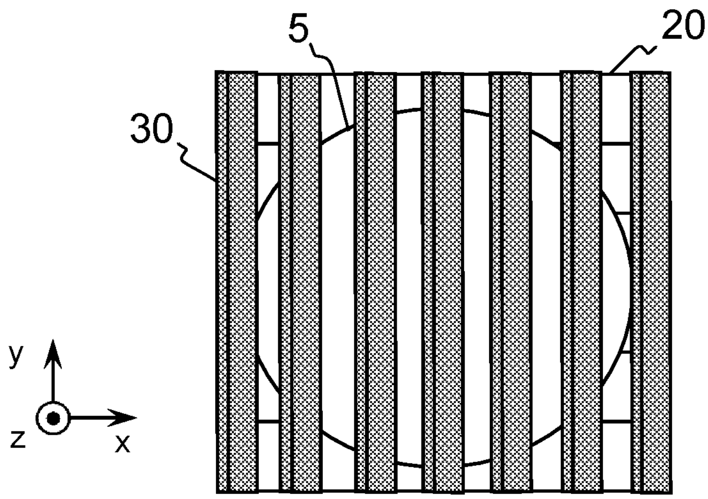

FIG. 17

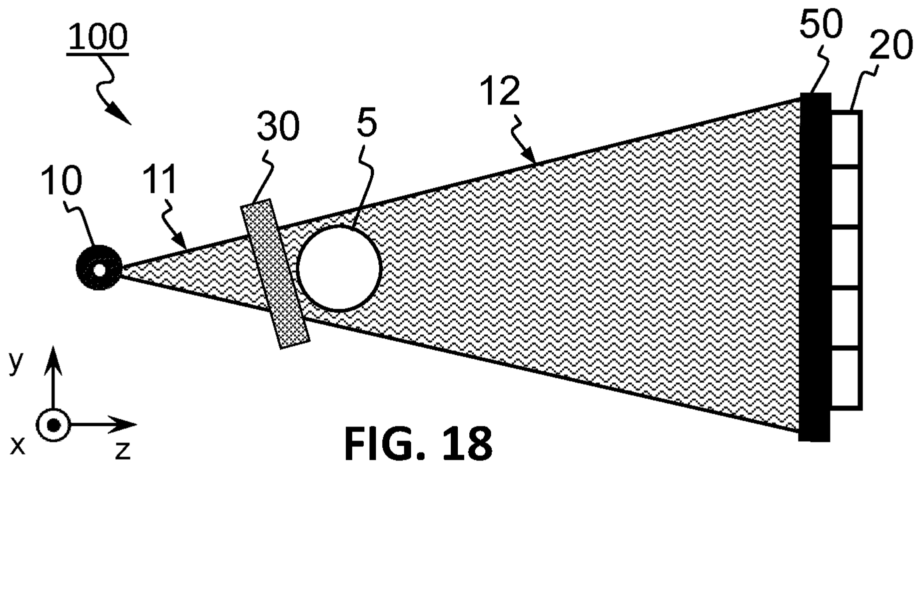

FIG. 18

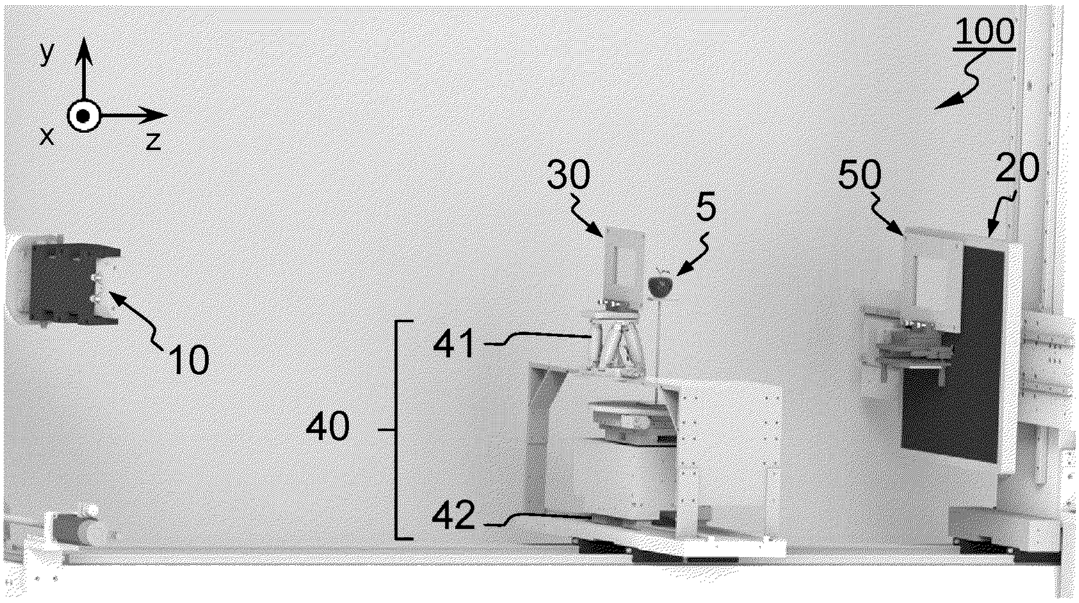

FIG. 19

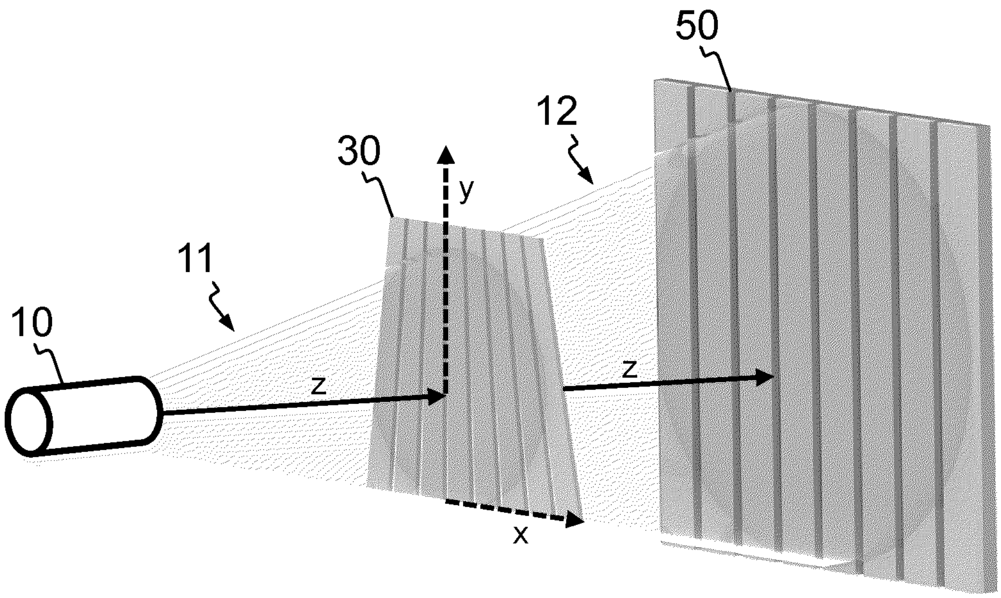

FIG. 20

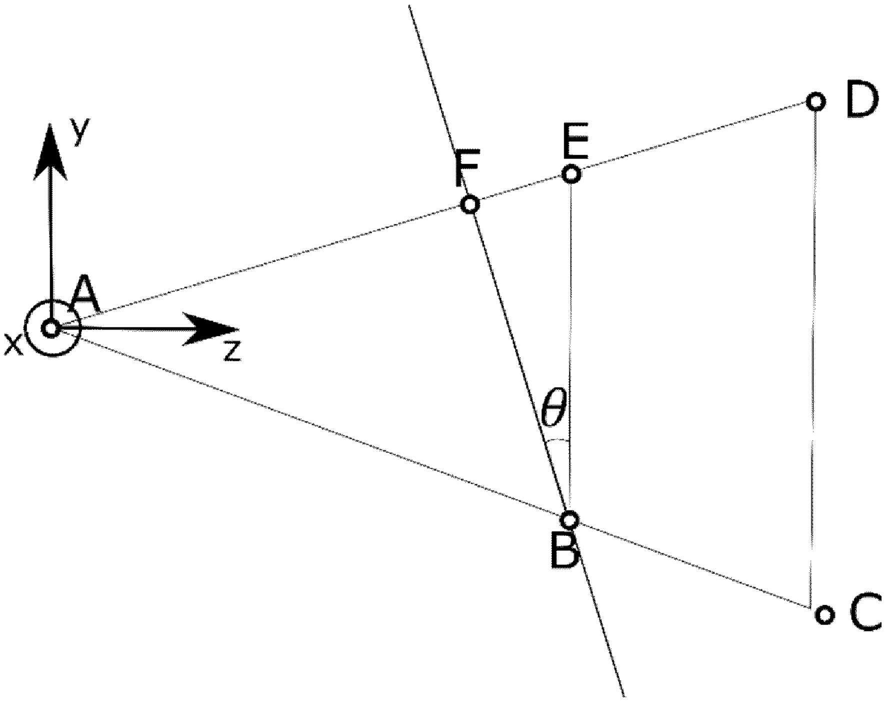

FIG. 21

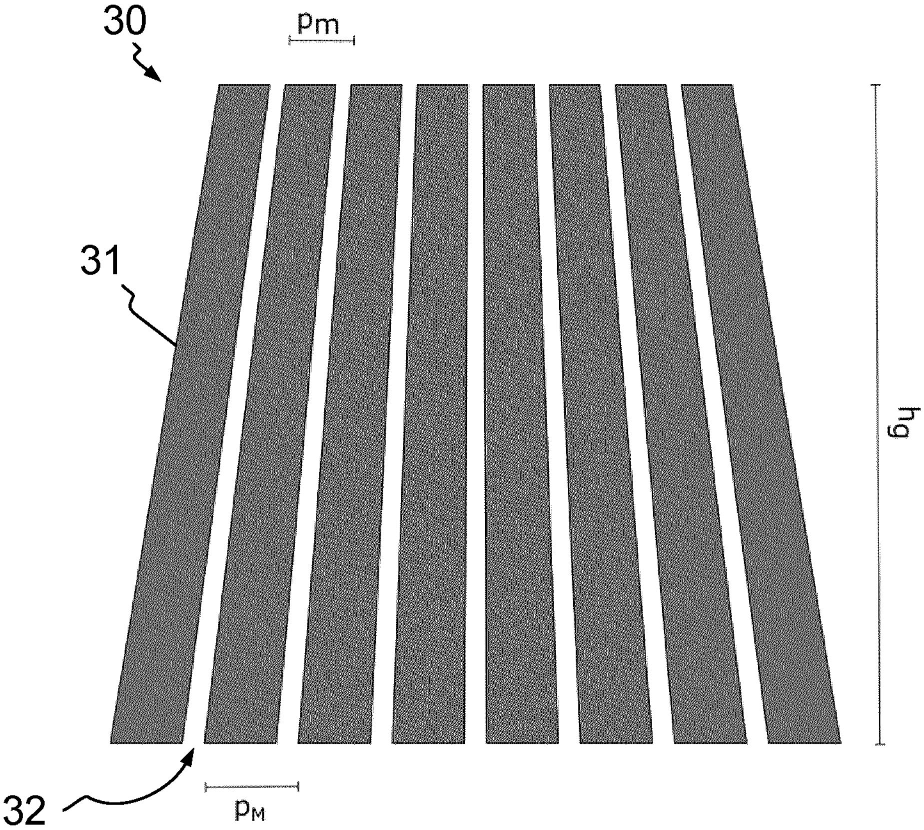

FIG. 22

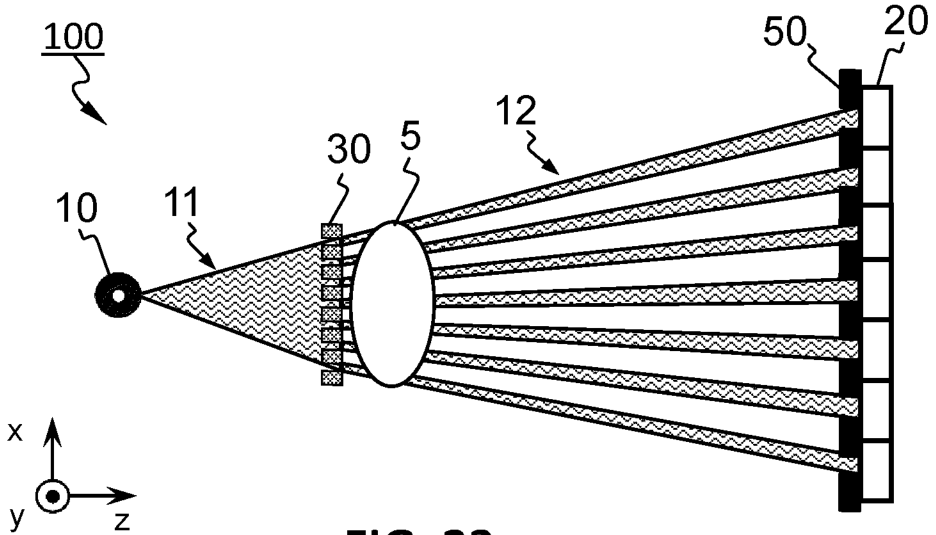

FIG. 23

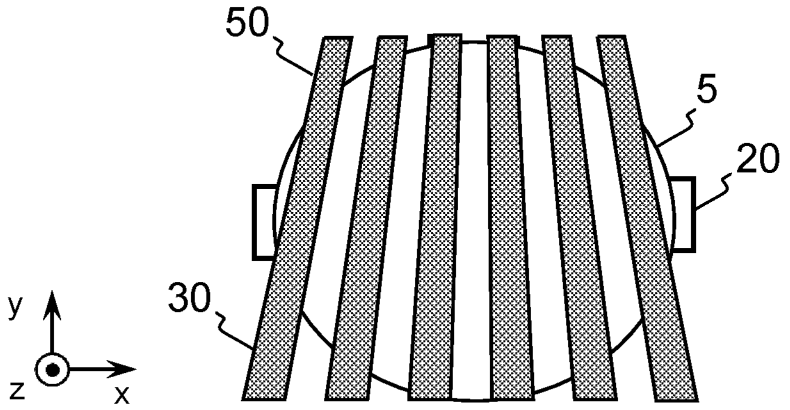

FIG. 24

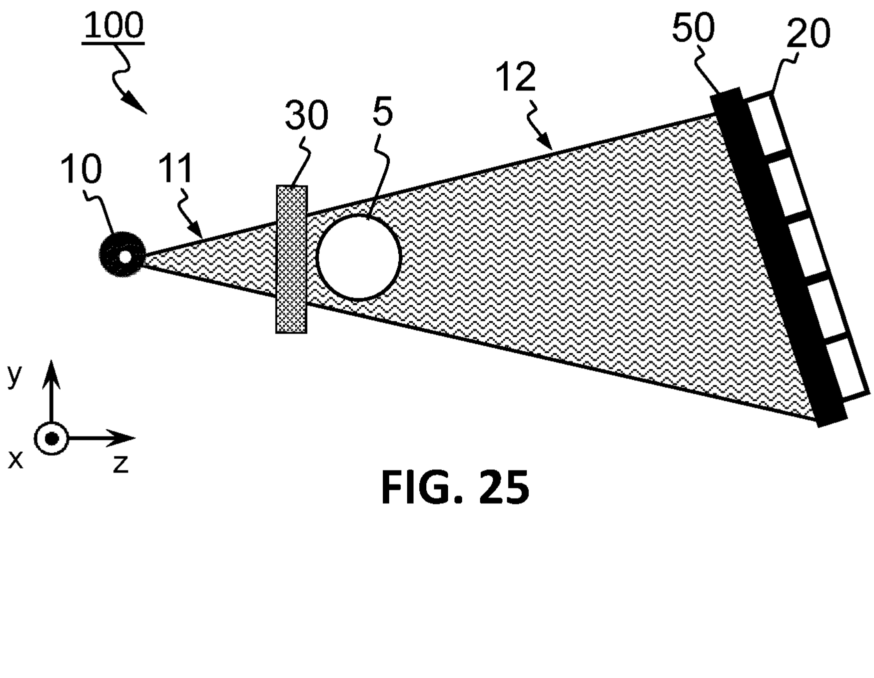

FIG. 25

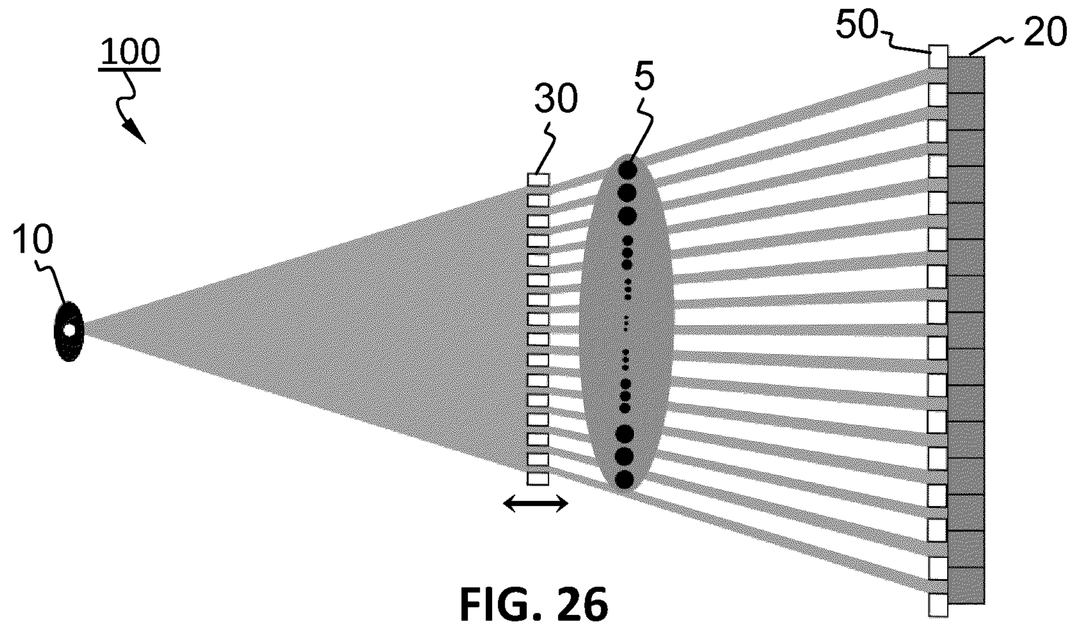

FIG. 26

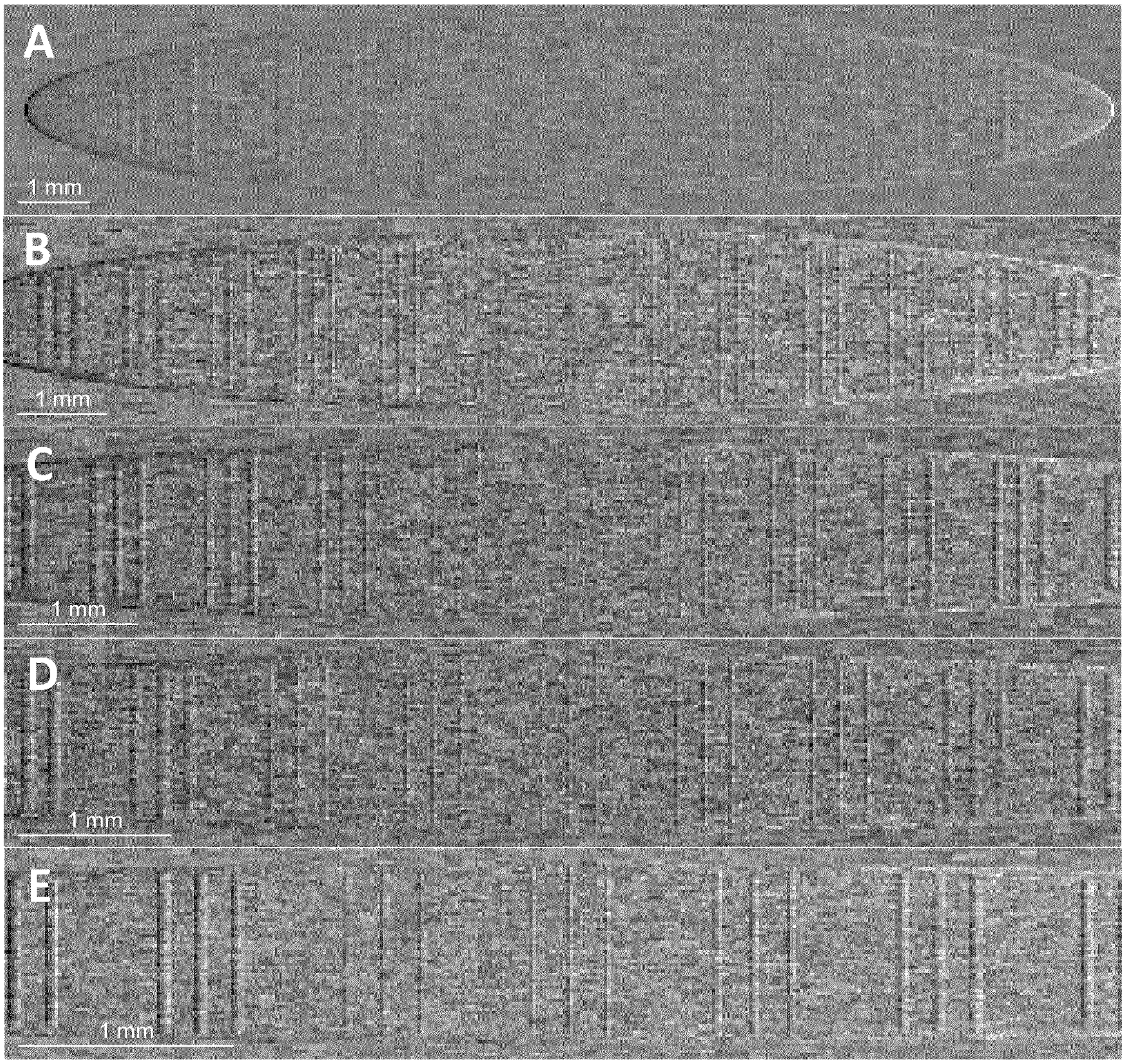

FIG. 27

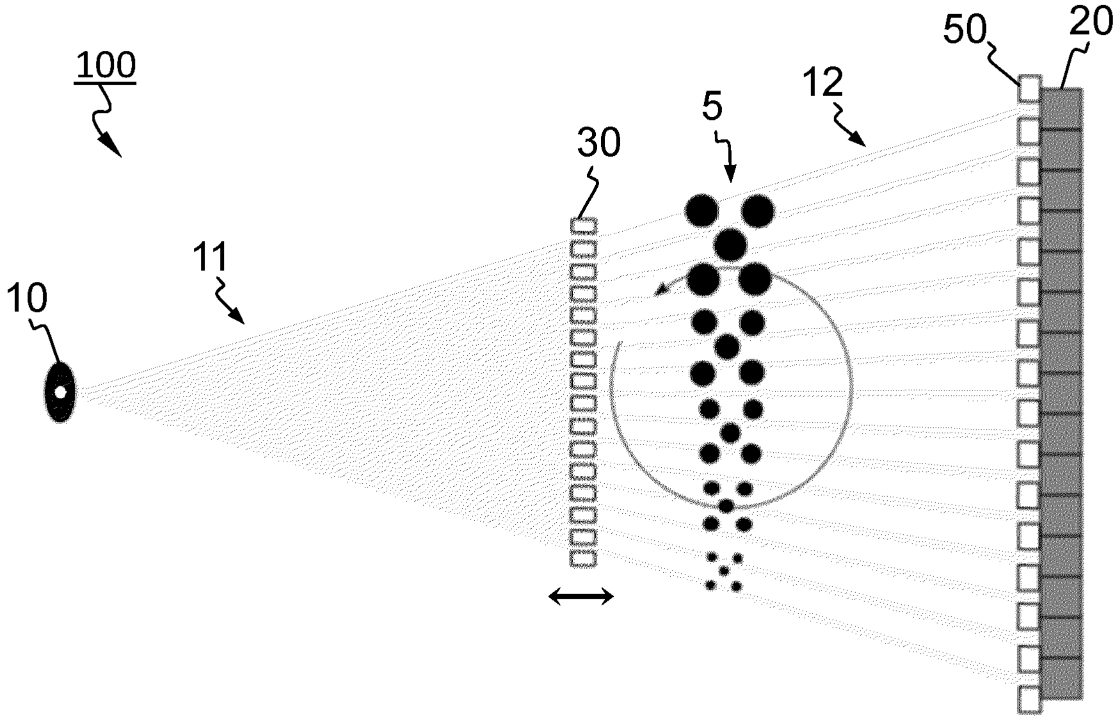

FIG. 28

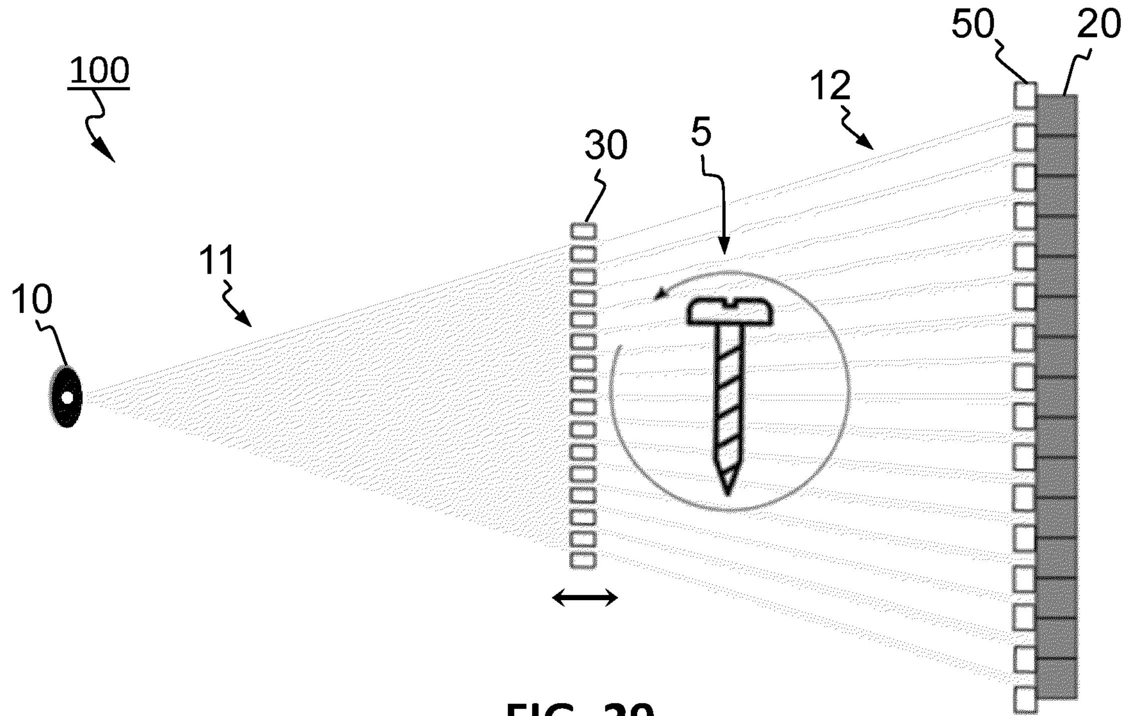

FIG. 29

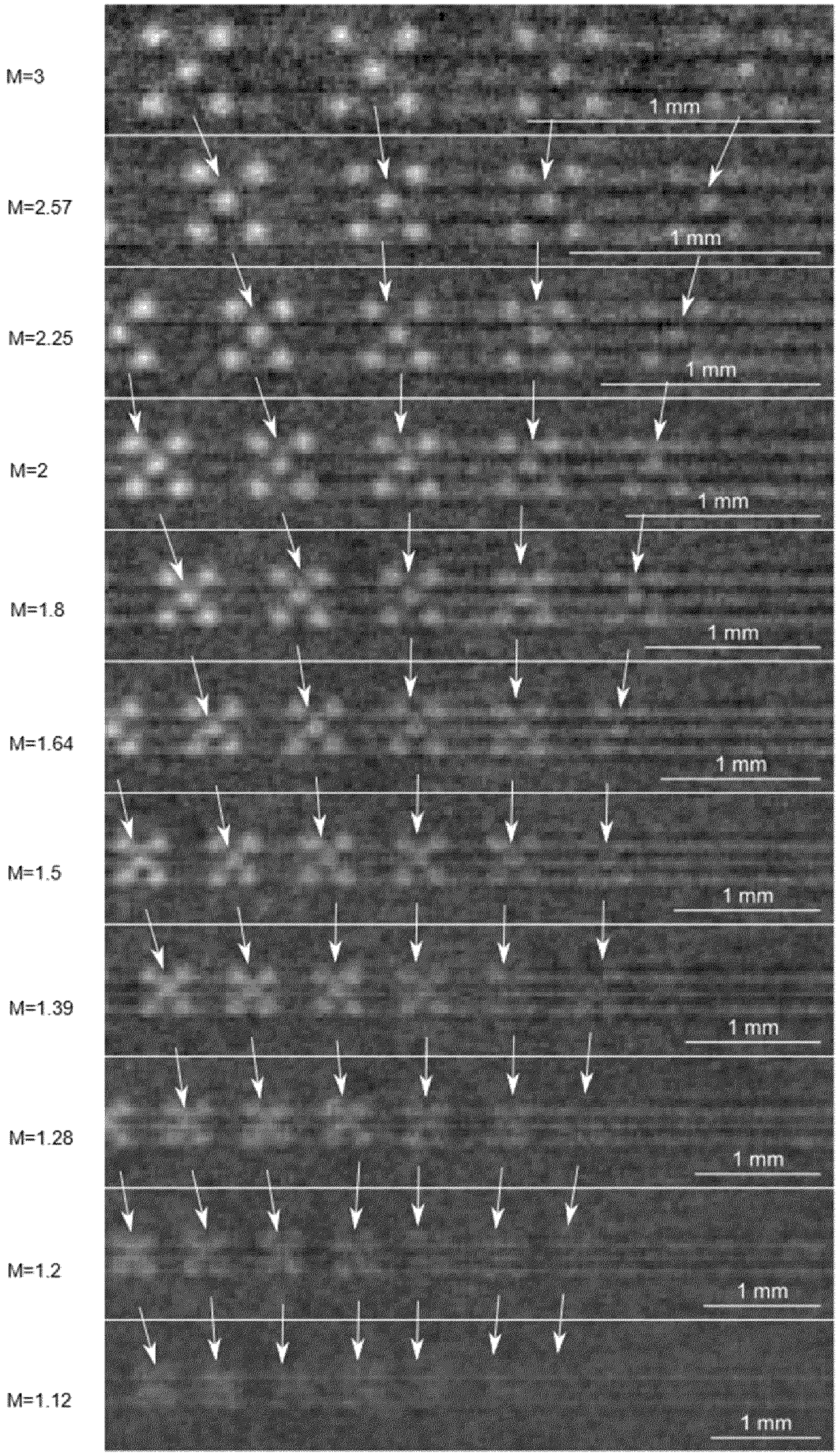
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FIG. 30

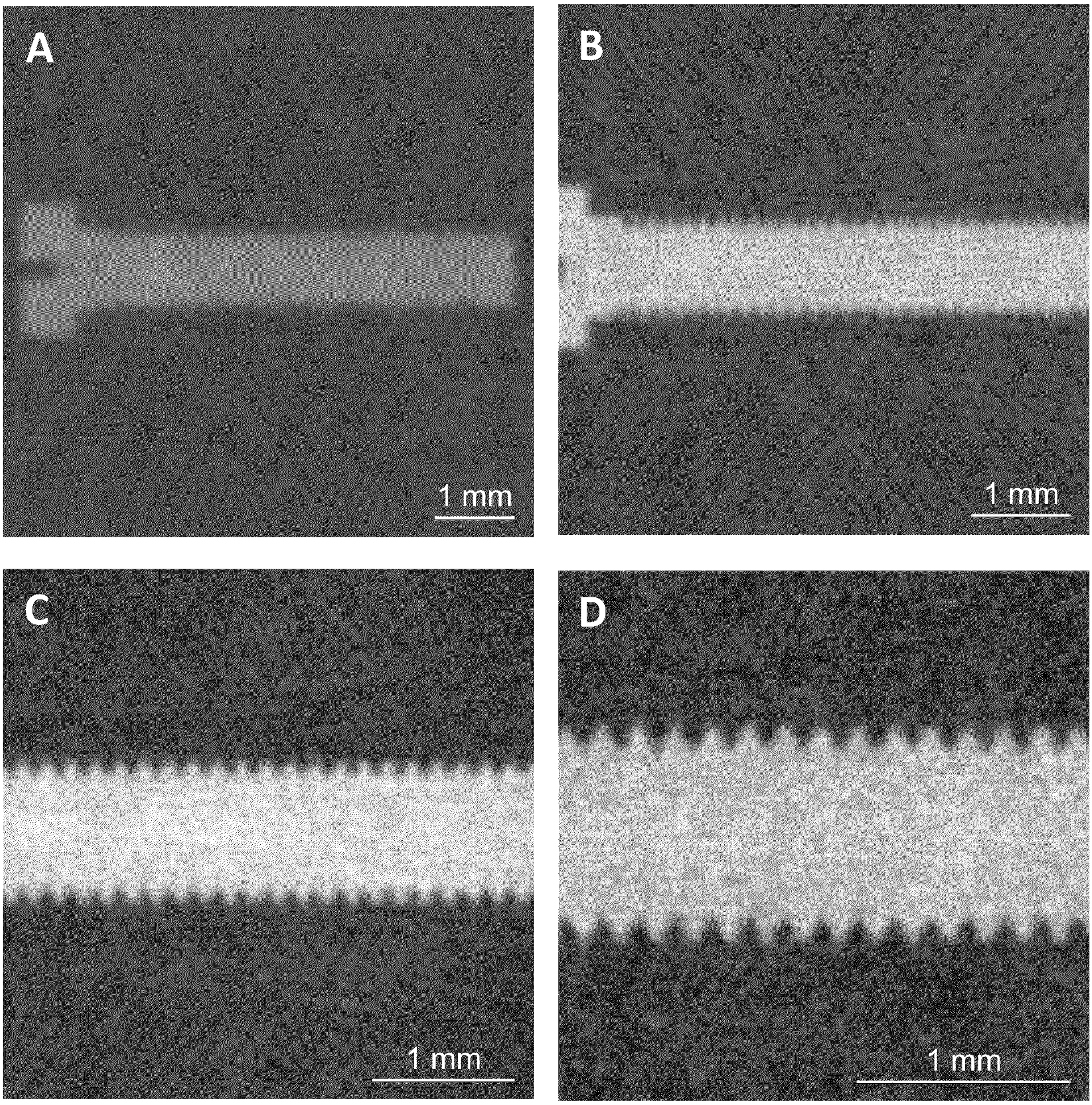

FIG. 31

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2025/062978

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N23/041 A61B6/00 G02B5/18 G21K1/06 G21K7/00
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)
G01N H05G A61B G02B G21K

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2011 153869 A (CANON KK) 11 August 2011 (2011-08-11) paragraph [0018] - paragraph [0023]; figures 1-8	1-15
A	EP 3 545 843 A1 (AGFA NV [BE]) 2 October 2019 (2019-10-02) paragraph [0030] - paragraph [0043]	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date
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"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
20 June 2025	02/07/2025

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Stavroulakis, E

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2025/062978

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2011153869 A	11-08-2011	JP 5578868 B2	27-08-2014
		JP 2011153869 A	11-08-2011
EP 3545843 A1	02-10-2019	NONE	