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(54) **Title:** METHOD AND SYSTEM FOR EVALUATING A VARIATION IN A PARAMETER OF A PATTERN
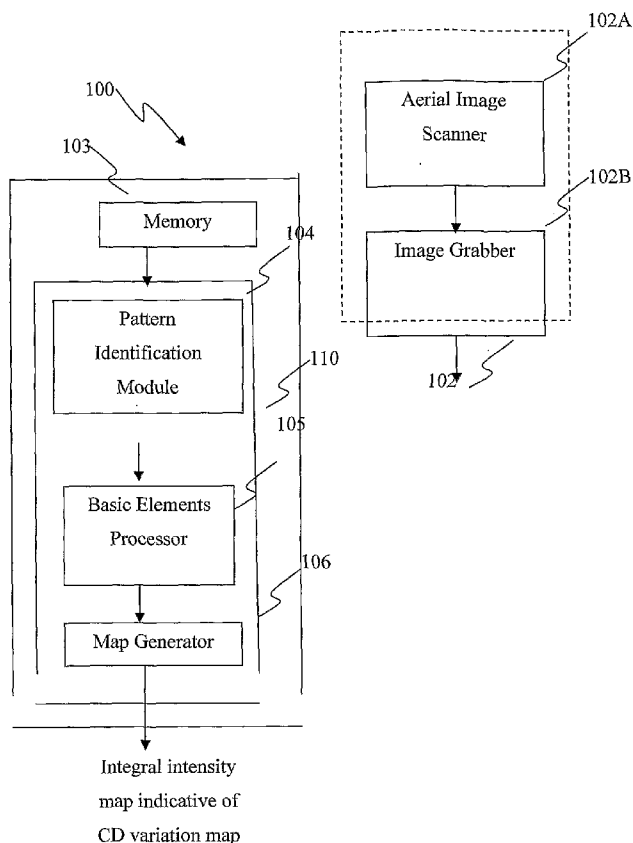
(57) **Abstract:** A method and system are presented for evaluating a variation of a parameter of a pattern , the method includes: processing data indicative of an aerial intensity image of at least a portion of a patterned article, and determining values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of a variation of at least one parameter of the pattern within said at least portion of the patterned article or of a variation of at least one parameter of a pattern manufactured by utilizing the patterned article.

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# METHOD AND SYSTEM FOR EVALUATING A VARIATION IN A PARAMETER OF A PATTERN

## FIELD OF THE INVENTION

5       This invention is generally in the field of automatic optical inspection of patterned articles, such as semiconductor wafers, printed circuit boards and reticles (also referred to as lithography masks),.

## BACKGROUND OF THE INVENTION

10      The performance of micro-electronic devices has always been limited by the variations found in the dimensions of their critical features, termed *critical dimensions or CD*. Micro-electronic devices are often manufactured using masks (or reticles) in a photolithography process. The latter is one of the principal processes in the manufacture of semiconductor devices, and consists of patterning the wafer's surface in accordance with the circuit design of the semiconductor devices to be produced. Such a circuit design is first patterned on a mask. Hence, in order to obtain operating semiconductor devices, the mask must be defect free. Moreover, the mask is often used in a repeated manner to create many dies on the wafer. Thus, any defect on the mask will be repeated multiple times on the wafer and will cause multiple devices to be defective. Establishing a production-worthy process requires tight control of the overall lithography process. Within this process, CD control is a determining factor with respect to device performance and yield.

        When the critical dimensions are large, systematic variations in the dimensions of the device, such as those caused by material physics or as a result of equipment or the production process, do not make large contributions to the overall error budget and can therefore be largely ignored. However, as the minimum size of critical features drops below about 65nm, systematic variations that were previously ignored can now consume a considerable portion of the overall error budget. Specifically, systematic mask CD errors can consume over 50% of the total wafer lithography process CD budget.

Therefore, various mask inspection tools have been developed and are available commercially. According to the known techniques of designing and evaluating masks, the mask is created and used to expose therethrough a wafer, and then a check is performed to determine whether the features of the mask have been transferred to the

5    wafer according to the design. Any variations in the final features from the intended design necessitate modifying the design, creating a new mask, and exposing a new wafer.

The above procedure can be made simpler using the Aerial Image Measurement System (AIMS). The AIMS is basically an engineering tool, which is intended for

10   development and testing of various mask designs. It is also helpful for checking how OPC and phase shift features would print on the wafer. Additionally, the system can be used to study various defects discovered by a mask inspection system, and test whether those defects would actually print on the wafer. Some systems have been developed using the principles of aerial imaging for the mask inspection, as disclosed for example

15   in U.S. Patents Nos. 5,481,624; 5,795,688; and 7,072,502. Also, the use of aerial imaging in the mask inspection is described in the article "Aerial-image-based off-focus inspection: lithography process window analysis during mask inspection", Shirley Hemar et al., Proceedings of SPIE, Volume 5256, 23rd Annual BACUS Symposium on Photomask Technology, December 2003, pp. 500-509.

20   Generally speaking, the AIMS™ is an optical system for evaluating masks under specific stepper or scanner settings of numerical aperture (NA), partial coherence of illumination or pupil filling, wavelength and illumination type (like circular, annular, quadrupole or dipole off-axis illumination). By flexible, automated adjustment of any setting to match conditions like in 193 nm exposure tools, it can emulate for any type of

25   masks like binary, OPC and phase shift, designed for 193 nm lithography. The image taken with the system is optically equivalent to the latent image incident on the photoresist of the wafer, but magnified and recorded with a CCD camera. Thus, the AIMS™ tool allows a rapid prediction of the wafer printability of critical features, like dense patterns or contacts, defects or repairs on the mask without the need to do real

30   wafer prints using the exposure tool and a following SEM measurement of the printed features.

There is a need to provide systems and methods for evaluating at least one parameter of a pattern.

## SUMMARY OF THE INVENTION

5          There is a need in the art for a novel system and method for monitoring (controlling, measuring, inspecting) variations of one or more pattern parameters within patterned articles, such as masks and reticles used for the manufacture of semiconductor devices. The pattern parameter(s) variations to be monitored relate to one or more parameters that have some meaningful information about a patterning process (e.g.
10        lithography), and may include for example CD variations, X- and Y-rotational moment for measuring shape deviation or any other such measurement. The measurement system should be simple, with preferably no need for a complicated recipe design, and should preferably be capable of generating the respective parameter variation map (e.g. CD map) concurrently with a regular procedure of inspecting the article (mask) for
15        defects. It is noted that the image is not necessarily an aerial intensity image. It is further noted that the evaluated pattern can eb a pattern generated by utilizing the mask and is not necessarily a pattern of the mask itself.

The monitoring system should preferably, in addition to the above, provide for compensating certain systematic errors in the data flow associated with the respective
20        parameter variation. In the case of CD variations control, in order to achieve these tasks, typically two steps are required, one consisting of CD measurements over the entire mask and processing measured data to generate a so-called "CD variation map" of the entire mask; and use of the "CD variation map" for said compensation which is done either by controlling the lithography parameters (e.g. dose variation over the field) or by
25        actively correcting the mask (e.g. changing transmission over the mask area). The CD variation map is usually generated by sampling the CD values at a large number of predefined locations, by means of SEM or AIMS measurement at each of those locations. This tends to be a time consuming and complicated process.

The present invention provides a novel monitoring system and method aimed at
30        generating a pattern parameter variation map, e.g. CD variation map, of at least a portion of or the entire patterned article (e.g. mask). Comparing the inventive approach

to those conventionally used in the metrology technique and defect detection technique, the following should be noted. The invention provides for monitoring the entire patterned area. This may be implemented using the pixel-by-pixel monitoring (typically used in defect detection technique) but, contrary to the defect detection technique, the invented approach does not need any "threshold based decision making". Alternatively, this may be implemented without any pixel-by-pixel monitoring method, and in this case, contrary to the metrology approach, the invention utilizes window-based monitoring (i.e. concurrent monitoring of a matrix of pixels).

In some embodiments of the invention, especially when dealing with the CD variations map, the invention takes advantage over an aerial intensity imaging (such as the AREA 193 aerial image scanner commercially available from Applied Materials Inc., and provides the measurement/control system (which may for example be implemented inside the aerial image based inspection system) for producing (e.g. concurrently with regular inspection) the intensity integral maps of the entire mask.

It is noted that certain functional of the intensity (e.g. the intensity integral) over the aerial image of a patterned article (mask) can be used to generate the pattern parameter variation map (e.g. a CD variation map) of the entire mask. More specifically, the inventors have found that the intensity integral over the aerial intensity image of the mask, and especially for a very dense pattern (i.e. very small critical dimensions), is linearly proportional to the CD variation of this pattern. Therefore, the "CD variation map" can be easily calculated from the integral of the aerial intensity image over the mask.

The "CD variation map" can be used for various applications, including but not limited to the following: using the CD variation map as a qualification criteria for a mask to be shipped out of the mask shop, as a method to monitor and improve mask process ("process control"), as an input to a "compensating" equipment for reducing the CD variation, as a real time feedback to the article inspection system for a better defect detection capability, an input to a mask model used in lithography simulations, for identifying the so-called "hot spots", being areas of larger than expected CD variation, where these "hot spots" can be used as the input to metrology tools such as CD SEM, or

4

reticle SEM, capable of carrying out more accurate CD measurements, as well as for providing correction maps for the illumination of lithography steppers.

Generally speaking, the present invention is based on the understanding that a certain functional (e.g. integral, or average) of the intensity of a light response (reflection and/or transmission) of the patterned area (measured either pixel-by-pixel or by windows) is indicative of the pattern parameter(s) variation (e.g. CD) of the entire patterned area in the patterned article.

According to one broad aspect of the invention, there is provided, a method for use in inspection of patterned articles, the method comprising: processing data indicative of an aerial intensity image of at least a portion of the patterned article, and determining  values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of a variation of at least one predetermined parameter of the pattern within said at least portion of the patterned article.

As indicated above, the term *"inspection"* used herein refers to either one of inspection, measurement or monitoring processes.

According to another broad aspect of the invention, there is provided, a method for use in inspection of patterned articles, the method comprising processing data indicative of an aerial intensity image of at least a portion of the patterned article, such as a mask or reticle, and determining  integrals of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said aerial image intensity integrals being indicative of a variation of critical dimensions of features of the pattern within said at least portion of the patterned article.

The data indicative of the aerial intensity image may be that generated by an aerial image scanner system.

The invention also provides for improving the accuracy of measurements of the pattern parameter variation by reducing sensitivity of the measurements to machine variations, such as intensity variations of an illuminator (laser source) over the whole image frame, and inhomogeneity of the brightness field (FOV variation). The intensity of the laser beam is typically instable. Though the intensity level is measured and

compensated for electronically, the final image still might have significant gain variations. The invention solves this problem by grabbing overlapping frames (preferably along both X- and Y-axis of scanning). These overlapping regions are used to calculate the laser intensity and FOV variation values, and correct the measurements

5    by compensating for the calculated variations. The system of the present invention produces the pattern parameter variation map with a one-frame resolution. As the sensitivity of the invented technique to machine variations is much lower, it is used to produce a map of higher resolution.

Preferably, the processing of the data indicative of the aerial intensity image

10   includes pattern recognition applied to the aerial intensity image data to identify, in the aerial intensity image, a predetermined reference pattern and generate corresponding pattern identification data. The pattern identification data may be in the form of the aerial intensity image data in which locations similar to the reference pattern are marked.

15   Preferably, the processing of the data indicative of the aerial intensity image includes dividing the aerial intensity image into basic elements of a predefined configuration, and utilizing the corresponding pattern identification data to select in the aerial intensity image the basic elements which correspond to the predetermined reference pattern. Then, a integral intensity value is determined for each or some of the

20   selected basic elements. The integral of the intensity values is obtained by summing the intensity values of all the locations within the basic element corresponding to the predetermined pattern. The basic elements which contain locations which do not correspond to the reference pattern are preferably masked.

The integral intensity values and data indicative of their corresponding basic

25   elements are then analyzed to produce data indicative of the intensity integral map. This procedure may include eliminating of outliers in the integral intensity values based on the data indicative of the corresponding basic elements. In some embodiments, a resolution of the intensity integral map is defined by the configuration of the basic element. In some other embodiments, averaging over a certain number of the basic

30   elements is carried out, thus reducing the resolution and reducing the measurement error.

The intensity integral map can be then processed to determine the feature dimensions' variation map, which is linearly proportional to the intensity integral map for a given illumination intensity used in obtaining the aerial intensity image data.

In some embodiments of the invention, dividing the aerial intensity image into the basic elements is performed using a grid of a predetermined configuration containing a plurality of elemental areas.

The basic element configuration may be selected such that the basic element contains an integer number of cycles of the pattern.

The integral intensity for at least a portion of the patterned article may be determined concurrently with the inspection of said article. Alternatively or additionally, the data indicative of the variation of the critical dimensions of the pattern features of said at least portion of the patterned article may be used to determine whether said article is to be removed from a production line or not. Similarly, the data may be analyzed to control one or more parameters of the article production process. Said data may provide an input for a compensating mechanism operable to reduce the variations in the critical dimensions. Also, the data about the CD variation within the patterned article may be used for adjusting the illumination used in the patterning process.

According to yet another broad aspect of the invention, there is provided a monitoring system for use in inspection of patterned articles, the monitoring system is configured and operable for processing data indicative of an aerial intensity image of at least a portion of a patterned article and determining values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of variations of at least one predetermined parameter of the pattern within said at least portion of the patterned article.

According to yet another broad aspect of the invention, there is provided a measurement system for use in inspection of patterned articles, the measurement system is configured and operable for processing data indicative of an aerial intensity image of at least a portion of a patterned article and determining integrals of the aerial image intensity for predetermined regions within said at least portion of the patterned article,

7

said aerial image intensity integrals being indicative of variations of critical dimensions of features of the pattern within said at least portion of the patterned article.

Preferably, the system includes a processor utility configured and operable for dividing the aerial intensity image into basic elements of a predetermined configuration, and determining the integral of the aerial image intensity for at least predetermined locations within at least some of the basic elements. Preferably, the processor operates to identify locations in the basic element as corresponding to features of a predetermined reference pattern.

According to an embodiment of the invention the control/measurement system includes a pattern identification utility configured for receiving the data indicative of the aerial intensity image, applying to this data a pattern recognition algorithm, using reference data indicative of a predetermined reference pattern, and generating pattern identification data. The latter is further processed by a so-called "basic elements processor" which divides the aerial intensity image into the basic elements of the predefined size, preferably also uses the pattern identification data to select those basic elements which correspond to the predetermined reference pattern, and obtains the intensity integral value for each of the basic elements (preferably for the selected basic element corresponding to the predetermined reference pattern). Then, these data indicative of the intensity integral values together with their corresponding basic elements are used by a map generator, which operates to produce the intensity integral map according to a required resolution (e.g. that defined by the size of the basic element of, if averaging is used, a lower resolution).

More specifically, the present invention is used for determination of the CD variation map, and using the intensity integral maps, the invention is therefore described below with respect to this specific application. However, it should be understood that the invention is not limited to these specific examples.

It is noted that the invention can be used together with an article inspection system, for example of a kind performing a defect inspection. Thus, the present invention is suitable for producing intensity integral maps and hence CD variation maps concurrently with regular inspection of the mask during the production process.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, an embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

5      **Fig. 1** is a block diagram of an example of a monitoring system of the present invention for mapping one or more parameters of a pattern in a patterned article;

**Fig. 2** is a block diagram representing the functioning of the basic elements processor suitable to be used in the system of Fig. 1;

**Figs. 3A to 3C** exemplify, respectively, an image of the layout of a specific

10     lithographic mask, and its corresponding intensity integral map and a relative intensity integral map obtained by the technique of the present invention;

**Figs. 4A to 4C** exemplify, respectively, an image of the layout of another lithographic mask, and its corresponding intensity integral map and relative intensity integral map;

15     **Fig. 5** schematically illustrate the principles of the embodiments of the invention aimed at compensating for the measurement error associated with the AIS system variations, such as the laser intensity variations and/or the FOV variations; and

**Fig. 6** exemplifies the principles of Fig. 5 for obtaining data for a 3x3 frame matrix.

20     **DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS**

It is according to one embodiment of the invention to present a monitoring (measurement/control/inspection) system for use in determining a map of the variations of at least one predetermined parameter (e.g. the critical dimensions) of a pattern of at least a portion of a patterned article (such as lithographic mask), utilizing data indicative

25     of the aerial intensity image. The latter can be input from an aerial image scanner system, such as the AREA 193. More specifically, the present invention is used for inspection of masks of a kind used in semiconductor industry, and is therefore described below with respect to this application.

A method for evaluating a variation of a parameter of a pattern is provided. The

30     method includes: processing data indicative of an aerial intensity image of at least a portion of a patterned article, and determining values of a certain functional of the aerial

image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of a variation of at least one parameter of the pattern within said at least portion of the patterned article or of a variation of at least one parameter of a pattern manufactured by utilizing the patterned article.

Conveniently, the certain functional of the aerial image intensity is the aerial image intensity integral.

Conveniently, the at least one parameter of the pattern includes a critical dimension (CD) of a pattern feature.

Conveniently, said processing of the data indicative of the aerial intensity image includes applying to the aerial intensity image data a pattern recognition algorithm to identify, in said aerial intensity image, a predetermined reference pattern and generate corresponding pattern identification data.

Conveniently, said processing of the data indicative of the aerial intensity image includes dividing the aerial intensity image into basic elements of a predefined configuration; utilizing the corresponding pattern identification data to select, in the aerial intensity image, the basic elements which correspond to the predetermined reference pattern, and determining the value of said intensity functional for each of the selected basic elements.

Conveniently, said processing of the data indicative of the aerial intensity image includes analyzing the intensity functional values and data indicative of their corresponding basic elements, and producing data indicative of intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within said at least portion of the patterned article.

Conveniently, each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

Conveniently, said value of the intensity functional is obtained by summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

Conveniently, said producing of the data indicative of the intensity functional map includes eliminating outliers in the intensity functional values based on the data indicative of the corresponding basic elements.

Conveniently, the stage of processing includes generating the aerial intensity image from multiple different frame images; and the method includes compensating for differences in the generation of the different frame images.

Conveniently, the generating includes: acquiring a pair of partially overlapping frame images that define an overlap area; and determining a difference in an acquisition of each of the pair of partially overlapping frame images in response to a difference between a visual representation of the overlap area in each of the two partially overlapping frame images.

Conveniently, the stage of processing includes generating the aerial intensity image from a continuous sequence of partially overlapping frame images that include the predefined regions.

Conveniently, the determining the difference includes multiplying the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

Conveniently, said determining of the values of the intensity functional for the at least portion of the patterned article is performed concurrently with the inspection of said article.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to

11

adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

Conveniently, the patterned article is a lithography mask.

A method for evaluating a variation of a parameter of a pattern is provided. The method includes: processing data indicative of an image of at least a portion of a patterned article, and determining values of a certain functional of the image for predetermined regions within said at least portion of the patterned article, said values of the image functional being indicative of a variation of at least one parameter of the pattern manufactured by utilizing the patterned article.

Conveniently, the stage of processing includes processing data indicative of an aerial intensity image and the determining includes determining values of a certain functional of the aerial image intensity.

Conveniently, said certain functional of the image is an image intensity integral.

Conveniently, said at least one parameter of the pattern includes a critical dimension (CD) of a pattern feature.

Conveniently, said processing of the data indicative of the image includes applying to image data a pattern recognition algorithm to identify, in the image, a predetermined reference pattern and generate corresponding pattern identification data.

Conveniently, said processing of the data indicative of the image includes dividing the image into basic elements of a predefined configuration; utilizing the corresponding pattern identification data to select, in the image, the basic elements which correspond to the predetermined reference pattern, and determining the value of the functional for each of the selected basic elements.

Conveniently, said processing of the data indicative of the image includes analyzing intensity functional values and data indicative of their corresponding basic elements, and producing data indicative of intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within said at least portion of the patterned article.

Conveniently, each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

12

Conveniently, said value of the intensity functional is obtained by summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

Conveniently, said producing of the data indicative of the intensity functional map includes eliminating outliers in the intensity functional values based on the data indicative of the corresponding basic elements.

Conveniently, the stage of processing includes generating the image from multiple different frame images; and the method includes compensating for differences in the generation of the different frame images.

Conveniently, the generating includes: acquiring a pair of partially overlapping frame images that define an overlap area; and determining a difference in an acquisition of each of the pair of partially overlapping frame images in response to a difference between a visual representation of the overlap area in each of the two partially overlapping frame images.

Conveniently, the stage of processing includes generating the image from a continuous sequence of partially overlapping frame images that include the predefined regions.

Conveniently, said determining a difference includes multiplying the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

Conveniently, said determining of the values of the functional for the at least portion of the patterned article is performed concurrently with the inspection of said patterned article.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to

13

provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

Conveniently, the patterned article is a lithography mask.

A system for evaluating a variation of a parameter of a pattern is provided. The system includes a processor that is adapted to: process data indicative of an aerial intensity image of at least a portion of a patterned article, and determine values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of a variation of at least one parameter of the pattern within said at least portion of the patterned article or of a variation of at least one parameter of a pattern manufactured by utilizing the patterned article.

Conveniently, said certain functional of the aerial image intensity is the aerial image intensity integral.

Conveniently, said at least one parameter of the pattern includes a critical dimension (CD) of a pattern feature.

Conveniently, the processor is adapted to apply to the aerial intensity image data a pattern recognition algorithm to identify, in said aerial intensity image, a predetermined reference pattern and generate corresponding pattern identification data.

Conveniently, the processor is adapted to divide the aerial intensity image into basic elements of a predefined configuration; and utilize the corresponding pattern identification data to select, in the aerial intensity image, the basic elements which correspond to the predetermined reference pattern, and determining the value of said intensity functional for each of the selected basic elements.

Conveniently, the processor is adapted analyze the intensity functional values and data indicative of their corresponding basic elements, and produce data indicative of intensity functional map for said at least portion of the patterned article indicative of

14

said at least one pattern parameter variation map within said at least portion of the patterned article.

Conveniently, each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

Conveniently, the processor is adapted to obtain a value of the intensity functional summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

Conveniently, the processor is adapted to eliminate outliers in the intensity functional values based on the data indicative of the corresponding basic elements.

Conveniently, the processor is adapted to generate the aerial intensity image from multiple different frame images and to compensate for differences in the generation of the different frame images.

Conveniently, the processor is adapted to receive partially overlapping frame images and to determine a difference in an acquisition of two partially overlapping frame images in response to a difference between the two partially overlapping frame images.

Conveniently, the processor is adapted to generate the aerial intensity image from a continuous sequence of partially overlapping frame images that include the predefined regions.

Conveniently, the processor is adapted to multiply the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

Conveniently, the processor is adapted to determine the values of the intensity functional for the at least portion of the patterned article while the patterned article is being inspected.

Conveniently, the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

15

Conveniently, the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

Conveniently, the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

Conveniently, said patterned article is a lithography mask.

A system for evaluating a variation of a parameter of a pattern is provided. The system includes a processor adapted to process data indicative of an image of at least a portion of a patterned article, and determining values of a certain functional of the image for predetermined regions within said at least portion of the patterned article, said values of the image functional being indicative of a variation of at least one parameter of the pattern manufactured by utilizing the patterned article.

Conveniently, the processor is adapted to process data indicative of an aerial intensity image and the determining includes determining values of a certain functional of the aerial image intensity.

Conveniently, said certain functional of the image is an image intensity integral.

Conveniently, said at least one parameter of the pattern includes a critical dimension (CD) of a pattern feature.

Conveniently, the processor is adapted to apply to the image data a pattern recognition algorithm to identify, in the image, a predetermined reference pattern and generate corresponding pattern identification data.

Conveniently, the processor is adapted to divide the image into basic elements of a predefined configuration; and utilize the corresponding pattern identification data to select, in the image, the basic elements which correspond to the predetermined reference pattern, and determining the value of said intensity functional for each of the selected basic elements.

Conveniently, the processor is adapted analyze the intensity functional values and data indicative of their corresponding basic elements, and produce data indicative of

intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within said at least portion of the patterned article.

Conveniently, each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

Conveniently, the processor is adapted to obtain a value of the intensity functional summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

Conveniently, the processor is adapted to eliminate outliers in the intensity functional values based on the data indicative of the corresponding basic elements.

Conveniently, the processor is adapted to generate the image from multiple different frame images and to compensate for differences in the generation of the different frame images.

Conveniently, the processor is adapted to receive partially overlapping frame images and to determine a difference in an acquisition of two partially overlapping frame images in response to a difference between the two partially overlapping frame images.

Conveniently, the processor is adapted to generate the image from a continuous sequence of partially overlapping frame images that include the predefined regions.

Conveniently, the processor is adapted to multiply the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

Conveniently, the processor is adapted to determine the values of the intensity functional for the at least portion of the patterned article while the patterned article is being inspected.

Conveniently, the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

Conveniently, the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

Conveniently, the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

A method for evaluating a variation of a pattern is provided. The method includes: processing data indicative of an aerial intensity image of at least a portion of the patterned article, and determining values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of a variation of at least one predetermined parameter of the pattern within said at least portion of the patterned article.

Conveniently, said certain functional of the aerial image intensity is the aerial image intensity integral.

Conveniently, said at least one parameter of the pattern includes critical dimensions (CD) of the pattern features.

Conveniently, said data indicative of the aerial intensity image is generated by an aerial image scanner system.

Conveniently, said data indicative of the aerial image intensity is in the form of successively scanned frames.

Conveniently, said data indicative of the aerial image intensity is in the form of successively scanned frames with an overlapping region between each two adjacent frames.

Conveniently, said processing of the data indicative of the aerial intensity image includes applying to the aerial intensity image data a pattern recognition algorithm to identify, in said aerial intensity image, a predetermined reference pattern and generate corresponding pattern identification data.

18

Conveniently, said pattern identification data includes the aerial intensity image data in which locations similar to the reference pattern are marked.

Conveniently, said processing of the data indicative of the aerial intensity image includes dividing the aerial intensity image into basic elements of a predefined configuration; utilizing the corresponding pattern identification data to select, in the aerial intensity image, the basic elements which correspond to the predetermined reference pattern, and determining the value of said intensity functional for each of the selected basic elements.

Conveniently, said processing of the data indicative of the aerial intensity image includes analyzing the intensity functional values and data indicative of their corresponding basic elements, and producing data indicative of intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within said at least portion of the patterned article.

Conveniently, a resolution of the intensity functional map is defined by the configuration of the basic element.

Conveniently, said processing includes averaging the intensity functional values of a plurality of the basic elements to produce the intensity functional map with a resolution lower than that defined by the size of the basic element and with smaller measurement errors.

Conveniently, said dividing of the aerial intensity image into the basic elements is performed using a grid of a predetermined configuration containing a plurality of elemental areas.

Conveniently, each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

Conveniently, said value of the intensity functional is obtained by summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

Conveniently, the basic elements which contain locations which do not correspond to the reference pattern are masked.

19

Conveniently, said producing of the data indicative of the intensity functional map includes eliminating outliers in the intensity functional values based on the data indicative of the corresponding basic elements.

Conveniently, said processing of the data indicative of the aerial intensity image of said at least portion of the patterned article includes producing data indicative of a relative intensity map for at least some regions of the pattern within said at least portion of the patterned article.

Conveniently, the method includes correcting said data indicative of the aerial image intensity to compensate for variations in at least one of the following: intensity of an illuminator used in the aerial image scanner system and field of view of the aerial image scanner system.

Conveniently, said correcting includes multiplying the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

Conveniently, said determining of the values of the intensity functional for the at least portion of the patterned article is performed concurrently with the inspection of said article.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to determine whether said article is to be removed from a production line or not.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

Conveniently, the method includes analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to

adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

Conveniently, said patterned article is a mask or reticle.

A system is provided. The system is configured and operable for processing data indicative of an aerial intensity image of at least a portion of a patterned article and determining   values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of variations of at least one predetermined parameter of the pattern within said at least portion of the patterned article.

Conveniently, the system includes a processor utility configured and operable for dividing data indicative of the aerial intensity image into basic elements of a predetermined configuration, and determining the  value of the aerial image intensity functional for at least predetermined locations within at least some of the basic elements.

Conveniently, the processor utility is configured and operable to identify said locations in the basic element as corresponding to features of a predetermined reference pattern.

Conveniently, said processor utility is operable to perform said dividing using a predetermined grid containing a plurality of elemental areas corresponding to said basic elements.

Conveniently, the system includes a pattern identification utility configured and operable for processing said aerial intensity image utilizing a predetermined reference pattern, and generating pattern identification data for said aerial intensity image.

Conveniently, the processor is configured and operable to receive said pattern identification data indicative of said aerial intensity image, and to identify, in the aerial intensity image, locations of the basic elements corresponding to the predetermined reference pattern.

Conveniently, said basic element is preconfigured such that it contains an integer number of cycles of the pattern.

21

Conveniently, said processor utility operates to determine the integral of the aerial image intensity for the basic element by summing the intensity values of said predetermined locations within the respective basic element.

Conveniently, the system includes a map generator utility configured and operable for receiving data indicative of the determined functional values of the aerial image intensity for at least predetermined locations together with their corresponding basic elements and generating a map of the intensity functional variation within said at least portion of the aerial intensity image with a resolution defined by the configuration of the basic element, said intensity functional map being indicative of a map of said at least one parameter of the pattern.

Conveniently, said processor utility is configured for masking locations of the aerial intensity image which do not correspond to the reference pattern.

Conveniently, the system is configured for communication with an external aerial image scanner system for receiving therefrom the data indicative of the aerial intensity image.

Conveniently, the system is configured to be integral with an aerial image scanner system, which generates said data indicative of the aerial intensity image.

Conveniently, the aerial image scanner system is configured to perform scanning of successive frames with an overlapping region between each two adjacent frames.

Conveniently, said processor utility is configured for correcting said data indicative of the aerial image intensity to compensate for variations in at least one of the following: intensity of an illuminator used in the aerial image scanner system and field of view of the aerial image scanner system.

Conveniently, said processor utility operates to perform said correcting by multiplying the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

Conveniently, the system is adapted to perform said determination of the intensity functional map of the at least portion of the patterned article concurrently with the article inspection by the aerial image scanner system.

22

Conveniently, said intensity functional map includes a relative intensity functional map for predetermined similarly patterned regions of said at least portion of the patterned article.

Conveniently, said patterned article is a lithography mask.

5      Reference is made to **Fig. 1** schematically showing, by way of a block diagram, an example of a monitoring system **100** of the invention. The system **100** can be associated with an aerial image scanner (AIS) system **102** (such as the AREA 193). The system **100** may be configured as a stand alone unit receiving or exchanging data with the AIS system **101**, or may be integral with the AIS system **102**. The AIS **102** is

10    configured and operable to generate and grab (acquire) the aerial image of a mask during regular mask inspection, and typically includes an aerial image scanning module **102A** and an image grabber **102B**.

In some embodiments of the invention, the AIS system **102** operating with its typical scanning mode is used. In some other embodiments of the invention the AIS

15    system **102** (its scanner unit **102A**) is operated according to the invention to provide an overlapping scanning, as will be described further below.

The monitoring system **100** is configured as a computer system including *inter alia* a memory utility **103** for storing *inter alia* certain reference data, and a processor (also referred to as processor utility) **110**. The processor utility **110** is configured and

20    operable for receiving and processing data indicative of an aerial intensity image (received from the AIS system **102**) of at least a portion of the mask and determining functional of the aerial image intensity for at least predetermined regions of mask (e.g., integral intensity map for the at least portion of the mask). This integral intensity map is indicative of a variation of the pattern parameter (e.g. critical dimensions of features of

25    the pattern) in the mask.

As shown in the example of **Fig. 1**, the processor utility **110** includes a features identifier module **104**, a so-called "basic elements processor" **105**, and a map generator **106**.

The feature identifier **104** is a software and/or hardware utility configured for

30    receiving, from the AIS system **102** (its image grabber **102B**), measured data indicative of the aerial intensity image and processing this data by an appropriate pattern

recognition algorithm. This can be implemented using reference data indicative of a predetermined reference pattern or the so-called "relevant pattern definition data". The feature identifier module 104 operates as a matcher utility to identify and mark, in the aerial images, all the locations which are similar to the relevant pattern.

5 The so-created pattern identification data is transferred to the basic elements processor 105. The basic elements processor 105 is configured and operable to divide the aerial intensity image into basic elements (windows) of a predefined size, use the pattern identification data to select those basic elements which correspond to the predetermined reference pattern, and process data corresponding to the selected basic

10 elements to obtain an intensity integral value (constituting a certain functional) for each of the selected basic elements. More specifically, the selected basic elements are those having similar patterns.

Data indicative of these intensity integral values together with their corresponding basic elements is then used by the Map Generator 106, which operates to

15 eliminate outliers and produce the "intensity integral map" according to a required resolution.

By recognizing that for dense patterns the intensity integral over an aerial image is linearly proportional to the critical dimensions (CD), the CD variation map is generated. Indeed, for a very dense pattern (such as the systematic variations in CD of a

20 mask) with the line width $W$ and pitch $P$, the aerial image intensity can be approximated by the following:

$$I(x) = I_0 \left( \frac{W}{P} + \frac{2MTF}{\pi} \sin(\frac{\pi W}{P}) \cos(\frac{2\pi x}{P}) \right)$$

where $I_0$ is the illumination intensity and $MTF$ is the modulation transfer

25 function. In this specific but not limiting example, circular illumination is considered (i.e. a substantially circular cross section of a light beam at the output of the light source unit). Then, the so-obtained functional values are summed and averaged. It should be understood that summing of the intensity values is an example of processing suitable to be used in the invention, however the invention is not limited to this specific example,

30 and alternatively, such procedures as STD or summing of the intensity gradient can be used.

24

Summing the intensity over an interval of length $X$ provides:

$$\overline{I(x)} = \frac{1}{X} \int_0^X I_0 \left( \frac{W}{P} + \frac{2MTF}{\pi} \sin(\frac{\pi W}{P}) \cos(\frac{2\pi x}{P}) \right) dx$$

When $X$ is much larger than $P$ we obtain:

$$\overline{I(x)} = I_0 \frac{W}{P}$$

Thus, for a given illumination intensity the integral of intensity (average intensity) over an aerial image of the patterned region is linearly proportional to the CD variation of this pattern. Therefore the CD variation map can be easily inferred from the intensity integral map. The resolution of this map is determined by the configuration of a predefined basic element (window) as will be described further below.

The configuration and operation of the basic element processor **105** is exemplified in **Fig. 2**. The basic element processor **105** includes a data divider utility **204**, a summing utility **206**, and preferably also a matcher utility **205**.

The divider utility **204** utilizes basic element configuration data **201** (reference data) which defines the predetermined configuration (at least the size) of a basic element. The image divider utility **204** is preprogrammed to divide the aerial intensity image into the basic elements (i.e. predefined configurable area elements), for example divides each frame (150x150 micron) into smaller blocks (elements) of few microns or few sub-micron each. This technique is based on the assumption that CD can be considered constant in the range of a few hundreds of microns. The basic element has an appropriate configuration, preferably such that it contains an integer number of cycles of the pattern. For example, the dividing may be performed using data indicative of a grid containing a plurality of elemental areas. The matcher utility **205** utilizes the pattern identification data to select, in the basic elements, locations corresponding to the reference pattern. The data output from the matcher utility **205** is then processed by the summing utility **206**, which sums, for each basic element, the intensity values for all the locations (pixels) corresponding to those of the reference pattern, thereby generating intensity integral values for the selected basic elements. The pixels whose intensity is summed are the pixels over the predefined configurable area element of the mask being

all the samples of the relevant pattern. All the basic elements which contain non relevant pixels (samples of non relevant pattern) are masked.

These intensity integrals data together with the corresponding data indicative of the basic elements' coordinates are transferred to the map generator (**106** in Fig. 1) which produces a corresponding intensity integral map with a required resolution. This may be a resolution defined by the configuration of the basic element; or by using averaging over a plurality of preconfigured basic elements, may be a lower resolution map (i.e. larger basic element's size) with smaller measurement errors. The map generator can plot the intensity map, and possibly also the relative intensity (die-to-die) map, for the entire mask.

It should be noted that the invented technique is not limited just to the measurement of intensity average over large areas. Every measurement carried out on a few discrete locations can used (with little modifications) in the invention on large areas covering the whole mask. For example, putting a threshold on a certain gray-level and counting all pixels exceeding this threshold (over some area) can be used. Areas containing a greater number of such pixels probably suffer from a CD variation problems (correlated to the direction of change - more pixels means larger CD). Another example might be the measurement of an average distance between the centers of all adjacent contacts (constituting a pattern feature) in a certain area. This measurement will show the stability of the periodic pattern (contacts in this case) over the whole map.

Reference is now made to **Figs, 3A-3C** and **Figs. 4A-4C** showing two examples, respectively, for the specific lithography masks' layout, and their respective intensity integral map and relative intensity integral map obtained using the above-described technique of the present invention.

**Fig. 3A** shows the layout of lithographic mask SM736, which was obtained using an optical imaging system with a numerical aperture of 0.9 and annular pupil filling σ of 0.92/0.69. **Fig. 3B** shows the intensity integral map of the same lithographic mask produced using the current invention. The overall mask structure is identical in both these figures showing an array of 8 cells. However whereas in the microscopic image of **Fig. 3A** these cells appear substantially flat and uniform, the intensity integral map of **Fig. 3B** reveals an intensity variation which is indicative of the corresponding

variation in the critical dimensions of cells' patterns. These intensity variations are more pronounced when viewed in a relative intensity map for two pairs of dies shown in **Fig. 3C**.

**Fig. 4A** shows an image of the layout of lithography mask SF314 containing an array of 24 cells, obtained with an optical imaging system with a numerical aperture of 0/8 and annular pupil filling σ of 0.85/0/55. **Fig. 4B** shows the intensity integral map of this mask, and **Fig. 4C** shows the relative intensity integral map.

The CD variation mapping system (**100** in Fig. 1) of the present invention may be used concurrently with regular mask inspection. In other words, the AIS system **102** may operate to inspect the mask for defects, while concurrently transmitting data initial image data (from the image grabber) to the mapping system **100**. The mapping system, as being configured as a computer system, may be a constructional part of a control unit of the AIS system. The mapping system may be adapted to be used as qualification criteria determining whether a mask is to be shipped out of the mask shop. Similarly, the map can be used as a monitor improving the mask production process or to provide an input for a compensating mechanism provided to reduce the variations in the critical dimensions. For example, the output data of the mapping system may be used to attenuate the illumination of some regions of the mask so as to reduce variations in the critical dimensions.

As indicated above, the system of the present invention is preferably configured to compensate for the measurement error associated with the AIS system variations, such as the laser intensity variations and/or the FOV variations. This is implemented by the measured data correction via overlapping regions between two adjacent scanned frames. In this connection, reference is made to **Fig. 5** showing the principles underlying this technique.

As shown two successively scanned frames (also referred to as frame images) *A* and *B* have an overlapping region **OR (also referred to as overlap area)**. This is the region in the frames *A* and *B* that has overcome the so-called double sampling but in two successive laser shots. Turning back to Fig. 1, to this end, the AIS system **102** is appropriately operated, either by an operator utility (now shown) of the monitoring system **100** or by a separate controller associated with the AIS system.

Generally, the measured data generated by the AIS system **102** and input to the monitoring system **100** is in the form of a grid of $N \times M$ frames. The system **100** operates to divide each frame into $D \times D$ square sub-frames, and to average the gray level of each sub-frame to provide $D \times D$ integral (functional) measurements. At least one row and
5    column of the measured data matrix are overlapped by two adjusting frames.

The model to be used may be as follows:

$$S_{m,n,u,v} = l_{m,n,u,v} g_{m,n} f_{u,v}$$

where $s_{m,n,u,v}$ is the true intensity integral value; $l_{m,n,u,v}$ is the intensity integral measure at sub-frame $u,v$ of frame $m,n$; $g_{m,n}$ is the inverse laser intensity gain (or the
10   laser intensity correction value) of frame $m,n$; $f_{u,v}$ is the inverse FOV value (or the FOV correction value) of sub-frames u,v.

**Fig. 6** exemplifies in a self-explanatory manner the so-obtained data fro 3x3 frame matrix.

According to the invention, the laser intensity correction values g are selected
15   such that the sum for all the intensity differences between the overlapping frames is minimal.

The compensation for FOV variations, which are the consistent bias of the CD measurements as a function of their placement in the frame and may be caused by brightness inhomogeneity, can be carried out based on the assumption that the FOV
20   variations are constant for all the frames. In this case, the FOV variations can be calculated using one of the following: (1) by averaging the intensity all the sub-frames by their placement in the frames, thus producing a $D \times D$ matrix of values, dividing each sub-frame by the appropriate average value; and (2) by calculating the FOV variations together with the laser intensity variations.

25   The following is the explanation of the technique of the present invention for compensation for the laser intensity variations according to the first option. Here, the FOV variations are assumed to be already corrected. For each sub-frame that is overlapped between two frames, its true CD measurement, which is known, should be the same in both frames. Since this gives more constraints than needed, and since the
30   CD measurement ought to have some error even after the FOV and laser intensity

variations have been minimized, regression algorithm is applied using all these constraints.

Let us suppose than there are $C$ instances of two frames overlapping the same sub frames; the c'th couple of overlapping sub-frames is denoted by $S_{m_c^1, n_c^1, u_c^1, v_c^1}$

5    and $S_{m_c^2, n_c^2, u_c^2, v_c^2}$

An error function $E$ is denoted as:

$$E = \sum_{c=1}^{C} \left( S_{m_c^1, n_c^1, u_c^1, v_c^1} - S_{m_c^2, n_c^2, u_c^2, v_c^2} \right)^2$$

10    and this function is minimized with respect to $g_{1,1}, ..., g_{m,n}$ under the constraint:

$$G = \sum_{m=1}^{M} \sum_{n=1}^{N} g_{m,n} - \sum_{m=1}^{M} \sum_{n=1}^{N} 1 = 0$$

which is required in order to make the solution single, and scales the solution so that the average laser intensity correction is 1.

Minimizing the function $E$ under the constraint $G=0$ is carried out using
15    Lagrange multipliers, and results in a linear system.

The following is the explanation of the technique of the present invention for compensation for the laser intensity variations according to the second option. Here, the FOV and laser intensity values are calculated together. Since minimizing the function $E$ with respect to both $g_{1,1}, ..., g_{m,n}$ and $f_{1,1}, ..., f_{m,n}$ results in a non-linear system, *log* of all
20    the intensity values is taken. A model for the CD variation measurements becomes as follows:

$$\widetilde{S}_{m,n,u,v} = \widetilde{l}_{m,n,u,v} + \widetilde{g}_{m,n} + \widetilde{f}_{u,v}$$

$$\widetilde{E} = \sum_{c=1}\left(\widetilde{S}_{m_c^1,n_c^1,u_c^1,v_c^1} - \widetilde{S}_{m_c^2,n_c^2,u_c^2,v_c^2}\right) + \lambda\sum_{m=1}\sum_{n=1}g_{m,n}^2 + \delta\sum_{u=1}\sum_{v=1}f_{m,n}^2$$

where $\widetilde{S}_{m,n,u,v} = \log\left(S_{m,n,u,v}\right)$ , etc.

The Error function $E$ is now defined as:

where $\lambda$ and $\delta$ are constants.

5      Function $E$ is minimized with respect to both $g_{1,1}, ..., g_{m,n}$ and $f_{1,1}, ..., f_{m,n}$.

The above-described technique can be extended for large mask areas, as follows: As the constraints on the laser intensity variations are all , small   errors in their assessment can accumulate to large errors over large distances. Thus the corrected  CD measurement might "drift" when applying this technique on areas in a scale of the

10     whole mask. In order to avoid this problem, when operating on large mask areas, more global constraints are added.

Our additional constraint concerns the statistical behavior of the laser intensity variations. It can be assumed that the laser intensity values have very small correlations over a long enough period of time, so that over a large-enough area they average to 1.

15     The scanned frames are divided to square areas (typically in the order of $10\times10$ frames), possibly with overlaps. Then, for each square, the squared deviation of its mean laser intensity value from 1 to the error function is added.

Formally, $K$ squares of frames are defined, each containing $P$ frames. This defines $K$ groups of laser intensity values, each with $P$ members:

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$$\left\{g_{m_p^k,n_p^k}\middle| 1 \le p \le P\right\} \quad k = 1...K$$

According to the above-described option 1, the new error function is:

$$E = \sum_{c=1}^{C}\left(s_{m_c^1,n_c^1,u_c^1,v_c^1} - s_{m_c^2,n_c^2,u_c^2,v_c^2}\right) + \alpha\sum_{k=1}^{K}\left(\frac{1}{P}\sum_{i=p}^{P}g_{m_p^k,n_p^k} - 1\right)^2$$

25     where $\alpha>0$ is some constant.

The technique of the invention can be generalized for wafer related data, to be easily applied on wafers or any other frame data series. The main goal is to obtain a

highly accurate measurement by averaging statistical information and avoiding machine data variation (by overlapping the grabbed data as described above).

Also, the invented technique can be extended to any kind of measurement on particular pattern (structure). In other words, the invention can be used for producing a global map (i.e., the whole mask map) of a certain measurement for a particular pattern, for example, generating a map of the line-end shortening measurement on a line and space pattern. The identification of the pattern can be performed by using database and matching algorithms (such as match filter), which were developed specially for the pattern behavior. For each scanned frame, the algorithm identifies the pattern within the frame and determines the required data.

Generally, the technique of the invention allows a user to select (manually, from the database) some particular patterns, and the algorithm will generate per each pattern a global map. In this case, the measurements are rather general without any connection to the pattern, such as the average intensity, the contour length, etc.

The global map is generated as follow: A user selects a pattern (structure) using the mask database. The patterns are kept in a compressed hierarchical database (such as Kd-tree). The control unit (algorithm) calibrates the patterns measurements (average intensity, contour length etc.) over the FOV, similar to the above-described FOV calibration. During scanning, the selected patterns are identified via the database (reference data) and measurements are performed on the scanned image. The identification is performed by using approximated nearest neighbor search methods.

The above-described methods (i.e. measurements on particular pattern, and the user defined pattern) for measuring on non-periodic patterns explain how to generate a single (feature/pattern/structure) measurement. For generation of a map for the whole mask, some data-processing (mainly averaging) needs to be performed over the single measurements, similar to the periodic-pattern method. The amount of averaging depends on the area that a single pixel represents. For example, if a pixel stands for an area of $25\mu m \times 25\mu m$, all the single measurements inside this area are averaged resulting with a single average measurement. If a pixel stands for an area which is a fraction number of frames (*frame size* = machine parameter), the overlapping scanning method is used to generate a continuous measurement map. It should be noted that in order to

31

determine what is the area size of a pixel, the following should be kept in mind: the larger the area (of the pixel), the lower the resolution of the map and the variance of the measurement, and *vice versa.*

5      Thus, the present invention provides a simple and effective solution for controlling the variation of one or more pattern parameter in a patterned article. The invention utilizes measured data from an aerial image scanner, operating either in its typical mode or overlapping scanning mode, and processing of this data to determine values of a certain functional of the aerial image intensity for predetermined regions.

10     Those skilled in the art will readily appreciate that various modifications and changes can be applied to the embodiments of the invention as hereinbefore described without departing from its scope defined in and by the appended claims.

15

CLAIMS:

1.      A method for evaluating a variation of a parameter of a pattern , the method comprising: processing data indicative of an aerial intensity image of at least a portion of a patterned article, and determining values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of a variation of at least one parameter of the pattern within said at least portion of the patterned article or of a variation of at least one parameter of a pattern manufactured by utilizing the patterned article.

2.      The method according to Claim 1, wherein said certain functional of the aerial image intensity is the aerial image intensity integral.

3.      The method according to Claim 1, wherein said at least one parameter of the pattern comprises a critical dimension (CD) of a pattern feature..

4.      The method according to Claim 1, wherein said processing of the data indicative of the aerial intensity image comprises applying to the aerial intensity image data a pattern recognition algorithm to identify, in said aerial intensity image, a predetermined reference pattern and generate corresponding pattern identification data.

5.      The method according to Claim 4, wherein said processing of the data indicative of the aerial intensity image comprises dividing the aerial intensity image into basic elements of a predefined configuration; utilizing the corresponding pattern identification data to select, in the aerial intensity image, the basic elements which correspond to the predetermined reference pattern, and determining the value of said intensity functional for each of the selected basic elements.

6.      The method according to Claim 5, wherein said processing of the data indicative of the aerial intensity image comprises analyzing the intensity functional values and data indicative of their corresponding basic elements, and producing data indicative of intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within said at least portion of the patterned article.

7.      The method according to Claim 5, wherein each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

33

8.   The method according to Claim 5, wherein said value of the intensity functional is obtained by summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

9.   The method according to Claim 6 wherein said producing of the data indicative of the intensity functional map comprises eliminating outliers in the  intensity functional values based on the data indicative of the corresponding basic elements.

10.   The method according to claim 1 wherein the stage of processing comprises generating the aerial intensity image from multiple different frame images; and wherein the method comprises compensating for differences in the generation of the different frame images.

11.   The method according to claim 10 wherein the generating comprises:  acquiring a pair of partially overlapping frame images that define an overlap area; and determining a difference in an acquisition of each of the pair of partially overlapping frame images in response to a difference between a visual representation of the overlap area in each of the two partially overlapping frame images.

12.   The method according to claim 10 wherein the stage of processing comprises generating the aerial intensity image from a continuous sequence of partially overlapping frame images that include the predefined regions.

13.   The method according to Claim 10, wherein the determining the difference comprises multiplying the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

14.   The method according to Claim 1, wherein said determining of the  values of the intensity functional for the at least portion of the patterned article is performed concurrently with the inspection of said article.

15.   The method according to Claim 1, comprising analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

16.     The method according to Claim 1, comprising analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

17.     The method according to Claim 1, comprising analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

18.     The method according to Claim 1, wherein said patterned article is a lithography mask.

19.     A method for evaluating a variation of a parameter of a pattern, the method comprising: processing data indicative of an image of at least a portion of a patterned article, and determining values of a certain functional of the image for predetermined regions within said at least portion of the patterned article, said values of the image functional being indicative of a variation of at least one parameter of the pattern manufactured by utilizing the patterned article.

20.     The method according to claim 19 wherein the stage of processing comprising processing data indicative of an aerial intensity image and wherein the determining comprises determining values of a certain functional of the aerial image intensity.

21.     The method according to claim 19, wherein said certain functional of the image is an image intensity integral.

22.     The method according to claim 19, wherein said at least one parameter of the pattern comprises a critical dimension (CD) of a pattern feature.

23.     The method according to claim 19, wherein said processing of the data indicative of the image comprises applying to image data a pattern recognition algorithm to identify, in the image, a predetermined reference pattern and generate corresponding pattern identification data.

24.     The method according to Claim 23, wherein said processing of the data indicative of the image comprises dividing the image into basic elements of a predefined configuration; utilizing the corresponding pattern identification data to select, in the image, the basic elements which correspond to the predetermined reference

pattern, and determining the value of the functional for each of the selected basic elements.

25.     The method according to Claim 24, wherein said processing of the data indicative of the image comprises analyzing intensity functional values and data indicative of their corresponding basic elements, and producing data indicative of intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within said at least portion of the patterned article.

26.     The method according to Claim 24, wherein each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

27.     The method according to Claim 24, wherein said value of the intensity functional is obtained by summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

28.     The method according to Claim 25 wherein said producing of the data indicative of the intensity functional map comprises eliminating outliers in the intensity functional values based on the data indicative of the corresponding basic elements.

29.     The method according to claim 19 wherein the stage of processing comprises generating the image from multiple different frame images; and wherein the method comprises compensating for differences in the generation of the different frame images.

30.     The method according to claim 29 wherein the generating comprises: acquiring a pair of partially overlapping frame images that define an overlap area; and determining a difference in an acquisition of each of the pair of partially overlapping frame images in response to a difference between a visual representation of the overlap area in each of the two partially overlapping frame images.

31.     The method according to claim 29 wherein the stage of processing comprises generating the image from a continuous sequence of partially overlapping frame images that comprise the predefined regions.

32.     The method according to Claim 29, wherein said determining a difference comprises multiplying the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of

adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

33.    The method according to Claim 19, wherein said determining of the values of the functional for the at least portion of the patterned article is performed concurrently with the inspection of said patterned article.

34.    The method according to Claim 19, comprising analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

35.    The method according to claim 19, comprising analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

36.    The method according to Claim 19, comprising analyzing the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

37.    The method according to Claim 19, wherein said patterned article is a lithography mask.

38.    A system for evaluating a variation of a parameter of a pattern, the system comprises a processor, wherein the processor is adapted to: process data indicative of an aerial intensity image of at least a portion of a patterned article, and determine values of a certain functional of the aerial image intensity for predetermined regions within said at least portion of the patterned article, said values of the aerial image intensity functional being indicative of a variation of at least one parameter of the pattern within said at least portion of the patterned article or of a variation of at least one parameter of a pattern manufactured by utilizing the patterned article.

39.    The system according to Claim 38 wherein said certain functional of the aerial image intensity is the aerial image intensity integral.

40.    The system according to Claim 38 wherein said at least one parameter of the pattern comprises a critical dimension (CD) of a pattern feature.

41. The system according to Claim 38 wherein the processor is adapted to apply to the aerial intensity image data a pattern recognition algorithm to identify, in said aerial intensity image, a predetermined reference pattern and generate corresponding pattern identification data.

5  42. The system according to Claim 41, wherein the processor is adapted to divide the aerial intensity image into basic elements of a predefined configuration; and utilize the corresponding pattern identification data to select, in the aerial intensity image, the basic elements which correspond to the predetermined reference pattern, and determining the value of said intensity functional for each of the selected basic

10  elements.

43. The system according to Claim 42, wherein the processor is adapted analyze the intensity functional values and data indicative of their corresponding basic elements, and produce data indicative of intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within

15  said at least portion of the patterned article.

44. The system according to Claim 43, wherein each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

45. The system according to Claim 44, wherein the processor is adapted to obtain a value of the intensity functional summing the intensity values of all the locations within

20  the basic element corresponding to the relevant pattern.

46. The system according to Claim 43 wherein the processor is adapted to eliminate outliers in the  intensity functional values based on the data indicative of the corresponding basic elements.

47. The system according to claim 38 wherein the processor is adapted to generate

25  the aerial intensity image from multiple different frame images and to compensate for differences in the generation of the different frame images.

48. The system according to claim 38 wherein the processor is adapted to  receive partially overlapping frame images and to determine a difference in an acquisition of two partially overlapping frame images in response to a difference between the two

30  partially overlapping frame images.

49.    The system according to claim 38 wherein the processor is adapted to generate the aerial intensity image from a continuous sequence of partially overlapping frame images that include the predefined regions.

50.    The system according to Claim 38, wherein the processor is adapted to multiply the measured intensity functional values for the overlapping regions by certain coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

51.    The system according to Claim 38, wherein the processor is adapted to determine the values of the intensity functional for the at least portion of the patterned article while the patterned article is being inspected.

52.    The system according to Claim 38 wherein the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.

53.    The system according to Claim 38 the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

54.    The system according to Claim 38 the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

55.    The system according to claim 38 wherein said patterned article is a lithography mask.·

56.    A system for evaluating a variation of a parameter of a pattern, the system comprising a processor adapted to process data indicative of an image of at least a portion of a patterned article, and determining values of a certain functional of the image for predetermined regions within said at least portion of the patterned article, said values of the image functional being indicative of a variation of at least one parameter of the pattern manufactured by utilizing the patterned article.

57.     The system according to claim 56 wherein the processor is adapted to  process data indicative of an aerial intensity image and to determine values of a certain functional of the aerial image intensity.

58.     The system according to claim 56, wherein said certain functional of the image is an image intensity integral.

59.     The system according to Claim 56 wherein said at least one parameter of the pattern comprises a critical dimension (CD) of a pattern feature.

60.     The system according to Claim 56 wherein the processor is adapted to  apply to the image data a pattern recognition algorithm to identify, in the image, a predetermined reference pattern and generate corresponding pattern identification data.

61.     The system according to Claim 60, wherein the processor is adapted to divide the   image into basic elements of a predefined configuration; and utilize the corresponding pattern identification data to select, in the   image, the basic elements which correspond to the predetermined reference pattern, and determining the value of said intensity functional for each of the selected basic elements.

62.     The system according to Claim 61, wherein the processor is adapted analyze the intensity functional values and data indicative of their corresponding basic elements, and produce data indicative of intensity functional map for said at least portion of the patterned article indicative of said at least one pattern parameter variation map within said at least portion of the patterned article.

63.     The system according to Claim 62, wherein each of said basic elements is configured such that it contains an integer number of cycles of the pattern.

64.     The system according to Claim 63, wherein the processor is adapted to obtain a value of the intensity functional summing the intensity values of all the locations within the basic element corresponding to the relevant pattern.

65.     The system according to Claim 64 wherein the processor is adapted to eliminate outliers in the   intensity functional values based on the data indicative of the corresponding basic elements.

66.     The system according to claim 56 wherein the processor is adapted to generate the   image from multiple different frame images and to compensate for differences in the generation of the different frame images.

67.    The system according to claim 56 wherein the processor is adapted to receive partially overlapping frame images and to determine a difference in an acquisition of two partially overlapping frame images in response to a difference between the two partially overlapping frame images.

5     68.    The system according to claim 56 wherein the processor is adapted to generate the image from a continuous sequence of partially overlapping frame images that include the predefined regions.

69.    The system according to Claim 56, wherein the processor is adapted to multiply the measured intensity functional values for the overlapping regions by certain
10    coefficients for each overlapping region sampled in the pair of adjacent successively scanned frames, said coefficients being optimized to provide minimal difference between the respective functional values.

70.    The system according to Claim 56, wherein the processor is adapted to determine the values of the intensity functional for the at least portion of the patterned
15    article while the patterned article is being inspected.

71.    The system according to Claim 56 wherein the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article for controlling one or more parameters of the article production process.
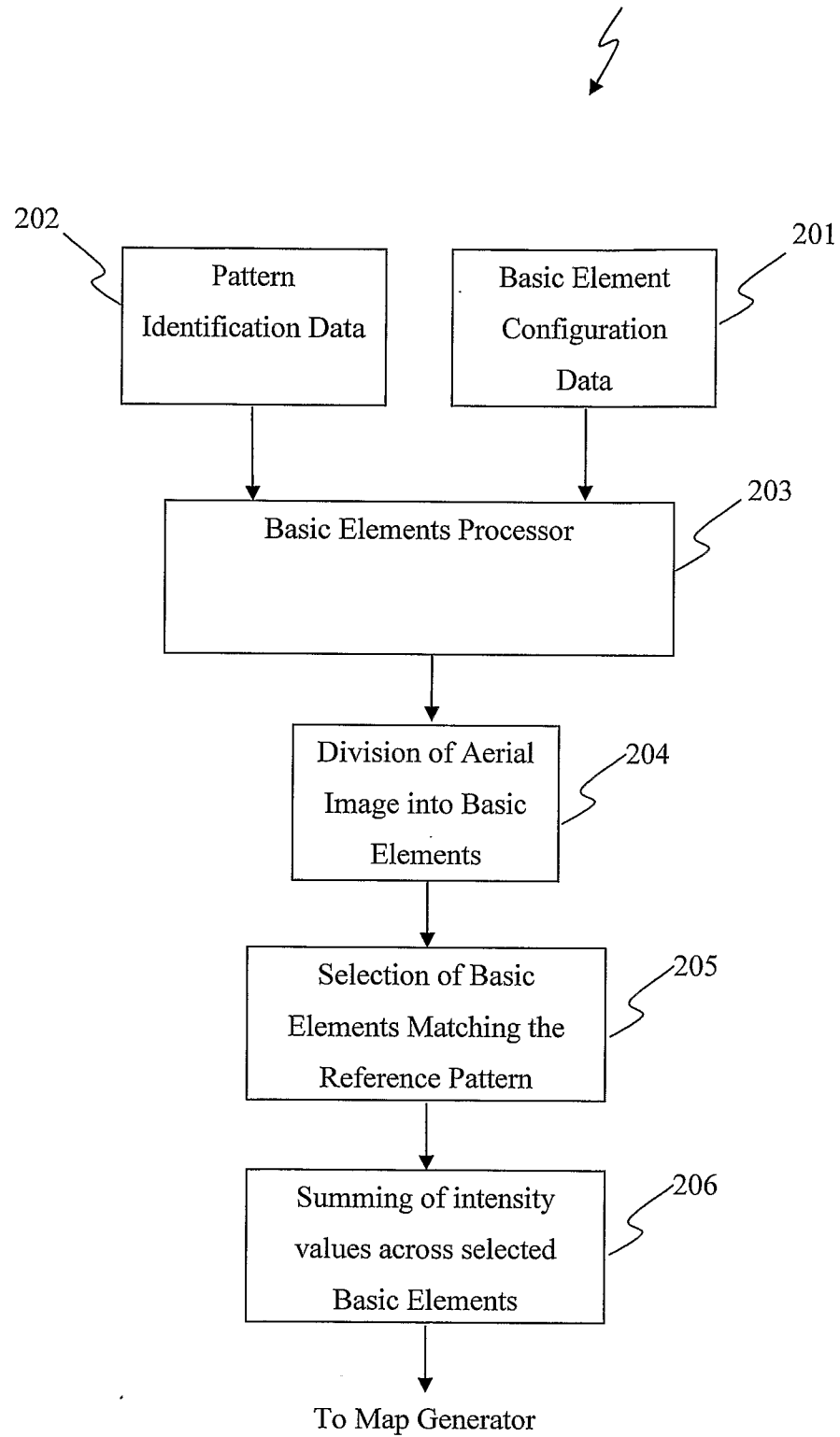
20    72.    The system according to Claim 56 the processor is adapted to analyze the data indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to provide an input for a compensating mechanism operable to reduce the variations in said at least one pattern parameter.

73.    The system according to Claim 56 the processor is adapted to analyze the data
25    indicative of the variation of said at least one pattern parameter of said at least portion of the patterned article to adjust illumination of the in the patterning process applied thereto to reduce variations in said at least one pattern parameter.

74.    The system according to claim 56 wherein said patterned article is a lithography mask.

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103

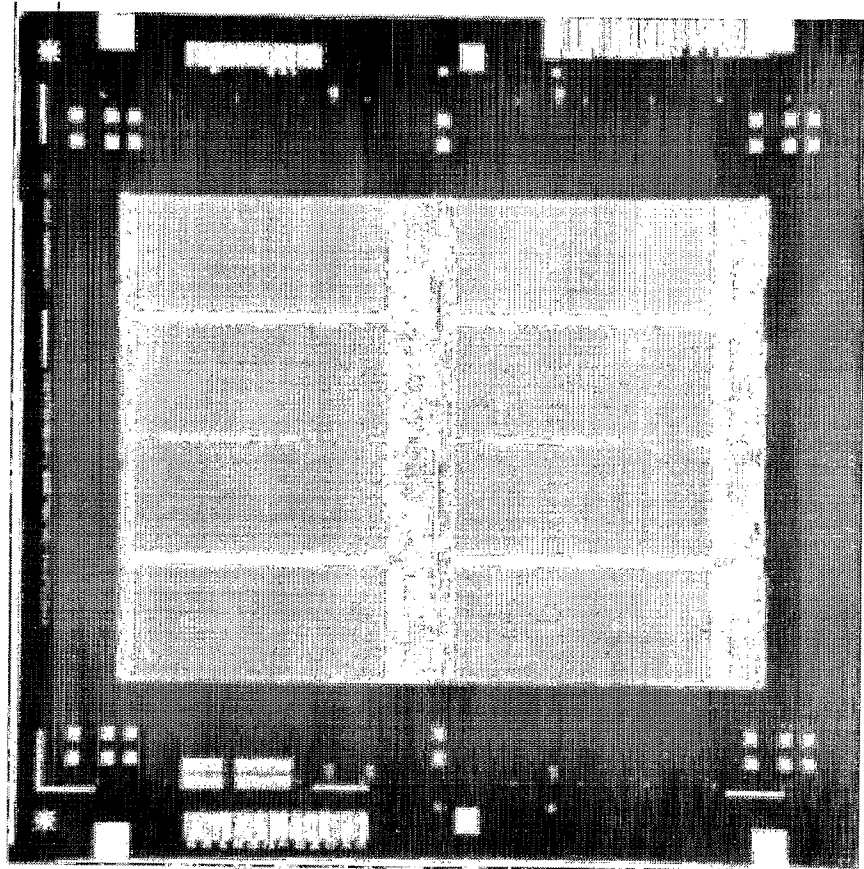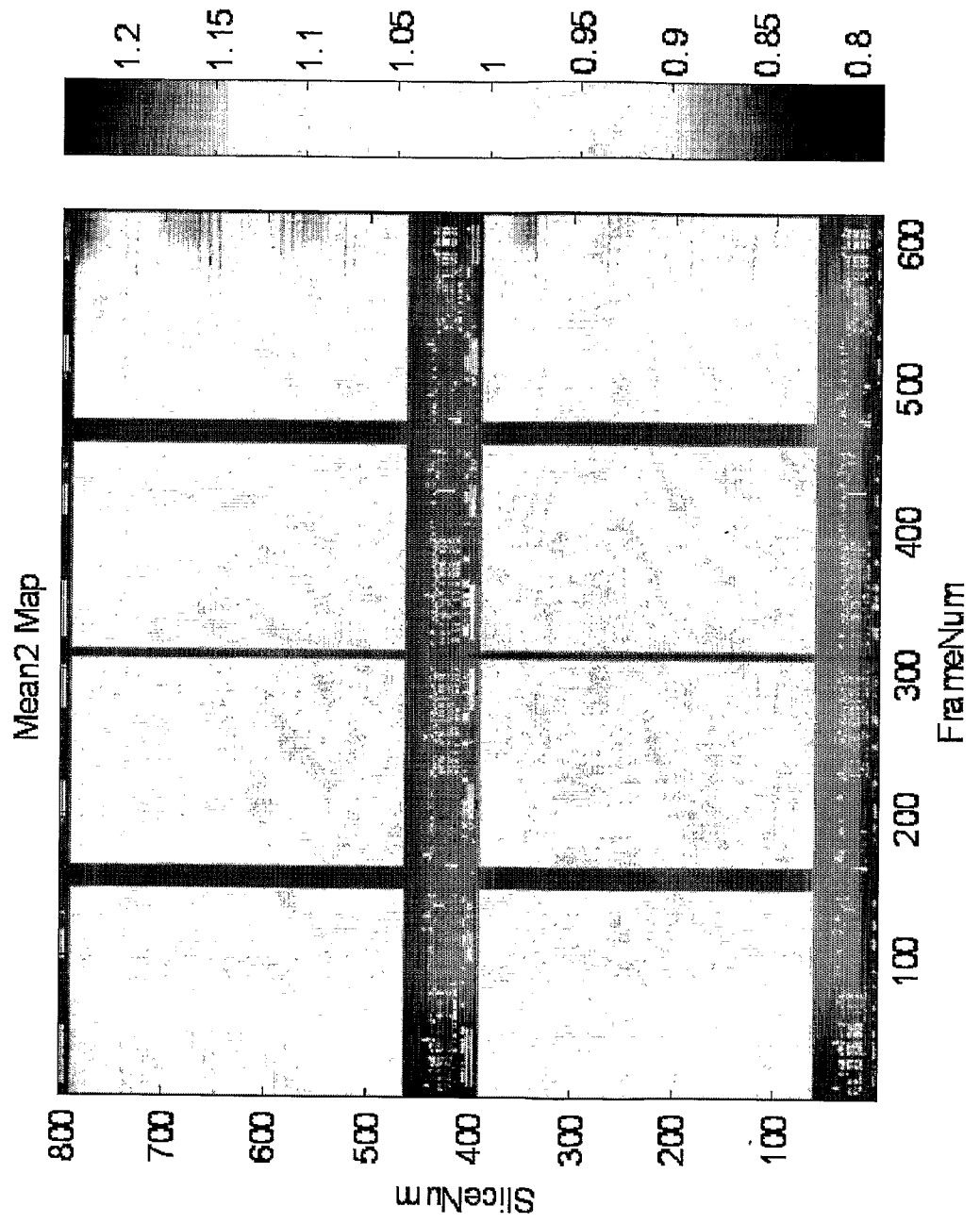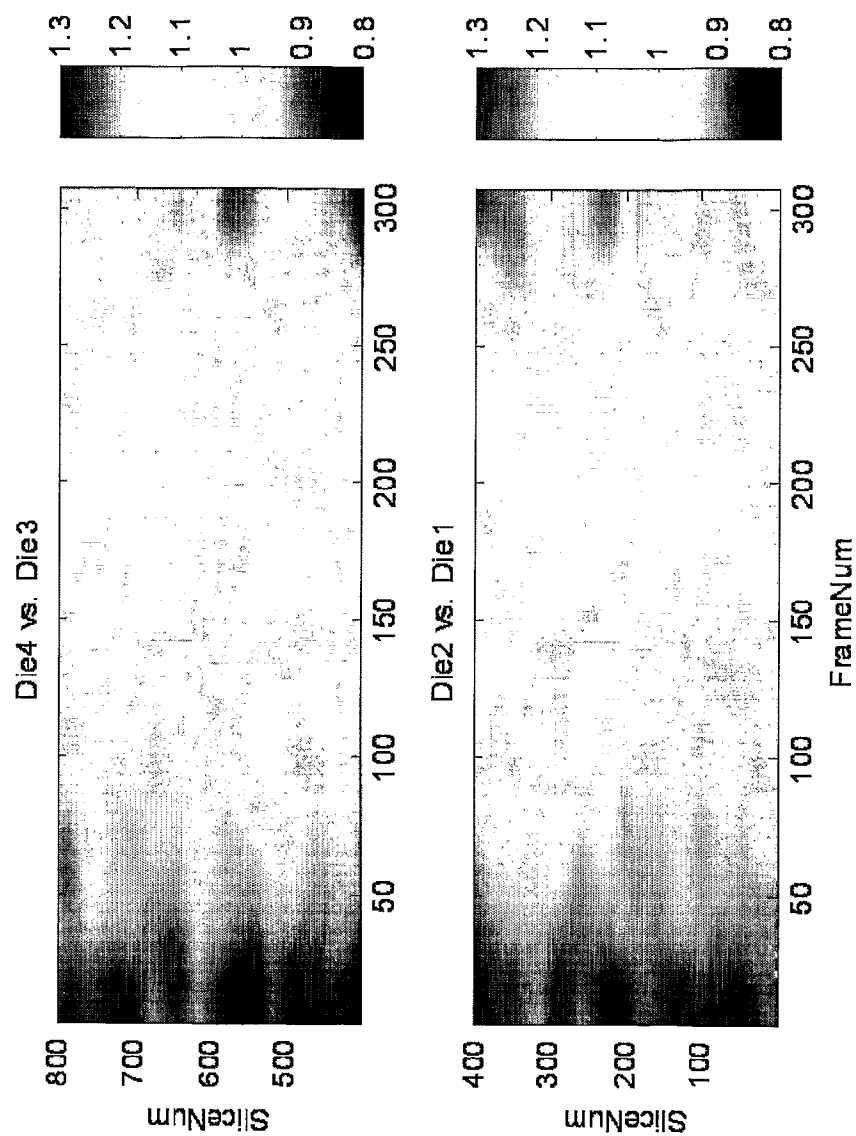Memory

104

Pattern
Identification
Module

110

105

Basic Elements
Processor

106

Map Generator

Integral intensity
map indicative of
CD variation map

102A

Aerial Image
Scanner

102B

Image Grabber

102

*Fig. 1*

202

```
Pattern
Identification Data
```

201

```
Basic Element
Configuration
Data
```

203

```
Basic Elements Processor
```

204

```
Division of Aerial
Image into Basic
Elements
```

205

```
Selection of Basic
Elements Matching the
Reference Pattern
```

206

```
Summing of intensity
values across selected
Basic Elements
```
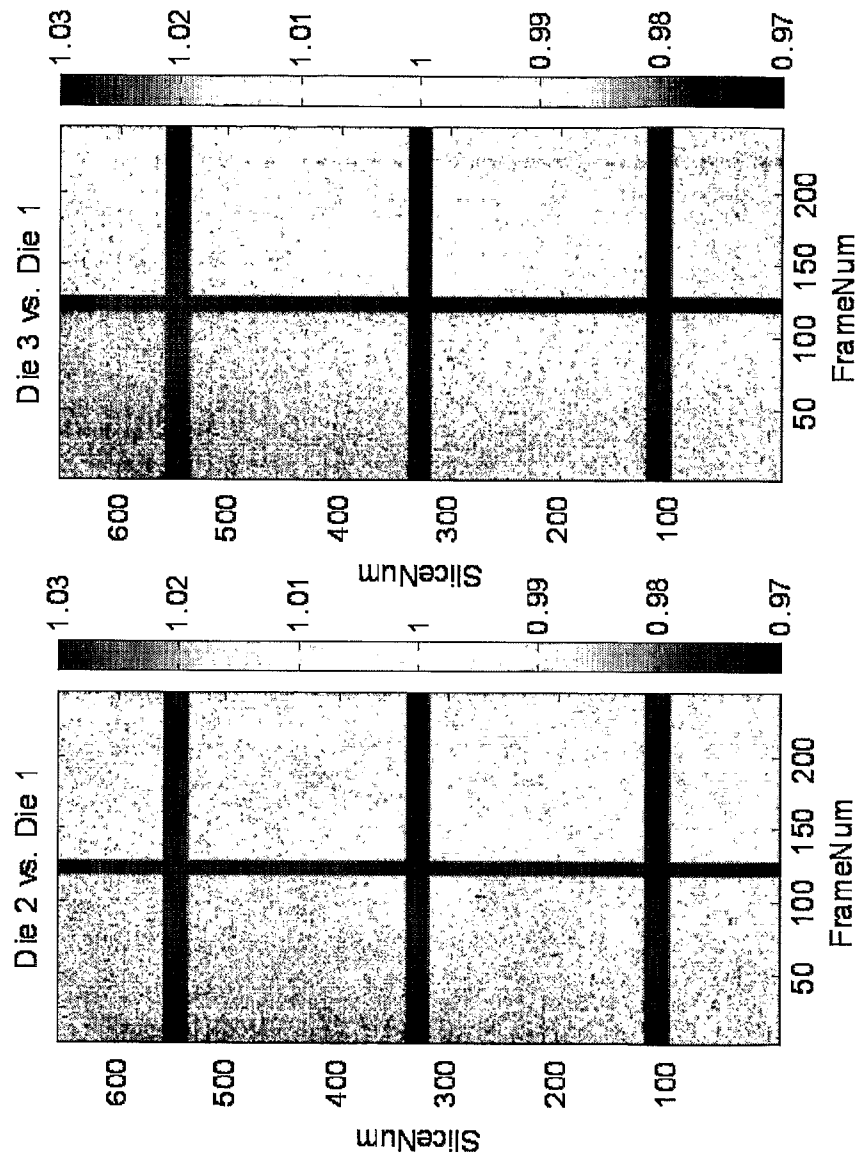
To Map Generator

*Fig. 2*

Fig. 3A

*Fig. 3B*

5/9



*Fig. 3C*

*Fig. 4A*

*Fig.4B*

*Fig. 4C*

*Fig. 5*



*Fig. 6*