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(54) Title: MOTION AND FOCUS BLUR REMOVAL FROM PATTERN IMAGES

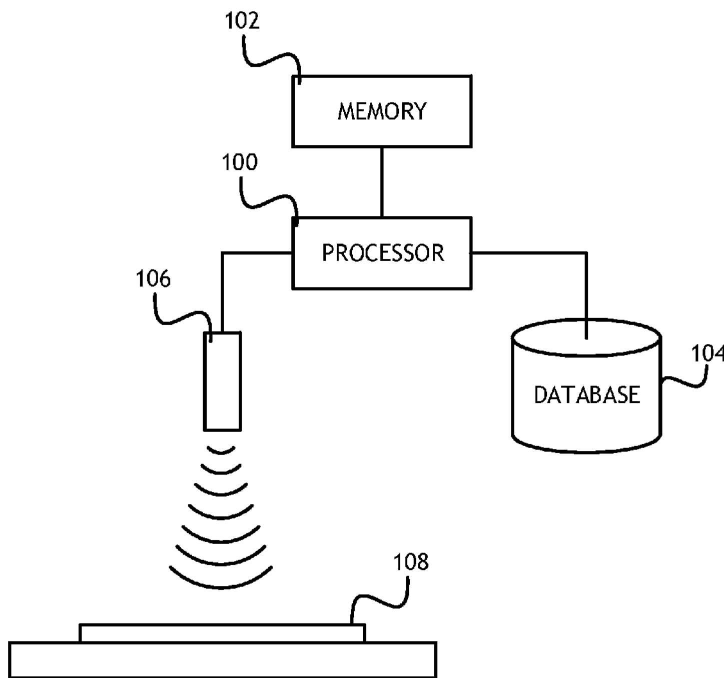

FIG. 1

(57) Abstract: A moving wafer imaging system processes wafer images to remove motion and focus blur by performing a blind deconvolution to determine an approximate point spread function. The approximate point spread function, estimated image noise and a Gaussian point spread function are used to compute a weighted point spread function. The weighted point spread function is used to filter out motion focus blur. Noise is then removed with a low-pass filter.

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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

MOTION AND FOCUS BLUR REMOVAL FROM PATTERN IMAGES

PRIORITY

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of United States Provisional Application Serial Number 61/904,366, filed November 14, 2013, which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention is directed generally toward wafer inspection, and more particularly toward removing error from a wafer inspection process.

BACKGROUND

[0003] As the demand for semiconductor devices increases the need for improved handling of semiconductor characterization data also increases. Wafer inspection data is commonly acquired via optical inspection tools from one or more wafer processing tools of semiconductor device fabrication lines. This acquired inspection data may be used to track the quality of fabricated semiconductor devices at each step of the semiconductor device production process, allowing a user to reject sub-standard devices and/or adjust the fabrication process in order to bring subsequently process devices within a selected tolerance level. The volume of wafer processing is generally very large and in-line inspection tools must accommodate wafers moving at speed.

[0004] In all systems (tools) used for defect detection and defect classification the wafer is aligned to one or both axes of the stage prior to making any measurements on the wafer. To be able to align the wafer, pattern matching is performed between a unique feature in the field of view and a template saved in the recipe.

[0005] To be able to perform a successful pattern match between a template and a unique feature on a wafer that is in the field-of-view, the stage should not be in

motion and the wafer should be in focus so that a good quality image can be acquired. Stage motion and focusing the wafer are typically done sequentially.

[0006] Images collected when stage move is still in progress or is settling after the end of a move have both motion and focus blur. Such images cannot be used for pattern matching.

[0007] Consequently, it would be advantageous if an apparatus existed that is suitable for removing motion and focus blur from wafer inspection images.

SUMMARY

[0008] Accordingly, the present invention is directed to a novel method and apparatus for removing motion and focus blur from wafer inspection images.

[0009] In at least one embodiment, a process for removing motion and focus blur from a wafer image includes performing a blind deconvolution to determine an approximate point spread function. The approximate point spread function, estimated image noise, and a Gaussian point spread function are used to compute a weighted point spread function. The weighted point spread function is used to filter out motion focus blur.

[0010] In another embodiment, a moving wafer imaging system processes wafer images by applying a Weiner filter with a weighted point spread function and a low-pass filter to remove noise. The weighted point spread function is based on an approximate point spread function, a Gaussian point spread function, and estimated image noise.

[0011] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention claimed. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate an embodiment of the invention and together with the general description, serve to explain the principles.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The numerous advantages of the present invention may be better understood by those skilled in the art by reference to the accompanying figures in which:

FIG. 1 shows a block diagram of an in-line wafer inspection system suitable for implementing embodiments of the present invention;

FIG. 2 shows a flowchart of a method for wafer inspection according to at least one embodiment of the present invention;

DETAILED DESCRIPTION

[0013] Reference will now be made in detail to the subject matter disclosed, which is illustrated in the accompanying drawings. The scope of the invention is limited only by the claims; numerous alternatives, modifications and equivalents are encompassed. For the purpose of clarity, technical material that is known in the technical fields related to the embodiments has not been described in detail to avoid unnecessarily obscuring the description.

[0014] Embodiments of the present invention may allow images of a wafer, taken while the wafer is in motion and before the imaging device is focused, to be used in pattern matching. An image is captured of a moving wafer, before the wafer is settled and the imaging device is completely focused. The image is then processed via a weighed deconvolution based on estimated image noise, a Gaussian point spread function, and an approximate point spread function.

[0015] A unique feature is chosen during recipe train time and is saved in the recipe as the template to use for pattern matching. The template is saved in the recipe using wafer co-ordinates. The template can also be a synthetic image that is generated offline and saved in the recipe. When a synthetic image is used as the template, the original co-ordinates determined during train time are used to navigate to the location where the pattern match is performed.

[0016] Referring to FIG. 1, a block diagram of an in-line wafer inspection system suitable for implementing embodiments of the present invention is shown. A system according to embodiments of the present invention may include a processor 100 configured for digital image processing. The processor 100 may be part of a larger wafer imaging system or incorporated into a wafer imaging device 106. The wafer imaging device 106 may be configured to brightfield or darkfield inspection, or any other suitable wafer image inspection process.

[0017] In at least one embodiment, a processor 100 executing computer executable program code stored in a memory device 102 may receive a wafer image from a wafer imaging device 106. The wafer imaging device 106 images moving wafers 108. Movement of the wafer 108 and minor variations in focus of the wafer imaging device 106 may cause blurring in the resulting image. The processor 100 may process the resulting images to remove or mediate motion and focus blur.

[0018] Referring to FIG. 2, a flowchart of a method for wafer inspection according to at least one embodiment of the present invention is shown. Once a stage has reached a location, before the stage settles, where pattern match is to be performed, the stage co-ordinates are saved in a log. The saved location may be used as the starting point for navigation to the next die.

[0019] In at least one embodiment, an image processing system receives 200 blurred images of a moving wafer and processes the image to remove motion and focus blur.

[0020] In at least one embodiment, the image processing system estimates 202 image noise. In one embodiment, image noise estimation 202 may be based on known properties of the fabrication process. For example, known properties of the fabrication process may include the speed of the wafer. In another embodiment, image noise estimation 202 may be based on known properties of the environment, such as light levels. In another embodiment, image noise estimation 202 may be

based on known properties of the imaging system, such as inherent qualities of the imaging device; noise level data accumulated over a period of use; or any other noise relevant factors.

[0021] In at least one embodiment, the image processing system also performs 204 a blind deconvolution on the blurred image. Deconvolution is an algorithm-based process used to reverse the effects of convolution on recorded data. Blind deconvolution refers to a deconvolution process without explicit knowledge of the point spread function (impulse response function) that caused the convolution. In at least one embodiment, based on the blind deconvolution, the image processing system identifies 206 an approximate point spread function.

[0022] A point spread function describes the response of an imaging system to a point source or point object. The point spread function may be thought of as the extended optical representation of an unresolved object in an image. In functional terms the point spread function is the spatial domain version of the transfer function of the imaging system. It is noted herein that the point spread function is a useful concept in Fourier optics, astronomical imaging, electron microscopy and other imaging techniques such as 3D microscopy (e.g. confocal laser scanning microscopy) and fluorescence microscopy. The degree of spreading of the point object is a measure for the quality of an imaging system. In non-coherent imaging systems such as fluorescent microscopes, telescopes, or optical microscopes, the image formation process is linear in power and described by linear system theory such that when two objects are imaged simultaneously, the result is equal to the sum of the independently imaged objects. The image of a complex object can then be seen as a convolution of the true object and the point spread function. However, when the detected light is coherent, image formation is linear in the complex field. Recording the intensity image then can lead to cancellations or other non-linear effects.

[0023] In at least one embodiment, the image processing system may determine

208 a modified Gaussian point spread function. The modified Gaussian point spread function may be a normalized statistical representation of the blur caused by the point spread function.

[0024] In at least one embodiment, the image processing system may calculate 210 a weighted point spread function based on at least one of the estimated image noise, the approximate point spread function, and the modified Gaussian point spread function. In at least one embodiment, the image processing system may apply predetermined weights to each of the components or dynamically determine weights based on features of the imaging system and wafer processing system that favor certain components over others. In at least one embodiment, the image processing system may then apply 212 a Weiner filter based on the weighted point spread function to deconvolve the original image. In signal processing, a Wiener filter is a filter used to produce an estimate of a desired random process by linear time-invariant filtering of an observed noisy process, assuming known stationary signal and noise spectra, and additive noise. A Wiener filter minimizes the mean square error between the estimated random process and the desired process.

[0025] In at least one embodiment, the image processing system may remove 214 noise from the deconvolved image with a low-pass filter, and output 216 the improved image.

[0026] Embodiments of the present invention reduce wafer alignment time because an image can be acquired before a stage has settled and the imaging device is focused, increasing the throughput of the wafer processing tool. The method can also be used in cases where the image is not focused completely due to incorrect focus calibration.

[0027] It is believed that the present invention and many of its attendant advantages will be understood by the foregoing description of embodiments of the present invention, and it will be apparent that various changes may be made in the

form, construction, and arrangement of the components thereof without departing from the scope and spirit of the invention or without sacrificing all of its material advantages. The form herein before described being merely an explanatory embodiment thereof, it is the intention of the following claims to encompass and include such changes.

CLAIMS

What is claimed is:

Claim 1. A semiconductor wafer inspection method comprising:

performing an image capture of a moving wafer with a wafer imaging device;

calculating, with a processor, a weighted point spread function based on one or more of an approximate point spread function, a Gaussian point spread function, and an estimated image noise value; and

performing, with the processor, a deconvolution on the image based on the weighted point spread function.

Claim 2. The method of Claim 1, wherein the deconvolution comprises applying a Weiner filter.

Claim 3. The method of Claim 1, further comprising applying, with the processor, a low-pass filter to remove noise.

Claim 4. The method of Claim 1, wherein the weighted point spread function comprises the approximate point spread function, the approximate point spread function being derived by a blind deconvolution.

Claim 5. The method of Claim 1, wherein the weighted point spread function comprises the modified Gaussian point spread function, the modified Gaussian point spread function being a statistical distribution of blur derived from a point source.

Claim 6. The method of Claim 5, wherein the weighted point spread function further comprises the approximate point spread function, the approximate point spread function being derived by a blind deconvolution.

Claim 7. The method of Claim 1, further comprising pattern matching the deconvolved image to a template.

Claim 8. A wafer inspection system comprising:

a processor;

a wafer imaging device connected to the processor; and

computer executable program code configured to instruct the processor to:

perform an image capture of a moving wafer with the wafer imaging device;

calculate a weighted point spread function based on one or more of an approximate point spread function, a Gaussian point spread function, and an estimated image noise value; and

perform a deconvolution on the image based on the weighted point spread function.

Claim 9. The wafer inspection system of Claim 8, wherein the deconvolution comprises applying a Weiner filter.

Claim 10. The wafer inspection system of Claim 8, wherein the computer executable program code is further configured to instruct the processor to apply a low-pass filter to remove noise.

Claim 11. The wafer inspection system of Claim 8, wherein the weighted point spread function comprises the approximate point spread function, the approximate point spread function being derived by a blind deconvolution.

Claim 12. The wafer inspection system of Claim 8, wherein the weighted point spread function comprises the modified Gaussian point spread function, the modified Gaussian point spread function being a statistical distribution of blur derived from

a point source.

Claim 13. The wafer inspection system of Claim 12, wherein the weighted point spread function further comprises the approximate point spread function, the approximate point spread function being derived by a blind deconvolution.

Claim 14. The wafer inspection system of Claim 8, wherein the computer executable program code is further configured to instruct the processor to pattern match the deconvolved image to a template.

Claim 15. A computer apparatus for processing semiconductor wafer images comprising:

a processor;

memory connected to the processor;

a data storage element connected to the processor;

a wafer imaging device connected to the processor; and

computer executable program code, stored in the memory, configured to instruct the processor to:

perform an image capture of a moving wafer with the wafer imaging device;

calculate a weighted point spread function based on one or more of an approximate point spread function, a Gaussian point spread function, and an estimated image noise value; and

perform a deconvolution on the image based on the weighted point spread function.

Claim 16. The computer apparatus of Claim 15, wherein the deconvolution comprises applying a Weiner filter.

Claim 17. The computer apparatus of Claim 15, wherein the computer executable program code is further configured to instruct the processor to apply a low-pass filter to remove noise.

Claim 18. The computer apparatus of Claim 15, wherein the weighted point spread function comprises the modified Gaussian point spread function, the modified Gaussian point spread function being a statistical distribution of blur derived from a point source.

Claim 19. The computer apparatus of Claim 18, wherein the weighted point spread function further comprises the approximate point spread function, the approximate point spread function being derived by a blind deconvolution.

Claim 20. The computer apparatus of Claim 15, wherein the computer executable program code is further configured to instruct the processor to pattern match the deconvolved image to a template stored in the data storage element.

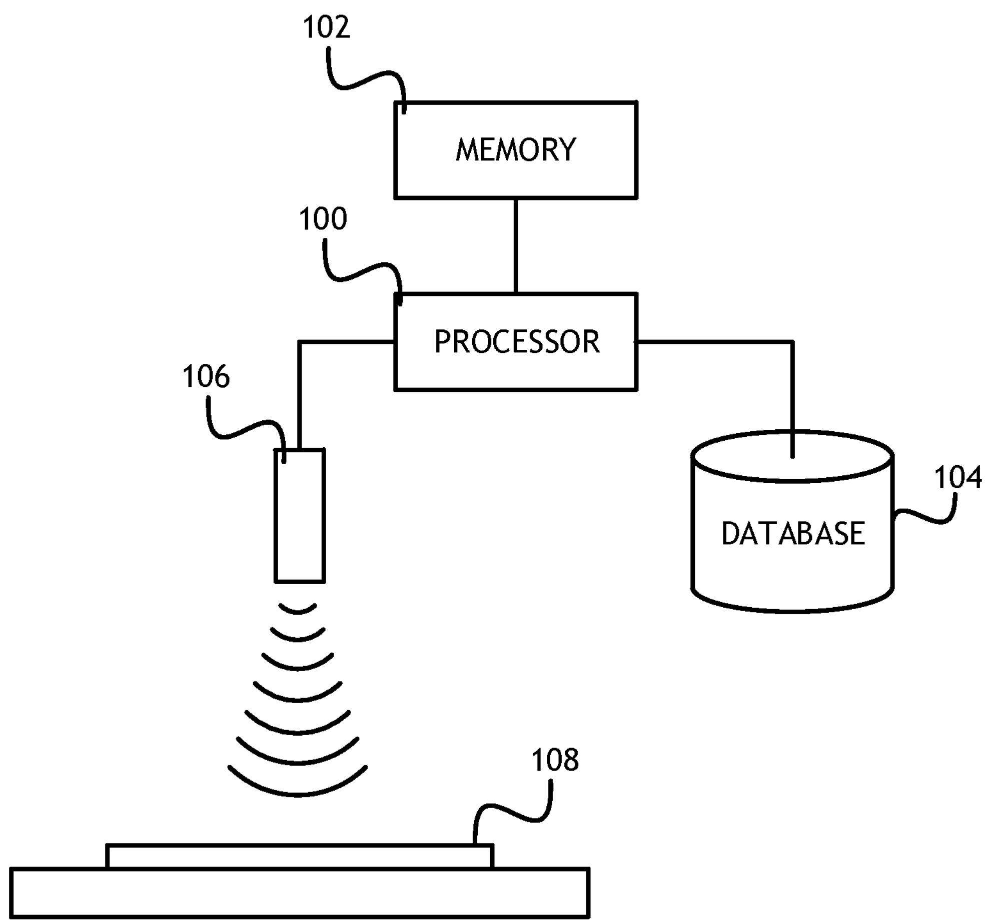

FIG. 1

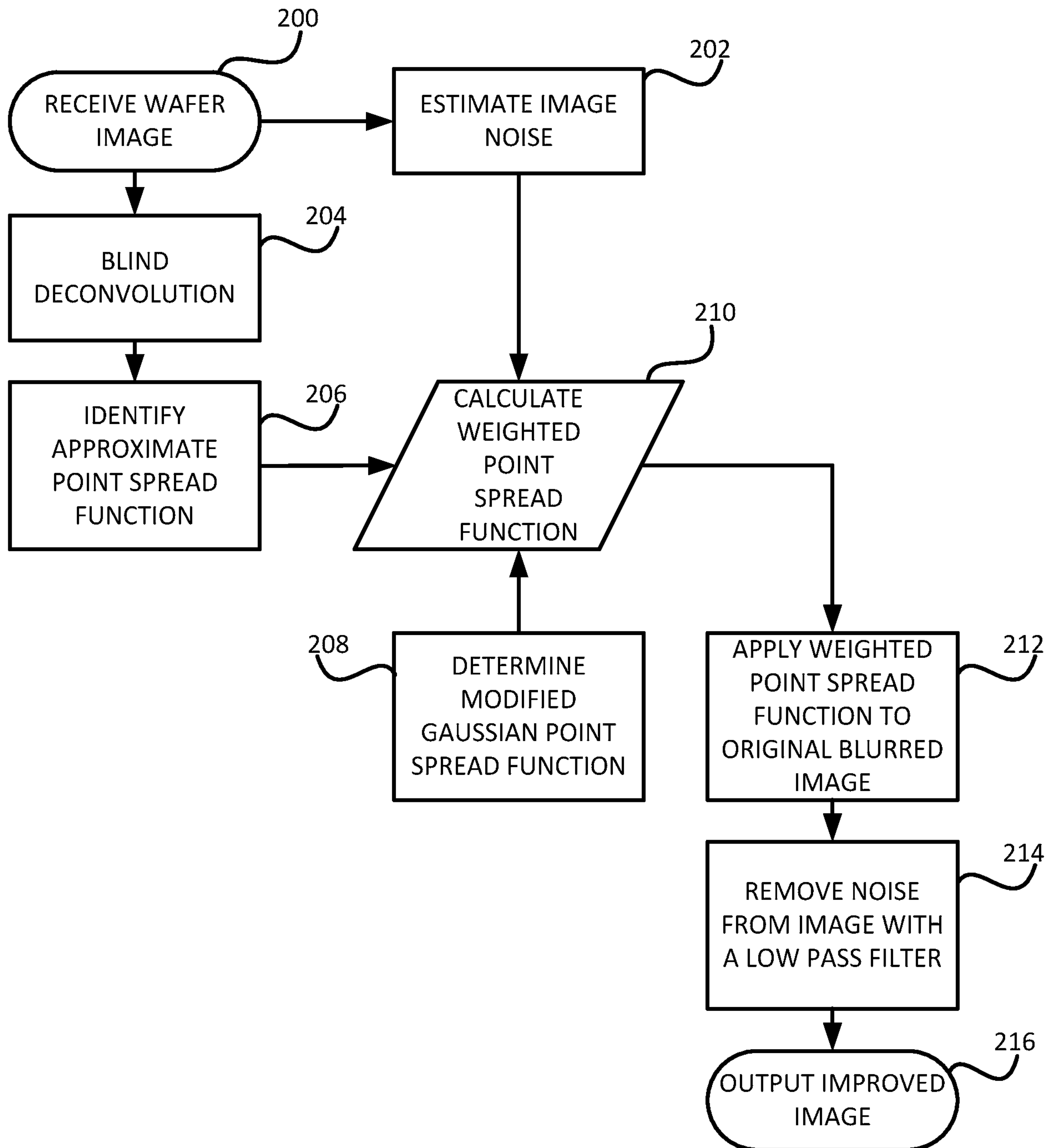

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/065555

A. CLASSIFICATION OF SUBJECT MATTER

H01L 21/66(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L 21/66; G06F 19/00; G06F 17/50; H04N 9/73; H04N 5/228; G06K 9/40; G06K 9/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: wafer, image, spread function, deconvolution, filter

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2008-0162061 A1 (HIROYOSHI MIYANO) 03 July 2008 See abstract, paragraphs [0003], [0033]-[0100], [0189]-[0192] and figure 4.	1,3-8,10-15,17-20 2,9,16
Y	US 2013-0227500 A1 (KYOHEI SAKAJIRI et al.) 29 August 2013 See abstract, paragraph [0019] and figures 11A-11D.	2,9,16
A	US 2011-0090352 A1 (SEN WANG et al.) 21 April 2011 See abstract, paragraphs [0048]-[0059] and figures 2-4.	1-20
A	US 2011-0128407 A1 (DAN LELESCU et al.) 02 June 2011 See abstract, paragraphs [0040]-[0054] and figure 1.	1-20
A	US 2007-0177799 A1 (ANASTASIA TYURINA) 02 August 2007 See abstract, paragraphs [0036]-[0049] and claims 1-3.	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

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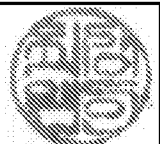

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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