US 20060066842A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0066842 A1**

Saunders et al. (43) **Pub. Date: Mar. 30, 2006**

(54) **WAFER INSPECTION WITH A CUSTOMIZED REFLECTIVE OPTICAL CHANNEL COMPONENT**

(76) Inventors: **Winston A. Saunders**, Hillsboro, OR (US); **James S. Clarke**, Portland, OR (US)

Correspondence Address:
BLAKELY SOKOLOFF TAYLOR & ZAFMAN
12400 WILSHIRE BOULEVARD
SEVENTH FLOOR
LOS ANGELES, CA 90025-1030 (US)

(21) Appl. No.: **10/956,288**

(22) Filed: **Sep. 30, 2004**

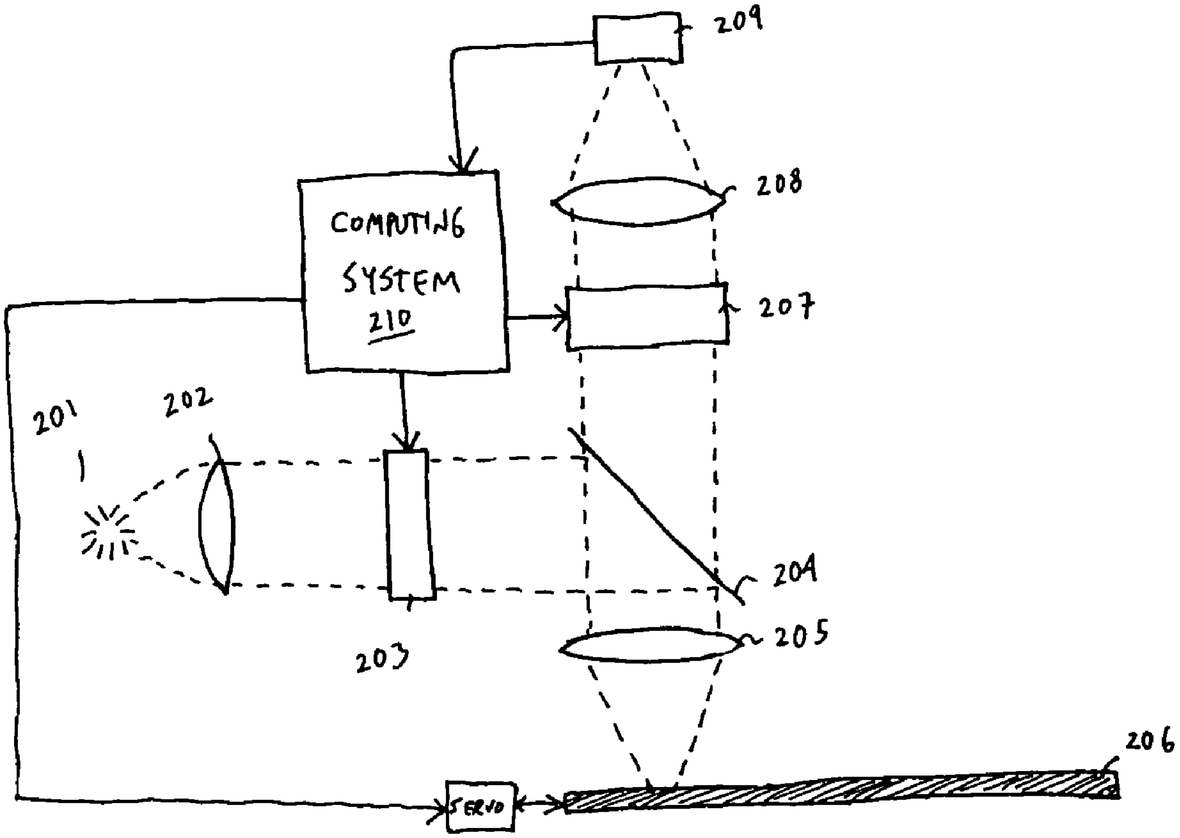
Publication Classification

(51) **Int. Cl.**
G01N 21/88 (2006.01)

(52) **U.S. Cl.** **356/237.1**

(57) **ABSTRACT**

A method is described that adjusts the position of a item and sets a tilt angle for each of a plurality of micro-mirrors of a digital micro-mirror device. The setting of the tilt angles is to establish a filter within the optical channel of an inspection tool that inspects the item. The filter is to reduce noise received at an optical detection device. The tilt angle settings are a function of the position. The method also includes comparing information from the optical detection device that describes an inspected region of the item's surface against an expected version of the information.



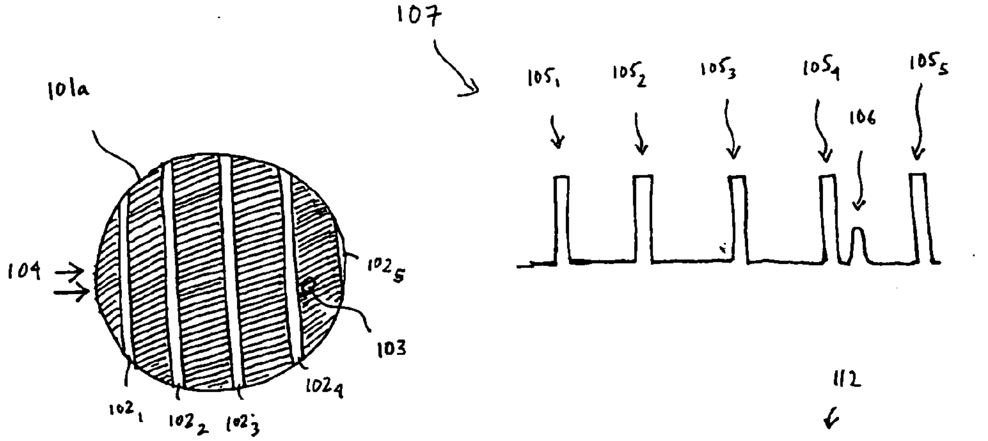

107
105_1
105_2
105_3
105_4
105_5
106
101a
104
102_5
103
102_1
102_2
102_3
102_4

FIG. 1A

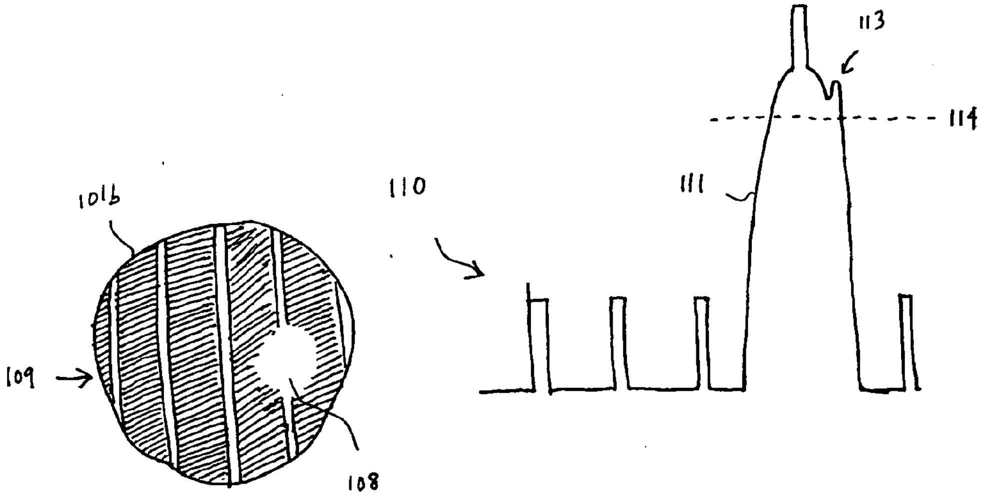

112
113
114
111
110
101b
109
108

FIG. 1B

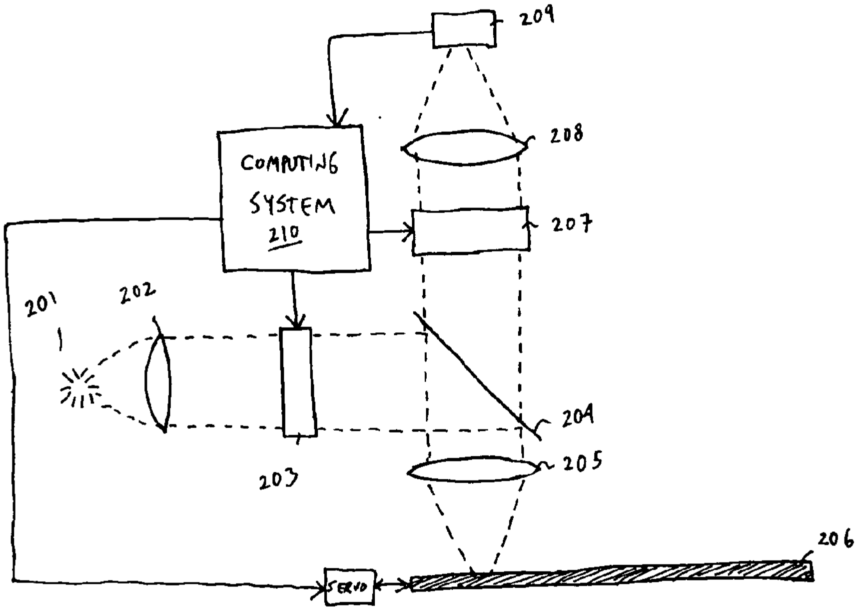


FIG. 2

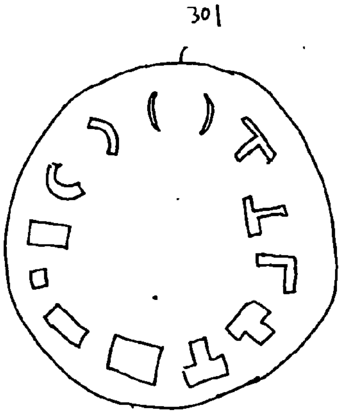


FIG. 3A

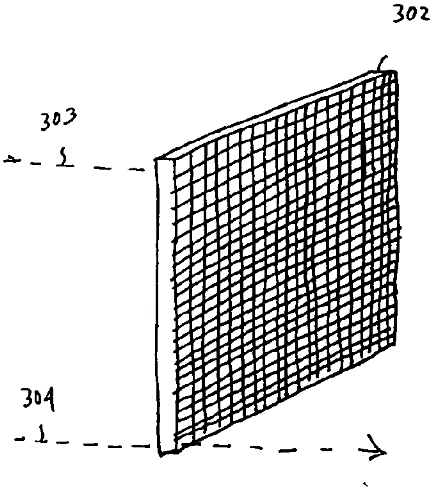


FIG. 3B

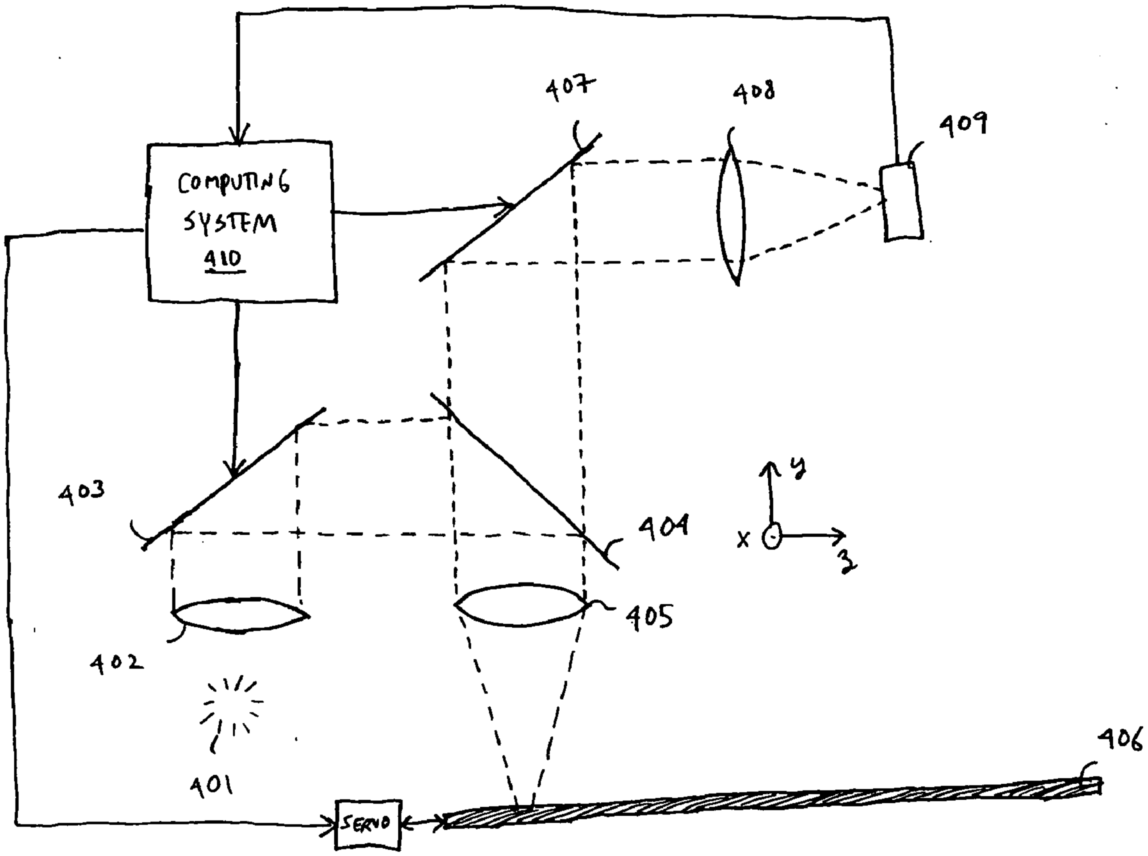

COMPUTING SYSTEM 410
407
408
409
403
404
405
402
401
406
SERVO
y
x
z

FIG. 4

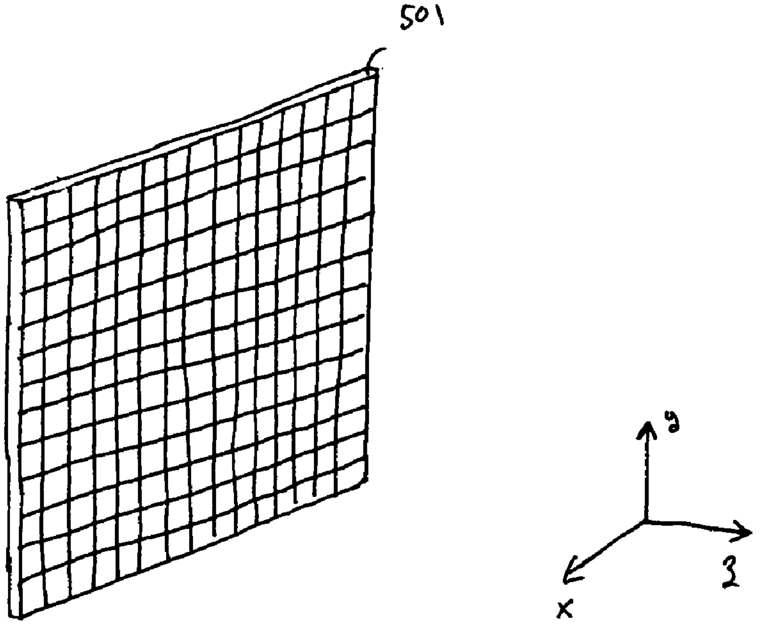


FIG. 5A

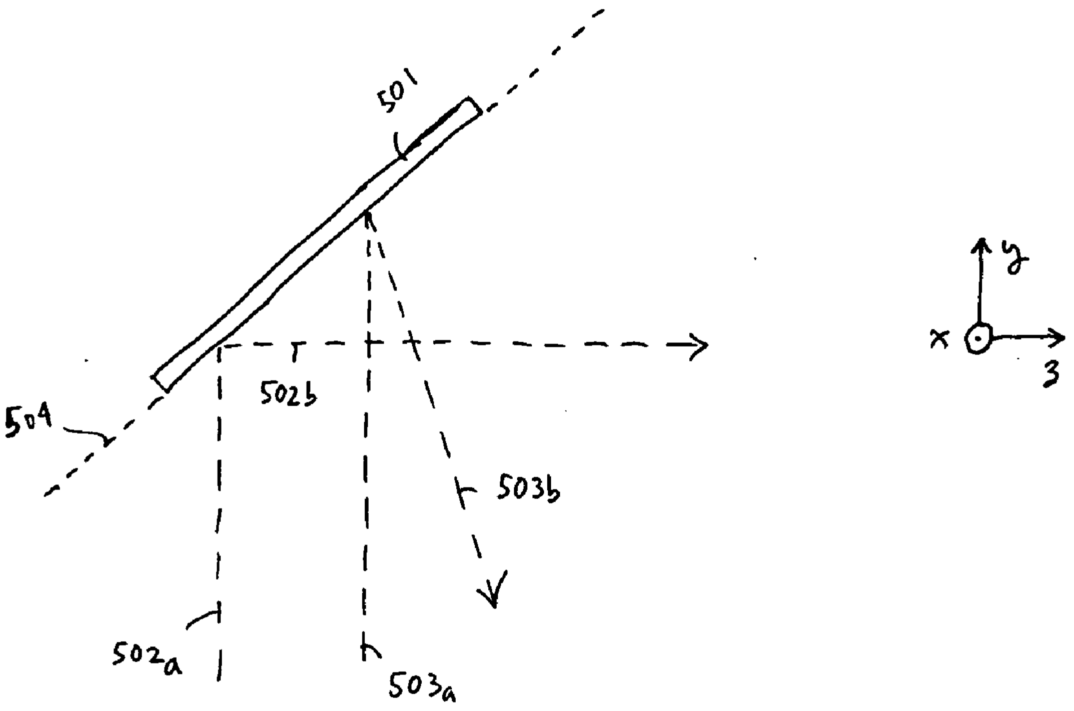


FIG. 5B

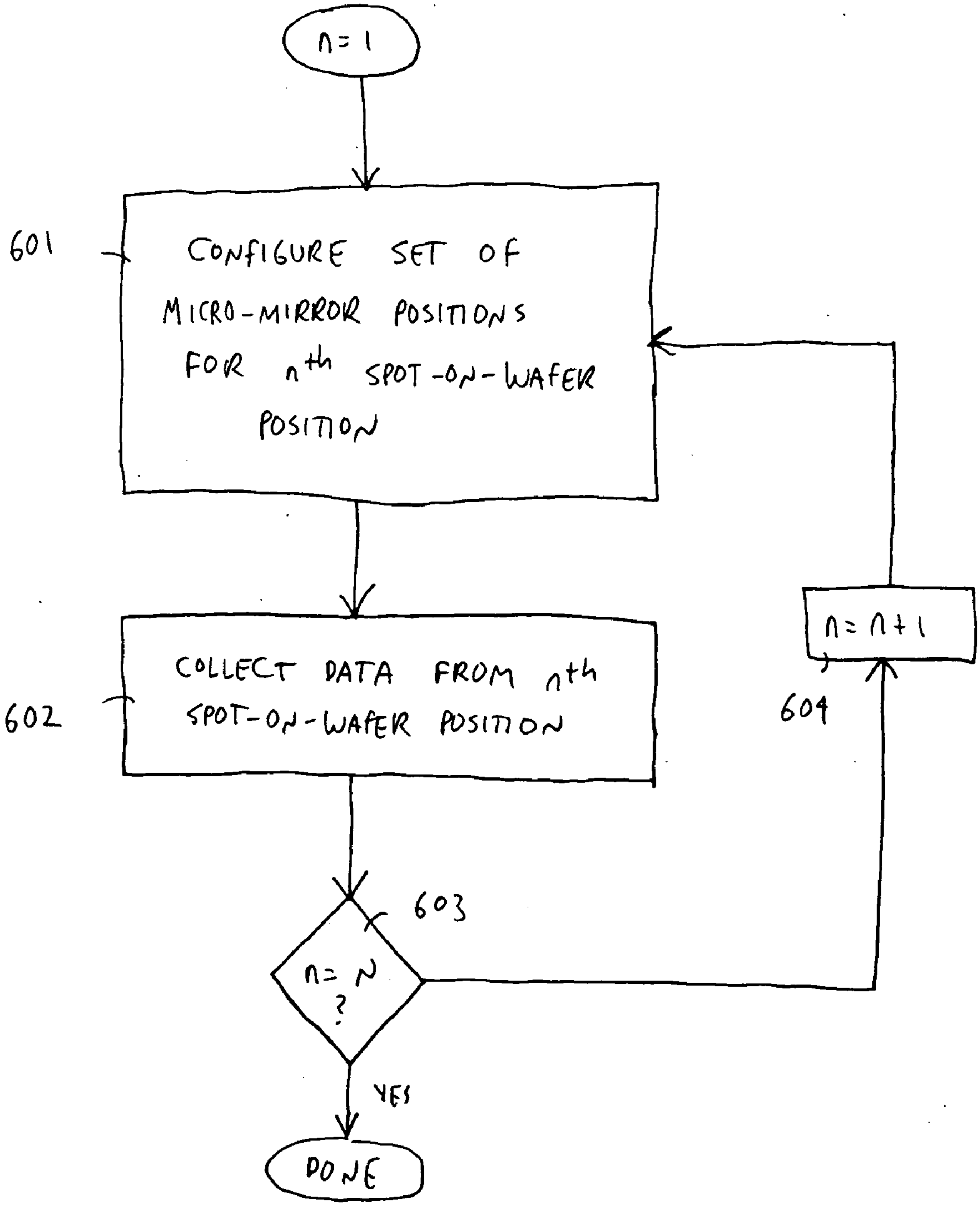

n=1
601
CONFIGURE SET OF MICRO-MIRROR POSITIONS FOR nth SPOT-ON-WAFER POSITION
602
COLLECT DATA FROM nth SPOT-ON-WAFER POSITION
603
n=N ?
YES
DONE
n=n+1
604

FIG. 6

WAFER INSPECTION WITH A CUSTOMIZED REFLECTIVE OPTICAL CHANNEL COMPONENT

FIELD OF INVENTION

[0001] The field of invention relates generally to wafer inspection, and, more specifically, to wafer inspection with a customized reflective optical channel component.

BACKGROUND

[0002] In the semiconductor arts multi-layer structures are created upon semiconductor wafers that comprise electrically conductive lines and vias surrounded by one or more electrically insulating dielectric layers. The lines, vias and dielectric layers may be said to be "pattered" into specific structures that implement specific circuitry. Because the dimensions of these patterns can be extremely small (e.g., current mass production technologies can reduce features to as small as 90 nm across), the impact of a manufacturing defect is becoming more important as is the difficulty in detecting it.

[0003] In order to detect manufacturing defects optically, a spot of light is focused on a region of the wafer's patterned structures. The reflected image of the patterned structure is captured through an optical channel and resolved on an optical detection device such as a photodetector or charge coupled device (CCD). Data produced by the optical detection device is then compared against "expected data"; where, the expected data corresponds to the data from the optical detection device if the manufactured patterns illuminated by the focused spot of light were properly manufactured.

[0004] **FIGS. 1***a* and **1***b* demonstrate a problem that exists with respect to the optical detection of a manufacturing defect. **FIG. 1***a* shows an example of a "noiseless" optical signal that is resolved to the optical detection device; and, **FIG. 1***b* shows an example of a "noisy" optical signal that is resolved to the optical detection device. Spot **101***a* corresponds to the illuminated spot of light that is focused on the wafer's structural patterns. As a simple example, the wafer's structural patterns are shown to include a repeating pattern of conductive lines $\mathbf{102}_1$ through $\mathbf{102}_5$ separated by a dielectric material region (which is drawn in **FIG. 1***a* as a shaded region).

[0005] Looking along axis **104**, a one-dimensional signal **107** should be resolved upon the optical detection device. Assuming the conductive lines have higher reflectivity of the focused spot of light than the dielectric material, enhanced optical intensity should be observed at the detector for the conductive lines as compared to the dielectric regions. Signal **107** indicates as much through optical intensity spikes $\mathbf{105}_1$ through $\mathbf{105}_5$ which are meant to correspond to conductive lines $\mathbf{102}_1$ through $\mathbf{102}_5$, respectively.

[0006] A manufacturing defect **103** is also observed in the image **101***a* of **FIG. 1***a*. This manufacturing defect may be the result of a thin layer of "spilled" conductive material, a "pit" or "void", etc. Whatever its form, the defect ultimately reproduces on the optical detection device as part of signal **107** with an intensityl **06** that is less than the intensity of the spikes $\mathbf{105}_1$ through $\mathbf{105}_5$ that are associated with the conductive lines $\mathbf{102}_1$ through $\mathbf{102}_5$.

[0007] **FIG. 1***b* shows an image **101***b* of the same region of the same wafer as depicted in **FIG. 1***a*, but with noise attributed to complications that arise from the optical processing of the reflected image from the wafer. Specifically, because the patterned structures on the wafer are "three dimensional" in the sense that the conductive lines $\mathbf{102}_1$ through $\mathbf{102}_5$ have "edges" that determine the lines' thickness, the light that reflects off of the wafer does not reflect uniformly off of the wafer surface. For example, a ray of light that impinges directly upon a flat portion of a conductive line may reflect perpendicular to the surface of the wafer while a ray of light that impinges at an edge of a conductive line may reflect at an angle other than perpendicular with the wafer surface (i.e., the angle of reflection is different for rays that impinge upon flat conductive line surfaces as opposed to conductive line edges).

[0008] As processed by the optical channel between the wafer and the optical detection device, the various components of light that reflect off of the wafer at varying angles depending on surface topography (and intensity depending on reflectivity) may constructively or de-constructively interfere so as to create bright or dark "noise" spots in the signal that is resolved on the optical detection device. **FIG. 1***b* shows such a bright noise spot **108** (also referred to as a "lobe") that might result, for instance, from the constructive interference of light reflected off of the edges of the conductive lines.

[0009] The portion **111** of the resolved signal **110** that corresponds to the lobe **108**, being a deviation from the noiseless signal **107**, corresponds to an item of noise that makes detection of the defect difficult or impossible. For example, with the lobe **108** being positioned around the defect itself, the resolved signal superimposes the intensity spikes **112**, **113** that correspond to conductive line $\mathbf{102}_4$ and defect **103**, respectively. At a minimum, owing to the intensity **111** of the lobe, it will more difficult to detect the signal from the defect **113** in **FIG. 1***b* as compared to the signal from defect **106** observed in **FIG. 1***a*. In an extreme case, if the lobe's intensity is beyond the saturation level **114** of the optical detector device, the defect will be impossible to detect (because the data from the optical detection device will clip at level **114**).

FIGURES

[0010] The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

[0011] **FIG. 1***a* shows a noiseless image for wafer defect inspection and a corresponding signal along a particular axis;

[0012] **FIG. 1***b* shows an exemplary noisy image for the wafer defect inspection of **FIG. 1***a* and a corresponding signal along the same axis;

[0013] **FIG. 2** shows a design for a wafer inspection tool;

[0014] **FIG. 3***a* shows an aperture wheel;

[0015] **FIG. 3***b* shows a liquid crystal array;

[0016] **FIG. 4** shows a wafer inspection tool that employs a digital micromirror device (DMD) as a filter;

[0017] **FIG. 5***a* shows a first perspective of a DMD;

[0018] **FIG. 5***b* shows a second perspective of a DMD;

[0019] **FIG. 6** shows a methodology that can be performed by the wafer inspection tool of **FIG. 4**.

DESCRIPTION

[0020] In order to address noise problems that result from the varying of reflective angles and reflectivity from a three dimensional patterned structure, engineers have attempted to impose filters in the optical processing channel used for optical defect detection. **FIG. 2** shows a depiction of an imaging system for detecting defects on a wafer **206**. A light source (e.g., a laser) **201** emits light that is collected by a lens **202**. The collected light travels through a filter **203** which filters the light as described in more detail further below.

[0021] The filtered light impinges upon a beam splitter **204** which directs the light toward the wafer **206** surface. The light from the beam splitter **204** is focused into a "spot" on the wafer **206** by a focusing lens **205**. The patterned features of the wafer **206** that are illuminated beneath the spot correspond to the features that are being inspected for a defect. Typically, the wafer **206** can be moved beneath the spot so that after a first region of the wafer is inspected, second and subsequent wafer regions can be inspected by adjusting the wafer position for each region to be inspected.

[0022] The light that is reflected from the wafer surface is collected and directed toward the optical detection device **209** (e.g., photodetector, charge coupled device (CCD) array, etc.). Along the optical channel between the wafer **206** and the optical detection device **209**, another filter **207** may exist (or, filter **207** may exist and filter **203** may not exist). The filters are configured to affect the light so as to reduce the noise that may be resolved onto the optical detection device **209**.

[0023] For example, considering the problem discussed above with respect to **FIG. 1***b*, filter **203** may be configured to filter out specific regions of light that that impinge on a conductive line edge and constructively interfere with other light (i.e., an attempt is made to filter out light that contributes to lobe **108**, **111** prior to focusing onto wafer **206**). Likewise, filter **207** may be configured to filter out specific regions of light that would otherwise constructively interfere with one another to form lobe **108**, **111** upon the optical detector **209**. By filtering out light that contributes to noise, the resolved signal at the detector will approach a "noiseless" signal (e.g., as depicted in **FIG. 1***a*) so as to make defect inspection easier.

[0024] Because each different region of the wafer that is inspected is expected to have "its own" patterned structure, and because the noise produced from reflected light is expected to exhibit differing features for differing patterned structures, the noise to be filtered out "changes" as a function of wafer position. For example, a first wafer region having conductive lines oriented along a "z" axis might produce a lobe at first position within the reflected image; while, a second wafer region having conductive lines oriented along an "x" axis might produce a lobe at a second position within the reflected image. The filtering profile of filters **203**, **207** must therefore be specially configured for each wafer position.

[0025] Filters **203**, **207** are therefore ideally capable of imposing different filtering characteristics that can be precisely specified. **FIG. 2** indicates that a computing system **210** which controls the wafer position is also used to set the filtering profile of each of the filters **203**, **207**. Here, the expected patterned structure beneath the focused light—and its corresponding noise—is known prior to the testing of the wafer **206**. As such, the computing system **210** can be programmed with the proper filtering profiles for each wafer position so that the noise that is created at each wafer position can be diminished at least to some degree.

[0026] **FIGS. 3***a* and **3***b* show different types of filters that have been used for the filters **203**, **207** discussed above. **FIG. 3***a* shows an aperture wheel **301** and **FIG. 3***b* shows a liquid crystal array **302**. The aperture wheel has a collection of different apertures around its circumference that each act as a filter having a specific filtering profile. Light is passed through a specific aperture by rotating the wheel such that the specific aperture is rotated into the light path.

[0027] **FIG. 3***b* shows an array **302** of liquid crystals. Each liquid crystal in the array **302** can have its optical transmissivity individually set (e.g., to pass light or to not pass light). For example as depicted in **FIG. 3***b*, the upper left liquid crystal in the array **302** is configured to not pass its incident light whereas the lower left liquid crystal in the array **302** is configured to pass its incident light.

[0028] A problem with the aperture wheel is that the number of apertures, and therefore the number of different filtering profiles that can be effected, is limited. The liquid crystal array **302**, although capable of a multitude of different filtering profiles owing to the discrete transmission control of its constituent liquid crystals, is expected to be less and less "workable" as the wavelength of the light from light source **201** is reduced in the coming years into the deep ultra violet (DUV) spectrum (so as to enable the detection of smaller wafer pattern features). Presently known liquid crystals are either highly absorptive or reflective in the DUV spectrum and therefore do not posses the transmission qualities for effecting a transmission filter as described just above with respect to **FIG. 3***b*.

[0029] A solution to these problems is to use a digital micro-mirror device (DMD) as a noise filter in an inspection tool. A DMD is an arrangement (e.g., an array) of small mirrors ("micro-mirrors"), where the tilt angle of each micro-mirror in the arrangement is capable of being individually set with digital information that is directed toward the DMD. Examples of DMDs include DLP™ DMDs from Texas Instruments, Inc. Because many materials are known to be reflective in the DUV spectrum, a DMD coated with one or more materials that are suitably reflective in the DUV spectrum should not experience a functional roll-off in the DUV spectrum as with liquid crystal arrays.

[0030] Moreover, because the tilt angle can be individually set for each mirror in the arrangement, the reflectivity of the DMD surface as a whole can be configured into a number of different filtering profiles. As such, the filtering profile variability associated with liquid crystal arrays is at least somewhat preserved but with workable functionality at least in the DUV spectrum. Even though aperture wheels are workable in the DUV spectrum, the limited selection of filtering profiles that is attainable with an aperture wheel should make a DMD based filter a better solution for filtering out the different types of noise profiles that may need to be filtered over the lifetime of the inspection tool.

[0031] **FIG. 4** shows a wafer inspection tool that employs DMD filters **403**, **407**. A light source (e.g., a laser, a lamp, etc.) **401** emits light that is collected by a lens **402**. The collected light travels through a DMD filter **403** which filters the light as described in more detail further below.

[0032] The filtered light impinges upon a beam splitter **404** which directs the light toward the wafer **406** surface. The light from the beam splitter **404** is focused into a "spot" on the wafer **406** by a focusing lens **405**. The patterned features of the wafer **406** that are illuminated beneath the spot correspond to the features that are being inspected for a defect. Like the system shown on **FIG. 2**, the wafer **406** can be moved beneath the spot so that after a first region of the wafer is inspected, second and subsequent wafer regions can be inspected by adjusting the wafer position for each region to be inspected.

[0033] The light that is reflected from the wafer surface is collected and directed toward the optical detection device **409**. Along the optical channel between the wafer **406** and the optical detection device **409**, another filter **407** may exist (or, filter **407** may exist and filter **403** may not exist). Like the system in **FIG. 2**, the filters are configured to affect the light so as to reduce the noise that may be resolved onto the optical detection device **409**. However, unlike the system of **FIG. 2**, the filters **403**, **407** use reflection—rather than transmission—as the mechanism by which light is passed through the channel.

[0034] **FIGS. 5***a* and **5***b* explore this aspect in more detail. **FIG. 5***a* shows the surface of a DMD device **501**. Note that the DMD surface is pixilated similar to that of a liquid crystal display. However, each pixel corresponds to a reflective mirror rather than a transmissive liquid crystal. Because the tilt angle of each mirror can be individually set, a first tilt angle can be used to reflect light so that it continues into the optical channel that is used to inspect the wafer; while, a second tilt angle can be used to reflect light so that it is reflected out of the optical channel that is used to inspect the wafer. Therefore, in order to establish a specific filtering profile, the mirrors that receive the regions of light that are intended to be filtered out are set to the second tilt angle; and, the mirrors that receive the regions of light that are not intended to be filtered out are set to the first tilt angle.

[0035] **FIG. 5***b* shows an example. The DMD device **501** of **FIG. 5***a* is shown oriented in **FIG. 5***b* at an angle that conforms to the position of DMD filter **403** of **FIG. 4**. Here, a tilt angle of 0° relative to the plane **504** of the DMD device **501** (i.e., a micro-mirror with its reflective surface lying along plane **504**) corresponds to a micro mirror being positioned to reflect its light into the optical channel. More specifically, referring to **FIGS. 4 and 5***b*, the plane of DMD filter **403**, **501** is oriented 45° relative to the z axis. As a consequence, any micro mirror having a tilt angle of 0° relative to the plane **504** of the DMD filter **403**, **501** will cause light **502***a* that is directed along the +y axis from light source **401** to be reflected along the +z axis **502***b* into beam splitter **404**. As such, a 0° tilt angle relative to the plane **504** of the DMD filter **403**, **501** corresponds to the "first" tilt angle defined above for those regions of light that are not supposed to be filtered out of the optical channel.

[0036] By contrast, micro mirrors oriented so as to face more toward the xz plane than the 0° tilt angle faces toward the xz plane will cause light **503***a* that is directed along the +y axis from light source **401** to be reflected **503***b* in the −y direction and out of the optical channel. As such, an orientation that faces more toward the xz plane than the 0° tilt angle corresponds to the "second" tilt angle described above for those regions of light that are supposed to be filtered out of the optical channel. The same analysis discussed above for DMD filter **403** also applies to DMD filter **407**.

[0037] Therefore specific filtering profiles can be established simply by setting to a fist tilt angle those micro-mirrors that receive light that is not supposed to be filtered out; and, setting to a second tilt angle those micro-mirrors that receive light that is supposed to be filtered out.

[0038] Similar to the discussion provided above with respect to the system shown in **FIG. 2**, because each different region of the wafer that is inspected is expected to have "its own" patterned structure, and because the noise produced from reflected light is expected to exhibit differing features for differing patterned structures, the noise to be filtered out "changes" as a function of wafer position. For example, a first wafer region having conductive lines oriented along the "z" axis might produce a lobe at first position within the reflected image; while, a second wafer region having conductive lines oriented along an "x" axis might produce a lobe at a second position within the reflected image. The filtering profile of filters **403**, **407** must therefore be specially configured for each wafer position.

[0039] Because each of the micro-mirrors of DMD filters **403**, **407** are capable of being individually adjusted the DMD filters **403**, **407** are capable of imposing different filtering characteristics that can be precisely specified. **FIG. 4** indicates that a computing system **410** which controls the wafer position is also used to set the filtering profile of each of the DMD filters **403**, **407** through the individual adjustment of their respective micro-mirrors (e.g., for each of the DMD filters **403**, **407**, a first group of micro mirrors are set to the above described "first" tilt angle and a second group of micro mirrors are set to the above described "second" tilt angle.

[0040] Here, as with the system in **FIG. 2**, the expected patterned structure beneath the focused light—and its corresponding noise—is known prior to the testing of the wafer **406**. As such, the computing system **410** can be programmed with the proper filtering profiles for each wafer position so that the noise that is created at each wafer position can be diminished at least to some degree.

[0041] **FIG. 6** shows a wafer inspection process that can be executed by the system observed in **FIG. 4**. The wafer inspection process may be implemented, at least in one embodiment, as program code that is executed upon the processing core of the computing system **410**. According to the process of **FIG. 6**, a set of micro-mirror positions are configured for a particular (nth) position on the wafer onto which the inspection light is focused **601**. If the system comprises two DMD filters (as observed in **FIG. 4**), the set includes the positions for both of the DMD filters.

[0042] In an embodiment, a first group of the set are configured to a first tilt angle that keeps light within the optical channel and a second group of the set are configured to a second tilt angle that reflects light out of the optical channel. The first DMD filter's first group and second group combination defines the first DMD filter's filtering profile.

The second DMD filter's first group and second group combination defines the second DMD filter's filtering profile.

[**0043**] The filtering should at least reduce to some degree the noise that is resolved to the optical detection device. The data from the optical detection device is collected **602** and, at some point, compared to data that represents the expected image at the nth wafer position. Deviations from the expected image and the collected data image are used to flag manufacturing defects. At least after the data is collected for the nth position wafer position, the wafer position is changed so that the focused light impinges upon the next wafer at a next wafer position **604** out of N total wafer positions **603**.

[**0044**] It should be noted that although the context of the above description has been directed to patterned semiconductor wafer inspection, the principles described herein can be applied to any item whose surface is to be inspected.

[**0045**] It is also to be understood that because embodiments of the methods of the present teachings may be implemented as one or more software programs, embodiments of the present teachings may be implemented or realized upon or within a machine readable medium. A machine readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine readable medium includes read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.); etc.

[**0046**] In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

1-4. (canceled)

5. A machine readable medium comprising program code that when executed on a computing system's processing core cause said computing system to perform a method, said method comprising:

adjusting the position of a item;

setting a tilt angle for each of a plurality of micro-mirrors of a digital micro-mirror device to establish a filter within the optical channel of an inspection tool that inspects said item, said filter to reduce noise received at an optical detection device, said tilt angle settings being a function of said position; and,

comparing information from said optical detection device that describes an inspected region of said item's surface against an expected version of said information.

6. The machine readable medium of claim 5 wherein said item is a semiconductor wafer comprising patterned features on its surface.

7. The machine readable medium of claim 5 wherein said method further comprises setting a tilt angle further comprises:

setting a first group of said micro-mirrors to a first tilt angle that reflects light into said optical channel;

setting a second group of said micro-mirrors to a second tilt angle that reflects light out of the optical channel.

8. The machine readable medium of claim 7 wherein said first tilt angle is 0° relative to the surface place of said digital micro-mirror device.

9. The machine readable medium of claim 5 wherein said method further comprises flagging a defect in said surface as a consequence of said comparing revealing a difference between said information and said expected version of said information.

10. The machine readable medium of claim 5 wherein said method further comprises:

setting a tilt angle for each of a plurality of micro-mirrors of a second digital micro-mirror device to establish a second filter within said optical channel, said second filter also to reduce noise received at said optical detection device, said tilt angle settings for said second digital micro-mirror device also being a function of said position.

11. The machine readable medium of claim 10 wherein said item is a semiconductor wafer comprising patterned features on its surface.

12. The machine readable medium of claim 10 wherein said method further comprises setting a tilt angle further comprises:

setting a first group of said micro-mirrors to a first tilt angle that reflects light into said optical channel;

setting a second group of said micro-mirrors to a second tilt angle that reflects light out of the optical channel.

13. The machine readable medium of claim 12 wherein said first tilt angle is 0° relative to the surface place of said digital micro-mirror device.

14. The machine readable medium of claim 10 wherein said method further comprises flagging a defect in said surface as a consequence of said comparing revealing a difference between said information and said expected version of said information.

15. The machine readable medium of claim 5 wherein said digital micro-mirror device is positioned at a location along said optical channel that resides between said optical channel's light source and said wafer.

16. The machine readable medium of claim 5 wherein said digital micro-mirror device is positioned at a location along said optical channel that resides between said wafer and said optical detection device.

17. A method, comprising:

adjusting the position of a item;

setting a tilt angle for each of a plurality of micro-mirrors of a digital micro-mirror device to establish a filter within the optical channel of an inspection tool that inspects said item, said filter to reduce noise received at an optical detection device, said tilt angle settings being a function of said position; and, comparing information from said optical detection device that describes an inspected region of said item's surface against an expected version of said information.

18. The method of claim 17 wherein said item is a semiconductor wafer comprising patterned features on its surface.

19. The method of claim 17 wherein said method further comprises setting a tilt angle further comprises:

setting a first group of said micro-mirrors to a first tilt angle that reflects light into said optical channel;

setting a second group of said micro-mirrors to a second tilt angle that reflects light out of the optical channel.

20. The method of claim 19 wherein said first tilt angle is 0° relative to the surface place of said digital micro-mirror device.

21. The method of claim 17 wherein said method further comprises flagging a defect in said surface as a consequence of said comparing revealing a difference between said information and said expected version of said information.

22. The method of claim 17 wherein said method further comprises:

setting a tilt angle for each of a plurality of micro-mirrors of a second digital micro-mirror device to establish a second filter within said optical channel, said second filter also to reduce noise received at said optical detection device, said tilt angle settings for said second digital micro-mirror device also being a function of said position.

23. The method of claim 22 wherein said item is a semiconductor wafer comprising patterned features on its surface.

24. The method of claim 22 wherein said method further comprises setting a tilt angle further comprises:

setting a first group of said micro-mirrors to a first tilt angle that reflects light into said optical channel;

setting a second group of said micro-mirrors to a second tilt angle that reflects light out of the optical channel.

25. The method of claim 24 wherein said first tilt angle is 0° relative to the surface place of said digital micro-mirror device.

26. The method of claim 22 wherein said method further comprises flagging a defect in said surface as a consequence of said comparing revealing a difference between said information and said expected version of said information.

27. The method of claim 17 wherein said digital micro-mirror device is positioned at a location along said optical channel that resides between said optical channel's light source and said wafer.

28. The method of claim 17 wherein said digital micro-mirror device is positioned at a location along said optical channel that resides between said wafer and said optical detection device.

* * * * *