TRANSLATING DETECTED WAFER DEFECT COORDINATES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to the field of semiconductor manufacturing. More particularly, the invention relates to semiconductor inspection and measurement.

2. Discussion of the Related Art

Inspection and measurement are important areas of semiconductor manufacturing. Measurement may be defined as the ability to precisely quantify physical, dimensional, or electrical properties of different materials. Numerous measurement tools are routinely used to monitor the quality of semiconductor manufacturing processes. Inspection relates to the ability to observe and quantify defects, and inspection tools include a variety of optical instruments used for these purposes. In sub-micron applications, inspection equipment such as scanning electrical microscopes (SEMs) are widely used.

As geometries get smaller, the ability to observe defects in wafers and reticles (masks) becomes more challenging and expensive. Existing wafer and reticle inspection tools find defects which can only be disposed when their location is understood. Typically, engineers spend many hours or days attempting to determine the location of defects in order to be able to classify and judge their impact on production yield. Consequently, defects are often disposed without regard to their location but rather only to its size.

Thus, there is a need for a method and apparatus for defect location, minimizing engineering defect reduction efforts, and improving the forecast of measures such as production yield.

SUMMARY OF THE INVENTION

There is a need for the following embodiments. Of course, the invention is not limited to these embodiments.

In accordance with one embodiment of the invention, defects in a device under test are located using CAD data for the device under test. An inspection image is provided of a device under test and coordinates of potential defects in the device under test are determined. Then the inspection image is converted into a predetermined image format. CAD data for the device under test is then used to produce a second image, also in the predetermined image format. The

CAD-derived image and the device-derived image are then aligned, and the coordinates of potential defects in the wafer are converted into CAD coordinates. The CAD coordinates are then used to navigate through the reticle for the wafer in order to located reticle defects corresponding to the detected wafer defects.

According to another aspect of the invention, an apparatus includes a stage for holding a wafer under test, an image and defect detection device coupled to the stage for producing an inspection image of the wafer under test and for producing stage coordinates of defects detected in the wafer under test, CAD data for the wafer under test, a control unit coupled to control the stage and the image and defect detection device, and a synchronization unit coupled to the control unit and to the image and defect detection device, for converting stage coordinates of defects in the wafer under test into wafer reticle coordinates as a function of both the inspection image of the wafer under test and the CAD data.

These, and other, embodiments of the invention will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following description, while indicating various embodiments of the invention and numerous specific details thereof, is given by way of illustration and not of limitation. Many substitutions, modifications, additions and/or rearrangements may be made within the scope of the invention without departing from the spirit thereof, and the invention includes all such substitutions, modifications, additions and/or rearrangements.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings accompanying and forming part of this specification are included to depict certain aspects of the invention. A clearer conception of the invention, and of the components and operation of systems provided with the invention, will become more readily apparent by referring to the exemplary, and therefore nonlimiting, embodiments illustrated in the drawings, wherein like reference numerals (if they occur in more than one view) designate the same or similar elements. The invention may be better understood by reference to one or more of these drawings in combination with the description presented herein. It should be noted that the features illustrated in the drawings are not necessarily drawn to scale.

FIG. 1 is an image of a wafer, illustrating an aspect of the invention.

FIG. 2 is an image of a reticle, illustrating an aspect of the invention.

FIG. 3 is an image of a repeater defect spread across different reticle fields, illustrating an embodiment of the invention.

FIG. 4 is a block diagram of a semiconductor inspection apparatus, representing an embodiment of the invention.

FIG. 5 is a flowchart of a translation method, representing an embodiment of the invention.

FIG. 6 is a synchronized CAD and wafer image, illustrating an aspect of the invention.

DETAILED DESCRIPTION

The invention and the various features and advantageous details thereof are explained more fully with reference to the nonlimiting embodiments that are illustrated in the accompanying drawings and detailed in the following description. It should be understood that the detailed description and the specific examples, while indicating specific embodiments of the invention, are given by way of illustration only and not by way of limitation. Various substitutions, modifications, additions and/or rearrangements within the spirit and/or scope of the underlying inventive concept will become apparent to those of ordinary skill in the art from this disclosure.

During inspection of wafers in a fabrication facility, repeater defects or anomalies may show up from time to time. Repeater defects are defects that are repeated in each reticle field of a wafer, and may be due to, for example, problems with the reticle mask or plate. When wafer defects are repeated from one reticle field to another, an inspection tool may flag such defects and store them in a defect file. The defect file contains the stage X-Y coordinates for each potential detected defect. Using the defect file in a review station, a review tool may be driven to the locations found in the wafer or die for that particular defect or missing feature. Unfortunately, the locations of the repeater in the defect file may be off by as much as approximately 5 to 15 microns from one repeater defect to another in a different reticle field. This offset may be due to, for example, stage inconsistencies from tool to tool or mechanical tolerances, making it difficult to translate defect positions between the wafer and the reticle mask.

The present invention may include a method and/or apparatus for determining the absolute X-Y location of semiconductor features or the like by using a computer-aided design (CAD) layout overlaid onto an inspection image. The features may be, for example, a defect or

an anomaly. The invention may include tagging the defect or missing feature by appending absolute CAD X-Y coordinates to the defect file.

In one embodiment, the CAD layout and the inspection image may be automatically synchronized. When the stage on the review tool moves across the die, the overlaid CAD image for a particular layer may move in tandem. This automated synchronization method may take both the image seen on the inspection tool screen and the generated CAD image. In another embodiment, an operator may be provided with the inspection image and the overlaid CAD drawing in the same screen. Once the synchronization described above is performed in accordance with the invention, the defect file for a particular wafer with repeater defects may be loaded into the inspection or review tool and driven to the particular defect or missing feature of interest. The defect's absolute CAD X-Y may be recorded in the form of a tagged defect file, or a tagged file.

Typically, reticle plates are four times larger than the device being printed and are a mirror image of the reticle field. In one embodiment, the CAD X-Y coordinates may be transformed accordingly to compensate for differences between the reticle plate and a reticle field. A reticle plate review tool, which is similar in structure to a fabrication inspection tool, can accurately be driven to the correct defect location using the CAD X-Y coordinates. Once the defective area is correctly found on the reticle plate, analysis tools may be used to determine possible problems with that particular feature.

In one embodiment, after repairing the reticle plate, a print test may be performed and the wafer inspection review tools may be returned to the same location in order to determine the output of the repair. Additional defect locations found on the plate at the mask shop may be also reported using the methods described herein, and wafer fabrication inline inspection tools may be driven to those same locations using absolute CAD X-Y coordinates.

Referring to **FIG. 1**, a wafer **105** is depicted, illustrating an aspect of the invention. In this exemplary embodiment, the wafer **105** may include, for example, six rows **100** of reticle fields **110**. Reticle fields **110** are formed in a known manner in an ordered pattern on Wafer **105** using step-and-repeat photolythographic processes. Typically, a reticle field **110** (which may correspond to an individual die) may contain undesirable defects **115**. The defects **115** may be chemical or structural irregularities that degrade the crystal structure of silicon or of the deposited materials that reside on the reticle field **110** surface.

Referring to **FIG. 2**, an individual reticle field **110** detailed in **FIG. 1** is depicted illustrating an aspect of the invention. The reticle field **110** includes defects **115**. In this

example, one of the defects **115** is a repeater defect **120**. The repeater defect **120** may repeat itself throughout some or all of the other reticle fields in wafer **105** detailed in **FIG. 1**.

If reticle fields **110** of wafer **105** depicted in **FIG. 1** were stacked onto a single reticle field shot showing only repeater defects, the spread associated with stage run out caused by the inspection tool would be seen as it scans across and down the wafer.

For example, referring to **FIG. 3**, the repeater defect **120** detailed in **FIG. 2** spread across different reticle fields is depicted illustrating one embodiment of the invention. A circle **305** indicates the actual position of the repeater defect **120**. A plurality of crossed squares **310** represent a single stack of the same defect in the same portion of different reticle fields located in different parts of the wafer. In one practical embodiment, the stage accuracy as the inspection system scans vertically and horizontally across the wafer may shows a spread of as much as 10 microns in each direction (ΔX and ΔY in **FIG. 3**). Thus, the same reticle defect that manifests itself in different reticle fields as a repeater defect may be perceived to be spread across an area of about 20 to 100 square microns in different reticle fields. In one embodiment, the invention may include a defect repeater automation method which finds common coordinates of defect locations within the wafer and outputs a tagged defect file populated with the CAD X-Y coordinates of repeater defects, aiding in failure analysis by providing the exact location of particular defects, and improving accuracy in existing reticle automation software.

Referring to **FIG. 4**, a block diagram of a semiconductor inspection apparatus **400** is depicted according to an exemplary embodiment of the invention. A stage **405** is coupled to a scanning device **410**, and it may include a device under test (DUT) **406**. The device under test **406** may be, for example, a wafer. The scanning device **410** may be, for example, a scanning electron microscope (SEM) or an optical device to provide an image of a wafer defect and/or surrounding features to a detection device **415**. A control unit **420** may be circuitry or a computer which controls, coordinates, and gathers information from the stage **405**, scanning device **410**, and detection unit **415**. A synchronization unit **425** is coupled to the control unit **420**, and a program storage media **430** is coupled to the synchronization unit **425**.

The scanning and detection devices **410**, **415** may be, for example, a scanning electron microscope (SEM) or an optical based system. The control unit **420** may move the stage **405** in space and control operation of the scanning and detection devices **410**, **415**. As the stage **405** moves under the inspection system, stage coordinates along with detection and scanning information may be kept track of by the control unit **420**. The control unit **420** and the synchronization unit **425** work in conjunction with each other to coordinate wafer and/or intra-

die locations for overlaying and synchronizing a CAD generated data **407** onto a captured inspection image **408** generated by the inspection tool (optical or SEM). The inspection image **408** may also be referred to as a DUT inspection image, a captured DUT image, or a wafer image. The control unit **420** may also provide the synchronization unit **425** with a defect file containing stage X-Y coordinates of defects and features.

The synchronization unit **425** processes the CAD data **407** and the inspection image **408**. The synchronization unit **425** operates to convert the CAD data **407** into a rendered image in a predetermined image format. The rendered image may be squared off at the ends to better represent the inspection image **408** provided by the inspection tool. Next, an alignment algorithm may be used for synchronizing and compensating for any offsets between the CAD data **407** and the inspection image **408**. In one embodiment, the synchronization unit **425** may overlay an image derived from the CAD data **407** onto the inspection image **408**, or vice versa. In another embodiment, the synchronization unit **425** may receive the inspection image **408** from the detection device **415** (for example, a wafer image or a reticle image), retrieve the CAD data **407** from a database (not shown), perform a synchronization operation, receive a defect file **421** from the control unit **420**, map a CAD feature coordinate to a reticle field defect coordinate, and provide the control unit **420** with tagged defect file **426** containing CAD X-Y coordinates of defects.

In practice, the synchronization unit **425** may be a programmable circuit, such as, for example, a computer, microprocessor or digital signal processor-based (DSP) circuit, that operates in accordance with instructions stored in the program storage media **430**. The program storage media **430** may be any type of readable memory including, for example, a magnetic or optical media such as a card, tape or disk, or a semiconductor memory such as a PROM or FLASH memory. The synchronization unit **425** may be implemented in software, such as, for example, a software defined algorithm, or the functions may be implemented by a hardware circuit, or by a combination of hardware and software.

When the synchronization unit **425** is a programmable circuit, a program, such as that presented below and discussed in detail with reference to **FIG. 5**, is stored in the program storage media **430** to create an apparatus in accordance with the present invention that operates in accordance with the methods of the present invention. In the alternative, the synchronization unit **425** may be hard-wired or may use predetermined data tables, or may be a combination of hard-wired and programmable circuitry.

Referring to **FIG. 5**, a flowchart of translation method **500** is depicted, representing an embodiment of the invention. The method **500** may be stored in the program storage media **430** and performed by the synchronization unit **425**, both detailed in **FIG. 4**. The inspection image **408** is processed by a first image conversion step **505** where a die image is converted from a raster scan or any other image format into a predetermined image format. The CAD image **407** is received from a database (not shown) and is processed by a lithography modeling step **510**, producing a rendered die or wafer image **506**. In one exemplary embodiment, the lithography modeling method performed by step **510** may use, for example, the Prolith lithography software available from Finle Technology, Inc. The rendered image **506** is further processed by a second image conversion step **515** that converts rendered image **506** into the same predetermined image format as that produced by block **505**. The predetermined image format may be any image format such as, for example, a tagged-image file format (TIFF) conversion, a joint photographic experts group image (JPEG), a graphic interchange format image (GIF), a printer description file (PDF), or any other image format.

The outputs of the image conversion steps **505**, **515** are processed by an alignment step **520**. The alignment of the two images, both in the same predetermined image format and at the same magnification, are matched by all the edge features of the image, yielding a map of inspection image to CAD image coordinates. Step **525** receives the defect file **421** containing stage X-Y coordinates of a defect and appends to it the corresponding CAD X-Y coordinates of the defect, outputting the tagged defect file **426**.

The alignment step **520** may use any of a variety of alignments methods. For example, the alignment step **520** may use a gradient descent method, such as an additive algorithm, a compositional algorithm, or an inverse compositional algorithm. While an additive algorithms estimate additive increments to alignment parameters, compositional algorithms estimate incremental warps. Gradient descent algorithms are well known to one of ordinary skill in the art. In one exemplary embodiment, the alignment method performed by step **520** may use, for example, the image alignment method used in the 8250 Series CD SEM tool, which is a critical dimension scanning electron micrograph tool for measuring very small features, made available by KLA-Tencor. In another embodiment, the invention may use the image alignment method used in the KLA-Tencor ES20 tool.

Referring to **FIGS. 4** and **5**, the invention includes a method and/or apparatus for providing the control unit **420** of a semiconductor inspection apparatus **400** with a map of wafer

coordinates to CAD coordinates. The control unit can perform a fine alignment of the stage **405**. The synchronization unit **425** may be useful in defect location.

Referring to **FIG. 6**, a synchronized CAD and wafer image **600** is depicted, illustrating an aspect of the invention. A square **605** represents a CAD element or feature, and a circle **610** represents a wafer element or feature. The overlaying of wafer and CAD images illustrated in **FIG. 6** is done by the alignment block **520** detailed in **FIG. 5**.

In one exemplary embodiment, the invention may be used to detect wafer or reticle defects through CAD navigation. A wafer element **615** found without a corresponding CAD feature indicates a possible wafer defect. For example, the wafer defect may be a missing contact. In another embodiment, the defect detection may be automated. The absolute defect location may be recorded in a defect file or a database.

In one embodiment, the invention may include synchronizing and overlaying a CAD image to a wafer image, automatically locating wafer defects on the resulting overlaid image, and adding absolute CAD X-Y coordinates of the wafer defects to a defect file or database. The invention may also include using the absolute CAD defect coordinates of a defect file or database for driving an inspection system and automatically locating defects in a reticle which correspond to the wafer defects.

The terms a or an, as used herein, are defined as one or more than one. The term plurality, as used herein, is defined as two or more than two. The term another, as used herein, is defined as at least a second or more. The terms including and/or having, as used herein, are defined as comprising (i.e., open language). The term coupled, as used herein, is defined as connected, although not necessarily directly, and not necessarily mechanically. The term program or software, as used herein, is defined as a sequence of instructions designed for execution on a computer system. A program, or computer program, may include a subroutine, a function, a procedure, an object method, an object implementation, an executable application, an applet, a servlet, a source code, an object code, a shared library/dynamic load library and/or other sequence of instructions designed for execution on a computer system.

The appended claims are not to be interpreted as including means-plus-function limitations, unless such a limitation is explicitly recited in a given claim using the phrase(s) "means for" and/or "step for." Subgeneric embodiments of the invention are delineated by the appended independent claims and their equivalents. Specific embodiments of the invention are differentiated by the appended dependent claims and their equivalents.

CLAIMS

What is claimed is:

1. A method of locating defects, comprising:

providing an inspection image of a device under test including detected coordinates of potential defects;

converting the inspection image into a first image in a predetermined image format;

providing CAD data for the device under test;

converting the CAD data into a second image in the predetermined image format;

aligning the first and second images;

converting the detected coordinates of potential defects into CAD coordinates; and

locating defects as a function of the CAD coordinates.

2. The method of claim 1, the device under test comprising a wafer.

3. The method of claim 1, the device under test comprising a die of a wafer.

4. The method of claim 1, further comprising, locating defects in a reticle for the device under test, as a function of the CAD coordinates.

5. The method of claim 1, the step of converting the CAD data into the second image comprising, performing a lithography modeling step.

6. The method of claim 1, the detected coordinates of potential defects comprising a defect file.

7. The method of claim 6, the step of converting the detected coordinates into CAD coordinates comprising, mapping the defect file to CAD coordinates to produce a tagged data file.

8. The method of claim 7, the defect file comprising wafer stage coordinates.

9. A program storage device, readable by a machine and tangibly embodying a representation of a program of instructions adapted to be executed by said machine to perform the method of claim 1.

10. A method for locating defects in a semiconductor wafer reticle, comprising:

generating a wafer image of a semiconductor wafer under test;

determining stage coordinates for detected potential defects in the wafer under test;

generating a CAD image from CAD data related to the semiconductor wafer under test;

aligning the wafer image and the CAD image and determining CAD coordinates from the stage coordinates; and

locating defects in a semiconductor wafer reticle for the semiconductor wafer under test as a function of the CAD coordinates.

11. A program storage device, readable by a machine and tangibly embodying a representation of a program of instructions adapted to be executed by said machine to perform the method of claim 10.

12. An apparatus for translating detected wafer defect coordinates into reticle coordinates, comprising:

a stage adapted to hold a wafer under test;

an image and defect detection device coupled to the stage for producing an inspection image of the wafer under test held by the stage, and for producing stage coordinates of defects detected in the wafer under test;

CAD data for the wafer under test;

a control unit coupled to control the stage and the image detection device; and

a synchronization unit coupled to the control unit and to the image detection device, for converting stage coordinates of defects in the wafer under test into wafer reticle coordinates as a function of both the inspection image of the wafer under test and the CAD data.