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(54) **EVALUATING SIDEWALL COVERAGE IN A SEMICONDUCTOR WAFER**

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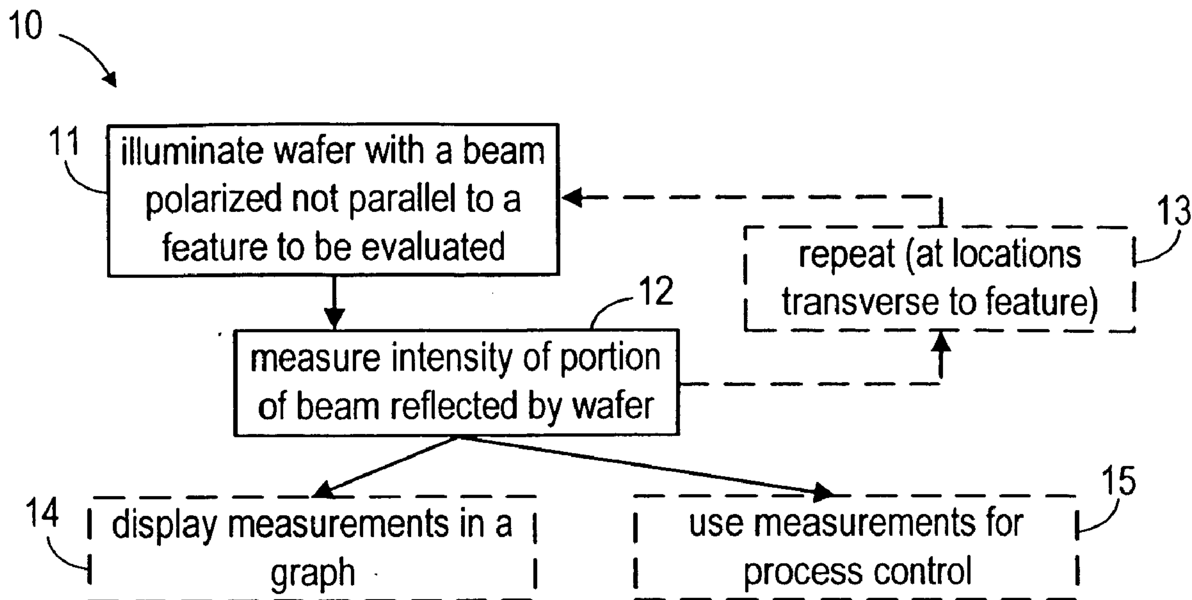
(57) **ABSTRACT**

A sidewall or other feature in a semiconductor wafer is evaluated by illuminating the wafer with at least one beam of electromagnetic radiation, and measuring intensity of a portion of the beam reflected by the wafer. Change in reflectance between measurements provides a measure of a property of the feature. The change may be either a decrease in reflectance or an increase in reflectance, depending on the embodiment. A single beam may be used if it is polarized in a direction substantially perpendicular to a longitudinal direction of the sidewall. A portion of the energy of the beam is absorbed by the sidewall, thereby to cause a decrease in reflectance when compared to reflectance by a flat region. Alternatively, two beams may be used, of which a first beam applies heat to the feature itself or to a region adjacent to the feature, and a second beam is used to measure an increase in reflectance caused by an elevation in temperature due to heat transfer through the feature. The elevation in temperature that is measured can be either of the feature itself, or of a region adjacent to the feature.



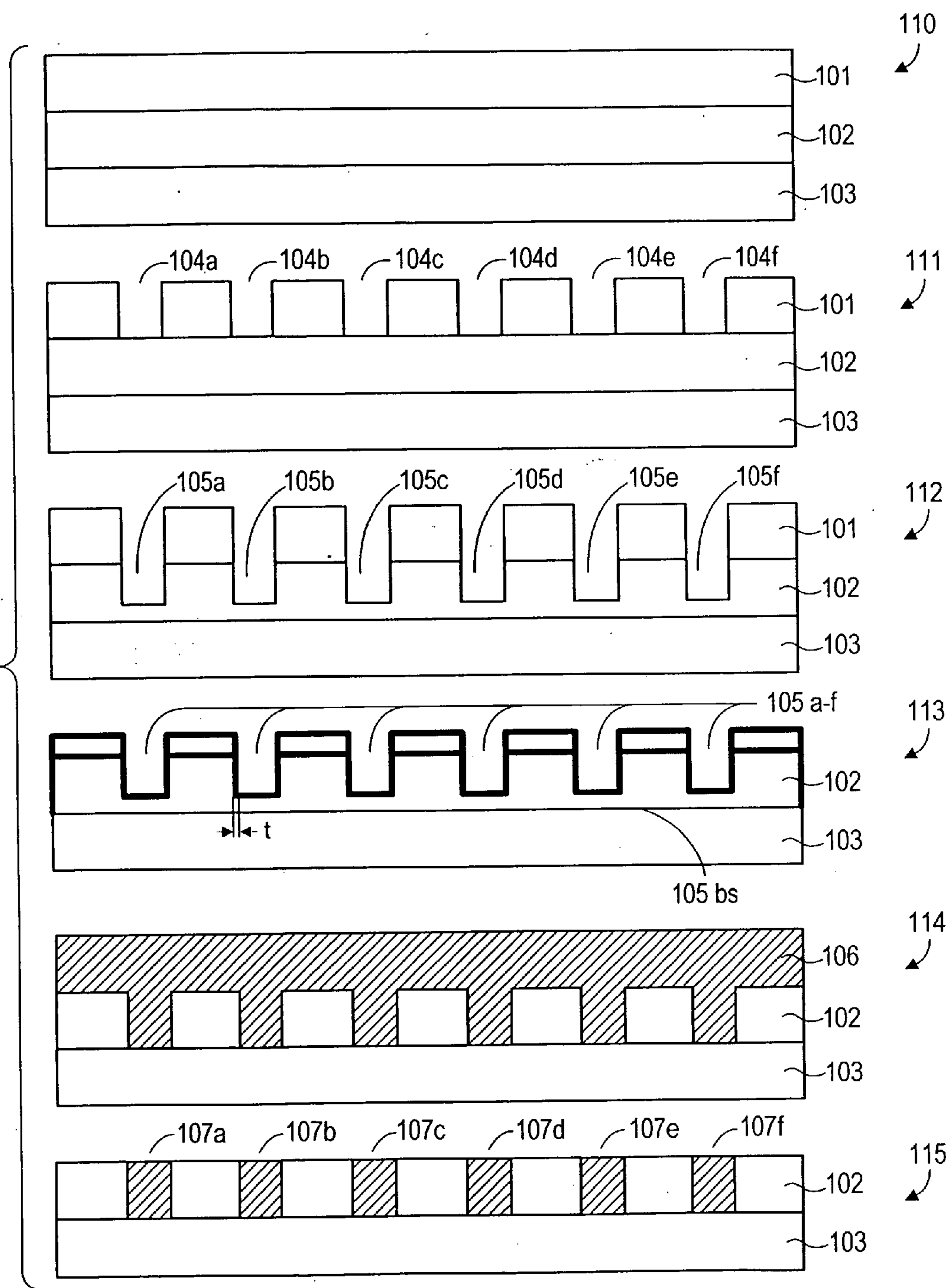


Fig.1 (Prior Art)

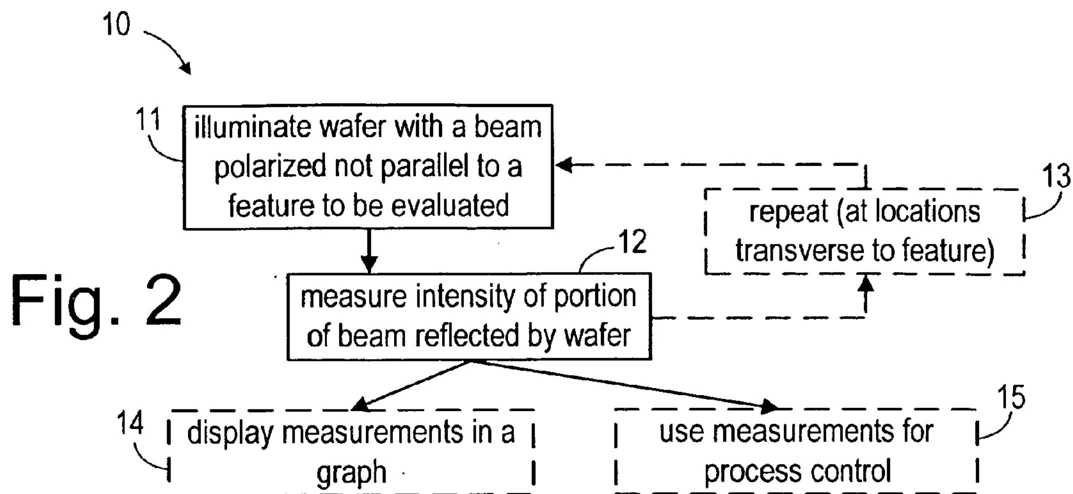


Fig. 2

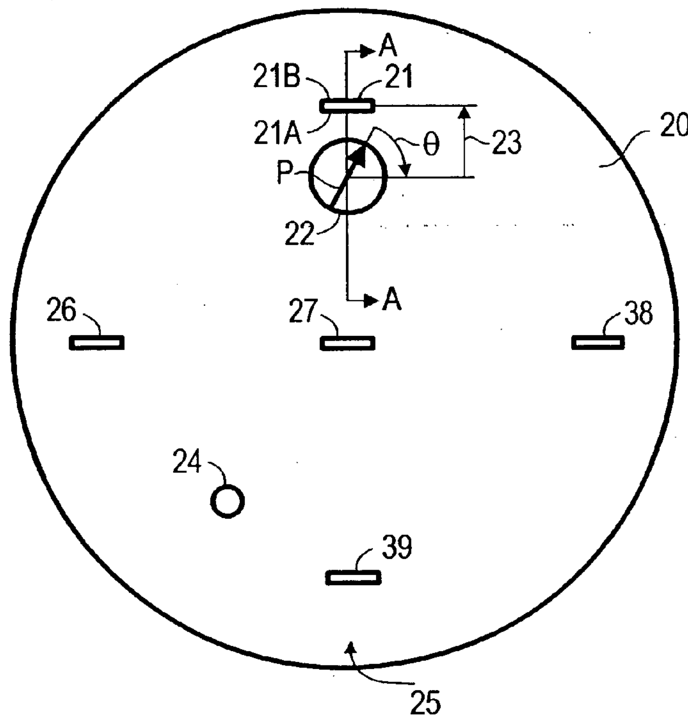


Fig. 3

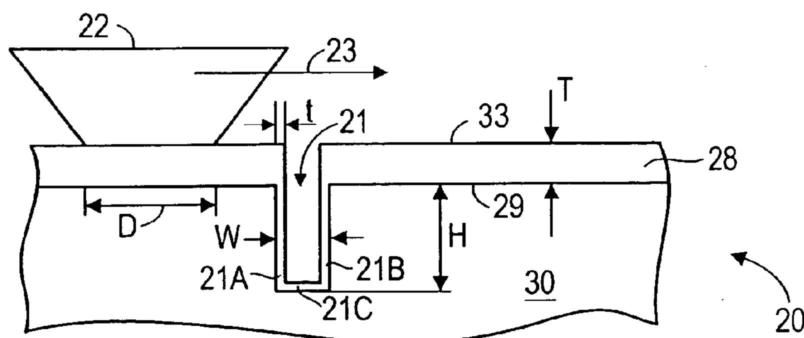
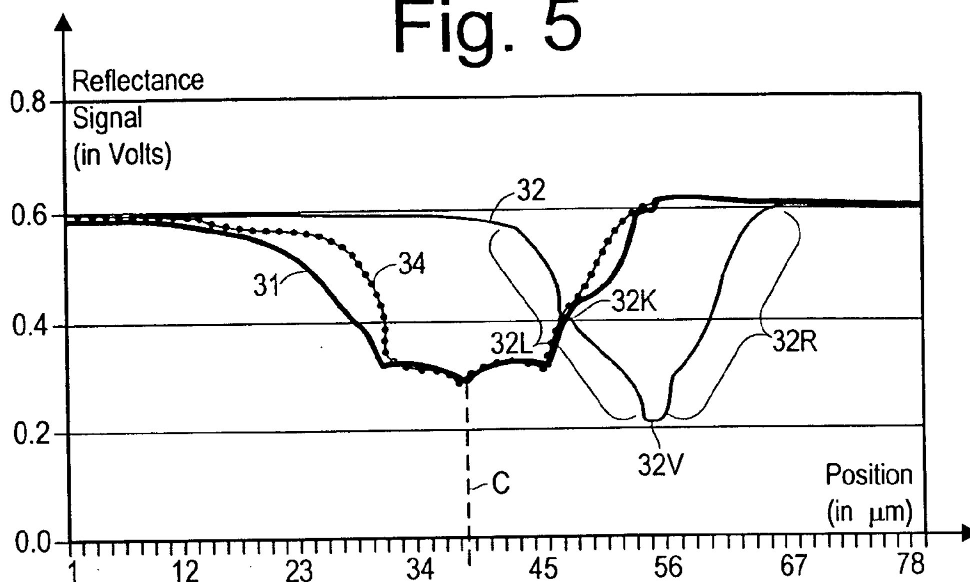


Fig.4

Fig. 5



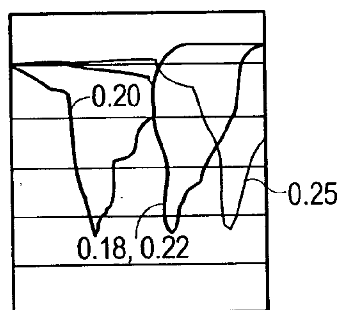


Fig. 7

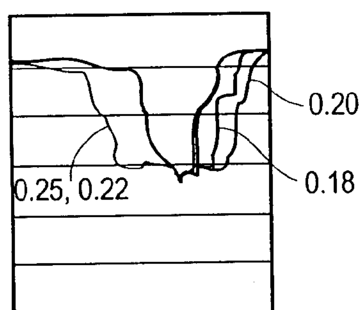


Fig. 8

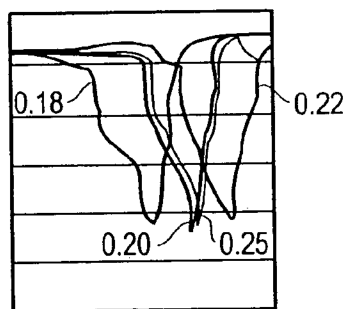


Fig. 9

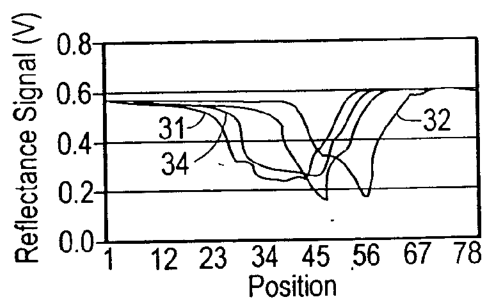


Fig. 6

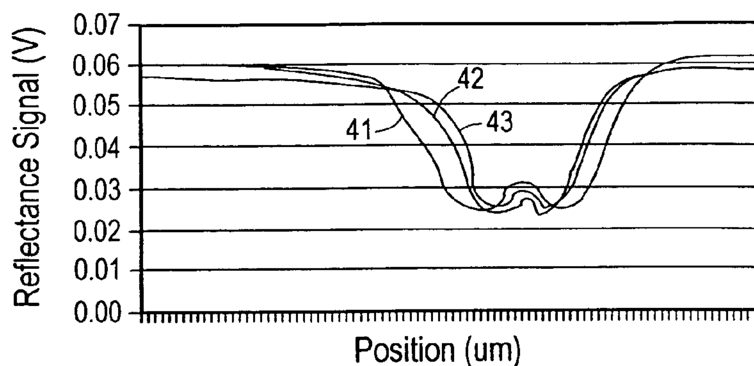


Fig. 10

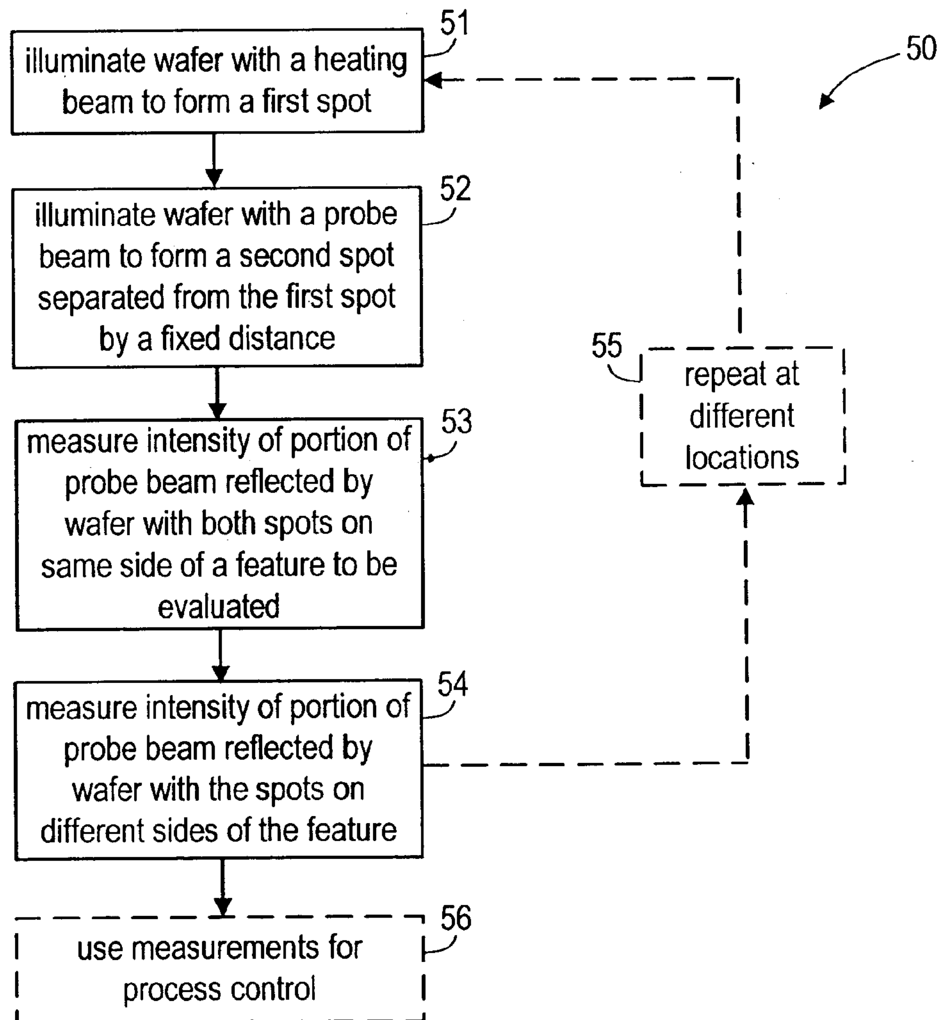


Fig. 11

Fig. 12

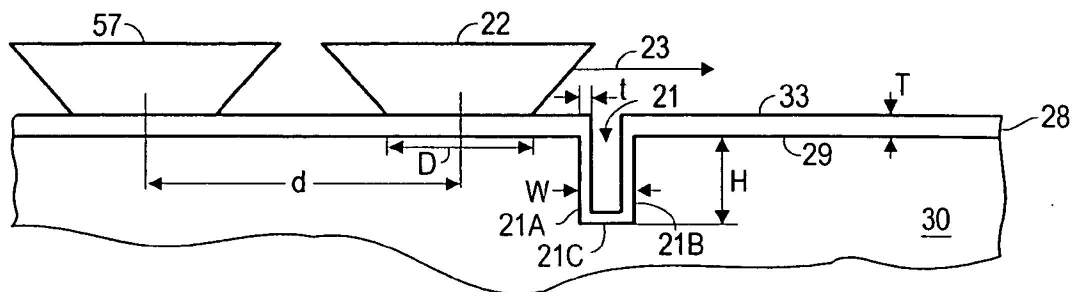


Fig. 13

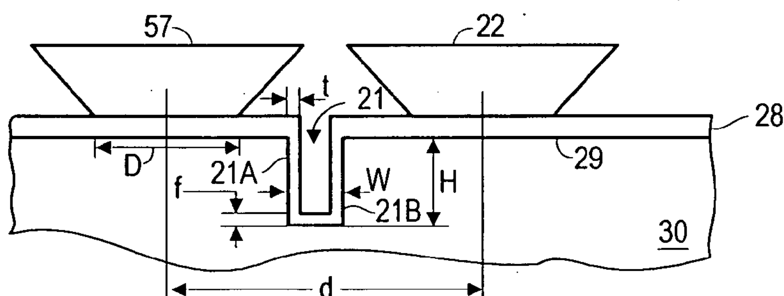


Fig. 14

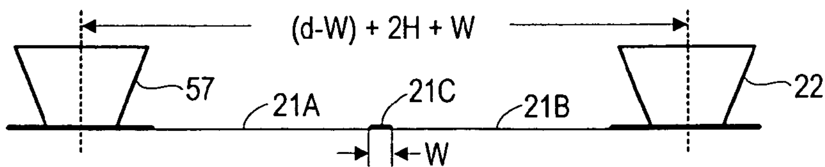


Fig. 15

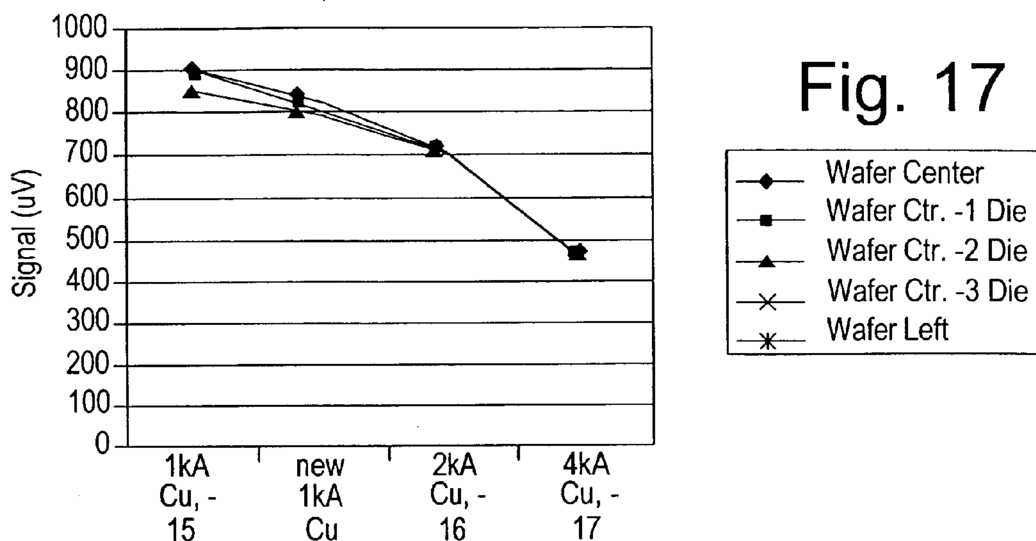
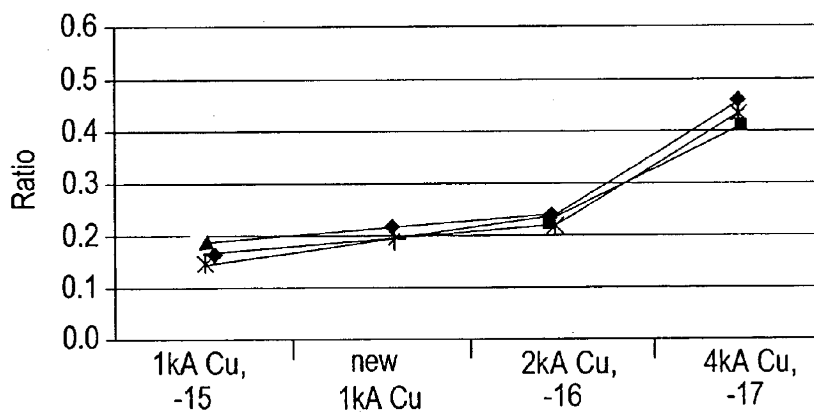


Fig. 17

Fig. 16



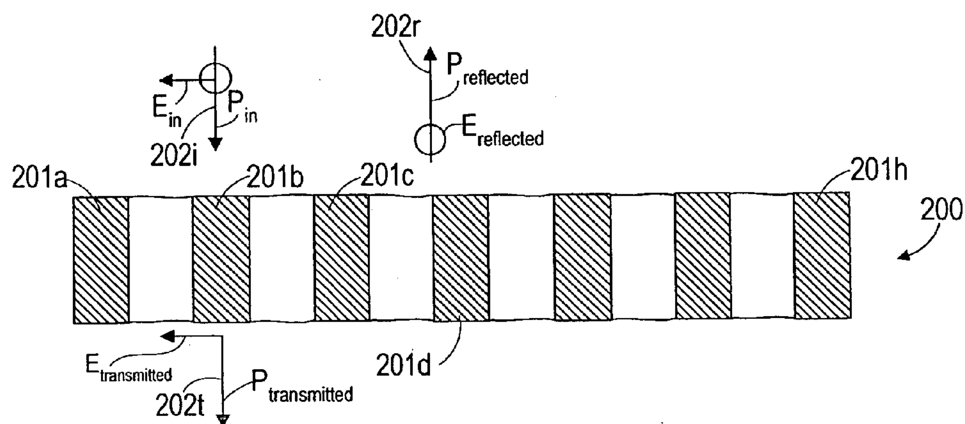


Fig. 18A

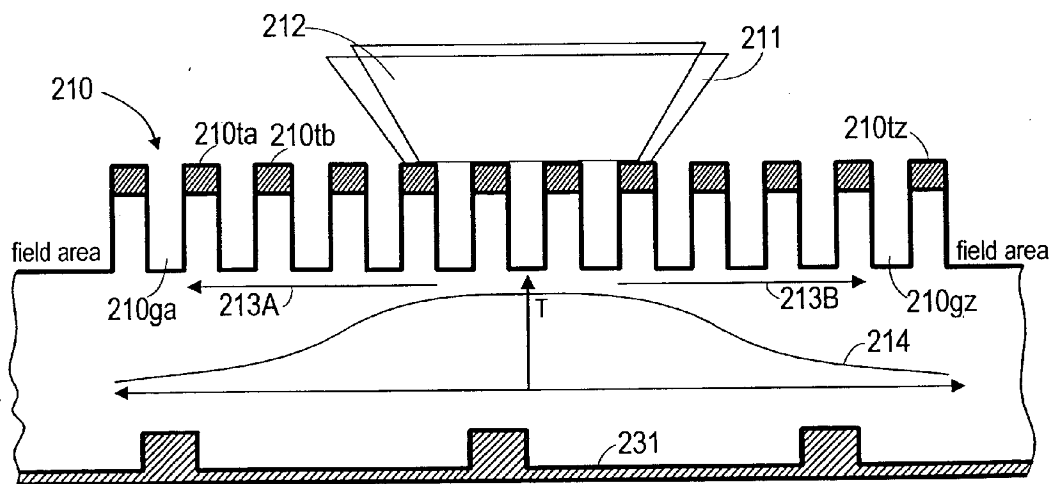


Fig. 18B

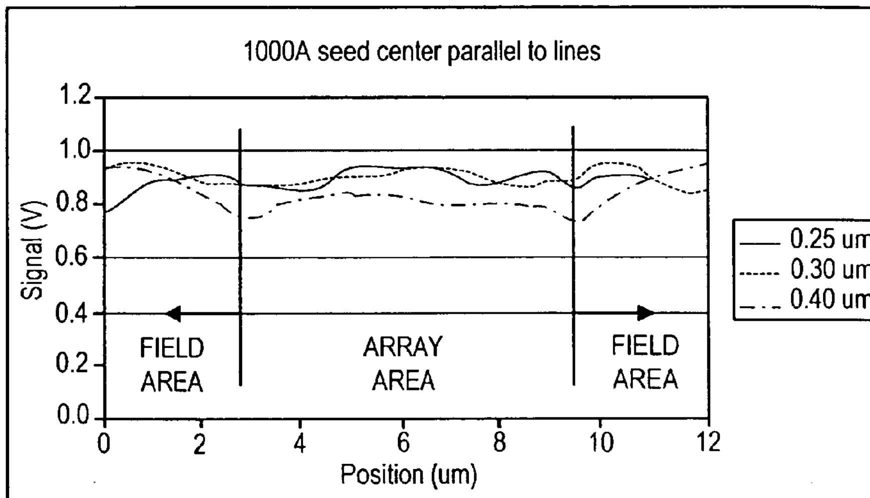


Fig. 19A

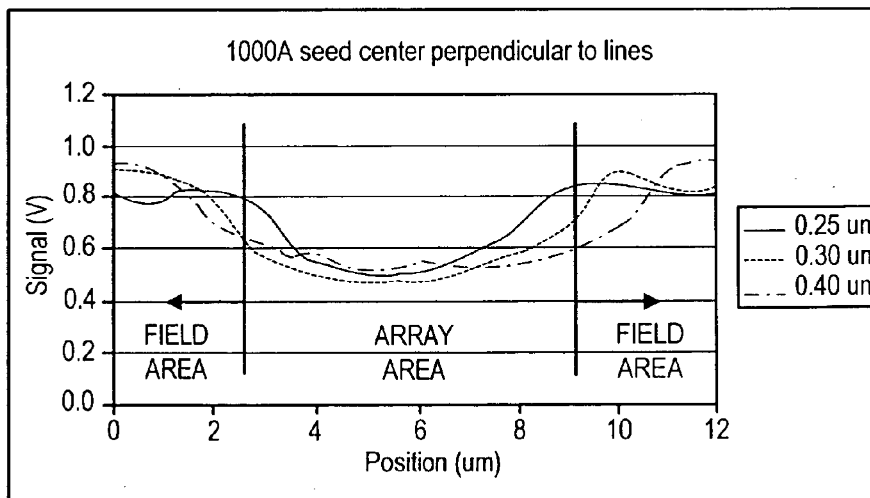


Fig. 19B

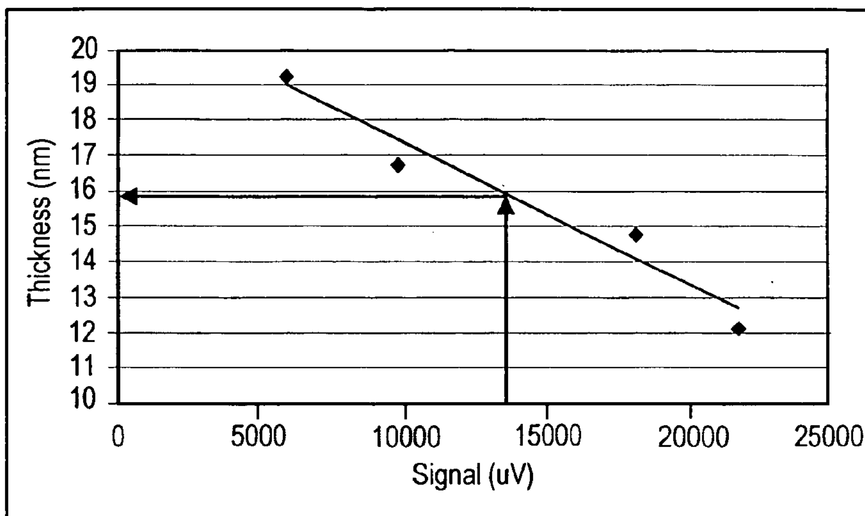


Fig. 20

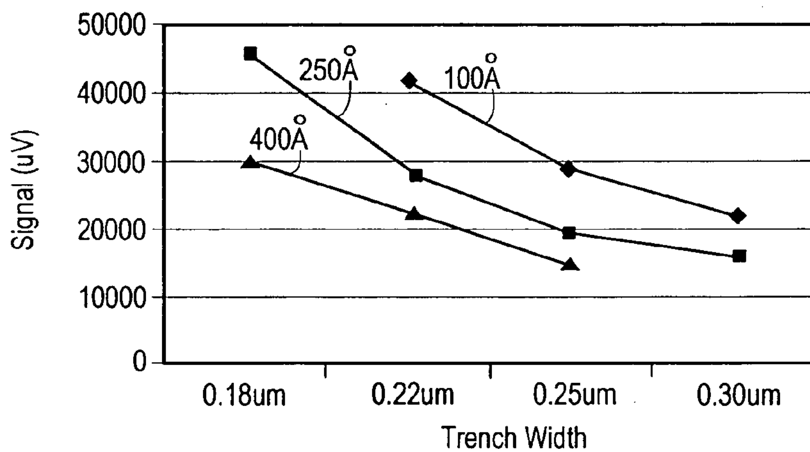


Fig. 21

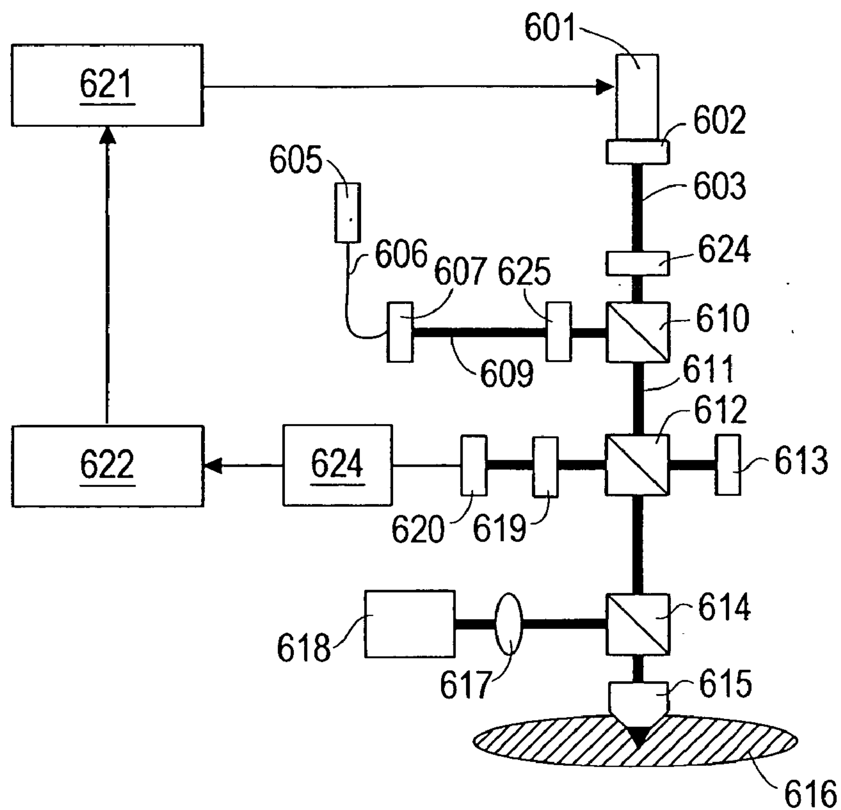


Fig.22

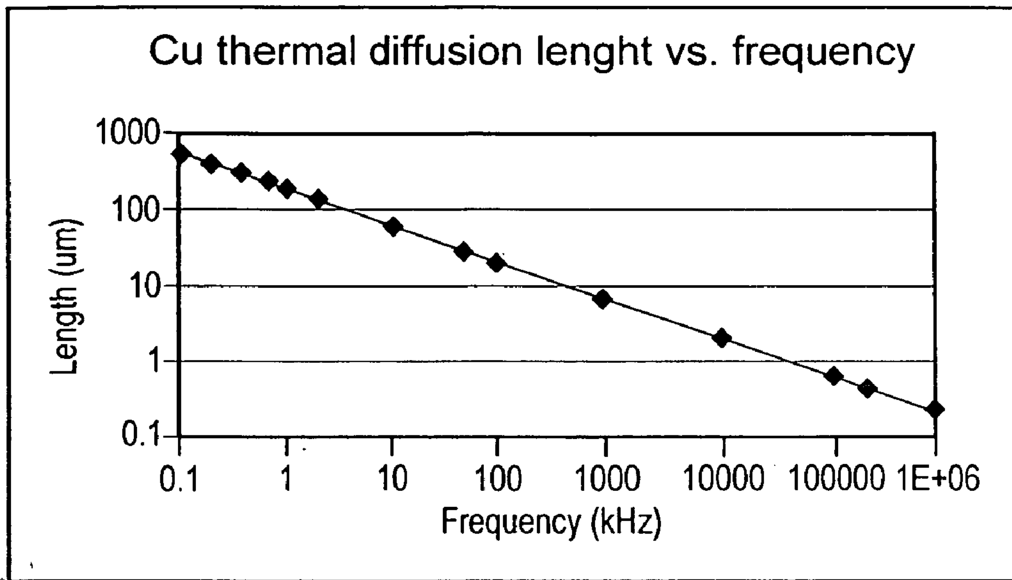


Fig. 23

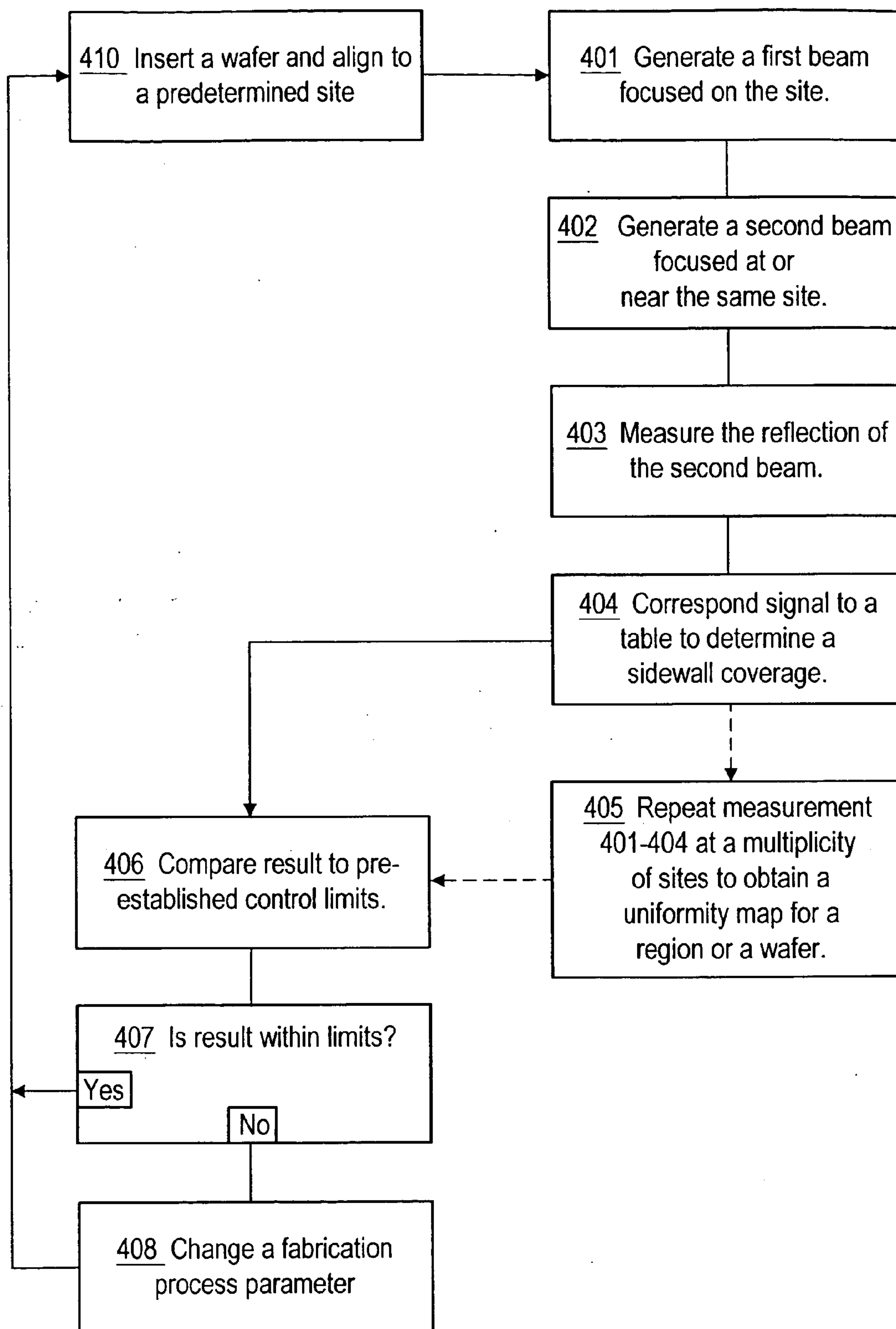


Fig. 24

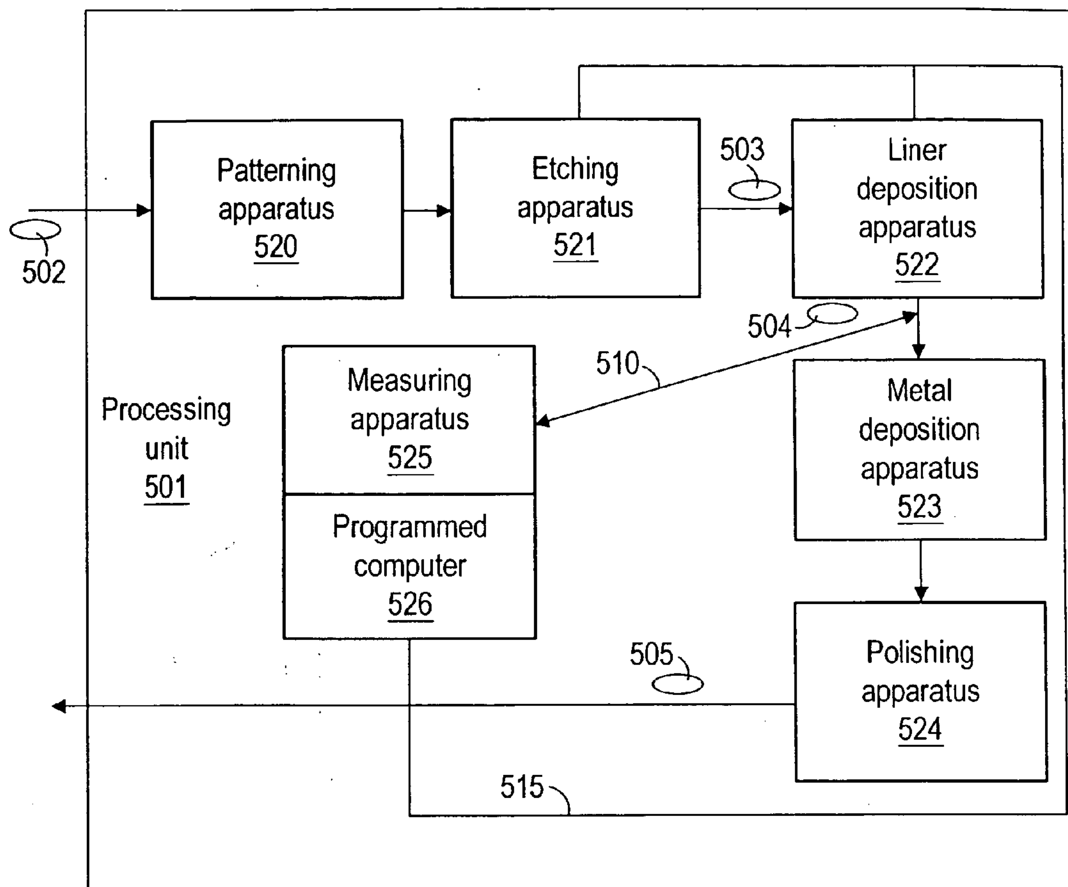


Fig. 25

EVALUATING SIDEWALL COVERAGE IN A SEMICONDUCTOR WAFER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to and incorporates by reference herein in their entirety the following commonly owned, U.S. Patent Applications:

[0002] Ser. No. 09/095,804 entitled "AN APPARATUS AND METHOD FOR EVALUATING A WAFER OF SEMICONDUCTOR MATERIAL", filed Jun. 10, 1998, by Peter G. Borden et al.;

[0003] Ser. No. 09/095,805 entitled "AN APPARATUS AND METHOD FOR MEASURING A PROPERTY OF A LAYER IN A MULTILAYERED STRUCTURE", filed Jun. 10, 1998 by Peter G. Borden et al.; and

[0004] Ser. No. 09/521,232 [attorney docket number M-7850 US] entitled "EVALUATING A PROPERTY OF A MULTILAYERED STRUCTURE", filed on Mar. 8, 2000 by Peter G. Borden et al.

BACKGROUND

[0005] Damascene structures in semiconductor substrates are so-named because they consist of metal lines formed in narrow grooves. These grooves may be <0.15 μm wide, and >0.5 μm deep, with a aspect ratios that may exceed 3:1 (ratio of height to width). Such damascene structures are typically formed in a multi-step process, of the type shown in **FIG. 1**. First, in step **110**, photoresist layer **101** is formed on insulator layer **102** over substrate **103**. Insulator **102** is a material such as silicon dioxide, and substrate **103** is silicon. In step **111**, photoresist layer **101** is patterned, forming grooves **104***a-f*. The structure is then etched in step **112**, forming grooves **105***a-f* in the insulator layer **102**. Note that the grooves are less deep than the thickness of the insulator **102**. The photoresist layer **101** is subsequently stripped. In step **113** the structure is coated with a barrier layer of a metal such as tantalum, followed by a seed layer of a metal such as copper, indicated as combined layers **105***bs*. The copper seed layer provides a conductive coating to allow electroplating of a thick copper layer onto the structure in step **114**, that material being shown as layer **106**. The seed layer may be 1000 Å thick on the surface, but only 100-200 Å thick on the walls of the grooves. Similarly, the tantalum layer may be 250 Å thick on the surface, but only 50 Å or less thick on the walls of the grooves. The tantalum layer prevents the copper from diffusing into the underlying layers; hence its name "barrier", and also improves adhesion of the copper to insulator **102**. In step **115** the electroplated layer **106** is polished away, leaving a fill of copper in the grooves.

[0006] The yield of this process depends on the thickness t of each sidewall of each groove. This is a parameter called sidewall coverage. If the sidewall coverage is too thin, then the coating may be discontinuous, or even non-existent. It then acts as a poor nucleating surface for the subsequent electrodeposition of subsequent thick layer **106**, causing problems such as void formation. These voids act as breaks in the metal line, either preventing current flow, or constricting current flow to the point where the line locally overheats and fails. If the coating is too thick, the top of the groove may close off, preventing adequate circulation of electrodeposition electrolyte, resulting in poor filling of the grooves. This problem is further aggravated as the technology advances, and the grooves become deeper and narrower A prior art method for measuring sidewall coverage uses transmission electron microscopy (TEM) imaging. In TEM imaging, a sample is prepared, either by using a focused ion beam that etches away a portion of the array, or by cleaving a sample and ion milling it to make it sufficiently thin so that it can be penetrated with high-energy electrons to form a TEM image. This is obviously a destructive method, since a portion of the integrated circuit must be physically removed. It is also slow, because adequate removal of material at any site may take many tens of minutes, and additional sample preparation, mounting and alignment may take hours. Thus, TEM imaging is useful for analytic diagnosis, but, being destructive and slow, is unsuitable for process control.

[0007] An abstract of a paper entitled "Mining Diagnostic Information from CD-SEM for Photolithography Control" by Haolin Zhang, available over the Internet at http://buffy.eecs.berkeley.edu/IRO/Summary/98abstracts/chapter5.html states that "Top view CD-SEM is a routine inspection tool in today's fabrication line. Even though relatively accurate critical dimensions can be obtained from a CD-SEM, much more information is hidden in the high resolution SEM images. The digitized SEM scan is a signal that may be used to monitor and diagnose the process sequence. We successfully used SEM traces of small test patterns to correctly infer two critical process parameters: focus distance and exposure dose. Principal component analysis (PCA) is applied to extract the characteristic feature behind the digitized SEM image. A feed-forward neural network trained by back propagation has been implemented to classify the different conditions. The sidewall profile of the pattern can also be studied by similar methodology. We plan to find an appropriate algorithm to relate the top view CD-SEM to the sidewall profile and film thickness. We will use an atomic force microscope (AFM) and/or cross-sectional SEM to extract sidewall information in order to calibrate the model."

[0008] The abstract of another paper, entitled "Real Time Monitoring of Grating Structures Using RCWA Modeling and Two-Channel Spectral Reflectometry" by Hsu-Ting Huang et al. available over the Internet at http://www.aps.org/mlet/MAR00/baps/abs/S6480.html states "We have previously demonstrated that specular SE or SR data from grating structures can be accurately analyzed using vector diffraction theory (using the rigorous coupled wave analysis method, RCWA) to extract the topography of surface relief gratings on wafers. In ex situ experiments, we have demonstrated that this method accurately yields critical dimensions, feature heights, and wall angles more complex sidewall shape information from deep sub-micron gratings. We have also reported on a high-speed, low-cost optical system, two channel spectroscopic reflectometry (2CSR), for in situ monitoring. Our current 2CSR system simultaneously measures |R_p|^2 and |R_s|^2 over the 370-850 nm spectral range at minimum sampling time of 6 ms. In this talk, we will show the first demonstrations of in situ, real-time monitoring of feature evolution in a reactive ion etching system (RIE). Using 2CSR and RCWA-based analysis we have successfully extracted the critical dimensions, wall shape, and feature height evolution of a 0.35 μm line/space photoresist grating during an O_2 RIE process. Cross-

sectional SEM photos before and after the etch runs will be shown which verify the high accuracy of this method. We will show variations in the topography evolution with changes in the RIE conditions. Measurement sensitivity issues and implications for industrial process control will be discussed."

SUMMARY

[0009] In accordance with the invention, a feature (such as a sidewall of a groove or a via hole, and formed of a reflective material) in a semiconductor wafer is evaluated by illuminating the wafer with at least one beam of electromagnetic radiation, and measuring intensity of a portion of the beam reflected by the wafer. Change in reflectance between measurements provides a measure of a property of the feature. The change may be either a decrease in reflectance or an increase in reflectance, depending on the embodiment.

[0010] One embodiment uses a single beam that is polarized in a direction substantially perpendicular to a longitudinal direction of the feature. A portion of the energy of the beam is absorbed by the feature, thereby to cause a decrease in reflectance when compared to reflectance of a flat region. A plot of reflectance as a function of distance across a groove, is symmetric when the two sidewalls have identical properties (such as sidewall thickness), and asymmetric when the sidewall coverage differs.

[0011] Instead of using a single beam, some embodiments use two beams that may or may not be polarized, and that may or may not form overlapping spots on the wafer. A first beam (called "heating beam") applies heat to the feature itself or to a region adjacent to the feature, and a second beam (called "probe beam") is used to measure an increase in reflectance caused by an elevation in temperature due to heat transfer through the feature. The elevation in temperature that is measured can be either of the feature itself, or of a region adjacent to the feature, depending on the embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** illustrates a prior art method for fabricating a semiconductor wafer.

[0013] **FIGS. 2 and 11** illustrate, in flow charts, acts performed in two embodiments of the invention.

[0014] **FIG. 3** illustrates, a relationship between polarization of a beam used in an act of **FIG. 2** and a longitudinal direction of a feature under evaluation, in a plan view of a semiconductor wafer.

[0015] **FIG. 4** illustrates, a cross-sectional view of the semiconductor wafer in the direction A-A of **FIG. 3**.

[0016] **FIGS. 5-10** illustrate, in graphs, change in reflectance as a function of distance, obtained from a scan across a groove in accordance with the invention.

[0017] **FIGS. 12 and 13** illustrate, in cross-sectional views, use of two beams in the embodiment of **FIG. 11**, with a first beam heating the semiconductor wafer and a second beam used to measure a change in reflectance due to heat from the first beam transferring through a feature.

[0018] **FIG. 14** illustrates a model for heat transfer in the configuration of **FIG. 13**.

[0019] **FIGS. 15 and 16** illustrate calibration curves used to look up properties of a feature in accordance with the method of **FIG. 11**.

[0020] **FIG. 17** provides a key for the graphs in **FIGS. 15 and 16**.

[0021] **FIGS. 18A and 18B** illustrate use of a beam polarized perpendicular to two types of array structures, to measure a property thereof, in another embodiment of the invention.

[0022] **FIGS. 19A and 19B** illustrate, in graphs, reflectance from the array structure of **FIG. 18B**, when the beam is respectively polarized parallel to, and perpendicular to the longitudinal direction of the array.

[0023] **FIGS. 20 and 21** illustrate, use of a predetermined curve to lookup thickness of a sidewall, based on a measure of reflectance of probe beams that are parallel polarized and perpendicular polarized respectively.

[0024] **FIG. 22** illustrates a measurement apparatus in one embodiment.

[0025] **FIG. 23** illustrates, in a graph, a relationship between modulation frequency and thermal wavelength.

[0026] **FIG. 24** illustrates in a flow chart, acts performed as described herein for performing process control.

[0027] **FIG. 25** illustrates a system for fabricating wafers using a reflectance measurement as described herein.

DETAILED DESCRIPTION

[0028] A method **10** (**FIG. 2**) in accordance with the invention, evaluates a feature **21**A in a semiconductor wafer **20** (**FIG. 3**) by illuminating the wafer **20** (see act **11** in **FIG. 2**) with a beam **22** of electromagnetic radiation (**FIG. 3**), and measuring intensity (see act **12**) of a portion of the beam **22** reflected by the wafer **20**. Such acts **11** and **12** may be repeated (as illustrated by act **13** in **FIG. 2**), e.g. at a number of positions that are located transverse to feature **21**A (or alternatively at positions located in-line with feature **21**A). For example, wafer **20** may be displaced in a plane perpendicular to the beam axis, and the beam is held stationary (although in an alternate embodiment, the beam could be moved and the wafer held stationary). For example, the beam is focused on the surface at a point below feature **21**A in **FIG. 3** and the wafer is moved down in the drawing thereby scanning the beam across the feature and towards the right in **FIG. 4** (which shows a cross-sectional view along the direction A-A in **FIG. 3**), to obtain a set of measurements. The set of measurements includes, in one embodiment, only two measurements (e.g. that are made at equal distances from feature **21**A on each side thereof), although in another embodiment a number of such measurements are made in a continuous fashion (in a scanning movement).

[0029] A change in intensity of the signal being measured (assuming all parameters (such as intensity of beam **22** incident on wafer **20**) are kept constant) provides a measure of a property (such as thickness t) of feature **21**A. The change may be either a decrease in reflectance or an increase in reflectance, depending on the embodiment. Therefore, a property of feature **21**A is measured by beam **22** in accordance with the invention (by monitoring a change in reflec-

tance) even though beam **22** forms on wafer **20** a spot of diameter D (e.g. 2 μm or 20,000 Å) that is one or more orders of magnitude larger than the thickness t (e.g. 50 Å) of feature **21**A. The measurements can be displayed to an operator, e.g. in a graph as illustrated by act **14** in **FIG. 2**. Alternatively, the measurements can be used automatically, for process control as illustrated by act **15**.

[**0030**] Feature **21**A may be, for example, a sidewall of a groove **21** that has another sidewall **21**B separated therefrom by a floor **21**C (**FIG. 4**). Alternatively, feature **21**A may be a sidewall of a via hole **24** (**FIG. 3**). Feature **21**A is typically formed of a reflective material that reflects a majority of the incident energy. Although feature **21**A is located at the top of wafer **20** relative to a notch **25** therein, such a feature that is being evaluated may be located anywhere in wafer **20**, e.g. on the left as illustrated by feature **26** or in the center as illustrated by feature **27**. Depending on the circuitry to be formed from wafer **20**, such a feature may form a part of such circuitry, or alternatively may be introduced into wafer **20** for evaluation of the fabrication process (i.e. a test feature). Furthermore, depending on the embodiment, feature **21**A may be a portion of a larger structure, such as an array as described later on.

[**0031**] In one exemplary wafer **20**, sidewalls **21**A and **21**B are formed by a conductive layer **28** (**FIG. 4**), of e.g. copper over tantalum, that is also formed over a top surface **29** of a substrate **30**. Typical dimensions are as follows. Groove width W is on the order of 0.18 μm (1800 Å) and height H on the order of 0.5 μm (5000 Å). Sidewall **21**A has a thickness on the order of 200 Å and thickness T of layer **28** (e.g. of copper) over surface **29** is on the order of 1000 Å.

[**0032**] Measurements of the type described herein provide at least two advantages over prior art methods: (1) the properties of a line of width much smaller than the beam diameter can be measured, and (2) the measurement indicates not only the sidewall coverage but relative coverage of the two walls.

[**0033**] In one embodiment (also called "single beam embodiment"), a feature **21**A which is part of groove **21** is illuminated by a beam **22** which is polarized in a direction P. In one implementation of this embodiment, direction P forms an angle θ with a longitudinal direction of feature **21**A. For beam **22** to be reflected by groove **21**, an electric field must be established in floor **21**C that matches the incident electric field. This induced field re-radiates, resulting in a reflected portion of beam **22**. When the incident electric field is parallel to groove **21**, this occurs, and groove **21** acts like the rest of layer **28**, reflecting all of the incident power other than a negligible fraction (e.g. less than 10%) that may be lost at the sidewalls **21**A and **21**B. Hence, the component of beam **22** that is polarized parallel to groove **21** is reflected. However, when the incident electric field is perpendicular to groove **21**, and when groove width W is smaller than the wavelength of beam **22**, and groove **21** is too narrow to set up a matching electric field. As a result, the reflection is very small and the component of beam **22** polarized perpendicular to groove **21** transmits as heat into substrate **30**, as if groove **21** did not exist.

[**0034**] For this reason, beam **22**'s polarization direction P is deliberately selected to be not parallel to feature **21**A. In the example illustrated in **FIG. 3**, angle θ>45°. Preferably, but not necessarily, angle θ≅90° (e.g. within 10% which is ±9°). Also, in this embodiment, the wavelength (e.g. 980 nm or 9800 Å) of beam **22** is larger than width W (2000 Å) of the feature (and therefore the spot size is also greater than the width of the feature) so that beam **22** is not reflected by feature **21**A in the same manner as a region adjacent to the feature. Instead, at least a portion of the energy of beam **22** is absorbed by feature **21**A.

[**0035**] In one implementation of the single beam embodiment, measurements (of a reflected portion of beam **22**) are repeatedly made during a scan (also called "transverse scan") across feature **21**A, in a direction **23** that is perpendicular to the longitudinal direction of feature **21**. The measurements, when plotted as a function of distance yield a curve (called "reflectance curve") which indicates properties across the cross-section of the feature. For example, a reflectance curve **31** (**FIG. 5**) is symmetric when the two sidewalls **21**A and **21**B of a groove **21** (**FIG. 4**) have similar or identical properties (such as sidewall thickness).

[**0036**] In this example, another reflectance curve **32** (**FIG. 5**) is asymmetric when the sidewall coverage differs for the two sidewalls **21**A and **21**B, e.g. when groove **21** is located at the top (see **FIG. 3**) of wafer **20** (relative to notch **25**). The asymmetry of curve **32** of this example is manifested in three forms: (a) a valley (minimum) 32V is offset from a center line C of groove **21**, (b) slopes on the two sides of the valley are different (with slope of left segment **32**L being more gradual than slope of right segment **32**R), and (c) left segment **32**L is piecewise linear, and has a "knee"**32**K (coincidentally at the intersection of curves **31** and **32**) whereas right segment **32**R is linear. Although three forms of asymmetry are manifested in this example, in other examples only one or two of these forms of asymmetry may be present. Also, depending on the example, other forms of asymmetry may be present as will be apparent to the skilled artisan. As another example, a reflection curve **34** for a groove **26** on the left side of wafer **20** is substantially symmetric. In this example, all three grooves **22**, **26** and **27** are parallel to one another, so that groove **21** is oriented perpendicular to a radius vector drawn from a center of the wafer **20**, and groove **26** is oriented parallel to the radius vector. Similar reflection curves are obtained for grooves located on the right of wafer **20**, and at the bottom (near notch **25**) of wafer **20** as illustrated in **FIG. 6**, described next.

[**0037**] **FIG. 6** shows the reflection curves from five grooves at the center and 0°, 90°, 180° and 270° positions, where 0° represents the wafer top, and 180° represents the wafer bottom. In this case, all five grooves are parallel, so that the 0° and 180° grooves are oriented perpendicular to the radius vector and the 90° and 270° grooves are oriented parallel to the radius vector. Such grooves may be formed in wafer **20** as "test" structures, for the purposes of monitoring the efficacy of the fabrication process as described herein. In **FIG. 6**, the scans are symmetric at the center and when the grooves are parallel to the radius, as in the locations of wafer center, wafer left, and wafer right, and asymmetric when the grooves are perpendicular to the radius and at the wafer periphery, as in locations of wafer top and wafer bottom.

[**0038**] The measurements plotted in **FIGS. 5 and 6** were performed with a single laser beam **22** focused on an exposed surface **33** of wafer **20**. Beam **22** was polarized with the electric field vector perpendicular to groove **21** (parallel

to the scan direction **23**). Beam **22** has a wavelength of 0.83 μm and a spot diameter on surface of **33** (**FIG. 4**) of 1.5 μm. Because of the perpendicular polarization, at least some laser light enters groove **21**, which reduces the reflection as beam **22** moves in direction **23** across groove **21**. A metal such as copper is highly reflective—on the order of 97%. Therefore, light absorbed in groove **21** measurably reduces the reflected signal. Because width W of groove **21** is small compared to diameter D of laser beam **22**, the intensity of the reflection measured through scan in direction **23** (as shown by curve **31** in **FIG. 5**) matches the intensity profile of beam **22** (which is approximately gaussian) when groove **21** is symmetric.

[**0039**] Depending on the process used to form wafer **20**, sidewalls **21**A and **21**B of groove **21** are not symmetric in all locations of wafer **20**. Specifically, reflection curves in **FIGS. 5-9** were generated by scans across grooves at different locations on wafers whose metal layers were deposited by physical vapor deposition (PVD, also known as sputter deposition). Specifically, **FIGS. 7-9** shows scans across single grooves of widths of 0.18, 0.20, 0.22 and 0.25 μm. **FIG. 7** illustrates scans across groove **39** near the lower edge of the wafers (near notch **25**; see **FIG. 3**), which are asymmetric. **FIG. 8** illustrates scans across a groove at the center of wafers (see groove **27** in **FIG. 3**), Which show symmetry. **FIG. 9** illustrates scans across a groove **21** at the top of the wafers, which are asymmetric. The asymmetry in **FIGS. 7 and 9** is repeatable and mirrored about the wafer center. Regardless of its position, the grooves **21**, **27** and **39** used to generate the reflection curves in **FIGS. 7-9** have the same direction, and run perpendicular to the wafer radius vector, and the electric field polarization is parallel to the wafer radius vector.

[**0040**] The reason for the difference in symmetry between the reflection curves of **FIGS. 5-9** is explained through understanding of the metal PVD deposition process. The copper is laid down in a sputter coater, with an target electrode above the wafer. By symmetry, the process is most uniform in the center, and least uniform at the edge. Near the edge, the wall of a groove facing the center has greater exposure to deposition than the wall facing away from the center. Thus, the 0° and 180° grooves **21** and **39**, which have walls facing to and away from the center, show asymmetry, and the 90° and 270° grooves **38** and **26**, which have both walls symmetric with respect to the deposition, show symmetry. Therefore, it is seen that the asymmetric profile indicates asymmetric deposition on the groove walls.

[**0041**] Not all metal depositions show such asymmetry, because different metals are deposited under different conditions. **FIG. 10** shows reflection curves **43**, **41** and **42** respectively represent measurements from scans across the top, center and bottom (notch) grooves of a wafer having tantalum (no copper) coating. Curves **41-43** are symmetric. This indicates that the asymmetry is not an artifact of the groove shape, but is truly indicative of asymmetric coating of the sidewalls.

[**0042**] Therefore, in one example, reflectance curves of two sidewalls located opposite to one another in a groove are compared to one another, either visually by an operator, or automatically (e.g. by comparison of slopes and/or distance of minimum from center and/or presence of knee) to identify symmetry/asymmetry. Depending on the embodiment, a measure of a sidewall's property can be extracted from a reflectance curve, e.g. the slope of the reflectance curve may be compared to slopes of such curves of wafers having properties determined by a prior art process (such as TEM), to determine sidewall thickness. Computation of slope (or other coefficient of a function fitted to the reflectance curve) is useful in process control, e.g. a process parameter used in formation of the feature on the wafer may be changed, when a limit (on the slope or other coefficient) is crossed.

[**0043**] Determining sidewall coverage as described above using a single probe beam **22** by generating a reflectance curve is feasible during process control because the process is non-destructive and non-contacting, and is sufficiently rapid to provide a high throughput of wafers (e.g. each measurement takes about 5 seconds per site, or for each point in a line scan). In addition, the area required for measurement of a reflectance curve is small—no larger than a few microns—which allows use directly in patterns where only a small number of lines (e.g. one line) are available for measurement, and enables resolution of fine-scale process non-uniformity, and monitoring of localized defects in a sidewall.

[**0044**] A change in reflectance over a feature also provides a measure of a property of the feature in the longitudinal direction, e.g. when scanning along the feature (also called "longitudinal scan"). Therefore, reflectance measurements of the single beam embodiment as described above can also be made in a longitudinal scan, e.g. to monitor uniformity in properties of a sidewall or a trace, along its length. A change in reflectance measurement during the longitudinal scan indicates a change in a property (such as thickness) of the sidewall. Regardless of the scan direction, the beam is polarized in a direction other than parallel to a longitudinal direction of the feature, so that at least a portion of the energy of the beam is absorbed by the feature, thereby to reduce reflectance over the feature.

[**0045**] Although an embodiment using a single beam **22** has been described above in reference to **FIGS. 3-10**, some embodiments use two beams that may or may not be polarized, and that may or may not form overlapping spots on wafer **20**. In two alternative embodiments, a first beam (called "heating beam") applies heat to the feature itself or to a region adjacent to the feature, and a second beam (called "probe beam") is used to measure an increase in reflectance caused by an elevation in temperature due to heat transfer through the feature. The elevation in temperature that is measured can be either of the feature itself, or of a region adjacent to the feature.

[**0046**] In one embodiment that uses two beams, wafer **20** is illuminated with two beams **57** and **22** (**FIG. 12**) that form spots (see acts **51** and **52** in **FIG. 11**) that are separated from one another by a fixed distance of separation d (see **FIGS. 12 and 13**). Beams **57** and **22** are focused on coplanar surfaces in this embodiment, although measurements of the type described herein can also be made with beams **57** and **22** focused on non-coplanar surfaces, e.g. as long as a thermal wave is not generated by an excessively high modulation frequency as described elsewhere herein.

[**0047**] Intensity of probe beam **22** reflected by wafer **20** is measured, with the spots on the same side of a feature to be evaluated (see act **53** in **FIG. 11**; see also **FIG. 12**) and on different sides of the feature (see act **54** in **FIG. 11**; see also

FIG. 12). A difference in intensity measurements in acts **53** and **54** is indicative of a property of the feature, which affects a temperature gradient that is formed in a horizontal direction between the two spots. Specifically, a layer **28** of conductive material in the feature extends outwards from the feature, so that in act **53** when beam **22** forms a spot in a region adjacent to the feature, heat injected by beam **57** travels for distance d (which is the separation distance) through layer **28**, and is sensed by measuring a reflected portion of beam **22**.

[**0048**] Typical dimensions are a spot separation distance of d=4 μm, a groove depth of H=0.5 μm, a groove width of W=0.2 μm, a field layer thickness of T=1000 Å, a sidewall thickness of t=200 Å, and a floor thickness of f=400 Å (see **FIG. 13**). In act **54**, when beams **57** and **22** are on opposites sides of a feature, heat under probe beam **22** must pass through a length (d-W) of layer **28**, H of sidewall **21**A, W of floor **21**C and H of sidewall **21**B, the combination of which may be modeled as illustrated in **FIG. 14**. The thinner coating H of sidewalls **21**A and **21**B has a greater impedance to the heat flow, and therefore its thickness governs the peak temperature. The thermal resistance can be modeled in a linear heat flow model:

$$R \propto \frac{d-W}{T_T} + \frac{W}{T_B} + \frac{2H}{T_w}$$

[**0049**] where T_T, T_B, and T_w are the thickness of the conductive material on the top, bottom and side-walls, d is the separation between the spots, W is the groove width, and H is the height of the sidewalls. Note that d>>W and both H>W and T_B>T_w, so the middle term is small compared to the first and last terms (the top and sidewall terms). The top and sidewall terms are comparable. However, the beam separation d is fixed and known and the top thickness T_T can be determined independently by placing both spots on the top film without the intervening groove (in which case the R, and, hence, the heat rise under the probe beam **22**, is now given by the first term since (d−W)~=d for d>>W). Therefore, the sensitivity of R to sidewall thickness T_w can be found assuming a constant groove depth H.

[**0050**] In one implementation, the intensity of heating beam **57** (**FIGS. 12-14**) is modulated at a predetermined frequency, so that the temperature at the spot of probe beam **22** varies in synchronization with the modulation. The frequency is chosen to be sufficiently low to avoid creation of a thermal wave as described elsewhere herein and in the related patent application Ser. Nos. 09/095,805 and 09/521,232 that were incorporated by reference above. Thereafter, reflectance is measured, by measuring intensity (referred to as measurement S_f) of a portion of the probe beam that is reflected by wafer **20**, and that is modulated at the predetermined frequency. The modulated electrical signal is detected by use of a lock-in amplifier as stated in the just-described patent applications.

[**0051**] Measurement S_f is proportional to the temperature under probe beam **22**. When the spots are formed on the same side of a groove, measurement S_f is converted using a calibration table obtained from independent measurement (under the same conditions) on layers (also called "films") of known thickness, thereby to determine the thickness T of layer **28**. Therefore, a graph (not shown) may be used to look up thickness T (alternatively measurements used to form such a graph may be used directly by a computer to determine thickness T, e.g. by interpolation). Instead of using graphs and/or measurements, the above-described first term can also be used to determine thickness T. **FIG. 15** shows signal for both beams on the same side of the groove (no thermal impedance due to the groove). In this case, the signal is expected to decline with metal thickness. This is because at constant laser power, the temperature to which the metal can be heated varies inversely with the metal thickness. Therefore, thicker films cannot be heated as much, and the signal is lower. This trend is seen in **FIG. 15** for four wafers. The first two have target copper thicknesses of 1000 Å. The third has a thickness of 2000 Å, and the fourth 4000 Å.

[**0052**] Next, while keeping the distance d between beams **57** and **22** fixed, the two beams are moved relative to wafer **20**, to place the spots on a site where a groove passes between the two spots, and the reflected portion of beam **22** is measured, thereby to yield measurement S_g Thereafter, a ratio of the previous measurement S_f to the current measurement S_g is used to look up the sidewall thickness, e.g. from a graph (which is obtained from independent measurement (under the same conditions) on grooves of known sidewall thickness). As before, alternatively the above relation (or a similar but more exact solution), with estimates of the groove height H, width W, and bottom thickness T_B may be used to extract the sidewall thickness t. **FIG. 16** show measurement identical to the one in **FIG. 15**, but with a 0.2 μm wide, 0.5 μm deep groove interposed between the two beams. The heating signal is normalized to the signal obtained without the groove to correct for the different temperatures to which the film can be heated, which is a function of the film thickness. This normalization is found by measuring with both beams placed on one side of the groove. The normalized signal with the groove between the two beams is called the "ratio". The ratio increases with thickness in the field because the thicker copper samples also have thicker sidewalls, so that the thermal impedance of the sidewalls is lower and more heat is conducted from the first beam to the second.

[**0053**] The measurement may be used to determine the sidewall thickness for a given groove dimension (width, depth) by correlating the measured ratio to a separate measurement of sidewall thickness obtained with any method well known in the art.

[**0054**] Alternately, this measurement may be used for process control. Consider the two samples labeled 1kA Cu and new 1kA Cu. These have the same nominal films, but the films differ due to process variation. A lower ratio indicates a thinner sidewall thickness. In the case shown here, a lower control limit of ratio=0.15 can be set and an upper limit of 0.25. Films measured in this ratio range are accepted; films outside this range are rejected.

[**0055**] Note that embodiments described above may be used in combination as follows. One embodiment measures the average sidewall thickness and another embodiment measures the asymmetry, showing the relative coverage of the two walls. The combination indicates that the average

thickness is within the proper range. The asymmetry measurement indicates that the average thickness is not in the acceptable range because the coating is too thick on one wall and too thin on the other. The asymmetry is correlated empirically, by measuring the slope **32**R and **32**L. Acceptable values are set based on measurements using TEM or SEM, or other prior art methods.

[**0056**] Another embodiment evaluates a wafer **20** having an array of metal lines **200**, with the lines labeled **201**_a-h_. Although the word "metal" is used, it is to be understood that lines **200** can be formed of any conductive material. **FIG. 18A** illustrates the cross-section of lines **200**, which is assumed to extend along an axis perpendicular to the plane of the paper. Array **200** is illuminated with a beam **202**_i_ of power Pin, which may be composed of electric field components parallel and perpendicular to lines **201**_a-h_. In **FIG. 18A**, the parallel component of beam **202**_i_ is shown as a circle and the perpendicular as an arrow Ein. The array line width is shown equal to the spacing (although this is not a constraint on the measurement) and the periodicity is smaller than the wavelength of the incident beam **202**_i_.

[**0057**] When illuminated by a beam **202**_i_, array **200** transmits a portion **202**_t_ and reflects another portion **202**_r_, wherein the portions being reflected and transmitted depend on the respective polarization directions, as discussed above. Specifically, array **200** behaves in a manner similar or identical to a wire grid polarizer as described in the above-referenced U.S. patent application Ser. No. 09/521,232 and in Handbook of Optics at pages 10-72 to 10-77, which pages are incorporated by reference herein in their entirety. However, unlike the conventional use of wire grid polarizer to polarize radio waves and far-infrared radiation, this embodiment uses array **200** to polarize near-infrared or visible light of either or both of beams **57** and **22**.

[**0058**] In accordance with the invention, the principle of wire grid polarizer can be extended to grooves that are completely coated with a conductor such as a metal, such as structure **210** illustrated in **FIG. 18B**, which may be formed by blanket deposition of metal on an arrea area that is surrounded by field areas. The extension of the principle of wire grid polarizer to a completely coated array **210** is unexpected for at least two reasons. First, the metal electrically connects the adjacent grid elements, unlike a wire grid polarizer. Second, light that would normally pass through structure **210** (polarized perpendicular to the grid elements) now has nowhere to go at the bottom, because the bottom is closed by layer **231**. Note that it is possible to employ the grooves of structure **210** as optical waveguides. The perpendicular polarization direction allows light to enter the grooves, exciting waaveguide modes. This excitation provides the ability to selectively heat within the grooves, providing a temperature increase that is a function of the sidewall thickness, in part because the sidewalls provide a thermal impedance to heat flow out of the grooves that varies inversely with sidewall thickness. This energy sets up a temperature profile **214** as illustrated in **FIG. 18B**.

[**0059**] Under the above-described conditions, transmission properties of structure **210** are similar to those observed with array **200**, wherein lines **201**_a_-**201**_f_ are independent of one another, as shown in **FIG. 18A**. Specifically, **FIG. 19A** shows the reflection signal in volts for 1 micron wavelength laser light as a 2 μm diameter spot is scanned across an array of grooves with trench widths from 0.25 to 0.40 μm coated from the top with 250 Å of Ta and 1000 Å of Cu. The arrays are 5 μm wide, so each scan begins on the left side field area, passes over the array area, and ends on the right side field area.

[**0060**] Note that there is no significant change (e.g. less than 20%) in reflection during the scan when using parallel polarization (**FIG. 19A**). Thus, the array area reflects substantially like the field area, as seen with the wire grid. However, the same experiment done with perpendicular polarization of the probe beam shows a dip (e.g. reduction by more than 20%) in reflection in the array area (in comparison to the field area), as seen in **FIG. 19B**. The magnitude of the dip provides an indication of the aspect ratio, as discussed next.

[**0061**] As illustrated by **FIGS. 19A-19B**, use of parallel polarization of heating beam **57** results in reflection from the tops of the grooves, with very little light (e.g. less than 20%) leaking into the grooves. Conversely, use of perpendicular polarization of heating beam **57** results in light passing into the grooves, where at least a portion of the non-absorbed light is absorbed to heat the groove walls (some fraction may transmit through the groove walls, since the metal on the walls may be thinner than the skin depth of the metal). Furthermore, light within the grooves is more effectively absorbed, since the grooves being deep and narrow (e.g. aspect ratio >2) act as light traps.

[**0062**] Therefore, a measurement of sidewall thickness t is made in one implementation in the following manner:

[**0063**] 1. Light polarized perpendicular to the grooves is shone onto the corrugated structure **210**, becomes absorbed and converted to heat; this heats the structure to a temperature inversely proportional to the sidewall thickness.

[**0064**] 2. A second laser polarized parallel to the grooves is shone on the structure **210**; due to its polarization, it only reflects from the tops of the grooves; alternatively second laser is polarized perpendicular to the grooves, and is reflected by the sidewalls.

[**0065**] 3. The reflectance is a function of temperature, so the reflection of the second laser is a measure of sidewall coverage.

[**0066**] Specifically, laser beam **211** (**FIG. 18B**), which forms a heating beam of this embodiment, is polarized perpendicular to the axis of the grooves in structure **210**. Structure **210** has groove floors **210**_ga_, **210**_gb_. . . **210**_gz_, tops **210**_ta_, **210**_tb_. . . **210**_tz_ and sidewalls therebetween. Because of the polarization of beam **211**, it pumps heat into the grooves (which include the sidewalls and the groove floors). This heat diffuses out of the illuminated region, to the cooler adjacent regions, as shown by the arrows **213**A and **213**B. This diffusion sets up a temperature profile **214** which is hottest at the center and cooler with distance from the laser beam **211**.

[**0067**] With respect to the absorption of light in the grooves, the typical case, in fact, is a cross between the two structures **200** and **210** shown in **FIGS. 18A and 18B**, the one extreme being that the metal lines are isolated and there is a transmission path through structure **200** for light polar-

ized perpendicular to the lines, and the other being the case of a thick metal coating that makes structure **210** completely opaque. The case typically is intermediate because the thickness of the metal on the sidewalls is on the order of the skin depth, that being the thickness at which the light intensity decays to 1/e due to absorption within the metal. For a wavelength of 0.83 μm, the 1/e absorption distance for copper is 125 Å, and for a barrier metal such as tantalum the 1/e absorption distance is 176 Å.

[**0068**] The temperature profile **214** (**FIG. 18B**) is governed by the thickness t of the sidewall coating (also called simply "sidewall"), because: first, the thickness of the tops **210***ta*-**210***tz* is uniform and independent of variation in groove properties, since the deposition on the tops **210***ta*-**210***tz* is in direct view of the deposition source; second, the thermal path through the groove floors **210***ga*-**210***gz* is much longer than the path through the tops **210***ta*-**210***tz* (for 0.5 μm deep grooves with half-pitch of 0.2 μm, the path length through the tops **210***ta*-**210***tz* is 0.2 μm and through the groove floors **210***ga*-**210***gz* is 1.2 μm); and third, the coating in the grooves is much thinner, and the thermal impedance is inversely proportional to the metal thickness. For example, the thickness on the tops **210***ta*-**210***tz* may be 0.1 μm and in the grooves 0.02 μm. In this case, the thermal impedance in the path through the grooves is 30 times than through the tops, so that the temperature profile is substantially governed by the sidewall thickness t.

[**0069**] Heat also flows along the length of the grooves and tops (i.e in the longitudinal direction, which is perpendicular to the plane of the paper in **FIG. 18B**). In this case, the cross section of the metal in the grooves (including the sidewalls and the floor) is about equal to the cross section at the top, so the heat flow in this axis is equally divided between the tops and the grooves, and the sidewall thickness variation contributes to about half of the temperature drop in this axis. Because the structure **210** is embedded in an insulator, parasitic heat leakage through conduction paths other than the metal does not adversely affect the measurement.

[**0070**] The peak temperature is measured using a second laser beam **212**, which forms a probe beam of this embodiment. Laser beam **212** is polarized either parallel or perpendicular to the grooves, depending on the implementation. When polarized parallel, laser beam **212** only reflects from the tops, thereby making its reflection independent of the groove properties. The reflectance of any metal is a function of temperature, so the reflection of parallel polarized beam **212** is a measure of the temperature profile of the tops, which in turn is governed by the sidewall thickness. Hence the measurements provide an indication of sidewall thickness.

[**0071**] **FIG. 20** presents measurements from a set of grooves with pitches ranging from 0.5 to 0.8 μm, the groove width being half the pitch. The grooves are 0.5 μm deep. The structures are completely coated with 250 Å of Ta and 1000 Å of Cu, and the sidewall coverage is a function of the width of the grooves (since the metal is impeded from coating the walls by virtue of the high aspect ratio). During calibration, the coverage is also measured independently, by any well known method, e.g. by sectioning the grooves using a focused ion beam and then imaging the cross-section with a scanning electron microscope. The graph in **FIG. 20** provides a calibration curve for use in process control. Once it has been obtained, the correlation line (**FIG. 20**) is used to calibrate the signal to the sidewall thickness. For example, a signal of 13,000 units corresponds to a sidewall coverage of 15.9 nanometers.

[**0072**] In an alternative embodiment, laser beam **211** is polarized perpendicular to the grooves, and is therefore reflected by sidewalls and groove floors of array **210**. As the sidewalls and floors are heated, the reflected portion of such a perpendicular polarized beam **211** also provides a measure of the temperature profile, and, hence, sidewall thickness. The measurement using perpendicular polarized beam **211** is more accurate and more sensitive than a corresponding measurement using parallel polarized beam **211**. The graph in **FIG. 21** provides a calibration curve for use in process control, based on use of perpendicular polarized beam **211**.

[**0073**] **FIG. 22** shows one implementation of a measurement apparatus in accordance with the invention. A first laser **601** has a wavelength of 830 nm and a maximum output power of 100 mW (Spectra Diode Laboratories model 2300). Collimating lens **602** forms a four mm diameter collimated beam **603** that is linearly polarized by virtue of the laser's output characteristics. The polarization direction may be optionally rotated using half-wave plate **624** to align the direction relative to a pattern of lines on the wafer. Half-wave plate **624** may be mounted on an actuator to be placed in or out of the beam. Beam **603** is referred to as the "heating beam", and is used to heat the measured area.

[**0074**] Second laser **605** is a semiconductor diode laser with a wavelength of 980 nm (Spectra Diode Laboratories model 6700). It is coupled to the system using optical fiber **606**, and the beam is collimated using lens **607**, providing a 4 mm diameter circularly polarized beam **609**. Beam **609** is linearly polarized using quarter-wave plate **625**. Beams **609** and **603** are combined using dichroic mirror **610**, forming single combined beam **611**. Beam **611** passes through beam splitter **612**, whose purpose is to send the return beam to the detector. A portion of beam **611** is detected using photocell **613**, which may be used to ensure proper calibration of the power of beam **611**. Beam **611** then passes through beam splitter **614** and focusing lens **615**, which is a 100× lens (Olympus, Tokyo Japan), focusing the combined beam on the wafer **616**.

[**0075**] The reflected light is re-collimated with lens **615**. 90:10 beam splitter **614** diverts the return beam **611** to an autofocus and imaging system consisting of lens **617** and camera **618** (an additional beam splitter, pinhole and detector for the autofocus are not shown). Lens **617** and camera **618** enables viewing of the sample to place the focus spot at the correct location. The autofocus system allows the focus spot of the laser beams to be maintained at the surface of the wafer **616**. Half of the power in beam **611** is then sent to optical narrow-band filter **619**, which passes the light from laser **605** (980 nm) but blocks the light from laser **601** (830 nm). The transmitted light passes to photodetector **620**, amplifier **624**, and lock-in amplifier **622**. The signal from lock-in amplifier **622** is then sent to a computer for analysis.

[**0076**] Lock-in amplifier **622** has a oscillator that serves as a reference signal for synchronous detection of the output of photocell **620** and amplifier **624**. This oscillator is used as an input to laser driver **621**, which provides a modulated drive for laser **601**. The modulation frequency is preferably <2 KHz. This is to avoid creation of thermal waves. Such waves are generated at higher modulation frequencies. Because of

the uneven (corrugated) geometry of structure **210**, any waves will cause reflections that will confuse the measurement, and must therefore be rigorously avoided.

[**0077**] Filter **19** is on an actuator so that it may be removed to enable use of laser **601** for single beam measurement. In this case, laser **605** is turned off, e.g. by closing a shutter.

[**0078**] The heat flow obeys the diffusion equation, which in its simplest form (one-dimension) is

$$\frac{\partial^2 T}{\partial x^2} + \frac{Q}{K} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \quad (1)$$

[**0079**] where T is the temperature rise above ambient, Q is the heat input per unit volume, K is the thermal conductivity, and α is the thermal diffusivity. Under sinusoidal excitation, the temperature is written as $T(z,t)=T(z)e^{j\omega t}$ where $\omega=2\pi f$ and f is the excitation frequency. In the region outside the heating spot, Q=0, and equation (1) is written as

$$\frac{\partial^2 T}{\partial x^2} - j\frac{\omega}{\alpha}T = 0 \quad (2)$$

[**0080**] which has a solution of the form

$$T(z) = T_0 \exp\left[(1+j)\left(\sqrt{\frac{\pi f}{\alpha}}\right)z\right],$$

[**0081**] which is a decaying wave with a wavelength

$$\lambda = \sqrt{\frac{\alpha}{\pi f}}.$$

[**0082**] The criterion for a "steady-state" measurement—that is, a measurement without the presence of an unwanted wave component—is $\lambda >> L$, where L is the length of the structure that is being measured, or, alternately, the length over which the temperature profile decays because of heat loss mechanisms such as diffusion into the insulator underneath the metal film. This sets up a relationship for the modulation frequency of

$$f << \frac{\alpha}{\pi L^2} \quad (3)$$

[**0083**] **FIG. 23** shows a graph of the frequency versus the length L. When L is on the order of 10 μm, the condition of equation (3), to avoid generation of a thermal wave, is met when the frequency is less than 10 KHz.

[**0084**] **FIG. 24** provides a flow chart of how the measurement is used for process control. In step **410** a wafer is inserted into the measurement system and aligned to a predetermined site. In step **401** the first heating beam is focused at the predetermined site. In step **402** the second measurement beam is focused on the same predetermined site. In step **403** the reflection of the second beam is measured to provide a signal. In step **404** the signal is corresponded to a predetermined value using a look-up table or a correlation function. This provides a sidewall coverage value. At this point, in step **405** the result may be stored and steps **401**-**404** may be repeated at other sites to provide a map of a region or of multiple sites on the wafer. The results of steps **404** or **405** are compared to predetermined control limits to see if the sidewall coverage is within the proper specification. If it is, the wafer is sent to the next process step and the measurement sequence is repeated on a new wafer. If it is not, an in step **408** an appropriate fabrication process parameter is changed and applied to the processing of further wafers, which then enter step **410** for measurement.

[**0085**] **FIG. 25** shows a block diagram of how the measurement is implemented as part of a damascene interconnect process flow. The process flow consists of passing a wafer **502** through a number of sequential process tools, including patterning apparatus **520**, etching apparatus **521**, etching apparatus **521**, liner deposition apparatus **522** (which deposits the barrier and seed layers, the combination of which is called the liner), metal deposition apparatus **523**, polishing apparatus **524**, and measuring apparatus **525**, which includes a programmed computer **526**. Wafer **502** is shown entering the liner deposition as wafer **503** and exiting as wafer **504**. In path **510** wafer **504** is measured using the flow chart sequence shown in **FIG. 7**.

[**0086**] If the measurement is within limits, the wafer is returned to the process flow for the next step, eventually being completed as wafer **505**. If not, the programmed computer sends, using connection **515**, a signal to the etching and liner deposition machines to make predetermined adjustments. Numerous modifications and adaptations of the above-described embodiments, implementations, and examples will become apparent to a person skilled in the art of using lasers to measure properties of semiconductor wafers. For example, in an alternative embodiment, instead of using a laser to generate a heating beam, another heat source (such as an electron gun and electron focusing column that forms an electron beam) is used to modulate the temperature T. Also, a probe beam used to measure the sidewall thickness as described herein can consist of x-rays.

[**0087**] For example, although in the embodiment illustrated in **FIGS. 18A and 18B**, heating beam **211** forms a spot that overlaps a corresponding spot formed by probe beam **212**, such measurements can also be performed with the spots being separated by a fixed distance, e.g. if the spots are formed on the feature being evaluated (aligned in the longitudinal direction) and if heating beam **211** is modulated. Moreover, although a polarized probe beam is described for use in the embodiment illustrated in **FIGS. 18A and 18B**, an unpolarized probe beam may be used in another embodiment.

[**0088**] In another example, a sidewall thickness measurement is made using two lasers, both polarized perpendicular to a groove, and following the sidewall thickness measurement, one laser is turned off and the wafer is scanned under the remaining laser beam. The symmetry of the scan is then observed to verify that the sidewall coating is even (i.e. has the same thickness) on both sides of the groove. In yet another example, one beam is not turned off and instead the

two beams are scanned along the longitudinal direction of the feature, thereby to provide a linear scan in terms of the sidewall thickness.

[0089] Moreover, structures other than semiconductor wafers (e.g., photomasks that include a glass substrate and are used to form the wafers, or an active matrix liquid crystal display) can also be evaluated as described herein.

[0090] Furthermore, instead of scanning as described herein, another embodiment performs hopping. Specifically, this embodiment involves a stepwise movement ("hopping") from one region to another region of the wafer when performing measurements of the type described herein (as opposed to scanning that continuously moves ("sweeps") the beam of electromagnetic radiation relative to the wafer. In the hopping process, the stage holds the wafer stationary for a moment (e.g., 1 second) while a measurement is taken in one region, and then moves to another region (e.g., of the same wafer).

[0091] Two regions in which measurements are made can be separated from each other, e.g., by distance which is same as the diameter of the beam. Alternatively, the two regions can touch each other or even overlap each other. When overlapping one another, the centers of the two regions may be separated by a small fraction of the diameter, e.g., by (1/10) D or less. Regardless of how close the regions are, the hopping process yields discrete values (one for each region) as compared to the sweeping process which yields a continuous signal. As described elsewhere herein, the regions can be physically located on different features (e.g. on the two sidewalls of a groove), so that an alternative embodiment involves hopping from feature to feature (when hopping among features). A combination of the just-described two types of hopping can also be used (i.e., moving between regions of the same feature and also moving between features).

[0092] Note that the just-described "hopping" can be performed from one region to a next region that touch each other, and a measurement from each region can be plotted in a graph, e.g., to indicate a profile of sidewall thickness across the regions. In another embodiment, hopping is performed between regions that overlap one another thereby to provide a more realistic measure of the average profile across these regions, as compared to non-overlapping regions.

[0093] Numerous modifications and adaptations of the above-described embodiments, implementations, and examples are encompassed by the attached claims.

1. A method of evaluating a feature in a semiconductor wafer, the method comprising:

illuminating the wafer with a beam of electromagnetic radiation having a majority of energy polarized in a direction other than parallel to a longitudinal direction of the feature; and

measuring intensity of a portion of the beam reflected by the wafer.

2. The method of claim 1 wherein:

the feature includes a sidewall of a groove; and

the act of measuring is performed repeatedly at a plurality of locations transverse to the longitudinal direction of the groove.

3. The method of claim 2 wherein:

the beam has a wavelength greater than thickness of the sidewall.

4. The method of claim 1 wherein:

the beam has a wavelength greater than a dimension of the feature; and

the beam forms on the wafer a spot of a diameter greater than the dimension.

5. The method of claim 1 wherein:

the feature includes a trace of reflective material.

6. The method of claim 1 wherein:

the wafer includes a layer located between a source of the beam and the feature; and

the layer is at least partially transmissive, so that the portion passes through the layer.

7. The method of claim 1 wherein:

the beam has a majority of energy polarized in a direction at least substantially perpendicular to the longitudinal direction.

8. The method of claim 1 wherein:

the beam has a predetermined wavelength; and

the method further comprises filtering light of a wavelength other than the predetermined wavelength.

9. The method of claim 1 wherein the wafer has a plurality of features including the feature, and the method further comprises:

performing the act of measuring for each feature of the plurality; and

comparing measurements of multiple features.

10. The method of claim 9 wherein:

each feature is a sidewall; and

the act of comparing includes comparing measurements of two sidewalls located opposite to one another in a groove.

11. The method of claim 1 wherein the beam is a first beam, and the method further comprises:

illuminating the wafer with a second beam of electromagnetic radiation.

12. The method of claim 11 wherein:

the first beam forms a first spot on the wafer, the second beam forms a second spot;

the act of measuring includes measuring with the first spot and the second spots located on opposite sides of the feature; and

the method further comprises measuring with the first spot and the second spots located on the same side of the feature.

13. The method of claim 11 wherein:

the second spot at least partially overlaps the first spot.

14. The method of claim 13 wherein:

the first beam has a first wavelength different from a second wavelength of the second beam;

the second beam is modulated at a predetermined frequency; and

the act of measuring includes measuring intensity of the second beam having the second wavelength and modulated at the predetermined frequency.

15. The method of claim 13 wherein:

the first beam is polarized substantially perpendicular to the longitudinal direction.

16. A method of evaluating wafers during fabrication, the method comprising:

forming a feature of conductive material in a wafer by using at least one process parameter;

illuminating the wafer with a beam of electromagnetic radiation having a majority of energy polarized in a direction other than parallel to a longitudinal direction of the feature; and

repeatedly measuring intensity of a portion of the beam reflected by the wafer at a plurality of locations transverse to the longitudinal direction; and

changing the process parameter depending on measurements obtained from the act of repeatedly measuring.

17. The method of claim 16 further comprising:

determining a coefficient of a function that fits the measurements;

comparing the coefficient against a predetermined limit and performing the changing based on an outcome of the comparing.

18. A method of evaluating a feature in a semiconductor wafer, the method comprising:

illuminating the wafer with two beams, each beam forming a spot; and

performing a measurement with the first spot and the second spots located on opposite sides of the feature.

19. The method of claim 18 wherein:

each of the two beams includes unpolarized light.

20. The method of claim 18 wherein:

each of the two beams includes light polarized in a direction other than parallel to a longitudinal direction of the feature.

21. The method of claim 18 wherein:

the method further includes modulating intensity of a first beam at a predetermined frequency, said predetermined frequency being sufficiently small to avoid creation of a wave; and

the act of performing includes measuring intensity of a portion of the second beam reflected by the wafer, the portion being modulated at the predetermined frequency.

22. The method of claim 18 further comprising:

performing a second measurement with the first spot and the second spots located on the same side of the feature.

23. A method of evaluating a feature in a semiconductor wafer, the method comprising:

illuminating the wafer with two beams, a first beam having a first intensity larger than a second intensity of a second beam, the first beam having a majority of energy polarized in a direction other than parallel to a longitudinal direction of the feature; and

measuring intensity of a portion of the second beam reflected by the wafer

24. The method of claim 22 wherein:

the method further includes modulating intensity of the first beam at a predetermined frequency, said predetermined frequency being sufficiently small to avoid creation of a wave; and

the act of measuring includes measuring intensity of a portion of the second beam reflected by the wafer, the portion being modulated at the predetermined frequency.

25. The method of claim 22 wherein:

each of the two beams is a laser beam.

26. The method of claim 22 wherein:

the first beam is an electron beam; and

the second beam is a laser beam.

27. The method of claim 22 wherein:

the first beam forms a first spot; and

the second beam forms a second spot that at least partially overlaps the first spot.

28. The method of claim 22 further comprising:

forming the feature by using at least one process parameter; and

changing the process parameter depending on measurements obtained from the act of measuring.

29. An apparatus for evaluating a feature in a wafer, the apparatus comprising:

a laser source for generating a beam polarized in a direction other than parallel to a longitudinal direction of the feature; and

a photosensitive element located in a path of radiation of electromagnetic energy from the wafer.

30. The apparatus of claim 29 further comprising:

a circuit coupled to the laser to move the beam along a line across the feature; and

a monitor for displaying a graph of a signal generated by the photosensitive element as a function of distance along the line.

31. The apparatus of claim 30 wherein:

the line is at least substantially perpendicular to the longitudinal direction of the feature.

32. The apparatus of claim 29 further comprising:

an oscillator capable of oscillating at a frequency lower than 25000 Hz, the oscillator being coupled to the laser source; and

a lock-in amplifier coupled to said oscillator and to said photosensitive element.

33. The apparatus of claim 32 wherein during operation:

said oscillator causes said laser source to generate said beam at an intensity modulated at said frequency; and

said lock-in amplifier generates a signal indicative of reflectivity of said wafer.

34. The apparatus of claim 29 further comprising:

a computer coupled to the photosensitive element and programmed to determine a dimension of the feature.

35. The apparatus of claim 34 further comprising:

a memory having encoded therein values generated from at least one test wafer having a feature of a known property;

wherein the computer is programmed to use a signal generated by the photosensitive element to look up a value of property for the wafer, based on the values in memory.

36. An apparatus comprising:

means for illuminating a semiconductor wafer with a beam of electromagnetic radiation having a majority of energy polarized in a direction other than parallel to a longitudinal direction of the feature; and

means for measuring intensity of a portion of the beam reflected by the wafer, the means for measuring being coupled to the means for illuminating.

37. The apparatus of claim 36 further comprising:

means for displaying measurements generated by the means for measuring, as a function of distance.

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