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(54) **CURVATURE-BASED EDGE BUMP QUANTIFICATION**

(75) Inventors: **Rabi Fettig**, Somerville, MA (US); **Jaydeep Kumar Sinha**, Mansfield, MA (US)

(73) Assignee: **KLA-TENCOR CORPORATION**, Milpitas, CA (US)

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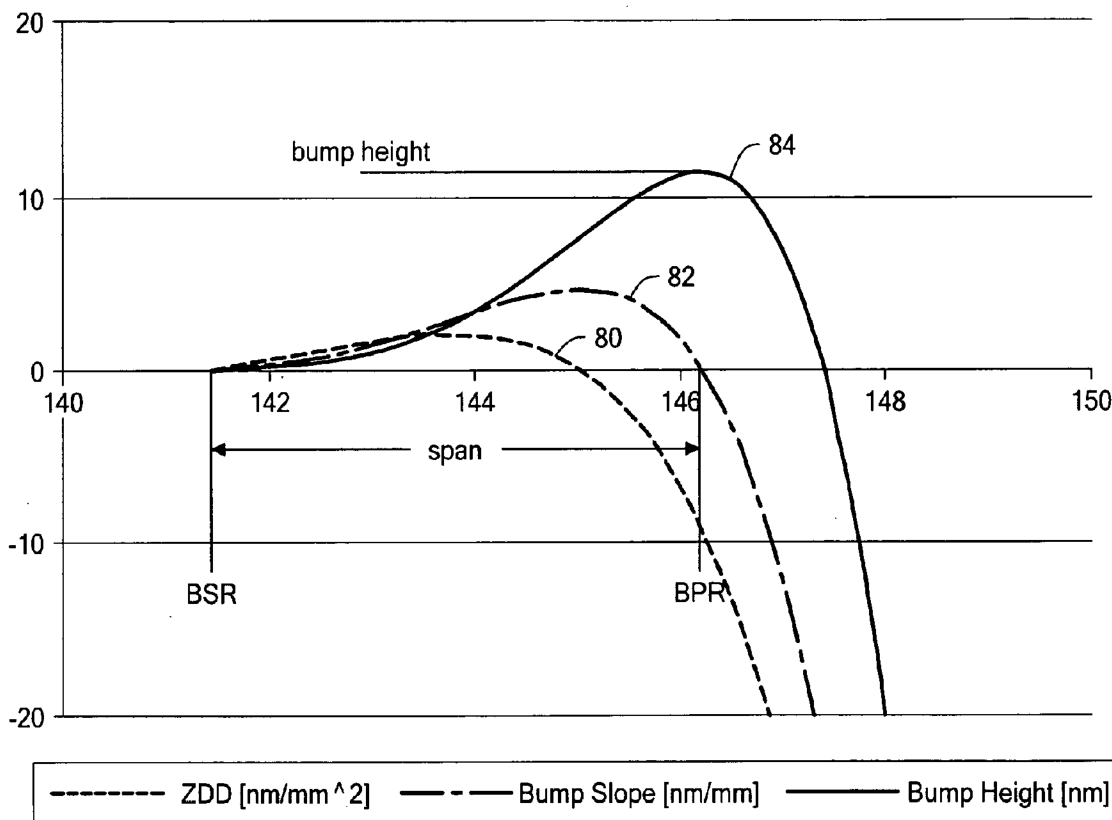
(57) **ABSTRACT**

Evaluating irregularities in surfaces of objects such as semiconductor wafers using a thickness profile of a surface section and analyzing the profile to obtain information of an irregularity start position, magnitude, and span along with surface slope and height information.



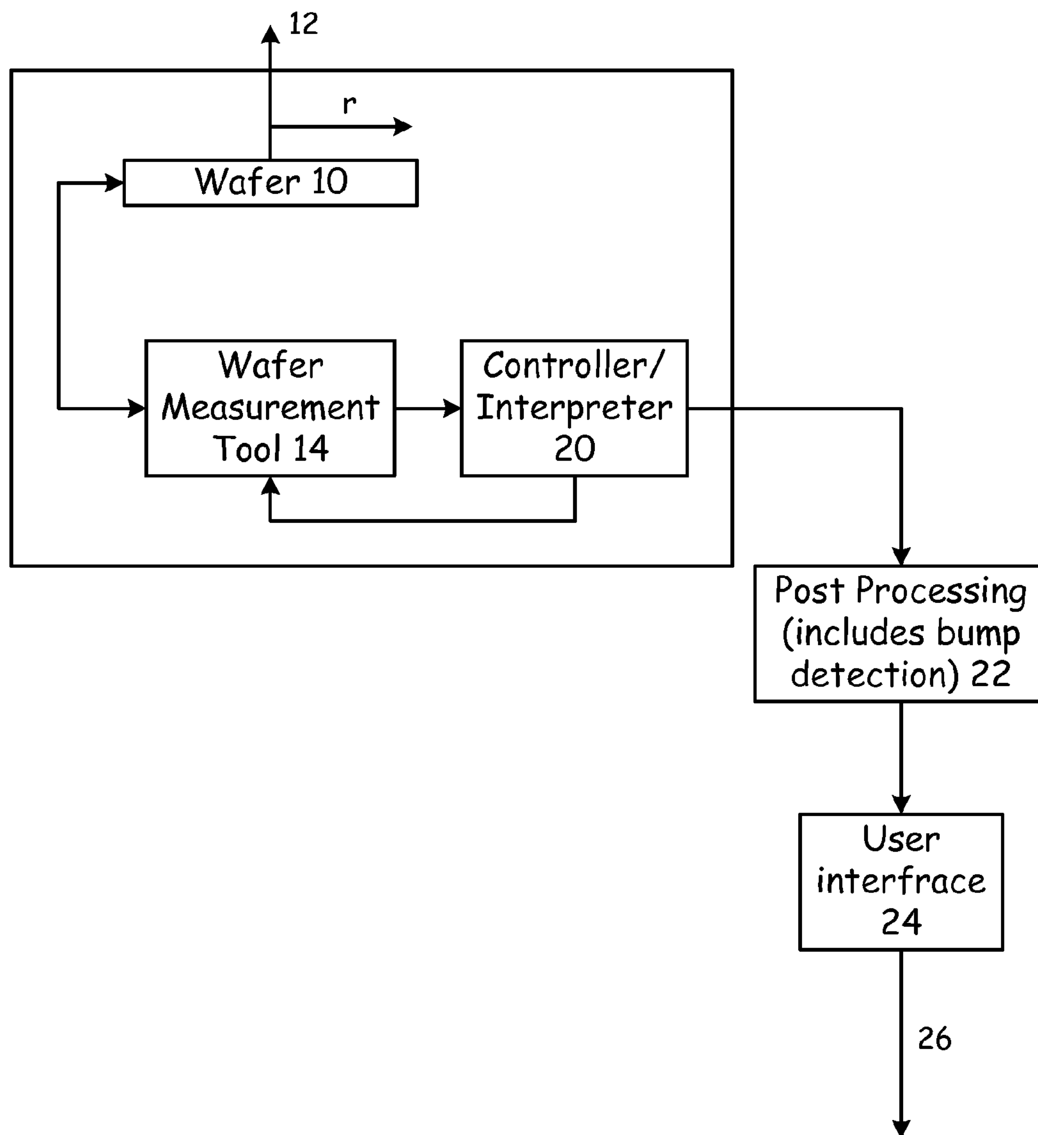



Fig. 1

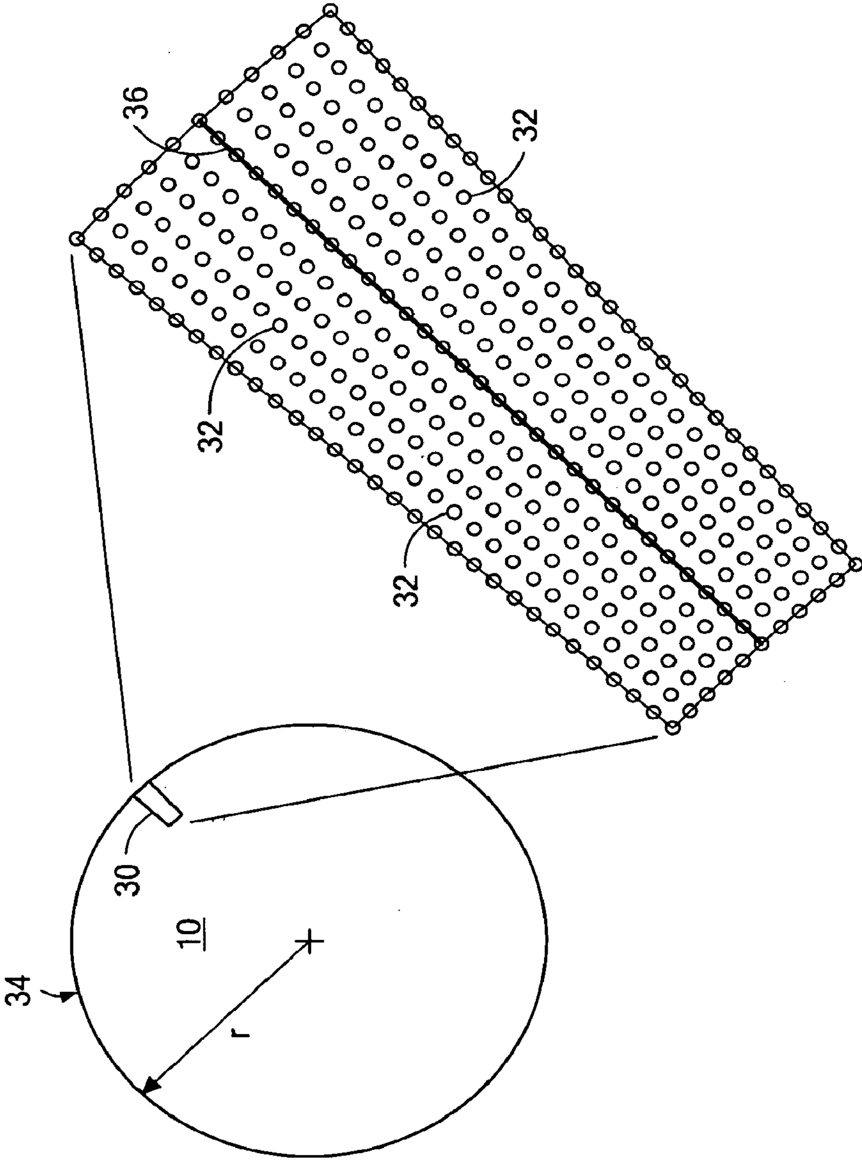



FIG. 2

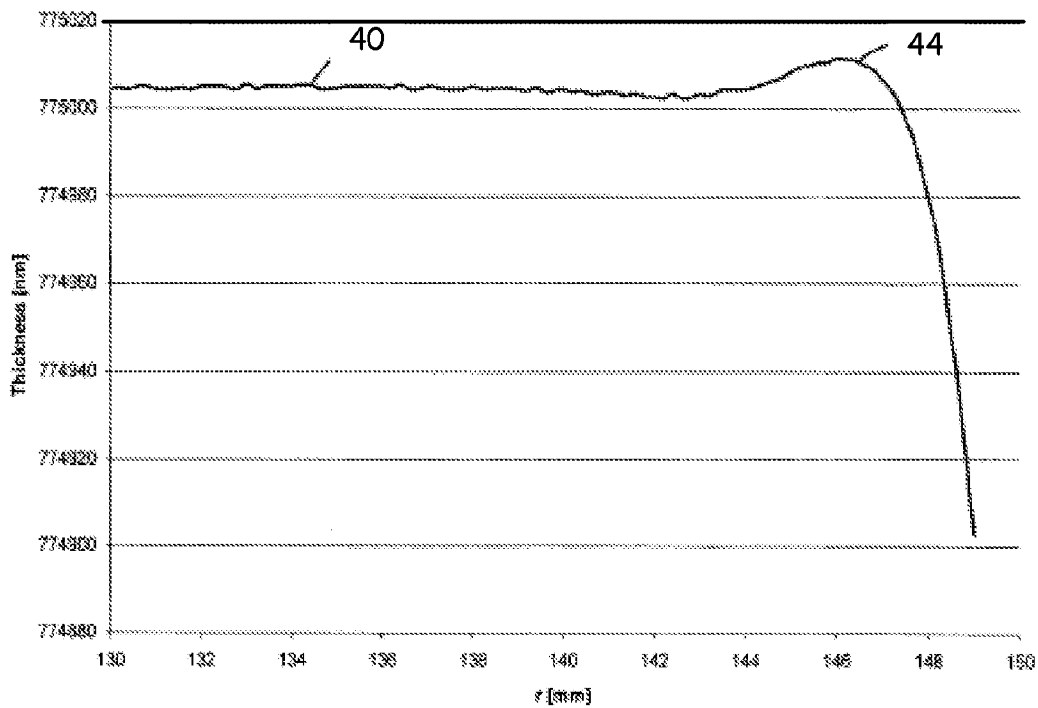



Fig. 3

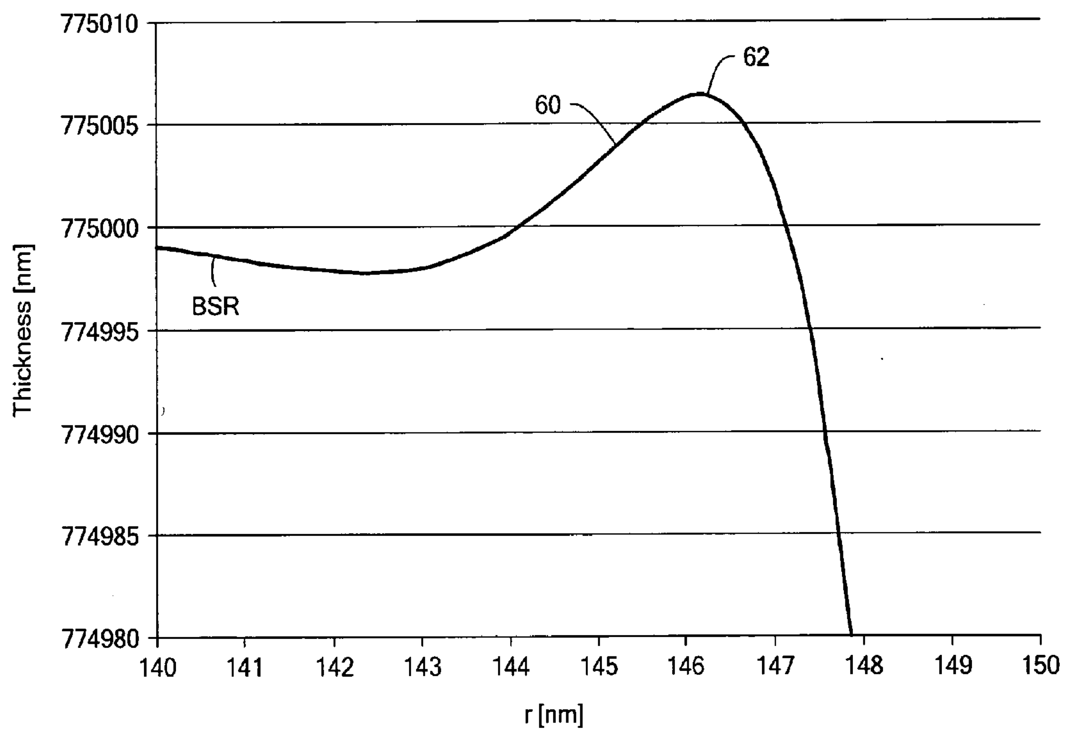



*FIG. 4*

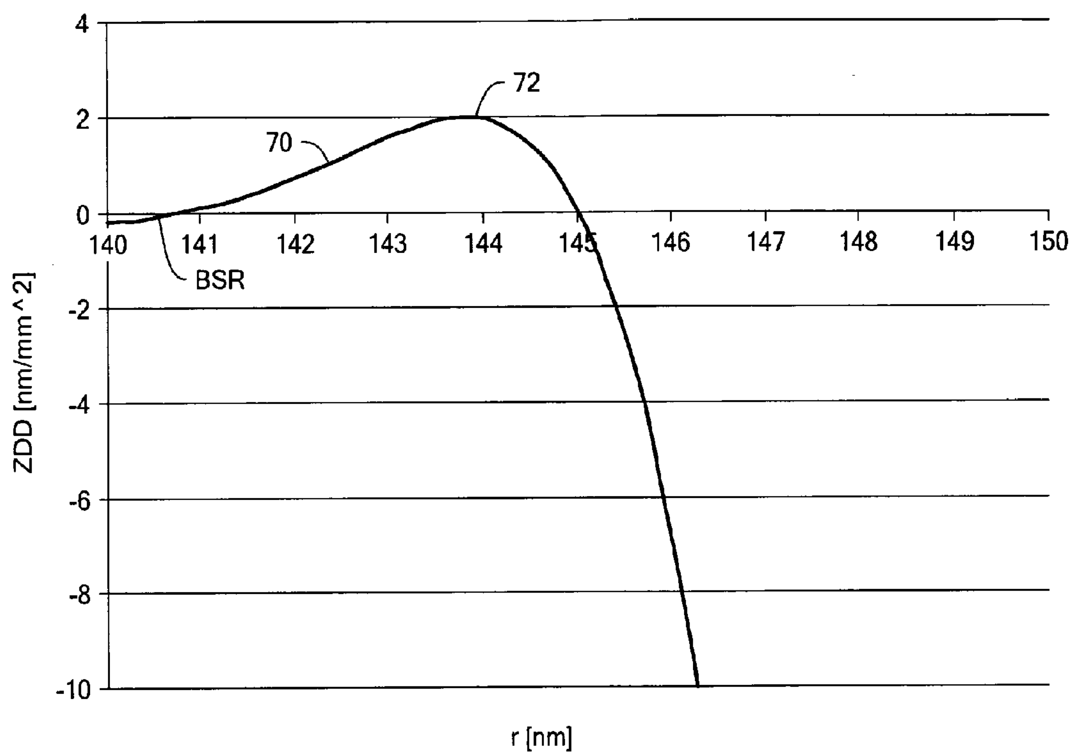



*FIG. 5*

$$S_b(r) = \int_{BSR}^{r} C(\rho)\,d\rho$$

*FIG. 6*

$$h_b(r) = \int_{BSR}^{r} \int_{BSR}^{\gamma} C(\rho)\,d\rho\,d\gamma$$

*FIG. 7*

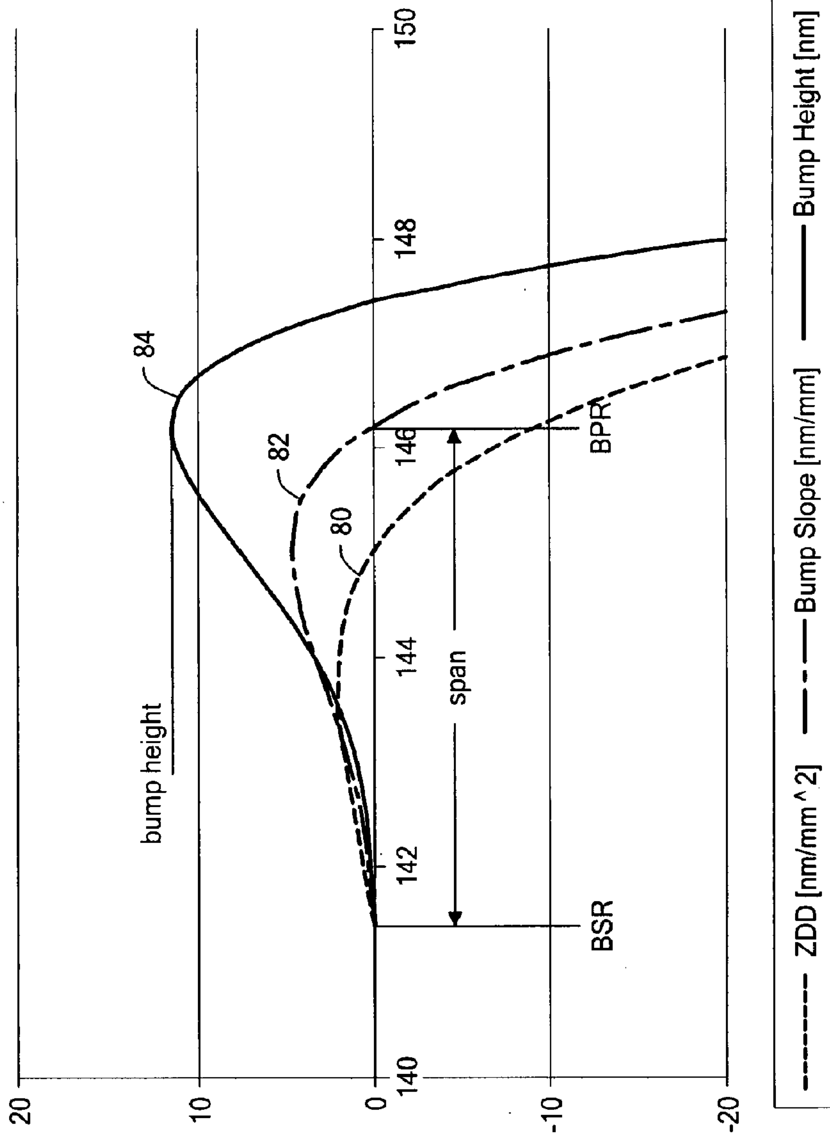



*FIG. 8*

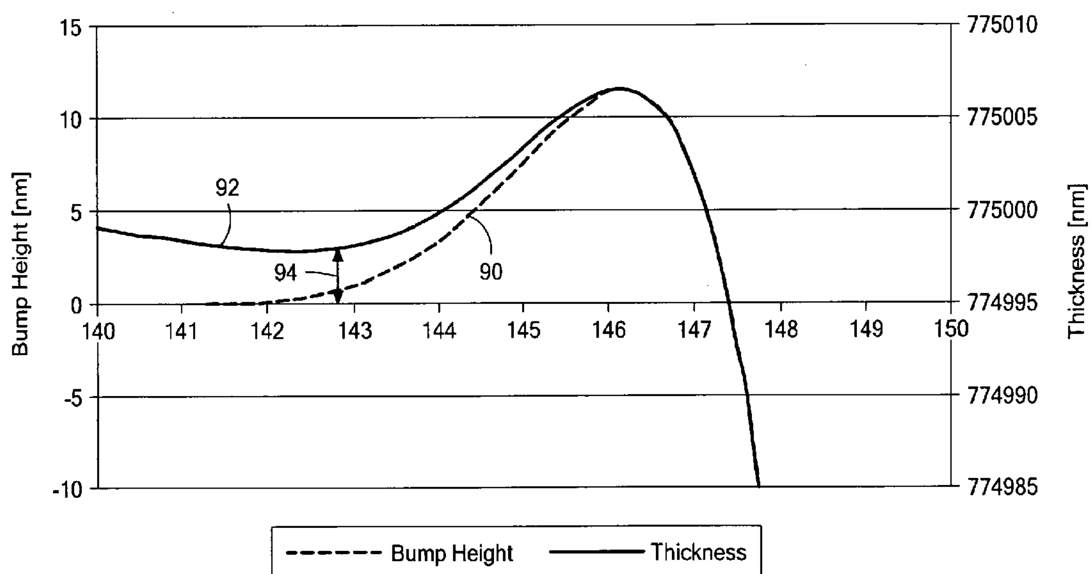



*FIG. 9*

# CURVATURE-BASED EDGE BUMP QUANTIFICATION

## CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** N/A

## STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

**[0002]** N/A

## BACKGROUND OF THE INVENTION

**[0003]** This application claims all rights and priority on prior pending U.S. patent application Ser. No. 11/789,037 filed 2007.04.23. The present invention relates to the measurement of surface topology of semiconductor wafers prior to their fabrication by semiconductor manufacturers into various micro circuits and other similar devices.

**[0004]** Semiconductor wafers are expensive real estate in that the manufacturers of semiconductor products need to know the quality of the surface area of the wafers, which can be as large as 300 cm across, before committing time, equipment and materials to process them into finished semiconductor products. If there is a sufficient perturbation in the surface profile of a portion of a semiconductor which could prevent its being processed into a finished product, that information needs to be known before the manufacturer proceeds so that that portion can be eliminated from processing. This problem is particularly severe in the edge areas of semiconductors where there tends to be a slope roll-off so that traditional thickness measurements by themselves are unlikely to reveal the presence of all or many bumps that affect the processing of finished semiconductor products.

**[0005]** Current processing and sensing techniques for a wafer surface profile are inadequate to accurately reveal the presence of a bump which exists as a significant variation from the local surface profile. Present techniques use a proximity probe which may, in fact, be a laser interferometer, to measure thickness of a wafer. This information is presently processed to provide a curvature profile by taking the second derivative of the curve representing data obtained by current probing technologies.

## BRIEF SUMMARY OF THE INVENTION

**[0006]** The present invention aims at providing additional information about the bump (or depression anomaly) characteristics and in particular information about its start point radially from the semiconductor wafer central axis, the span of the bump to its maximum height and the actual height or departure from local surface level. That level is typically tilted with respect to a plane perpendicular to the wafer axis. Current semiconductor manufacturers need this additional information in order to accurately assess the suitability of all regions of a semiconductor wafer for processing purposes. The fact that a wafer may slope or roll off towards its edge does not necessarily disqualify it for purposes of producing finished semiconductor processes but a departure from the local plane of curvature could be a significant impediment.

**[0007]** The present invention provides additional signal processing which allows or provides the values of start point, peak point and distance therebetween which are essential to industry users. This data is obtained from the profile or second derivative curve by a process of integration of the profile value from the point where a rise in the local plane is first detected to outwardly extending radial points. A single integral will provide slope information about the wafer surface as a function of radius. The invention further provides for a double integral of the profile of curvature which will, in fact, provide surface normalized height information showing bumps and other perturbations above the local surface plane. Further, processing allows the maximum in the height information to be determined which can be used by manufacturers to judge the severity of the local departure from norm or bump.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

**[0008]** These and other features of the present invention are illustrated in the figure, and accompanying detailed description wherein:

**[0009]** FIG. **1** illustrates a wafer surface condition evaluation system with which the invention is operative and which provides data reflecting profiles of the wafer front surface, back surface, or thickness;

**[0010]** FIG. **2** illustrates data acquisition points on a semiconductor wafer surface as practiced in the invention;

**[0011]** FIG. **3** illustrates a typical profile obtained from utilization of the measuring apparatus of FIG. **1**;

**[0012]** FIG. **4** illustrates a typical thickness profile;

**[0013]** FIG. **5** illustrates a corresponding ZDD profile as practiced in the invention;

**[0014]** FIG. **6** illustrates processing of the data of FIG. **5** according to the present invention;

**[0015]** FIG. **7** illustrates further processing of the data of FIG. **5** according to the invention;

**[0016]** FIG. **8** illustrates graphically wafer anomaly data from processing according to the invention;

**[0017]** FIG. **9** illustrates the difference in detected surface anomalies between thickness data and anomaly measurements according to the invention.

## DETAILED DESCRIPTION OF THE INVENTION

**[0018]** As seen in FIG. **1**, the present invention operates in the environment of testing of a semiconductor wafer **10** for surface characteristics which is typically accomplished by spinning the wafer about its center on an axis **12** with a sensor or wafer measurement tool **14** of a type known in the art to measure distance to the wafer **10**. The sensor output is processed by a system **20** in conjunction with a microprocessor **22** to develop a profile, such as thickness or front/back surface distance, of the wafer **10** as it spins. Output information representing thickness or other parameters can be provided to a user interface **24** for use by I/O devices **26**.

**[0019]** In FIG. **2**, a top view of the wafer **10** is shown illustrating part of typical processing of the thickness information provided by the sensor **14** and associated electronics. In particular, in a sector **30** the sensor head **14** makes a plurality of measurements **32**, typically of thickness. The sector **30** may span a distance of 5° or more along the edge **34** of the wafer **10**. The sector **30** typically includes data taken within that angle over a distance between and 1 and 5-10 mm from the edge **34**. In typical application, the data in the segment **30** is averaged so as to provide thickness information along a radius vector **36**. While the invention is particularly useful at an edge, it may also be used over the whole wafer or other parts thereof.

**[0020]** Typical processing of information from the sensor **14**, as described with respect to FIG. **2**, will yield a profile curve **40** in FIG. **3**, in this case a thickness profile. Such a profile **40** typically has a plurality of small surface unevennesses. A larger anomaly would be classified as a bump **44**, or possibly a void, or inverted bump. It is with information about such anomalies **44** that the invention is concerned. The profile **40** of thickness illustrates a gradual roll-off or reduction in thickness illustrated in FIG. **3**, as the edge **34** of the wafer is reached.

**[0021]** FIG. **4** illustrates an expanded view of a thickness profile in the range of 140 to 150 mm from wafer center as a curve **60**. When an anomaly **62** such as a bump is present, the change in the ($2^{nd}$ slope derivative) of curve **60** will go from negative to positive. This point marks a bump start radius (BSR). Second derivative processing converts the curve **60** of FIG. **4** to a ZDD profile **70** in FIG. **5**. The profile **70** is typically referred to as the ZDD profile or metric. See Document No. 4209 of Semiconductor Equipment and Materials International, 3081 Zanker Road, San Jose, Calif. 95134-2127. That document bears a publication date of Nov. 6, 2006 and is incorporated herein by reference.

**[0022]** While both curves **60** and **70** illustrate the presence of respective bumps **62** and **72**, the start position of the bump in FIG. **4** is rather indeterminate from mere thickness measurement given the roll-off nature of the wafer at its edge. In FIG. **5** however, because of the second derivative properties, the beginning of the bump (BSR), or void, is identifiable as the zero crossing in the profile curve, or second derivative curve, **70**.

**[0023]** The demands of modern semiconductor processing and the cost of semiconductor real estate demands even better information about bumps or other anomalies be provided to the semiconductor manufacturer from testing of the raw semiconductor wafers. In order to accomplish that, the processing of FIGS. **6** and **7**, typically by processor **22**, which has provided the curve **70** of FIG. **5**, is employed.

**[0024]** The processor **22** acts on the profile data of FIG. **5** to perform the integration of FIG. **6** in which r represents the radius as shown in FIG. **1** and is the variable of integration. The integration is from the bump start radius (BSR) out to the actual radius r. This provides a slope database. Height information is found using the integration of FIG. **7** in which a double integral is formed first from BSR to y using the integration variable p followed by the integral from BSR to radius r using variable $\gamma$. The function C represents the curvature or ZDD profile **70** of FIG. **5**. From the integration $h_b$, a function of radius r, the bump peak radius (BPR) is calculated as the radius of the peak value bump height, of the double integral. A void would be a minimum. The bump height is calculated as the peak value of the distance between that point and BSR is calculated as the radial span of the bump or anomaly. This information calculated by processor **22** provides the bump start point, the bump height and the radial distance between them, valuable information for the semiconductor manufacturers.

**[0025]** FIG. **8** illustrates these effects of the processing of the invention. A curve **80** corresponds to the profile **70** of Fig. S. Curve **82** illustrates the results of the first integral processing of FIG. **6** to provide the slope $S_b$ information. The curve **84** illustrates the $h_b$ bump height information from the double integral of FIG. **7**. This information clearly allows the calculation of the bump peak radius or maximum height (BPR) in curve **84**. The span is the distance between BSR and BPR and the height as given from the processor **22** evaluation of the maximum value of curve **84** using known technologies.

**[0026]** The wafer tends to slope downward at the edges so that simple thickness information cannot readily be used to identify a variation in height relative to the near value of the slope throughout the edge region. This is illustrated in FIG. **9** which shows a gap **94** in minimum height between the thickness curve **90** and the bump height curve **92**.

**[0027]** The above description is illustrative only and the inventions scope is provided by the following claims.

**1-36**. (canceled)

**37**. A wafer surface profile tool for characterizing an anomaly on the wafer, comprising:

an input for receiving sensed height information within at least a sector at an edge of the wafer,

a processor for,

determining a shape profile for the wafer along at least a radial line within the sector, the shape profile comprising the sensed height information,

processing the shape profile to produce a ZDD profile, representing a radial double derivative of the sensed height information,

processing the ZDD profile to produce a slope profile,

determining an anomaly span metric from the slope profile,

processing the ZDD profile to produce a height profile, and

determining an anomaly height metric from the height profile, and an output for providing at least the anomaly span metric and the anomaly height metric.

**38**. The wafer surface profile tool of claim **37**, wherein the slope profile is produced from the ZDD profile by:

$$S_b(r)=\int_{BSR}^{r} C(\rho)d\rho$$

where

$S_b(r)$=the slope profile,

r=radius of the wafer,

$C(\rho)$=the ZDD profile, and

BSR=a bump start radius.

**39**. The wafer surface profile tool of claim **37**, wherein the height profile is produced from the ZDD profile by:

$$h_b(r)=\int_{BSR}^{r}\int_{BSR}^{\gamma} C(\rho)d\rho d\gamma$$

where

$S_b(r)$=the slope profile,

r=radius of the wafer,

$C(\rho)$=the ZDD profile, and

BSR=a bump start radius.

**40**. The wafer surface profile tool of claim **37**, wherein the anomaly is a bump.

**41**. The wafer surface profile tool of claim **37**, wherein the anomaly is a recess.

* * * * *