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(54) **PROCESSING OF SIGNALS FROM AN IN-SITU MONITORING SYSTEM IN CHEMICAL MECHANICAL POLISHING**

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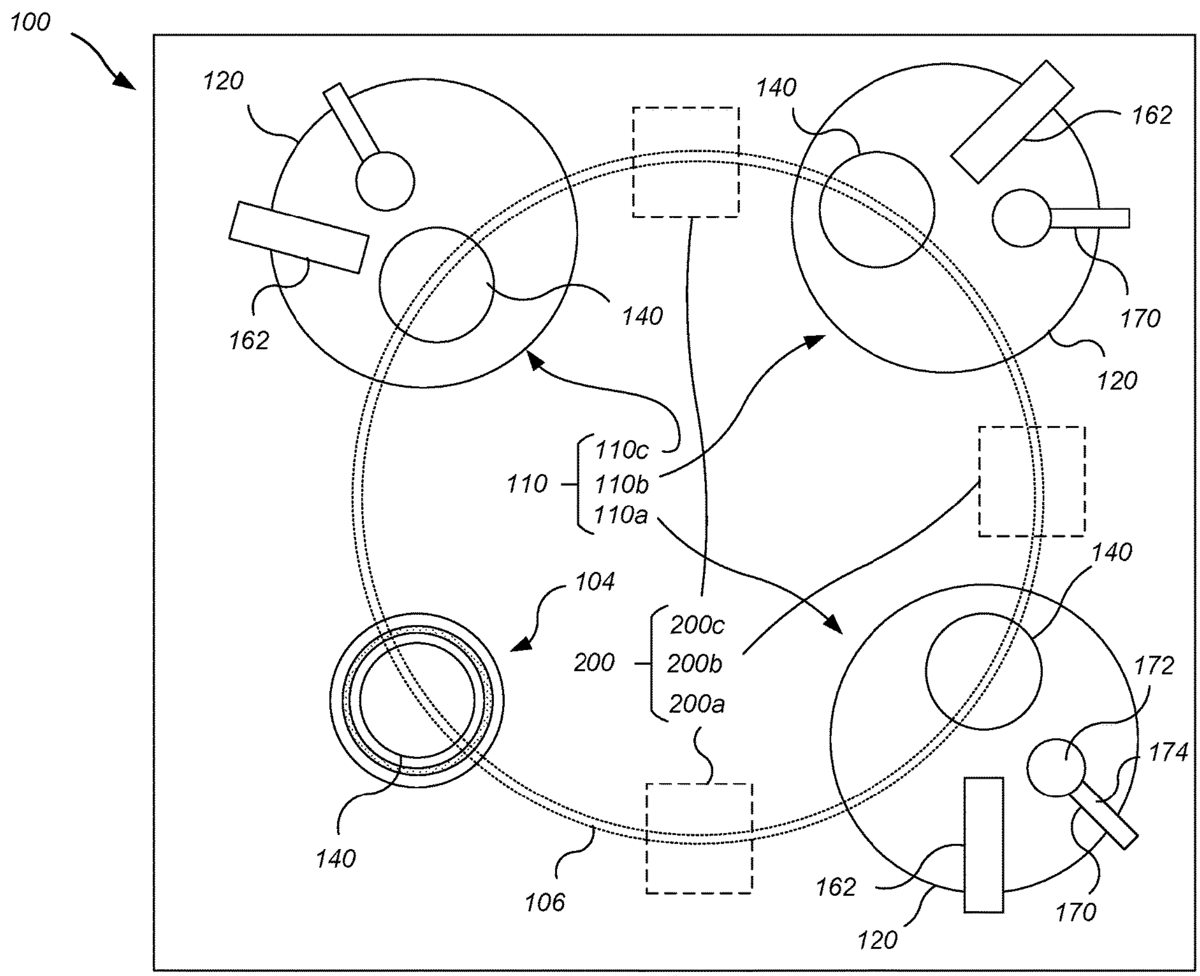
(57) **ABSTRACT**

A technique for acquiring reference traces includes measuring an angular orientation of a calibration substrate, rotating a carrier head and a platen to respective predetermined angular positions, and bringing the calibration substrate into contact with a polishing pad on the platen. The platen and the carrier head are rotated with the calibration substrate in contact with the polishing pad. The calibration substrate is monitored by sweeping a sensor of an in-situ monitoring system across the calibration substrate to generate a sequence of reference traces with each respective reference trace of the sequence of reference traces corresponding to a respective sweep of a sequence of sweeps by the sensor, and with each reference trace including a series of signal values. The sequence of reference traces is stored and each reference trace is labelled to distinguish an order of the reference traces within the sequence.



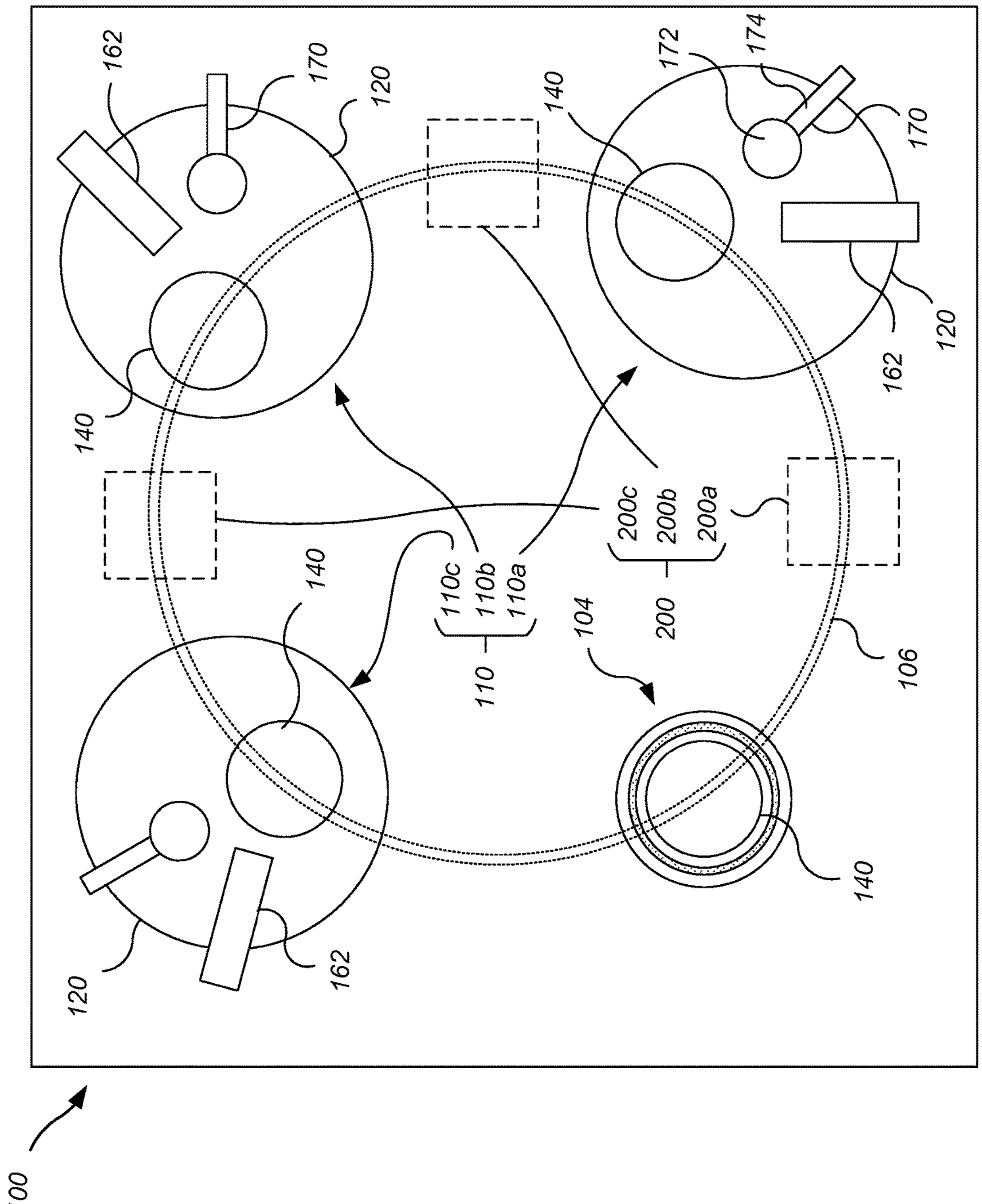

100
104
106
110
110a
110b
110c
120
140
162
170
172
174
200
200a
200b
200c

FIG. 1

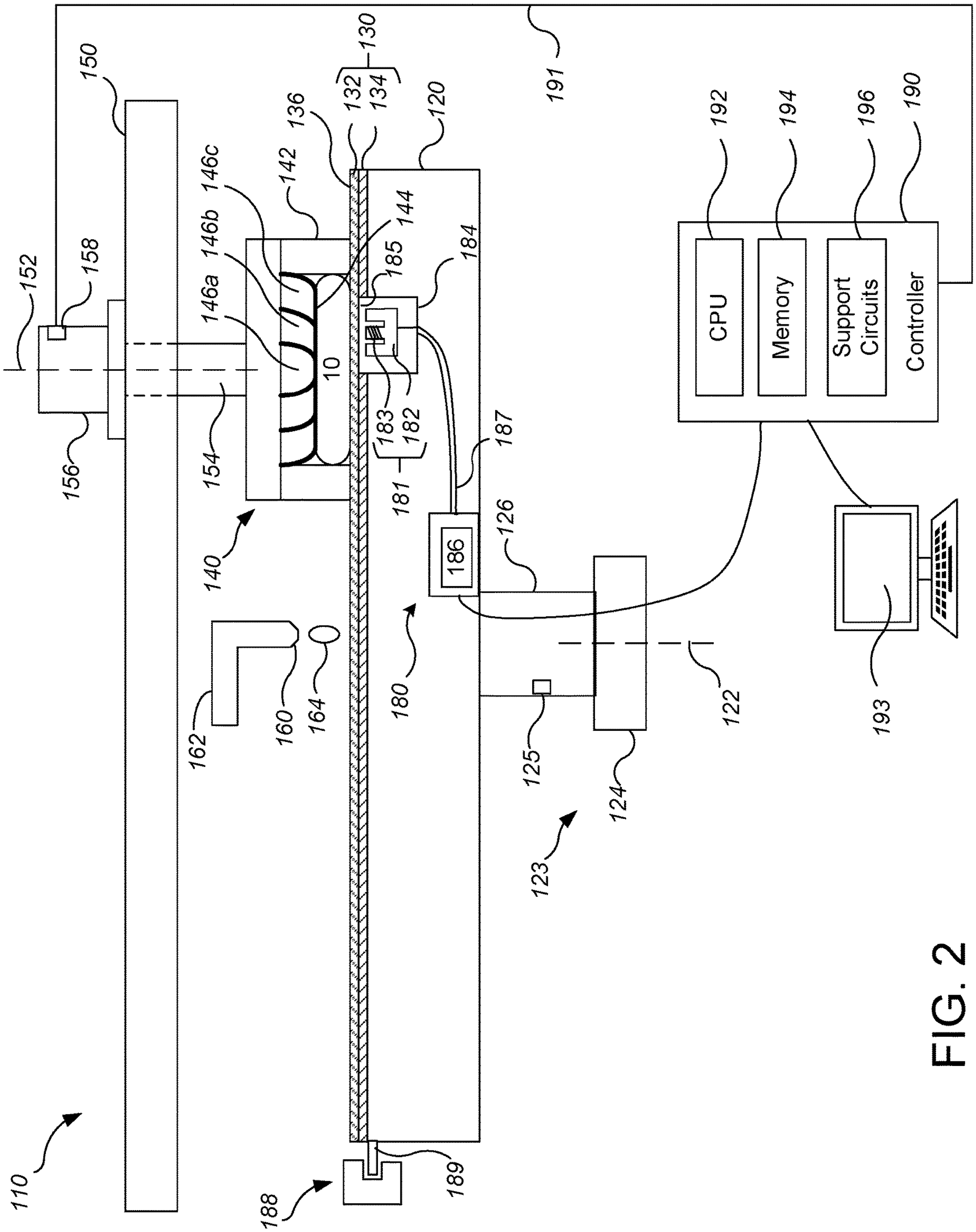

110
150
152
158
156
154
140
146a
146b
146c
142
144
10
136
132
134
130
120
185
184
183
182
181
187
186
126
180
162
160
164
125
122
124
123
191
192
194
196
190
CPU
Memory
Support Circuits
Controller
193
188
189

FIG. 2

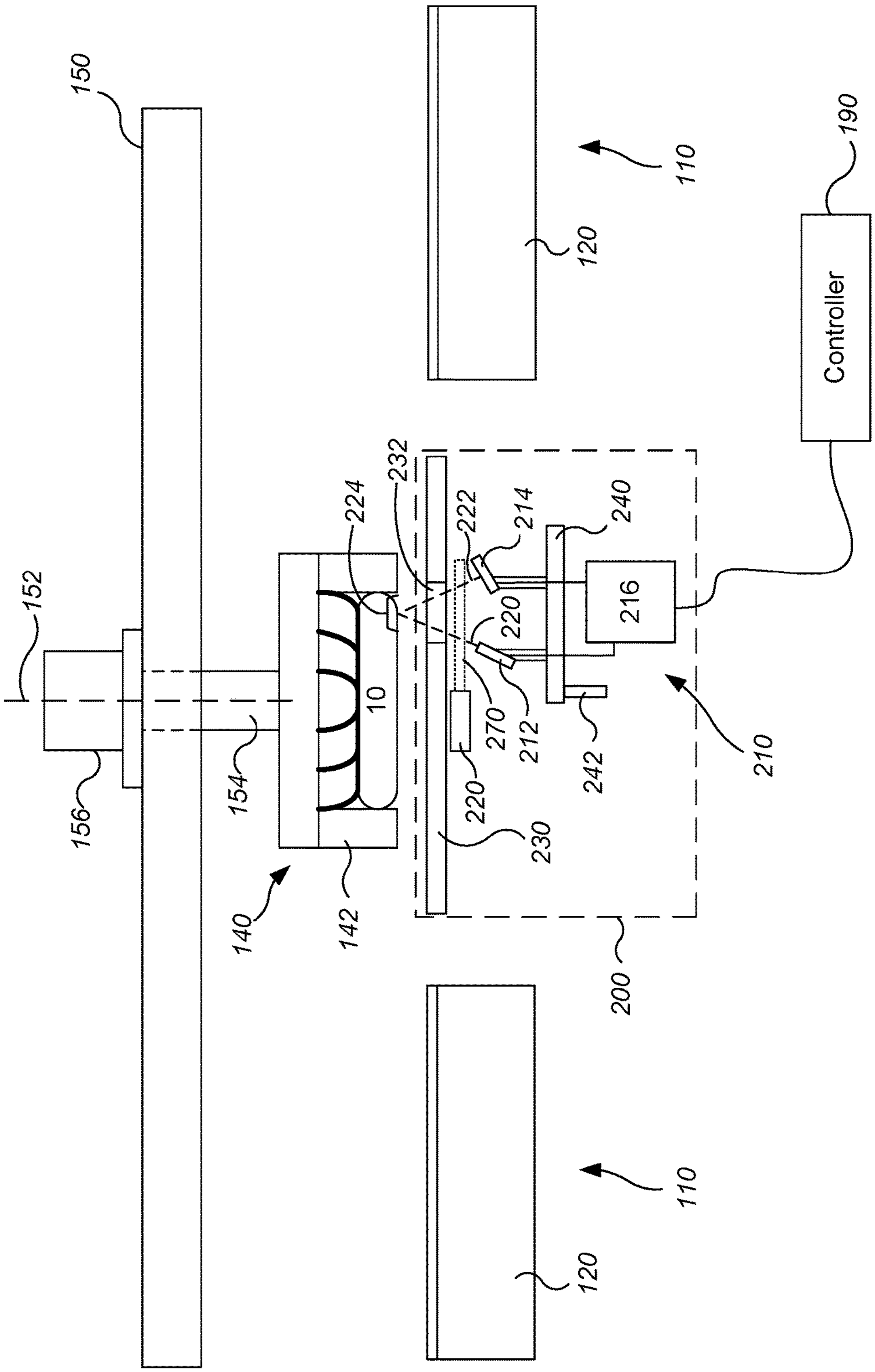

150
152
156
154
140
142
10
224
232
222
214
240
216
220
270
212
242
220
230
200
210
110
120
190
Controller
110
120

FIG. 3

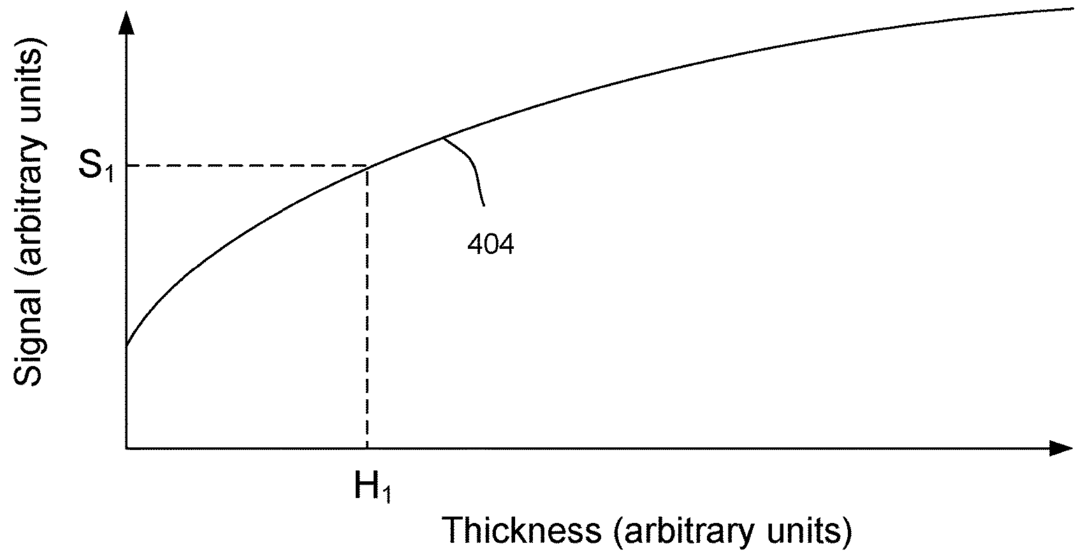

Signal (arbitrary units)
S_1
404
H_1
Thickness (arbitrary units)

FIG. 4A

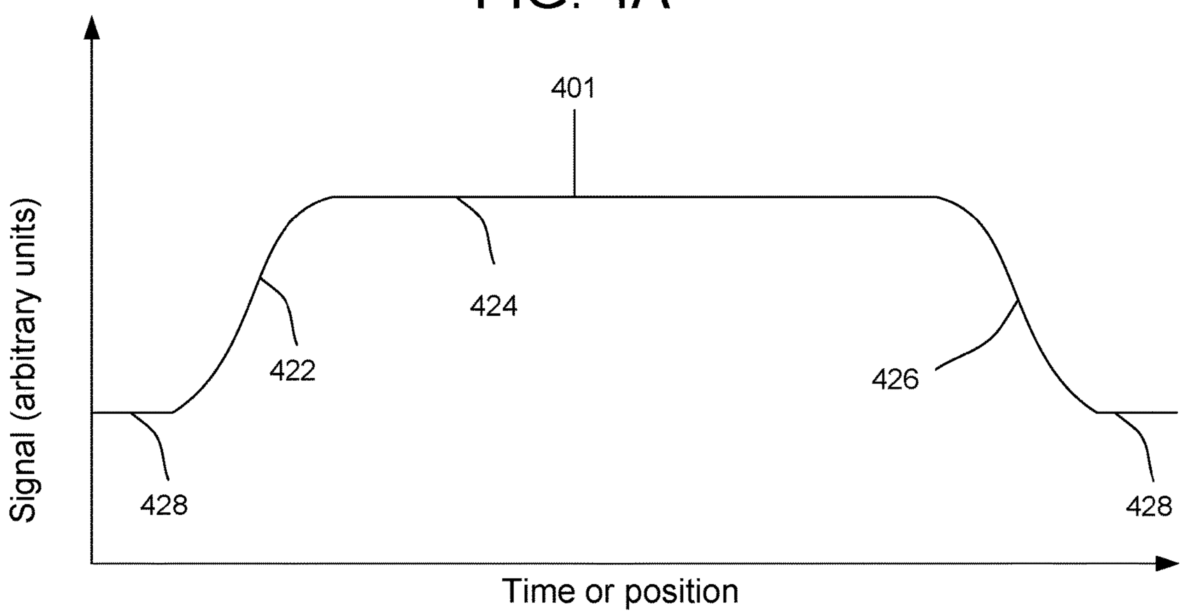

Signal (arbitrary units)
401
424
422
426
428
428
Time or position

FIG. 4B

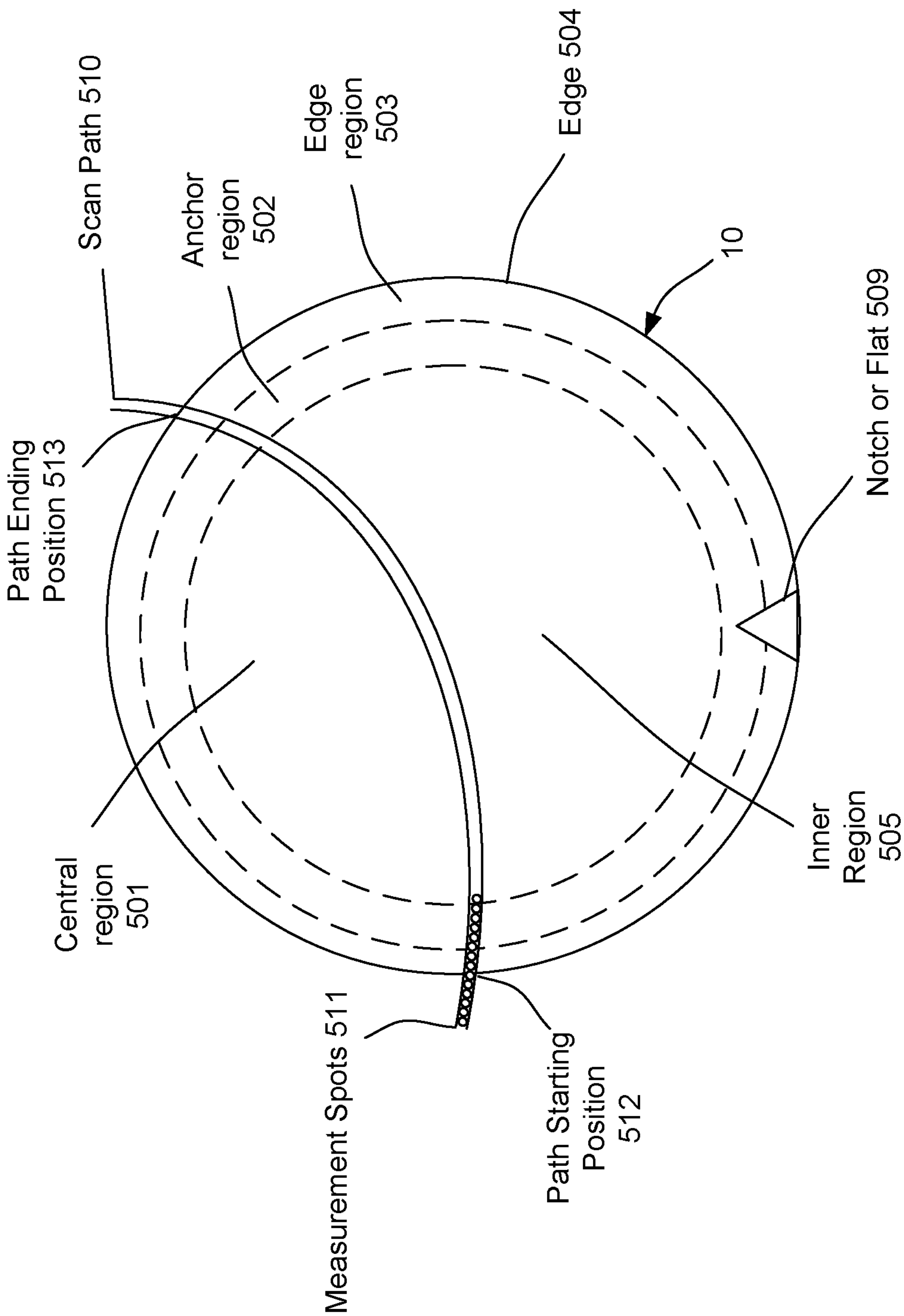

Scan Path 510
Anchor region 502
Edge region 503
Edge 504
10
Path Ending Position 513
Notch or Flat 509
Central region 501
Inner Region 505
Measurement Spots 511
Path Starting Position 512

FIG. 5A

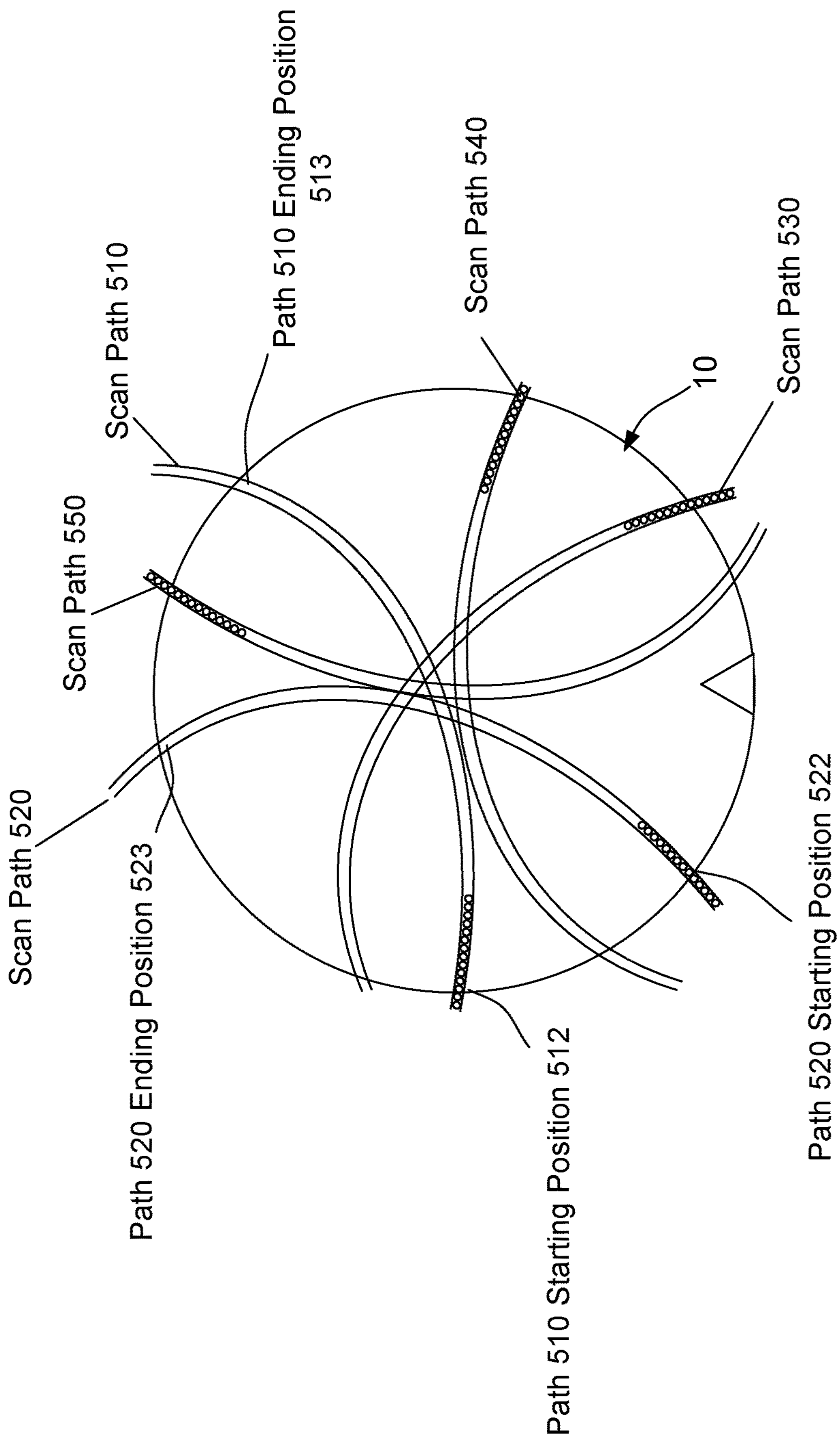

Scan Path 510
Path 510 Ending Position 513
Scan Path 540
Scan Path 530
10
Scan Path 550
Scan Path 520
Path 520 Ending Position 523
Path 510 Starting Position 512
Path 520 Starting Position 522

FIG. 5B

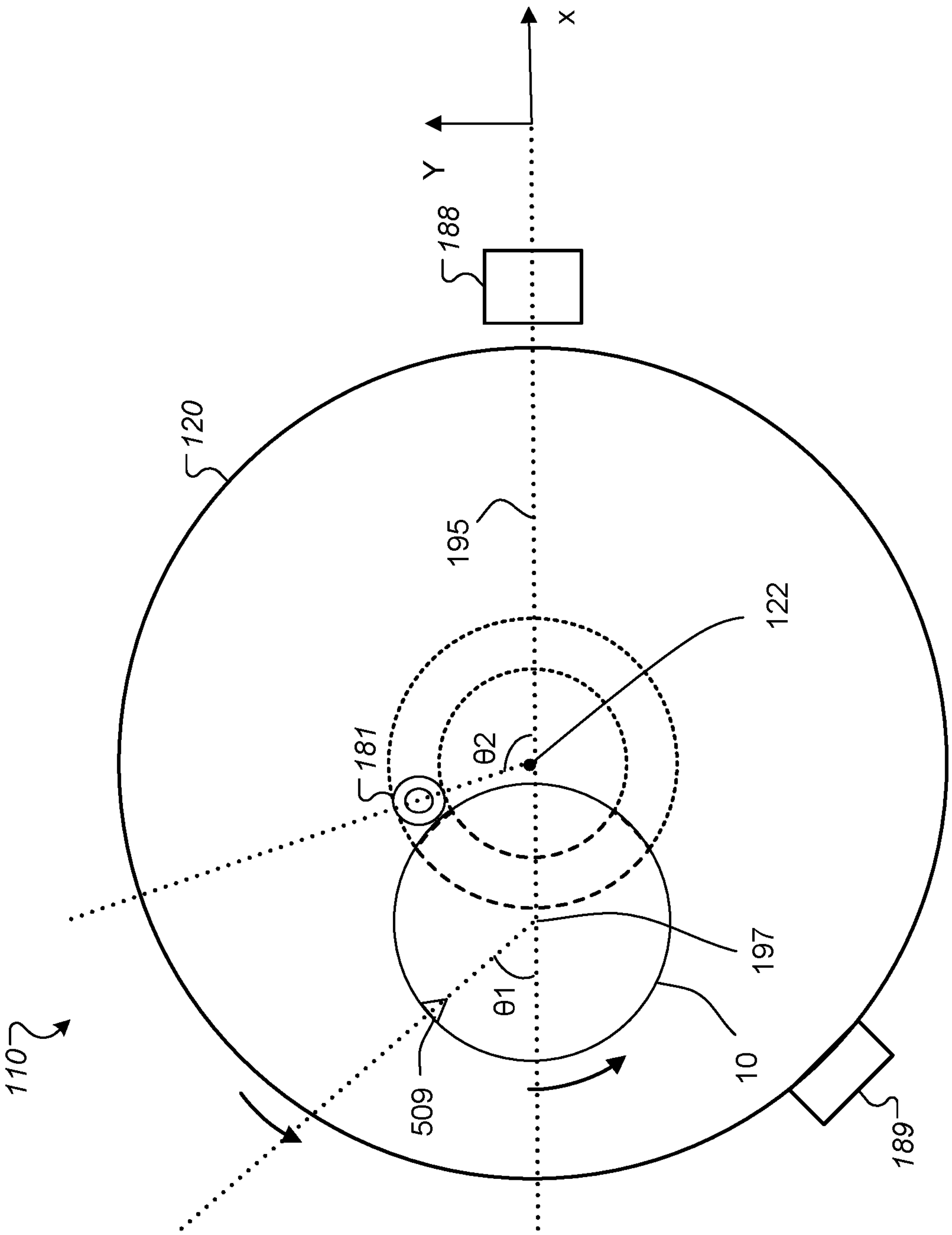


FIG. 5C

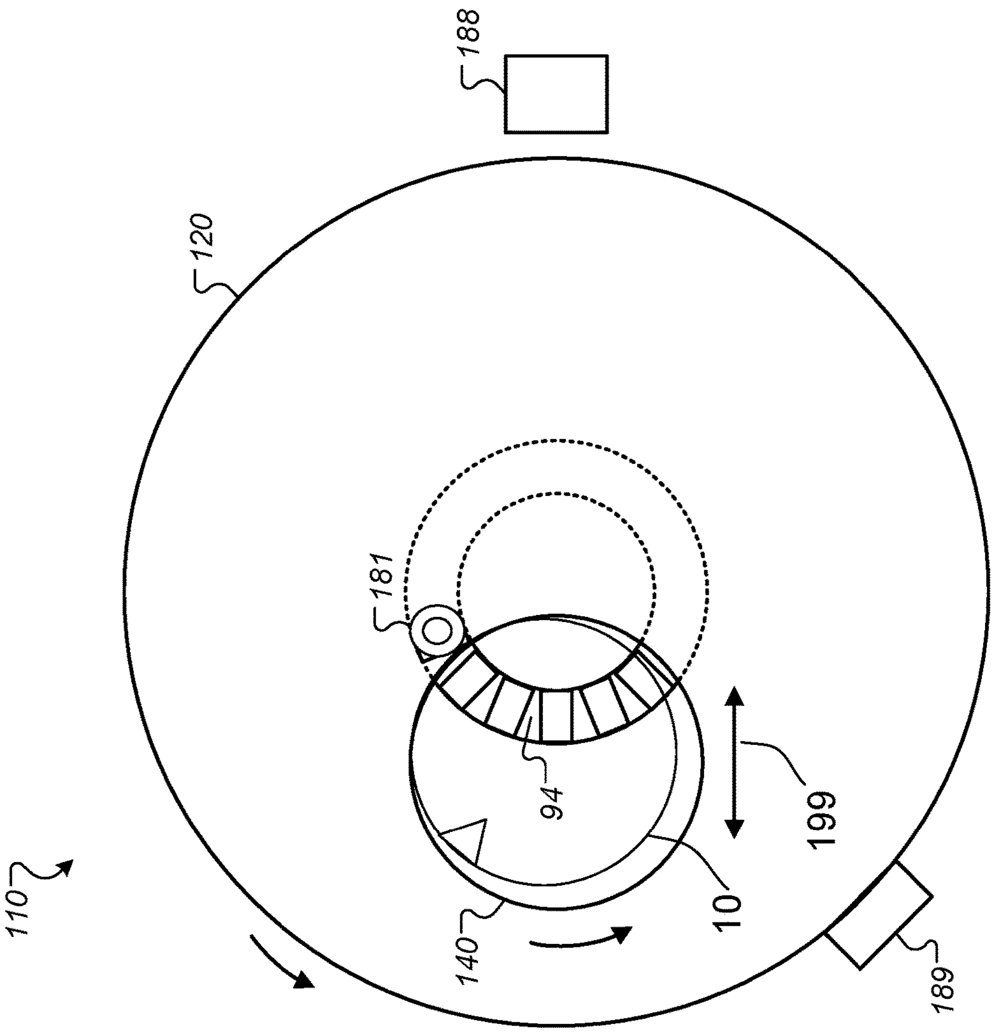


FIG. 5D

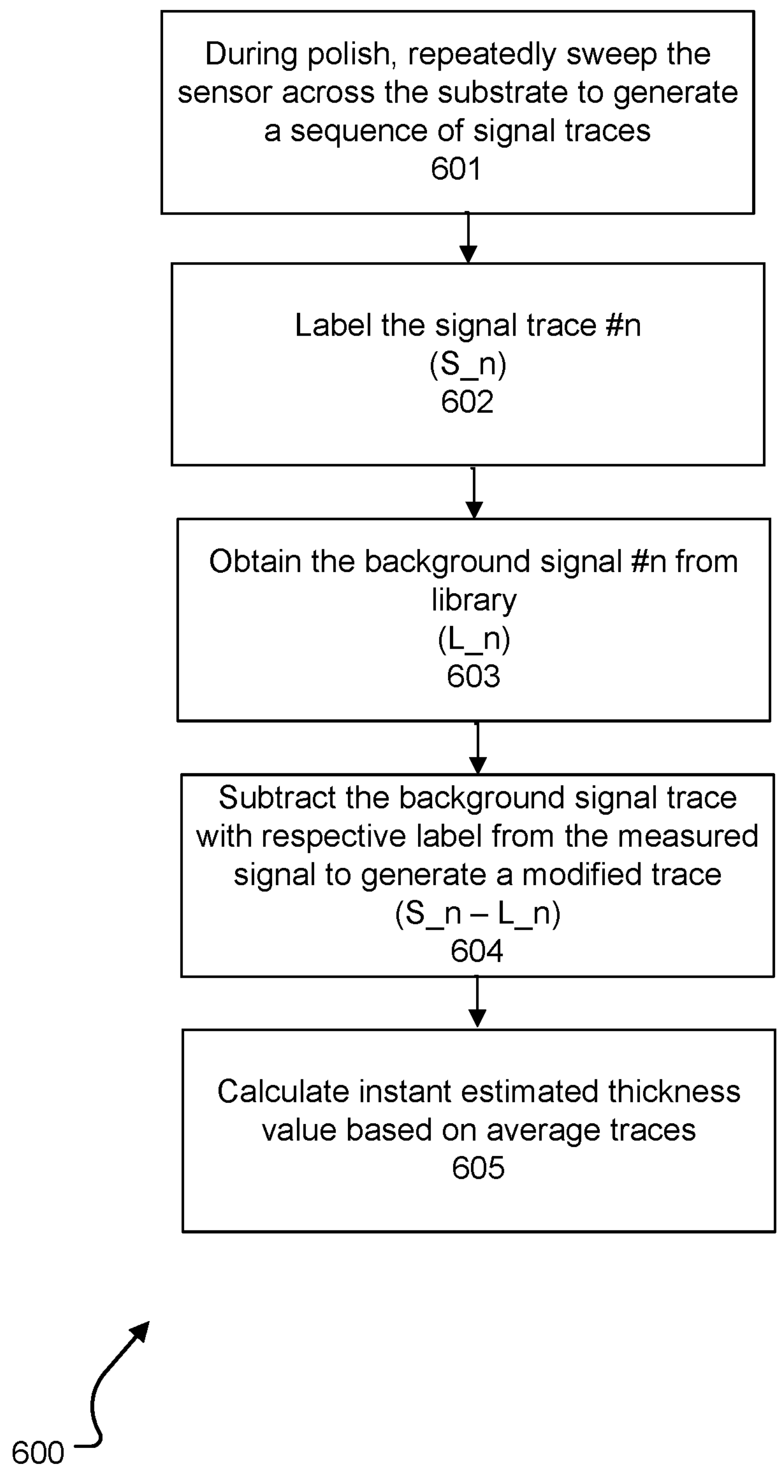

During polish, repeatedly sweep the sensor across the substrate to generate a sequence of signal traces
601
Label the signal trace #n
(S_n)
602
Obtain the background signal #n from library
(L_n)
603
Subtract the background signal trace with respective label from the measured signal to generate a modified trace
(S_n – L_n)
604
Calculate instant estimated thickness value based on average traces
605
600

FIG. 6

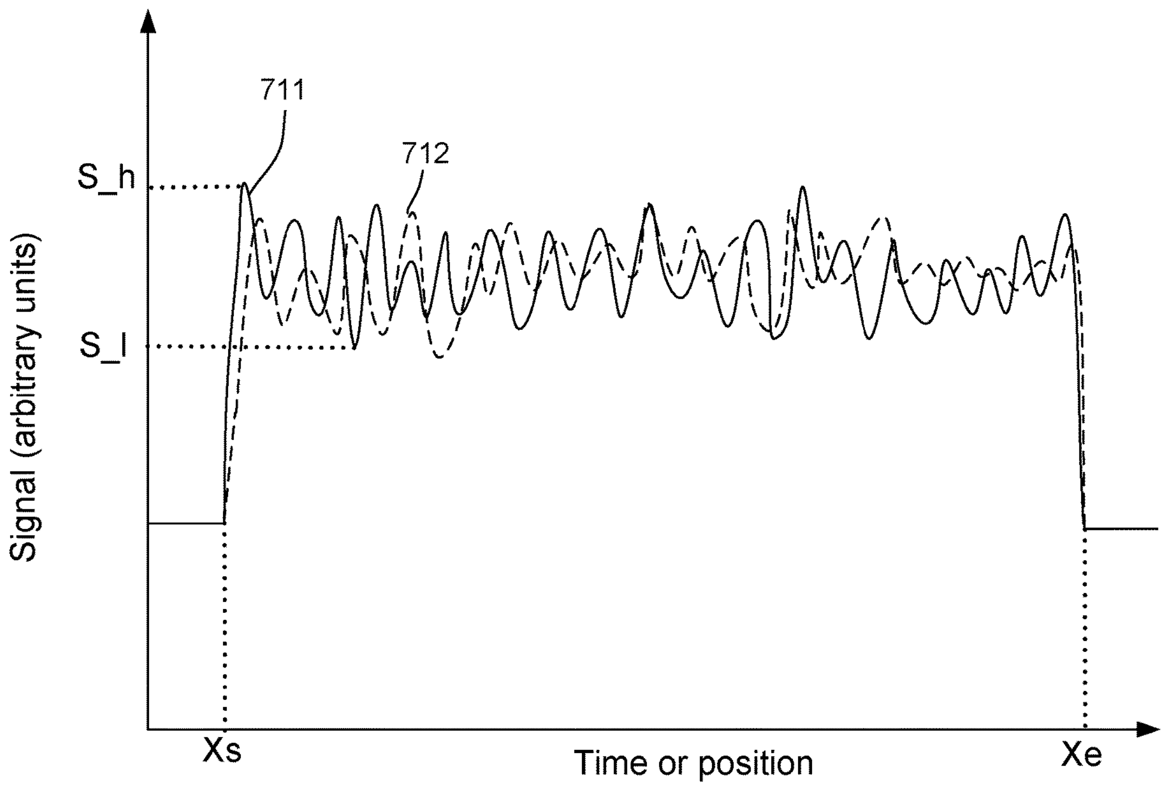

711
712
S_h
S_l
Signal (arbitrary units)
Xs
Xe
Time or position

FIG. 7A

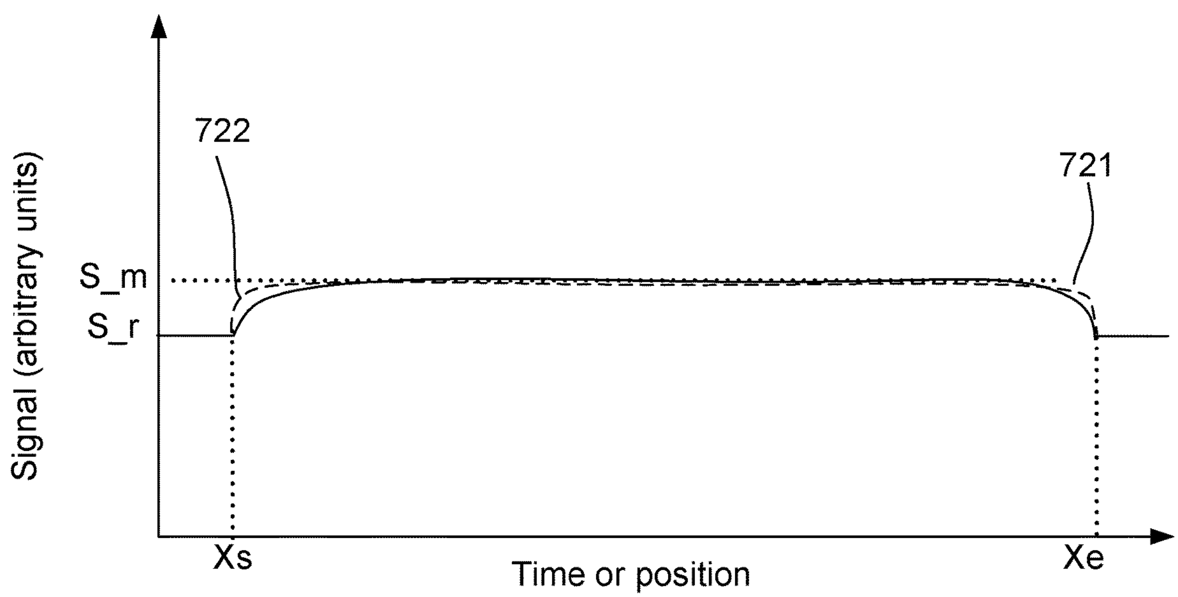

722
721
S_m
S_r
Signal (arbitrary units)
Xs
Xe
Time or position

FIG. 7B

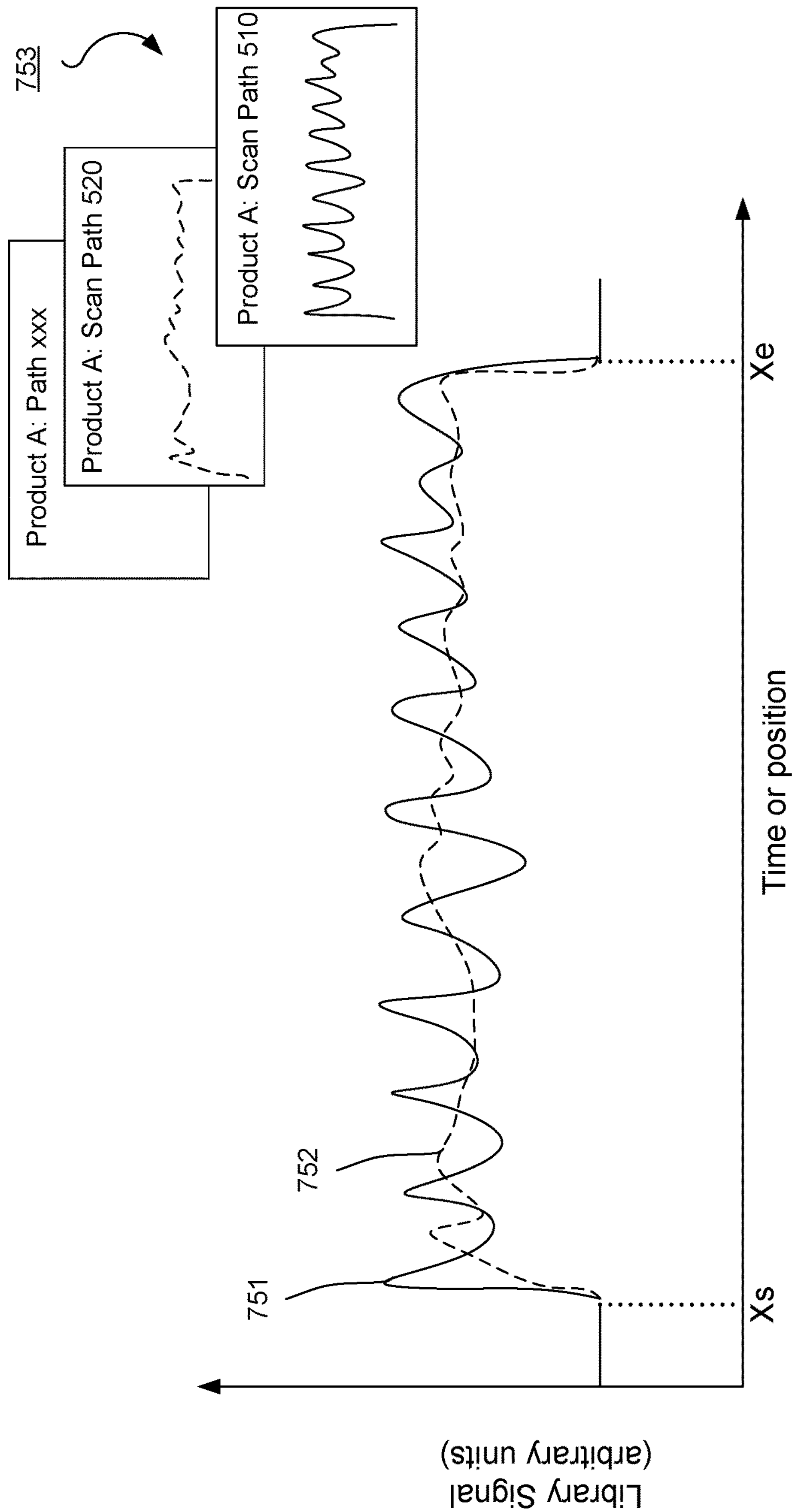

753
Product A: Path xxx
Product A: Scan Path 520
Product A: Scan Path 510
751
752
Xs
Xe
Time or position
Library Signal
(arbitrary units)

FIG. 7C

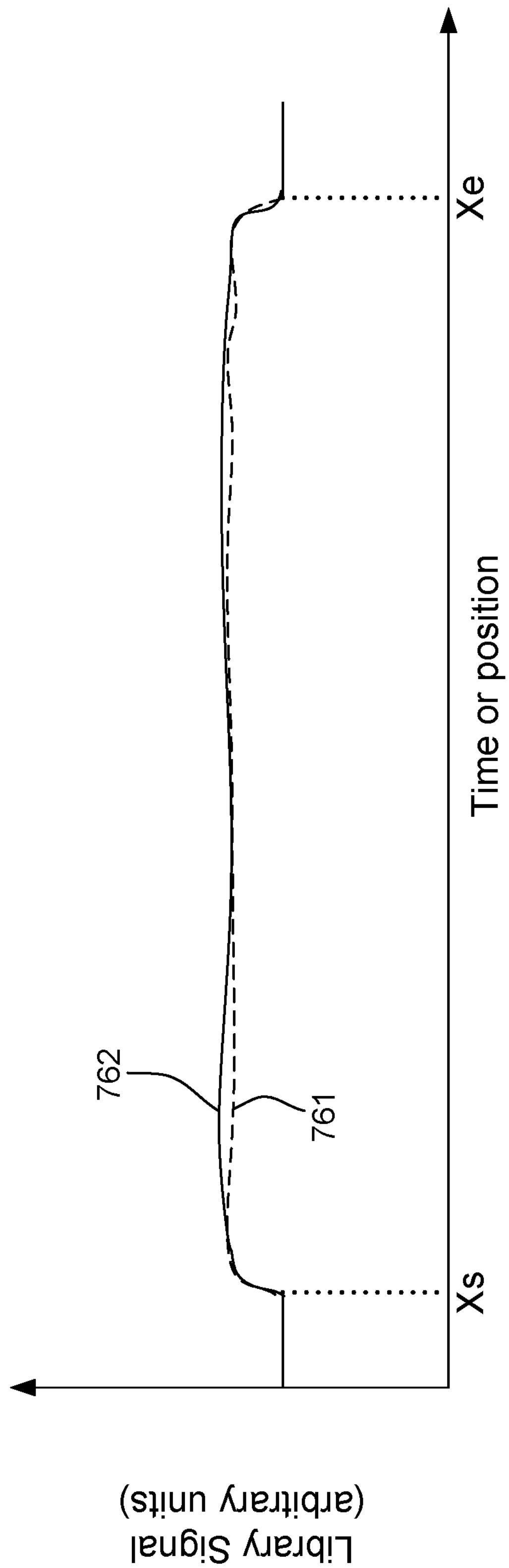
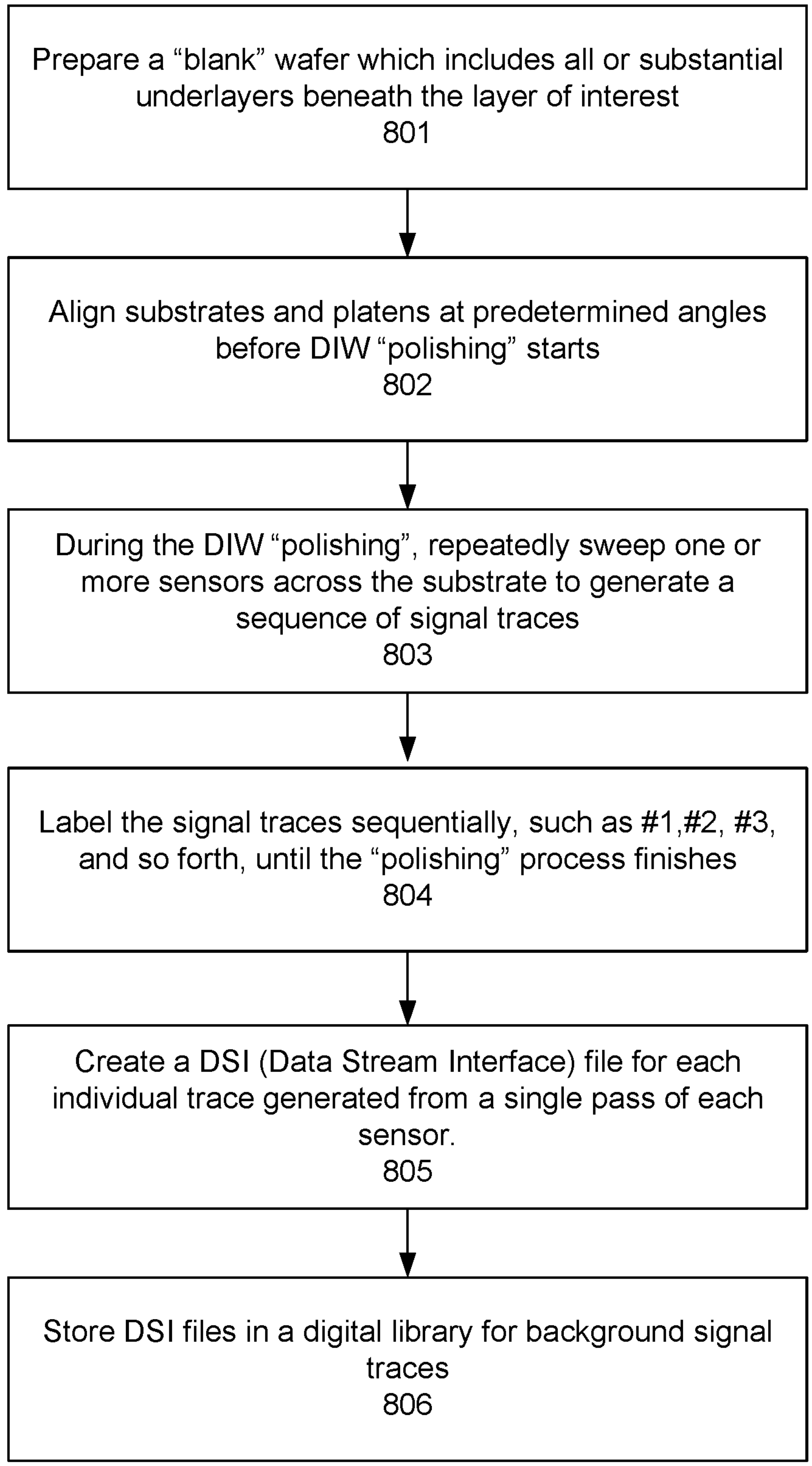

Library Signal
(arbitrary units)
Time or position
Xs
Xe
762
761

FIG. 7D


Prepare a "blank" wafer which includes all or substantial underlayers beneath the layer of interest
801
Align substrates and platens at predetermined angles before DIW "polishing" starts
802
During the DIW "polishing", repeatedly sweep one or more sensors across the substrate to generate a sequence of signal traces
803
Label the signal traces sequentially, such as #1,#2, #3, and so forth, until the "polishing" process finishes
804
Create a DSI (Data Stream Interface) file for each individual trace generated from a single pass of each sensor.
805
Store DSI files in a digital library for background signal traces
806

800

FIG. 8

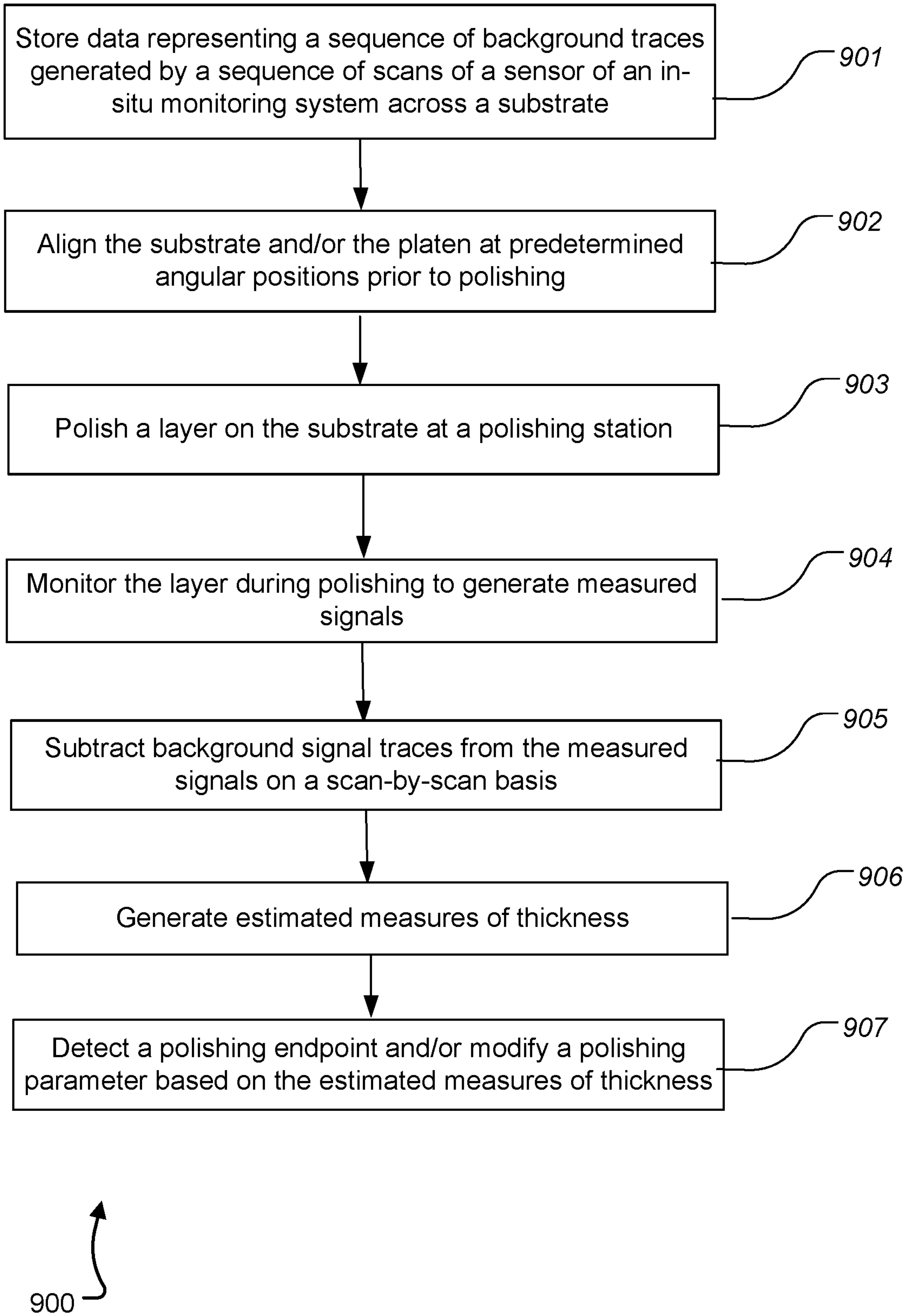

Store data representing a sequence of background traces generated by a sequence of scans of a sensor of an in-situ monitoring system across a substrate
901
Align the substrate and/or the platen at predetermined angular positions prior to polishing
902
Polish a layer on the substrate at a polishing station
903
Monitor the layer during polishing to generate measured signals
904
Subtract background signal traces from the measured signals on a scan-by-scan basis
905
Generate estimated measures of thickness
906
Detect a polishing endpoint and/or modify a polishing parameter based on the estimated measures of thickness
907
900

FIG. 9

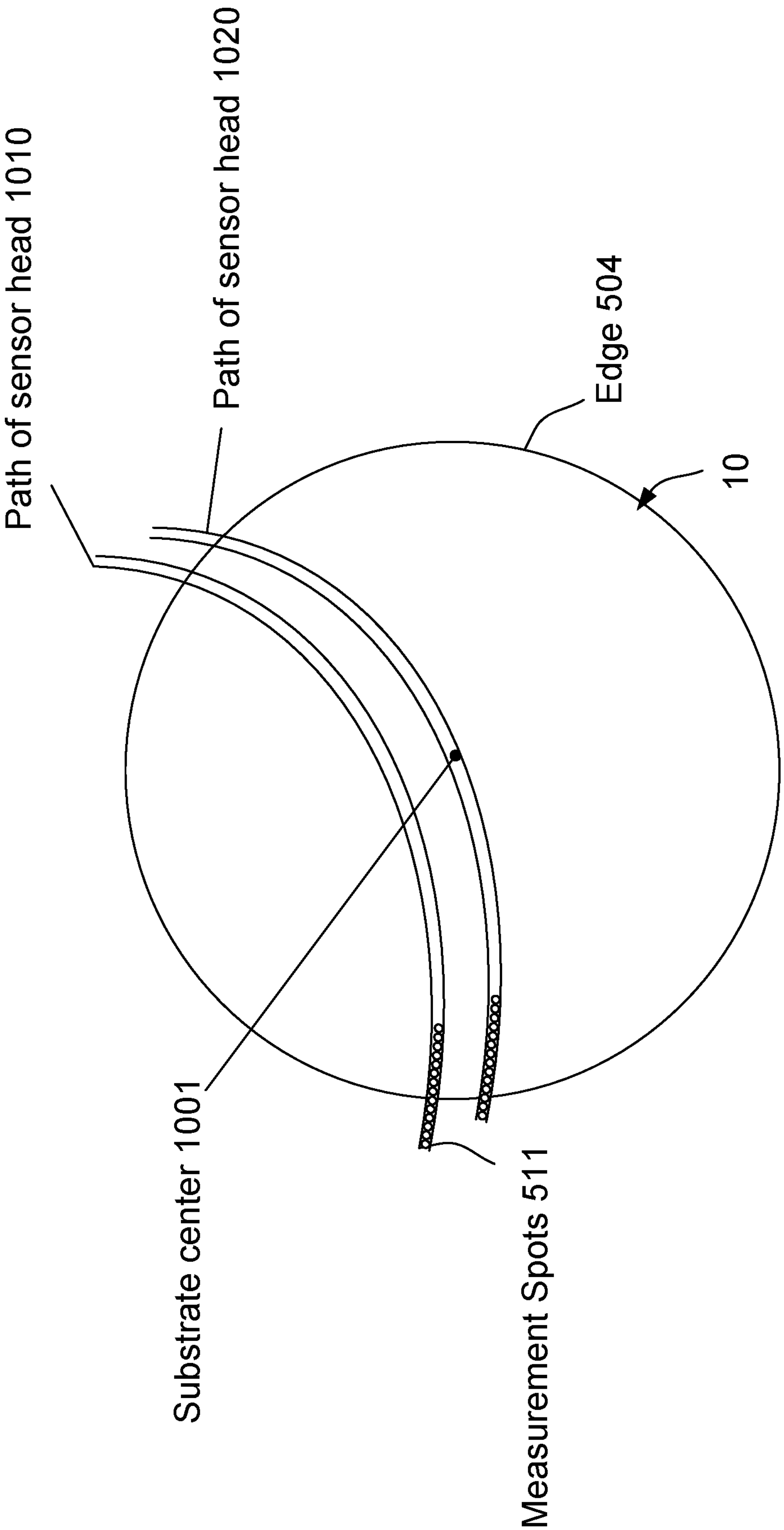

Path of sensor head 1010
Path of sensor head 1020
Edge 504
10
Substrate center 1001
Measurement Spots 511

FIG. 10A

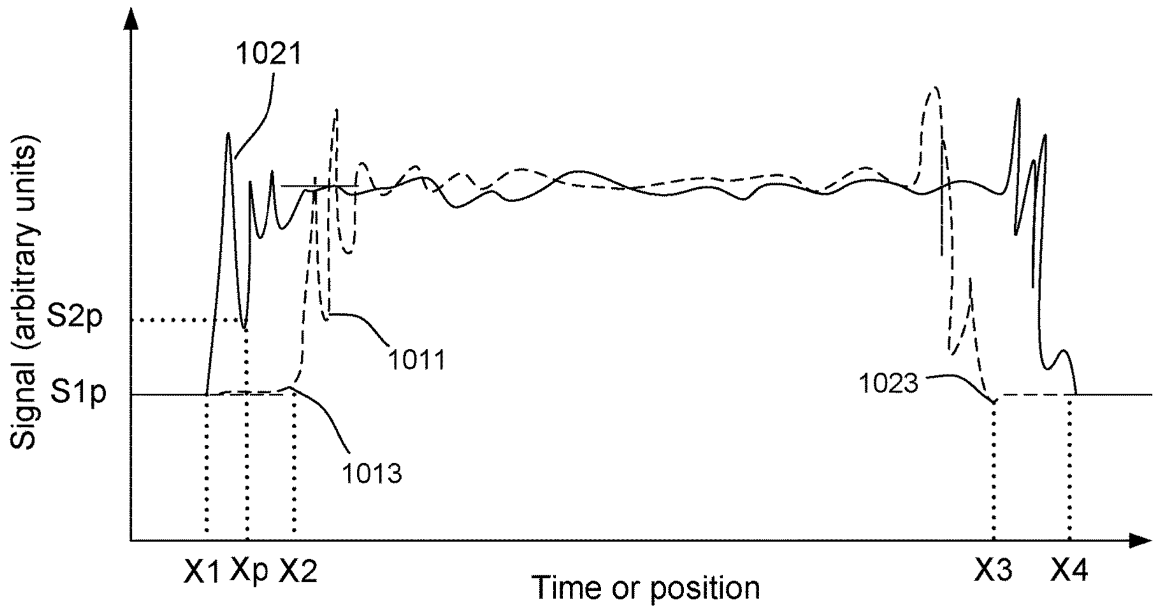


FIG. 10B

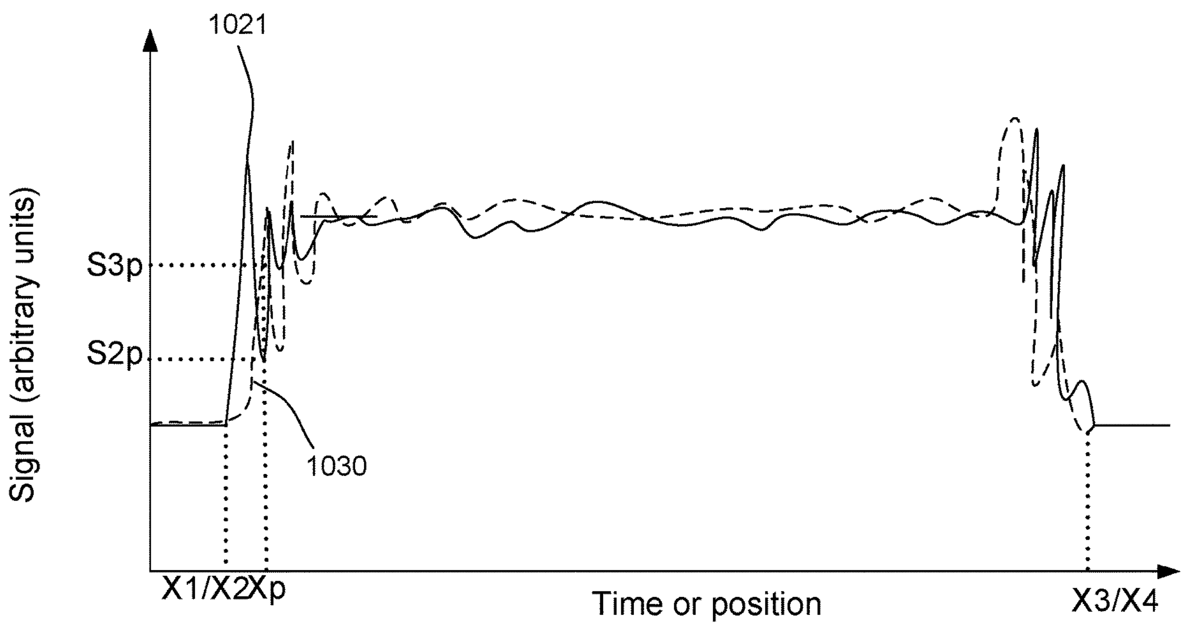


FIG. 10C

PROCESSING OF SIGNALS FROM AN IN-SITU MONITORING SYSTEM IN CHEMICAL MECHANICAL POLISHING

TECHNICAL FIELD

[0001] The present disclosure relates to in-situ monitoring during polishing of a substrate.

BACKGROUND

[0002] An integrated circuit is typically formed on a substrate (e.g. a semiconductor wafer) by the sequential deposition of conductive, semiconductive or insulative layers on a silicon wafer, and by the subsequent processing of the layers.

[0003] One fabrication step involves depositing a filler layer over a non-planar surface, and planarizing the filler layer until the non-planar surface is exposed. For example, a conductive filler layer can be deposited on a patterned insulative layer to fill the trenches or holes in the insulative layer. The filler layer is then polished until the raised pattern of the insulative layer is exposed. After planarization, the portions of the conductive layer remaining between the raised pattern of the insulative layer form vias, plugs and lines that provide conductive paths between thin film circuits on the substrate. In addition, planarization may be used to planarize the substrate surface for lithography.

[0004] Chemical mechanical polishing (CMP) is one accepted method of planarization. This planarization method typically requires that the substrate be mounted on a carrier head. The exposed surface of the substrate is placed against a rotating polishing pad. The carrier head provides a controllable load on the substrate to push it against the polishing pad. A polishing liquid, such as slurry with abrasive particles, is supplied to the surface of the polishing pad.

[0005] One problem in CMP is determining whether the polishing process is complete, i.e., whether a substrate layer has been planarized to a desired flatness or thickness, or when a desired amount of material has been removed. Variations in the slurry composition, the polishing pad condition, the relative speed between the polishing pad and the substrate, the initial thickness of the substrate layer, and the load on the substrate can cause variations in the material removal rate. These variations cause variations in the time needed to reach the polishing endpoint. Therefore, determining the polishing endpoint merely as a function of polishing time can lead to non-uniformity within a wafer or from wafer to wafer.

[0006] In some systems, a substrate is monitored in-situ during polishing, e.g., through the polishing pad. For example, optical sensors may be used for in-situ monitoring of the substrate. Alternately (or in addition), an eddy current sensing system may be used to induce eddy currents in a conductive layer. In either case, the signal from the sensor can be used to determine the thickness of the layer on the substrate during polishing.

SUMMARY

[0007] In one aspect, data is stored representing a sequence of background traces generated by a sequence of scans of a sensor of an in-situ monitoring system across a substrate prior to or after polishing of a layer on the substrate. For each respective sweep of a plurality of sweeps of a sensor of an in-situ monitoring system across the substrate during polishing of the substrate, a sequence of raw signal values is received that provides a measured trace for the respective sweep in a sequence of measured traces. For each respective measured trace in the sequence of measured traces, a respective background trace that has an equivalent position in the sequence of background traces is subtracted from the respective measured trace to generate a modified trace and thus provide a sequence of modified traces. A sequence of estimated thickness values is generated based on the sequence of modified traces, and a polishing endpoint is detected or a polishing parameter is modified based on the sequence of estimated thickness values.

[0008] In another aspect, an angular orientation of a calibration substrate is measured, a carrier head holding the calibration substrate is rotated to a first predetermined angular position based on the measured angular orientation, and a platen is rotated to a second predetermined angular position. The calibration substrate is brought into contact with a polishing pad on the platen with calibration substrate at the first predetermined angular position and the platen at the second predetermined angular position. The platen and the carrier head are rotated with the calibration substrate in contact with the polishing pad. The calibration substrate is monitored by sweeping a sensor of an in-situ monitoring system across the calibration substrate to generate a sequence of reference traces with each respective reference trace of the sequence of reference traces corresponding to a respective sweep of a sequence of sweeps by the sensor, and with each reference trace including a series of signal values. The sequence of reference traces is stored and each reference trace is labelled to distinguish an order of the reference traces within the sequence.

[0009] Certain implementations can include one or more of the following advantages. An in-situ monitoring system, e.g., an eddy current monitoring system, can generate a signal as one or more sensors scan across a substrate. The system can place the substrate notch and the sensor at predetermined desired angular positions, so that the relative positioning of the sensor and the substrate notch is consistent before each polishing process commences. A consistent starting angular position can improve the likelihood that the sensor will follow a consistent series of paths across the substrate on a wafer-to-wafer basis. Consequently, this system can enhance measurement accuracy by subtracting a signal representing a scan of an underlying layer from the measured signals on a per-scan-path basis. The modified signal, in turn, can be used for a more accurate thickness calculation. This can improve end point control and improve adjustment of polishing parameters to reduce within-wafer non-uniformity (WIWNU) and water-to-wafer non-uniformity (WTWNU).

[0010] The details of one or more implementations are set forth in the accompanying drawings and the description below. Other aspects, features and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0011] FIG. **1** is a schematic plan view of an example of a polishing apparatus.

[0012] FIG. **2** is a schematic side view, partially cross-sectional, of a chemical mechanical polishing station that includes an eddy current monitoring system.

[0013] FIG. **3** is a schematic side view of an example of an inter-platen notch finder.

[0014] FIG. **4**A is a schematic graph of a static formula for determining substrate thickness based on measured signals.

[0015] FIG. **4**B is a schematic graph of simplified measured signals obtained while monitoring locations on a substrate.

[0016] FIG. **5**A is a schematic top view of a substrate being scanned by a sensor head of a polishing apparatus for a single pass.

[0017] FIG. **5**B is a schematic top view of a substrate being scanned by a sensor head of a polishing apparatus for multiple passes.

[0018] FIG. **5**C is a schematic top view of relative angular positions of a substrate and a platen.

[0019] FIG. **5**D is a schematic top view of oscillations between a substrate and its carrier head during a polishing process.

[0020] FIG. **6** is a flow diagram of an example process for subtracting background signal traces from measured signal traces on a scan-by-scan basis.

[0021] FIG. **7**A is a schematic graph of two measured signal traces from two scan paths.

[0022] FIG. **7**B is a schematic graph of ground-truth measurement from two scan paths.

[0023] FIG. **7**C is a schematic graph of background traces from two scan paths.

[0024] FIG. **7**D is a schematic graph of two modified traces after subtracting background traces on a scan-by-scan basis.

[0025] FIG. **8** is a flow diagram of an example process for generating a digital library storing background traces.

[0026] FIG. **9** is a flow diagram of an example process for polishing a substrate.

[0027] FIG. **10**A is a schematic top view illustrating a shift in sensor scan paths.

[0028] FIG. **10**B is a schematic graph illustrating a shift in scan traces along the x-axis.

[0029] FIG. **10**C is a schematic graph of a scaled trace aligned with an unscaled trace along the x-axis.

[0030] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0031] A polishing apparatus can use an in-situ monitoring system, e.g., an eddy current monitoring system, to detect the thickness of an outer layer that is being polished on a substrate. During polishing of the outer layer, the in-situ monitoring system can determine the thickness of different locations of the layer on the substrate. The thickness measurements can be used to trigger a polishing endpoint and/or to adjust processing parameters of the polishing process in real time. For example, a substrate carrier head can adjust the pressure on the backside of the substrate to increase or decrease the polishing rate of the locations of the outer layer. The polishing rate can be adjusted so that the locations of the layer are substantially the same thickness after polishing. The CMP system can adjust the polishing rate so that polishing of the locations of the layer completes at about the same time. Such profile control can be referred to as real time profile control (RTPC).

[0032] An in-situ monitoring system, e.g., an eddy current monitoring system, can be subject to signal distortion due to noise originating from the underlying layers. For example, underlying metal layers with high conductivity can generate unwanted contribution to the signal measured by the eddy current sensor, which interferes with the monitoring of the conductive layer of primary interest. In particular, as compared to polishing of "blank" wafers, during polishing of a patterned wafer used for integrated circuit device fabrication, the sensor scans across regions with differing density and arrangement of metal features, resulting in variation in the signal. Moreover, this problem grows worse as the number of metal layers in the device substrate increase. In addition, because each scan of the sensor across the substrate can follow a different path, the signal varies from scan-to-scan. This heightened noise relative to the signal can introduce noise into the calculation of layer thickness. This reduces the precision of controlling polishing parameters, e.g. endpoint and/or polishing rate, and consequently result in large WIWNU and WIWNU. To mitigate this issue, the system can utilize methods such as scan signal averaging to reduce noise. However, there are situations where this method is ineffective, particularly when the variation from one scan to another exceeds the signal of the film of interest.

[0033] A technique to address this issue is to align each substrate consistently to a specific angular orientation relative to the eddy current sensor before commencing the chemical mechanical polishing process. Maintaining this consistent starting angular orientation increases the likelihood that the sensor will follow a repeatable path while scanning each substrate. The scan-to-scan variation can be reduced by subtracting the underlayer noise from the measure signals on a per-scan-path basis. As a result, film thickness monitoring precision is enhanced, benefiting both within-wafer uniformity (WIWU) and wafer-to-wafer uniformity (WTWU).

Polishing Station

[0034] FIG. **1** is a plan view of a chemical mechanical polishing apparatus **100** for processing one or more substrates. The polishing apparatus **100** includes a plurality of polishing stations **110**. For example, the polishing apparatus can include three polishing stations **110***a*, **110***b*, and **110***c*. The polishing apparatus **100** also includes at least one carrier head **140**, e.g., four carrier heads **140**. The polishing apparatus **100** also includes a transfer station **104** for loading and unloading substrates from the carrier heads **140**. The stations of the polishing apparatus **100**, including the transfer station **104** and the polishing stations **110**, can be positioned at substantially equal angular intervals around the center of the platform.

[0035] Referring to FIG. **2**, each polishing station **110** includes a polishing pad **130** supported on a rotatable platen **120**. The polishing pad **130** can be a two-layer polishing pad with an outer polishing layer **132** and a softer backing layer **134** (see FIG. **2**). A top surface of the polishing layer **132** can provide a polishing surface **136**.

[0036] Returning to FIG. **1**, for a polishing operation, one carrier head **140** can be positioned at each polishing station **110**. Another additional carrier head **140** can be positioned in the transfer station **104** to exchange a polished substrate for an unpolished substrate while the other substrates are being polished at the polishing stations **110**.

[0037] The carrier heads **140** are held by a support structure, e.g., a rotatable carousel or a carriage suspended from a track, that can cause carrier head to move along a **106** path that passes, in order, each polishing station **110***a*-**110***c* and the transfer station **104**.

[0038] Referring to FIGS. **1** and **2**, each polishing station **110** can include a port **160**, e.g., at the end of an arm **162**, to dispense polishing liquid **164**, such as abrasive slurry, onto the polishing pad **130**. Each polishing station **110** of the polishing apparatus **100** can also include pad conditioning apparatus **170** to abrade the polishing pad **130** to maintain the polishing surface **136** in a consistent abrasive state. For example, the conditioning apparatus can include a conditioning head **172** with a conditioning disk at the end of an arm **174**.

[0039] As shown in FIG. **2**, the platen **120** at each platen **120** is operable to rotate about an axis **122**. For example, a motor **124** can turn a drive shaft **126** to rotate the platen **120**. Each motor **124** can include an encoder **125** that measures the angular position or rotation rate of the associated drive shaft **126**. The associated drive shafts can have respective reference angular positions that are recognized by the encoder **125** to measure the number of revolutions of the drive shafts.

[0040] Each carrier head **140** is operable to hold a substrate **10** against the polishing pad **130**. Each carrier head **140** can include a retaining ring **142** to retain the substrate **10** below a flexible membrane **144**. Each carrier head **140** can also include a plurality of independently controllable pressurizable chambers defined by the membrane, e.g., three chambers **146*a*-146*c***, which can apply independently controllable pressurizes to associated zones on the flexible membrane **144** and thus on the substrate **10**. Although only three chambers are illustrated in FIG. **2** for ease of illustration, there could be one or two chambers, or four or more chambers, e.g., five chambers.

[0041] Each carrier head **140** is suspended from the support structure **150**, and is connected by a drive shaft **154** to a carrier head rotation motor **156** so that the carrier head can rotate about an axis **152**. Optionally each carrier head **140** can oscillate laterally, e.g., driven by a carriage on the track, by a motor that oscillates the carrier head radially, or by rotational oscillation of the carousel itself.

[0042] In operation, the platen is rotated about its central axis, and each carrier head is rotated about its central axis **152** and translated laterally across the top surface of the polishing pad.

[0043] An in-situ monitoring system can include an in-situ monitoring system **180** installed in the platen **120** to monitor the progress of the polishing operation and/or measure a thickness of the layer on the substrate **10** that is being polished. The in-situ monitoring system **180** can use an optical sensor, e.g., a spectrometer, an eddy current sensor, a capacitive sensor, a friction sensor, etc.

[0044] A controller **190**, such as a programmable computer, is connected to each motor **124**, **156** to independently control the rotation rate of the platen **120** and the carrier heads **140**. For example, each motor **156** can include an encoder **158** that measures the angular position or rotation rate of the associated drive shaft **154**. The associated drive shafts can have respective reference angular positions that are recognized by the encoder **158** to measure the number of revolutions of the drive shafts.

[0045] The controller **190** is also connected to pressure regulators to control the pressures in the chambers **146*a*-146*c***. In particular, the controller **190** can be configured to receive thickness measurements from the in-situ monitoring system and control the pressures in the chambers **146*a*-146*c*** to provide improved polishing uniformity.

[0046] The controller **190** can include a central processing unit (CPU) **192**, a memory **194**, and support circuits **196**, e.g., input/output circuitry, power supplies, clock circuits, cache, and the like. The memory is connected to the CPU **192**. The memory is a non-transitory computable readable medium, and can be one or more readily available memory such as random access memory (RAM), read only memory (ROM), floppy disk, hard disk, or other form of digital storage. In addition, although illustrated as a single computer, the controller **190** could be a distributed system, e.g., including multiple independently operating processors and memories.

Eddy Current Monitoring System

[0047] The in-situ-monitoring system can be an eddy current monitoring system **180**. The eddy current monitoring system **180** includes a drive system to induce eddy currents in a conductive layer on the substrate and a sensing system to detect eddy currents induced in the conductive layer by the drive system. The eddy current monitoring system **180** includes a core **182** positioned in a recess **184** to rotate with the platen, at least one coil **183** wound around a portion of the core **181**, and drive and sense circuitry **186** connected by wiring **187** to the coil **183**. The combination of the core **182** and coil **183** can provide a sensor head **181**. In some implementations, the core **182** can project above the top surface of the platen **120**, e.g., into a recess **185** in the bottom of the polishing pad **130**.

[0048] The drive and sense circuitry **186** is configured to apply an oscillating electric signal to the coil **187** and to measure the resulting eddy current. A variety of configurations are possible for the drive and sense circuitry and for the configuration and position of the coil(s), e.g., as described in U.S. Pat. Nos. 6,924,641, 7,112,960 and 8,284,560, and in U.S. Patent Publication Nos. 2011-0189925 and 2012-0276661. The drive and sense circuitry **186** can be located in the same recess **183** or a different portion of the platen **120**, or could be located outside the platen **120** and be coupled to the components in the platen through a motor **124**.

[0049] In operation the drive and sense circuitry **186** drives the coil **183** to generate an oscillating magnetic field. At least a portion of magnetic field extends through the polishing pad **130** and into substrate **10**. If a conductive layer is present on substrate **10**, the oscillating magnetic field generates eddy currents in the conductive layer. The eddy currents cause the conductive layer to act as an impedance source that is coupled to the drive and sense circuitry **186**. As the thickness of the conductive layer changes, the impedance changes, and this can be detected by the drive and sense circuitry **186**.

[0050] Alternatively or in addition, an optical monitoring system, which can function as a reflectometer or interferometer, can be secured to the platen **120** in the recess **184**. If both systems are used, the optical monitoring system and eddy current monitoring system can monitor the same portion of the substrate.

[0051] The polishing stations **110** can also include a position sensor **188**, such as an optical interrupter, to sense when the sensor head **181** is beneath the substrate **10**. For example, the optical interrupter could be mounted at a fixed point opposite the carrier head **140**. A flag **189** is attached to the periphery of the platen. The point of attachment and length of flag **189** is selected so that it interrupts the optical signal of sensor **188** while the sensor head **181** sweeps beneath substrate **10**.

[0052] The signals can pass from the eddy current monitoring system **180** to the controller **190** through the rotary electrical union **123**. Alternatively, the circuitry **186** could communicate with the controller **190** by a wireless signal.

[0053] Since the sensor head **181** sweeps beneath the substrate with each rotation of the platen, information on the conductive layer thickness is accumulated in-situ and on a continuous real-time basis (once per platen rotation). The controller **190** can be programmed to sample measurements from the monitoring system **180** when the substrate **10** generally overlies the sensor head **181** (as determined by the position sensor). The measurements from the monitoring systems can be displayed on the output device **193** during polishing to permit the operator of the device to visually monitor the progress of the polishing operation, although this is not required.

[0054] Assuming the thickness of the layer varies across the substrate, the change in the position of the sensor head with respect to the substrate **10** can result in a change in the signal from the in-situ monitoring system **160**. The time varying sampled signal resulting from a single sweep of the sensor below the substrate may be referred to as a trace. So variation in the signal across a trace can indicate variation in the layer thickness across the substrate. In addition, as polishing progresses, the thickness of the conductive layer changes, and the sampled signals vary with time. So trace-to-trace differences can indicate variation in the layer thickness over time.

[0055] In operation, the polishing stations **110** can use the eddy current monitoring system **180** to determine when the bulk of the filler layer has been removed and/or to determine when an underlying layer has been substantially exposed. Possible process control and endpoint criteria for the detector logic include local minima or maxima, changes in slope, threshold values in amplitude or slope, or combinations thereof.

[0056] The controller **190** can be programmed to divide the measurements from the eddy current monitoring system **180** from each sweep beneath the substrate into a plurality of sampling zones, to calculate the radial position of each sampling zone, and to sort the amplitude measurements into radial ranges, as discussed in U.S. Pat. No. 6,399,501. After sorting the measurements into radial ranges, information on the film thickness can be fed in real-time into a closed-loop controller to periodically or continuously modify the polishing pressure profile applied by a carrier head in order to provide improved polishing uniformity.

[0057] The controller **190** can use a correlation curve that relates the signal measured by the in-situ monitoring system **180** to the thickness of the layer being polished on the substrate **10** to generate an estimated measure of the thickness of the layer being polished. An example of a correlation curve **404** is shown in FIG. **4**A. In the coordinate system depicted in FIG. **4**A, the horizontal axis represents the value of the signal received from the in-situ monitoring system **180**, whereas the vertical axis represents the value for the thickness of the layer of the substrate **10**. For a given signal value, the controller **190** can use the correlation curve **404** to generate a corresponding thickness value. The correlation curve **404** can be considered a “static” formula, in that it predicts a thickness value for each signal value regardless of the time or position at which the sensor head obtained the signal. The correlation curve can be represented by a variety of functions, such as a polynomial function, or a look-up table (LUT) combined with linear interpolation.

[0058] Referring to FIG. **5**D, changes in the position of the sensor head with respect to the substrate **10** can result in a change in the signal from the in-situ monitoring system **180**. That is, as the sensor head scans across the substrate **10**, the in-situ monitoring system **180** will make measurements for multiple regions **94**, e.g., measurement spots, at different locations on the substrate **10**.

Notch Finder Station

[0059] Referring to FIGS. **1**, and **3**, the polishing apparatus **100** can also include one or more notch-finding stations **200**. In some implementations, a notch-finding station **200***a* is positioned on the path **106** at a spot between the transfer station **104** and a first polishing station, e.g., polishing station **110***a*. One or more notch-finding stations **200***b*, **200***c* can be positioned on the path **106** travelled by the carrier heads **140** between two polishing stations **200**.

[0060] In some implementations, the polishing system includes two inter-platen notch-finding stations **200***b*, **200***c*. The two inter-platen notch-finding stations **200***b*, **200***c* could be on the path **106** on opposite sides of a polishing station, e.g., the second polishing station **110***b*.

[0061] In some modes of operation, the substrate orientation is measured at a notch-finding station **200** located before a polishing station **110** along the path **106**, and then moved forward along the path **106** to the polishing station **110** and polished at that polishing station **110**. However, in some modes of operation, the substrate orientation can be measured at a notch-finding station **200** located after a polishing station **110** along the path **106**, and then moved backward along the path **106** to the polishing station **110** and polished at that polishing station **110**. The substrate can then be moved forward again along the path **106** to the next polishing station, optionally stopping at the notch-finding station **200** before being polished at the next polishing station.

[0062] FIG. **3** illustrates an implementation of a notch finding station **200** positioned between two platens **120** of two polishing stations **110** that are adjacent along the path. This implementation of the notch finding station **200** has an optical notch detector **210** that includes a light source **212**, a light detector **214**, and circuitry **216** for sending and receiving signals between the controller **190** and the light source **212** and light detector **214**. The optical notch detector **210** can also be considered to include some of the functionality implemented, e.g., software, in the controller **190**.

[0063] The light source **212** is located such that a carrier head **140** can be positioned on the path **106** where the substrate **10** can scanned by the optical notch detector **210**. In particular, the light source **212** generates a light beam **220** that can be reflected by the substrate **10**, and the light detector **214** is positioned to receive a reflected light beam **222** from the substrate **10**. The light detector **214** can be positioned where the light beam **220** and reflected light beam **22** have equal incidence angles, e.g., such that the light detector **214** is receiving reflected (rather than scattered) light. Although FIG. **3** illustrates the light beam **220** travelling in a straight line to the substrate **10**, one or more mirrors can be positioned in the optical path of the light beam **220**.

[0064] To operate, the carrier head **140** is positioned in the notch finding station **200** with the substrate **10** positioned above and spaced apart from the optical components of the at the optical notch detector **210**. In particular the carrier head **140** is positioned such that the light beam **220** impinges the substrate **10** in an impingement spot **224** that contacts or overlaps the substrate edge **16**. The carrier head **140** rotates so that the substrate **10** rotates, thus sweeping the light beam along the circumference of the substrate **10**. Since the membrane **144** will have a different reflectivity than the substrate **10**, the signal from the detector **214** should change when the notch **12** passes across the light beam **220**. The notch position can thus be detected based on variation of the intensity signal from the detector **214**.

[0065] For some processes, it is useful to have each substrate oriented to a consistent angular position before polishing commences. The wafer notch can be oriented by rotating its carrier head. If the polishing operation has some inherent angular variation, e.g., due to a pattern of features on the substrate, then a consistent starting angular position can improve the ability to compensate for such variation, e.g., by application of varying pressure by the chambers inside the carrier head. In addition, a consistent starting angular position can improve the likelihood that the eddy current monitoring system **180** traces a consistent series of paths across the substrate on a wafer-to-wafer basis, thus making processing of the signal from the in-situ monitoring system more reliable.

Signal Processing

[0066] FIG. **5**A shows a schematic top view of a substrate being scanned by a sensor head of a polishing apparatus for one scan path **510**. The scan path starts at position **512** on the leading edge of the substrate **10** and ends at position **513** on the trailing edge of the substrate **10**. As noted above, changes in the position of the sensor head with respect to the substrate **10** can result in a change in the signal from the in-situ monitoring system **180**. That is, as the sensor head scans across the substrate **10**, the in-situ monitoring system **180** will make measurements for multiple regions, e.g., measurement spots **511**, at different locations on the substrate **10**.

[0067] FIG. **4**B illustrates a graph (shown for illustration of the process; no graph need be generated or displayed in operation) that shows a simplified signal **401** from the in-situ monitoring system **180** during a single pass of the sensor head below the substrate **10**. For a given trace, the signal can be captured (and thus the graph can represent the signal) as a function of measurement time or of position, e.g., radial or diameter position, of the measurement on the substrate. In either case, different portions of the signal **401** correspond to measurement spots **94** at different locations on the substrate **10** scanned by the sensor head. Thus, the graph **420** depicts, for a given location of the substrate scanned by the sensor head, a corresponding measured signal value from the signal **401**. Although the signal **401** is illustrated as a continuous line, in practice the signal **401** will be composed of a sequence of individual signal values.

[0068] Referring to FIGS. **5**A and **4**B, the signal **401** includes a first portion **422** that corresponds to locations in an edge region **503** of the substrate **10** when the sensor head crosses a leading edge of the substrate **10**, a second portion **424** that corresponds to locations in a central region **501** of the substrate **10**, and a third portion **426** that corresponds to locations in edge region **503** when the sensor head crosses a trailing edge of the substrate **10**. The signal can also include portions **428** that correspond to off-substrate measurements, i.e., signals generated when the sensor head scans areas beyond the edge **504** of the substrate **10** in FIG. **5**A.

[0069] The edge region **503** can correspond to a portion of the substrate where measurement spots **94** of the sensor head overlap the substrate edge **504**. The sensor head may scan these regions on its path **510** and generate a sequence of measurements that correspond to a sequence of locations along the path **510**.

[0070] Although the second portion **424** is illustrated as flat, this is for simplicity, and a real signal in the second portion **424** would likely include fluctuations due both to noise and to variations in the layer thickness. The second portion **424** corresponds to the monitoring location scanning the central region **501**.

[0071] During a polishing process, the sensor conducts multiple scans, with each scan measuring the thickness at various radial positions across the substrate. Due to the differing rotation rate of the carrier head **140** and the platen **120**, and due to the lateral oscillation of the carrier head, the scan paths are not consistent. As illustrative in FIG. **5**B, the substrate **10** is shown having been scanned by a sensor head along five distinct paths, **510**, **520**, **530**, **540**, and **550**. Because the multiple scan **510-550** follow distinct paths, they cover areas with differing density and arrangement of metal features, resulting in scan-to-scan variation due to underlayer noise.

[0072] FIG. **7**A illustrates a graph (shown for illustration of the process; no graph need be generated or displayed in operation) that shows two traces **711**, **712** from the in-situ monitoring system **180** during two passes of the sensor head beneath the substrate **10**, with the traces **711**, **712** including noise fluctuations. For example, the signal trace **711** could be obtained from the scan path **510**, and the signal trace **712** could be obtained from the scan path **520** (see FIG. **5**B). As noted above, each trace can be stored as a function of measurement time or of position, e.g., radial position, of the measurement on the substrate. The fluctuation in a single trace **711** or **712** can be due to both variation in the thickness across the substrate of the layer being polished and underlayer noise. On the other hand, the scan-to-scan variation between these traces **711**, **712** occurs because the sensor travels along two distinct scan paths, covering different arrangement of underlying metal structures.

[0073] Although only two traces are illustrated in FIG. **7**A, the system can acquire three or more traces with each trace obtained from a single pass of a sensor. Multiple traces can be obtained through a single sensor with multiple scans, multiple sensors with a single scan, or multiple sensors with multiple scans.

[0074] In this example, the scan signal traces **711** and **712** obtained from two distinct scan paths have notable variations: the signal trace **711** displays larger noise fluctuations from the underlayer signals compared to the signal trace **712**. However, other variations are possible. As noted above, the difference can be attributed to the distinct scan paths covering areas with varying density and arrangement of underlying metal features. Specifically, in the case of the signal trace **711**, S_h corresponds to a peak value, while S_**1** represents a valley value. The magnitude of signal fluctuation in the signal trace **711** is then given by S_h-S_**1**.

[0075] Referring to FIG. **7**B, which is an exemplary graph illustrating a ground truth measurement of a target layer, excluding any influence from underlayers. Ground truth value is often measured through methods such as a four-point probe technique or scanning a calibration wafer containing solely the layer of interest. In particular, for the ground truth signal trace **721**, S_m is its mean signal values, while S_r is the signal value reference for off-substrate measurements, i.e., signals generated when the sensor head scans areas beyond the edge **504** of the substrate **10** (see FIG. **5**A). Absent underlayer noise, the difference between S_m and S_r provides an accurate measurement of the target layer's thickness.

[0076] As illustrated in FIGS. **7**A and **7**B, the magnitude of noise fluctuations (S_h-S_**1**) for the measured signal trace **711** can be higher than its ground truth value (S_m-S_r) due to underlayer noises. Consequently, this leads to a substantial noise-to-signal ratio, reducing the accuracy of thickness calculations based on the measured signals.

[0077] To address this high noise-to-signal ratio issue, the controller **190** can incorporate a data processing program which subtracts background traces on a scan-by-scan basis. These background traces represent scans of a calibration or test substrate having the same patterning as the substrate undergoing process but immediately before deposition of the conductive layer being polished, or after polishing of the layer until an underlying layer is exposed. That is, the calibration substrate would include all of the same layers, in the same patterning, as the substrate being polished, except for the layer, e.g., the conductive layer, that is to be polished and monitored.

[0078] In some implementations, this approach includes sequentially labeling both the measured traces and the background traces, starting from the first scan (e.g., labeled as #1) and progressing through to the final scan at the end of the polishing process (e.g., labeled as #n, where n is the total number of scans conducted during a CMP process). The background trace is subtracted from the measured trace bearing the equivalent label number on a scan-by-scan basis.

[0079] For further illustration, FIG. **6** is a flow-diagram of an example for subtraction of background signal traces from measured signals on a scan-by-scan basis to reduce noises.

[0080] During CMP process, the one or more sensors are repeatedly swept (**601**) across a substrate to generate a sequence of measured traces.

[0081] The controller **190** labels (**602**) the measured trace. In some implementations, the label can be determined based on the ordinal position of the measured trace in the sequence of measured trace. For example, the first measured trace produced during an initial pass of a sensor is assigned the label #1, the second measured trace from the second pass of a sensor is labeled as #2, and so forth, until the polishing process is completed. If there are a total of n sensor scans throughout the entire polishing procedure, the measured traces are labeled from #1 to #n. Referring back to FIG. **7**A, the measured trace **711**, generated during the scan path **510**, can be labeled as #1, whereas the measured trace **712**, originating from the scan path **520**, can be labeled as #2. Other methods of labeling can be used, so long as it is possible to determine a background trace that occurred at the same scan ordinal position in the sequence of scans as the measured trace.

[0082] The controller **190** obtains a (**603**) corresponding background traces from a digital library. In particular, the controller **190** can obtain the background trace having the same label as the measured trace.

[0083] Assuming the library of background traces is properly generated, the corresponding background trace would be the one generated using the same scan path as the measured scan trace. For example, FIG. **7**C illustrates the background traces derived from two distinct scan paths. Specifically, the background trace **751** originates from the scan path **510** from the first scan (e.g., label #1), and will be the corresponding background trace for the first measured trace **711** (e.g., also label #1). Similarly, the second background trace **752** is generated from the scan path **520** from the second scan (e.g., label #2), and thus will the corresponding background trace for the measured signal trace **712** (e.g., also label #2).

[0084] The controller **190** subtracts (**604**) the background trace with the equivalent label from the measured trace to generate a modified trace. The subtraction process is executed on a scan-to-scan basis with equivalent positions in the sequence of signal traces. For example, returning to FIGS. **7**A and **7**C, the background signal trace **751** is subtracted from the measured signal trace **711** because they share the same position, #1, in the sequence of traces; likewise, the background signal trace **752** is subtracted from the measured signal trace **712** due to their equivalent position, #2. If there are a total of n scans, this identical subtraction process is carried out for each scan.

[0085] The measured signal trace and the background signal trace can have the same labeling system. For example, both measured signal traces and background signal traces can be labeled based on its ordinal position within the sequence of traces. An ordinal position of each trace in the sequence of traces can be provided by ordering of the data. For example, as noted above, the background trace **751** and the measured signal trace **711** can be labeled #1 because they are the first entry in the sequence of traces, generated from the first scan path **510**; the background trace **752** and the measured signal trace **712** can be labeled #2 because they are the second entry in the sequence of traces, generated from the second scan path **520**.

[0086] The subtraction can be conducted immediately after each sensor scan or following a specified number of sensor scans, which can be defined within the controller **190**. For example, if the subtraction is set to be conducted immediately after each scan, then following the first scan path, the background signal trace produced by the scan path #1 is retrieved from the library and then subtracted from the measured signal trace for the scan path #1; likewise, after the second scan path, the background signal trace produced by the scan path #2 is retrieved and then subtracted from the measured signal trace for the scan path #2, and so on.

[0087] If the specified number of scans is set to 2, which means that the subtraction is done after every 2 sensor scans, but the subtraction is still performed on a scan-to-scan basis. For example, after the first scan #1, a subtraction is not performed; but after the second scan #2, the background signal traces for both scan path #1 and #2 are retrieved together from the library. The background signals are then subtracted from the measured signal traces respectively on scan-by-scan basis, that is, background signal #1 is subtracted from measured signal trace #1, background signal #2 is subtracted from measured signal trace #2.

[0088] In some implementations, the apparatus **100** can be configured to allow for changes in the number of scans required prior to subtraction at different stages of the polishing, making it adaptable to varying conditions. For example, the apparatus **100** can be set to perform subtraction after every 5 scans at the beginning of a polishing process, when initial film thickness deviates significantly from a target thickness. As the polishing progresses, especially when measured thickness approaches the target thickness, the apparatus **100** can change to perform the subtraction immediately after each scan for more timely calculation.

[0089] In some implementations, the polishing system **100** has at least one notch finding station **200** to measure an angular orientation of the substrate **10** prior to polishing. By measuring the angular orientation of the substrate prior to polishing, the substrate **10** substrate can be rotated a specified angular position. Consequently, the positioning of the substrate notch or flat is consistent before each polishing process commences.

[0090] Referring to FIG. **5**C, which is a schematic top view of a CMP polishing station, the controller **190** causes the carrier head **140** to rotate the substrate **10** prior to polishing to an angular orientation where the substrate notch or flat **509** is positioned at a particular predetermined angular position in the stationary frame of reference, e.g., the frame of reference of the base that holds the substrates. For example, the predetermined angle θ_1, can be relative to an axis **195** that passes through both the axis of rotation **122** of the platen **120** and the center **197** of the carrier head **140**. In some implementations, this axis can pass through the fixed-position sensor **188**. The controller **190** can be configured such that' the notch or flat of each substrate to be polished is consistently aligned at this specified angular position before the polishing process begins for that substrate.

[0091] The controller **190** is also configured to rotate the platen **120** to a specified angular position before commencing polishing of the substrate **10**. The sensor head **181** can be fixed on the rotating platen **120** such that the sensor head **181** rotates with the platen **120**. This predetermined angular position, θ2, as depicted in FIG. **5**C, can be relative to the axis **195**. With both the platen and the substrate consistently beginning at specific angular positions, the sensor head **181** should follow a consistent series of paths across the substrate on a substrate-to-substrate basis. Returning to FIG. **5**B, provided that the relative angular position between the substrate **10** and the sensor head **181** remains consistent from one substrate to another, the initial scan path **510** can consistently commence at the path start position **512** and conclude at the path ending position **513** for each substrate, while for the second scan, the scan path **520** can consistently commence at the path start position **522** and conclude at the path ending position **523** for each substrate. Likewise, for the third, fourth and subsequent scans, the starting and ending positions of each path would also remain consistent from one substrate to another. Consequently, for equivalent positions within the sequence of scans, the sensor's path exhibits repeatability from substrate to substrate.

[0092] Referring back to FIG. **7**C, if each consecutive background trace, e.g., traces **751** and **752**, is generated with the same angular alignment as the corresponding measured traces, e.g., traces **711** and **712**, they will trace the same scan paths **510** and **520**. This angular alignment of the substrate **10** and the platen **120** before polishing results in a more accurate subtraction of the underlying signal trace on a scan-by-scan basis.

[0093] For example, FIG. **7**D illustrates modified signal traces using background signal subtractions on a scan-by-scan basis, when both the platen **120** and the substrate **10** consistently begin at specified angular positions. For example, the modified signal trace **761** is obtained by subtracting the background signal **751** from the measured signal **711**, while the modified signal trace **762** is obtained by subtracting the background signal **752** from the measured signal trace **712**. Employing background subtraction on a scan-by-scan basis, the modified signal traces offer more accurate representation of ground truth values for the target layer (see FIGS. **7**B and **7**D).

[0094] As noted above, the polishing apparatus **100** can include three polishing stations **110**. The substrate notch alignment can be done at each notch finding station **200***a*, **200***b*, **200***c* prior to polishing at the next polishing station **110***a*, **110***b*, **110***c*, respectively (see FIG. **1**). Similarly, each polishing station **110** can have an encoder **125** that measures the angular position or rotation rate of the associated drive shaft **126**, and a motor **124** that can turn a drive shaft **126** to rotate the platen **120** to a specified angular position prior to polishing (see FIG. **2**).

[0095] The specified angular position can vary among different polishing stations **110** and notch finders **200**. Specifically, three polishing stations **110***a*, **110***b*, **110***c*, may each employ a distinct angular alignment for the substrate **10** and the platen **120**. Nevertheless, the angular positioning needs remain consistent from one substrate to another for the same polishing station **110**.

[0096] FIG. **8** is a flow-diagram of an example for creating a background signal library.

[0097] A calibration substrate is prepared (**801**) to include the same underlayers and the same pattern beneath the layer of interest, as a production substrate. The calibration substrate can either excluding the layer of interest itself, or have the layer of interested remaining only in trenches in an exposed layer. For example, a calibration substrate having the same pattern and including the same layers as a production substrate can be prepared, and then polished until the underlying layer is exposed.

[0098] This calibration substrate is used to establish a background signal library for the layer of interest; it need not be intended for use in production of integrated circuits. The calibration substrate can be created by processing all or a substantial portion of the underlayers on a substrate until reaching the layer of interest. Alternatively, the calibration substrate can be obtained by polishing a substrate with all layers (including the layer to be polished in production) until the underlying layer is exposed. A unique calibration substrate will be needed for each product, as different products have different patterns with distinct underlayer layouts and metal configurations, and thus will generate different background traces.

[0099] The controller **190** causes the carrier head **140** and platen **120** to rotate to position (**802**) the wafer notch or flat **509** of the calibration substrate and the platen **120** at their respective predetermined angular positions.

[0100] The platen **120** rotates to repeatedly sweep (**803**) one or more sensors across the substrate to generate a sequence of background traces during a "simulated polishing" process. In this simulated polishing process, the carrier head and platen rotate at the same speeds and the carrier had rotates at the same rate as will occur during regular polishing of a product substrate. However, deionized water (DIW) is utilized in place of slurry for dispensed liquid **164** (see FIG. **2**), ensuring that no actual polishing of the "calibration substrate" occurs. In other words, the thickness of the exposed top layer of the "calibration substrate" should remain unchanged throughout the "simulated polishing" process. In addition, the pressure in the carrier head can be reduced, e.g., the chambers can be vented to atmosphere, to avoid polishing.

[0101] Process parameters for polishing the calibration substrate are set to mirror those of a real polishing process, including, but not limited to, platen **120**'s rotation rate, substrate **10**'s rotation rate, the angular positions of platen **120**. The "polishing" duration can be set equal to or longer than that of a real polishing process to encompass all potential unique scan paths generated during a real polishing process. Consequently, for a given product, the total number of background traces in the digital library may equal or exceed that of an actual polishing on a production substrate.

[0102] The controller **190** labels (**804**) the background traces sequentially from each sensor, such as #1, #2, #3, and so forth, until the "simulated polishing" process finishes. As noted above, alternative labeling methods can also be utilized.

[0103] The controller **190** stores (**805**) each individual background trace. The stored background traces provide a library of background traces. In some implementations, each trace is stored as a separate digital file. If there are a total of n traces generated throughout the entire "simulated polishing" process, then there will be a total of n files, with labels from #1 to #n. The file format includes, but not limited to, Data Stream Interface (DSI) file.

[0104] In some implementations, there are two or more sensors of the in-situ monitoring system **180** which are supported on the rotating platen **120**. Each sensor can travel a distinct path within a single rotation of the platen, and the labeling of the signal traces is specific to each sensor and each scan path. Therefore, a signal trace's position in the sequence of measured traces is contingent upon both the sensor and the scan path it follows. To illustrate, if there are three sensors, and each sensor generates 100 scan paths over the entire polishing process, a total of 300 signal traces would be created, and these can be sequentially labeled from #1 to #300. Consequently, corresponding background traces for the given product are also generated using the same configuration of three sensors, resulting in a digital library with a minimum of 300 traces. When performing scan-by-scan subtraction, the subtraction process involves matching the position in the sequence of background traces and measured traces to produce a sequence of 300 modified traces.

[0105] In some implementations, where multiple sensor heads are supported on the platen, a scan averaging method can be employed to consolidate the modified traces collected from the multiple within a single platen rotation. Using the example mentioned earlier, for each platen rotation, three sensors generate three measured signal traces. By subtracting the background signal trace on a scan-by-scan basis from these three measured signal traces, three modified signal traces are obtained. Subsequently, the average of these three modified signal traces is computed, resulting in a single averaged modified signal trace. This averaged trace represents the mean value for that particular platen rotation. If the entire polishing process comprises a total of 100 platen rotations, this scan averaging method would yield 100 averaged traces. These 100 averaged traces are then used to calculate the instant thickness of the substrate **10**. In conjunction with scan-by-scan subtraction method, this scan averaging method can further diminish background noise originating from underlayers.

[0106] In addition or alternatively, a scan averaging method can be applied prior to the subtraction of background signals. Specifically, an averaged trace is generated by averaging the measured traces gathered from different sensors within a single platen rotation, and then the corresponding background trace is subtracted from the averaged traces. To illustrate using the previously mentioned example, for each platen rotation, three sensors produce three measured signal traces. Before subtraction the average of these three measured signal traces is firstly computed, yielding a single averaged signal trace. Subsequently, the respective background trace is subtracted from this averaged signal trace to yield a modified signal trace. The respective background trace can be obtained by averaging the three corresponding background traces. In other words, the subtraction is achieved by deducting an averaged background trace from an averaged measured signal for each platen rotation. The resulting modified signal trace is then employed to calculate the instant thickness of the substrate **10**.

[0107] When both the carrier head **140** rotation rate and the platen **120** rotation rate remain constant throughout the polishing process, under ideal circumstances, scan paths may repeat themselves after a specific number of scans. However, if there is a loosened mechanical connection between the substrate **10** and its carrier head **140**, as illustrated in FIG. **5**D, it can lead to horizontal oscillations **199** of the substrate **10** relative to its carrier head **140** during the polishing operation. This oscillation **199**, in turn, causes a displacement in the scan traces.

[0108] FIG. **10**A illustrates an example of the path displacement from scan path **1010** to scan path **1020** due to loosened mechanical connection. Because of this displacement, the path **1020** travels through the substrate center **1001** and covers a greater distance than the path **1010**. Consequently, the path **1020** experiences a longer scanning time compared to path **1010**.

[0109] Referring to FIG. **10**B, the X-axis on the graph can be a measurement time or a position, e.g., radial position, of the measurement on the substrate. The scan signal trace **1021** is generated by the scan path **1020**, starting at X1 and ending at X4. The scan signal trace **1011** is generated by the scan path **1010**, starting at X2 and ending at X3. Due to the shorter distance covered by the scan path **1010**, the duration of its signal trace (X3-X2) is also shorter in comparison to the duration of the signal trace **1021** (X4-X1).

[0110] Within this context, Xp is an arbitrary point located between X1 and X2. S2*p* signifies the measurement taken at the substrate edge region **503** for the signal trace **1021**, while S1*p* is the off-substrate measurement for the signal trace **1011** at Xp (i.e., signals generated when the sensor head scans areas beyond the edge **504** of the substrate **10**). This situation can introduce challenges when applying a scan-by-scan subtraction and/or scan averaging method at Xp, because S1*p* represents an off-substrate measurement that holds no meaningful value in the calculation of signals for the substrate **10**.

[0111] In some implementations, the scan-by-scan subtraction method is conducted on signal traces that share the same time or position. For example, as illustrated in FIGS.

7A, 7C and 7D, both signal traces (711,712) and background traces (751, 752) start at the same time or position denoted as Xs and end at the same time or position denoted as Xe. Consequently, the modified signal traces (761, 762) maintain the same time or position.

[0112] In some implementations, a scaling trace is utilized to ensure that each trace spans from the same starting time or position to the same ending time or position. For example, referring to FIG. 10C, the scaled signal trace 1030 is derived by scaling the signal trace 1011 along the x-axis in a manner that aligns its starting and ending points with those of signal trace 1021, specifically matching X2 to X1 and X3 to X4. The scaling can be conducted using methods, including without limitation a Min-Max scaling. The Min-Max scaling method scales the original value to a specific range using the following formular for each data point x, x_scaled=(x−min_original)*(max_new-min_new)/(max_original-min_original)+min_new, where x is the original data point; min_original and max_original are the minimum and maximum values in the original range; min_new and max_new are the minimum and maximum values in the new range.

[0113] Subsequently, the scan-by-scan subtraction and/or the averaging method is applied to both the signal trace 1021 and the scaled signal trace 1030. For example, at the time or position Xp, S3*p* represents the scaled signal value originating from the signal trace 1011, and S2*p* represents the unscaled signal value from the signal trace 1021. Specifically, when considering signal trace 1021 as a "measured" signal trace and signal trace 1030 as a scaled "background" trace derived from the same scan path, the scan-by-scan background subtraction can be expressed as S3*p*-S2*p* at Xp.

[0114] In addition or alternatively, the polishing apparatus 100 can detect a leading edge of the trace and a trailing edge of the trace. For example, in FIG. 10B, the edge 1013 corresponds to the leading edge of the signal trace 1011, while the edge 1023 corresponds to the trailing edge of the signal trace 1011. The polishing apparatus 100 can be configured to detect such edges.

[0115] In some implementations, the polishing apparatus 100 can apply edge reconstruction. Edge construction refers to the process of controlling and optimizing the removal of material at the edges of a substrate during the polishing process. The edge of a substrate can present unique challenges during CMP because it is more susceptible to non-uniform material removal and damage compared to the central region. Edge construction can involve various techniques and strategies to achieve uniformity and minimize edge defects.

[0116] In some implementations, the edge reconstruction employs a neural network, as described in U.S. Patent Publication Nos. 2018-0304435. As illustrated in FIG. 4B, the variation in the signal intensity in the portions 422, 426 is caused in part by measurement region of the sensor overlapping the substrate edge, rather than an intrinsic variation in the thickness or conductivity of the layer being monitored. Consequently, this distortion in the signal 401 can cause errors in the calculating of a characterizing value for the substrate, e.g., the thickness of the layer, near the substrate edge.

[0117] To address this problem, the controller 190 can include a neural network to generate a modified signal corresponding to one or more locations of the substrate 10 based on the measured signals corresponding to those locations. The neural network is configured to, when trained appropriately, generate modified signals that reduce and/or remove the distortion of computed signal values near the substrate edge. The system obtains estimated measures of thickness generated by the neural network based on input values that include measured signals for each location in a group of locations of the substrate. The system also obtains ground truth measures of thickness for each location in the group of locations. The system can generate ground truth measures of thickness using an electrical impedance measuring method, such as the four-points probe method.

[0118] The system then computes a measure of error between the estimated measures of thickness and the ground truth measures of thickness and updates one or more parameters of the neural network based on the measure of error. If the polishing apparatus uses such a neural network to generate modified signals based on the measured signals generated by the in-situ monitoring system, the apparatus can compensate for the distortions, e.g., reduced signal strength, at the substrate edge.

[0119] Referring back to FIG. 6, after obtaining modified signal traces using various signal processing methods as mentioned above, the controller 190 calculates (605) estimated thickness values based on modified traces. Each estimated thickness value represents the thickness of the layer being polished at the time the measured trace was acquired.

[0120] As illustrated in FIG. 4A, for a given modified signal value, the polishing apparatus 100 can use the correlation curve 404 to generate a corresponding thickness value. The correlation curve 404 can be considered a "static" formula, in that it predicts a thickness value for each modified signal value regardless of the time or position at which the sensor head obtained the signal. The correlation curve can be represented by a variety of functions, such as a polynomial function, or a look-up table (LUT) combined with linear interpolation. With the correlation curve 404, a sequence of estimated thickness values can thus be generated using modified signal values. Each thickness profiling includes thickness values as a function of time or radial position on the substrate 10, as illustrated in FIG. 7A. FIG. 9 is a flow-diagram of an example process 900 for polishing a substrate 10.

[0121] A sequence of background traces generated by a sequence of scans of one or more sensors across a substrate are stored (901), e.g., in a memory of the controller 190. An example process for generating a digital library of background traces is given in FIG. 8.

[0122] The substrate 10 and the platen 120 are positioned at respective predetermined angular positions prior to polishing (902). The polishing apparatus 100 polishes (903) a layer on the substrate 10 and monitors (904) the layer during the polishing to generate measured signal values for different locations on the layer, e.g., using the in-situ monitoring system 180.

[0123] Background traces are subtracted from the measured signal traces on a scan-by-scan basis (905). As described above, this can include determining the background trace that has the same ordinal position in the scanning sequence as the measured trace, and subtracting that background trace from the measured trace. As noted above, this scan-by-scan subtraction method can be further combined with other signal processing methods, such as, a scan averaging method by taking an average of multiple signal traces, a neutral network configured to generate modified signals that reduce the distortion of computed signal values near the substrate edge, scaling the signal trace to match position such that each trace extends along a same start time or position to a same end time or position, etc.

[0124] An estimated measure of thickness is generated (**906**) for each location of the different locations based on the measured signal for the location.

[0125] A polishing endpoint is detected and/a polishing parameter is modified (**907**) based on each estimated measures of thickness.

[0126] The monitoring system can be used in a variety of polishing systems. Either the polishing pad, or the carrier head, or both can move to provide relative motion between the polishing surface and the substrate. The polishing pad can be a circular (or some other shape) pad secured to the platen, a tape extending between supply and take-up rollers, or a continuous belt. The polishing pad can be affixed on a platen, incrementally advanced over a platen between polishing operations, or driven continuously over the platen during polishing. The pad can be secured to the platen during polishing, or there can be a fluid bearing between the platen and polishing pad during polishing. The polishing pad can be a standard (e.g., polyurethane with or without fillers) rough pad, a soft pad, or a fixed-abrasive pad.

[0127] Although the discussion above focuses on an eddy current monitoring system, the correction techniques can be applied to other sorts of monitoring systems, e.g., optical monitoring systems. In addition, although the discussion above focuses on a polishing system, the correction techniques can be applied to other sorts of substrate processing systems, e.g., deposition or etching systems, that include an in-situ monitoring system with a sensor that scans across the substrate.

[0128] A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A computer program product for controlling a polishing system, the computer program product residing on a non-transitory computer readable medium and comprising instructions for causing one or more computers to:

store data representing a sequence of background traces generated by a sequence of scans of a sensor of an in-situ monitoring system across a substrate prior to or after polishing of a layer on the substrate;

for each respective sweep of a plurality of sweeps of a sensor of an in-situ monitoring system across the substrate during polishing of the substrate, receive a sequence of raw signal values that provides a measured trace for the respective sweep in a sequence of measured traces;

for each respective measured trace in the sequence of measured traces, subtract a respective background trace that has an equivalent position in the sequence of background traces from the respective measured trace to generate a modified trace and thus provide a sequence of modified traces;

generate a sequence of estimated thickness values based on the sequence of modified traces; and

at least one of detect a polishing endpoint or modify a polishing parameter based on the sequence of estimated thickness values.

2. The computer program product of claim **1**, comprising instructions receive a measurement of an angular orientation of the substrate prior to polishing, and to rotate the substrate to a first predetermined angular position prior to polishing.

3. The computer program product of claim **2**, comprising instructions to rotate a platen supporting a polishing pad used for the polishing of the substrate to a second predetermined angular position prior to polishing the layer on the substrate.

4. The computer program product of claim **3**, comprising instructions to count a number of rotations of the platen to provide an ordinal position of the measured trace in the sequence of measured traces.

5. The computer program product of claim **1**, comprising instructions to average traces accumulated from different sensors within a single rotation of a platen to generate an averaged trace.

6. The computer program product of claim **5**, comprising instructions to subtract the respective background trace from the averaged trace.

7. The computer program product of claim **1**, comprising instructions to scale the measured traces such that each measured trace extends from a same start time or position to a same end time or position.

8. The computer program product of claim **7**, comprising instructions to detect a leading edge of the trace and a trailing edge of the trace.

9. The computer program product of claim **1**, comprising instructions to perform edge reconstruction on each trace.

10. The computer program product of claim **9**, wherein the instructions to perform edge reconstruction include instructions to process portions of the modified trace corresponding to an edge of the substrate through a neural network.

11. The computer program product of claim **1**, comprising instructions to store data representing an ordinal position of each background trace in the sequence of background traces.

12. The computer program product of claim **1**, wherein an ordinal position of each background trace in the sequence of background traces is provided by ordering of the data.

13. The computer program product of claim **1**, wherein the instructions to generate the sequence of estimated thickness values comprise instructions to generating a sequence of measured thickness profiles, each thickness profiling including thickness values as a function of time or radial position on the substrate.

14. The computer program product of claim **13**, wherein the instructions to generate a measured thickness profile in the sequence of measured thickness profiles comprises instructions to convert modified signal values from a modified trace to thickness values using a correlation curve.

15. A method of chemical mechanical polishing, comprising:

storing data representing a sequence of background traces generated by a sequence of scans of a sensor of an in-situ monitoring system across a substrate prior to or after polishing of a layer on the substrate;

polishing the layer on a substrate;

monitoring the layer during the polishing with the in-situ monitoring system, including repeatedly sweeping the sensor of the in-situ monitoring system across substrate such that each sweep generates a sequence of raw signal values that provides a measured trace and the repeated sweeping provides a sequence of measured traces;

for each respective measured trace in the sequence of measured traces, subtracting a respective background trace that has an equivalent position in the sequence of background traces from the respective measured trace to generate a modified trace and thus provide a sequence of modified traces;

generating a sequence of estimated thickness values based on the sequence of modified traces; and

at least one of detecting a polishing endpoint or modifying a polishing parameter based on the sequence of estimated thickness values.

16. The method of claim **15**, comprising measuring an angular orientation of the substrate prior to polishing, and rotating the substrate to a first predetermined angular position prior to polishing.

17. The method of claim **16**, comprising rotating a platen supporting a polishing pad for the polish of the substrate to a second predetermined angular position prior to polishing the layer on the substrate.

18. The method of claim **17**, comprising counting a number of rotations of the platen to provide an ordinal position of the measured trace in the sequence of measured traces.

19. A polishing system, comprising:

a platen to support a polishing pad;

a carrier head to hold a substrate in contact with the polishing pad;

a motor to generate relative motion between the carrier head and the platen;

an eddy current monitoring system to monitor the substrate during polishing; and

a controller configured to

store data representing a sequence of background traces generated by a sequence of scans of a sensor of the in-situ monitoring system across the substrate prior to or after polishing of a layer on the substrate,

for each respective sweep of a plurality of sweeps of the sensor of the in-situ monitoring system across the substrate during polishing of the substrate, receive from the in-situ monitoring system a sequence of raw signal values that provides a measured trace for the respective sweep in a sequence of measured traces,

for each respective measured trace in the sequence of measured traces, subtract a respective background trace that has an equivalent position in the sequence of background traces from the respective measured trace to generate a modified trace and thus provide a sequence of modified traces,

generate a sequence of estimated thickness values based on the sequence of modified traces, and

at least one of detect a polishing endpoint or modify a polishing parameter based on the sequence of estimated thickness values.

20. The system of claim **19**, wherein the controller is configured to receive a measurement of an angular orientation of the substrate prior to polishing, and to rotate the substrate to a first predetermined angular position prior to polishing.

21. The system of claim **20**, wherein the controller is configured to rotate a platen supporting a polishing pad used for the polishing of the substrate to a second predetermined angular position prior to polishing the layer on the substrate.

22. The system of claim **21**, wherein the controller is configured to count a number of rotations of the platen to provide an ordinal position of the measured trace in the sequence of measured traces.

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