(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 November 2009 (05.11.2009)

PCT

(10) International Publication Number
WO 2009/134865 A2

(51) International Patent Classification: *H01L 21/304* (2006.01)

(21) International Application Number: PCT/US2009/042085

(22) International Filing Date: 29 April 2009 (29.04.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/049,965 2 May 2008 (02.05.2008) US

(71) Applicant (*for all designated States except US*): **APPLIED MATERIALS, INC.** [US/US]; 3050 Bowers Avenue, Santa Clara, CA 95054 (US).

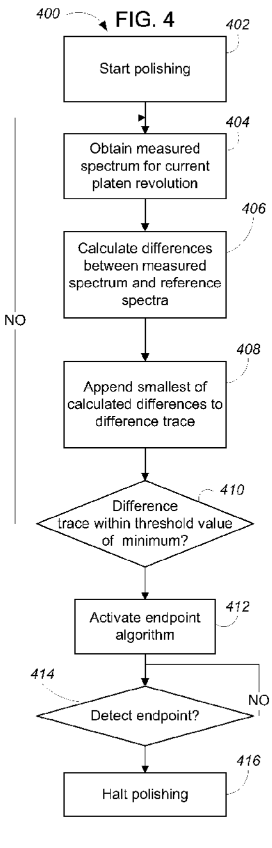
(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **QIAN, Jun** [CN/US]; 575 Dublin Way, Sunnyvale, CA 94087 (US). **DHANDAPANI, Sivakumar** [IN/US]; 494 White Chapel Avenue, San Jose, CA 95136 (US). **LEE, Harry, Q.** [US/US]; 1501 Ben Roe Drive, Los Altos, CA 94024 (US). **OSTERHELD, Thomas, H.** [US/US]; 1195 Barbara Avenue, Mountain View, CA 94040 (US). **ZHU, Zhize** [CN/US]; 10282 Terry Way #3, Cupertino, CA 95014 (US).

(74) Agent: **GOREN, David, J.**; Fish & Richardson P.C., P.O. Box 1022, Minneapolis, MN 55440-1022 (US).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

[Continued on next page]

(54) Title: ENDPOINT DETECTION IN CHEMICAL MECHANICAL POLISHING USING MULTIPLE SPECTRA



(57) Abstract: A computer implemented method includes obtaining at least one current spectrum with an in-situ optical monitoring system, comparing the current spectrum to a plurality of different reference spectra, and determining based on the comparing whether a polishing endpoint has been achieved for the substrate having the outermost layer undergoing polishing. The current spectrum is a spectrum of light reflected from a substrate having an outermost layer undergoing polishing and at least one underlying layer. The plurality of reference spectra represent spectra of light reflected from substrates with outermost layers having the same thickness and underlying layers having different thicknesses.

WO 2009/134865 A2

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

ENDPOINT DETECTION IN CHEMICAL MECHANICAL POLISHING USING MULTIPLE SPECTRA

BACKGROUND

The present invention relates to generally to spectrographic monitoring of a substrate during chemical mechanical polishing.

An integrated circuit is typically formed on a substrate by the sequential deposition of conductive, semiconductive, or insulative layers on a silicon wafer. One fabrication step involves depositing a filler layer over a non-planar surface and planarizing the filler layer. For certain applications, the filler layer is planarized until the top surface of a patterned layer is exposed. A conductive filler layer, for example, can be deposited on a patterned insulative layer to fill the trenches or holes in the insulative layer. 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. For other applications, such as oxide polishing, the filler layer is planarized until a predetermined thickness is left over the non planar surface. In addition, planarization of the substrate surface is usually required for photolithography.

Chemical mechanical polishing (CMP) is one accepted method of planarization. This planarization method typically requires that the substrate be mounted on a carrier or polishing head. The exposed surface of the substrate is typically placed against a rotating polishing disk pad or belt pad. The polishing pad can be either a standard pad or a fixed abrasive pad. A standard pad has a durable roughened surface, whereas a fixed-abrasive pad has abrasive particles held in a containment media. The carrier head provides a controllable load on the substrate to push it against the polishing pad. A polishing liquid, such as a slurry with abrasive particles, is typically supplied to the surface of the polishing pad.

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. Overpolishing (removing too much) of a conductive layer or film leads to increased circuit resistance. On the other hand, underpolishing (removing too little) of a conductive layer leads to electrical shorting. Variations in the initial thickness of the substrate layer, the slurry composition, the polishing pad condition, the relative speed between the polishing pad and the substrate, 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, the polishing endpoint cannot be determined merely as a function of polishing time.

SUMMARY

In one general aspect, a computer implemented method includes obtaining at least one current spectrum with an in-situ optical monitoring system, comparing the current spectrum to a plurality of different reference spectra, and determining based on the comparing whether a polishing endpoint has been achieved for a substrate having an outermost layer undergoing polishing. The current spectrum is a spectrum of light reflected from a substrate having an outermost layer undergoing polishing and at least one underlying layer. The plurality of reference spectra represent spectra of light reflected from substrates with outermost layers having the same thickness and underlying layers having different thicknesses.

Implementations can include one or more of the following. Determining whether the polishing endpoint has been achieved may include calculating differences between the current spectrum and the reference spectra. Determining whether the polishing endpoint has been achieved may include determining whether at least one of the differences has reached a threshold value. The at least one of the differences may be a smallest difference. Determining whether the polishing endpoint has been achieved may include activating an endpoint detection algorithm when at least one of the differences has reached a threshold value. Determining whether the polishing endpoint has been achieved may include generating a difference trace that includes multiple points, each point representing a smallest of the differences calculated for a revolution of the platen. The endpoint detection algorithm may include determining whether the difference trace has reached a minimum. Determining whether the difference trace has reached a minimum may include calculating a slope of the difference trace or determining whether the difference trace has risen to a threshold value above the minimum. The reference spectra may be generated empirically or generated from theory.

In another aspect, a computer program product, encoded on a tangible program carrier, operable to cause data processing apparatus to perform operations comprising the steps of the method above.

As used in the instant specification, the term substrate can include, for example, a product substrate (e.g., which includes multiple memory or processor dies), a test substrate, a bare substrate, and a gating substrate. The substrate can be at various stages of integrated circuit fabrication, e.g., the substrate can be a bare wafer, or it can include one or more deposited and/or patterned layers. The term substrate can include circular disks and rectangular sheets.

Possible advantages of implementations of the invention can include one or more of the following. The endpoint detection system can be less sensitive to variations between substrates in the underlying layers or pattern, and thus reliability of the endpoint system can be improved. The use of multiple reference spectra (as oppose to a single reference spectrum) improves accuracy in endpoint determination by providing a difference or endpoint trace that is generally smoother than a trace generated by using a single reference-spectrum technique.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the invention will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a substrate.

FIG. 2 shows a chemical mechanical polishing apparatus.

FIG. 3 is an overhead view of a polishing pad and shows locations where in-situ measurements are taken.

FIG. 4 is a flow diagram of determining a polishing endpoint.

FIG. 5 illustrates a difference trace from a spectrographic monitoring system.

FIG. 6 is a flow diagram of another implementation of determining a polishing endpoint.

Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

Referring to FIG. 1, a substrate 10 can include a wafer 12, an outermost layer 14 that will undergo polishing, and one or more underlying layers 16, some of which are typically patterned, between the outermost layer 16 and the wafer 12. One potential problem with spectrographic endpoint detection during chemical mechanical polishing is that the thickness(es) of the underlying layer(s) can vary from substrate to substrate. As a result, substrates in which the outermost layer has the same thickness can actually reflect different spectra, depending on the underlying layer(s). Consequently, a target spectrum used to trigger a polishing endpoint for some substrates may not function properly for other substrates, e.g., if the underlying layers have different thicknesses. However, it is possible to compensate for this effect by comparing spectra obtained during polishing against multiple spectra, where the multiple spectra represent variations in the underlying layer(s).

FIG. 2 shows a polishing apparatus 20 operable to polish a substrate 10. The polishing apparatus 20 includes a rotatable disk-shaped platen 24, on which a polishing pad 30 is situated. The platen is operable to rotate about axis 25. For example, a motor can turn a drive shaft 22 to rotate the platen 24.

Optical access 36 through the polishing pad is provided by including an aperture (i.e., a hole that runs through the pad) or a solid window. The solid window can be secured to the polishing pad, although in some implementations the solid window can be supported on the platen 24 and project into an aperture in the polishing pad. The polishing pad 30 is usually placed on the platen 24 so that the aperture or window overlies an optical head 53 situated in a recess 26 of the platen 24. The optical head 53 consequently has optical access through the aperture or window to a substrate being polished. The optical head is further described below.

The polishing apparatus 20 includes a combined slurry/rinse arm 39. During polishing, the arm 39 is operable to dispense a polishing liquid 38, such as a slurry. Alternatively, the polishing apparatus includes a slurry port operable to dispense slurry onto polishing pad 30.

The polishing apparatus 20 includes a carrier head 70 operable to hold the substrate 10 against the polishing pad 30. The carrier head 70 is suspended from a support structure 72, for example, a carousel, and is connected by a carrier drive shaft 74 to a carrier head rotation motor 76 so that the carrier head can rotate about an axis 71. In addition, the carrier head 70 can oscillate laterally in a radial slot formed in the support structure 72. In operation, the platen is rotated about its central axis 25, and the carrier head is rotated about its central axis 71 and translated laterally across the top surface of the polishing pad.

The polishing apparatus also includes an optical monitoring system, which can be used to determine a polishing endpoint as discussed below. The optical monitoring system includes a light source 51 and a light detector 52. Light passes from the light source 51, through the optical access 36 in the polishing pad 30, impinges and is reflected from the substrate 10 back through the optical access 36, and travels to the light detector 52.

A bifurcated optical cable 54 can be used to transmit the light from the light source 51 to the optical access 36 and back from the optical access 36 to the light detector 52. The bifurcated optical cable 54 can include a “trunk” 55 and two “branches” 56 and 58.

As mentioned above, the platen 24 includes the recess 26, in which the optical head 53 is situated. The optical head 53 holds one end of the trunk 55 of the bifurcated fiber cable 54, which is configured to convey light to and from a substrate surface being polished. The optical head 53 can include one or more lenses or a window overlying the end of the bifurcated fiber cable 54. Alternatively, the optical head 53 can merely hold the end of the trunk 55 adjacent the solid window in the polishing pad. The optical head 53 can hold the above described nozzles of the flushing system. The optical head 53 can be removed from the recess 26 as required, for example, to effect preventive or corrective maintenance.

The platen includes a removable in-situ monitoring module 50. The in-situ monitoring module 50 can include one or more of the following: the light source 51, the light detector 52, and circuitry for sending and receiving signals to and from the light source 51 and light detector 52. For example, the output of the detector 52 can be a digital electronic signal that passes through a rotary coupler, e.g., a slip ring, in the drive shaft 22 to the controller for the optical monitoring system. Similarly, the light source can be turned on or off in response to control commands in digital electronic signals that pass from the controller through the rotary coupler to the module 50.

The in-situ monitoring module can also hold the respective ends of the branch portions 56 and 58 of the bifurcated optical fiber 54. The light source is operable to transmit light, which is conveyed through the branch 56 and out the end of the trunk 55 located in the optical head 53, and which impinges on a substrate being polished. Light reflected from the substrate is received at the end of the trunk 55 located in the optical head 53 and conveyed through the branch 58 to the light detector 52.

In one implementation, the bifurcated fiber cable 54 is a bundle of optical fibers. The bundle includes a first group of optical fibers and a second group of optical fibers. An optical fiber in the first group is connected to convey light from the light source 51 to a substrate surface being polished. An optical fiber in the second group is connected to received light reflecting from the substrate surface being polished and convey the received light to a light detector. The optical fibers can be arranged so that the optical fibers in the second group form an X like shape that is centered on the longitudinal axis of the bifurcated optical fiber 54 (as viewed in a cross section of the bifurcated fiber cable 54). Alternatively, other arrangements can be implemented. For example, the optical fibers in the second group can form V like shapes that are mirror images of each other. A suitable bifurcated optical fiber is available from Verity Instruments, Inc. of Carrollton, Texas.

The light source 51 is operable to emit white light. In one implementation, the white light emitted includes light having wavelengths of 200 – 800 nanometers. A suitable light source is a xenon lamp or a xenon mercury lamp.

The light detector 52 can be a spectrometer. A spectrometer is basically an optical instrument for measuring intensity of light over a portion of the electromagnetic spectrum. A suitable spectrometer is a grating spectrometer. Typical output for a spectrometer is the intensity of the light as a function of wavelength.

The light source 51 and light detector 52 are connected to a computing device operable to control their operation and to receive their signals. The computing device can include a microprocessor situated near the polishing apparatus, e.g., a personal computer. With respect to control, the computing device can, for example, synchronize activation of the light source 51 with the rotation of the platen 24. As shown in FIG. 3, the computer can cause the light source 51 to emit a series of flashes starting just before and ending just after the substrate 10 passes over the in-situ monitoring module. (Each of points 301-311 depicted represents a location where light from the in-situ monitoring module impinged and reflected off.) Alternatively, the computer can cause the light source 51 to emit light continuously starting just before and ending just after the substrate 10 passes over the in-situ monitoring module. In either case, the signal from the detector can be integrated over a sampling period to generate spectra measurements at a sampling frequency. Although not shown, each time the substrate 10 passes over the monitoring module, the alignment of the substrate with the monitoring module can be different than in the previous pass. Over one rotation of the platen, spectra are obtained from different radii on the substrate. That is, some spectra are obtained from locations closer to the center of the substrate and some are closer to the edge. In addition, over multiple rotations of the platen, a sequence of spectra can be obtained over time.

In operation, the computing device can receive, for example, a signal that carries information describing a spectrum of the light received by the light detector 52 for a particular flash of the light source or time frame of the detector. Thus, this spectrum is a spectrum measured in-situ during polishing.

Without being limited to any particular theory, the spectrum of light reflected from the substrate 10 evolves as polishing progresses due to changes in the thickness of the outermost layer, thus yielding a sequence of time-varying spectra. Moreover, particular spectra are exhibited by particular thicknesses of the layer stack.

The computing device can process the signal to determine an endpoint of a polishing step. In particular, the computing device can execute logic that determines, based on the measured spectra, when an endpoint has been reached.

In brief, the computing device can compare the measured spectra to multiple reference spectra, and uses the results of the comparison to determine when an endpoint has been reached.

As used herein, a reference spectrum is a predefined spectrum generated prior to polishing of the substrate. A reference spectrum can have a pre-defined association, i.e., defined prior to the polishing operation, with a value of a substrate property, such as a thickness of the outermost layer. A reference spectrum can be generated empirically, e.g., by measuring the spectrum from a test substrate having a known layer thicknesses, or generated from theory.

A reference spectrum can be a target spectrum, which can be an endpoint-process compensated target spectrum or an uncompensated target spectrum. An uncompensated target spectrum refers to a spectrum exhibited by the substrate when the outermost layer has a target thickness. By way of example, a target thickness can be one to three microns. Alternatively, the target thickness can be zero, for example, when the film of interest is cleared so that an underlying film is exposed. However, there may be a lag time between the system receiving a spectrum representing the target thickness and the time that polishing halts (which can be due to the endpoint detection algorithm needing spectra from multiple platen rotations, time for instructions to be transmitted from controller to processing system, and time needed to halt rotation of the platen). Therefore, the polishing endpoint can be set at a time prior to achieving the target thickness. An endpoint-process compensated target spectrum is a spectrum that when used to trigger a polishing endpoint under a particular endpoint algorithm and polishing control system results in the substrate having substantially the target thickness, e.g., significantly closer to the target thickness than if no compensation for the lag time were made.

As noted above, there are multiple reference spectra for a particular thickness of interest for the outermost layer. Such is the case because differing thicknesses in the underlying layer(s) for different substrates can result in different spectra even if the outermost layer has the same thickness. In addition, substrates for different integrated chip products will have different patterning of the layers, which also can result in different spectra even if the outermost layer has the same thickness. Thus, there can be multiple spectra for a particular thickness of the outermost layer, and the multiple spectra can include spectra that are different from each other because of differing thicknesses in the underlying layer(s) or differing patterns due to the substrate being intended to provide different products.

The reference spectra are collected prior to the polishing operation, and the association of each reference spectrum with its associated substrate property is stored. The reference spectra can be determined empirically.

For example, to determine a target spectrum, a property of a "set-up" substrate with the same pattern as the product substrate can be measured pre-polish at a metrology station. The substrate property can be the thickness of the outermost layer. The set-up substrate is then polished while spectra are collected. The set-up substrate can be removed periodically from the polishing system, and its properties measured at a metrology station. The substrate can be overpolished, i.e., polished past a desired thickness, so that the spectrum of the light that reflected from the substrate when the target thickness is achieved can be obtained.

The measured thicknesses and the collected spectra are used to select, from among the collected spectra, one or more spectra determined to be exhibited by the substrate when it had a thickness of interest. In particular, linear interpolation can be performed using the measured pre polish film thickness and post polish substrate thicknesses to determine the time and corresponding spectrum exhibited when the target thickness was achieved. The spectrum or spectra determined to be exhibited when the target thickness was achieved are designated to be the target spectrum or target spectra.

These steps can then be repeated for one or more additional set-up substrates with the same pattern as the product substrate but with a different thicknesses of the underlying layer(s) to generate additional reference spectra. Thus, the resulting collection of reference spectra includes target spectra for the same target thickness but which differ from each other because of differing thicknesses in the underlying layer(s).

Alternatively or in addition, these steps can then be repeated for one or more additional set-up substrates with different patterns from the product substrate to generate additional reference spectra. Thus, the resulting collection of reference spectra includes target spectra for the same target thickness but which differ from each other because of differing patterns.

Optionally, the spectra collected are processed to enhance accuracy and/or precision. The spectra can be processed, for example: to normalize them to a common reference, to average them, and/or to filter noise from them.

In addition, some or all of the reference spectra can be calculated from theory, e.g., using an optical model of the substrate layers.

FIG. 4 shows a method 200 for using spectra based endpoint determination logic to determine an endpoint of a polishing step. A product substrate is polished using the above-described polishing apparatus (step 402). At each revolution of the platen, the following steps are performed.

At least one spectrum of light reflecting off a substrate surface being polished is measured (step 404). Optionally, multiple spectra can be measured, e.g., spectra measured at different radii on the substrate can be obtained from a single rotation of platen, e.g., at points 301-311 (FIG. 3). If multiple spectra are measured, a subset of one or more of the spectra can be selected for use in the endpoint detection algorithm. For example, spectra measured at sample locations near the center of the substrate (for example, at points 305, 306, and 307 shown in FIG. 3) could be selected. The spectra measured during the current platen revolution are optionally processed to enhance accuracy and/or precision.

A difference between each of the selected measured spectra and each of the reference spectra is calculated (step 406). The reference spectra can be a target spectra. In one implementation, the difference is a sum of differences in intensities over a range of wavelengths. That is,

$$Difference = \sum_{\lambda=a}^{b} abs\,(I_{current}(\lambda) \; - \; I_{reference}(\lambda))$$

where a and b are the lower limit and upper limit of the range of wavelengths of a spectrum, respectively, and $I_{current}(\lambda)$ and $I_{reference}(\lambda)$ are the intensity of a current spectra and the intensity of the target spectra for a given wavelength, respectively. Alternatively, the difference can be calculated as a mean square error, that is:

$$Difference = \sum_{\lambda=a}^{b} (I_{current}(\lambda) \; - \; I_{reference}(\lambda))^2$$

One way to calculate a difference between each of the current spectra and each of the reference spectra is to select each of the current spectra. For each selected current spectra, the difference is calculated against each of the reference spectra. Given current spectra *e, f,* and *g*, and reference spectra *E, F,* and *G*, for example, a difference would be calculated for each of the following combinations of current and reference spectra: *e* and *E*, *e* and *F*, *e* and *G*, *f* and *E*, *f* and *F*, *f* and *G*, *g* and *E*, *g* and *F*, and *g* and *G*.

The smallest of the calculated differences is appended to a difference trace (step 408). The difference trace is usually updated once per platen revolution. The difference trace is generally a plot of one of the calculated differences (in this case the smallest of the differences calculated for the current platen revolution). As an alternative to the smallest difference, another of the differences, for example, a median of the differences or the next to smallest difference, can be appended to the trace.

Optionally, the difference trace can be processed, for example, smoothing the difference trace by filtering out a calculated difference that deviates beyond a threshold from preceding one or more calculated differences.

Whether the difference trace is below a threshold value is determined (step 410). Once the difference trace crosses the below the threshold, endpoint logic is initiated and can be applied to detect an endpoint condition, e.g., the minimum of the difference trace (step 412). For example, the endpoint can be called when the different trace begins to rise past a particular threshold value of the minimum, or called if the slope of the difference trace falls below a threshold that is near zero, or other window logic can be applied. Once the endpoint logic detects the endpoint condition (step 414), polishing is halted (step 416).

In some implementations, once the difference trace falls below a threshold value, the particular reference spectrum that provided the closest match, e.g., the smallest difference from the measured spectrum, is then used as the only reference spectrum for the remainder of the endpoint determination process. This ensures that endpoint is based on a target spectra that represents a substrate in which the underlying layers are similar to the substrate being polished.

By using multiple reference spectra representing substrates with underlying layers of different thicknesses, the endpoint detection system becomes less sensitive to variations in the underlying layers, and thus reliability of the endpoint system can be improved. Similarly, by using multiple reference spectra representing substrates with different patterns, the endpoint detection system becomes less sensitive to variations in the pattern, and thus reliability of the endpoint system can be improved.

If the difference trace is NOT determined to have reached a threshold range of a minimum, polishing is allowed to continue and steps 404, 406, 408, are repeated as appropriate.

FIG. 5 is an exemplary graph of a difference trace as a function of time illustrates the thresholds. Trace 502 is the difference trace, which can already be filtered and smoothed. Endpoint detection 508 is activated when the smoothed difference trace 502 reaches a threshold value 504 above the minimum 506.

FIG. 6 shows a method 600 for determining an endpoint of a polishing step. Prior to the polishing operation, reference spectra are generated, e.g., collected empirically, such as by polishing a set up substrate and measuring the spectra, or calculated from theory, e.g., using an optical model of the substrate layers. The spectra are stored in a library. However, unlike the process of FIG. 4 in which only target spectra representing the target thickness are used, the reference spectra in the library represent substrates with a variety of different thicknesses in the outer layer. The measured spectra are then compared to the spectra in the library and one of the spectra in the library is selected as a match.

The spectra are indexed so that each spectrum from the collection of spectra representing a substrate with a particular underlying layer thickness has a unique index value (spectra representing substrates with different underlying layer thicknesses can be associated with the same index value). The indexing is implemented so that the index values are sequenced in an order in which the spectra were measured or are expected to be measured during polishing. An index value can be selected to monotonically increase as polishing progresses, e.g., the index values can be proportional, e.g., linearly proportional, to a number of platen rotations. Thus, each index number can be a whole number, and the index number can represent the expected platen rotation at which the associated spectrum would appear. The library can be implemented in memory of the computing device of the polishing apparatus.

A substrate from the batch of substrates is polished (step 602), and the following steps are performed for each platen revolution. One or more spectra are measured to obtain a current spectra for a current platen revolution (step 604). The spectra stored in the library which best fits the current spectra is determined (step 606). The index of the library spectrum that is the best fit to the current spectrum is determined from the library (step 608), and is appended to an endpoint index trace (step 610). As discussed above, the index can be determined prior to the polishing operation and stored, e.g., as database that relates the spectra to the index, for later access. Endpoint is called when the endpoint trace reaches the index of the target spectrum (step 612).

In some embodiments, the indexes that are matched to each obtained spectrum are plotted according to time or platen rotation. A line is fit to the plotted index numbers using robust line fitting. Where the line meets the target index defines the endpoint time or rotation.

As discussed above, by using multiple reference spectra representing substrates with underlying layers of different thicknesses, the endpoint detection system becomes less sensitive to variations in the underlying layers, and thus reliability of the endpoint system can be improved.

A method that can be applied during the endpointing process is to limit the portion of the library that is searched for matching spectra. The library typically includes a wider range of spectra than will be obtained while polishing a substrate. The wider range accounts for spectra obtained from a thicker starting outermost layer and spectra obtained after overpolishing. During substrate polishing, the library searching is limited to a predetermined range of library spectra. In some embodiments, the current rotational index N of a substrate being polished is determined. N can be determined by searching all of the library spectra. For the spectra obtained during a subsequent rotation, the library is searched within a range of freedom of N. That is, if during one rotation the index number is found to be N, during a subsequent rotation which is X rotations later, where the freedom is Y, the range that will be searched from (N + X) - Y to (N + X) + Y. For example, if at the first polishing rotation of a substrate, the matching index is found to be 8 and the freedom is selected to be 5, for spectra obtained during the second rotation, only spectra corresponding to index numbers 9 ± 5 are examined for a match.

Embodiments of the invention and all of the functional operations described in this specification can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structural means disclosed in this specification and structural equivalents thereof, or in combinations of them. Embodiments of the invention can be implemented as one or more computer program products, i.e., one or more computer programs tangibly embodied in an information carrier, e.g., in a machine-readable storage device or in a propagated signal, for execution by, or to control the operation of, data processing apparatus, e.g., a programmable processor, a computer, or multiple processors or computers. A computer program (also known as a program, software, software application, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file. A program can be stored in a portion of a file that holds other programs or data, in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub-programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application-specific integrated circuit).

The above described polishing apparatus and methods can be applied 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. For example, the platen may orbit rather than rotate. The polishing pad can be a circular (or some other shape) pad secured to the platen. Some aspects of the endpoint detection system may be applicable to linear polishing systems, e.g., where the polishing pad is a continuous or a reel-to-reel belt that moves linearly. The polishing layer can be a standard (for example, polyurethane with or without fillers) polishing material, a soft material, or a fixed-abrasive material. Terms of relative positioning are used; it should be understood that the polishing surface and substrate can be held in a vertical orientation or some other orientation.

Particular embodiments of the invention have been described. Other embodiments are within the scope of the following claims. For example, the actions recited in the claims can be performed in a different order and still achieve desirable results.

What is claimed is:

CLAIMS

1. A computer implemented method comprising:

obtaining at least one current spectrum with an in-situ optical monitoring system, the current spectrum being a spectrum of light reflected from a substrate having an outermost layer undergoing polishing and at least one underlying layer;

comparing the current spectrum to a plurality of different reference spectra, the plurality of reference spectra representing spectra of light reflected from substrates with outermost layers having the same thickness and underlying layers having different thicknesses; and

determining based on the comparing whether a polishing endpoint has been achieved for the substrate having the outermost layer undergoing polishing.

2. The method of claim 1, wherein determining whether the polishing endpoint has been achieved includes calculating differences between the current spectrum and the reference spectra.

3. The method of claim 2, wherein determining whether the polishing endpoint has been achieved includes determining whether at least one of the differences has reached a threshold value.

4. The method of claim 3, wherein the at least one of the differences is a smallest difference from the differences.

5. The method of claim 3, wherein the at least one of the differences is a median difference from of the differences.

6. The method of claim 2, wherein determining whether the polishing endpoint has been achieved includes activating an endpoint detection algorithm when at least one of the differences has reached a threshold value.

7. The method of claim 6, wherein determining whether the polishing endpoint has been achieved includes generating a difference trace that includes multiple points, each point representing a smallest of the differences calculated for a revolution of the platen.

8. The method of claim 7, wherein the endpoint detection algorithm includes determining whether the difference trace has reached a minimum.

9. The method of claim 8, wherein determining whether the difference trace has reached a minimum includes calculating a slope of the difference trace.

10. The method of claim 7, wherein the endpoint detection algorithm includes determining whether the difference trace has risen to a threshold value above the minimum.

11. The method of claim 1, wherein the reference spectra are generated empirically.

12. The method of claim 1, wherein the reference spectra are generated from theory.

13. The method of claim 1, further comprising obtaining a plurality of current spectra at different times.

14. The method of claim 13, wherein the plurality of current spectra include a sequence of current spectra from a plurality of sweeps of the in-situ optical monitoring system across the substrate.

15. The method of claim 13, wherein the plurality of current spectra include a plurality of current spectra from a same sweep of the in-situ optical monitoring system across the substrate.

16. The method of claim 14, further comprising comparing the plurality of current spectra from the same sweep to the plurality of reference spectra to generate a plurality of differences between the current spectra and the reference spectra..

17. The method of claim 15, further comprising, determining a smallest of the plurality of differences and using the smallest of the plurality of differences to determine whether a polishing endpoint has been achieved.

18. A computer program product, encoded on a tangible program carrier, operable to cause data processing apparatus to perform operations comprising:

obtaining at least one current spectrum with an in-situ optical monitoring system, the current spectrum being a spectrum of light reflected from a substrate having an outermost layer undergoing polishing and at least one underlying layer;

comparing the current spectrum to a plurality of different reference spectra, the plurality of reference spectra representing spectra of light reflected from substrates with outermost layers having the same thickness and underlying layers having different thicknesses; and

determining based on the comparing whether a polishing endpoint has been achieved for the substrate having the outermost layer undergoing polishing.

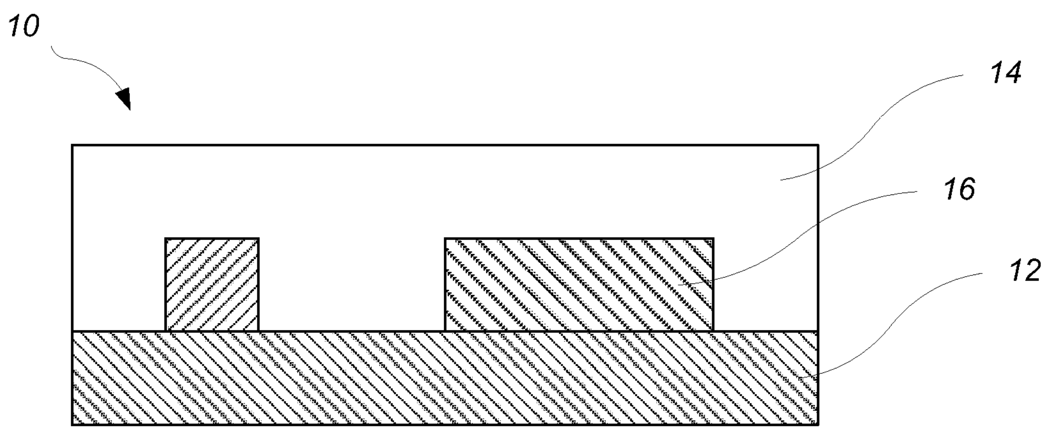


FIG. 1

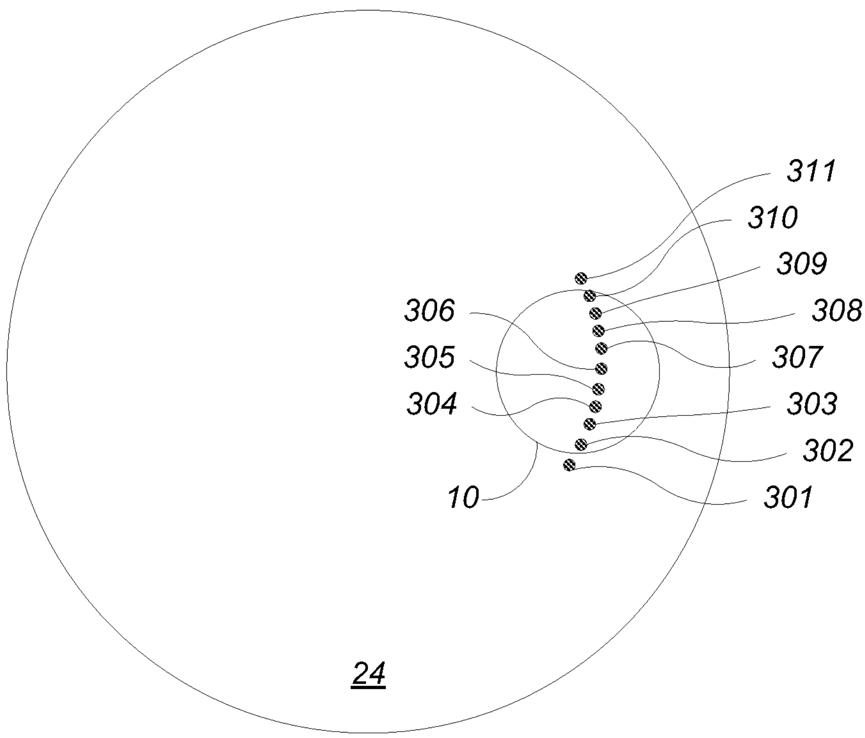


FIG. 3

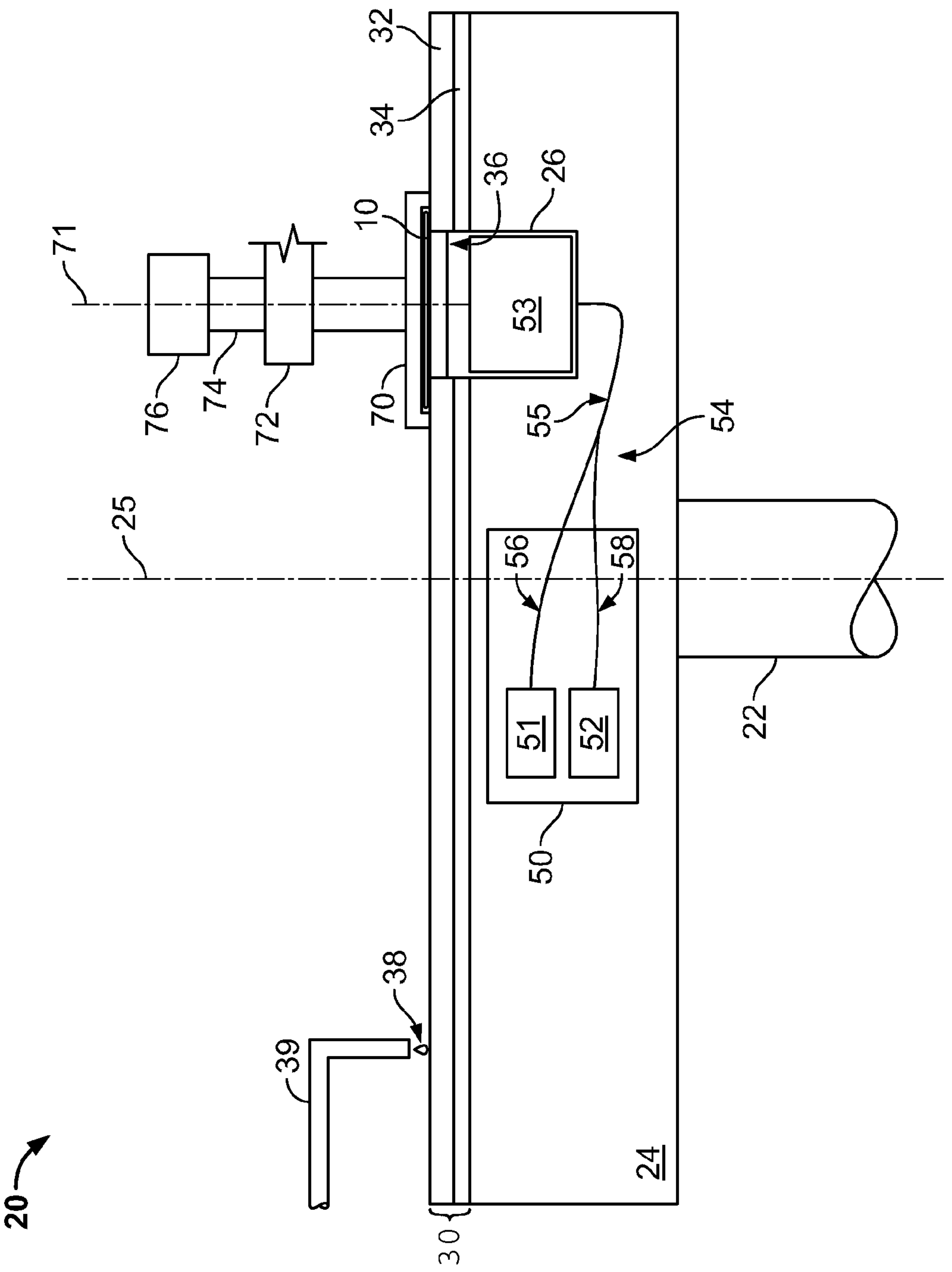

20
71
76
74
72
70
10
36
26
32
34
53
55
54
25
56
58
51
52
50
22
24
38
39
30

FIG. 2

FIG. 4

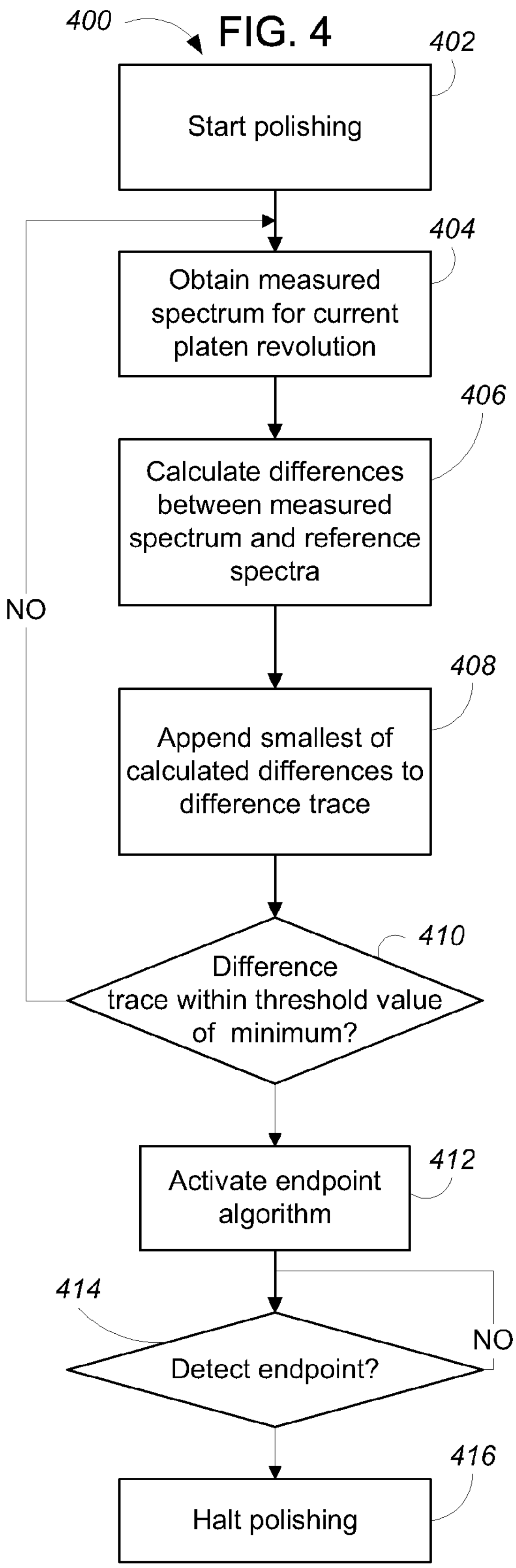
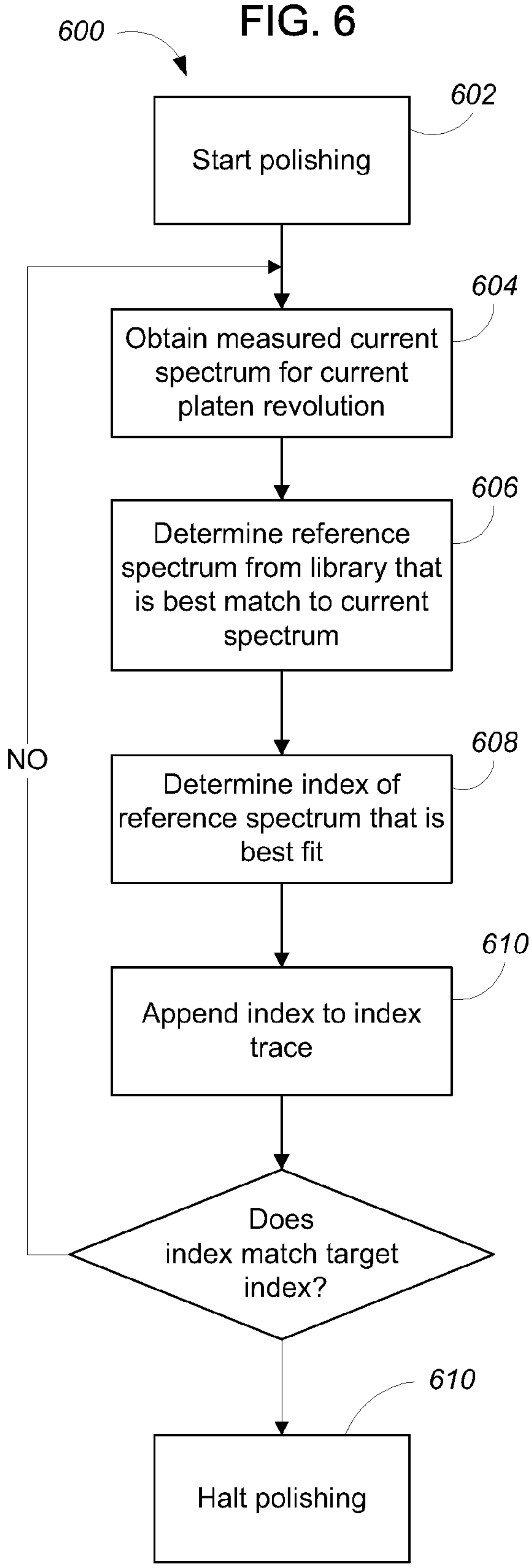

400
402
Start polishing
404
Obtain measured spectrum for current platen revolution
406
Calculate differences between measured spectrum and reference spectra
408
Append smallest of calculated differences to difference trace
410
Difference trace within threshold value of minimum?
NO
412
Activate endpoint algorithm
414
Detect endpoint?
NO
416
Halt polishing

FIG. 6


600
602
Start polishing
604
Obtain measured current spectrum for current platen revolution
606
Determine reference spectrum from library that is best match to current spectrum
608
Determine index of reference spectrum that is best fit
610
Append index to index trace
Does index match target index?
NO
610
Halt polishing

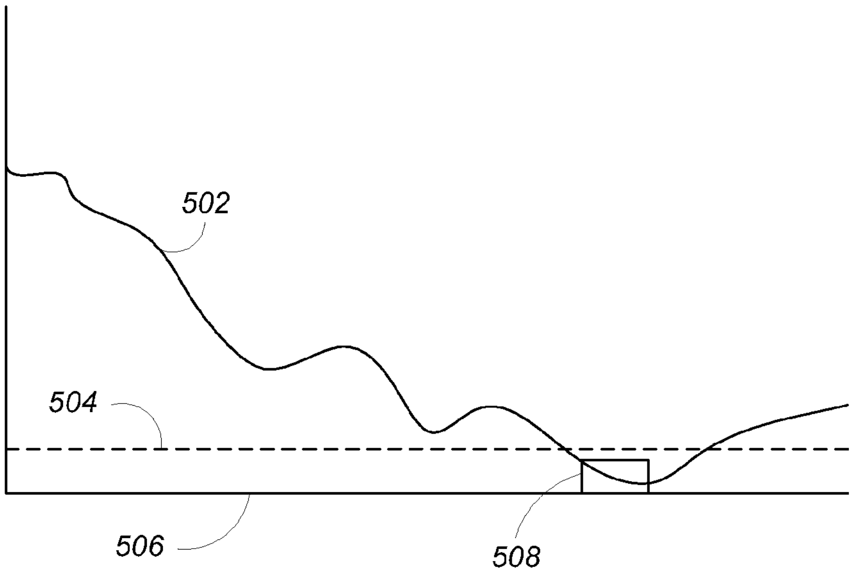


FIG. 5