

METHODS AND APPARATUS FOR THE IN-PROCESS DETECTION OF WORKPIECES

RELATED APPLICATIONS

This application is related to United States patent application number 08/781,132, filed
5 January 9, 1997, entitled "Methods and Apparatus for the In-Process Detection of Workpieces with
a Monochromatic Light Source," which is related to United States patent application number
08/683,150, filed July 18, 1996, entitled "Methods and Apparatus for the In-Process Detection of
Workpieces in a CMP Environment."

TECHNICAL FIELD

10 The present invention relates, generally, to methods and apparatus for detecting the
presence of extraneous objects on a processing element during a chemical mechanical
planarization (CMP) process, and more particularly to an improved technique for detecting the in-
situ, in-process loss or breakage of a semiconductor wafer using reflective optics.

BACKGROUND ART AND TECHNICAL PROBLEMS

15 The production of integrated circuits begins with the creation of high-quality
semiconductor wafers. During the wafer fabrication process, the wafers may undergo multiple
masking, etching, and dielectric and conductor deposition processes. Because of the high precision
required in the production of these integrated circuits, an extremely flat surface is generally needed
on at least one side of the semiconductor wafer to ensure proper accuracy and performance of the
20 microelectronic structures being created on the wafer surface. As the size of integrated circuits
continues to decrease and the number of microstructures per integrated circuit increases, the need
for precise wafer surfaces becomes more important. Therefore, between each processing step, it
is usually necessary to polish or planarize the surface of the wafer to obtain the flattest surface
possible.

25 For a discussion of chemical mechanical planarization (CMP) processes and apparatus, see,
for example, *Arai, et al.*, U.S. Patent No. 4,805,348, issued February, 1989; *Arai, et al.*, U.S.
Patent No. 5,099,614, issued March, 1992; *Karlsrud, et al.*, U.S. Patent No. 5,329,732, issued July,
1994; *Karlsrud et al.*, U.S. Patent No. 5,498,196, issued March, 1996; and *Karlsrud, et al.*, U.S.
Patent No. 5,498,199, issued March, 1996.

30 Such polishing is well known in the art and generally includes attaching one side of the
wafer to a flat surface of a wafer carrier or chuck and pressing the other side of the wafer against
a flat polishing surface. In general, the polishing surface includes a polishing pad that has an
exposed abrasive surface of, for example, cerium oxide, aluminum oxide, fumed/precipitated silica
or other particulate abrasives. Commercially available polishing pads can be formed of various

materials known in the art. Typically, a polishing pad may be formed from a blown polyurethane, such as the IC and GS series of polishing pads available from Rodel Products Corporation in Scottsdale, Arizona. The hardness, density, color, reflectivity, and other characteristics of the polishing pad may vary from application to application, *e.g.*, according to the material that is to be polished.

During the polishing or planarization process, the workpiece or wafer is typically pressed against the polishing pad surface while the pad rotates about its vertical axis. In addition, to improve the polishing effectiveness, the wafer may also be rotated about its vertical axis and oscillated back and forth over the surface of the polishing pad. It is well known that polishing pads tend to wear unevenly during the polishing operation, causing surface irregularities to develop on the pad. To ensure consistent and accurate planarization and polishing of all workpieces, these irregularities must be removed.

During the CMP process, workpieces occasionally become dislodged from the workpiece carrier, or they may break during polishing. If a dislodged workpiece, a part of a broken workpiece, or other extraneous material is allowed to remain on the polishing table, it could contact other workpieces and/or workpiece carriers on the same polishing table and thereby damage or destroy all of the workpieces on the table. Accordingly, it is desirable to detect the presence of a broken or dislodged workpiece immediately and to terminate processing until the situation can be rectified. Typically, this requires a thorough cleaning and/or replacement of the polishing pad, so that workpiece fragments and other debris can be removed so that they do not damage other intact workpieces.

Presently known systems for detecting the loss of workpieces or for detecting broken workpieces are unsatisfactory in several regards. For example, currently known systems may be limited to operation with a small number of similarly colored polishing pads. Such known systems may be ineffective for detecting wafer loss on a dark colored polishing pad or in an environment where the polishing pad may become discolored over time. Present systems may also be inadequate in CMP environments that employ a large amount of polishing slurry and/or polishing slurry having a variety of colors. Furthermore, the presence of slurry, deionized water, iodine (or other CMP compounds) on the pad and on the wafer itself tend to mask the reflected light signal, preventing the signal from being properly detected by the photo detector. Consequently, many presently known workpiece detection schemes often emit "false" readings whereupon machines are shut down and processing halted even though all disks remain intact within their respective carriers.

Therefore, a technique for detecting lost or dislodged workpieces on a CMP polishing pad is thus needed which overcomes the shortcomings of the prior art.

SUMMARY OF THE INVENTION

In accordance with the present invention, methods and apparatus are provided which
5 overcome many of the shortcomings of the prior art.

In accordance with one preferred embodiment, a probe is suitably mounted proximate the upper surface of a CMP polishing table, such that the probe projects a beam of light at the polishing table surface, wherein the beam comprises a narrow band of wavelengths; in a particularly preferred embodiment, a monochromatic light source is employed.

10 In accordance with a further aspect of the present invention, the probe further includes a detector for detecting a portion of the light that is reflected from the polishing table. The detector is configured to apply the reflected signal to a converter which converts the reflected light into an analog electrical signal.

In accordance with a further aspect of the present invention, the output of the converter is
15 applied to a processor that produces an output indicative of the presence of extraneous material on the polishing pad.

An alternate embodiment of the present invention utilizes a substantially broad band light source rather than a monochromatic light source. In this embodiment, the output of the detector is processed by a control algorithm that accurately determines whether a wafer or a wafer fragment
20 is present on the polishing pad by analyzing the reflective characteristics of the detected signal.

In accordance with yet a further aspect of the present invention, if a dislodged or fragmented wafer is detected on the polishing pad, the processor will send a signal to a CMP machine controller, immediately stopping processing of the CMP machine, or at least those processes which could be adversely affected by the lost or fragmented workpiece.

25 The above and other advantages of the present invention may be realized in one form by an apparatus for detecting the presence of a workpiece on a polishing pad during CMP processing. Such an apparatus may include a probe assembly disposed proximate the polishing pad such that the probe establishes intermittent optical communication with the polishing pad as at least one workpiece is processed on the polishing pad, a light source configured to direct an input light
30 signal at a surface of the polishing pad, a receptor configured to capture a portion of the input signal which is scattered from the surface of the polishing pad, a processor configured to process the captured signal and generate an output indicative of the presence or absence of a workpiece on the polishing pad.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

Figure 1 is a perspective view of an exemplary CMP machine useful in the context of the present invention;

Figure 2 is a top view of the CMP machine of **Figure 1**, showing an exemplary orientation
5 of a probe assembly in accordance with the present invention;

Figure 3 is a schematic view of a probe assembly applying an interrogation signal to a polishing pad and capturing a reflected signal therefrom, and further including various processing components for detecting the loss of a wafer based on the reflected signal;

Figure 4 is a schematic view of the configuration of the probe assembly of **Figure 3**
10 directed at a light colored polishing pad;

Figure 5 is a schematic view of the probe configuration of **Figure 4** with a wafer in the field of view of the probe;

Figure 6 is a schematic view of the configuration of the probe assembly of **Figure 3** directed at a dark colored polishing pad;

Figure 7 is a schematic view of the probe assembly of **Figure 6** with a wafer in the field
15 of view of the probe;

Figure 8 is a schematic view of a probe assembly in accordance with an alternate embodiment of the present invention; and

Figure 9 is a schematic representation of an exemplary processing circuit employed by the
20 alternate embodiment shown in **Figure 8**.

DETAILED DESCRIPTION OF PREFERRED EXEMPLARY EMBODIMENT

The subject invention relates to the in-process detection of a dislodged or fractured workpiece on a polishing pad using at least an optical interrogation signal, an optical detector for detecting a reflected signal in response to the interrogation signal, and a processor for analyzing
25 the output of the optical detector to determine if a workpiece is on the pad. The preferred embodiment set forth herein relates to the detection of semiconductor wafers on a chemical mechanical planarization (CMP) polishing pad; it will be appreciated, however, that the principles of the present invention may be employed to detect workpieces or other materials in a variety of processing (*e.g.*, polishing or planarization) environments such as, for example, hard disks and the
30 like.

Referring now to **Figures 1-2**, a wafer polishing apparatus 100 in the form of a CMP system is shown embodying the present invention. Wafer polishing apparatus 100 suitably comprises a wafer polishing machine which accepts wafers from a previous processing step,

polishes and optimally rinses the wafers, and reloads the wafers back into wafer cassettes for subsequent processing.

Discussing now the polishing apparatus 100 in more detail, apparatus 100 includes an unload station 102, a wafer transition station 104, a polishing station 106, and a wafer rinse and load station 108. In accordance with a preferred embodiment of the present invention, one or more of cassettes 110, each holding a plurality of wafers, are placed into the machine at unload station 102. Next, a robotic wafer carrier arm 112 removes the wafers from cassettes 110 and places them, one at a time, on a first wafer transfer arm 114. Wafer transfer arm 114 then lifts and moves the wafer into wafer transition section 104. That is, transfer arm 114 suitably sequentially places an individual wafer on each one of a plurality of wafer pick-up stations 116 which reside on a rotatable table 120 within wafer transition section 104. Rotatable table 120 also suitably includes a plurality of wafer drop-off stations 118 which alternate with pick-up stations 116. After a wafer is deposited on one of the plurality of pick-up stations 116, table 120 will rotate so that a new station 116 aligns with transfer arm 114. Transfer arm 114 then places the next wafer on the new empty pick-up station 116. This process continues until all pick-up stations 116 are filled with wafers. In the preferred embodiment of the invention, table 120 includes five pick-up stations 116 and five drop-off stations 118.

Next, a wafer carrier apparatus 122, having individual wafer carrier elements 124, suitably aligns itself over table 120 so that respective carrier elements 124 are positioned directly above the wafers which reside in respective pick-up stations 116. The carrier apparatus 122 then drops down and picks up the wafers from their respective stations and moves the wafers laterally such that the wafers are positioned above polishing station 106. Once above polishing station 106, carrier apparatus 122 suitably lowers the wafers, which are held by individual elements 124, into operative engagement with a polishing pad 126 disposed upon a lap wheel 128. During operation, lap wheel 128 causes polishing pad 126 to rotate about its vertical axis, for example, in a counter-clockwise direction as shown by arrow 134. At the same time, individual carrier elements 124 spin the wafers about their respective vertical axes and oscillate the wafers back and forth across pad 126 (substantially along arrow 133) as they press against the polishing pad. In this manner, the surface of the wafer will be polished or planarized.

After an appropriate period of processing time, the wafers are removed from polishing pad 126, and carrier apparatus 122 transports the wafers back to transition station 104. Carrier apparatus 122 then lowers individual carrier elements 124 and deposits the wafers onto drop-off stations 118. The wafers are then removed from drop-off stations 118 by a second transfer arm

130. Transfer arm 130 suitably lifts each wafer out of transition station 104 and transfers them into wafer rinse and load station 108. In the load station 108, transfer arm 130 suitably holds each wafer while it is being rinsed. After a thorough rinsing, the wafers are reloaded into cassettes 132, which then transports the wafer to subsequent stations for further processing or packaging.

5 Although CMP machine 100 is shown having five polishing stations, it will be appreciated that the present invention may be employed in the context of virtually any number of polishing stations. Moreover, the present invention may also be employed in circumstances where not all of the polishing stations are functioning at the same time. For example, many standard wafer cassettes carry twenty-four individual workpieces in a single cassette. Consequently, because there
10 are often five workpiece chucks on a single CMP machine, often times the last four disks within a cassette are polished at one time, leaving the fifth disk-holder empty.

 With continued reference to **Figure 2**, a respective probe assembly 129 is suitably configured on wafer carrier apparatus 122 near each carrier element 124. In accordance with a particularly preferred embodiment of the invention, each probe assembly 129 is suitably configured
15 to optically engage at least a portion of the polishing pad surface adjacent each carrier element 124 to detect the presence of extraneous material, such as a loose screw, a wafer, or a wafer fragment on the surface of polishing pad 126 as described in greater detail below in conjunction with **Figures 3 and 8**. In the context of this description, polishing pad 126 is one example of a processing element with which the present invention may be configured to interact.

20 In accordance with a further aspect of the invention, apparatus 100 may suitably comprise a probe 127 configured to measure surface characteristics of wafers being polished by CMP apparatus 100. A detailed description of an analogous probe configuration is disclosed in U.S. Patent Application Serial No. 08/687,710, filed July 26, 1996, and entitled *Methods and Apparatus for the In-Process Measurement of Thin Film Layers*.

25 Referring now to **Figure 3**, an exemplary probe assembly 129 in accordance with the present invention suitably comprises a housing 310 having a bifurcated fiber probe 312, a light source 318, a photodetector 320, an analog to digital (A/D) converter 322, a processor 324, and a CMP controller 326. Exemplary workpieces 306 are shown being held by carrier elements 124 and polished by polishing table 126 as described above in conjunction with **Figures 1 and**
30 **2**. For clarity, the other components of apparatus 100 are omitted from **Figure 3**. Probe assembly 129 is suitably mounted proximate to (and preferably above) polishing table 128 and polishing pad 126 such that housing 310 and probe 312 are directed at the top surface of polishing pad 126. In particular, probe 312 may be mounted under the multi-head transport

assembly (MHTA) which is part of carrier apparatus 122 in an area that will allow the probe to have a field of view which encompasses only a desired portion of the polishing pad.

In accordance with the illustrated embodiment, housing 310 with probe 312 is suitably mounted above and adjacent to each carrier element 124 so that a field of view 313 of each probe 312 is directly in front of the carrier element. That is, if table 128 and pad 126 are rotating counter-clockwise, as shown by arrow 134 (see also Figure 2), probe 312 is configured such that a wafer (or wafer fragment) will enter field of view 313 immediately upon becoming dislodged from the carrier. In this manner, probe assembly 129 will detect a dislodged wafer or wafer fragment as soon as possible and will stop the machine before other wafers can be damaged. Similarly, if table 128 and pad 126 are rotating clockwise, probe 312 will be configured so that field of view 313 is directed to the opposite side of each carrier element 124.

In accordance with an alternate embodiment of the present invention, housing 310 and probe 312 may be angled so that field of view 313 is not substantially perpendicular with pad 126. As discussed below in more detail, housing 310 and probe 312 may advantageously be angled with respect to the pad to achieve optimum readings.

In accordance with a particularly preferred embodiment of the present invention, and with continued reference to Figure 3, probe 312 suitably comprises a transmitter cable 314 through which light is transmitted from light source 318 to probe 312 and onto the top surface of polishing pad 126. Similarly, probe 312 further comprises a receptor cable 316 through which light reflected from the polishing pad and surface is transmitted to photodetector 320. Photodetector 320 receives the reflected light energy and converts it into an analog electrical signal 328 which in turn is converted to a digital signal 330 at A/D converter 322. Processor 324 receives digital signal 330 from converter 322 and analyzes it according to an algorithm (discussed below) to determine if the signal is indicative of wafer or wafer fragments being present on the polishing pad. If a wafer or wafer fragment is detected, processor 324 sends a signal 332 to CMP controller 326 which, in turn, immediately shuts down the machine. It will be appreciated that the top surface of the polishing pad may be sampled by probe assembly 129 at any desired rate or the sampling may be substantially continuous.

In accordance with a further aspect of the present invention, light source 318 suitably comprises any source capable of applying the desired light signal to the surface of the pad. For example, a tungsten halogen light source capable of emitting a broad band light signal, for example in the range of 350 to 2,000 nm, and most preferably in the range of 400 to 850 nm. A suitable halogen light source may comprise a model number L73A98, available from Gilway



Corporation of Massachusetts.

Although cables 314 and 316 suitably comprise fiber optic cables in the preferred embodiment, virtually any conductor may be employed which satisfactorily delivers an interrogation signal (e.g., a light signal) to the workpiece and captures at least a portion of the signal reflected by the workpiece. Similarly, photodetector 320 and A/D converter 322 may suitably comprise virtually any photodetector and A/D converter currently available. In the preferred embodiment, photodetector suitably comprises a model number S2386, available from the Hamamatsu Corporation of Japan. Similarly, in the preferred embodiment, A/D converter 322 suitably comprises a 16 channel, 12 bit, 330 kHz converter configured as a PCMCIA interface with processor 324, such as, for example, model number PCMCIA-16DAS, available from the Mission Peak Optics Company of Fremont, California.

Processor 324 suitably comprises any general purpose controller capable of receiving an output signal 330 from A/D converter 322 and calculating various parameters from signal 326. In the preferred embodiment, processor 324 is suitably configured to interpret signal 330 and thereby determine, based on a predetermined algorithm, if a wafer or wafer fragment is present on polishing pad 126. The algorithm is suitably configured to distinguish between the reflective characteristics of the polishing pad and the workpiece being polished, regardless of the type of polishing pad used or the style of workpiece being polished. Thus, even with the presence of large amounts of slurry and/or deionized water, the processor will be able to detect the presence of a wafer or wafer fragment on the pad. In a particularly preferred embodiment, processor 324 suitably comprises any general purpose personal computer.

Processor 324 is also suitably configured to output signal 332 to CMP controller 326. In the preferred embodiment, signal 332 is a binary signal indicating the presence or absence of a workpiece on the polishing pad. It will be understood, however, that signal 332 may embody any suitable information or characteristics about the polishing pad surface 126 necessary to convey the proper information to the CMP controller 326.

In accordance with the preferred embodiment, if signal 332 indicates that a wafer a fragment has become dislodged from a carrier 124, CMP controller 326 will quickly shut down the motors on the system, stopping processing and ensuring that the other wafers being polished, and the CMP machine itself, are minimally damaged. In a particularly preferred embodiment of the invention, controller 326 may comprise a separate control device connected to the CMP machine's main processor/controller, or controller 326 may be configured as part of the main unit. Further, controller 326 may be configured as part of processor 324. As will

be appreciated by one skilled in the art, controller 326 comprises any type and configuration of controller capable of shutting down the CMP machine.

The operation and configuration of probe assembly 129, and in particular an exemplary method (algorithm) of interpreting the optical signal from probe 312 will now be described in conjunction with Figures 4-7. As briefly discussed above, different types of polishing pads exhibit different reflective characteristics. In particular, CMP polishing apparatus 100 which is discussed in more detail above, may utilize at least two different kinds of pads: a primary polishing pad which generally exhibits a substantially light or white color; and a secondary polishing pad which generally exhibits a much darker color. Because of the difference in pad colors and configurations, the angular placement of probe 312 may vary for each pad. Accordingly, it may be preferable to employ two or more probes on apparatus 100 for each carrier element 124, e.g., one for each different type of pad used. Alternatively, apparatus 100 may include only one probe for each carrier element, such that when the polishing pads are changed, the angular alignment of the probe is also changed accordingly.

Referring now to Figures 4 and 5, the configuration of housing 310 and probe 312 will now be discussed for a primary, light-colored pad. In accordance with the preferred embodiment, housing 310 and probe 312 are suitably disposed at an angle of about 30° to about 60° and preferably about 45° with respect to polishing pad 126. This angle is illustrated as angle A in Figures 4 and 5. Similarly, probe 312 is also suitably disposed about 30° to about 60° and preferably about 45° from the vertical axis of pad 126. This is shown in Figures 4 and 5 as angle A'.

During operation, probe 312 suitably projects a white light down onto polishing pad 126 near carrier element 124 (not shown in Figures 4 and 5). Given the characteristics of the primary, light-colored pad, reflected light 340 will be reflected from the pad in substantially all directions as shown by arrows 340 in Figure 4. In this manner, the receptor sensor of probe 312 will receive some of the reflected light. As a consequence of the pressure of the slurry, deionized water flow ripple, air bubbling, carrier agitation, and long term discoloration of the pad, the energy received by probe 312 is generally about 50% to about 75% of the light energy which would otherwise be received absent these factors. As the pad becomes more discolored, the amount of received light will decrease. Using a light-colored pad, the amount of light received probably will not be reduced by more than 50%.

Referring now to Figure 5, if a wafer or wafer fragment becomes dislodged from a carrier element, at least a portion of the white light radiated from probe 312 will contact the

wafer or wafer fragment, as opposed to the polishing pad. In accordance with this aspect of the invention, because of the distinct reflective properties of the wafer, the light energy will be reflected upwards from the wafer in a more condensed pattern as shown in Figure 5 as light rays 342 substantially defining a cone C-C'. In accordance with this aspect of the invention, cone C-C' is at an angle from the vertical of about 20° - 40°, and preferably about 30° from the perpendicular to wafer 306. Therefore, because probe 312 is oriented at an angle of about 45° from perpendicular (angle A'), the probe will not appreciably detect the light reflected from the wafer. When the processor 324 receives a signal indicating that the light reflected by the wafer is not received by the probe, the processor determines that a wafer or wafer fragment was detected and thus sends a signal to CMP controller 326 to shut off the machine.

Referring now to Figures 6 and 7, the scattering characteristics of the secondary, darker pad will now be discussed. In accordance with this embodiment of the invention, housing 310 and probe 312 are angularly oriented at about 80° - 90° and preferably about 85° from the plane of the pad (angle D), or about 0° - 10° and preferably about 5° from perpendicular to the pad (angle D'). In accordance with this aspect of the invention, white light 343 is directed to the surface of pad 126 near carrier element 124 (not shown in Figures 6 and 7). Because of the dark coloration of the secondary pad, most of the light energy is absorbed so that probe 312 will detect little, if any, scattering. Further, by orienting the probe at an angle of about 5°, the light reflected by the slurry and deionized water will be outside the field of view of the probe, thus ensuring that the probe detects little or no scattering.

Referring now to Figure 7, if a wafer or wafer fragment comes within the field of view of light 343, the light will be reflected back up in an area of about +/- 30° from perpendicular to the wafer (cone C - C') as discussed above. Accordingly, because probe 312 is now angularly oriented at about only 5° from perpendicular, it will receive the scattered light from the wafer. Thus, if processor 324 receives a signal indicating the presence of reflected light, the processor will determine that a wafer is present and send a signal to CMP controller 326 to stop the machine.

It should be noted that the reflective characteristics of the light and dark polishing pads are likely to differ from each other; therefore, as different types of pads are used, the angular orientation of housing 310 and probe 312 may be adjusted accordingly.

Referring now to Figure 8, a schematic representation of probe assembly 129 in accordance with an alternate embodiment of the present invention is illustrated in the context of a typical CMP environment. Rather than utilizing a broad band light source, probe assembly 129

suitably includes an infrared LED emitter 812 configured to emit a substantially monochromatic light beam for use as an interrogation signal 814, a detector 815 configured to receive a reflected signal 816 produced in response to interrogation signal 814, and a converter 818 configured to convert reflected signal 816 into a control signal 820 having an analog voltage associated therewith. It should be appreciated that control signal 820 may be associated with any number of measurable electrical characteristics and that control signal 820 may be a digital representation rather than an analog signal.

In the exemplary alternate embodiment, probe assembly 129 is an integral component that contains at least emitter 812, detector 815, and converter 818 within housing 310. Probe assembly 129 is suitably selected such that emitter 812 is capable of applying the desired light signal to the surface 822 of polishing pad 126. As described above, interrogation signal 814 may be a substantially monochromatic infrared light beam generated by an LED source. One preferred probe assembly 129 is commercially available from Sunx, Ltd. of Japan (currently identified as part number RS-120HF-2-SAS). Those skilled in the art will appreciate that the present invention may utilize any suitable probe assembly 129 capable of producing interrogation signal 814, receiving reflected signal 816, and producing control signal 820.

In accordance with this alternate embodiment of the present invention, and with continued reference to **Figure 8**, emitter 812 suitably directs interrogation signal 814 to an area upon the top surface 822 of polishing pad 126. Reflected signal 816, which may be reflected from polishing pad 126, wafer fragments (or other extraneous material), slurry, or the like, is transmitted to detector 815. Detector 815 receives the reflected light energy, which is subsequently converted by converter 818 into control signal 820. Converter 818 is preferably connected to a processor 826, which is configured to process control signal 820 and to produce an output signal 828 indicative of the presence of extraneous material within a field of view 824 on polishing pad 126. It should be noted that processor 826 may be incorporated into processor 324 (described above in connection with **Figure 3**) or may be a separate component that otherwise cooperates with the CMP machine. As described in more detail below, processor 826 produces output signal 828 when control signal 820 has an analog voltage level between a predetermined range.

As described above, processor 826 indicates the presence of extraneous material proximate the area within field of view 824 when the analog voltage is measured within the predetermined range. Consequently, apparatus 100 refrains from indicating the presence of extraneous material proximate field of view 824 when the analog voltage is not measured within the predetermined range. The voltage range indicative of the presence of extraneous material is preferably

established by performing empirical reflectivity tests for workpieces (*e.g.*, semiconductor wafers) under a variety of operating conditions and environments. The voltage range may also be selected according to the operating specifications of probe 129 or other components of apparatus 100. It should be appreciated that the predetermined range is substantially independent of physical characteristics of polishing pad 126, for example, the color, reflectivity, age, or the like. Furthermore, because the voltage range is associated with the reflectivity of the wafer, the voltage range may also be configured to be substantially independent of physical characteristics of the polishing slurry used during the CMP procedure.

Prior to performing the CMP procedure, a relatively lower voltage range indicative of a first number of polishing pads having a first reflectivity range and a relatively higher voltage range indicative of a second number of polishing pads having a second reflectivity range may be established via similar empirical testing. For example, in accordance with the preferred embodiment of apparatus 100, the predetermined voltage range for wafer detection is approximately 6-8 volts, the voltage range indicative of light colored polishing pads 126 is below approximately 6 volts, and the voltage range indicative of dark colored polishing pads 126 is above approximately 8 volts. The respective voltage ranges are preferably selected such that they do not overlap. Consequently, in practice, the likelihood of false detection is reduced. It should be noted that these exemplary voltage ranges are not intended to limit the scope of the present invention, and that the actual voltage levels may vary from application to application.

Apparatus 100 may incorporate an initial training procedure for establishing the reflectivity characteristics of the current polishing pad 126 prior to the CMP planarization procedure. Such a training procedure may be desirable to compensate for fluctuations in the reflectivity of the polishing pad 126 due to wear, discoloration, or the like. The training (or calibration) procedure may be particularly useful when different polishing pads 126 are employed from time to time. An exemplary training procedure may involve directing a training signal (analogous to interrogation signal 814) at an area of polishing pad 126, *e.g.*, proximate field of view 824. The training procedure is preferably conducted without a wafer coupled to carrier element 124, therefore, a reflected training signal (analogous to reflected signal 816) is produced via reflection from polishing pad 126. Of course, the training procedure may be performed with any desired amount of slurry, water, or other "normal" processing materials present to simulate the intended operating environment.

The reflected training signal is detected by detector 815 and converted into an output test signal (analogous to output signal 820) by converter 818. Subsequently, processor 826, or any

suitable computing device (not shown) may establish the voltage range associated with the output test signal, *i.e.*, the voltage range indicative of the reflectivity of the current polishing pad. The voltage range may be suitably established by performing statistical analyses, *e.g.*, conventional averaging or forecasting algorithms, on a number of individual test measurements or samples.

5 As with the embodiment described above in connection with **Figures 3-7**, if a wafer or wafer fragment is detected, processor 826 preferably sends output signal 828 to CMP controller 326 which, in turn, may immediately shut down the machine. Output signal 828 may alternatively, or additionally, trigger warning devices or control various other components of apparatus 100. Rather than disabling the machine, output signal 828 may suitably adjust an appropriate operating
10 parameter of the system to reduce or eliminate the likelihood of damage. In the preferred embodiment, emitter 812 and detector 815 operate in a substantially continuous manner and processor 826 samples control signal 820 at a suitable sampling rate. Alternatively, top surface 822 of the polishing pad may be sampled by probe assembly 129 and sampled control signals may be subsequently processed by processor 826. In the preferred embodiment, processor 826 samples
15 control signal 820 at a frequency of approximately 1000 samples/second. As described in more detail below, the sampling rate may vary according to the desired detection sensitivity or other application specific parameters.

Processor 826 may include any general purpose controller capable of receiving control signal 820 from converter 818 and producing output signal 828. In the preferred embodiment,
20 processor 826 is suitably configured to interpret control signal 820 and thereby determine whether a wafer or wafer fragment is present on polishing pad 126. Processor 826 is suitably configured to distinguish between the reflective characteristics of polishing pad 126 and extraneous material that may be present upon polishing pad 126, regardless of the type of polishing pad 126 and slurry used or the style of workpiece 306 being polished. Thus, even with the presence of large amounts
25 of slurry and/or deionized water, processor 826 is adapted to detect the presence of a wafer or wafer fragment on polishing pad 126. In a particularly preferred embodiment, processor 826 suitably includes a number of digital processing components (described below).

As described above, processor 826 is also suitably configured to generate output signal 828, which may be fed to CMP controller 326. In the preferred embodiment, output signal 828 is a
30 binary signal indicating the presence or absence of a workpiece (or other extraneous material) on polishing pad 126. It will be understood, however, that output signal 828 may embody any suitable information or characteristics about surface 822 of polishing pad 126 necessary to convey the proper information to CMP controller 326.

With reference to **Figure 9**, an exemplary circuit 900 employed by processor 826 is illustrated as a schematic diagram. Although **Figure 9** depicts two similar processing circuits, those skilled in the art will recognize that processor 826 may incorporate any number of processing circuits depending upon, *inter alia*, the number of probes 129 or the number of emitters 812
5 utilized by apparatus 100. For the sake of clarity and brevity, only one processing circuit will be described herein.

Circuit 900 generally includes at least an analog-to-digital converter (ADC) 902, a voltage monitoring element 904, and an output element 906. Control signal 820 is preferably fed to an analog input 908 associated with ADC 402. In the preferred embodiment, analog input 908 is
10 suitably connected to a calibration circuit 910 configured to calibrate processor 826 such that, when control signal 820 is indicative of extraneous material, an input 912 to ADC 902 is substantially within the predetermined voltage range. In other words, calibration circuit 910 may be suitably adjusted to compensate for variations in the level of control signal 820 produced by the particular probe 129 or small variations in operating parameters due to electrical tolerances of the
15 hardware. As shown in **Figure 9**, calibration circuit 910 may include a network of resistors 914 and/or potentiometers 916 that function as a voltage divider. It should be noted that calibration circuit 910 may be alternatively realized with a variety of electronic components and configured in any number of ways.

The output of calibration circuit 910, *i.e.*, input 912, may be connected to a circuit adapted
20 to control the detection sensitivity of processor 826. In the preferred embodiment, this circuit is realized by a 22 microfarad coupling capacitor 918 connected between input 912 and the analog ground associated with ADC 902. The precise value of coupling capacitor 918 is selected to suitably damp any analog voltage spikes that may be generated by probe 129. For example, control signal 820 may exhibit transient characteristics in response to certain operating conditions, such
25 as a sudden flow or ripple of slurry or water. Coupling capacitor 918 controls the rate of change of input 912 to appropriately reduce the likelihood of false detection of extraneous material on surface 822 of polishing pad 126. Coupling capacitor 918 may be adjustable to enable fine tuning of the detection sensitivity of processor 826.

Input 912, which may be a derivation of control signal 820, is suitably sampled by ADC
30 902 to thereby produce a number of control signal samples (not shown). The analog control signal samples are then converted into corresponding digital words 920 by ADC 902. The preferred embodiment employs an eight-bit ADC 902 commercially available as part number ADC0804LCN, from Texas Instruments. In the preferred embodiment, circuit 900 is configured

such that ADC 902 provides a digital output resolution of approximately 0.5 volts. As shown in **Figure 9**, ADC 902 need not utilize all eight output bits, and digital words 920 are preferably five bits long.

Voltage monitoring element 904 is configured to receive at least one output bit from ADC 902. Element 904 preferably monitors each digital word 920 to determine if the current digital word 920 is indicative of a current control signal sample having a voltage level between the predetermined range associated with the detection of a wafer, a wafer fragment, or other extraneous material. In the preferred embodiment, element 904 is realized by a 74LS11 AND gate suitably coupled to the output of ADC 902. For example, in the preferred configuration that monitors for voltages within the range of 6-8 volts, element 904 includes a first input associated with an output bit representing two volts and a second input associated with an output bit representing four volts. Thus, when the current digital word 920 represents an analog voltage of at least six volts but less than eight volts, the output of element 904 is a logic high. If the current digital word 920 represents an analog voltage less than six volts or greater than eight volts, then the output of element 904 is a logic low. Element 904 may employ additional or alternative components as necessary for the specific application.

The output 922 of voltage monitoring element 904 is preferably connected to the input of output element 906. As described above, output 922 may be a single-bit binary signal. Output element 906 is configured such that output signal 828 (see **Figure 8**) is produced when a predetermined number of consecutive digital words indicate that the respective control signal samples have voltage levels between the predetermined detection range for extraneous material. Accordingly, output element 906 provides a measure of confidence to reduce the likelihood of false detection, *i.e.*, processor 826 produces output signal 828 when a repeatable control signal 820 is measured.

In the exemplary embodiment shown in **Figure 9**, output element 906 employs an eight-bit shift register 924 coupled to a 74LS30 NAND gate 926. Shift register 924, which is commercially available from Texas Instruments as part number 74LS164, operates in a conventional manner such that all eight output bits become logic high only when digital output 922 is logic high for eight consecutive samples. In response to such a state, NAND gate 926, produces a logic low state for output signal 828. Output signal 828 may be coupled to directly to CMP controller 326 or, alternatively, to any suitable circuit (not shown) for further processing.

It should be appreciated that the various logic states may be reversed or altered in a variety of ways known to those familiar with digital processing without departing from the scope of the

present invention. Furthermore, the various components shown in **Figure 9** need not be discrete elements, and the present invention may utilize any number of ICs, ASICs or other semiconductor chips for purposes of circuit 900. Those skilled in the digital signal processing art will also recognize that the functionality of circuit 900 may alternatively be realized with software programming instructions rather than with the hardware implementation shown in **Figure 9**.

The operation and configuration of probe assembly 129, and in particular an exemplary method of interpreting the optical signal from emitter probe 812 will now be described in conjunction with **Figure 8**.

As briefly discussed above, different types of polishing pads 126 exhibit different reflective characteristics. As also described above, probe 129 is desirably positioned at an angle relative to surface 822 of polishing pad 126. Probe 129, and emitter 812 in particular, is positioned such that interrogation signal 814 is directed toward polishing pad 126 at an angle 832 between 10 and 20 degrees, and preferably at an angle of approximately 15 degrees, relative to surface 822. The alignment angle may be selected according to the optical characteristics of polishing pad 126, the extraneous material to be detected, or probe 129 itself. The use of probe 129 enables the present invention to operate consistently under a variety of conditions and with a number of different polishing pads 126 without having to adjust angle 832.

During operation, emitter 812 suitably projects a substantially monochromatic light onto polishing pad 126 near carrier element 124. Given the characteristics of polishing pad 126, reflected signal 816 will be reflected from the pad generally toward detector 815. It should be appreciated that an amount of light may be reflected in various directions not shown in **Figure 8**, and that detector 815 may only receive some of the light reflected from polishing pad 126, as discussed above in connection with **Figure 3**. If a wafer or a wafer fragment becomes dislodged from carrier element 124, at least a portion of interrogation signal 814 radiated from emitter 812 will contact the wafer or wafer fragment, as opposed to polishing pad 126. In accordance with this aspect of the invention, because of the distinct reflective properties of the wafer (relative to polishing pad 126), the amount of light energy contained in reflected signal 816 will be different than the amount reflected from polishing pad 126 alone. When processor 826 receives control signal 820 in response to a reflected signal 816 from a wafer rather than from polishing pad 126, processor generates output signal 828 to CMP controller 326 to shut off the machine or to commence other corrective action.

Although the subject invention is described herein in conjunction with the appended drawing figures, it will be appreciated that the invention is not limited to the specific form shown.

Various modifications in the selection and arrangement of parts, components, and processing steps may be made in the implementation of the invention. For example, although the light sources, controller, emitter, detector, converters, and processors are illustrated in the Figures in schematic form, it will be appreciated that only the probes need be disposed proximate the workpieces and polishing pad; the processor and other components may be disposed remotely from the workpiece as desired. These and other modifications may be made in the design and arrangement of the various components which implement the invention without departing from the spirit and the scope of the invention as set forth in the appended claims.

5

CLAIMS

What is claimed is:

1. An apparatus for detecting the presence of a workpiece on a polishing pad during CMP processing, comprising:
 - 5 a probe assembly disposed proximate said polishing pad associated with the CMP machine, such that said probe establishes intermittent optical communication with said polishing pad as at least one workpiece is processed on said polishing pad;
 - a light source configured to direct an input light signal at a surface of said polishing pad;
 - a receptor configured to capture a portion of said input signal which is scattered from the
 - 10 surface of said polishing pad; and
 - a processor configured to process said captured signal and generate an output indicative of the presence or absence of a workpiece on said polishing pad.
2. The apparatus of claim 1, wherein said signal source comprises a tungsten halogen light source.
- 15 3. The apparatus of claim 1, wherein said processor comprises a photodetector for converting said captured light signal into an analog electrical signal.
4. The apparatus of claim 3, wherein said processor further comprises an analog to digital converter for converting said analog electrical signal to a digital signal.
5. The apparatus of claim 4, wherein said processor further comprises a controller for
- 20 analyzing said digital signal from said analog to digital converter to determine the absence or presence of a workpiece on said polishing pad.
6. The apparatus of claim 1 further comprising a CMP controller operatively connected to said processor, wherein said CMP controller stops the CMP processing upon the indication that a workpiece is present on said polishing pad.
- 25 7. The apparatus of claim 1, wherein said polishing pad is a light colored polishing pad.
8. The apparatus of claim 7, wherein said light source and said receptor are directed at said polishing pad at an angle of about 45° from said polishing pad.
9. The apparatus of claim 1, wherein said polishing pad is a dark colored polishing
- 30 pad.
10. The apparatus of claim 9, wherein said light source and said receptor are directed at said polishing pad at an angle of about 85° from said polishing pad to eliminate a wet surface effect.





11. A method for detecting the presence of a workpiece on a polishing pad during a CMP process, comprising the steps of:

- (a) moving at least one workpiece on a surface of a rotating polishing pad such that said at least one workpiece is polished by said rotating polishing pad;
- 5 (b) disposing a probe above said surface of said polishing pad, such that said probe engages said surface of said polishing pad in a nonconducting manner during the polishing process;
- (c) applying an interrogation signal from said probe to said polishing pad surface;
- (d) capturing a scattered signal from said polishing pad surface; and
- 10 (e) analyzing said scattered signal to thereby obtain a substantially real time data pertaining to the absence or presence of a workpiece on said polishing pad surface.

12. The method according to claim 11, wherein said probe is configured to optically engage said polishing pad surface.

13. The method according to claim 11, wherein said step (b) further comprises directing
15 said probe at said polishing pad surface at an angle of about 45° from said polishing pad surface.

14. The method according to claim 11, wherein said step (b) further comprises directing said probe at said polishing pad surface at an angle of about 85° from said polishing pad surface.

15. The method according to claim 11, wherein step (e) utilizes scattering angle characteristics of surface conditions on said polishing pad to determine the absence or presence
20 of said workpiece on said polishing pad.

16. The method according to claim 15, wherein said wafer on said polishing pad has different scattering angle characteristics than said polishing pad.

17. In a workpiece processing system having a processing element and a carrier element configured to hold a workpiece against said processing element, a method for detecting the
25 presence of extraneous material on said processing element during operation of said workpiece processing system, said method comprising the steps of:

directing an interrogation signal at an area of said processing element proximate said carrier element;

30 detecting a reflected signal produced in response to said interrogation signal;
converting said reflected signal into a control signal;

indicating the presence of said extraneous material proximate said area when said control signal is measured within a predetermined range; and

refraining from indicating the presence of said extraneous material proximate said area





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when said control signal is not measured within said predetermined range.

18. A method according to claim 17, wherein said interrogation signal is generated by a substantially monochromatic light source.

19. A method according to claim 18, wherein said light source is an infrared LED
5 emitter.

20. A method according to claim 17, wherein said indicating step indicates when said workpiece is dislodged from said carrier element and wherein said extraneous material comprises said workpiece.

21. A method according to claim 17, wherein said processing element comprises a
10 polishing pad having a relatively planar polishing surface and said directing step directs said interrogation signal at an angle between 10 and 20 degrees relative to said polishing surface.

22. A method according to claim 17, further comprising the step of adjusting an operating parameter of said workpiece processing system in response to said indicating step.

23. A method according to claim 17, wherein said control signal has an associated
15 analog voltage and said method further comprises the steps of:

establishing a first range for said analog voltage indicative of a first number of processing elements having a first reflectivity range;

establishing said predetermined range for said analog voltage such that said predetermined range is indicative of said extraneous material; and

20 establishing a second range for said analog voltage indicative of a second number of processing elements having a second reflectivity range.

24. A method according to claim 17, wherein said workpiece processing system comprises a chemical mechanical planarization (CMP) system configured to perform a planarization procedure, and said method further comprises the steps of:

25 directing a training signal at said area of said processing element proximate said carrier element prior to said planarization procedure;

detecting a reflected training signal produced in response to said training signal;

converting said reflected training signal into an output test signal having an analog voltage;

and

30 establishing a range for said analog voltage of said output test signal, said range being indicative of the reflectivity of said processing element.

25. In a chemical mechanical planarization (CMP) system having a polishing pad and a carrier element configured to hold a workpiece against said polishing pad, an apparatus for



detecting the presence of extraneous material on said polishing pad during a planarization procedure, said apparatus comprising:

means for generating an interrogation signal for establishing optical communication with an area of said polishing pad proximate said carrier element during said planarization procedure;

5 a detector configured to receive a reflected signal produced in response to said interrogation signal;

means for converting said reflected signal into a control signal having an analog voltage, said means for converting being in communication with said detector; and

a processor connected to said means for converting, said processor being configured to process said control signal and to produce an output indicative of the presence of said extraneous material proximate said area when said analog voltage level is within a predetermined range.

26. An apparatus according to claim 25, wherein said means for generating comprises an infrared LED emitter.

27. An apparatus according to claim 25, wherein said polishing pad has a relatively planar polishing surface and said means for generating is positioned such that said interrogation signal is directed toward said polishing pad at an angle between 10 and 20 degrees relative to said polishing surface.

28. An apparatus according to claim 25, wherein said processor comprises:
an analog-to-digital converter (ADC) configured to sample said control signal to thereby produce a number of control signal samples and to convert said control signal samples into a corresponding number of digital words; and

means for monitoring each of said digital words to determine if a current digital word is indicative of a current control signal sample having a voltage level between said predetermined range.

29. An apparatus according to claim 28, wherein said processor further comprises means for producing said output, said means for producing being configured such that said output is produced when a predetermined number of consecutive ones of said digital words are indicative of control signal samples having said voltage level between said predetermined range.

30. An apparatus according to claim 28, further comprising means for controlling the detection sensitivity of said processor, said means for controlling being connected to an analog input of said ADC.

31. An apparatus according to claim 28 further comprising means for calibrating said processor such that, when said control signal is indicative of said extraneous material, an input to



said ADC is substantially within said predetermined range, wherein said means for calibrating receives said control signal and is connected to an analog input of said ADC.

32. An apparatus according to claim 25, wherein said predetermined range is substantially independent of physical characteristics of said polishing pad.

5 33. An apparatus according to claim 32, wherein said planarization procedure employs a polishing slurry disposed upon said polishing pad and wherein said voltage range is substantially independent of physical characteristics of said polishing slurry.

34. A processor circuit for processing a control signal associated with a reflected signal produced in response to an interrogation signal directed at an area of a processing element utilized
10 in a workpiece processing system, said processor circuit comprising:

an analog-to-digital converter (ADC) configured to sample said control signal to thereby produce a number of control signal samples and to convert said control signal samples into a corresponding number of digital words;

means for monitoring each of said digital words to determine if a current digital word is
15 indicative of a current control signal sample having an electrical characteristic between a predetermined range; and

means for producing an output indicative of the presence of an extraneous material proximate said area when a predetermined number of consecutive ones of said digital words are indicative of control signal samples having said electrical characteristic between said
20 predetermined range.

35. A processor circuit according to claim 34, further comprising means for calibrating said processor circuit such that, when said control signal is indicative of said extraneous material, an input to said ADC is substantially within said predetermined range, wherein said means for calibrating receives said control signal and is connected to an analog input of said ADC.

25 36. A processor circuit according to claim 34, further comprising means for controlling the detection sensitivity of said processor circuit, said means for controlling being connected to an analog input of said ADC.



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