

[0021] In one embodiment, the instrumented substrate 110 includes one or more sensors 111 and support circuitry. The support circuitry may include, but is not limited to, one or more processors (e.g., microprocessor), memory 114, communication circuitry 116 and/or a power supply circuitry 118. FIG. 1C illustrates a simplified schematic view of the instrumented substrate 110, in accordance with one embodiment of the present disclosure. In one embodiment, as shown in FIG. 1C, the one or more sensors 111 and support circuitry of the instrumented substrate 110 are disposed on the surface of the substrate 110. In another embodiment, the one or more sensors 111 and the support circuitry of the instrumented substrate 110 are disposed within the substrate 110 (e.g., disposed within a cavity of the substrate 110).

[0022] The one or more sensors 111 of the instrument substrate 110 may include any sensor known in the art suitable for measuring one or more conditions of the instrumented substrate 110 as it passes through a semiconductor automation system. In one embodiment, the one or more sensors 111 include one or more motion sensors. For example, the one or more sensors 111 may include, but are not limited to, a triaxial accelerometer, magnetometer, and/or gyroscope. In another embodiment, the one or more sensors 111 include one or more additional sensors. For example, the one or more sensors 111 include, but are not limited to, a sensor for measuring contamination levels, a humidity sensor for measuring humidity, a gas sensor for measuring the presence of selected gases, a chemical sensor for measuring the presence of selected compounds/chemicals, a temperature sensor for measuring temperature, a pressure sensor for measuring pressure and/or an audio sensor for measuring sound levels. It is noted that the list of sensors provided above is not limiting and is provided merely for illustrative purposes.

[0023] Referring again to FIG. 1B, in one embodiment, the one or more sealable containers 120 include one or more processors 122, memory 124, communication circuitry 126, one or more sensors 121 and/or power supply circuitry 128. As noted previously herein, the one or more processors 122, memory 124, communication circuitry 126, one or more sensors 121 and/or power supply circuitry 128 of the one or more sealable containers 120 may be used to expand the capabilities of the one or

more instrumented substrates 110. In another embodiment, the server 130 includes one or more processors 132, memory 134 and communication circuitry 136.

[0024] The one or more sensors 121 of the sealable container 120 may serve to measure and monitor various conditions of the sealable container 120 and/or the instrumented wafer 110 contained within the sealable container 120. For example, the one or more sensors 121 of the sealable container 120 measure motion (e.g., acceleration, rotational velocity, and the like) associated with the transport of the sealable container 120, which allows the system 100 to locate the sealable container 120 and the instrumented substrate 110 in a semiconductor fabrication automation system.

[0025] The one or more sensors 121 of the sealable container 120 may include any sensor known in the art suitable for measuring one or more conditions within the sealable container 120 as it passes through a semiconductor automation system. In one embodiment, the one or more sensors 121 include one or more motion sensors. For example, the one or more sensors 121 may include, but are not limited to, a triaxial accelerometer, magnetometer, and/or gyroscope. In another embodiment, the one or more sensors 121 include one or more additional sensors. For example, the one or more sensors 121 include, but are not limited to, a sensor for measuring contamination levels, a humidity sensor for measuring humidity, a gas sensor for measuring the presence of selected gases, a chemical sensor for measuring the presence of selected compounds/chemicals, a temperature sensor for measuring temperature, a pressure sensor for measuring pressure and/or an audio sensor for measuring sound levels. It is noted that the list of sensors provided above is not limiting and is provided merely for illustrative purposes.

[0026] The one or more processors 112, 122 and 132 of the instrumented substrate 110, the sealable container 120 and/or the server 130 may include any one or more processing elements known in the art. In this sense, the one or more processors may include any microprocessor-type device configured to execute software algorithms and/or program instructions. It should be recognized that the data processing steps described throughout the present disclosure may be carried out by anyone of the

processors 112, 122 and 132. In general, the term “processor” may be broadly defined to encompass any device having one or more processing or logic elements, which execute program instructions from a non-transitory memory medium (e.g., memory 114, 124 and/or 134). Moreover, different subsystems of the system 100 may include processor or logic elements suitable for carrying out at least a portion of the steps described throughout the present disclosure. Therefore, the above description should not be interpreted as a limitation on the present invention but merely an illustration.

[0027] The memory 114, 124 and 134 of the instrumented substrate 110, the sealable container 120 and the server 130 may include any data storage medium known in the art suitable for storing program instructions executable by the associated one or more processors. For example, the memory 114, 124 and/or 134 may include a non-transitory memory medium. For instance, the memory may include, but is not limited to, a read-only memory, a random access memory, a magnetic or optical memory device (e.g., disk), a magnetic tape, a solid state drive and the like. In another embodiment, it is noted herein that the memory is configured to store one or more results from the system 100 and/or the output of the various steps described herein. In another embodiment, the memory 114, 124 and/or 134 store the program instructions for causing the one or more associated processors to carry out various data processing steps described through the present disclosure.

[0028] In one embodiment, a communication link is established between the communication circuitry 116 of the instrumented substrate 110 and the communication circuitry 126 of sealable container 120. For example, one or more data signals 117 indicative of the one or more conditions measured by the one or more sensors 111 of the instrumented substrate 110 are transmitted via substrate communication circuitry 116 to the container communication circuitry 126. The sealable container 120 may then transfer one or more additional data signals 127 indicative of the sensor data having been stored in the container 120 to the server 130 via the communication link between container communication circuitry 126 and server communication circuitry 136.

[0029] In one embodiment, the communication link between the instrumented wafer 110 and the sealable container 120 is established via a wireless connection. Any

or more conditions of the sealable container 120 with the container sensors 121, the sealable container 120 may then transfer one or more additional data signals acquired from the sealable container sensors 121 to the server 130 via container communication circuitry 126.

[0037] Referring again to FIG. 1B, in one embodiment, the instrumented substrate 110 includes power supply circuitry 118. The power supply circuitry 118 may supply power to the one or more sensors 111 and support circuitry (e.g., one or more processors 112, memory 114 and/or communication circuitry 116) of the instrumented substrate 110. In one embodiment, the power supply circuitry 118 includes one or more rechargeable batteries. In another embodiment, the power supply circuitry 118 includes one or more replaceable batteries. In another embodiment, in the case of a rechargeable battery, the instrumented wafer 110 may include a wireless battery charger, whereby the wireless battery charger receives energy remotely from an external source and then, in turn, charges the one or more rechargeable batteries.

[0038] In another embodiment, the sealable container 120 includes power supply circuitry 128. The power supply circuitry 128 of the sealable container 120 may supply power to the instrumented wafer 110 contained within the sealable container (see FIG. 1D). As described in greater detail further herein, electrical energy may be transferred from a power source of the sealable container 120 via a direct connection (e.g., copper wire) or by inductive coupling. In one embodiment, the power supply circuitry 128 of the sealable container 120 includes one or more replaceable batteries. In one embodiment, the power supply circuitry 128 of the sealable container 120 includes one or more rechargeable batteries.

[0039] FIG. 1E illustrates a schematic view 150 of a recharging station 152 for recharging one or more rechargeable batteries of the sealable container 120. In one embodiment, the recharging station 152 wirelessly supplies electrical power to the sealable container 120. In another embodiment, in the case where the sealable container 120 includes one or more rechargeable batteries, the sealable container 120 includes a wireless battery charger, whereby the wireless battery charger receives energy remotely from the charging station 152 and then, in turn, charges the one or

more rechargeable batteries of the sealable container 120. For example, the sealable container 120 may include one or more RF receiving coils (not shown), whereby the energy is inductively transferred from one or more RF transmission coils of the charging station 152 and then, in turn, energy collected by the one or more RF receiving coils charges the one or more rechargeable batteries of the sealable container 120.

[0040] The system 100 may include any number of charging stations 152 and may be located at any position throughout the semiconductor automation system. For example, one or more charging stations 152 may be located at or near any OHT accessible location (e.g., stockers, buffers, under-track storage, load-ports and etc.). In another embodiment, the charging station 152 is equipped with communication circuitry (not shown in FIG. 1E). For example, the communication circuitry of the charging station may transfer sensor data from the memory 124 of the sealable container 120 or the memory of the instrumented substrate 110 via communication circuitry 126 or 116 respectively. Further, the datalink established between the communication circuitry 126 of the sealable container 120 and/or the communication circuitry 116 of the instrumented substrate 110 may be established via a wireless (e.g., WIFI, BLUETOOTH and the like) or transmission line (e.g., TCP/IP or fiberline) connection.

[0041] FIG. 1F illustrates a simplified schematic view 160 of the instrumented wafer 110 equipped with a wireless charger 162 and one or more rechargeable batteries 163 electrically coupled to the wireless charger 162. For example, the wireless battery charger 162 may include one or more RF coils 167, which may inductively receive energy from an external power transfer device or devices. In turn, electrical energy may be transferred to one or more rechargeable batteries 163, which then power the other various electronic components of the instrumented substrate 110.

[0042] FIG. 1G illustrates a simplified schematic view 161 of an external power transfer device 165 suitable for transferring power to one or more RF receiving coils 167 of the instrumented substrate 110. In one embodiment, the external power transfer device 165 includes a set of RF transmission coils 164, which serve to inductively transfer power from the external power transfer device 165 to the RF receiving coil 167 of the wireless battery charger 162 of the instrumented wafer 110.

[0054] FIG. 2 illustrates graph 200 depicting sensor data measured with the one or more sensors 111 of the instrumented substrate 110 used to perform a teach sequence, in accordance with one embodiment of the present disclosure. Graph 200 illustrates acceleration (measured with one or more motion sensors of the one or more sensors 111) as a function of time for tracking vibration experienced by the instrumented substrate 110 and, thus, product substrates.

[0055] In one embodiment, after the sensor data is acquired from the one or more sensors 111, the system 100 can display, via user interface 135, the sensor data along with other system information to enable a user to identify physical locations and critical activities. For example, one or more critical activities may include, but are not limited to, picking up the substrate 110 from the sealable container 120 by a robotic end effector. By way of another example, one or more critical activities may include, but are not limited to, placing the substrate 110 on a measurement stage. This and like information may be captured during the teach cycle and stored as teach data.

[0056] It is noted that the substrate 110 takes a physical path as it is moved through the equipment of semiconductor automation system and gather condition/parameter data associated with the movement (and other physical conditions) of the substrate via the one or more sensors 111. In one embodiment, the collected motion data (e.g., acceleration, time and/or gyroscope data) may be used to mathematically reconstruct the motion of the instrumented substrate 110. In another embodiment, the collected motion data (e.g., acceleration, time and/or gyroscope data) may be used to mathematically reconstruct the physical path of the instrumented substrate 110 through the semiconductor automation system. In turn, the constructed path may be displayed on the display of the user interface 135. In another embodiment, the areas along the constructed path may be labeled by the user, thereby providing geographical context for the location. In another embodiment, the motion of the instrumented substrate 110 may be labeled by the user, thereby providing mechanical context for the motion. It is noted that the understanding of the mechanical context of the motion of the instrumented substrate 110 aids in identifying various mechanism failures along the semiconductor fabrication automation system.

[0057] For example, as shown in FIG. 2, in the case of placement of a substrate onto an aligner, the user may label or tag this location as "ALIGNER." It is noted that a substrate aligner (e.g., semiconductor wafer aligner) acts to spin the substrate at high speed about an axis. The labeling of this area as ALIGNER allows for this area to be meaningfully noted in future events occurring at this location, compared with other similar aligners on other equipment, or compared to a theoretical model of how such an aligner should perform. It is noted that any number of areas along the constructed path may be labeled by the user. Additional areas include, but are not limited to, one or more sealable container or one or more substrate stages, which may be labeled as FOUP or STAGE respectively, as shown in FIG. 2.

[0058] In another embodiment, program instructions executed by the one or more processors 132 of server 130 may analyze the sensor data to observe changes in the state of the instrumented substrate 110, such as, but not limited to, directional changes registered by the one or more sensors 111 (e.g., accelerometer and/or gyroscope). In another embodiment, these changes in state can be automatically selected and highlighted by the server 130. In turn, the server 132 may transmit a request to label these changes of state to a user via the user interface 135. A series of potential changes of state are depicted in FIG. 2 and are labeled as 202, 204, 206, 208, 210, 212, 214, 216 and 218. These points correspond to different changes of state as the substrate 110 is removed from the sealable container, aligned, processed by the given process tool and then placed back into the sealable container 120. As shown in FIG. 2, point 202 corresponds to the substrate 110 being picked from the sealable container 120 (FOUP). Point 204 corresponds to the placement of the substrate 110 on the aligner. Point 206 corresponds to the start of the alignment of the substrate 110. Point 208 corresponds to the substrate 110 being picked from the aligner. Point 210 corresponds to the placement of the substrate 110 onto a stage. Point 212 corresponds to the execution of a process recipe. Point 214 corresponds to the substrate 110 being picked from the stage. Point 216 corresponds to the placement of the substrate 110 back into the sealable container 120.

[0059] It is noted herein that regular monitoring generates data streams which can be compared to the stored baseline either in real-time or offline. Additional data such as the physical location of the substrate 110 may be determined by sensors 111 and/or 121, such as gyroscope and accelerometer, and may be used to segment the new data and compare each segment with the corresponding segment from the known good baseline data. In another embodiment, the sensor data may be compared to one or more waveforms to identify the behavior of the given segment. For example, the measured sensor data may be compared to one or more simulated waveforms to identify the behavior of the given segment. By way of another example, the measured sensor data may be compared to a waveform from the sensors 111 and/or 121 when the instrument substrate 110 and/or sealable container 120 are in a proper or accepted operating state. By way of another example, the measured sensor data may be compared to a waveform obtained with sensors 111 and/or 121 when the instrument substrate 110 and/or sealable container 120 in an unacceptable operating state. In this regard, a waveform library may be generated, whereby the system 100 may collect waveforms from sensors 111 and/or 121 for various expected problems. In another embodiment, the segment may be compared to a set of segments of similar type across a number of pieces of equipment. For example, the waveform associated with an aligner may be compared to all (or a portion of) aligners in the semiconductor factory. In another embodiment, the data may be processed and the results compared to pre-selected thresholds (e.g., maximum deviations) or other markers derived from the sensor data.

[0060] Based on the information provided by the teach data, the implications of any deviation between the baseline and a later measurement can be interpreted to determine if there is a problem with one or more portions of the semiconductor automation system. It is further noted that the one or more processors 132 may identify possible errors in the handling of the substrate 110 as it moves from location to location. For example, point 218 in FIG. 2 may correspond to an error or problem when the substrate 110 was transferred to the stage. Once a deviation or possible problem has been identified the context data enables analysis to determine a likely root cause or causes of the given deviation. As the system is utilized new root causes may be

the instrumented substrates 110 appear to be standard metrology equipment in the factory system. It is noted that standard equipment may communicate with the factory system controller 140 (e.g., one or more MES servers 140) according to a selected communications protocol. For example, the selected communications protocol may include an industry standard communications protocol consistent with standards defined by the Semiconductor Equipment and Materials Institute (SEMI). These standards are referred to as SEMI Equipment Communications Standards (SECS) and Generic Equipment Model (GEM).

[0063] In one embodiment, the one or more servers 130 of system 100 may connect to the system controller (e.g., MES) and interact with the system controller 140 as if it were measurement equipment. The server 130, which is integrated with the automated metrology station 302, may interface with the instrumented wafer 110 and/or the FOUP 120 to establish the parameters of a measurement mission and gather the results. Once the results are gathered by the server, the FOUP 120 or the instrumented wafer 110 may determine that an exception case has occurred. This exception may be reported to the system controller 140 (e.g., MES) as a warning or as an alarm. In another embodiment, the system server 130 may directly communicate with other factory systems and users via methods such as, but not limited to, web-based graphical user interfaces, mobile devices, text messages, or emails.

[0064] FIG. 4 illustrates a process flow diagram 400 depicting a set of steps 400 carried out by the system 100 when monitoring a target tool 304 of a semiconductor factory, in accordance with one embodiment of the present disclosure. In step 402, the instrumented wafer 110 and the FOUP 120 are prepared for a mission by the server 130 of station 302. For example, a measurement recipe may be loaded onto the instrumented wafer 110. It is noted that the server 130 may act as a proxy measurement instrument in the semiconductor factory 300 for all the metrology instruments gathering data.

[0065] In step 404, the FOUP 120 is transferred from the station 302 to the target tool 304. For example, the OHT 306 may pick the FOUP 120 from the station 302 and transport the FOUP 120 to the target tool 304 (e.g., etcher). In step 406, the product

wafers contained in the FOUP 120 are processed by the target tool 304. For example, in the case of an etcher, the etcher may apply a selected etcher recipe (e.g., Etcher PM recipe). In step 408, while the target tool 304 processes the product wafers, the instrumented wafer 110 measures one or more conditions of the instrumented wafer 110. For example, the instrumented wafer 110 may measure one or more conditions of the instrumented wafer 110 via sensors 111 (shown in FIG. 1B). Further, the FOUP 120 may measure one or more conditions of the FOUP 120 or the wafer 111 via sensors 121 (shown in FIG. 1B). In step 410, the measured sensor data of step 408 is transmitted to the server 130. For example, the measured sensor data may be transferred from the instrumented wafer 110 to the FOUP 120. In turn, the FOUP 120 may transfer the measured sensor data to the server 130. By way of another example, the measured sensor data may be transferred directly from the instrumented wafer 110 to the server 130. In addition, the measurement context may be provided with the sensor data. For example, in the case of an etcher, the sensor data may be correlated on the server 130 with Etcher 1 using Etcher PM recipe. The server can use these tags and the parameters of a stored recipe to compare the resulting data to baseline or other data.

[0066] In step 412, it is determined if additional tools are to be measured in the mission. In the case where additional tools should be measured, the process 400 moves back to step 404 and steps 404-412 are repeated. For example, following measurement of the first target tool 304 (e.g., first etcher), the OHT 306 may transport the FOUP 120 to a second target tool (e.g., second etcher). It is further noted that a batch of one or more instrumented wafers 110 may be issued as a "lot" to follow this test process, thereby triggering measurement of the two target tools (e.g., etchers) and interpretation of the data.

[0067] In step 414, the FOUP 120 is transferred back to the station 302. In step 416, the FOUP 120 may transfer sensor data from the FOUP 120 to the station 302. For example, the FOUP 120 may transfer sensor data from the FOUP 120 to the server 130 of station 302. In step 418, the station 302 analyzes the sensor data received from the FOUP 120. For example, the server 130 of station 302 analyzes the sensor data

received from the FOUP 120. For instance, any of the analysis techniques described previously herein may be used to analyze the sensor data. In step 420, the station 302 transfers the analyzed data to the system controller 140. For example, the server 130 of station 302 may transfer the analyzed data to the system controller 140. In the event the analysis of the sensor data identifies a problem, then an alarm or warning message may be sent to the host, independent of the mission and job. Further, the text of the alarm may identify the location of the problem, indicator of detected symptoms, and an estimate of the root cause. For example, a textual report, such as that depicted in FIG. 4B may be provided to a user via user interface 135.

[0068] It is noted herein that some components of the semiconductor factory 300 may be better analyzed by a segment-type analysis. For example, the transport components (e.g., OHT) that transport material around the factory may be measured and the vibration data and/or other data may be analyzed with the computed physical location data based on motion sensor data (e.g., accelerometer data, magnetometer data and gyroscope data). Deviations that can be identified as systemic track problems may be physically located using the sensor data. In addition, deviations that follow the transport component may also be identified. It is noted herein that basic moves, such as left, right straight, hoist up and hoist down, may be categorized accordingly and analyzed by comparing the measured sensor data to a baseline or set point for that type of segment.

[0069] All of the methods described herein may include storing results of one or more steps of the method embodiments in the memory. The results may include any of the results described herein and may be stored in any manner known in the art. The storage medium may include any storage medium described herein or any other suitable storage medium known in the art. After the results have been stored, the results can be accessed in the storage medium and used by any of the method or system embodiments described herein, formatted for display to a user, used by another software module, method, or system, etc. Furthermore, the results may be stored "permanently," "semi-permanently," temporarily, or for some period of time. For example, the storage medium may be random access memory (RAM), and the results may not necessarily persist indefinitely in the storage medium.