METHODS AND APPARATUS TO PREDICT ETCH RATE UNIFORMITY FOR QUALIFICATION OF A PLASMA CHAMBER

BACKGROUND OF THE INVENTION

[Para 1] Advances in plasma processing have provided for growth in the semiconductor industry. In today's competitive market, the ability to minimize waste and produce high quality semiconductor devices gives the device manufacturer a competitive edge. Accordingly, tight control of the processing environment is generally needed to achieve satisfactory results during substrate processing.

[Para 2] Those skilled in the art are aware that the condition of a processing chamber may affect the quality of the semiconductor devices being produced. Accordingly, the ability to accurately qualify a processing chamber may reduce the cost of ownership of the processing tool and reduce waste. In an example, by accurately qualifying a processing chamber, a recipe may be adjusted to account for the chamber condition. In another example, by accurately qualifying a processing chamber, the processing chamber may be maintained in good working condition, thereby extending the life of the chamber and reducing the potential for waste. As discussed herein, the term "qualify a processing chamber" refers to the process of identifying the condition of a processing chamber and or/ the steps required to bring the chamber into compliance.

[Para 3] A metrology method may be employed to qualify a processing chamber. With a metrology method, an actual metrology tool may be employed to take measurements such as film thicknesses or critical dimensions (CDs) of a substrate. An example of a commercially available instrument that can make such measurements is an ASET-F5x thin film metrology system from KLA-Tencor Corporation. The measurements may be performed before and after the substrate is processed. After the measurement data have been collected, the etch rates and/or CD bias values for a substrate may be determined. From the spatial map of measured etch rates and/or CD bias values, uniformity may be calculated. As discussed herein, uniformity may be calculated by taking the standard deviation of the etch rates and/or CD bias values.

[Para 4] Although the metrology method may provide an accurate method for qualifying a processing chamber, the metrology method can be an expensive and time-consuming procedure. In an example, the task of measuring the CD bias of just a single substrate may take up to one hour. As a result, most measurements may be taken after a substrate lot has

been processed instead of between substrates. For this reason, an entire substrate lot may be damaged before a problem may be identified.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[Para 5] The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

[Para 6] Fig. 1 shows a simple flow chart illustrating a method for constructing a predictive etch rate model for qualifying a processing chamber.

[Para 7] Fig. 2, shows in an embodiment of the invention, a generic overview of a method for constructing a subsystem health check (SSHC) predictive model for qualifying a processing chamber.

[Para 8] Fig. 3 shows, in an embodiment of the invention, one implementation for constructing an SSHC predictive model.

[Para 9] Fig. 4A shows a polar scan of a substrate.

[Para 10] Fig. 4B shows, in an embodiment of the invention, a simple diagram illustrating etch rate uniformity using concentric circles to partition the substrates measurement points.

[Para 11] Fig. 5 shows, in an embodiment, a simple flow chart illustrating a method for applying an SSHC predictive model for qualifying a processing chamber.

DETAILED DESCRIPTION OF EMBODIMENTS

[Para 12] The present invention will now be described in detail with reference to a few embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention.

[Para 13] Various embodiments are described hereinbelow, including methods and techniques. It should be kept in mind that the invention might also cover articles of manufacture that includes a computer readable medium on which computer-readable instructions for carrying out embodiments of the inventive technique are stored. The computer readable medium may include, for example, semiconductor, magnetic, opto-magnetic, optical, or other forms of computer readable medium for storing computer readable code. Further, the invention may also cover apparatuses for practicing embodiments of the

invention. Such apparatus may include circuits, dedicated and/or programmable, to carry out tasks pertaining to embodiments of the invention. Examples of such apparatus include a general-purpose computer and/or a dedicated computing device when appropriately programmed and may include a combination of a computer/computing device and dedicated/programmable circuits adapted for the various tasks pertaining to embodiments of the invention.

[Para 14] A virtual metrology method may be employed to qualify a processing chamber. The current virtual metrology method may be based on a predictive model for a specific processing chamber. To construct a predictive model, data collected during processing of a set of film substrates may be correlated against a set of on-wafer measurements such as the spatial maps of etch rates and/or CD bias data that may be calculated based on pre and post-processing measurement data for the same set of film substrates.

[Para 15] To facilitate discussion, Fig. 1 shows a simple flow chart illustrating a method for constructing a predictive etch rate model for qualifying a processing chamber.

[Para 16] At a first step 100, the process of constructing a predictive model is initiated. The predictive model can begin at any stage during a wet clean cycle.

[Para 17] At a next step 102, pre-processing measurement data is acquired for a set of substrates. In order to construct a predictive model, a set of test substrates is employed. The set of test substrates is usually a set of film substrates or SensArray wafers. Usually, a film substrate is a non-patterned substrate with a film layer. Before processing the set of substrates, pre-processing measurement data for a set of data points on each film substrate is acquired. In an example, the thickness of each film substrate is measured.

[Para 18] At a next step 104, the set of film wafers is processed. Instead of using the actual recipe used to process product wafers, a modified version of the recipe may be employed. The modified recipe may be a simpler version of the production recipe and may exhibit the same etch behavior as the production recipe. During the process, a set of sensors (such as optical emission sensor, pressure measurement sensor, temperature measurement sensor, gas measurement sensor, and the like) is employed to capture processing data.

[Para 19] After substrate processing has ended, at a next step 106, post-processing measurement data is acquired for the processed test substrates.

[Para 20] At a next step 108, the difference between the pre and post-processing measurement data (etch depth) for each data point may be calculated and an average etch rate may be determined for each film substrate.

[Para 21] At a next step 110, a predictive model is constructed. The predictive model may be based on the measured spatial maps of etch rates and the processing data collected by the sensors. In an example, the calculated average etch rates are set as target etch rate values in the predictive model. The processed data is then correlated against the target etch rate values to construct a predictive model. However, even after a predicted model has been constructed, the predictive model may still required constant updates. Updates may occur due to changing conditions of the processing chamber during the course of a scheduled maintenance cycle.

[Para 22] In an example, drift may occur due to changing chamber conditions, deposition on the sensors, and the like. In order to account for the drift, the predictive model may be normalized based on a given set of known drift values. In an example, after a wet clean, the processing chamber may be at an ideal state in which no drift has occurred. However, after a few weeks of substrate processing, the gas distribution subsystem may have experienced a few percent drift. To account for the drift, the predictive model may be adjusted accordingly.

[Para 23] In another example, as part of a wet clean, the chamber wall may have been cleaned and scrubbed and the corroded hardware parts may have been replaced. If the predictive model has been originally constructed when the processing chamber "is not clean," the predictive model may have to be adjusted to account for the "new" chamber condition.

[Para 24] Due to the changing chamber condition, a compensatory or moving window model may be provided (step 112) to update the predictive model. In other words, steps 102 – 108 may be repeated on a new set of film substrates. The results from the new test run may then be utilized to update the predictive model.

[Para 25] Although a predictive model may be constructed from a virtual metrology method, there are several limitations to the current virtual metrology method.

[Para 26] First, the current virtual metrology method does not provide an accurate method for qualifying a processing chamber since uniformity can not be determined from the predictive model. Even if the predictive model can accurately predict the average etch rate and/or CD bias for a substrate, the number as provided by the predictive model is still only an average number. Those skilled in the art are aware that the actual etch rates and/or CD bias values may vary across the surface of the substrate. For this reason, the average etch rate, for example, may not represent the actual etch rate values across the surface of the substrate. Thus, uniformity can not be determined. As a result, the predictive model may not always accurately qualify the processing chamber.

[Para 27] Another limitation is that very often the robustness of the predictive model is dependent upon the granularity of the processing data being collected by the sensors. Most of the processing tools have sensors that are unable to provide the necessary data granularity that may be required to construct a robust predictive model. Even if the sensors are available to provide the high fidelity data that may be needed to construct the predictive model, most processing tool lacks the capability to perform the analysis. As a result, most predictive models provide errors that are larger than desirable.

[Para 28] In addition to the aforementioned limitations, the expense of constructing and maintaining a predictive model can become quite costly. In an example, a typical predictive model may cost about a few hundred thousand dollars to construct and maintain. The cost is partly due to the expensive film substrates that are being utilized. Even after the predictive model has been constructed, additional cost may be incurred each time the predictive model has to be updated. Additionally, even though less expensive substrates may be available, a device manufacturer may be required to continue using the more expensive film substrate in the production environment if the device manufacturer wants to utilize the predictive model in qualifying a processing chamber.

[Para 29] In accordance with embodiments of the invention, methods are provided for creating a subsystem health check (SSHC) predictive model for qualifying a processing chamber. Embodiments of the invention include methods for constructing an SSHC predictive model that may be applied toward less expensive substrates (such as non-film substrates) which in most cases can be reused a finite number of times. Embodiments of the invention also include methods for qualifying a processing chamber based on uniformity. Embodiments of the invention further include methods for implementing the SSHC predictive model in a production environment.

[Para 30] In this document, various implementations may be discussed using etch rate as an example. This invention, however, is not limited to etch rate and may be applied to other process parameters, such as CD bias, for example. Instead, the discussions are meant as examples and the invention is not limited by the examples presented.

[Para 31] In an embodiment of the invention, a method is provided in which an SSHC predictive model is built utilizing data from at least two different substrate types. In an example, the on-wafer measurements for film substrates may be correlated against data collected during analogous processing of a set of non-film substrates. In an aspect of the invention, the inventors herein realized that measurement data from one type of substrate may

be correlated against sensor data from a second type of substrate if a relationship can be established between the two data sets.

[Para 32] In an example, a relationship exists between metrology data for a set of film substrates and sensor data for the same set of film substrates. This relationship is the basis for the predictive model in the prior art. If the same modified recipe is applied to a set of non-film substrates (such as the less expensive bare silicon substrates), a correlation may be established between the two sets of sensor data since the data are being collected in the same processing environment. Through substitution, a correlation may be established between the measurement data of the set of film substrates and the sensor data for the set of non-film substrates. Based on this correlation, an SSHC predictive model for qualifying a processing chamber may be constructed from sensor data collected from non-film substrates.

[Para 33] To further eliminate drift and/or noise in an SSHC predictive model, in an embodiment, data may be collected at different periods within a wet clean cycle. In an example, an SSHC predictive model may be constructed based on data sets collected at the beginning of a wet clean cycle, in the middle of a wet clean cycle, and toward the end of a wet clean cycle. Thus, the SSHC predictive model (unlike the prior art predictive model) does not have to be updated each time the processing chamber undergoes a wet clean since the SSHC predictive model already accounts for such a situation. Additionally, similar data sets between different chambers with the same hardware configurations can be used to ascertain and eliminate chamber-to-chamber variations (such as those brought on by installation and sensor-to-sensor variations).

[Para 34] As previously mentioned, one of the limitations of the predictive model of the prior art is that the predictive model is usually based on data that may lack granularity. In order to provide the required data needed for constructing a robust SSHC predictive model, sensors that are capable of collecting highly granular data may be employed. Examples of sensors include but are not limited to, for example, VI probe sensor, OES sensor, pressure sensor, and the like.

[Para 35] With a higher volume of data at a higher granularity, a robust data analysis module may be employed to process the data and to construct an SSHC predictive model. In an embodiment, the robust data analysis module is a fast processing computing engine that can be configured to handle a large volume of data. In addition, the robust data analysis module may be configured to receive the processing data directly from the sensors instead of having the data being relayed through a fabrication facility host controller or even through a

process module controller. Application Number 12/555,674, filed on September 8, 2009, by Huang et al. describes an example analysis computer suitable for performing the analysis.

[Para 36] In an embodiment, an SSHC predictive model may be employed to predict uniformity. Those skilled in the art are aware that the etch rate may not be uniform across the surface of a substrate. Many factors can impact uniformity. For example, the angle at which gas may be distributed into the processing chamber may affect uniformity. In another example, the power distribution within the processing chamber may affect uniformity.

[Para 37] Even though the etch rate may not be uniform across the surface of a substrate, empirical evidence shows certain area of the substrate may have substantially the same etch rate. In an embodiment of the invention, the substrate may be divided (in an abstract sense) into three concentric circles, and the area within each concentric circle is considered to empirically have the same uniformity. In an embodiment, uniformity may be calculated from the etch rates of the processed substrate. First, the average etch rate for each concentric circle is determined. Then each average etch rate is multiplied by the number of data points measured within the concentric circle (or in the case of the non-film substrates which did not have metrology measurements, they are multiplied by the number of measurement points there was supposed to be ("virtual" points) by a metrology tool (see Fig 4)). The values for all three concentric circles are added and an average etch rate for the substrate may be calculated. Uniformity is then determined by calculating the standard deviation of each concentric circle average etch rate against the overall average etch rate of the substrate. The overall substrate uniformity is then determined by calculating the standard deviation of all the actual or "virtual" etch depths and computing its percentage with respect to the average etch rate.

[Para 38] Once an SSHC predictive model is constructed, the SSHC predictive model may be migrated into production. Since the SSHC predictive model is constructed partly based on data collected from non-film substrates, the cost of implementing the SSHC predictive model in a production environment is significantly less than the predictive model of the prior art. One reason for the significant cost reduction is that the SSHC predictive model can be applied toward processing data collected from less expensive non-film substrates. In addition, the reduced measurement requirements offer up savings due to fewer metrology tools being required to meet with production needs. The faster turnaround time for qualification of the chamber may also result in fewer at-risk production wafers being processed since problems with the process chamber can be detected faster. Accordingly, the

SSHC predictive model provides an effective model for qualifying a processing chamber while effectively reducing ownership cost.

[Para 39] The features and advantages of the present invention may be better understood with referenced to the figures and discussions that follow.

[Para 40] Fig. 2, shows in an embodiment of the invention, a generic overview of a method for constructing a subsystem health check (SSHC) predictive model for qualifying a processing chamber.

[Para 41] At a first step 202, pre-processing measurement is performed on a set of film substrates. Similar to the prior art, a metrology tool (such as a KLA-Tencor thin film metrology tool) may be employed to take the measurements, such as measuring thickness of the substrate. Since the thickness of a substrate may vary across the entire substrate, different data points on the substrate (such as the data points shown in the 49 points polar scan of substrate 402 in Fig. 4A) may be measured.

[Para 42] At a next step 204, the set of film substrates are processed. Similar to the prior art, a modified recipe may be employed within the test environment. The modified recipe may be a simpler version of the production recipe and tends to simulate the etch behavior of the production recipe.

[Para 43] Those skilled in the art are aware that a parameter change may influence an average etch rate and/or uniformity of a substrate. Thus, in order to accurately qualify a processing chamber, parameter changes may have to be accounted for in creating an SSHC predictive model. In order to improve the robustness of the model, the system response to potential changes in production is assessed. Recipe parameters may be changed as one or more test substrates are processed. In an example, the first few substrates (three substrates, for example) may be executed with the basic modified recipe. For the fourth and fifth substrates, the pressure value may be changed to account for the pressure level change that may occur in the processing chamber. In another example, the gas flow distribution may be adjusted for the next four substrates so that a larger percentage of total gas flows towards the center of the substrate to offset slightly higher edge etch rate which may occur due to eroded chamber consumables (which are typically found near the edge of the substrates).

[Para 44] After the set of film substrates has been processed, at a next step 206, a set of non-film substrates (such as bare silicon substrates) may be processed using the same modified recipe as applied to the set of film substrates. In an example, if the pressure value was increased for the fourth film substrate, then the same pressure value is applied toward the

fourth non-film substrate. While the non-film substrates are being processed, sensors may also be collecting processing data. In an embodiment, the order of processing the set of film substrates and the set of non-film substrates does not limit the invention. In other words, either step 204 or step 206 can occur first.

[Para 45] As previously mentioned in the prior art, one of the limitations of the prior art method is due to the granularity of data being collected. In an embodiment, the methods described in this document are applied in a processing tool that supports sensors (such as VI probe sensor, OES sensor, pressure sensor, and the like) that may be capable of collecting highly granular data. Additionally, a fast processing computing analysis module may be implemented to quickly process and analyze the data. In an embodiment, the fast processing computing analysis module may be an advanced process and equipment control system (APECS). The APECS module may be configured to analyze a plurality of data quickly (in situ) and may be able to provide feedback to the processing module (PM) controller of the processing chamber to enable the PM controller to predict the etch rate and/or uniformity for the next incoming substrate. Application Number 12/555,674, filed on September 8, 2009, by Huang et al. describes an example analysis computer suitable for performing the analysis.

[Para 46] After substrate processing has ended, at a next step 208, post-processing measurement data is acquired. In an example, post-processing measurement data at the same set of data points (as seen in Fig. 4A, for example) may be collected for each processed film substrate.

[Para 47] At a next step 210, the difference between the pre and post-processing measurement data is calculated and an average etch rate and/or uniformity may be calculated for each film substrate. Discussion about uniformity is provided in detail in Fig. 3 and Fig. 4 below.

[Para 48] In one embodiment, to further eliminate noise and/or drift, steps (202 - 210) for constructing an SSHC predictive model may be performed at least twice. In an embodiment, the steps may be performed at the beginning of a wet clean cycle (*i.e.*, after maintenance has been performed on the processing chamber) and toward the end of a wet clean (*i.e.*, time period before the next maintenance is performed). In addition, data may also be collected during the middle of a wet clean cycle.

[Para 49] Once data has been collected, at a next step 212, the sensor processing data and the metrology data may be correlated and an SSHC predictive model for qualifying a processing chamber may be constructed. In an embodiment, the SSHC predictive model may

be based on a partial least squares model. A partial least squares model is a technique for finding relationships between two sets of data. The partial least squares model may have a similar aim to that of least squares linear fitting but is usually used when there are multiple independent variables (in an input matrix X) and possibly multiple dependent variables (in an input matrix Y). In the partial least squares model the Y variables are not continuous but instead consist of a set of independent discrete values or classes. The analysis aims to find linear combinations of the X variables that can be used to classify the input data into one of these discrete classes.

[Para 50] As can be appreciated from Fig. 2, a method is provided for the construction of an SSHC predictive model that may take into account conditions of the processing chamber at different time periods during a wet clean cycle. Even if the SSHC predictive model, as describe in Fig. 2, may require additional time to be constructed (in comparison to the method described in Fig. 1), once constructed, the SSHC predictive model does not have to be constantly updated (as required by the prior art method). Thus, the resources required to construct an SSHC predictive model is usually a one time cost instead of a continual expense (as required by the prior art method). In addition, since the SSHC predictive model may be applied against data collected from non-film substrates, the cost of ownership is significantly reduced since the device manufacturer does not have to continue to utilize the more expensive film substrates within the production environment in order to effectively apply the SSHC predictive model.

[Para 51] Fig. 3 shows, in an embodiment of the invention, one implementation for constructing an SSHC predictive model.

[Para 52] At a first step 302, a first set of data is collected. In an embodiment, the first set of data is collected at the beginning of a wet clean cycle (after maintenance has been performed on the processing chamber). The first set of data may include processing data collected by the sensors on a set of non-film substrates and the metrology data collected on a first set of film substrates. In other words, steps 202 – 210 of Fig. 2 is performed on the set of non-film substrates and the first set of film substrates. In an embodiment, the first set of film substrate and the set of non-film substrates may include the same number of substrates.

[Para 53] At a next step 304, a second set of data is collected. In an embodiment, step 304 is optional. The data collected during step 304 may be employed as validation data. Step 304 is usually performed during the middle of the wet clean cycle in order to account for

potential drift that may occur. In an example, some of the hardware components (such as the gas distribution system, for example) may have drifted after several production runs.

[Para 54] Unlike a film substrate, a non-film substrate may be processed multiple times. Those skilled in the art are aware that non-film substrates (such as bare silicon substrates) may be processed up to about 10-15 times at least before the non-film substrates may no longer be able to handle further processing. Thus, the same set of non-film substrates that have previously been etched in step 302 may be processed again in step 304 and later in step 306.

[Para 55] At a next step 306, a third set of data is collected. In an embodiment, the third set of data is collected toward the end of a wet clean cycle. The third set of data includes processing data collected by the sensors on a set of non-film substrates (may be the same set of non-film substrates from step 304) and the metrology data collected on a third set of film substrates.

[Para 56] By collecting data from different time periods during a wet clean cycle, an SSHC predictive model may be able to capture the behavior of a processing chamber through a normal wet clean cycle.

[Para 57] At a next step 308, the system checks to determine if sufficient model set data has been collected. As discussed herein, model set data refers to data collected in steps 302 and 306.

[Para 58] If insufficient model set data exists, then at a next step 310, more data is collected before analysis may begin. Insufficient data may have been collected if not enough film substrates have been processed, for example. In another example, some of the processed data collected by the sensors may be deemed unacceptable and cannot be utilized in constructing the SSHC predictive model.

[Para 59] However, if a sufficient amount of model set data exists, then at a next step 312, the system may check to see if a control limit has been specified. In an embodiment, a control limit is an error range that may be acceptable to the user. Since the SSHC predictive model is being constructed based on highly granular data, the control limit may be set as low as two to three percent.

[Para 60] If the control limit has not yet been set, then at a next step 314, the system may request the control limit to be provided.

[Para 61] However, if the control limit has been specified, then at a next step 316, the system may begin the process of constructing an SSHC predictive model. The SSHC

predictive model may include the average etch rates as target etch rates correlated to the sensor processing data.

[Para 62] Target etch rates may be calculated using the model set metrology data. In an example, a substrate location may have a pre-processing measurement of about 500 nm. Once the substrate has been processed, the thickness of the substrate at the same location is now 375nm. Given that the etch depth is the difference between the pre and post-processing measurements, the etch depth at a given data point (*e.g.*, orientation of 0 degree, radius of 115mm) is 125nm. If the process time for the substrate is 2 minutes, then the etch rate is 62.5nm per minute for that data point (*e.g.*, substrate location). Once the etch rate has been determined, each of the data points on the substrate may now be associated with an etch rate.

[Para 63] Unlike the prior art, the average etch rate of the substrate is not calculated by adding all the etch rate values and dividing the total etch rate value by the number of data points. Instead, the average etch rate of the substrate is based on a concept that the etch rates are not the same across a substrate. Instead, empirical tests have shown that a substrate may be divided (in an abstract manner) into three concentric circles (as shown by concentric circles 450, 440 and 430 of Fig. 4B) with each data point within a concentric circle having similar etch rates.

[Para 64] To facilitate discussion, assume that the average etch rates are 62.5nm/minute, 72.5nm/minute and 82.5nm/minute for concentric circle 450 (ER1), concentric circle 440 (ER2), and concentric circle 430 (ER3), respectively. After the three average etch rates are determined, each average etch rate may be normalized. In an example, concentric circle 450 has nine data points. Accordingly, the average etch rate (62.5nm/minute) is multiplied by 9. After the average etch rate has been normalized, the overall average etch rate is calculated by combining the three normalized average etch rates and dividing the total by the number of data points (in this example, measurements have been taken at 49 data points). In this example, the overall average etch rate for the substrate is 75.6nm/minute.

[Para 65] Once the average etch rates have been calculated, uniformity may then be calculated. As aforementioned, the etch rate values of a substrate may be divided into three concentric circles. In other words, the etch rate at a given data point within a concentric circle may be essentially the same. Thus, the substrate is substantially uniform within a concentric circle. Accordingly, the uniformity for a concentric circle may be determined by calculating the standard deviation of the average etch rate for a concentric circle to the overall average etch rate for the substrate.

[Para 66] At a next step 318, the model set predicted etch rates and uniformity may be calculated using the sensor processing data collected. The etch rates and uniformity for the non-film substrates may be predicted using the previously established correlation between sensor data and metrology information (i.e. partial least squares modeling).

[Para 67] At a next step 320, the system checks to determine if validation data has been collected. As aforementioned, validation data may be collected during the optional step 304. If validation data exists, then at a next step 322, the average etch rates and uniformity based on the validation data may be calculated.

[Para 68] At a next step 324, the SSHC model predicted etch rate and uniformity for the validation data set is compared against actual metrology measurements. This step may be utilized to validate the SSHC predictive model.

[Para 69] Once the comparison has been performed, the system may proceed to a next step 326. Similarly, if no validation data exists, the system may proceed to next step 326.

[Para 70] At next step 326, the system may compare the predictive error rate against the control limit. In an example, if the control limit is three percent, then the predictive error rate has to be no larger than three percent.

[Para 71] If the predictive error is not acceptable, then at a next step 328, a warning is issued notifying the user that the SSHC predictive model may have to be adjusted.

[Para 72] However, if the predictive error rate is acceptable, then at a next step 330, the SSHC predictive model may be moved into production and may be made available for qualifying a processing chamber.

[Para 73] Fig. 5 shows, in an embodiment, a simple flow chart illustrating a method for applying an SSHC predictive model in qualifying a processing chamber. Before a production run, a subsystem health check test may be executed. In other words, the SSHC predictive model may be applied against data collected from a test substrate to determine the health condition of the processing chamber.

[Para 74] At a first step 504, a user may activate the SSHC predictive model. User specifications (*e.g.*, recipe, filename, and the like) may be entered. This information may also be pulled from a library 502. The library 502 may include recipe specific parameters (such as upper control limit, lower control limit, target etch rate, uniformity, and the like).

[Para 75] At a next step 506, the system may perform a pre-emptive assessment. A pre-emptive assessment may be performed in order to determine the readiness state of the processing chamber.

[Para 76] If the pre-emptive assessment fails (e.g., outside a predefined threshold range), at a next step 526, the system may determine the source of the alarm (failure). In an embodiment, the source of alarm may result from connectivity, change in frequency, and/or change in temperature (528).

[Para 77] If the source of alarm is due to connectivity, one or more sensors may not be properly connected. If a sensor is incorrectly connected, the sensor is unable to capture processing data.

[Para 78] Another source of alarm may be due to a large change in frequency. In an example, the frequency as recorded by the electrical probe (such as the VI probe sensor) and the frequency as reported by the generator are compared against one another. If the difference between the two frequencies is above a threshold (*e.g.*, too large), a problem may exist with the VI probe sensor, for example. In an example, the VI probe sensor may be too hot. In another example, the VI probe sensor may have been disabled.

[Para 79] Yet another source of alarm may be due to a large change in temperature between the current temperature within the processing chamber and the desired set point temperature (*i.e.*, recipe temperature). In an example, when the processing tool is first turned on, the temperature within the processing chamber may require a few minutes to reach the desired set point temperature. The system checks to make sure the temperature within the processing chamber is within a desired threshold before processing may begin.

[Para 80] Once the system passes the pre-emptive assessment, then at a next step 508, the system checks to determine if an SSHC predictive model exists.

[Para 81] If an SSHC predictive model does not exist, then at a next step 522, an SSHC predictive model is constructed (as described in Fig. 2 and/or Fig. 3).

[Para 82] However, if an SSHC predictive model exists, then the substrate is processed and processing data is collected. In an embodiment, the SSHC predictive model is applied against processing data to predict the etch rate and/or uniformity (calculated data) for the current substrate (step 510).

[Para 83] At a next step 512, the system checks to determine if the etch rate and uniformity is within the control limit. If the etch rate and/or uniformity is not within the control limit, then at a next step 514, a failure notification may be issued. The failure notice may provide details about the potential problem that may exist within the processing chamber. In an example, the failure notice may indicate that the recipe may have to be adjusted to account for the drift within the processing chamber. In another example, the failure notice may

indicate that there was a sudden increase in temperature during substrate processing, which could have been brought on by insufficient coolant to regulate chamber temperature.

[Para 84] However, if the etch rates and uniformity are within the control limits, then at a next step 516, the system may check to determine if an SSHC verification degree is satisfied. In an example, the user may have set a limit indicating that the processing chamber is within good working condition if the etch rates and uniformity for three consecutive substrates are within the control limit.

[Para 85] If the SSHC verification degree has not been met, then at a next step 518, the system may continue to the next substrate (return to step 510). Steps 510 through 518 are iterative. In an embodiment, steps 510 through 518 may be performed until the SSHC verification degree has been satisfied. In another embodiment, inability to satisfy the SSHC verification degree within a predetermined number of substrates may result in a failure notice to the user, thereby, informing the user about a potential problem with the system.

[Para 86] However, if the SSHC verification degree is satisfied, then at a next step 520, the processing chamber has passed the subsystem health check and the production run may begin.

[Para 87] As can be appreciated from the foregoing, methods are provided for qualifying a processing chamber. By extrapolating data from two or more test runs during a wet clean cycle, an SSHC predictive model may be constructed that take into account changes that may occur during a wet clean cycle. With a robust SSHC predictive model, the SSHC predictive model provides an effective model for qualifying a processing chamber while effectively reducing ownership cost.

[Para 88] While this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and equivalents, which fall within the scope of this invention. Although various examples are provided herein, it is intended that these examples be illustrative and not limiting with respect to the invention.

[Para 89] Also, the title and summary are provided herein for convenience and should not be used to construe the scope of the claims herein. Further, the abstract is written in a highly abbreviated form and is provided herein for convenience and thus should not be employed to construe or limit the overall invention, which is expressed in the claims. If the term "set" is employed herein, such term is intended to have its commonly understood mathematical meaning to cover zero, one, or more than one member. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention.

It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

CLAIMS

What is claimed is:

1. A method for predicting etch rate uniformity for qualifying health status of a processing chamber during substrate processing of a set of substrates, comprising:

executing a recipe on a first substrate of said set of substrates;

receiving processing data from a first set of sensors during said executing of said recipe;

analyzing said processing data utilizing a subsystem health check predictive model to determine calculated data, said calculated data including at least one of etch rate data and uniformity data, wherein said subsystem health check predictive model is constructed by correlating a first set of data and a second set of data, said first set of data includes measurement data from a set of film substrates and said second set of data includes processing data collected during analogous processing of a set of non-film substrates;

performing a comparison of said calculated data of said first substrate against a set of control limits as defined by said subsystem health check predictive model; and

generating a warning if said calculated data is outside of said set of control limits.

2. The method of claim 1 further including performing a pre-emptive assessment to determine the readiness state of said processing chamber.

3. The method of claim 2 wherein if said pre-emptive assessment is outside a predefined threshold, determining source of problem.

4. The method of claim 1 further including pulling data from a library to support said subsystem health check predictive model.

5. The method of claim 1 wherein said set of control limits is user-configurable.

6. The method of claim 1 further including if said calculated data is within said set of control limits, validating a verification degree to determine if a predefined number of substrates have passed said comparison between said calculated data and said set of control limits.

7. The method of claim 1 wherein said subsystem health check predictive model is constructed from data collected from a time period, wherein said time period being one of at the beginning of a wet cycle, during said wet cycle, and at the end of said wet cycle.

8. The method of claim 7 wherein said subsystem health check predictive model is constructed from data collected from one time period.

9. The method of claim 7 wherein said subsystem health check predictive model is constructed from data collected from at least two time periods.

10. A processing chamber health check arrangement for qualifying a processing chamber of a plasma processing system, comprising:

a pre-assessment module for determining the readiness of said processing chamber;

a library for storing at least one of recipes and recipe parameters; and

a subsystem health check predictive model configured for

receiving processing data from a first set of sensors during substrate processing;

analyzing said processing data to determine a set of calculated data, wherein said set of calculated data includes at least one of etch rate data and uniformity data;

comparing said set of calculated data to a set of predefined control limits; and

generating warning when said set of calculated data is outside of said set of predefined control limits;

wherein said subsystem health check predictive model is constructed by

obtaining a first set of data from a first set of substrates, said first set of substrates being a set of film substrates, wherein said first set of data includes pre-processing measurement data and post-processing measurement data, said post-processing measurement data being collected after executing a recipe on said first set of substrates,

collecting a second set of data from a second set of substrates, wherein said second set of data is collected by a set of sensors during execution of an analogous execution of said recipe on a set of non-film substrates, and

correlating said first set of data with said second set of data to construct said subsystem health check predictive model.

11. The processing chamber health check arrangement of claim 10 wherein said subsystem health check predictive model further including if said calculated data is within said set of control limits, validating a verification degree to determine if a

predefined number of substrates have passed said comparison between said calculated data and said set of control limits.

12. The processing chamber health check arrangement of claim 10 wherein said subsystem health check predictive model is constructed from data collected from a time period, wherein said time period being one of at the beginning of a wet cycle, during said wet cycle, and at the end of said wet cycle.

13. The processing chamber health check arrangement of claim 12 wherein said subsystem health check predictive model is constructed from data collected from one time period.

14. The processing chamber health check arrangement of claim 12 wherein said subsystem health check predictive model is constructed from data collected from at least two time periods.

15. An article of manufacture comprising a non-transitory program storage medium having computer readable code embodied therein, said computer readable code being configured for predicting etch rate uniformity for qualifying health status of a processing chamber during substrate processing of a set of substrates, comprising:

code for executing a recipe on a first substrate of said set of substrates;

code for receiving processing data from a first set of sensors during said executing of said recipe;

code for analyzing said processing data utilizing a subsystem health check predictive model to determine calculated data, said calculated data including at least one of etch rate data and uniformity data, wherein said subsystem health check predictive model is constructed by correlating a first set of data and a second set of data, said first set of data includes measurement data from a set of film substrates and said second set of data includes processing data collected during analogous processing of a set of non-film substrates;

code for comparing said calculated data of said first substrate against a set of control limits as defined by said subsystem health check predictive model; and

code for generating a warning if said calculated data is outside of said set of control limits.

16. The article of manufacture of claim 15 further including code for performing a pre-emptive assessment to determine the readiness state of said processing chamber.

17. The article of manufacture of claim 15 further including code for pulling data from a library to support said subsystem health check predictive model.

18. The article of manufacture of claim 15 further including if said calculated data is within said set of control limits, code for validating a verification degree to determine if a predefined number of substrates have passed said comparison between said calculated data and said set of control limits.

19. The article of manufacture of claim 15 wherein said subsystem health check predictive model is constructed from data collected from a time period, wherein said time period being one of at the beginning of a wet cycle, during said wet cycle, and at the end of said wet cycle.