SYSTEMS AND METHODS FOR CALIBRATING END EFFECTOR ALIGNMENT USING AT LEAST A LIGHT SOURCE

BACKGROUND OF THE INVENTION

[0001] In the processing of semiconductor substrates (e.g., wafers), plasma is often employed. In plasma processing, the wafers are processed using a plasma processing system, which typically includes a plurality of processing modules. The substrate (e.g., wafer) is disposed on a chuck inside a processing module during plasma processing.

[0002] In order to move a wafer in and out of the process module, the wafer is typically placed on an end effector and transferred onto the chuck. The end effector is a structural component configured for supporting the wafer during wafer transfer. The end effector is typically disposed on a robot arm. Fig. 1 shows a representative prior art end effector 102 for supporting a wafer 104 during wafer transfer. For illustration purposes, a portion of a robot arm 106 is also shown.

[0003] Generally speaking, during a wafer transfer sequence, the robot arm first moves the end effector to pick up the wafer from a wafer storage cassette or station. Once the wafer is positioned on the end effector, the robot arm would then move the wafer into the plasma process module through a door in the processing module. The robot arm then positions the end effector and the wafer over the chuck and then places the wafer on the chuck for plasma processing.

[0004] In order to ensure that the wafer is processed properly (thereby ensuring controllable and repeatable process results), the wafer needs to be centered on the chuck during plasma processing. If the end effector is perfectly centered relative to the chuck and the wafer is perfectly centered relative to the end effector, then the wafer would be perfectly centered relative the chuck when the robot arm places the wafer on the chuck.

[0005] From the robot arm controller's perspective, it is important to know the center of the chuck to enable the robot arm controller to center the end effector over the chuck for the purpose of wafer placement. Accordingly, for any given plasma processing module, the robot arm controller needs to be taught the position of the chuck and the chuck center. In other words, the robot arm controller needs to ascertain, in its own coordinate system, the exact location of the chuck and the chuck center since each chuck may be positioned slightly differently in each processing module due to, for example, machining and/or manufacturing and/or assembly tolerances .

[0006] To compensate for the end effector/chuck mis-alignment, the typical strategy during calibration involves moving the robot arm to a position where the center defined by the end effector (herein referred to as the "end effector center" or the "end effector-defined center ") actually aligns with the center of the chuck. To accomplish end effector calibration, it is necessary that the operator be able to ascertain the actual end effector/chuck alignment position. In the prior art, the alignment of the end effector-defined center to the chuck center is accomplished using a fabricated mechanical fixture which fits on the edge of the chuck or attaches to the process module interior.

[0007] The mechanical fixture has a key feature (essentially a centering protrusion for the end effector), which allows the end effector to rest right up against the key feature of the calibration fixture. Since the fixture is centered relative to the chuck, when the end effector rests against the key feature of the fixture, the end effector would be centered on the chuck. Typically, positioning the end effector against the key feature is accomplished by an operator pulling or pushing the end effector against the key feature so that the end effector rests against the key feature.

[0008] After the operator has positioned the end effector against the key feature, the operator then registers the robot arm position with the robot control system so that the robot control system can record, in the robot control's coordinate system, the position of the robot arm that achieves this actual end effector/chuck alignment.

[0009] During production, the robot arm moves the end effector to the coordinates associated with this effector/chuck alignment position. If the wafer is centered with respect to the end effector, the fact that the end effector-defined center now actually aligns with the chuck center would cause the wafer to be centered relative to the chuck when the wafer is placed by the robot arm on the chuck for wafer processing. In co-pending patent applications entitled "SYSTEMS AND METHODS FOR CALIBRATING END EFFECTOR ALIGNMENT IN A PLASMA PROCESSING SYSTEM," Attorney Docket Number LMRX-P143/P1747 and "SYSTEMS AND METHODS FOR DYNAMIC ALIGNMENT BEAM CALIBRATION", Attorney Docket Number LMRX-P144/P1748, filed on even date herewith by the inventors herein and incorporated herein by reference, techniques have been proposed to address this end effector/chuck mis-alignment. Details pertaining to techniques discussed in the aforementioned two patent applications "SYSTEMS AND METHODS FOR CALIBRATING END EFFECTOR ALIGNMENT IN A PLASMA PROCESSING SYSTEM," and "SYSTEMS AND METHODS FOR DYNAMIC ALIGNMENT BEAM CALIBRATION" may be reviewed in Discussion A and Discussion B hereinbelow.

[0010] However, there are disadvantages with the prior art technique for centering the end effector relative to the chuck for calibration purposes. First of all, there are many types of chucks and processing modules in existence. Therefore, in order to use the mechanical fixture approach to perform calibration, many different mechanical fixtures must be fabricated and stocked.

[0011] Also, affixing a physical mechanical fixture, which may have one or more hard metal edges or surfaces, on the chuck may potentially damage the chuck. Additionally, if this calibration is done in the field after some plasma cycles have been executed in the processing module (e.g., in response to a concern that the end effector may not be centered relative to the chuck following a production run), the attachment of a physical calibration fixture on the chuck may cause deposited particles on or near the chuck to flake off into the processing chamber. During the subsequent processing cycles, such particles constitute particle contamination, which is undesirable.

[0012] Additionally, because the calibration is performed at atmospheric pressure, the prior art calibration technique may not effectively duplicate the conditions that exist during production. This is because during production, components of the processing module may be placed under vacuum, causing one or more components to shift due to the pressure differential between the vacuum environment and the ambient atmosphere. Since the calibration conditions do not faithfully duplicate the production conditions, accurate calibration may not be possible.

[0013] Furthermore, if the positioning of the end effector at the end effector/chuck alignment position is performed manually (e.g., involving the operator pulling or pushing the end effector to rest up against the key feature of the mechanical fixture), there may be a shift in the robot arm position when the operator releases the robot arm to go and register this end effector/chuck alignment position with the robot arm controller. This shift may occur for many reasons, including for example the fact that the robot motors are de-energized. When the robot arm pulls away, even by a small amount that may be imperceptible to the robot operator, this shift may result in inaccuracy in the calibration process. If the calibration process is inaccurate, inaccurate wafer placement during production may occur, leading to decreased yield and an increase in the rejection and/or failure rate for the fabricated products.

SUMMARY OF INVENTION

[0014] The invention relates, in an embodiment, a method for calibrating alignment of an end effector with respect to a chuck in a plasma processing system. The method including providing a first light beam from the end effector to said chuck. The method

including moving the end effector along a predefined calibration path such that the first light beam traverses a surface of the chuck. The method also includes receiving a set of reflected light signals, the set of reflected light signals being generated at least when the surface reflects the first light beam during the moving. The method including analyzing the set of reflected light signals to identify three or more discontinuities. The three or more discontinuities are related to three or more reflected light signals generated when the first light beam encounters an edge of the chuck. The method also including determining three or more coordinate data points based on the three or more discontinuities, the three or more coordinate data points representing three or more points on the edge of the chuck. The method includes determining a center of the chuck based on the three or more coordinate data points.

[0015] The above summary relates to only one of the many embodiments of the invention disclosed herein and is not intended to limit the scope of the invention, which is set forth in the claims herein. These and other features of the present invention will be described in more detail below in the detailed description of the invention and in conjunction with the following figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] 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:

[0017] Fig. 1 shows a representative prior art end effector for supporting a wafer during wafer transfer.

[0018] Fig. 2A shows, in accordance with an embodiment of the present invention, a portion of an in-situ optical end effector calibration arrangement for calibrating the end effector relative to the chuck center.

[0019] Fig. 2B shows, in accordance with an embodiment of the present invention, a portion of an in-situ optical end effector calibration arrangement for calibrating the vertical position of the end effector in-situ.

[0020] Fig. 3A shows, in accordance with an embodiment of the present invention, an illustrative flow chart for the in-situ optical end effector calibration method that calibrates the end effector to the chuck center.

[0021] Fig. 3B shows, in accordance with an embodiment of the present invention, an illustrative flow chart for the in-situ optical end effector calibration method for calibrating the vertical position of the end effector.

[0022] Fig. A1 of Discussion A shows a representative prior art end effector for supporting a wafer during wafer transfer.

[0023] Fig. A2 of Discussion A shows, in accordance with an embodiment of the present invention, a schematic representation of a plasma processing system illustrating a top view of at least a portion of an in-situ optical end effector calibration system for calibrating the end effector in-situ.

[0024] Fig. A3 of Discussion A shows, in accordance with an embodiment of the present invention, an illustrative flow chart for the in-situ optical end effector calibration method.

[0025] Fig. B1 of Discussion B shows a representative prior art end effector for supporting a wafer during wafer transfer.

[0026] Fig. B2 of Discussion B shows, in accordance with an embodiment of the present invention, schematic representation of a plasma processing system illustrating a top view of at least a portion of an optical wafer-centering system for enabling the creation or simulation of a correctly centered wafer/end effector assembly for DA beam calibration purposes.

[0027] Fig. B3 of Discussion B shows, in accordance with an embodiment of the present invention, a illustrative flow chart of the steps for creating or simulating a centered wafer relative to the end effector-defined center using an optical wafer-centering technique in order to facilitate DA beam calibration.

[0028]

DETAILED DESCRIPTION OF EMBODIMENTS

[0029] 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.

[0030] Various embodiments are described herein below, 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.

[0031] Embodiments of the invention relate to methods and apparatus for registering the center of the chuck to the robot arm controller so that the robot arm controller can ascertain, in the robot coordinate system, the position of the chuck and the chuck center in the processing module. Embodiments of the invention also relate to in-situ methods and apparatus for calibrating the vertical position of the end effector relative to the upper surface of the chuck.

[0032] In an aspect of the present invention, the inventors herein recognize that the robot arm controller typically, in its own coordinate system, the current position of the robot arm. Since the end effector is attached to the robot arm, the robot arm controller can also relate, in its own coordinate system, the current position of the end effector to the robot arm controller's own coordinate system.

[0033] In one or more embodiments of the present invention, the current position of the end effector (which position the robot arm controller can ascertain in its own coordinate system) is correlated with certain features of the chuck in order to accomplish end effector calibration. In one or more embodiments, an optical end effector alignment technique is employed in which a light source (e.g., a laser beam) is affixed to the end effector, and the end effector is sent on a predefined calibration path over the chuck in order to obtain data points pertaining to the chuck for end effector calibration.

[0034] A sensor is employed to acquire reflected light as the light beam from the light source traverses over the chuck, including the chuck's outer periphery, along the calibration path. The reflected light is analyzed for discontinuities that are indicative of the change in the reflected light as the light source encounters the chuck's outer edge. The robot arm controller correlates the occurrences of discontinuity with the robot arm coordinates at which these discontinuities occur. If three or more data points (comprising discontinuity detections and corresponding robot arm coordinates) are obtained, extrapolation logic may then be employed to extrapolate, in the robot arm controller coordinate system, the circle that

represents the chuck and/or the chuck center. This extrapolation may be performed using off-the-shelf software tools such as for example the Keyence communication software for use with CV-3002 Series Controller CV-H3N, available from Keyence Corporation of Woodcliff Lake, NJ.

[0035] Having known the coordinate for the chuck center, the robot arm controller can calibrate the end effector to the chuck center. Note that with the proposed optical end effector calibration technique, the use of a specialized hardware fixture that attaches to the chuck for the purpose of centering the end effector to the chuck is no longer necessary. Accordingly, the disadvantages and risks associated with the prior art specialized hardware fixture approach are advantageously eliminated.

[0036] Further, it is not necessary to position the light source (e.g., laser source) at the end effector-defined center for the purpose of performing optical end effector calibration. In other words, the light source can be offset from the end effector-defined center, if desired. As long as the offset from the light source location on the end effector to the end effector-defined center is known, this offset may be taken into account when computing the circle that represents the chuck and/or the chuck center for the purpose of aligning the end effector-defined center to the center of the chuck or for calculating the actual movement required by the robot arm to allow the end effector to center a production wafer on the chuck. Still further, it is not necessary to position the sensor on the end effector itself. As long as there is a sensor disposed such that that sensor is capable of acquiring the sufficient reflected light for the purpose of detecting the aforementioned discontinuities, the sensor itself can be place at any desired location inside or outside of the processing module.

[0037] The features and advantages of the invention may be better understood with reference to the figures and discussions that follow.

[0038] Fig. 2A shows, in accordance with an embodiment of the invention, a portion of an in-situ optical end effector calibration arrangement including a laser source 202 (which is integrated with a sensor in the example of Fig. 2) mounted at the tip of an end effector 204. As mentioned, for end effector calibration purposes, the light source may be disposed anywhere on the end effector as long as the offset between the light source and end effector-defined center is known.

[0039] There is also shown a chuck 206, representing a chuck mounted in the processing module of a plasma processing system. During calibration, the robot arm controller (not shown) moves the robot arm along a predefined calibration path to generate at least three chuck-edge data points. The movement of the robot arm along the calibration path

causes a light beam 208 provided by laser source 202 to traverse along a path 210 as shown. In one or more embodiments, path 210 includes at least two sections, each of the two sections including at least two points on periphery 250 of chuck 206. While light beam 208 moves along path 210, the sensor records the reflected light and analyzes the reflected light for discontinuity.

[0040] As light beam 206 strikes position 212a along periphery 250 of chuck 206, a discontinuity in the reflected light is ascertained by the logic analyzing the reflected light. When the discontinuity event is detected, the robot arm controller notes its own robot arm position in its own coordinate system. As the beam moves along path 210, the beam strikes positions 212b and 212c at the chuck edge, and two additional discontinuity events are ascertained. Again, the robot arm controller correlates the ascertained discontinuities with the contemporaneous robot coordinates. After the movement of the robot arm causes light beam 208 to complete its traversal along path 210, three discontinuity points, along with their corresponding robot coordinates, are acquired.

[0041] Logic may then be employed to extrapolate the circle representing chuck 206 from the three discontinuity points. Note that since the discontinuity points are recorded in the robot coordinate system, the circle representing the chuck 206 can be readily computed in the robot coordinate system. Further, the center of the chuck 206 can also be readily computed in the robot coordinate system.

[0042] Note that path 210 may represent any arbitrary path configured to traverse the chuck's periphery at three or more locations to generate at least three discontinuity points. Generally speaking, the robot operator has a rough idea where the chuck would be located and could program, in an embodiment, the robot arm controller to move the robot arm in a manner that efficient generates widely-spaced discontinuity points to ensure that the circle representing chuck 206 can be accurately computed. An example tool to perform such calculation may be the Keyence communication software for use with CV-3002 Series Controller CV-H3N, available from Keyence Corporation of Woodcliff Lake, NJ.

[0043] Fig. 2B shows, in accordance with an embodiment of the invention, an optical arrangement for calibrating the vertical position of the end effector relative to the upper surface of the chuck. Fig. 2B shows a light source 230 (e.g., a laser source) disposed to transmit a light beam 232 (e.g., a laser beam) through a window 234 in a wall of the processing module. Although the window is shown to be disposed on the far wall of the processing module (e.g., the wall that is opposite the door through which wafers are inserted and removed), such location is not an absolute requirement.

[0044] The height of light beam 232 may represent, in an embodiment, the desired height above chuck 206 for positioning end effector 240 during wafer transfer. A sensor (not shown) is disposed on the end effector to allow the robot control system to determine when the light beam 232 strikes end effector 240 as end effector 240 moves along a vertical calibration path (e.g., in the Z direction across beam 232).

[0045] When light beam 232 is detected by the sensor disposed at the tip of end effector 240, the robot arm controller may record, in the robot coordinate system, the contemporaneous robot arm vertical position. During wafer transfer, the recorded vertical position of the robot arm may be employed for vertically positioning the end effector.

[0046] As an alternative, light source 230 may be mounted inside processing chamber 242 and window 234 may be eliminated.

[0047] Alternatively or additionally, it is possible to analyze the reflected light from light source 232 and analyze for discontinuity in order to calibrate the vertical position of the end effector. In one or more embodiments, as the robot arm controller commands end effector 240 to move along the vertical calibration path across light beam 232, a sensor may be employed to acquired the detected light from light source 230. When light beam 232 strikes end effector 240, a discontinuity in the reflected light may be ascertained. This discontinuity may be correlated with the current coordinate of the robot arm, thereby essentially recording the robot coordinates for the vertical height of the laser beam above the chuck. When the reflected light approach is employed, it is possible to mount a sensor in any suitable location, including locations not disposed on or near end effector 240, for acquiring light reflected off light source 230.

[0048] Fig. 3A shows, in accordance with an embodiment of the present invention, a simplified flow chart for implementing optical end effector calibration relative to the chuck center. In step 302, a light source (such as a laser source) is attached to the end effector. In step 304, the end effector, along with the attached light source, is moved along a predefined trajectory path above the upper surface of the chuck.

[0049] During the movement of the end effector over the upper surface of the chuck, a light beam from the light source is directed at the upper surface of the chuck. The reflected light from the light source is acquired and analyzed for discontinuities (step 306). If a discontinuity is received (path "YES" of 308), the robot coordinates for the robot arm position is recorded (310). The process continues (arrow 312) until a predefined number of discontinuities and their corresponding robot arm coordinates are obtained or until the trajectory traversal is completed.

[0050] After the requisite continuity points are acquired, extrapolation logic may be employed to ascertain the chuck periphery, radius, and center. In one or more embodiments, at least three discontinuity points are desired although, depending on the trajectory defined by the robot arm controller, additional points can be obtained as well for the purpose of optical end effector calibration to the chuck center.

[0051] Fig. 3B shows, in accordance with an embodiment of the present invention, a simplified flow chart for calibrating the vertical position of the end effector relative to the upper surface of the chuck. In the flow chart of Fig. 3B, the vertical position of a laser beam (such as laser beam 232 of Fig. 2B) is ascertained for the purpose of vertically positioning the end effector during wafer transport and/or when preparing to place the wafer on the chuck. In step 370, a light source (such as a laser source) is attached to either the inside wall of the processing module at the desired height above the chuck or outside the processing module as shown in Fig. 2B. The laser source is aimed to transmit a laser beam substantially parallelly to the upper surface of the chuck at the desired height for end effector vertical positioning.

[0052] In step 372, a sensor that is capable of sensing the laser beam is attached to the end effector and configured such that the sensor is impinged upon by the laser beam as the end effector moves along a vertical calibration path, e.g., in the Z direction (down toward the chuck and/or up away from the chuck upper surface). In step 374, the end effector, including the aforementioned sensor, is moved in the Z direction across the laser beam. If the laser beam is detected by the sensor, the contemporaneous robot coordinates for the robot arm position is recorded. This vertical position may be employed by the robot arm controller for vertically positioning the end effector during wafer transfer and/or in preparation for wafer placement on the chuck.

[0053] As can be appreciated from the foregoing, embodiments of the invention enable the robot arm controller to ascertain, in the robot coordinate system, the position of the chuck and the chuck center in any given processing module. Alternatively or additionally, the robot arm controller can also ascertain, if desired, the robot coordinates corresponding to the vertical position of the robot arm during wafer transfer.

[0054] Since the use of a specialized hardware fixture that attaches to the chuck for the purpose of centering the end effector to the chuck is no longer necessary, the disadvantages with the prior art may be avoided. For example, by performing the calibration in-situ, the conditions during production is faithfully reproduced, resulting in a more accurate calibration process. These conditions include, for example, similar vacuum conditions and similar robot servo parameters. Since a mechanical fixture is not employed, the cost

[0055] Furthermore, the use a non-contact, non-physical calibration technique eliminates the possibility of calibration-related chuck damage and calibration-related particle contamination, making it possible to perform the calibration more frequently and/or in the middle of a production run without risking chamber and/or fabricated device damage.

[0056] DISCUSSION A [START]

[0057] In the processing of semiconductor substrates (e.g., wafers), plasma is often employed. In plasma processing, the wafers are processed using a plasma processing system, which typically includes a plurality of processing modules. The substrate (e.g., wafer) is disposed on a chuck inside a processing module during plasma processing.

[0058] In order to move a wafer in and out of the process module, the wafer is typically placed on an end effector and transferred onto the chuck. The end effector is a structural component configured for supporting the wafer during wafer transfer. The end effector is typically disposed on a robot arm. Fig. A1 shows a representative prior art end effector A102 for supporting a wafer A104 during wafer transfer. For illustration purposes, a portion of a robot arm A106 is also shown.

[0059] Generally speaking, during a wafer transfer sequence, the robot arm first moves the end effector to pick up the wafer from a wafer storage cassette or station. Once the wafer is positioned on the end effector, the robot arm would then move the wafer into the plasma process module through a door in the processing module. The robot arm then positions the end effector and the wafer over the chuck and then places the wafer on the chuck for plasma processing.

[0060] In order to ensure that the wafer is processed properly (thereby ensuring controllable and repeatable process results), the wafer needs to be centered on the chuck during plasma processing. If the end effector is perfectly centered relative to the chuck and the wafer is perfectly centered relative to the end effector, then the wafer would be perfectly centered relative the chuck when the robot arm places the wafer on the chuck.

[0061] From the robot controller's perspective, it is important to know the center of the chuck to enable the robot controller to center the end effector over the chuck for the purpose of wafer placement. Accordingly, for any given plasma processing module, the robot controller needs to be taught the position of the chuck and the chuck center. In other words, the robot controller needs to ascertain in its own coordinate system the exact location of the chuck and the chuck center since each chuck may be positioned slightly differently in

each processing module due to, for example, machining and/or manufacturing and/or assembly tolerances.

[0062] To compensate for the end effector/chuck mis-alignment, the typical strategy during calibration involves moving the robot arm to a position where the center defined by the end effector (herein referred to as the "end effector center" or the "end effector-defined center ") actually aligns with the center of the chuck. To accomplish end effector calibration, it is necessary that the operator be able to ascertain the actual end effector/chuck alignment position. In the prior art, the alignment of the end effector center to the chuck center is accomplished using a fabricated mechanical fixture which fits on the edge of the chuck or attaches to the process module interior. The mechanical fixture has a key feature (essentially a centering protrusion for the end effector), which allows the end effector to rest right up against the key feature of the calibration fixture. Since the fixture is centered relative to the chuck, when the end effector rests against the key feature of the fixture, the end effector center would be centered on the chuck. Typically, positioning the end effector against the key feature is accomplished by an operator pulling or pushing the end effector against the key feature so that the end effector rests against the key feature.

[0063] After the operator has positioned the end effector against the key feature, the operator then registers the robot arm position with the robot control system so that the robot control system can record, in the robot control's coordinate system, the position of the robot arm that achieves this actual end effector/chuck alignment.

[0064] During production, the robot arm moves the end effector to the coordinates associated with this effector/chuck alignment position. If the wafer is centered with respect to the end effector, the fact that the end effector center now actually aligns with the chuck center would cause the wafer to be centered relative to the chuck when the wafer is placed by the robot arm on the chuck for wafer processing.

[0065] However, there are disadvantages with the prior art technique for centering the end effector relative to the chuck for calibration purposes. First of all, there are many types of chucks and processing modules in existence. Therefore, in order to use the mechanical fixture approach to perform calibration, many different mechanical fixtures must be fabricated and stocked. Also, affixing a physical mechanical fixture, which may have one or more hard metal edges or surfaces, on the chuck may potentially damage the chuck. Additionally, if this calibration is done in the field after some plasma cycles have been executed in the processing module (e.g., in response to a concern that the end effector may not be centered relative to the chuck following a production run), the attachment of a physical

calibration fixture on the chuck may cause deposited particles on or near the chuck to flake off into the processing chamber. During the subsequent processing cycles, such particles constitute particle contamination, which is undesirable.

[0066] Additionally, because the calibration is performed at atmospheric pressure, the prior art calibration technique may not effectively duplicate the conditions that exist during production. This is because during production, components of the processing module may be placed under vacuum, causing one or more components to shift due to the pressure differential between the vacuum environment and the ambient atmosphere. Since the calibration conditions do not faithfully duplicate the production conditions, accurate calibration may not be possible.

[0067] Furthermore, if the positioning of the end effector at the end effector/chuck alignment position is performed manually (e.g., involving the operator pulling or pushing the end effector to rest up against the key feature of the mechanical fixture), there may be a shift in the robot arm position when the operator releases the robot arm to go and register this end effector/chuck alignment position with the robot controller. This shift may occur for many reasons, including for example the fact that the robot motors are de-energized. When the robot arm pulls away, even by a small amount that may be imperceptible to the robot operator, this shift may result in inaccuracy in the calibration process. If the calibration process is inaccurate, inaccurate wafer placement during production may occur, leading to decreased yield and an increase in the rejection and/or failure rate for the fabricated products.

[0068] Fig. A1 shows a representative prior art end effector for supporting a wafer during wafer transfer.

[0069] Fig. A2 shows, in accordance with an embodiment of the present invention, a schematic representation of a plasma processing system illustrating a top view of at least a portion of an in-situ optical end effector calibration system for calibrating the end effector in-situ.

[0070] Fig. A3 shows, in accordance with an embodiment of the present invention, an illustrative flow chart for the in-situ optical end effector calibration method.

[0071] Embodiments of the invention relate to in-situ methods and apparatus for performing end effector calibration without using a mechanical fixture or to suffer disadvantages associated with the prior art end effector calibration approach. As aforementioned, to perform end effector calibration, the end effector center or the end effector-defined center (i.e., the center defined/determined by the end effector, which may or may not necessarily be a mass or geometric center of the end effector) needs to be aligned

with the chuck center. To determine the actual end effector/chuck alignment, the prior art employs a mechanical fixture, which involves many disadvantages as discussed earlier.

[0072] In one or more embodiments of the invention, an in-situ optical technique is employed to determine the actual end effector/chuck alignment position. This determination process generates data that enables the robot controller to move the robot arm by a requisite amount during production to account for end effector/chuck mis-alignment.

[0073] In one or more embodiments of the invention, the in-situ optical end effector calibration technique involves taking a still image of the end effector and the chuck when the end effector and the chuck are in their theoretical end effector/chuck alignment (i.e., the position the end effector occupies relative to the chuck when the robot controller believes the end effector is theoretically centered with respect to the chuck). The end effector is provided with one or more visual indicators that enable the processing unit to determine from the still image taken the end effector-defined center. The chuck similarly has one or more visual indicators (such as the generally circular outline of the chuck periphery) to enable the processing unit to determine the center of the chuck.

[0074] Once the end effector center and the chuck center are determined by the processing unit, the offset (i.e., the "delta") between these two centers is computed. The position vector that is required to move the end effector from the theoretical end effector/chuck alignment position to the actual end effector/chuck alignment position is then computed. This position vector is then provided to the robot controller to enable the robot controller to compensate for end effector/chuck mis-alignment.

[0075] In one or more embodiments, the in-situ optical technique employs an image acquisition device (e.g., a camera and/or a lens) that can obtain the optical image of the end effector and the chuck while the end effector and the chuck are placed in the plasma processing chamber under production conditions. In other words, during the end effector calibration process, the plasma processing chamber may be placed under a vacuum condition substantially similar to the vacuum condition that exists during production. The camera and/or lens may be placed inside the plasma processing chamber or preferably outside the plasma processing chamber but has optical access (e.g., through an appropriately designed window or aperture) to an area of the end effector and the chuck that contain the aforementioned visual indicators. By performing calibration under conditions that are substantially identical to the conditions experienced during production, calibration errors that arise due to pressure differential may be substantially eliminated.

[0076] In one or more embodiments of the invention, the end effector is provided with a scribe line. The scribe line is positioned on the end effector such that during in-situ optical calibration, a still image may be taken of the scribe line. The scribe line on the end effector is configured, in an embodiment, to be an arc of a circle, the center of which coincides with the end effector-defined center. By ascertaining the arc and the center of the circle of which the scribe line/arc is a part of, the end effector-defined center may be determined. However, in other embodiments, it is contemplated that any alternative reference mark that can be employed to derive the end effector-defined center may also be employed.

[0077] Furthermore, during in-situ optical calibration, the image acquisition apparatus (camera and/or lens) is positioned such that the image also takes in part or all of the chuck periphery or visual indicators of or on the chuck that can be used to deduce the center of the chuck. As in the case with the end effector, one or more visual indicators may be provided for the chuck to allow the processing unit to ascertain the center of the chuck. In an embodiment, the outer periphery of the chuck itself constitutes such a desired visual indicator.

[0078] By ascertaining the circle that is described by the chuck visual indicator (e.g., the chuck circular periphery in an embodiment), the center of the chuck may be determined in an embodiment. As mentioned, once the end effector center and the chuck center are determined, the difference ("delta") may be determined and provided to the robot control system as a correcting factor to compensate for end effector/chuck mis-alignment.

[0079] The features and advantages of the invention may be better understood with reference to the figures and discussions that follow.

[0080] Fig. A2 shows, in accordance with an embodiment of the present invention, a schematic representation of a plasma processing system A220 illustrating a top view of at least a portion of an in-situ optical end effector calibration system A200 for calibrating the end effector in-situ (e.g., in plasma processing system A220 under semiconductor device production conditions) and without the need of a mechanical fixture. As seen in Fig. A2, the in-situ optical end effector calibration system A200 includes an end effector A202 having thereon a scribe mark A204. The scribe mark A204, in the example of Fig. A2, is an arc representing a portion of a circle, the center of which coincides with the center defined by the end effector A202. The determination of the center of a circle and the scribing of such an arc associated with the circle are within the skills of one skilled in the art.

[0081] Fig. A2 also shows a chuck A206, representing the chuck within a processing module. The in-situ optical end effector calibration technique is configured to determine, using an in-situ optical method, the center of the chuck and the end effector-defined center in order to generate the necessary correction vector for the robot arm control system A222. During calibration, an image acquisition device A250 (e.g., a camera disposed above end effector A202 and chuck A206) may take at least a still image of at least a portion of end effector A202, including scribe mark A204, and of at least a portion of chuck A206. Note that a portion of chuck A206 may be hidden under end effector A202 if the image is taken from overhead from a camera and/or lens arrangement.

[0082] Nevertheless, a processing unit A224 (for example, included in logic module A210) may be able to reconstruct the circle that is formed by the circular periphery of chuck A206 as well as determine the center of that circle (which represents the center of chuck A202). Likewise, processing unit A224 (for example, included in logic module A210) may be able to reconstruct the circle of which scribe line/arc A204 is a part of as well as to determine the center of that circle. This circle is represented in Fig. A2 by dashed circle A212.

[0083] Fig. A2 also shows an end effector center A214, representing the end effector-defined center A202 as determined by the aforementioned processing unit A224. A chuck center A216 is also shown, representing the center of chuck A206. The difference vector A218 from end effector center A214 to chuck center A216 is then generated. Since end effector center A214 represents the theoretical end effector/chuck alignment position and chuck enter A216 represents the actual end effector/chuck alignment position, the positional difference vector A218 represents the correction that is needed to align the end effector center A214 with chuck center A216. When end effector A214 is aligned with chuck center A216, the actual end effector/chuck alignment is achieved. By providing this difference vector A218 to the robot control system A222, the robot control system A222 is able to move the robot by a distance and direction provided by the positional difference vector A218 from end effector center A214 during production, thereby effectively correcting for the end effector/chuck mis-alignment.

[0084] Fig. A3 shows, in accordance with an embodiment of the present invention, an illustrative flow chart for the in-situ optical end effector calibration method. The method may be performed by, for example, utilizing one or more of the components discussed with reference to the example of Fig. A2. In step A302, the end effector is moved by the robot arm to the theoretical end effector/chuck alignment, i.e., the position the robot control system

deems have theoretically centered the end effector relative to the chuck. In step A304, a still image is taken of the end effector, the visual indicator on the end effector, and the chuck in the manner discussed in connection with Fig. A2.

[0085] In step A306, image processing is undertaken to acquire the visual indicator on the end effector (e.g., the aforementioned scribe mark) and to determine the circle that is formed by the outer periphery of the chuck. To assist the processing unit, the camera and/or lens may be configured such that the light frequency, the lighting condition, the aperture, the focus, and/or the field-of-view, etc., is optimal for the processing unit to acquire the visual indicators that provide the data to determine the end effector center and the chuck center.

[0086] In an embodiment, step A308 involves generating a plurality of data points along contrasting pixels in the image and performing curve fitting to re-create the desired circles. Such image processing techniques and curve fitting techniques are well-known to those skilled in the art in other fields and can be accomplished using many generic off-the-shelf processing unit packages (such as for example the Keyence communication software for use with CV-3002 Series Controller CV-H3N, available from Keyence Corporation of Woodcliff Lake, NJ).

[0087] In step A310, the end effector-defined center is ascertained from the circle recreated by the processing unit from the end effector visual indicator (e.g., the scribe line). In step A312, the center of the chuck is ascertained from the circle recreated by the processing unit from the chuck visual indicator (e.g., the outer periphery of the chuck). In step A314, the difference vector from the end effector center to the chuck center is determined. In step A316, this difference vector is provided to the robot control system to enable the robot control system to move the robot arm during production to compensate for the end effector/chuck mis-alignment.

[0088] As can be appreciated from the foregoing, embodiments of the invention achieve end effector calibration in a manner that is substantially free of the disadvantages associated with the prior art mechanical fixture calibration approach. By performing the calibration in-situ, the conditions during production is faithfully reproduced, resulting in a more accurate calibration process. These conditions include, for example, similar vacuum conditions and similar robot servo parameters. Since a mechanical fixture is not employed, the cost associated with manufacturing and keeping a large inventory of different mechanical calibration fixtures for different plasma processing modules is eliminated. Furthermore, the use a non-contact, non-physical calibration technique eliminates the possibility of calibration-related chuck damage and calibration-related particle contamination, making it possible to

perform the calibration more frequently and/or in the middle of a production run without risking chamber and/or fabricated device

[0089] DISCUSSION A [END]

[0090] DISCUSSION B [START]

[0091] In the processing of semiconductor substrates (e.g., wafers), plasma is often employed. In plasma processing, the wafers are processed using a plasma processing system, which typically includes a plurality of processing modules. The substrate (e.g., wafer) is disposed on a chuck inside a processing module during plasma processing.

[0092] In order to move a wafer in and out of the processing module, the wafer is typically placed on an end effector and transferred onto the chuck. The end effector is a structural component configured for supporting the wafer during wafer transfer. The end effector is typically disposed on a robot arm. Fig. B1 shows a representative prior art end effector B102 for supporting a wafer B104 during wafer transfer. For illustration purposes, a portion of a robot arm B106 is also shown.

[0093] Generally speaking, during a wafer transfer sequence, the robot arm first moves the end effector to pick up the wafer from a wafer storage cassette or station. Once the wafer is positioned on the end effector, the robot arm would then move the wafer into the plasma processing module through a door in the processing module. The robot arm then positions the end effector and the wafer over the chuck and then places the wafer on the chuck for plasma processing.

[0094] In order to ensure that the wafer is processed properly (thereby ensuring controllable and repeatable process results), the wafer needs to be centered on the chuck during plasma processing. If the end effector is correctly centered relative to the chuck and the wafer is correctly centered relative to the end effector, then the wafer would be correctly centered relative the chuck when the robot arm places the wafer on the chuck. However, for many reasons, some of which are discussed below, this ideal scenario is rarely the case.

[0095] Due to machining and/or manufacturing tolerances between the various components of the processing chamber, it is possible that the center defined by the end effector (herein referred to as the "end effector center" or the "end effector-defined center ") is slightly offset relative to the center of the chuck in a given processing module. As a result, it is possible that the center defined by the end effector may not be correctly aligned with the center of the chuck at the robot arm position that the robot controller deems to be the correct position for wafer placement. If this end effector/chuck mis-alignment is not compensated for during production, the wafer may be inaccurately placed relative to the chuck center

during wafer processing. In a co-pending patent application entitled "SYSTEMS AND METHODS FOR CALIBRATING END EFFECTOR ALIGNMENT IN A PLASMA PROCESSING SYSTEM," Attorney Docket Number LMRX-P143/P1747, filed on even date herewith by the inventors herein and incorporated herein by reference, techniques have been proposed to address this end effector/chuck mis-alignment.

[0096] However, even if the end effector center is correctly aligned with the chuck center (or can be made to achieve the effect of a correct alignment), there exists another potential source of error that may result in wafer/chuck mis-alignment during production. That is, different production wafers may be positioned on the end effector differently. If the end effector center is not correctly or consistently aligned with the center of the wafers, wafer/chuck mis-alignment may still occur during production. In this case, even though the end effector center is correctly aligned with the chuck center, the wafer/end effector mis-alignment will cause the wafer to be offset relative to the chuck when the end effector deposits the wafer on the chuck for processing.

[0097] Unlike the end effector/chuck misalignment problem, which tends to be a consistent error for all wafers in a given processing module since that alignment error arises from chamber component tolerances and robot calibration issues, the wafer/end-effector mis-alignment may vary with each production wafer. In other words, each production wafer may be positioned on the end effector differently, resulting in differences in the mis-alignment. Accordingly, the solution to address such end effector/wafer misalignment requires a dynamic approach, i.e., one that can adjust for the error of each individual production wafer relative to the end effector during production.

[0098] In the prior art, the end effector/wafer mis-alignment is addressed using a dynamic alignment beam approach. A dynamic alignment (DA) beam detection system typically employs two beams (i.e. laser beams) located at the entrance of the plasma processing module door. As the wafer moves through the DA beams (with the beams being orthogonal to the wafer translation plane), the DA beams are broken as the wafer enters the beam, and then resumed at the point where the wafer is no longer present. This pattern of beam signal break-then-make generates a production DA beam pattern.

[0099] In the dynamic alignment beam approach, it is necessary to obtain a reference DA beam pattern, i.e., the DA beam pattern that is generated when a wafer that is correctly centered on the end effector moves through the DA beams. By comparing the production DA beam pattern (i.e., the beam pattern obtained for a production wafer) with the reference DA

beam pattern, an error vector may be obtained. The robot controller can them move the robot arm by the requisite amount to correct for the end effector/wafer mis-alignment during production. Further information regarding dynamic alignment beams may be found in, for exampled, issued US Patent Nos. 6,502,054 and 6,629,053, incorporated herein by reference.

[00100] The process of obtaining a reference DA beam pattern is referred to herein as DA beam calibration. In order to calibrate the DA beams, it is necessary then to acquire or obtain a DA beam calibration assembly that includes a wafer correctly centered on the end effector and to move that DA beam calibration assembly through the DA beams so a reference DA beam pattern can be acquired.

[00101] In the prior art, the DA beam calibration assembly is obtained using a fabricated disk, which simulates a wafer. The disk has a downward protruding flange that fits on a notch of the end effector (such as notch B110 of end effector B102 in Fig. B1). Once the disk is fitted to the notch of the end effector, this combination simulates a correctly centered wafer with respect to end effector. The combination of simulated wafer/end effector is then moved by the robot arm into the processing module in a straight line trajectory path toward the chuck through the DA beams in order to obtain a reference DA beam pattern.

[00102] However, there are disadvantages with the prior art technique of using a wafer-simulating disk to create a calibration assembly for the purpose of obtaining a reference DA beam pattern. First of all, attaching a physical mechanical fixture (such as the wafer-simulating disk) on the end effector may potentially damage the end effector.

Additionally, if this calibration is done in the field after some plasma cycles have been executed in the processing module, the placement of a physical or mechanical fixture on the end effector may cause deposited particles on or near the end effector to flake off into the processing module. During the subsequent processing cycles, such particles constitute particle contamination, which is undesirable.

[00103] Additionally, because the calibration is performed at atmospheric pressure, the prior art calibration technique may not effectively duplicate the conditions that exist during production. This is because during production, components of the processing module may be placed under vacuum, causing one or more components to shift due to the differential in pressures between the vacuum environment and the ambient atmosphere. Since the calibration conditions do not faithfully duplicate the production conditions, accurate calibration may not be possible. If the calibration process is inaccurate, inaccurate wafer placement during production may occur, leading to decreased yield and an increase in the product rejection and/or failure rate.

[00104] Embodiments of the invention relate to methods and apparatus for creating a DA beam calibrating assembly for the purpose of calibrating the DA (dynamic alignment) beams. In an embodiment, the wafer-centering requirement (of the calibration wafer relative to the end effector) of the DA beam calibrating assembly is simulated using the robot arm movement to compensate for an incorrectly centered calibration wafer on the end effector. An optical wafer-centering method is employed to determine the amount of correction required by the robot arm to compensate for the incorrect end effector/wafer alignment. By compensating for the incorrect end effector/wafer alignment using robot arm movement, the effect of a correctly centered wafer on an end effector is achieved through simulation.

[00105] Once the robot arm has moved by a requisite amount to compensate for the incorrect end effector/wafer alignment (using compensation data acquired through the aforementioned optical wafer-centering method), the resultant DA beam calibrating assembly may be moved through the DA beams to obtain the desired reference DA beam pattern. Advantageously, embodiments of the invention achieve DA beam calibration without the need of a mechanical fixture (e.g., wafer-simulating disk) or suffering the disadvantages associated with the prior art DA beam calibration approach.

[00106] In one or more embodiments of the invention, an optical wafer-centering technique is employed to determine the location of the calibration wafer (i.e., the wafer employed for DA beam calibration) relative to the end effector-defined center. Note that the calibration wafer may represent any wafer or wafer blank that is substantially similar to the wafers used in production. This optical wafer-centering process produces data that enables the robot controller to move the robot arm by a requisite amount to adjust for any offset between the calibration wafer center and the end effector center.

[00107] In one or more embodiments of the invention, at least a still image is taken of at least a portion of the calibration wafer and at least a portion of the end effector when the calibration wafer is disposed on the end effector. The end effector is provided with one ore more visual indicators that enable a processing unit to determine, from the still image taken, the end effector-defined center. In one or more embodiments of the invention, the end effector is provided with a scribe line (or any reference mark that forms an arc of a circle). The scribe line is positioned on the end effector such that a still image may be taken of the scribe line even if a wafer is disposed on the end effector. The scribe line on the end effector is configured, in an embodiment, to be an arc of a circle, the center of which coincides with the end effector-defined center. By ascertaining the arc and the center of the circle of which the scribe line is a part of, the end effector-defined center may be determined.

[00108] The wafer similarly has one ore more visual features (such as the generally circular outline of the wafer periphery) to enable the processing unit to determine the center of the wafer. As in the case with the end effector, one or more visual indicators may alternatively or additionally be provided for the calibration wafer to allow the processing unit to more efficiently ascertain the center of the wafer. In a preferred embodiment, however, the outer periphery of the wafer itself constitutes such a desired visual indicator. Once the wafer center and the end effector center are determined by the processing unit, the offset (i.e., the "delta") between these two centers are computed.

[00109] Generally speaking there are at least two techniques to correct a wafer/end effector misalignment. The first technique is physical correction. Physical correction is accomplished by moving the end effector and wafer to a holding station. The wafer is then placed on the holding station and then the robot arm moves the end effector by a distance "delta" to correct for the offset found by the optical wafer-centering method. The end effector then picks up the wafer again for optical analysis. In effect, a physical repositioning the wafer on the end effector is performed. The process may be performed iteratively until the wafer is found to have centered satisfactorily on the end effector.

[00110] The second technique to correct a wafer/end effector misalignment is to move the robot arm, which effectively moves the end effector and wafer assembly, by the error correction vector based on data determined by the optical wafer-centering process. This movement simulates, to the DA beams, the wafer position that the calibration wafer would have occupied had the calibration wafer been correctly centered on the end effector. After such correction, the end effector/wafer assembly may be moved through the DA beams (preferably in a straight line) to acquire the desired reference DA beams.

[00111] The features and advantages of the invention may be better understood with reference to the figures and discussions that follow.

[00112] Fig. B2 shows, in accordance with an embodiment of the present invention, a schematic representation of a plasma processing system B220 illustrating a top view of at least a portion of an optical wafer-centering system for enabling the creation or simulation of a correctly centered wafer/end effector assembly for DA beam calibration purposes. As seen in Fig. B2, the optical wafer-centering system includes an end effector B202 having thereon a scribe mark B204. The scribe mark B204, in the example of Fig. B2, is an arc representing a portion of a circle, the center of which coincides with the end effector-defined center.

[00113] Fig. B2 also shows a wafer B206, representing the calibrating wafer to be employed to create the reference DA beam pattern. The optical wafer-centering system is

configured to determine, using an optical method, the center of the wafer and the end effector-defined center in order to perform actual centering of the wafer on the end effector or to simulate a correctly centered wafer on the end effector for DA beam calibration purposes.

[00114] During optical wafer centering, an image acquisition device B250 (e.g., a camera disposed above end effector B202 and wafer B206) may take at least a still image of end effector B202, including scribe mark B204, and of wafer B206. Note that a portion of end effector B202 may be hidden under wafer B206 if the still image is taken from overhead from a camera and/or lens arrangement. Irrespective, it is important that some or all of scribe mark B204 be captured in the still image.

[00115] A processing unit B224 (for example, included in logic module B208) may be able to reconstruct the circle that is formed by the circular periphery of wafer B206 as well as to determine the center of that circle (which represents the center B210 of wafer B206). Likewise, processing unit B224 (for example, included in logic module B208) may be able to reconstruct the circle of which scribe line B204 is a part of as well as to determine the center of that circle. This circle is represented in Fig. B2 by dashed circle B212.

[00116] Fig. B2 also shows an end effector center B214, representing the end effector-defined center B202 as determined by the aforementioned processing unit. The delta B216 (i.e. the calculated difference from wafer center B210 to end effector center B214) is then generated. This delta B216, representing the correction factor employed by the robot arm to move the calibration wafer from its current position (which is incorrectly centered relative to the end effector) to the position that the correctly centered calibration wafer would have occupied.

[00117] In other words, once this correction is made by the robot arm, the wafer disposed on the end effector will appear to the DA beams in the same way that a wafer correctly centered on the end effector would appear. By recording the break-and-make patterns of the DA beams, a reference DA beam pattern may be obtained. As discussed, this reference DA beam pattern may be used during production to compare against the production DA beam pattern (i.e., the DA beam pattern made with a production wafer) to determine the amount of robot arm correction required for that production wafer during production.

[00118] Alternatively, as discussed earlier, the robot arm may move the calibration wafer to a holding station or holding jig. Once the calibration wafer is deposited on the holding station or holding jig, the robot arm may move the end effector by the positional correction vector (obtained during the optical wafer-centering process) to reposition the end effector relative to the calibration wafer. The process of imaging, analyzing for offsets, and

repositioning the wafer on the end effector may be performed iteratively until the wafer is centered on the end effector satisfactorily. The resultant calibration fixture (i.e., a correctly centered wafer on the end effector) is then employed to obtain the reference DA beam pattern in the manner discussed earlier.

[00119] In an embodiment, the optical wafer-centering system may be performed in-situ (e.g., using a camera and/or lens arrangement that can obtain a still image while the wafer and the end effector are disposed inside the processing module). In the same or in an alternate embodiment, the processing module is placed under conditions that substantially approximate the production conditions. Although not absolutely necessary, in-situ optical wafer centering and/or in-situ DA beam calibration advantageously allows centering and/or calibration to be performed in conditions substantially similar to the production conditions, thereby reducing centering-related errors and/or calibration-related errors.

[00120] Once the still image is taken in-situ, the assembly that includes the calibration wafer and the end effector is removed from the processing module. Any desired correction may then be made to account for the end effector/wafer mis-alignment. After the correction is made, the assembly that includes the calibration wafer and the end effector is introduced into the processing module again through the DA beams to produce the desired reference DA beam pattern.

[00121] In another embodiment, the optical wafer-centering technique may be performed outside of the processing module. Once the still image is taken and analyzed and any necessary correction is made, the calibration assembly that includes the calibration wafer and the end effector is introduced into the processing module again through the DA beams to produce the desired DA beam pattern.

[00122] Fig. B3 shows, in accordance with an embodiment of the present invention, a illustrative flow chart of the steps for creating or simulating a centered wafer relative to the end effector-defined center using an optical wafer-centering technique in order to facilitate DA beam calibration. The method may be performed by, for example, utilizing one or more of the components discussed with reference to the example of Fig. B2. In step B302, a wafer is placed on the end effector such that a still image, including one or more visual indicators on the end effector and one or more visual indicator of the wafer can be taken.

[00123] In step B304, a still image is taken of the end effector, the one ore more visual indicators on the end effector, and the wafer in the manner discussed in connection with Fig. B2.

[00124] In step B306, image processing is undertaken to determine the one or more visual indicator on the end effector (e.g., the aforementioned scribe line) and to determine the circle that is formed by the outer periphery of the wafer. In an embodiment, the still image is analyzed for contrast. To assist a processing unit, the camera and/or lens may be configured such that the light frequency, the lighting condition, the aperture, the focus, the field-of-view, etc., are optimal for determining the contrast and to allow the processing unit to acquire the visual indicators that provide data to determine the end effector center and the wafer center. One in art would readily appreciate from the foregoing that the control of these parameters and conditions, as well as other image-related parameters, may be undertaken to improve the contrast in the image and/or render image processing more accurate.

[00125] In an embodiment, step B308 involves generating a plurality of data points along contrasting pixels in the still image and performing curve fitting to re-create the desired circle. Such image processing techniques and curve fitting techniques are well-known to those skilled in the art in other fields and can be accomplished using many generic off-the-shelf processing unit packages (such as for example the Keyence communication software for use with CV-3002 Series Controller CV-H3N, available from Keyence Corporation of Woodcliff Lake, NJ).

[00126] In step B310, the end effector-defined center is ascertained from the circle recreated by the processing unit from the end effector visual indicator (e.g., the scribe line).

[00127] In step B312, the center of the wafer is ascertained from the circle recreated by the processing unit from the wafer visual indicator (e.g., the outer periphery of the wafer).

[00128] In step B314, the difference between the two centers (i.e. the calculated difference from wafer center to end effector center) is then generated. For example, in an embodiment, the DA beam patterns are employed to reconstruct the two circles representing the two wafers (e.g., the production wafer and the calibration wafer) in order to ascertain their centers (and the difference between the wafer centers). An algorithm is then employed in order to determine the positional correction vector required to move the robot arm to allow the wafer that is incorrectly centered with respect to the end effector to appear to the DA beams as if that wafer is corrected centered with respect to the end effector.

[00129] In step B316, this error vector is provided to the robot controller to allow the robot controller to perform the compensation. Once the end effector/wafer mis-alignment is compensated for, the calibration fixture that includes the calibrating wafer and the end effector is moved through the DA beams, preferably in a straight-line manner, to obtain the aforementioned reference DA beam pattern.

[00130] As can be appreciated from the foregoing, embodiments of the invention facilitate the acquisition of a reference DA beam pattern in a manner that is free of the disadvantages associated with the prior art mechanical fixture approach. Furthermore, the elimination of the need to use an especially constructed disk for simulating a correctly centered wafer eliminates the introduction of unfamiliar hardware into the plasma processing module, thereby reducing the possibility of calibration-related end effector damage and calibration-related particle contamination.

[00131] 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. For example, although the visual indicator of the example herein is an arc, any other visual marking capable of enabling the processing unit to produce the end effector center and/or the wafer center may be employed.

[00132] DISCUSSION B [END]

[00133] Although various examples are provided herein, it is intended that these examples be illustrative and not limiting with respect to the invention. 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 calibrating alignment of an end effector with respect to a chuck in a plasma processing system, said method comprising:

providing a first light beam from said end effector to said chuck;

moving said end effector along a predefined calibration path such that said first light beam traverses a surface of said chuck;

receiving a set of reflected light signals, said set of reflected light signals being generated at least when said surface reflects said first light beam during the moving;

analyzing said set of reflected light signals to identify three or more discontinuities, wherein said three or more discontinuities are related to three or more reflected light signals generated when said first light beam encounters an edge of said chuck;

determining three or more coordinate data points based on the three or more discontinuities, said three or more coordinate data points representing three or more points on said edge of said chuck; and

determining a center of said chuck based on the three or more coordinate data points.

2. The method of claim 1 further comprising mounting a light source to an end effector defined center of said end effector for generating said first light beam.

3. The method of claim 1 further comprising mounting a light source at known offset distance from an end effector defined center of said end effector for generating said first light beam.

4. The method of claim 1 wherein said three or more discontinuities are four or more discontinuities.

5. The method of claim 1 further comprising providing said center of said chuck to a robot controller to enable said robot controller to calibrate said end effector to said center of said chuck.

6. A method of claim 1 further comprising

providing a second light beam such that said second light beam is transmitted parallel to an upper surface of said chuck at a predetermined height above said upper surface of said chuck;

moving said end effector along a second predefined calibration path;

detecting said second light beam when a sensor encounters said second light beam, said sensor being mounted to said end effector; and

recording one or more coordinate data points, said one or more coordinate data points representing one or more detections of said second light beam.

7. An end effector calibration system for calibrating alignment of an end effector with respect to a chuck in a plasma processing system, said system comprising:

a light source, said light source configured for providing a first light beam from said end effector to said chuck;

a robot arm, said robot arm configured for moving said end effector along a first predefined calibration path such that said first light beam traverses a surface of said chuck;

a sensor, said sensor configured for receiving a set of reflected light signals, said set of reflected light signals being generated at least when said surface reflects said first light beam during the moving;

a processing unit, said processing unit configured for at least one of

analyzing said set of reflected light signals to identify three or more discontinuities, wherein said three or more discontinuities are related to three or more reflected light signals generated when said first light beam encounters an edge of said chuck,

determining three or more coordinate data points based on the three or more discontinuities, said three or more coordinate data points representing three or more points on said edge of said chuck, and

determining a center of said chuck based on the three or more coordinate data points.

8. The system of claim 7 wherein said light source is configured to be mounted to an end effector defined center of said end effector for generating said first light beam.

9. The system of claim 7 wherein said light source is configured to be mounted a known offset distance from an end effector defined center of said end effector for generating said first light beam.

10. The system of claim 7 wherein at least a portion of said sensor is implemented inside a plasma processing chamber.

11. The system of claim 7 wherein said three or more discontinuities are four or more discontinuities.

12. A system of claim 7 further comprising

a second light source for providing a second light beam, said second light beam configured to be transmitted parallel to an upper surface of said chuck at a predetermined height above said upper surface of said chuck,

wherein said robot arm is also configured for moving said end effector along a second predefined calibration path,

at least one of said sensor and a second sensor is configured for detecting said second light beam when said sensor encounters said second light beam, said second sensor being mounted to said end effector, and

said processing unit is also configured for recording one or more coordinate data points, said one or more coordinate data points representing one or more detections of said second light beam.

13. A method for calibrating a vertical position of an end effector relative to an upper surface of a chuck, in a plasma processing system, said method comprising:

providing a light beam such that said light beam is transmitted parallel to said upper surface of said chuck at a predetermined height above said upper surface of said chuck;

moving said end effector along a predefined calibration path;

detecting said light beam when a sensor encounters said light beam, said sensor being mounted to said end effector; and

recording one or more coordinate data points, said one or more coordinate data points representing one or more detections of said light beam.

14. The method of claim 13 further comprising mounting a light source to a inside wall of a processing module at said desired height above said upper surface of said chuck for generating said light beam.

15. The method of claim 13 further comprising mounting at least a portion of a light source inside a processing module for generating said light beam.