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SYSTEM FOR THERMAL TESTING A WAFER CHUCK AND METHODS FOR PERFORMING THE SAME

Abstract

A system for testing a wafer chuck includes: a thermal test vehicle (TTV) that includes a substrate and thermal probes disposed on the substrate; and a vehicle controller configured to control heating of the substrate by the thermal probes and to store temperature data generated by the thermal probes.

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Background/Summary

BACKGROUND

[0001] The semiconductor industry has continually grown due to continuous improvements in integration density of various electronic components, e.g., transistors, diodes, resistors, capacitors, etc. For the most part, these improvements in integration density have come from successive reductions in minimum feature size, which allows more components to be integrated into a given area.

[0002] In addition to smaller electronic components, improvements to the packaging of components seek to provide smaller packages that occupy less area than previous packages. Examples of the type of packages for semiconductors include quad flat pack (QFP), pin grid array (PGA), ball grid array (BGA), flip chips (FC), three-dimensional integrated circuits (3DICs), wafer level packages (WLPs), package on package (POP), System on Chip (SoC) or System on Integrated Circuit (SoIC) devices. Some of these 3D devices (e.g., 3DIC, SoC, SoIC) are prepared by placing chips over chips on a semiconductor wafer level. These three-dimensional devices provide improved integration density and other advantages, such as faster speeds and higher bandwidth, because of the decreased length of interconnects between the stacked chips. However, there are many challenges related to the testing of high performance semiconductor devices, such as three-dimensional devices.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0004] FIG. **1** is a schematic view of a chuck testing system including a thermal test vehicle (TTV), according to various embodiments of the present disclosure.

[0005] FIG. **2**A is a partially transparent view of a chuck of FIG. **1**.

[0006] FIG. **2**B is a plan view of a TTV of FIG. **1** disposed on the chuck.

[0007] FIG. **2**C is an enlarged view of a thermal probe of the TTV of FIG. **2**B.

[0008] FIG. **3** is a partially transparent plan view of a TTV disposed on a wafer chuck, according to various embodiments of the present disclosure.

[0009] FIG. **4** is a flow diagram illustrating a chuck testing method according to various embodiments of the present disclosure.

[0010] FIG. **5** is a graph showing probe power and temperature measurements taken during continuous ramp heating and pulse ramp heating tests, according to various embodiments of the present disclosure.

DETAILED DESCRIPTION

[0011] The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0012] Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly. Unless explicitly stated otherwise, each element having the same reference numeral is presumed to have the same material composition and to have a thickness within a same thickness range.

[0013] The 3D packaging of integrated circuit chips on a semiconductor wafer involves the vertical stacking of semiconductor devices on a wafer substrate and is considered a key packaging technique in the post-Moore's law era. For example, logic and memory chips or device layers may be vertically stacked to form a 3D structure. 3D packaging increases the density of semiconductor device layers of a chip, which reduces not only the footprint of the semiconductor device but also beneficially reduces a current flow path between device layers, as compared to other 2D packaging methods that include semiconductor devices arranged in a horizontal plane.

[0014] In order to provide further compact packaging, wafer substrates may be thinned by various grinding processes, such as back grinding. In general, such methods include supporting a wafer between a rotating chuck and a counter rotating grinding wheel, while cooling the wafer with deionized water. The reduced size and weight of thinned wafers provides for the production of smaller and more compact circuits, such as integrated circuit packages for use in compact electronic devices.

[0015] However, thinned wafers may be more susceptible to unwanted changes in wafer topography. In particular, wafer topography is the thickness distribution of a wafer, which may greatly impact wafer quality. The topography of a semiconductor wafer may directly impact the number of device layers that may be formed thereon and/or may even cause difficulties during subsequent processing and/or testing. For example, thinner semiconductor wafers may be more susceptible to warpage due to thermal variations and/or warpage due to surface variations in an underlying support device such as a wafer chuck.

[0016] A wafer prober is a machine used to verify the functionality of integrated circuits formed on a wafer. A wafer prober may be used to electrically test integrated circuits formed on a wafer. The wafer prober may include a probe card including a set of microscopic contacts or probes. During testing, the probes may be moved into electrical contact with a wafer under test. The wafer under test may be vacuum mounted on a wafer chuck. The electrical testing of high performance devices may require a high voltage and/or a high current, which may generate high temperatures in tested devices. High temperatures may reduce product yields and/or damage probe cards. For example, high temperatures may damage contact pads, probe tips, and/or transistors.

[0017] Wafer chucks may be designed to dissipate heat generated during wafer testing. However, the heat dissipation performance of different wafer chucks may vary by a wide margin. For example, wafer chucks may be designed to operate at extremely high or extremely low temperatures. Wafer chucks may have widely varying temperature ramping speeds. In addition, the heat dissipation performance of wafer chucks may vary from chuck-to-chuck, even among in wafer chucks produced in the same batch or manufacturing process. The heat dissipation performance of a wafer chuck may also vary in different regions of the same wafer chuck. Moreover, different wafer chucks may have very different heat dissipation capabilities.

[0018] The surface flatness of a wafer chuck may also affect heat dissipation performance. For example, surface flatness irregularities may result in contact area variations, which may in turn produce higher and/or lower amounts of wafer-to-chuck heat transfer in different regions of a wafer. As such, maximizing the surface flatness of a wafer chuck may produce ideal contact area for a wafer. Surface flatness and/or heat dissipation uniformity may be especially important when testing thinned semiconductor devices since such devices are more susceptible to thermal and surface flatness variations. For example, small surface and/or temperature variations may result in the disconnection of a wafer from a test prober due to wafer warping. In addition, temperature variations resulting from inadequate cooling may result in excess heat accumulation, which may damage a semiconductor wafer being tested.

[0019] Currently, there is no standardized method of measuring chuck characteristics, such as surface flatness and/or heat dissipation performance. As such, it may be difficult to identify wafer chucks that are suitable for particular applications and to insure wafer chuck quality control. For example, other methods of wafer chuck testing may involve placing a product semiconductor wafer on a chuck, positioning a prober card over the wafer and in electrical contact with contact pads or elements of the wafer, and then utilizing a special test program to apply current to the product semiconductor wafer, in order to heat the product semiconductor wafer and stress the wafer chuck. However, the results of such testing is highly case specific. In addition, such testing often results in prober card damage. Therefore, there is a desire to provide improved wafer chuck performance and quality control testing.

[0020] FIG. **1** is a schematic view of a wafer chuck testing system **10**, according to various embodiments of the present disclosure. FIG. **2**A is a partially transparent view of a wafer chuck **310** of FIG. **1**, FIG. **2**B is a plan view of a thermal test vehicle (TTV) **200** of FIG. **1** disposed on the wafer chuck **310**, and FIG. **2**C is an enlarged view of a thermal probe **210** of the TTV **200** of FIG. **2**B.

[0021] Referring to FIGS. **1-2**C, the system **10** may include a vehicle controller **100** and a thermal test vehicle (TTV) **200**. In various embodiments, the system **10** may be used in conjunction with a wafer prober **300** that may include a wafer chuck **310**, a wafer chuck support **320**, a cooler **330**, and a prober controller **350**.

[0022] The vehicle controller **100** may include a processor **102**, a display **104**, one or more switches **106**, power contacts **110**, and/or sensor contacts **112**. The processor **102** may be a central processing unit including a control unit, a logic unit (e.g., a programmable logic circuit), and/or a memory. The processor **102** may be electrically connected to the display **104**, the switch **106**, the power contacts **110**, and the sensor contacts **112**. The processor **102** may be configured to execute testing protocols stored in the memory. For example, the processor **102** may be configured to control power output to the power contacts **110** based on a testing protocol that may be selected using the switch **106**. The processor **102** may also be configured to process and/or store data from the sensor contacts **112**, such as temperature data.

[0023] In some embodiments, the prober controller **350** may be a computer configured to control the wafer prober **300**. The vehicle controller **100** may be electrically connected to the prober controller **350**. For example, data collected by the vehicle controller **100** from the TTV **200** may be stored and/or analyzed in the prober controller **350**.

[0024] The wafer chuck **310** may have a flat upper surface configured to support a wafer during wafer testing. The wafer chuck **310** may include at least one position sensor **312** to determine the position of a wafer on the upper surface of the wafer chuck **310**. The wafer chuck **310** may be configured to absorb heat from a wafer during testing. For example, the wafer chuck **310** may be formed of a thermally conductive material, such as a metal or ceramic material. The wafer chuck **310** may also include an internal coolant line **314** configured to receive a cooling fluid such as water, nitrogen, or clean dry air. In some embodiments, the coolant line **314** may be arranged in generally concentric rings as shown in FIG. **2**A. However, the wafer chuck **310** may have any suitable coolant line **314** configuration, such as a serpentine configuration, a parallel configuration, or the like. In some embodiments, the wafer chuck **310** may have two or more coolant lines **314**.

[0025] The cooler **330** may be configured to circulate the cooling fluid through the coolant line **314** to cool the wafer chuck **310**. In some embodiments, the cooler **330** may include a heat exchanger or the like to cool the cooling fluid. For example, the cooler **330** may be configured to cool relatively high temperature cooling fluid received from the wafer chuck **310** and provide relatively low temperature cooled cooling fluid to the wafer chuck **310**.

[0026] The temperature of the cooling fluid may increase as it flows through the wafer chuck **310**, due to absorbing heat from the wafer chuck **310**. As such, the heat dissipation properties of the wafer chuck **310** may vary throughout all portions of the wafer chuck **310**. For example, the center of the wafer chuck **310** may be capable of absorbing more heat than other regions of the wafer chuck **310**, due to the configuration of the coolant line **314**. Manufacturing defects in the wafer chuck **310** and/or coolant line **314** may also result in wafer chuck **310** temperature variations. For example, surface flatness variations, material density variations, and/or coolant line diameter variations may produce temperature variations in the wafer chuck **310** during heating and/or cooling processes.

[0027] Accordingly, the TTV **200** may be configured to detect temperature variations in the wafer chuck **310**. For example, the TTV **200** may be configured to detect temperature variations of as little as 0.25° C. or less. As shown in FIGS. **2**B and **2**C, the TTV **200** may include a substrate **202** having a bottom surface and an opposing top surface, and one or more thermal probes **210** disposed on the top surface of the substrate **202**. The bottom surface of the substrate **202** may be planar and may be configured to directly contact the planar top surface of the wafer chuck **310**.

[0028] In various embodiments, the TTV **200** may include any suitable number of thermal probes **210**. For example, the TTV **200** may include seven (7) thermal probes **210**A-**210**G as shown in FIG. **2**B. However, a greater or lesser number of thermal probes **210** may be used. For example, the TTV **200** may include from 4 to 14 thermal probes **210**, such as from 5 to 12 thermal probes **210**, or from 6 to 10 thermal probes **210**. The substrate **202** may be a wafer formed of a semiconductor material, such a silicon, gallium arsenide, gallium nitride, silicon carbide, or the like. However, the substrate **202** may be formed of any suitable thermally conductive material, such as a metal or ceramic material.

[0029] The thermal probes **210** may include a heater **212**, an inner temperature sensor **214**, and an outer temperature sensor **216**. The thermal probes **210** may be disposed directly on the upper surface of the substrate **202** and may be electrically connected to the vehicle controller **100** using wires **116**. For example, the heaters **212** may be connected to corresponding power contacts **110**, and the temperature sensors **214**, **216** may be connected to corresponding sensor contacts **112**.

[0030] The heaters **212** may include annular resistive or inductive heating elements, for example, and may be disposed in direct thermal contact with the substrate **202**. In some embodiments, the heaters **212** may have a diameter D ranging from 15 mm to 25 mm, such as from 18 mm to 22 mm, or about 20 mm, and an inner diameter DI ranging from 3 mm to 13 mm, such as from 6 mm to 10 mm, or about 8 mm. However, the present disclosure is not limited to any particular heater **212** dimensions.

[0031] The temperature sensors **214**, **216** may be any suitable type of temperature sensor, such as a thermocouple, a silicon-based sensor, a thermistor, combinations thereof, or the like. In some embodiments, the temperature sensors **214**, **216** may be replaced by, or used in conjunction with, one or more optical temperature sensors disposed above the substrate **202**. The inner temperature sensor **214** may be disposed directly on the substrate **202**, inside of the corresponding heater **212**. The outer temperature sensor **216** may be disposed directly on the substrate **202**, outside of the corresponding heater **212**. In various embodiments, the inner and outer temperature sensors **214**, **216** may be disposed approximately the same distance from a corresponding heater **212**. For example, the inner temperature sensor **214** and outer temperature sensor **216** may be disposed within 5 mm of the corresponding heater **212**. The inner temperature sensor **214** and outer temperature sensor **216** of each thermal probe **210** may be aligned in any direction. For example, inner temperature sensor **214** and outer temperature sensor **216** of one or more of the thermal probes **210** may be aligned parallel to an X axis or a perpendicular Y axis of the substrate **202**. In other embodiments, the inner temperature sensor **214** and outer temperature sensor **216** of one or more of the thermal probes **210** may be aligned with a corresponding radial axis of the substrate **202**.

[0032] According to various embodiments, one or more of the thermal probes **210** may be configured to completely or at least partially vertically overlap with the coolant line **314**. For example, in some embodiments, the radial center of the inner temperature sensor **214** and the radial center of the heater **212** may directly overlap with the coolant line **314**. In some embodiments, one or the inner temperature sensor **214** and the outer temperature sensor **216** may completely or partially vertically overlap with the coolant line **314**, and the heater **212** may partially vertically overlap with the coolant line **314**.

[0033] In some embodiments, the diameter of the substrate **202** may be approximately the same as the diameter of the wafer chuck **310** to be tested. For example, the diameter of the substrate **202** may be within about +/−5% of the diameter of the wafer chuck **310**. For example, the exemplified wafer chuck **310** may have a diameter of 310 mm and the substrate **202** may have a diameter of 300 mm. In the alternative, the wafer chuck **310** may have a diameter of 300 mm and the substrate **202** may have a diameter of 302 mm.

[0034] The thermal probes **210** may be arranged in various locations on the substrate **202**. Herein, the location of a thermal probe **210** may be measured with respect to the radial center of the heater **212**, taken in a direction parallel to the surface of the wafer chuck **310**. For example, the TTV **200** may include a first probe **210**A located at the radial center of the substrate **202**. In some embodiments, the center of the first probe **210**A may be disposed at a radial distance L**3** from the edge of the wafer chuck **310** that ranges from 140 mm to 170 mm, such as from 150 mm to 160 mm, or 155 mm.

[0035] The TTV **200** may include a second probe **210**B and a third probe **210**C that may be disposed a radial distance L**2** from the edge of the wafer chuck **310** that ranges from 65 mm to 110 mm, such as from 75 mm to 100 mm, or 85 mm. The second probe **210**B and third probe **210**C may be disposed on a radial axis Z that is disposed at an angle A**1** with respect to an X axis and/or Y axis of the wafer chuck **310**. Angle A**1** may range from 0 to 90°, such as from 20° to 70°, from 30° to 60°, from 40° to 50°, or 45°.

[0036] The TTV **200** may include a fourth probe **210**D, a fifth probe **210**E, a sixth probe **210**F, and a seventh probe **210**G that may be disposed a radial distance L**1** from the edge of the wafer chuck **310** that ranges from 35 mm to 60 mm, such as from 40 mm to 55 mm, or 45 mm to 50 mm. The third probe **210**C and fourth probe **210**D may be disposed on a radial axis R that is disposed at an angle A**2** with respect to an X and/or Y axis of the wafer chuck **310**. Angle A**2** may range from 0 to 90°, such as from 20° to 70°, from 30° to 60°, from 40° to 50°, or 45°. In some embodiments, the R axis may be perpendicular to the Z axis.

[0037] FIG. **3** is a partially transparent plan view of a TTV **200** disposed on a wafer chuck **310**, according to various embodiments of the present disclosure. Referring to FIG. **3**, the thermal probes **210** may be disposed within a distance L**4** of the middle of a corresponding portion of the coolant line **314** of the wafer chuck **310**. For example, distance L**4** may range from 0 mm to 30 mm, such as from 0 mm to 20 mm, or from 0 mm to 10 mm. In some embodiments, the thermal probes **210** may at least partially vertically overlap with the coolant line **314**.

[0038] In various embodiments, the inner temperature sensor **214** and outer temperature sensor **216** of each thermal probe **210** may be arranged in any direction. In some embodiments, at least one of the thermal probes **210**, such as the fifth probe **210**E, may be disposed adjacent to a position sensor **312** of the wafer chuck **310** and may be utilized to determine the position of the TTV **200** relative to the wafer chuck **310**. In some embodiments, at least one of the thermal probes **210**, such as the seventh probe **210**G, may be disposed adjacent to inlet and/or outlet portions of the coolant line **314**.

[0039] In some embodiments, the TTV **200** may include an eighth probe **210**H and a ninth probe **210**I. The eighth probe **210**H and ninth probe **210**I may be disposed along a Y axis of the TTV.

[0040] FIG. **4** is a flow diagram illustrating a chuck testing method according to various embodiments of the present disclosure. FIG. **5** is a graph showing probe power and temperature measurements taken during continuous ramp heating and pulse ramp heating tests, according to various embodiments of the present disclosure.

[0041] Referring to FIGS. **1**, **4**, and **5**, in operation **402**, the method may include disposing a TTV **200** on a wafer chuck **310** of a wafer prober **300**. For example, the TTV **200** may be disposed on a top surface of the wafer chuck **310** and held in position using a suction or vacuum force. Thermal probes **210** of the TTV **200** may be electrically connected to a vehicle controller **100** and/or a prober controller **350**, for example using wires. The position of the TTV **200** may be determined using position sensors **312** of the wafer chuck **310**. In particular, the TTV **200** may be positioned such that two or more of the probes **210** completely or at least partially overlap with the internal coolant line **314** of the chuck **310** in a vertical direction perpendicular to the top surface of the chuck **310**. The vertical overlap of the probes **210** and the coolant line **314** may be important for collecting temperature data from portions of the top surface of the chuck **310** that have the highest heat transfer with the cooling fluid in the coolant line **314**.

[0042] In operation **404**, power may be supplied to heaters **212** of the thermal probes **210** to heat the substrate **202**. A cooling fluid may be circulated via coolant line **314** though the wafer chuck **310** during the heating. In some embodiments, the power may be increased according to a continuous ramp heating profile or a pulse ramp heating profile. However, any suitable heating profile may be used.

[0043] For example, during continuous ramp heating, during a first time period during which no power is applied to the heaters, temperature data generated by the inner and outer temperature sensors of each thermal probe **210** may be recorded. A first wattage may then be applied to the heater **212** and temperature data may be recorded, for second time period. A higher second wattage may then be applied to the heaters **212** and temperature data may be recorded for a third time period. A higher third wattage may then be applied to the heaters **212** and temperature data may be recorded for a fourth time period. The first time period, second time period, third time period, and fourth time period may be the same or may be different. In some embodiments, the time periods where no voltage is applied may be sufficient for the temperature of the TTV **200** to return to a baseline temperature (e.g., a temperature of the wafer chuck **310** prior to the application of a voltage to the heaters **212**). For example, in some embodiments, the first time period, second time period, third time period, and fourth time period may each range from about 10 seconds to about 3 minutes, such as from about 20 seconds to about 2 minutes, from about 30 seconds to about 1 minute and 30 seconds, or from about 45 second to about 1 minute. This process may be continued for any number of time periods until a set maximum wattage is applied. In various embodiments, the process may be repeated for one or more cycles.

[0044] During pulse ramp heating, a first wattage may be applied to the heaters **212** and temperature generated by inner and outer temperature sensors of each thermal probe **210** may be recorded, for a first time period. No power may be applied to the heaters and temperature data may be recorded for a second time period. A higher second wattage may be applied to the heaters and temperature data may be recorded for a third time period. No power may be applied to the heaters and temperature data may be recorded for a fourth time period. The first time period, second time period, third time period, and fourth time period may be the same or may be different. In some embodiments, the time periods where no voltage is applied may be sufficient for the temperature of the TTV **200** to return to a baseline temperature (e.g., a temperature of the wafer chuck **310** prior to the application of a voltage to the heaters **212**). For example, in some embodiments, the first time period, second time period, third time period, and fourth time period may each range from about 10 seconds to about 3 minutes, such as from about 20 seconds to about 2 minutes, from about 30 seconds to about 1 minute and 30 seconds, or from about 45 second to about 1 minute. This process may be continued for any number of time periods until a set maximum wattage is applied. In various embodiments, the process may them be repeated for one or more cycles.

[0045] In some embodiments, operation **404** may be repeated using different coolant flow rates and/or temperatures. In other embodiments, operation **404** may be repeated using different ramp heating profiles. In various embodiments, the wattage applied to the heaters **212** may be increased from time period to time period by an amount ranging from 10 watts to 50 watts, such as from 20 to 30 watts, or about 25 watts. A maximum wattage applied to the heaters **212** may be 200 watts or more.

[0046] In operation **406**, temperature data generated by the thermal probes **210** may be stored in the vehicle controller **100**. In various embodiments, operations **404** and **406** may be performed simultaneously. For example, the temperature data may be recorded during the cycling of the heaters.

[0047] In operation **408**, the temperature data may be analyzed to determine the thermal characteristics of the wafer chuck **310**. For example, the temperature data collected from each thermal probe **210** may be compared to determine the thermal consistency of the wafer chuck **310**. Excessive probe-to-probe temperature variations may indicate a chuck defect. The temperature data may also be analyzed to determine a maximum heat dissipation capability of the wafer chuck **310**. The temperature data may alternatively or additionally be analyzed to determine a temperature ramping rate of the wafer chuck **310**. In some embodiments, the temperature data may be analyzed to determine the physical characteristic consistency of the wafer chuck, such as the flatness of the top surface of the wafer chuck **310** and/or the consistency of the diameter of the coolant channels **314** of the wafer chuck **310**.

[0048] The temperature data may be processed in the vehicle controller **100** by the processor **102**. In the alternative, the temperature data may be provided to the wafer prober **300** and processed by the prober controller **350**. As such, the computing power and/or complexity of the processor **102** may be reduced. However, the present disclosure is not limited to any particular processing apparatus or processing location.

[0049] In various embodiment the method may optionally include operation **410**. In operation **410**, the thermal characteristics determined in operation **408** may be compared to the thermal characteristics required for a particular application. For example, in embodiments in which the thermal characteristics of the wafer chuck **310** exceed the minimum thermal characteristic requirements of the application, the wafer chuck **310** may be recommended to the customer for the specific application.

[0050] In some embodiments, the method may further include testing multiple chucks of the same type (e.g., the same model of wafer chuck from the same vender) in order to determine whether the wafer chucks have a wafer chuck to wafer chuck thermal physical characteristics consistency sufficient to satisfy the requirements of a customer. In other embodiments, the method may include testing multiple wafer chucks from multiple different venders to determine the thermal and/or physical characteristics thereof and/or to determine the wafer chuck to wafer chuck characteristic consistency of each model of wafer chuck. The thermal and/or physical characteristics of each model of wafer chuck may then be compared, in order to determine which model of wafer chuck best satisfies the requirements of a customer. As such, a particular model and vender may be recommended to a customer.

[0051] According to various embodiments, provided is a chuck testing system **10** that allows for standardized testing of wafer chucks **310** for a variety of applications. The system includes a TTV **200** that may replace the testing apparatus, application-specific semiconductor wafer, and prober card currently used for chuck testing. The system **10** may include a vehicle controller **100** that may be configured to control TTV **200** heating power and process time and may be configured to record temperature data generated by the TTV. In addition, the chuck testing system **10** may beneficially provide testing data that is not specific to a particular product semiconductor wafer or wafer orientation. The chuck testing system **10** may also unify hardware specifications for all customers, and especially for customers in the field of high-performance computing testing. The chuck testing system may provide full coverage for a testing surface of a wafer chuck to ensure complete wafer chuck thermal uniformity.

[0052] In an embodiment, the chuck testing system **10** may include thermal probes, wherein each thermal probe **210** includes: a heater **212**; and temperature sensors **214**, **216**. In one embodiment, in each thermal probe **210**: the heater **212** is annular; and the temperature sensors **214**, **216** may include: an inner temperature sensor **214** disposed inside of the heater **212**; and an outer temperature sensor **216** disposed outside of the heater **212**. In one embodiment, in each thermal probe **210** the inner temperature sensor **214** and the outer temperature sensor **216** may be disposed within 5 mm of the heater **212**. In one embodiment, the temperature sensors **214**, **216** may include a thermocouple, a silicon-based sensor, a thermistor, or combinations thereof. In one embodiment, the chuck testing system **10** may include a substrate **202** wherein the substrate **202** may include a semiconductor material, a metal, or a ceramic material. In one embodiment, the vehicle controller **100** may include: power contacts **110** electrically connected to heaters **212** of the thermal probes **210**; sensor contacts **112** electrically connected to temperature sensors **214**, **216** of the thermal probes **210**; a processor **102** configured to control power output from the power contacts to the heaters and to store temperature data provided to the sensor contacts **112** from the temperature sensors **214**, **216**; a switch **106** electrically connected to the processor **102**; and a display **104** electrically connected to the processor **102**. In one embodiment, the chuck testing system **10** may further include a wafer prober **300** that includes: a wafer chuck support **320**; a wafer chuck **310** disposed on the wafer chuck support **320** and having a top surface that is configured to vertically support a wafer **202**; a cooler **330** configured to provide a cooling fluid to the wafer chuck **310**; and a prober controller **350** configured to control the wafer prober **300** and process the temperature data stored in the vehicle controller **100**. In one embodiment, the TTV **200** may be disposed on the wafer chuck **310**, such that the substrate **202** covers at least 95% of the upper surface of the wafer chuck **310**. In one embodiment, the wafer chuck **310** includes an internal cooling line; and the temperature sensors **214**, **216** at least partially vertically overlap with the cooling line. In one embodiment, the wafer chuck **310** includes a position sensor **312**; and one of the temperature sensors **214**, **216** vertically overlaps with the position sensor **312**.

[0053] According to another aspect of the present disclosure, a system **10** for testing a wafer chuck **310**, may include: a wafer prober **300** that includes: a wafer chuck **310** that includes an internal coolant line; and a cooler **330** configured to circulate a cooling fluid through the internal coolant line **314**; a thermal test vehicle (TTV) **200** including: a substrate **202** disposed on a top surface of wafer chuck **310**; and thermal probes **210** configured to heat the substrate **202** and generate temperature data, the thermal probes **210** disposed on the substrate **202** such that at least two of the thermal probes **210** at least partially overlap with the internal coolant line **314** in a vertical direction perpendicular to the top surface of the wafer chuck **310**; and a vehicle controller **100** configured to provide power to the thermal probes **210** and store the temperature data.

[0054] In one embodiment, the thermal probes **210** may include: heaters **212** configured to heat the substrate **202**; and temperature sensors **214**, **216** configured to generate the temperature data. In one embodiment, each thermal probe **210** may include: an annular temperature sensor; an inner temperature sensor **214** disposed inside of the annular temperature sensor; and an outer temperature sensor **216** disposed outside of the annular temperature sensor. In one embodiment, the vehicle controller **100** may include: power contacts **110** electrically connected to the heaters **212**; sensor contacts **112** electrically connected the temperature sensors **214**, **216**; and a processor **102** configured to control a wattage provided to the heaters **212** and to store temperature data provided to the sensor contacts **112** from the temperature sensors **214**, **216**; a switch **106** electrically connected to the processor **102**; and a display **104** electrically connected to the processor **102**. In one embodiment, the processor **102** may be configured to cycle the wattage supplied to the heaters **212** according to a continuous ramp profile or a pulse ramp profile. In one embodiment, the wafer prober **300** may include a probe controller **350** configured to process the temperature data to determine thermal properties of the wafer chuck **310**.

[0055] In various embodiments, provided is a method of testing a wafer chuck **310** configured to support a semiconductor wafer, the method comprising: disposing a thermal test vehicle (TTV) **200** on the wafer chuck **310**, the TTV **200** comprising: a substrate **202** disposed on the top surface of wafer chuck **310**; and thermal probes **210** disposed on the substrate **202**; supplying power to the thermal probes **210** to heat the substrate **202**; recording temperature data generated by the thermal probes **210**; and processing the temperature data to determine the thermal properties of the wafer chuck **310**.

[0056] The various embodiments disclosed herein provide a number of unique and useful features to improve the ability to thermal test wafer check. These features include a programmable logic controller (PLC) for a TTV **200** wafer control. The various embodiment systems may provide for automatic temperature data collection and quality control result analysis. The various embodiments provide full coverage for wafer chuck uniformity check. The various features allow the various embodiments to be able to heat a wafer and sense the wafer temperature without a tester, test program, and probe card. The various embodiments may provide a ready standard jig to detect low performance during new installations or pre-maintain. The various embodiments may allow for unified hardware specification to test a variety of wafers from a variety of potential customers. The various embodiments may further allow for a unified standard for new cooling system development or evaluation.

[0057] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

1. A system for testing a wafer chuck, comprising: a thermal test vehicle (TTV) comprising: a substrate; and thermal probes disposed on the substrate; and a vehicle controller configured to control heating of the substrate by the thermal probes and to store temperature data generated by the thermal probes.

2. The system of claim 1, wherein each thermal probe comprises: a heater; and temperature sensors.

3. The system of claim 2, wherein in each thermal probe: the heater is annular; and the temperature sensors comprise: an inner temperature sensor disposed inside of the heater; and an outer temperature sensor disposed outside of the heater.

4. The system of claim 3, wherein in each thermal probe the inner temperature sensor and the outer temperature sensor are disposed within 5 mm of the heater.

5. The system of claim 2, wherein the temperature sensors comprise a thermocouple, a silicon-based sensor, a thermistor, or combinations thereof.

6. The system of claim 1, wherein the substrate comprises a semiconductor material, a metal, or a ceramic material.

7. The system of claim 1, wherein the vehicle controller comprises: power contacts electrically connected to heaters of the thermal probes; sensor contacts electrically connected to temperature sensors of the thermal probes; a processor configured to control power output from the power contacts to the heaters and to store temperature data provided to the sensor contacts from the temperature sensors; a switch electrically connected to the processor; and a display electrically connected to the processor.

8. The system of claim 1, further comprising a wafer prober comprising: a wafer chuck support; a wafer chuck disposed on the wafer chuck support and having a top surface that is configured to vertically support a wafer; a cooler configured to provide a cooling fluid to the wafer chuck; and a prober controller configured to control the wafer prober and process the temperature data stored in the vehicle controller.

9. The system of claim 8, wherein the TTV is disposed on the wafer chuck, such that the substrate covers at least 95% of the upper surface of the wafer chuck.

10. The system of claim 8, wherein: the wafer chuck comprises an internal cooling line; and the temperature sensors at least partially vertically overlap with the cooling line.

11. The system of claim 8, wherein: the wafer chuck comprises a position sensor; and one of the temperature sensors vertically overlaps with the position sensor.

12. A system for testing a wafer chuck, comprising: a wafer prober comprising: a wafer chuck comprising an internal coolant line; and a cooler configured to circulate a cooling fluid through the internal coolant line; a thermal test vehicle (TTV) comprising: a substrate disposed on a top surface of wafer chuck; and thermal probes configured to heat the substrate and generate temperature data, the thermal probes disposed on the substrate such that at least two of the thermal proves at least partially overlap with the internal coolant line in a vertical direction perpendicular to the top surface of the wafer chuck; and a vehicle controller configured to provide power to the thermal probes and store the temperature data.

13. The system of claim 12, wherein the thermal probes comprise: heaters configured to heat the substrate; and temperature sensors configured to generate the temperature data.

14. The system of claim 13, wherein each thermal probe comprises: an annular temperature sensor; an inner temperature sensor disposed inside of the annular temperature sensor; and an outer temperature sensor disposed outside of the annular temperature sensor.

15. The system of claim 13, wherein the vehicle controller comprises: power contacts electrically connected to the heaters; sensor contacts electrically connected the temperature sensors; and a processor configured to control a wattage provided to the heaters and to store temperature data provided to the sensor contacts from the temperature sensors; a switch electrically connected to the processor; and a display electrically connected to the processor.

16. The system of claim 15, wherein the processor is configured to cycle the wattage supplied to the heaters according to a continuous ramp profile or a pulse ramp profile.

17. The system of claim 15, wherein the wafer prober comprises a probe controller configured to process the temperature data to determine thermal properties of the wafer chuck.

18. A method of testing a wafer chuck configured to support a semiconductor wafer, the method comprising: disposing a thermal test vehicle (TTV) on the wafer chuck, the TTV comprising: a substrate disposed on the top surface of wafer chuck; and thermal probes disposed on the substrate; supplying power to the thermal probes to heat the substrate; recording temperature data generated by the thermal probes; and processing the temperature data to determine thermal properties of the wafer chuck.

19. The method of claim 18, wherein the supplying power to the thermal probes comprises cycling a wattage provided to heaters of the thermal probes according to continuous ramp profile or a pulse ramp profile.

20. The method of claim 18, further comprising determining whether the wafer chuck is suitable for a particular application by comparing the thermal properties of the wafer chuck to thermal properties required by the particular application.