

BONDING APPARATUS, SYSTEM, AND METHOD OF BONDING

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of Singapore application No. 10201900578Q filed January 23, 2019, the contents of it being hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] Various aspects of this disclosure relate to a bonding apparatus. Various aspects of this disclosure relate to a bonding system. Various aspects of this disclosure relate to a method of bonding a first substrate and a second substrate.

BACKGROUND

[0003] Wafer level or chip level bonding with eutectic metals is one of the standard processes in the fabrication of some of microelectromechanical system (MEMS) devices in the semiconductor industry. These eutectic metal bonding are required (i) for electrical connections between bottom and top wafers, or (ii) for hermetic sealing around a MEMS device.

[0004] A few of the most common eutectic metals used to date include silver-tin (AgSn), copper-tin (CuSn), indium-tin (InSn) and aluminum-germanium (AlGe). A suitable eutectic metal alloy may be selected depending on the required application, pre-deposited materials on the wafer, and consideration of additional processing steps in the downstream.

[0005] Recently, bonding using AlGe is becoming more widespread as AlGe is complementary metal oxide semiconductor (CMOS) compatible. However, compared to other common eutectic metal alloys, AlGe has the highest eutectic temperature of 419 °C. Heating entire wafers with devices to this high temperature can cause several issues such as (i) stressing of pre-deposited films due to over curing, (ii) delamination of pre-deposited films, (iii) wafer warping due to film stress,

and (iv) potential wafer breaking during bonding or just after bonding caused by higher internal stress.

[0006] The remaining issues with such high temperature bonding are related to the bonding methodology. Those issues are discussed with the explanation of current method of bonding with conventional bonders.

[0007] In conventional bonders, wafer aligning, and wafer bonding are carried out in two separate modules called aligning chamber and bonding chamber. Two wafers are aligned with the use of suitable aligning technology in the aligning chamber, e.g. face-to-face aligning, face-to-back aligning, infrared (IR) aligning etc. Once the aligning process is completed, wafers are clamped onto a metal plate called a bond-chuck in order to not to prevent misalignment of the wafers until the wafers are bonded in the bond chamber. FIG. 1A is a schematic showing two aligned wafers 1, 2 clamped to a bond-chuck 3. The clamping tools are not shown in FIG. 1A for simplicity. Some of the commercial bonders come with spacers 4 placed between the two wafers 1, 2 so that space between two wafers 1, 2 can be vacuumed effectively in the bond chamber before bonding. However, prolonged vacuuming also can be used to get the same vacuum level in case if spacers 4 are not used during the clamping step. The pre-deposited and pre-patterned bonding structure 5 may include germanium (Ge), and the pre-deposited and pre-patterned bonding structure 6 may include aluminum (Al).

[0008] FIG. 1B is a schematic of a conventional bonder in which the two aligned wafers 1, 2 with bond-chuck 3 are placed on the bottom stage 7. The bond chamber also includes a load/lock gate 10 and a vacuum system 11. During the bonding, the chamber is vacuumed using the vacuum system 11 before the spacers 4 are removed. The top stage 8 is brought down by application of force using piston 9. The pre-deposited and pre-patterned bonding structure 5 may be on wafer 1, while the pre-deposited and pre-patterned bonding structure 6 may be on wafer 2. The wafer stage 7 is heated slightly above the eutectic melting point so that the Ge and Al metals mutually diffuse and react to form inter-metallic compound (IMC) that bond two wafers together. In general, the metals are transformed into liquid form first before forming eutectic alloy. As a result of reaction going through a liquid phase, this may result in hermetically sealed bonding, and is commonly used to make vacuum tight sealing around devices.

[0009] FIG. 1C shows the cross-sectional side view and the top view of the wafer 2 with aluminum (Al) lines 6 around a microelectromechanical system (MEMS) device 12. FIG. 1D shows the cross-sectional side view and the top view of the wafer 1 with germanium (Ge) lines 5.

[0010] The lines 5, 6 may be prepared for hermetic bonding with or without vacuuming. The structures 5, 6 may include aluminum-germanium (AlGe) alloy instead of Ge and Al respectively. During the bonding process, the alloy gets melted and forms a hermetic bond. The thickness and width of each metal line may be in the range of from 0.5 μm to 2 μm , and from 20 μm to 100 μm , respectively.

[0011] In order to get uniform bonding characteristics, the temperature of the entire wafer has to be the same. However, designing the wafer stage to get fairly good temperature uniformity is extremely difficult. Generally, the temperature non-uniformity over the wafer stage in most of commonly available bonders lies in the range of 3% to 10% with respect to set temperature. With the increase of stage temperature, the temperature non-uniformity also increases. Accordingly, in case of AlGe bonding, the temperature variation across a 300 mm wafer could be as high as 10 $^{\circ}\text{C}$ to 40 $^{\circ}\text{C}$ with respect to the set temperature. This may result in several problems. For instance, if the stage temperature is set close to eutectic temperature, some parts of the wafer may not get heated to eutectic temperature, resulting in poor or no bonding. However, if the stage temperature is set considerably higher than eutectic temperature to compensate for the temperature variation of wafers, some parts of wafers may get overheated, resulting in Al splashing around the bonding area. Splashed Al around bond-area can cause short circuiting with electrical connection inside the die. Both of these issues may result in lower device yield.

[0012] FIGS. 2A-B illustrate the Al splashing issue. FIG. 2A is a schematic showing a cross-sectional side view of the arrangement of the wafers 1, 2 before heating. FIG. 2B is a schematic showing a cross-sectional side view of the arrangement of the wafers 1, 2 after heating. The wafer 2 may include MEMS device 12 as highlighted above. As shown in FIG. 2A, prior to bonding, the Ge line 5 is on the Al line 6, and is separated from the Al line 6 by an Al/Ge interface. During the bonding process, wafers 1, 2 are heated from the bottom stage 3, therefore heat flows from the bottom stage 3 to the bottom wafer 2, and then from the bottom wafer 2 to the top wafer 1. In order to heat the Ge line 5 to eutectic temperature, the bottom wafer 2 has to be heated to a temperature slightly above the eutectic temperature. Once the Ge line 5 gets heated, Ge starts diffusion into Al.

Here, it should be noted that as the whole Al line 6 is heated to a temperature above eutectic temperature, therefore, once Ge starts diffusion, Al diffuses from the Al/Ge interface towards the Al/silicon (Si) interface between the Al line 6 and the Si wafer 2. As the Al:Ge ratio at the interface reaches 49:51 by weight, melted alloy AlGe 13 is formed. The bond interface is under bonding force therefore, and as melted AlGe 13 is formed, the melted AlGe 13 spreads out from its boundary lines to the device areas over the device 12. This may damage the devices, resulting in overall lower yield.

[0013] Another issue with conventional wafer heating is that the wafers 1, 2 may get highly stressed or warped after bonding. As the wafers 1, 2 are bonded at higher temperature (~440 °C) where wafers 1,2 are thermally expanded, wafers 1, 2 may get stressed during the cooling down to room temperature, generating wafer bow that even can lead to wafer de-bonding, cracks, or breaking, particularly for thinned wafers.

[0014] The third disadvantage is that the wafers 1, 2 may get misaligned during high-temperature bonding. In order to get precise alignment, both top and bottom wafers 1, 2 have to be precisely at the same temperature. In practice however, this is quite difficult and there may normally be 1 °C to 4 °C degrees of variation between the top wafer 1 and the bottom wafer 2. This temperature variation may generate run-out misalignment that can be in the range of 2 μm to 10 μm , specially at the wafer edges.

[0015] The fourth disadvantage is that some of the devices that need to be bonded may not be able to heat to high temperature, for example up to 430°C for Al-Ge bonding, due to pre-deposited films like polyamide or other carbonic films. In general, most carbonic films may not be able to be heated over 200 °C. Therefore, heating the whole wafer to Al-Ge eutectic bonding temperature may not be possible without a change in materials.

SUMMARY

[0016] Various embodiments may provide a bonding apparatus. The bonding apparatus may include a chamber configured to receive a bond-chuck, and a plate that is configured to cooperate with the bond-chuck to hold a first arrangement and a second arrangement. The first arrangement may include a first substrate and an aluminum (Al) bond structure in contact with the first substrate,

and the second arrangement may include a second substrate and a germanium (Ge) bond structure in contact with the second substrate. The bonding apparatus may additionally include a scanner configured to provide an infrared beam through the plate, the second substrate, and the germanium bond structure to heat the aluminum bond structure in contact with the germanium bond structure, so that the germanium bond structure is also heated by conduction of heat from the aluminum bond structure. The bonding apparatus may further include an actuator configured to apply a bonding force on the aluminum bond structure and the germanium bond structure, thereby forming an aluminum-germanium (AlGe) bond structure bonding the first substrate and the second substrate.

[0017] Various embodiments may relate to bonding a first substrate and a second substrate. The method may include providing a first arrangement and a second arrangement within a chamber, the first arrangement and the second arrangement arranged between a bond-chuck and a plate (also referred to as clamp plate). The first arrangement may include the first substrate and an aluminum bond structure in contact with the first substrate, and the second arrangement may include the second substrate and a germanium bond structure in contact with the second substrate. The method may also include heating the aluminum bond structure in contact with the germanium bond structure by using a scanner to provide an infrared beam through the plate (clamp plate), the second substrate, and the germanium bond structure, so that the germanium bond structure is also heated by conduction of heat from the aluminum bond structure. The method may further include, in applying a bonding force on the aluminum bond structure and the germanium bond structure by using an actuator to form an aluminum-germanium bond structure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

FIG. 1A is a schematic showing two aligned wafers clamped to a bond-chuck.

FIG. 1B is a schematic of a conventional bonder in which the two aligned wafers with bond-chuck are placed on the bottom stage.

FIG. 1C shows the cross-sectional side view and the top view of the wafer with aluminum (Al) lines around a microelectromechanical system (MEMS) device.

FIG. 1D shows the cross-sectional side view and the top view of the wafer with germanium (Ge) lines.

FIG. 2A is a schematic showing a cross-sectional side view of the arrangement of the wafers before heating.

FIG. 2B is a schematic showing a cross-sectional side view of the arrangement of the wafers after heating.

FIG. 3 is a general illustration of a bonding apparatus according to various embodiments.

FIG. 4 is a general illustration of bonding a first substrate and a second substrate according to various embodiments.

FIG. 5 is a general illustration of a method of forming a bonding apparatus.

FIG. 6A is a schematic showing a cross-sectional side view of two wafers clamped by a bond-chuck and a plate (also referred to as a clamp plate) according to various embodiments.

FIG. 6B is a schematic showing a bonding apparatus according to various embodiments.

FIG. 6C is a schematic showing a cross-sectional side view of a part of the substrates before bonding according to various embodiments.

FIG. 6D is a schematic showing a cross-sectional side view of a part of the wafers after bonding according to various embodiments.

FIG. 6E is a schematic showing a perspective view showing a part of the bonding apparatus according to various other embodiments.

FIG. 6F shows a plot of transmission (in percent or %) as a function of wavelength (in micrometers or μm) showing the transmission profile of a 2 mm thick optical grade germanium sample.

FIG. 7 is a schematic showing a bonding system according to various embodiments. The bonding system may be an integrated system configured to carry out wafer bonding using an automated procedure.

DETAILED DESCRIPTION

[0019] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced.

These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, and logical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0020] Embodiments described in the context of one of the methods or apparatuses/systems is analogously valid for the other methods or apparatuses/systems. Similarly, embodiments described in the context of a method are analogously valid for an apparatus, and vice versa.

[0021] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0022] The word "over" used with regards to a deposited material formed "over" a side or surface, may be used herein to mean that the deposited material may be formed "directly on", e.g. in direct contact with, the implied side or surface. The word "over" used with regards to a deposited material formed "over" a side or surface, may also be used herein to mean that the deposited material may be formed "indirectly on" the implied side or surface with one or more additional layers being arranged between the implied side or surface and the deposited material. In other words, a first layer "over" a second layer may refer to the first layer directly on the second layer, or that the first layer and the second layer are separated by one or more intervening layers.

[0023] In the context of various embodiments, the articles "a", "an" and "the" as used with regard to a feature or element include a reference to one or more of the features or elements.

[0024] In the context of various embodiments, the term "about" or "approximately" as applied to a numeric value encompasses the exact value and a reasonable variance.

[0025] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0026] Various embodiments may address or mitigate various problems highlighted above. Various embodiments may address or mitigate issues related to (i) maintaining a good temperature

uniformity across the wafer, (ii) wafer stress, (iii) wafer warpage, (iv) higher likelihood of misalignment, and/or (v) heating full wafers with organic films to high-temperature related to conventional bonding methods and apparatuses.

[0027] FIG. 3 is a general illustration of a bonding apparatus according to various embodiments. The bonding apparatus may include a chamber configured to receive a bond-chuck, and a plate (also referred to as a clamp plate) that is configured to cooperate with the bond-chuck to hold a first arrangement and a second arrangement. The first arrangement may include a first substrate and an aluminum (Al) bond structure in contact with the first substrate, and the second arrangement may include a second substrate and a germanium (Ge) bond structure in contact with the second substrate. The bonding apparatus may additionally include a scanner configured to provide an infrared beam through the plate, the second substrate, and the germanium bond structure to heat the aluminum bond structure in contact with the germanium bond structure, so that the germanium bond structure is also heated by conduction of heat from the aluminum bond structure. The bonding apparatus may further include an actuator configured to apply a bonding force on the aluminum bond structure and the germanium bond structure, thereby forming an aluminum-germanium (AlGe) bond structure bonding the first substrate and the second substrate.

[0028] In other words, the bonding apparatus may include chamber for accommodating a bond-chuck and a plate that clamp the first substrate and the second substrate. An Al bond structure may be on the first substrate, and a Ge bond structure may be on the second substrate. The Ge bond structure may be in contact with the Al bond structure. The bonding apparatus may also include a scanner which is configured to provide an infrared beam that can pass through the plate, the second substrate, the Ge bond structure to heat the Al bond structure. The apparatus may further include an actuator to apply a bonding force on the Al bond structure and the Ge bond structure so that the Al bond structure and the Ge bond structure are in close contact for interdiffusion to form a resultant bond structure of AlGe.

[0029] For avoidance of doubt, FIG. 3 serves to provide a general illustration of the bonding apparatus according to various embodiments, and does not serve to limit for instance the arrangement, size, shapes, orientation etc. of the various features of the apparatus.

[0030] The second substrate may be closer to the scanner or the plate compared to the first substrate, while the first substrate may be closer to the bond-chuck compared to the second substrate.

[0031] The second substrate may be arranged above the first substrate. The plate may be above the second substrate, and the scanner may be above the plate. The bond-chuck may be below the first substrate. The first substrate may be a semiconductor wafer such as a silicon wafer or a glass wafer. The second substrate may be another semiconductor wafer such as a silicon wafer or a glass wafer.

[0032] The aluminum bond structure may include or consist of aluminum. The germanium bond structure may include or consist of germanium. The aluminum-germanium bond structure may include or consist of aluminum-germanium.

[0033] In various embodiments, the aluminum bond structure may be a spot or a line. Similarly, the germanium bond structure, may be a spot or a line. The resultant aluminum-germanium bond structure may also be a spot or a line.

[0034] In various embodiments, an electromechanical system may be configured to move the scanner. The scanner may be a laser scanner. The scanner may be a movable scanner. The scanner may be configured to form a resultant aluminum-germanium bond line from a germanium bond line and an aluminum bond line.

[0035] In various embodiments, the scanner may be arranged within the chamber.

[0036] The infrared beam may be an infrared laser beam. The infrared beam may have a wavelength that is able to pass through the plate, the second substrate, and the germanium bond structure to heat the aluminum bond structure in contact with the germanium bond structure. The infrared beam may have a diameter less than or equal that the width of the aluminum bond structure and/or the germanium bond structure.

[0037] The bonding apparatus may include an alignment marks inspection system configured to detect the aluminum bond structure and the germanium bond structure. The alignment marks inspection system may be a part of the scanner or may be a separate system. The alignment marks inspection system may include a detector or a camera. The alignment marks inspection system may further include a processor or computer coupled to the detector or camera.

[0038] In various embodiments, the plate may be a quartz plate. The plate may be configured to allow the infrared beam to pass through. The plate that is used for cooperating with the bond-chuck to clamp the first substrate and the second substrate.

[0039] In various embodiments, the actuator may further include a piston and a piston plate coupled to the piston. The actuator may further include a plurality of rods coupling the piston plate to the piston. The piston plate may be a metal plate. The piston plate may include a liner hole for the infrared beam to pass through. The liner hole may be elongated. In other words, a length of the liner hole may be greater than a width of the liner hole. The infrared beam may move along the length of the liner hole as the scanner moves. The bonding apparatus may further include a rotating system configured to rotate the plate so that the liner hole is also moved. The movement of the liner hole may allow different underlying bond structures or lines to be heated by the infrared beam passing through the liner hole. The rotating system may be an electromechanical system.

[0040] In various other embodiments, the actuator may include a piston and a metal piece, e.g. a cylindrical metal piece, coupled to the piston. A central region of the metal piece may be attached or joined to the piston. An end region of the metal piece may be configured to be in contact with the clamp plate. The piston may be configured to apply the bonding force through the metal piece. The metal piece may define a space with the clamp plate to hold the scanner.

[0041] In various embodiments, the bonding apparatus may also include a vacuum system connected to the chamber, the vacuum system configured to reduce or set a pressure within the chamber before bonding.

[0042] The bonding apparatus may include an infrared source coupled to the scanner, the infrared source configured to generate the infrared beam. The infrared source may be a laser generator.

[0043] In various embodiments, the infrared source may be arranged outside of the chamber. In various embodiments, the infrared source may be arranged outside of the space defined by the metal piece and the clamp plate. The infrared beam may be transmitted from the infrared source to the scanner through a hole on the metal piece. In various other embodiments, the infrared source may be held within the space together with the scanner.

[0044] In various embodiments, the aluminum bond structure may be heated by the infrared beam to a temperature above 423°C.

[0045] In various embodiments, the second substrate may be or may include a silicon wafer, and the germanium bond structure may be in (direct) contact with the silicon wafer. In various other embodiments, the second substrate may include a silicon wafer, and a silicon oxide or silicon nitride film on the silicon wafer. The germanium bond structure may be in contact with the silicon oxide or silicon nitride film.

[0046] Similarly, in various embodiments, the first substrate may be or may include a silicon wafer, and the aluminium bond structure may be in (direct) contact with the silicon wafer. In various other embodiments, the first substrate may include a silicon wafer, and a silicon oxide or silicon nitride film on the silicon wafer. The aluminium bond structure may be in contact with the silicon oxide or silicon nitride film.

[0047] Various embodiments may relate to a bonding system including the bonding apparatus as described herein.

[0048] In various embodiments, the bonding system may include a cleaning module configured to clean the first substrate and the second substrate before bonding. The bonding system may also include an alignment and clamping module configured to arrange the first substrate and the second substrate so that the aluminum bond structure and the germanium bond structure are aligned before bonding, and further configured to clamp the first substrate and the second substrate using the plate, i.e. clamp plate, and the bond-chuck. The bonding system may additionally include a handling module configured to transfer the first substrate and the second substrate between the cleaning module, the alignment and clamping module and a bonding module including the bonding apparatus.

[0049] FIG. 4 is a general illustration of bonding a first substrate and a second substrate according to various embodiments. The method may include, in S1, providing a first arrangement and a second arrangement within a chamber, the first arrangement and the second arrangement arranged between a bond-chuck and a plate (also referred to as clamp plate). The first arrangement may include the first substrate and an aluminum bond structure in contact with the first substrate, and the second arrangement may include the second substrate and a germanium bond structure in contact with the second substrate. The method may also include, in S2, heating the aluminum bond structure in contact with the germanium bond structure by using a scanner to provide an infrared beam through the plate (clamp plate), the second substrate, and the germanium bond structure, so

that the germanium bond structure is also heated by conduction of heat from the aluminum bond structure. The method may further include, in S3, applying a bonding force on the aluminum bond structure and the germanium bond structure by using an actuator to form an aluminum-germanium bond structure.

[0050] In other words, the method may include providing the first substrate with the aluminum bond structure and the second substrate with the germanium bond structure in a chamber. The aluminum bond structure may be in contact with the germanium bond structure, and the first substrate and the second substrate may be clamped between a clamp plate and a bond-chuck. A scanner may then be used to provide an infrared beam which passes through the clamp plate, the second substrate and the germanium bond structure to heat the aluminum bond structure. The aluminum bond structure may also heat up the germanium bond structure that is in contact with the aluminum bond structure. A compressive bonding force may be applied on the aluminum bond structure and the germanium bond structure so that the interdiffusion of aluminum and germanium may occur, thereby forming an alloy of aluminum and germanium.

[0051] For avoidance of doubt, FIG. 4 serves to provide a general illustration of a method of bonding a first substrate and a second substrate according to various embodiments, and may not be in sequence. For instance, S3 may occur at the same time as S2, before S2, or after S2.

[0052] In various embodiments, the method may include moving the scanner using an electromechanical system.

[0053] In various embodiments, the method may include detecting the aluminum bond structure and the germanium bond structure using an alignment marks inspection system.

[0054] In various embodiments, the actuator may include a piston and a piston plate coupled to the piston. The piston plate may include a liner hole for the infrared beam to pass through. In various embodiments, the method may further include rotating the piston plate using a rotating system so that the liner hole is moved.

[0055] In various other embodiments, the actuator may include a piston and a metal piece, e.g. a cylindrical metal piece, coupled to the piston.

[0056] In various embodiments, the method may include reducing a pressure within the chamber before bonding.

[0057] In various embodiments, the scanner may be arranged within the chamber.

[0058] In various embodiments, the bonding of the first substrate and the second substrate may form a hermetic seal or a vacuum hermetic seal, or may electrically connect one or electrical connections included in the first substrate with one or more electrical connections included in the second substrate via the aluminum-germanium bond structure.

[0059] In various embodiments, the first substrate and the second substrate may be cleaned before bonding. The cleaning of the first substrate and the second substrate may be carried out using a cleaning module. After cleaning and before bonding, the first substrate and the second substrate may be arranged so that the aluminum bond structure and the germanium bond structure are aligned. The plate, i.e. the clamp plate, and the bond-chuck may be used to clamp the first substrate and the second substrate. The alignment and clamping may be carried out in an alignment and clamping module. A handling module may be used to transfer the first substrate and the second substrate between the cleaning module, the alignment and clamping module and a bonding module including the bonding apparatus.

[0060] FIG. 5 is a general illustration of a method of forming a bonding apparatus. The method may include, in T1, forming a chamber configured to receive a bond-chuck, and a plate (also referred to as clamp plate) that is configured to cooperate with the bond-chuck to hold a first arrangement and a second arrangement. The first arrangement may include a first substrate and an aluminum (Al) bond structure in contact with the first substrate, and the second arrangement may include a second substrate and a germanium (Ge) bond structure in contact with the second substrate. The bonding apparatus may additionally include, in T2, providing a scanner configured to provide an infrared beam through the plate (clamp plate), the second substrate, and the germanium bond structure to heat the aluminum bond structure in contact with the germanium bond structure, so that the germanium bond structure is also heated by conduction of heat from the aluminum bond structure. The bonding apparatus may further include, in T3, providing or forming an actuator configured to apply a bonding force on the aluminum bond structure and the germanium bond structure, thereby forming an aluminum-germanium (AlGe) bond structure bonding the first substrate and the second substrate.

[0061] In other words, the method may include forming a chamber for receiving the first and second substrate clamped between a bond-chuck and a clamp plate, providing the scanner which is used to provide an infrared beam through the clamp plate, the second substrate, and the

germanium bond structure to heat the aluminum bond structure, and providing an actuator used to apply a compressive bonding force on the germanium bond structure and the aluminum bond structure so that interdiffusion of aluminum and germanium may occur.

[0062] For avoidance of doubt, serves to provide a general illustration of a method of forming an apparatus according to various embodiments, and may not be in sequence. For instance, T1 may occur before, after or at the same time as T2.

[0063] In various embodiments, the method may include providing an electromechanical system configured to move the scanner. The electromechanical system may be attached or connected to the scanner.

[0064] In various embodiments, the method may include forming or providing an alignment marks inspection system configured to detect the aluminum bond structure and the germanium bond structure.

[0065] In various embodiments, the method may include connecting a vacuum system to the chamber. The vacuum system may be configured to reduce a pressure within the chamber before bonding.

[0066] In various embodiments, the method may include coupling or connecting an infrared source to the scanner. The infrared source may be configured to generate the infrared beam.

[0067] Various embodiments may provide an apparatus or hardware configuration for Al-Ge eutectic bonding. The bonding structures, such as metal lines, may be heated by infrared (IR) radiation.

[0068] FIG. 6A is a schematic showing a cross-sectional side view of two wafers 101, 102 clamped by a bond-chuck 103 and a plate 106 (also referred to as a clamp plate) according to various embodiments. The top wafer 101 may be transparent to infrared (IR) light. The top wafer 101 may be configured to allow infrared light in the range of about 0.8 μm to about 1.5 μm to pass through. A plurality of aluminum bond structures 105 may be formed on or in contact with the bottom wafer 102, while a plurality of germanium bond structures 104 may be formed on or in contact with the top wafer 101. The aluminum bond structures 105 may be formed by depositing aluminum on the bottom wafer 102, and patterning the deposited aluminum. Similarly, the germanium bond structures 104 may be formed by depositing germanium on the top wafer 101, and patterning the deposited germanium. For simplicity, only one of the aluminum bond structures

105 and one of the germanium bond structures 104 are labelled. The two wafers 101, 102 may be aligned such that each of the aluminum bond structures 105 is in contact with a respective germanium bond structure 104.

[0069] After the two wafers 101, 102 are aligned, the clamp plate 106, such as a quartz plate, may be placed on the top wafer 101. The plate 106 and the bond-chuck 103 may clamp the two wafers 101, 102 (using suitable clamps 127) so that the two wafers 101, 102 do not move relative to each other until bonding gets completed. The quartz plate 106 may be required to be thick enough to withstand the bonding force that is subsequently applied. The thickness of quartz plate 106 may, for instance, be of a suitable value in the range from 10 mm to about 20 mm.

[0070] FIG. 6B is a schematic showing a bonding apparatus according to various embodiments. The assembly of the two aligned wafers 101, 102, the bond-chuck 103 and the plate 106 may be arranged or placed on a bonding stage 107. The bonding stage 107 may not be required to have embedded heaters for heating the wafers 101, 102. The bonding force may be applied by piston 111 through a cylindrical-shaped metal piece 108. The metal piece 108 may be a cylinder with an open end and a closed end. The piston 111 may be attached or joined to the metal piece 108 (at the center of the closed end). The metal piece 108 may have an inner diameter that is greater than the diameters of the wafers 101, 102. The metal piece 108 and the plate 106 may define a space or cavity. A scanner 109 may be arranged within this space or cavity. The scanner 109 may be a laser scanner configured to provide or emit a laser beam 110. An infrared source such as a laser generator may be used to generate the laser beam. The laser generator may be coupled to the laser scanner 109, for instance, via optical fibers. In various embodiments, the laser generator may be arranged together with the laser scanner 109 within the space or cavity. In various other embodiments, the laser generator may be arranged outside the chamber or outside the space/cavity. The laser beam generated by the laser generator may be provided to the laser scanner 109 through a hole in the metal piece. The laser generator may be arranged outside the chamber or outside the space/cavity, as the laser generator may be too large to be arranged within the chamber or within the space/cavity.

[0071] The laser scanner may include a camera. The camera may be part of an alignment marks inspection system. The alignment marks inspection system or the camera may be used to detect the metal bond lines 104, 105. After an Al bond line 105 and a corresponding Ge bond line 104 in

contact with the Al bond line 105 are identified, the laser scanner 109 may provide a laser beam 110 onto the surface of the Al bond line 105 through the quartz plate 106, the top silicon wafer 101, and the Ge bond line 104. The laser scanner 109 may be moved to scan the laser beam 110 along the Al bond line 105.

[0072] Quartz, silicon, and germanium are transparent to infrared radiation. As such, germanium is deposited on the top wafer 101 so that the subsequently formed Ge bond line 104, which allows the laser beam 110 to pass through, is nearer to the laser scanner 109. The laser beam 110 may then pass through the Ge bond line 104 before impinging onto the Al bond line 105. The heat may then be transferred via conduction to the Al/Ge interface for heating of Ge and subsequent bonding. Various embodiments may obtain better performance.

[0073] Alternatively, Al may be deposited on the top wafer 101, resulting in the formation of an Al bond line on the top wafer 101. The Al bond line may be heated by the laser beam. Heat may then be transferred to the Al-Ge bond interface for bonding. However, as the Al bond line is heated from the Al/Si interface to the Al/Ge interface, the Ge may diffuse up to the Al/Si interface. This may result in AlGe splashing, and spreading beyond the width of the initial bond lines, thereby resulting in the damage of the devices, and leading to lower yield.

[0074] There may be a requirement to deposit various films on a silicon wafer during semiconductor or MEMS devices fabrication. Only films that allow infrared light, i.e. films that are transparent to infrared light (e.g. SiO_2 , Si_3N_4), may be deposited on the top silicon wafer.

[0075] The thickness of the Al bond line 105 or Ge bond line 104 may be of any value selected in the range from 100 nm to 1 micron. In case if the bonding height has to be higher, e.g. around 2 μm , a dummy material may be used below the Al lines, copper (Cu). Cu may be suitable as Cu deposition and patterning are much easier than Al. The minimum width of the Al bond line or Ge bond line may be determined by the width of laser beam 110 and its alignment accuracy. In general, the width of the Ge bond line 104 or the Al bond line 105 may be of any value in the range from 10 micron to 200 microns.

[0076] Operation

[0077] In the first step, the two wafers 101, 102 may be aligned and clamped onto the bond chuck 103 with the help of the quartz plate 106. Alignment may be carried out by commercially available aligners. As the alignment is done at room temperature, a higher degree of alignment can

be obtained, generally in the range of $\pm 0.5 - 2$ microns. The aligned wafers 101, 102 may be placed inside the bond chamber (via lock/load gate 128). The chamber may be reduced or set to a predetermined pressure with the use of vacuum system 112. During bonding, the top side piston 111 may be brought down until the cylindrical-shaped metal piece 108 attached or joined to the piston 111 touches the quartz plate 106. The AlGe bonding comes in the category of eutectic bonding. Therefore, there may be no need to apply very high bonding force for the bonding. The only requirement is that the bonding force should be high enough for better physical contact between Al and Ge. In general, 20kN to 50kN bonding force for bonding two 300 mm wafers may be sufficient.

[0078] The IR camera inside the IR laser scanner 109 may detect the Al bond line and the Ge bond line around a single die. The laser scanner IR 109 may then transmit the laser beam 110 on to the Al bond line. The laser beam may scan along the Al bond line. The laser beam 110 may directly hit the Al surface after transmitting through quartz, Si and Ge materials. The heated Al material may then heat the Ge material in contact with the Al material as the Ge and Al materials are in good physical contact. After the Ge material gets heated, fast inter-diffusion may happen, thereby forming an intermetallic AlGe alloy.

[0079] Only a few microns square area of the Al bond structure surface may be irradiated and get heated by the laser beam 110. The heated depth of Al may be controlled by the irradiation time. A few microns thick, e.g. 2 μm -5 μm , of the Al bond line and of the Ge line may get heated. As such, the heat flow from the bond interface to Si wafer may be significantly reduced, thereby reducing or eliminating generation of thermal stress between the bond lines and the Si wafers due to bonding.

[0080] As mentioned above, the Al bond line 105 and the Ge bond line 104 may be detected by the camera inside the laser scanner 109. In various other embodiments, the global aligning marks on the substrate or wafers may first be detected. The processor or computer connected to the laser scanner 109 may include software on the die-layout on the wafers. The software may guide the laser scanner 109 to scan the laser beam over the bond lines 104, 105.

[0081] The laser scanner 109 may be a movable unit. When bonding is completed for one die, the scanner 109 may move to the next die and carry on the same process. This process may continue until all the dies on the wafers 101, 102 gets bonded. The bonding force may then be

released, and the chamber pressure may be brought back to atmospheric pressure. The bonded wafers 101, 102 may be unloaded together with the bond chuck 103 and plate 106. The bonded wafer stack may then be removed from the bond chuck 103 with the use of an automated mechanical system or manually.

[0082] The bond interface temperature may be controlled by varying the IR radiation energy and exposure time. The infrared source may be a suitable laser source such as a laser generator or any other suitable infrared source. The width of the laser beam 110 may be adjusted to the width of the bond lines 104, 105 with the use of an appropriate optical system within the scanner 109. The movement or scanning of the laser beam 110 may be electro-mechanically controlled from the scanner 109 over the bond lines on individual devices.

[0083] Various embodiments may relate to Al-Ge bonding without Al-Ge getting splashed out. This is explained with reference to FIGS. 6C-D. FIG. 6C is a schematic showing a cross-sectional side view of a part of the substrates 101, 102 before bonding according to various embodiments. FIG. 6D is a schematic showing a cross-sectional side view of a part of the wafers 101, 102 after bonding according to various embodiments. As shown in FIGS. 6C-D, the bottom wafer may include a device area 130.

[0084] As the laser beam 110 passes through the top wafer 101 and the Ge bond line 104 onto the Al bond line 105, heating may start from the Al surface at the Al/Ge bond interface, not from the Al/Si interface. As the Al/Ge bond interface is heated up, heat may flow to the Ge bond line since the Al bond line 105 and the Ge bond line 104 are pressed together and hence have good physical contact. With the increase of bond interface temperature, inter-diffusion of Al and Ge may also increase. When the temperature of the Al/Ge bond interface reaches 423 °C, the Al-Ge alloy in region 129 formed may melt and may form eutectic AlGe. By controlling the width of laser beam 110 and by accurate laser beam focusing, only the center of the interface between the Al bond line 105 and the Ge bond line 104 may get heated. As such, the heating and melting area may be controlled. Therefore, even if the Al-Ge alloy in region 129 melts, the melted Al-Ge alloy does not spread as the melted Al-Ge alloy are kept within the widths of the Al bond line 105 and Ge bond line 104 by the un-melted parts of the Al bond line 105 and the Ge bond line 104, and may not come into contact with the device area 130.

[0085] FIG. 6E is a schematic showing a perspective view showing a part of the bonding apparatus according to various other embodiments. In various embodiments, the actuator may include a piston 118 and a piston plate 113 (instead of metal piece 108 shown in FIG. 6B) that transmits the force from the piston 118 onto the wafers 101, 102 and the bond lines 104, 105.

[0086] The piston plate 113 may be made of stainless steel. Thickness of the plate 113 may be of any suitable thickness in the range from 10 mm to 20 mm. There may be a liner hole 114 going through the center of piston plate 113. The width 115 of the liner hole 114 may be kept small, preferably below 10 mm. The length of the liner hole may be at least 5 mm longer than wafer diameter, for example 305 mm for a bonding apparatus for 300 mm diameter wafers.

[0087] The piston plate 113 may be connected to the piston 118 via two angled rods 116a, 116b. The bonding apparatus may also include an electromechanical unit 117 at the junction of the piston 118 and two angled rods 116a, 116b. The electromechanical unit 117 may be used to rotate the piston plate 113 around the axis of piston 118.

[0088] The infrared laser scanner 109 may be positioned or placed just above the liner hole 114. The infrared laser scanner 109 may be fixed to the piston plate 113 such that the scanner 109 can move along the liner hole 114.

[0089] During the operation, the piston 118 may apply the bonding force on to the substrates 101, 102 and the bond lines 104, 105 via the piston plate 113. Then, the scanner 109 may scan and provide the laser beam 110 to the bond lines 104, 105 of dies that are exposed through the liner hole 114, thereby bonding these bond lines 104, 105. The bond lines 104, 105 that are scanned and which are heated may lie within the liner hole 114. After all the dies that lie within the linear hole are bonded, the bonding force may be released, the piston plate 113 may be rotated with the use of electromechanical unit 117. The bond lines 104, 105 of dies that appears within the linear hole 114 after the piston plate 113 is rotated may then be scanned and heated to be bonded.

[0090] FIG. 6F shows a plot of transmission (in percent or %) as a function of wavelength (in micrometres or μm) showing the transmission profile of a 2 mm thick optical grade germanium sample. FIG. 6F shows that the germanium sample has good transmissivity for infrared wavelengths of about 2 μm to about 14 μm .

[0091] FIG. 7 is a schematic showing a bonding system according to various embodiments. The bonding system may be an integrated system configured to carry out wafer bonding using an automated procedure.

[0092] The bonding system may include a wafer pre-cleaning module 119, a wafer aligning and clamping module 120, a wafer bonding module 121, a wafer de-clamping module 122, an automated wafer handling equipment front end module 123 (with wafers 125), a wafer cassette 124, and a wafer handling module 126. The pre-cleaning module 119 may be configured to clean the wafers 125 before bonding, e.g. using a plasma assisted wafer cleaning method, in which radio frequency (rf) power is applied to the wafer stage to generate the plasma. The wafer aligning and clamping module 120 may be configured to arrange the wafers 125 so that the bond structures are aligned before bonding, and further configured to clamp the wafers 125 using the clamp plate and the bond-chuck. The wafer bonding module 121 may include a bonding apparatus as described herein. The wafer de-clamping module 122 may be configured to separate the wafers from the bond-chuck and the clamp plate after bonding. The wafer cassette 124 may be configured to store the wafers 125 before and after processing. The wafer handling module 126 may be configured to transfer the wafers 125 between the cleaning module 119, the alignment and clamping module 120, the bonding module 121, the wafer de-clamping module 122, and/or the automated wafer handling equipment front end module 123. The automated wafer handling equipment front end module 123 may be configured to hold the wafers 125 retrieved from the cassette 125 for pickup or transfer by the wafer handling module before processing, or to be transferred back the cassette 125 after processing. The system shown in FIG. 7 may allow fully automated wafer level bonding to be carried out.

[0093] The method described herein may allow only the Ge-Al bonding interface to get heated. Therefore, the heated region may be limited to bond interface. Even the silicon (Si) behind the Ge bond structure and the Al bond structure may not get heated.

[0094] Various embodiments may reduce or prevent the splashing of melted AlGe. Various embodiments may increase the overall device yield.

[0095] There may be little or no thermal expansion of wafers causing alignment mismatch since the top and bottom substrates do not get heated. Various embodiments may also help to reduce the required metal line width.

[0096] There may be no need for heaters in the wafer stage to heat wafers. Various embodiments may lower the equipment cost, thereby manufacturing cost.

[0097] Various embodiments may be applied to other eutectic metal as well. However, in case of other metal alloys, the top metal layer may get heated, thus the surrounding local area of Si may also get heated.

[0098] In various embodiments, the bonding apparatus may include a chamber configured to receive a bond-chuck, and a plate that is configured to cooperate with the bond-chuck to hold a first arrangement and a second arrangement. The first arrangement may include a first substrate and a first metal bond structure in contact with the first substrate, and the second arrangement may include a second substrate and a second metal bond structure in contact with the second substrate. The bonding apparatus may also include a scanner configured to provide an infrared beam through the plate for providing heat to the first metal bond structure and/or the second bond structure. The bonding apparatus may also include an actuator configured to apply a bonding force on the first metal structure and the second metal structure to form a resultant bond structure for bonding the first substrate and the second substrate.

[0099] In various embodiments, the method of bonding a first substrate and a second substrate may include providing a first arrangement and a second arrangement within a chamber, the first arrangement and the second arrangement arranged between a bond-chuck and a plate. The first arrangement may include a first substrate and a first metal bond structure in contact with the first substrate, and the second arrangement may include a second substrate and a second metal bond structure in contact with the second substrate. The method may also include providing heat to the first metal bond structure and/or the second bond structure by using a scanner to provide an infrared beam through the plate. The method may also include applying a bonding on the first metal structure and the second metal structure by using an actuator to form a resultant bond structure for bonding the first substrate and the second substrate.

[00100] In various embodiments, a method of forming a bonding apparatus may include forming a chamber configured to receive a bond-chuck, and a plate that is configured to cooperate with the bond-chuck to hold a first arrangement and a second arrangement. The first arrangement may include a first substrate and a first metal bond structure in contact with the first substrate, and the second arrangement may include a second substrate and a second metal bond structure in contact

with the second substrate. The method may also include providing a scanner configured to provide an infrared beam through the plate for providing heat to the first metal bond structure and/or the second bond structure. The method may further include providing or forming an actuator configured to apply a bonding force on the first metal structure and the second metal structure to form a resultant bond structure for bonding the first substrate and the second substrate.

[00101] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

1. A bonding apparatus comprising:

a chamber configured to receive a bond-chuck, and a plate that is configured to cooperate with the bond-chuck to hold a first arrangement and a second arrangement, wherein the first arrangement comprises a first substrate and an aluminum bond structure in contact with the first substrate, and the second arrangement comprises a second substrate and a germanium bond structure in contact with the second substrate;

a scanner configured to provide an infrared beam through the plate, the second substrate, and the germanium bond structure to heat the aluminum bond structure in contact with the germanium bond structure, so that the germanium bond structure is also heated by conduction of heat from the aluminum bond structure; and

an actuator configured to configured to apply a bonding force on the aluminum bond structure and the germanium bond structure, thereby forming an aluminum-germanium bond structure bonding the first substrate and the second substrate.

2. The bonding apparatus according to claim 1, further comprising:

an electromechanical system configured to move the scanner.

3. The bonding apparatus according to claim 1 or claim 2,

wherein the infrared beam is an infrared laser beam.

4. The bonding apparatus according to any one of claim 1 to claim 3, further comprising:

alignment marks inspection system configured to detect the aluminum bond structure and the germanium bond structure.

5. The bonding apparatus according to any one of claim 1 to claim 4,

wherein the actuator comprises a piston and a piston plate coupled to the piston;

wherein the piston plate comprises a liner hole for the infrared beam to pass through; and

wherein the bonding apparatus further comprises a rotating system configured to rotate the piston plate so that the liner hole is moved.

6. The bonding apparatus according to any one of claim 1 to claim 4,
wherein the actuator comprises a piston and a metal piece coupled to the piston.
7. The bonding apparatus according to any one of claim 1 to claim 6, further comprising:
a vacuum system connected to the chamber, the vacuum system configured to reduce a pressure within the chamber before bonding.
8. The bonding apparatus according to any one of claim 1 to claim 7, further comprising:
an infrared source coupled to the scanner, the infrared source configured to generate the infrared beam.
9. The bonding apparatus according to claim 8, further comprising:
wherein the infrared source is arranged outside of the chamber.
10. The bonding apparatus according to any one of claim 1 to claim 9,
wherein the aluminum bond structure is heated by the infrared beam to a temperature above 423°C.
11. The bonding apparatus according to any one of claim 1 to claim 10,
wherein the second substrate comprises a silicon wafer; and
wherein the germanium bond structure is in contact with the silicon wafer.
12. The bonding apparatus according to any one of claim 1 to claim 10,
wherein the second substrate comprises a silicon wafer, and a silicon oxide or silicon nitride film on the silicon wafer, and

wherein the germanium bond structure is in contact with the silicon oxide or silicon nitride film.

13. A bonding system comprising the bonding apparatus according to any one of claim 1 to claim 12.

14. The bonding system according to claim 13, further comprising:

a cleaning module configured to clean the first substrate and the second substrate before bonding;

an alignment and clamping module configured to arrange the first substrate and the second substrate so that the aluminum bond structure and the germanium bond structure are aligned before bonding, and further configured to clamp the first substrate and the second substrate using the plate and the bond-chuck; and

a handling module configured to transfer the first substrate and the second substrate between the cleaning module, the alignment and clamping module and a bonding module comprising the bonding apparatus.

15. A method of bonding a first substrate and a second substrate, the method comprising providing a first arrangement and a second arrangement within a chamber, the first arrangement and the second arrangement arranged between a bond-chuck and a plate, wherein the first arrangement comprises the first substrate and an aluminum bond structure in contact with the first substrate, and the second arrangement comprises the second substrate and a germanium bond structure in contact with the second substrate;

heating the aluminum bond structure in contact with the germanium bond structure by using a scanner to provide an infrared beam through the plate, the second substrate, and the germanium bond structure, so that the germanium bond structure is also heated by conduction of heat from the aluminum bond structure; and

applying a bonding force on the aluminum bond structure and the germanium bond structure by using an actuator to form an aluminum-germanium bond structure.

16. The method according to claim 15, further comprising:

moving the scanner using an electromechanical system.

17. The method according to claim 15 or claim 16, further comprising:

detecting the aluminum bond structure and the germanium bond structure using an alignment marks inspection system.

18. The method according to any one of claim 15 to claim 17,

wherein the actuator comprises a piston and a piston plate coupled to the piston;
wherein the piston plate comprises a liner hole for the infrared beam to pass through; and

wherein the method further comprises rotating the piston plate using a rotating system so that the liner hole is moved.

19. The method according to any one of claim 15 to claim 18, further comprising:

reducing a pressure within a chamber before bonding.

20. The method according to any one of claim 15 to claim 19,

wherein the bonding of the first substrate and the second substrate forms a hermetic seal or a vacuum hermetic seal, or electrically connects one or electrical connections comprised in the first substrate with one or more electrical connections comprised in the second substrate via the aluminum-germanium bond structure.