Title

SEMICONDUCTOR STRUCTURE AND METHOD OF FORMING THE SAME

Cross Reference To Related Applications

[0001] This application is a continuation of PCT Application No. PCT/ CN2018/093692 filed on June 29, 2018, the entire contents of which are incorporated herein by reference.

Background of the Invention

[0002] 1. Field of the Invention

[0003] The present invention generally relates to semiconductor technology, and more specifically, to a semiconductor structure and method of forming the same.

[0004] 2. Description of the Prior Art

[0005] In the technology platform of a three-dimensional (3D) chip, at least two wafers with semiconductor devices formed thereon are usually bonded together through wafer bonding technology to increase the integration of IC. In current wafer bonding technology, silicon oxide based film or silicon nitride based film are usually used as a bonding film at the wafer bonding interface.

[0006] In prior art, silicon oxide film and silicon nitride film are used as a bonding film. However, the bonding strength of these kinds of film is not sufficient, so that defects easily happen in the process to affect the yield of product.

[0007] Furthermore, metal interconnections will be formed in the bonding film. In the process of hybrid bonding, the metal interconnections may easily cause diffusion phenomenon at the bonding interface to affect the performance of product.

[0008] Accordingly, how to increase the quality of wafer bonding is currently an urgent topic in the development of 3D chip.

Summary of the Invention

[0009] The technical matter solved by the present invention is

to provide a semiconductor structure and a method of forming the same.

[0010] The present invention provides a semiconductor structure, wherein the semiconductor structure includes a first substrate and a first adhesive/bonding stack on the surface of first substrate. The first adhesive/bonding stack includes at least one first adhesive layer and at least one first bonding layer, and the materials of first adhesive layer and first bonding layer are different, the material of first bonding layer includes dielectric materials like silicon (Si), nitrogen (N) and carbon (C), and the material of first adhesive layer includes dielectric material like silicon and nitrogen.

[0011] Optionally, the surface of first substrate contacts the first adhesive layer, and a surface of first adhesive/bonding stack is a surface of the first bonding layer.

[0012] Optionally, the atomic concentration of carbon in the first bonding layer is larger than 0% and smaller than 50%.

[0013] Optionally, the atomic concentration of carbon in the first bonding layer is uniform, or the atomic concentration of carbon in the first bonding layer gradually changes along with the increase of thickness of the first bonding layer.

[0014] Optionally, the first adhesive layer further includes carbon, and the atomic concentration of carbon in the first adhesive layer is uniform, or the atomic concentration of carbon in the first adhesive layer gradually changes along with the increase of thickness of the first adhesive layer.

[0015] Optionally, the atomic concentration of carbon in the first adhesive/bonding stack gradually changes in a direction of thickness of the first adhesive/bonding stack.

[0016] Optionally, the compactness of each layer in the first adhesive/bonding stack gradually changes in a direction of thickness of the first adhesive/bonding stack.

[0017] Optionally, the thickness of first bonding layer is larger than 100 Å, and the thickness of first adhesive layer is larger than 10 Å.

[0018] Optionally, the semiconductor structure further includes a second substrate, wherein a second adhesive/bonding stack is formed on the surface of second substrate, and the surfaces of second adhesive/bonding stack and first adhesive/bonding stack are correspondingly bonded together.

[0019] Optionally, the second adhesive/bonding stack and the first adhesive/bonding stack have the same material and structure.

[0020] Optionally, the semiconductor structure further includes a first bonding pad penetrating through the first adhesive/bonding stack and a second bonding pad penetrating through the second adhesive/bonding stack, wherein the first bonding pad and the second bonding pad are correspondingly bonded and connected together.

[0021] The technical solution by the present invention further provides a method of forming a semiconductor structure, which includes the steps of providing a first substrate and forming a first adhesive/bonding stack on the surface of first substrate, wherein the first adhesive/bonding stack includes at least one first bonding layer and at least one first adhesive layer, and the materials of first adhesive layer and the first bonding layer are different. The material of first bonding layer includes dielectric material like silicon (Si), nitrogen (N) and carbon (C), and the material of first adhesive layer includes dielectric material like Si and N.

[0022] Optionally, the atomic concentration of carbon in the first bonding layer is larger than 0% and smaller than 50%.

[0023] Optionally, the atomic concentration of carbon in the first bonding layer is uniform, or the atomic concentration of carbon in the first bonding layer gradually changes along with the thickness of first bonding layer.

[0024] Optionally, the first adhesive layer further includes carbon, and the atomic concentration of carbon in the first adhesive layer is uniform, or the atomic concentration of carbon in the first adhesive layer gradually changes along with the

increase of thickness of the first adhesive layer.

[0025] Optionally, the atomic concentration of carbon in the first adhesive/bonding stack gradually changes in a direction of thickness of the first adhesive/bonding stack, or the compactness of each layer in the first adhesive/bonding stack gradually changes in a direction of thickness of the first adhesive/bonding stack.

[0026] Optionally, the thickness of first bonding layer is larger than 100 Å, and the thickness of first adhesive layer is larger than 10 Å.

[0027] Optionally, the semiconductor structure forming method further includes the steps of providing a second substrate, forming a second adhesive/bonding stack on the surface of second substrate, and correspondingly bonding the surfaces of second adhesive/bonding stack and the surface of first adhesive/bonding stack.

[0028] Optionally, the second adhesive/bonding stack and the first adhesive/bonding stack have the same material and structure.

[0029] Optionally, the semiconductor structure forming method further includes the steps of forming a first bonding pad penetrating through the first adhesive/bonding stack, forming a second bonding pad penetrating through the second adhesive/bonding stack, and correspondingly bonding the first bonding pad and the second bonding pad when correspondingly bonding the surface of second adhesive/bonding stack and the surface of first adhesive/bonding stack.

[0030] The semiconductor structure of present invention includes a first substrate and a first adhesive/bonding stack on the surface of first substrate, wherein the first adhesive/bonding stack is a composite bonding layer and includes at least one first adhesive layer and at least one first bonding layer. The first adhesive/bonding stack and the surface of first substrate may provide higher adhesive force. The bonding interface therebetween would also have higher bonding force after bonding

and may prevent the diffusion of metal materials at the bonding interface, thereby improving the performance of semiconductor structure.

[0031] These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

Brief Description of the Drawings

[0032] FIG. 1 to FIG. 4 are schematic figures sequentially illustrating a forming process of a semiconductor structure in accordance with an embodiment of the present invention;

[0033] FIG. 5 is a schematic figure of a semiconductor structure in accordance with an embodiment of the present invention; and

[0034] FIG. 6 is a schematic figure of a semiconductor structure in accordance with an embodiment of the present invention.

Detailed Description

[0035] In the following detailed description of the invention, reference is made to the accompanying drawings, which form a part hereof, and in which is shown, by way of illustration, specific embodiments in which the semiconductor structure and the method of forming the same of the invention may be practiced.

[0036] Please refer to FIG. 1 to FIG. 4, which are schematic figures sequentially illustrating a process of forming a semiconductor structure in accordance with an embodiment of the present invention.

[0037] Please refer to FIG. 1. First provide a first substrate 100.

[0038] The first substrate 100 includes a first semiconductor substrate 101, a first device layer 102 formed on the surface of first semiconductor substrate 101.

[0039] The first semiconductor substrate 101 may be single-crystal silicon substrate, germanium (Ge) substrate, silicon-

germanium (SiGe) substrate, silicon-on-insulator (SOI) substrate or germanium- on-insulator (GOI) substrate, etc. Suitable first semiconductor substrate 101 may be selected depending on actual requirement of the device, but not limited thereto. In preferred embodiment, the first semiconductor substrate 101 is a single-crystal silicon wafer.

[0040] The first device layer 102 includes semiconductor devices formed on first semiconductor substrate 101, metal interconnections connecting the semiconductor devices, dielectric layers covering the semiconductor devices and the metal interconnections, etc. The first device layer 102 may be multilayer or single-layer structure. In the embodiment, the first device layer 102 includes dielectric layers and 3D NAND structure formed in the dielectric layers.

[0041] Please refer to FIG. 2. A first adhesive/bonding stack 200 is formed on the surface of first substrate 100. The first adhesive/bonding stack 200 includes at least one stacked first bonding layer 201 and at least one stacked first adhesive layer 202. The surface of first adhesive/bonding stack opposite to the first substrate is bonding surface.

[0042] In the embodiment, the first adhesive/bonding stack 200 includes the first adhesive layer 202 on the surface of first substrate 100 and the first bonding layer 201 on the surface of first adhesive layer 202.

[0043] The materials of first bonding layer 201 and first adhesive layer 202 are different. More specifically, the first bonding layer 201 and first adhesive layer 202 may include the same elements, but with different element concentration, or the first bonding layer 201 and first adhesive layer 202 may include different elements. The first adhesive layer 202 and the first bonding layer 201 may be sequentially formed by using individual chemical vapor deposition (CVD) processes. In the embodiment, the first adhesive layer 202 and the first bonding layer 201 is formed by using plasma enhanced chemical vapor deposition (PECVD) processes.

[0044] The material of first bonding layer 201 includes the dielectric materials like silicon (Si), nitrogen (N) and carbon (C). The material of first adhesive layer 202 includes the dielectric materials like silicon (Si) and nitrogen (N). The first bonding layer 201 and the first bonding layer 202 may be further doped with at least one element of oxygen (O), hydrogen (H), phosphorus (P) and fluorine (F), depending on the reagent gas using in the PECVD process and the requirement of products. For example, the material of first bonding layer 201 may be doped silicon nitride, doped silicon oxynitride and doped silicon carbonitride, etc. The material of first adhesive layer 202 may be silicon nitride and silicon oxynitride, etc.

[0045] In an embodiment, the reagent gas using in the PECVD process of forming the first adhesive layer 202 includes SiH_4 and NH_3, with the flow ratio of SiH_4 to NH_3 larger than 0.5 under a radio frequency power larger than 300W. The reagent gas using in the PECVD process of forming the first bonding layer 201 includes one of trimethylsilane or tetramethylsilane and NH_3 , with the flow ratio of trimethylsilane or tetramethylsilane to NH_3 larger than 0.5 under a radio frequency power larger than 300W.

[0046] In another embodiment, the first adhesive layer 202 and the bonding layer 201 may be formed by performing a treatment to the dielectric materials. For example, after a silicon oxide film is formed on the surface of first substrate 100, performing a nitrogen doping process to the silicon oxide film to form the first adhesive layer 202. A silicon nitride film is then formed on the surface of first adhesive layer 202 and is doped with carbon to form a first bonding layer 201. Suitable material and treatment for the dielectric film may be selected depending on the materials of first adhesive layer 202 and first bonding layer 201 to be formed.

[0047] The element concentration in the first bonding layer 201 and the first adhesive layer 202 may be adjusted by controlling the process parameters of forming the first bonding layer 201

and the first adhesive layer 202, so that the bonding force between the first substrate 100 and the first adhesive layer 202 and between the first adhesive layer 202 and the first bonding layer 201 and the dielectric constant of first adhesive/bonding stack 200 may be adjusted.

[0048] The first bonding layer 201 is on the top of first adhesive/bonding stack 200. The carbon in first bonding layer 201 may efficiently increase the bonding force between the first bonding layer 201 and other bonding layers in a bonding process. The higher the carbon concentration, the stronger the bonding force to another bonding layer resulted in bonding process. In an embodiment, the atomic concentration of carbon in the first bonding layer is larger than 0% and smaller than 50%.

[0049] The first adhesive layer 202 has higher silicon atomic concentration, thereby increasing the compactness of first adhesive layer 202 and the bonding force to the first bonding layer 201 and the first device layer 102. In an embodiment, the atomic concentration of silicon in the first adhesive layer 202 is larger than 20%. The first adhesive layer 202 further includes carbon, and its carbon atomic concentration is smaller than the carbon atomic concentration in the first bonding layer 201. In comparison to the method that forming the first bonding layer 201 directly on the surface of first device layer 102, the adhesive force between the first adhesive/bonding stack 200 and the first device layer 102 in the embodiment may be effectively improved since the bonding force between the first adhesive layer 202 and the first device layer 102 is stronger.

[0050] Since the bonding force between different materials is related to material compositions at both sides of the bonding interface, the bonding force would get stronger if the material compositions are similar. In order to further increase the bonding force between the first adhesive layer 202 and the first device layer 102, process parameters may be gradually adjusted during the formation of first adhesive layer 202 to gradually change element concentrations in the first adhesive layer 202,

so that the material composition of first device layer 102 and first adhesive layer 202 at two sides of the bonding interface would be similar. In an embodiment, the parameters of deposition process are adjusted along with the increase of thickness of the first adhesive layer 202 during the process of forming the first adhesive layer 202, so that the silicon atomic concentration in the first adhesive layer 202 may gradually change along with the increase of thickness of the first adhesive layer 202. In another embodiment, the other element concentrations in the first adhesive layer 202 may also be adjusted depending on the material on the surface of the first device layer 102. For example, the carbon atomic concentration in the first adhesive layer 202 may be uniform, or the carbon atomic concentration may gradually change along with the increase of thickness of first bonding layer. In another embodiment, the parameters of deposition process may remain unchanged during the formation of first adhesive layer 202 so that the element concentrations in different thickness levels of the first adhesive layer 202 may also remain unchanged.

[0051] In order to further increase the bonding force between the first adhesive layer 202 and the first bonding layer 201, process parameters may be gradually adjusted during the formation of the first bonding layer 201 to gradually change element concentrations of the first bonding layer 201, so that the material composition of first bonding layer 201 and first adhesive layer 202 at two sides of the bonding interface would be similar. In an embodiment, the parameters of deposition process are adjusted along with the increase of thickness of the first bonding layer 201 during the process of forming the first bonding layer 201, so that the carbon atomic concentration may gradually change along with the increase of thickness of the first bonding layer 201. In another embodiment, the carbon atomic concentration may be gradually decreased or may be gradually increased then gradually decreased along with the increase of thickness of the first bonding layer 201. In another embodiment,

the parameters of deposition process may remain unchanged during the formation of first bonding layer 201 so that the element concentrations in different thickness levels of the first bonding layer 201 may remain unchanged.

[0052] The thickness of first bonding layer 201 is larger than the thickness of first adhesive layer 202 to ensure that the first bonding layer 201 may provide sufficient bonding thickness when bonding the first bonding layer 201 to other bonding layers. In an embodiment, the thickness of first adhesive layer 202 is larger than 10 Å, and the thickness of first bonding layer 201 is larger than 100 Å.

[0053] In another embodiment, the first adhesive/bonding stack 200 may include at least three stacked sub-layers. In an embodiment, the first adhesive/bonding stack 200 includes a first adhesive layer 202 and at least two first bonding layers 201. The materials of different first bonding layers 201 may be the same or different. In another embodiment, the first adhesive/bonding stack 200 may include at least two first adhesive layers 202 and a first bonding layer 201. The first adhesive/bonding stack 200 may include multiple alternatingly stacked first adhesive layer 202 and first bonding layer 201. In the situation that the first adhesive/bonding stack 200 includes at least three sub-layers, the surface of first substrate 100 would contact the first adhesive layer 202 and the surface of first adhesive/bonding stack 200 will be a surface of first bonding layer 201, so that the surfaces of first adhesive/ bonding stack 200 and the first device layer may have higher adhesive forces to provide stronger bonding force when bonding the first adhesive/bonding stack 200 to other bonding layers.

[0054] In an embodiment, the carbon concentration in the first adhesive/bonding stack 200 would gradually change in a direction of thickness of the first adhesive/bonding stack 200. In another embodiment, the compactness of each layer in the first adhesive/ bonding stack 200 would gradually change in a direction of thickness of the first adhesive/bonding stack 200.

[0055] Please refer to FIG. 3. In another embodiment, the method further includes providing a second substrate 300 and forming a second adhesive/bonding stack 400 on the surface of second substrate 300.

[0056] The second substrate 300 includes a second semiconductor substrate 301 and a second device layer 302 on the surface of second semiconductor substrate 301.

[0057] The second adhesive/bonding stack 400 is formed on the surface of second device layer 302 by using CVD process. In the embodiment, the second adhesive/bonding stack 400 includes at least one first bonding layer 401 and at least first adhesive layer 402. Specific material and structure of the second adhesive/bonding stack 400 may refer to the description of first adhesive/bonding stack 200 in the embodiment above. No more redundant description will be herein provided. In an embodiment, the material and structure of second adhesive/bonding stack 400 is identical to the ones of above-described first adhesive/bonding stack 200.

[0058] Please refer to FIG. 4. The surfaces of second adhesive/ bonding stack 400 and first adhesive/bonding stack 200 are correspondingly bonded and fixed. During the bonding process, the first bonding layer 401 on the surface of second adhesive/bonding stack 400 is bonded to the first bonding layer 201 on the surface of first adhesive/bonding stack 200.

[0059] Both of the first bonding layer 401 and the first bonding layer 201 include carbon element, which is partially in the form of $-CH_3$. The $-CH_3$ may be easily oxidized into -OH and may form Si-O bonds in the bonding process, so that more Si-O bonds may be formed on the bonding interface to provide stronger bonding force. In an embodiment, the bonding force between the first bonding layer 401 and the first bonding layer 201 is larger than 2 J/m^2, while the bonding force in prior art is usually smaller than 1.5 J/m^2 since its bonding layer contain no carbon element.

[0060] In an embodiment, the first substrate 100 is a substrate with 3D NAND memory formed thereon, and the second substrate 200

is a substrate with peripheral circuit formed thereon.

[0061] In another embodiment, the above-mentioned adhesive/ bonding stack may be formed on both sides of a substrate to realize the bonding solution with at least three substrates.

[0062] Please refer to FIG. 5. In another embodiment, the method further includes forming a first bonding pad 501 penetrating through the first adhesive/bonding stack 200, forming a second bonding pad 502 penetrating through the second adhesive/bonding stack 400, correspondingly bonding the first bonding pad 501 and the second bonding pad 502 when correspondingly bonding the surface of second adhesive/bonding stack 400 to the surface of first adhesive/bonding stack 200.

[0063] The first bonding pad 501 and the second bonding pad 502 may be connected to semiconductor devices and metal interconnections in the first device layer 102 and the second device layer 302, respectively.

[0064] The method of forming first bonding pad 501 includes: performing a patterning process to the first adhesive/bonding stack 200 to form openings penetrating through the first adhesive/bonding stack 200, filling the openings with metal material and performing a planarization process to form first bonding pads 501 filling up the openings, using the same method to form the second bonding pad 502 in the second adhesive/bonding stack 400, and bonding the first bonding pad 501 and the second bonding pad 502 to realize the electrical connection between the semiconductor devices in first device layer 102 and second device layer 302.

[0065] The materials of first bonding pad 501 and second bonding pad 502 may be metal material like copper (Cu) and tungsten (w), etc. The bonding interface between the first adhesive/bonding stack 200 and the second adhesive/bonding stack 400 is a bonding interface between the first bonding layers 201 and the first bonding layers 401. The carbon element included in the first bonding layers 201 and the first bonding layers 401 may efficiently block and prevent the material diffusion of first

bonding pads 501 and second bonding pad 502 at the bonding interface, thereby improving the performance of semiconductor structure.

[0066] The above-described method may also be used in the bonding of multiple substrates. Please refer to FIG. 6. In an embodiment of present invention, the method further includes: providing a third substrate 600, forming a third adhesive/bonding stack 700 and a fourth adhesive/bonding stack 800 respectively at two opposite surfaces of the third substrate 600, bonding the surfaces of third adhesive/bonding stack 700 and first adhesive/bonding stack 200, bonding the surfaces of fourth adhesive/bonding stack 800 and second adhesive/bonding stack 400 to form tri-layer bonding structure.

[0067] In the embodiment, the third adhesive/bonding stack 700 includes a first adhesive layer 702 and a first bonding layer 701. The fourth adhesive/bonding stack 800 includes a first adhesive layer 802 and a first bonding layer 801. The surfaces of first bonding layer 801 and first bonding layer 401 are bonded together, and the surfaces of first bonding layer 701 and first bonding layer 201 are bonded together.

[0068] In another embodiment, the third adhesive/bonding stack 700 and the fourth adhesive/bonding stack 800 may be another structure. The method of forming third adhesive/bonding stack 700 and fourth adhesive/bonding stack 800 may refer to the forming method of first adhesive/bonding stack 200 in the embodiment above. No redundant description will be therein provided.

[0069] In the embodiment, the method further includes: forming a third bonding pad 703 in the third adhesive/bonding stack 700, forming a fourth bonding pad 803 in the fourth adhesive/bonding stack 800, bonding the third bonding pad 703 and the first bonding pad 501, and bonding the fourth bonding pad 803 and the second bonding pad 502.

[0070] In another embodiment, the above-described method may be used to form a bonding structure with at least four layers.

[0071] In the embodiment above, forming a bonding layer with composite structure on the substrate surface may provide higher adhesive force to the substrate surface. The bonding interface therebetween will also have higher bonding force after bonding and may prevent the diffusion of metal materials at the bonding interface, thereby improving the performance of semiconductor structure.

[0072] Please note that, in the technical solution of present invention, the type of semiconductor devices in individual substrates of semiconductor structure is not limited to those mentioned in the embodiments. In addition to 3D NAND, it may be complementary metal-oxide-semiconductor (CMOS), CMOS image sensor (CIS) or thin-film transistor (TFT), etc.

[0073] The embodiment of present invention further provides a semiconductor structure.

[0074] Please refer to FIG. 2, which is a schematic figure of a semiconductor structure in an embodiment of the present invention.

[0075] The semiconductor structure may include a first substrate 100 and a first adhesive/bonding stack 200 on the surface of first substrate 100, wherein the first adhesive/bonding stack 200 includes at least one stacked first bonding layer 201 and at least one stacked first adhesive layer 202, and the materials of the first adhesive layer 202 and first bonding layer 201 are different. The material of first bonding layer 201 includes dielectric material like silicon, nitrogen and carbon, and the material of first adhesive layer 202 includes dielectric material like silicon and nitrogen.

[0076] The first substrate 100 includes a first semiconductor substrate 101, a first device layer 102 formed on the surface of first semiconductor substrate 101.

[0077] The first semiconductor substrate 101 may be single-crystal silicon substrate, germanium (Ge) substrate, silicon-germanium (SiGe) substrate, silicon-on-insulator (SOI) substrate or germanium- on-insulator (GOI) substrate, etc. Suitable first

semiconductor substrate 101 may be selected depending on actual requirement of the device, but not limited thereto. In preferred embodiment, the first semiconductor substrate 101 is a single-crystal silicon wafer.

[0078] The first device layer 102 includes semiconductor devices formed on first semiconductor substrate 101, metal interconnections connecting the semiconductor devices, dielectric layers covering the semiconductor devices and the metal interconnections, etc. The first device layer 102 may be multilayer or single-layer structure. In an embodiment, the first device layer 102 includes dielectric layers and 3D NAND structure formed in the dielectric layers.

[0079] The first adhesive/bonding stack 200 includes a first bonding layer 201 on the surface of first substrate 100 and a first adhesive layer 202 on the surface of first bonding layer 201. The materials of first bonding layer 201 and first adhesive layer 202 may be different. More specifically, the first bonding layer 201 and first adhesive layer 202 may include the same elements, but with different element concentrations, or the first bonding layer 201 and first adhesive layer 202 may include different elements.

[0080] The material of first bonding layer 201 includes the dielectric materials like silicon (Si), nitrogen (N) and carbon (C). The material of first adhesive layer 202 includes the dielectric materials like silicon (Si) and nitrogen (N). The first bonding layer 201 and the first bonding layer 202 may be further doped with at least one element of oxygen (O), hydrogen (H), phosphorus (P) and fluorine (F), depending on the reagent gas using in the PECVD process and the requirement of products. For example, the material of first bonding layer 201 may be doped silicon nitride, doped silicon oxynitride and doped siicon carbonitride, etc. The material of first adhesive layer 202 may be silicon nitride and silicon oxynitride, etc.

[0081] The element concentration in the first bonding layer 201 and the first adhesive layer 202 may be adjusted by controlling

the process parameters of forming the first bonding layer 201 and the first adhesive layer 202, so that the adhesive force between material layers and the dielectric constant of first adhesive/ bonding stack 200 may, therefore, be adjusted.

[0082] The first bonding layer 201 is on the top of first adhesive/bonding stack 200. The carbon in first bonding layer 201 may efficiently increase the bonding force between the first bonding layer 201 and another bonding layer in bonding process. The higher the carbon concentration, the stronger the bonding force to other bonding layers in the bonding process. In an embodiment, the atomic concentration of carbon in the first bonding layer 201 is larger than 0% and smaller than 50%.

[0083] The first adhesive layer 202 has higher silicon atomic concentration, thereby increasing the compactness of first adhesive layer 202 and the bonding force to the first bonding layer 201 and the first device layer 102. In an embodiment, the silicon atomic concentration in the first adhesive layer 202 is larger than 20%, and its carbon atomic concentration is smaller than the carbon atomic concentration in the first bonding layer 201. In comparison to the method that forming the first bonding layer 202 directly on the surface of first device layer 102, the adhesive force between the first adhesive/bonding stack 200 and the first device layer 102 in the embodiment may be effectively improved since the adhesive force between the first adhesive layer 202 and the first device layer 102 is stronger.

[0084] Since the bonding force between different materials is related to material compositions at both sides of the bonding interface, the bonding force would get stronger if the material compositions are similar. In order to further increase the adhesive force between the first adhesive layer 202 and the first device layer 102, the element concentrations in the first adhesive layer 202 would gradually change along with the thickness of first adhesive layer 202, so that the material composition of first device layer 102 and the material at two sides of the first adhesive layer 202 would be similar. In an

embodiment, the silicon atomic concentration in the first adhesive layer 202 may gradually change along with the increase of thickness of the first adhesive layer 202. In another embodiment, the other element concentrations in the first adhesive layer 202 may also be changed depending on the material on the surface of the first device layer 102. In another embodiment, the element concentrations in different thickness levels of the first adhesive layer 202 may remain unchanged to provide uniform atomic concentration.

[0085] In order to further increase the adhesive force between the first adhesive layer 202 and the first bonding layer 201, the element concentrations of the first bonding layer 201 may gradually change along with the thickness, so that the material composition of first bonding layer 201 and the materials at two sides of the first adhesive layer 202 would be similar. In an embodiment, the carbon atomic concentration in the first bonding layer 201 may be gradually increased along with the increase of thickness of the first bonding layer 201. In another embodiment, the carbon atomic concentration in the first bonding layer 201 may be gradually decreased or may be gradually increased then gradually decreased along with the increase of thickness of the first bonding layer 201. In another embodiment, the element concentrations in different thickness levels of the first bonding layer 201 may remain unchanged to provide uniform atomic concentration.

[0086] The thickness of first bonding layer 201 is larger than the thickness of first adhesive layer 202 to ensure that the first bonding layer 201 may provide sufficient bonding thickness when bonding the first bonding layer 201 to other bonding layers. In an embodiment, the thickness of first adhesive layer 202 is larger than 10 Å, and the thickness of first bonding layer 201 is larger than 100 Å.

[0087] In another embodiment, the first adhesive/bonding stack 200 may include at least three sub-layers. In an embodiment, the first adhesive/bonding stack 200 includes a first adhesive layer

202 and at least two first bonding layers 201. The materials of different first bonding layers 201 may be the same or different. In another embodiment, the first adhesive/bonding stack 200 may include at least two first adhesive layers 202 and a first bonding layer 201. The first adhesive/bonding stack 200 may include multiple alternatingly stacked first adhesive layer 202 and first bonding layer 201. In the situation that the first adhesive/bonding stack 200 includes at least three sub-layers, the surface of first substrate 100 would contact the first adhesive layer 202, and the surface of first adhesive/bonding stack 200 will be a surface of first bonding layer 201, so that the surfaces of first adhesive/ bonding stack 200 and the first device layer 102 may have higher adhesive forces to generate stronger bonding force when the first adhesive/bonding stack 200 is bonded to other bonding layers.

[0088] In an embodiment, the carbon concentration in the first adhesive/bonding stack 200 would gradually change in a direction of thickness of the first adhesive/bonding stack 200. In another embodiment, the compactness of each layer in the first adhesive/ bonding stack 200 would gradually change in a direction of thickness of the first adhesive/bonding stack 200.

[0089] Please refer to FIG. 4, which is a schematic figure of a semiconductor structure in accordance with another embodiment of the present invention.

[0090] In the embodiment, the semiconductor structure further includes a second substrate 300, wherein a second adhesive/bonding stack 400 is formed on the surface of second substrate 300. The surfaces of second adhesive/bonding stack 400 and first adhesive/ bonding stack 200 are correspondingly bonded and fixed.

[0091] The second substrate 300 includes a second semiconductor substrate 301 and a second device layer 302 on the surface of second semiconductor substrate 301. In the embodiment, the second adhesive/ bonding stack 400 includes at least one first bonding layer 401 and at least one first adhesive layer 402.

Specific material and structure of second adhesive/bonding stack 400 may refer to the description of first adhesive/bonding stack 200 in the embodiment above. No more redundant description will be herein provided. In an embodiment, the material and structure of second adhesive/ bonding stack 400 are identical to the ones of above-mentioned first adhesive/bonding stack 200.

[0092] The first bonding layer 401 on the top of second adhesive/bonding stack 400 would be bonded to the surface of first bonding layer 201 on the top of first adhesive/bonding stack 200. Both of the first bonding layer 401 and the first bonding layer 201 include carbon element, which is partially in the form of $-CH_3$. The $-CH_3$ may be easily oxidized into -OH and may form Si-O bonds in the bonding process, so that more Si-O bonds may be formed in the bonding interface to provide stronger bonding force.

[0093] In another embodiment, the semiconductor structure may include at least three substrates, wherein adjacent substrates are all bonded together by using the composite bonding layer in the embodiment of present invention.

[0094] Please refer to FIG. 5, which is a schematic figure of a semiconductor structure in accordance with another embodiment of the present invention.

[0095] In the embodiment, the semiconductor structure further includes a first bonding pad 501 penetrating through the first adhesive/ bonding stack 200, a second bonding pad 502 penetrating through the second adhesive/bonding stack 400, wherein the surface of second adhesive/bonding stack 400 and the surface of first adhesive/ bonding stack 200 are correspondingly bonded and fixed together, and the first bonding pad 501 and the second bonding pad 502 are also correspondingly bonded and connected together.

[0096] The first bonding pad 501 and the second bonding pad 502 may be connected to semiconductor devices and metal interconnections in the first device layer 102 and the second device layer 302, respectively.

[0097] The materials of first bonding pad 501 and second bonding pad 502 may be metal material like copper (Cu) and tungsten (w), etc. The bonding interface between the first adhesive/bonding stack 200 and the second adhesive/bonding stack 400 is a bonding interface between the first bonding layers 201 and the first bonding layers 401. The carbon element included in the first bonding layers 201 and the first bonding layers 401 may efficiently block and prevent the material diffusion of first bonding pads 501 and second bonding pad 502 at the bonding interface, thereby improving the performance of semiconductor structure.

[0098] In an embodiment, the first substrate 100 is a substrate with 3D NAND memory formed thereon, and the second substrate 200 is a substrate with peripheral circuit formed thereon.

[0099] Please refer to FIG. 6, which is a schematic figure of a semiconductor structure in accordance with another embodiment of the present invention.

[0100] In the embodiment, the semiconductor structure further includes a third substrate 600. A third adhesive/bonding stack 700 and a fourth adhesive/bonding stack 800 are formed respectively at two opposite surfaces of the third substrate 600, wherein the surfaces of third adhesive/bonding stack 700 and first adhesive/ bonding stack 200 are correspondingly bonded and fixed together, and the surfaces of fourth adhesive/bonding stack 800 and second adhesive/bonding stack 400 are bonded and fixed together, to constitute a tri-layer bonding structure.

[0101] In the embodiment, the third adhesive/bonding stack 700 includes a first adhesive layer 702 and a first bonding layer 701. The fourth adhesive/bonding stack 800 includes a first adhesive layer 802 and a first bonding layer 801. The surfaces of first bonding layer 801 and first bonding layer 401 are bonded and fixed together, and the surfaces of first bonding layer 701 and first bonding layer 201 are bonded and fixed together.

[0102] In another embodiment, the third adhesive/bonding stack 700 and the fourth adhesive/bonding stack 800 may be another

structure. The material and structure of third adhesive/bonding stack 700 and fourth adhesive/bonding stack 800 may refer to the ones of first adhesive/bonding stack 200 in the embodiment above. No redundant description will be therein provided.

[0103] In the embodiment, a third bonding pad 703 is further formed in the third adhesive/bonding stack 700, and a fourth bonding pad 803 is further formed in the fourth adhesive/bonding stack 800, wherein the third bonding pad 703 and the first bonding pad 501 are bonded together, and the fourth bonding pad 803 and the second bonding pad 502 are bonded together.

[0104] In another embodiment, the above-described method may be used to form a bonding structure with at least four layers.

[0105] Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

Claims

What is claimed is:

1. A semiconductor structure, comprising:

a first substrate; and

a first adhesive/bonding stack on a surface of said first substrate, wherein said first adhesive/bonding stack comprises at least one first adhesive layer and at least one first bonding layer, and materials of said first adhesive layer and said first bonding layer are different, a material of said first bonding layer comprises dielectric material of silicon, nitrogen and carbon, and a material of said first adhesive layer comprises dielectric material of silicon and nitrogen,

wherein thickness of said first bonding layer is larger than thickness of said first adhesive layer.

2. The semiconductor structure of claim 1, wherein said surface of said first substrate contacts said first adhesive layer, and a surface of said first adhesive/bonding stack is a surface of said first bonding layer.

3. The semiconductor structure of claim 1, wherein an atomic concentration of carbon in said first bonding layer is larger than 0% and smaller than 50%.

4. The semiconductor structure of claim 1, wherein an atomic concentration of carbon in said first bonding layer is uniform, or said atomic concentration of carbon in said first bonding layer gradually changes along with the increase of thickness of said first bonding layer.

5. The semiconductor structure of claim 1, wherein said first adhesive layer further comprises carbon, and an atomic concentration of carbon in said first adhesive layer is uniform, or said atomic concentration of carbon in said first adhesive

layer gradually changes along with the increase of thickness of said first adhesive layer.

6. The semiconductor structure of claim 5, wherein an atomic concentration of carbon in said first adhesive/bonding stack gradually changes in a direction of thickness of said first adhesive/bonding stack.

7. The semiconductor structure of claim 1, wherein a compactness of each layer in said first adhesive/bonding stack gradually changes in a direction of thickness of said first adhesive/bonding stack.

8. The semiconductor structure of claim 1, wherein a thickness of said first bonding layer is larger than 100 Å, and a thickness of said first adhesive layer is larger than 10 Å.

9. The semiconductor structure of claim 1, further comprising a second substrate, wherein a second adhesive/bonding stack is formed on a surface of said second substrate, and a surface of said second adhesive/bonding stack is correspondingly bonded to a surface of said first adhesive/bonding stack.

10. The semiconductor structure of claim 9, wherein said second adhesive/bonding stack and said first adhesive/bonding stack have the same material and structure.

11. The semiconductor structure of claim 9, further comprising:

a first bonding pad penetrating through said first adhesive/ bonding stack; and

a second bonding pad penetrating through said second adhesive/ bonding stack, wherein said first bonding pad is correspondingly bonded to said second bonding pad.

12. A method of forming a semiconductor structure, comprising:

providing a first substrate; and

forming a first adhesive/bonding stack on a surface of said first substrate, wherein said first adhesive/bonding stack comprises at least one first bonding layer and at least one first adhesive layer, and materials of said first adhesive layer and said first bonding layer are different, a material of said first bonding layer comprises dielectric material of silicon, nitrogen and carbon, and a material of said first adhesive layer comprises dielectric material of silicon and nitrogen,

wherein thickness of said first bonding layer is larger than thickness of said first adhesive layer.

13. The method of forming a semiconductor structure of claim 12, wherein an atomic concentration of carbon in said first bonding layer is larger than 0% and smaller than 50%.

14. The method of forming a semiconductor structure of claim 12, wherein an atomic concentration of carbon in said first bonding layer is uniform, or said atomic concentration of carbon in said first bonding layer gradually changes along with the increase of thickness of said first bonding layer.

15. The method of forming a semiconductor structure of claim 12, wherein said first adhesive layer further comprises carbon, and an atomic concentration of carbon in said first adhesive layer is uniform, or said atomic concentration of carbon in said first adhesive layer gradually changes along with the increase of thickness of said first adhesive layer.

16. The method of forming a semiconductor structure of claim 15, wherein an atomic concentration of carbon in said first adhesive/ bonding stack gradually changes in a direction of thickness of said first adhesive/bonding stack, or a compactness of each

layers in said first adhesive/bonding stack gradually changes in a direction of thickness of said first adhesive/bonding stack.

17. The method of forming a semiconductor structure of claim 12, wherein a thickness of said first bonding layer is larger than 100 Å, and a thickness of said first adhesive layer is larger than 10 Å.

18. The method of forming a semiconductor structure of claim 12, further comprising:

providing a second substrate;

forming a second adhesive/bonding stack on a surface of said second substrate; and

correspondingly bonding a surface of said second adhesive/ bonding stack to a surface of said first adhesive/bonding stack.

19. The method of forming a semiconductor structure of claim 18, wherein said second adhesive/bonding stack and said first adhesive/ bonding stack have the same material and structure.

20. The method of forming a semiconductor structure of claim 18, further comprising:

forming a first bonding pad penetrating through said first adhesive/bonding stack;

forming a second bonding pad penetrating through said second adhesive/bonding stack; and

correspondingly bonding said first bonding pad and said second bonding pad when bonding said surface of said second adhesive/ bonding stack to said surface of said first adhesive/bonding stack.