Description

Title of Invention: Method of Bonding a First Substrate and a Second Substrate

Priority Claim

This application claims the benefit of priority from Singapore Patent Application No. 10201406863T filed on October 23, 2014, the content of which is incorporated herein by reference in its entirety for all purposes.

Technical Field

The present invention generally relates to a method for bonding a first substrate and a second substrate (e.g. a semiconductor chip and a semiconductor wafer). More particularly, it relates to a method of two-step bonding using an adhesive material to align and secure the first substrate before carrying out permanent bonding on the first substrate, the adhesive material and the second substrate.

Background Art

In conventional chip-on-wafer (COW) fabrication, a method typically known as flip chip bonding is used. As shown in Fig. 1A, a first substrate **102** (e.g. chip) primarily comprises connections **104a, 104b** extending from one side of the substrate **102** and solder caps **106a, 106b** fabricated on the vertex (e.g. surfaces facing a second substrate) of the connections **104a, 104b**. In other words, the solder caps **106a, 106b** are fabricated on the tip of the connections **104a, 104b**. As shown in Fig. 1B, the first substrate **102** with connections **104a, 104b** (e.g. copper pillars) are aligned and permanently bonded to a second substrate **110** (e.g. a wafer) by heating an assembly **112** (including the first substrate **102** and the second substrate **110**) to a solder-melting temperature and using an applied force on the first and second substrate **102**, **110**. Flip chip bonding is an established one-step process to obtain permanent bonding. However, the use of solder caps **106a, 106b** may result in the solder being pressed out when a bonding force is applied on the first and second substrate **102**, **110**. If the separation between the connections **104a, 104b** is small, the solder caps **106a, 106b** may transverse the connections **104a, 104b**

and span across the solder caps **106a, 106b**. The span across the solder caps **106a, 106b** is typically known as a solder bridge **106c**. The solder bridge **106c** may cause electrical shortage, and could result in device failure.

Bridging of the solder caps **106a, 106b** is typically avoided using a method of solder-less bonding. Solder caps **106a, 106b** are absent in the first substrate **102** and the second substrate **110** bonded using the method of the solder-less bonding. The first substrate **102** is first brought into alignment with second substrate **110** using a flip chip bonder. The assembly is then transferred to a global chip bonder, where the chips are permanently bonded to the wafer by heating up the assembly and using an applied force. An exemplary technique used to bond the first substrate **102** permanently to the second substrate **110** is diffusion bonding. However, misalignments between the first substrate **102** and the second substrate **110** may occur in the fabrication process, especially during the transfer between different chip bonders. Misalignments may result in defects and circuit open/shortage, which can cause device failure or affect device reliability.

Thus, what is needed is a method of bonding the first substrate and the second substrate that seeks to address some of the above problems. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

Summary of Invention

An aspect of the present invention provides a method for bonding a first substrate and a second substrate, the first substrate having at least one first connection extending from one side of the first substrate, the method comprising fabricating a first adhesive material around and along a height of the at least one first connection; and bonding the at least one first connection, the first adhesive material, and the second substrate.

Brief Description of Drawings

The accompanying figures where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with a present embodiment.

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings in which:

Fig.1

Figs. 1A and 1B show a cross-sectional view of a first substrate and a second substrate being bonded in accordance with a conventional method.

Fig.2

Fig. 2 shows a flowchart illustrating a method of bonding a first substrate and a second substrate in accordance with an embodiment of the present invention.

Fig.3

Figs. 3A and 3B show cross-sectional diagrams illustrating the first and the second substrates prior to, and after being bonded in accordance with a first embodiment of the present invention.

Fig.4

Figs. 4A and 4B show cross-sectional diagrams illustrating the first and the second substrates prior to and after being bonded in accordance with a second embodiment of the present invention.

Fig.5

Figs. 5A and 5B show cross-sectional diagrams illustrating the first and the second substrates prior to and after being bonded in accordance with a third embodiment of the present invention.

Fig.6

Figs. 6A and 6B show cross-sectional diagrams illustrating the first and the second substrates prior to and after being bonded in accordance with a fourth embodiment of the present invention.

Fig.7

Figs. 7A to 7C show cross-sectional and plan views of the first and the second substrates in accordance with embodiments of the present invention.

Fig.8

Fig. 8 shows a flowchart illustrating the method for fabricating the first substrate used in the first, second, third and fourth embodiments.

Fig.9

Figs. 9A to 9W show cross-sectional diagrams illustrating embodiments of the method described in Fig. 8.

Fig.10

Figs. 10A and 10B show a graphical representation of how viscosity changes with temperature when a first adhesive material is a thermoset polymer and a thermoplastic polymer respectively.

Description of Embodiments

The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description. Herein, a method for bonding a first substrate and a second substrate is presented in accordance with present embodiments having the advantages of improved alignment, higher mechanical strength, better electrical conductivity, greater device reliability and higher density of connections with fine pitches.

In an embodiment, a substrate may be understood to mean any package comprising semiconductor material, including but not limited to a semiconductor integrated circuit (IC) chip, semiconductor integrated circuit (IC) die or semiconductor wafer.

Fig. 2 shows a flowchart **200** illustrating a method of bonding the first substrate and the second substrate in accordance with an embodiment of the present invention.

With reference to Fig. 2, the method for bonding a first substrate having at least one first connection extending from one side of the substrate and a second substrate is illustrated. The method comprises firstly, as described in step **202**, fabricating a first adhesive material around

and along a height of the at least one first connection and secondly, as described in step **204,** bonding the at least one first connection, the first adhesive material and the second substrate. It is obvious to a person skilled in the art that additional steps may be performed before, during and/or after the steps **202** and **204** in various embodiments of the method. The first adhesive material comprises a material selected from a group comprising tin, indium and a polymer material suitable for fabricating around and along the at least one first connection. Examples of polymer materials that are suitable include a thermoset polymer and a thermoplastic polymer.

In an embodiment, the step **204** of bonding the at least one first connection, the first adhesive material, and the second substrate is performed using a flip chip technique. The first substrate is first brought into alignment with the second substrate by a flip chip bonder and pressed together with a bonding force while heating the first and the second substrate to a melting temperature of the first adhesive material when the first adhesive material is a metal. The flip chip bonder is a precision instrument used to align and bond one or more substrates onto another substrate using pressure and/ or heat.

In other embodiments, the first substrate is first brought into alignment with the second substrate by the flip chip bonder and pressed together with a bonding force while heating the first and the second substrate to a predetermined melt-viscosity temperature when the first adhesive material is a polymer. The first adhesive material may comprise a thermoset polymer, or a thermoplastic polymer. An example of the predetermined melt-viscosity temperature of the thermoset polymer is shown in Fig. 10A, while an example of the predetermined melt-viscosity temperature of the thermoplastic polymer is shown in Fig. 10B.

Fig. 10A shows a graphical representation **1000** of how viscosity changes with temperature when the first adhesive material is the thermoset polymer. A thermoset polymer has a viscosity value **1006** when it is in an intermediate reaction stage known as a B-stage by a person skilled in the art. The B-stage is an intermediate reaction stage in the reaction of thermoset polymers, wherein the thermoset polymer softens when heated and is only partially cured. In other words, the thermoset polymer may not entirely fuse. An example of a B-stage thermoset polymer is a resin in an uncured thermosetting system. Curing of the thermoset polymer can be induced by the action of temperature or suitable radiation, or both. As the temperature increases, the thermoset polymer in the viscous state will change irreversibly into an infusible and insoluble material by curing. The viscosity of the thermoset polymer accordingly will first drop to a lowest melt-viscosity value **1002** before increasing to a viscosity value **1008** as the curing process

completes. With reference to step **204,** the predetermined melt-viscosity temperature when the first adhesive material is the thermoset polymer is shown as a lowest melt-viscosity temperature **1004** after the B-stage. In other words, the lowest melt-viscosity temperature **1004** is one at which the thermoset polymer reaches its lowest viscosity. The lowest melt-viscosity temperature **1004** corresponds to the lowest melt-viscosity **1002** of the thermoset polymer. Therefore, in step **204,** the first substrate is first brought into alignment with the second substrate by the flip chip bonder and pressed together with a bonding force while heating the first and the second substrate to a lowest melt-viscosity temperature after the B stage of the first adhesive material when the first adhesive material is the thermoset polymer.

Fig. 10B shows a graphical representation **1010** of how viscosity changes with temperature when the first adhesive material is the thermoplastic polymer. The viscosity of the thermoplastic polymer decreases monotonically with an increase in the temperature. In a low temperature, the thermoplastic polymer will be in a solid state, with a viscosity value **1020**. As the temperature increases, the viscosity value of the thermoplastic polymer decreases; at sufficiently high temperatures, the thermoplastic polymer may be in a liquid state with viscosity value **1022**. In step **204,** the predetermined melt-viscosity temperature when the first adhesive material is the thermoplastic polymer is shown as melt-viscosity temperature **1016**, which corresponds to a material viscosity **1014.** The predetermined melt-viscosity temperature **1016** is one at which the corresponding material viscosity **1014** is below a predetermined viscosity **1012**, while at the same time, below temperature **1018**, which corresponds to 200 degree Celsius. In other words, a low melt-viscosity temperature when the first adhesive material is the thermoplastic material is one at which the material viscosity is beyond a predetermined viscosity, and at the same time, below 200 degree Celsius. The predetermined viscosity **1012** may be selected such that in the heating duration of the step **204**, the first adhesive material effectually flows and bonds the at least one first connection, the first adhesive material, and the second substrate during the heating duration. Therefore, in step **204**, the first substrate is first brought into alignment with the second substrate by the flip chip bonder and pressed together with a bonding force while heating the first and the second substrate to the low melt-viscosity temperature of less than 200 degree Celsius when the first adhesive material is a thermoplastic polymer.

Additionally, the heating duration may be in a range of a few seconds, to effectually prevent the consumption of the first adhesive material caused by diffusion into the at least one first connection. The first and the second substrates are quickly cooled after step **204**, and beneficially seals the at least one first connection within the first adhesive material. In

embodiments of the present invention, the melting point of the first adhesive material is lower than a melting point or a eutectic point temperature of the at least one first connection material. Advantageously, the step **204** of bonding the at least one first connection, the first adhesive material, and the second substrate reduces chances of misalignments between the first and second substrate during subsequent fabrication processes.

In an embodiment, the step **204** is repeated to bond at least one first substrate (e.g. IC die) to a single second substrate (e.g. semiconductor wafer) using a flip chip technique. Once the at least one first substrate is bonded to the single second substrate, the assembly of the at least one first substrate and the single second substrate are placed in a global wafer bonder, wherein the step **204** of bonding the first connection, the first adhesive material and the single second substrate is performed using a global bonder technique. A bonding force is applied on the at least one first substrate and the single second substrate, and the assembly is heated to the eutectic point temperature of the first connection material. As the first adhesive material softens and deforms, the bonding force is transmitted through the at least one first connection. Bonding between the at least one first connection, the first adhesive material and the second substrate then occurs. Permanent bonds are formed through diffusion bonding between the at least one first connection, the first adhesive material and the second substrate. Advantageously, the use of the proposed method for bonding the first substrate and the second substrate can result in strong bonding between the at least one first connection and the second substrate if similar materials are used. The permanent bond formed has advantage in higher mechanical strength and better electrical conductivity. The permanent bond will have the same coefficient of thermal expansion (CTE) across the at least one first connection and the second substrate, leading to greater device reliability.

Figs. 3A and 3B show cross-sectional diagrams illustrating the first and the second substrates prior to, and after being bonded in accordance with a first embodiment of the present invention.

Referring to Fig. 3A, the arrangement **300** shows a first substrate **302**, an at least one first connection **306a, 306b** extending from one side of the first substrate **302**, a first adhesive material **308a**, **308b** around and along a height of the at least one first connection **306a, 306b** respectively and at least one UBM portion **310a, 310b** on the second substrate **304** provided below and away from the first substrate **302**.

In an embodiment, the first adhesive material **308a** is fabricated around and along the at least one first connection **306a** in step **202** as described in the above. The first adhesive material

308a may be a cylindrical structure around and along the first connection **306a**. In other embodiments, there may be more than one first connection **306a**. As shown in Fig. 3A, there are first connections **306a, 306b, 306c** extending from the one side of the first substrate **302**. The first connections **306a, 306b, 306c** may be spaced apart from one another at an equal distance or a different distance. In an embodiment, as shown in Fig. 3A, the first adhesive material **308a**, **308b** is provided around and along the height of the first connections **306a, 306b** that are at the peripheral of the first substrate **302**. In other words, the first connections that are located in the centre of the first substrate **302** will not be provided a first adhesive material. One such example is the first connection **306c**. Referring to Fig. 3A, the second substrate **304** is provided below and away from the first substrate **302**. The at least one under bump metallization (UBM) portion is provided on the second substrate **304**. In an embodiment, there are more than one UBM portions. As shown in Fig. 3A, there are UBM portions **310a, 310b, 310c** provided on the second substrate **304**. In an embodiment, as shown in Fig. 3A, the UBM portions **310a, 310b, 310c** are evenly spaced apart on the second substrate **304**, wherein centrelines of the UBM portions **310a, 310b, 310c** are aligned with centrelines of the corresponding first connections **306a, 306b, 306c** on the first substrate **302**.

Referring to Fig. 3B, the arrangement **312** shows the first substrate **302**, with the at least one first connection **306a, 306b, 306c** extending from one side of the first substrate **302** bonded to the at least one UBM portion **310a, 310b, 310c** on the second substrate **304** after step **204**. In step **204**, the first adhesive material **308a**, **308b** and the first connections **306a, 306b** are bonded to the second substrate **304**. In an embodiment, the first adhesive material **308a**, **308b** and the first connections **306a, 306b** are first bonded together before subsequently bonded to the second substrate **304**. As illustrated in Fig. 3B, the first adhesive material **308a**, **308b** are shown tapered as the first adhesive material **308a**, **308b** melts and reflows when the assembly **312** is heated to a melting temperature of the first adhesive material **308a**, **308b** when the first adhesive material **308a**, **308b** is a metal. In an embodiment, the first substrate **302** is first brought into alignment with the second substrate **304** by the flip chip bonder and pressed together with a bonding force while heating the first and the second substrate **302, 304** to the lowest melt-viscosity temperature after the B stage of the first adhesive material **308a**, **308b** when the first adhesive material **308a**, **308b** is the thermoset polymer. In another embodiment, the first substrate **302** is first brought into alignment with the second substrate **304** by the flip chip bonder and pressed together with a bonding force while heating the first and the second substrate **302, 304** to the low melt-viscosity temperature of less than 200 degree Celsius when

the first adhesive material **308a**, **308b** is the thermoplastic polymer. The first adhesive material **308a**, **308b** may remain straight, as the duration of heating the assembly **312** in step **204** and adhesive thickness of the first adhesive material **308a**, **308b** can be controlled. Advantageously, with reference to Figs. 2 and 3, the method for bonding a first substrate and a second substrate as presented avoids the formation of the solder bridge **106c**. The method of bonding as presented alleviates concerns on formation of the solder bridge **106c**, and facilitates higher density of connections with fine pitches.

In an embodiment, the at least one first connection **306a, 306b, 306c** can be fabricated using electrochemical plating. The at least one first connection **306a, 306b, 306c** comprises a material selected from a group comprising copper, gold, aluminum, tin and indium. The first adhesive material **308a**, **308b** can fabricated using an electroless deposition technique (e.g. electroless plating), and the first adhesive thickness is in a range of 100nm to 2µm. In other embodiments, the first adhesive thickness may not be limited to the typical range of 100nm to 2µm, and can be varied accordingly. As mentioned in the above, the first adhesive material **308a**, **308b** comprises a material selected from but not limited to a group comprising tin, indium and a polymer material suitable for fabricating around and along the at least one first connection **306a, 306b**. The UBM portions **310a, 310b, 310c** on the second substrate **304** comprise a material selected from but not limited to a group comprising copper, gold, aluminum, tin and indium and can be fabricated using physical vapour deposition (PVD). Advantageously, the UBM portions **310a, 310b** fabricated using PVD has an extremely smooth surface, with surface roughness of around 1nm. The smooth surface increases area of surface contact during bonding of the first adhesive material **308a**, **308b** to the corresponding at least one UBM portion. The smooth surface also effectively lowers the bonding force required for bonding the first connections **306a, 306b, 306c** to the UBM portions **310a, 310b, 310c**.

Figs. 4A and 4B show cross-sectional diagrams illustrating the first and the second substrates prior to and after being bonded in accordance with a second embodiment of the present invention.

Referring to Fig. 4A, the arrangement **400** shows a first substrate **302**, an at least one first connection **306a, 306b, 306c, 306d** extending from one side of the first substrate **302**, a first adhesive material **308a**, **308b, 308c, 308d** around and along a height of the at least one first connection **306a, 306b, 306c, 306d** and at least one UBM portion **310a, 310b, 310c, 310d** on the second substrate **304** provided below and away from the first substrate **302**.

In the second embodiment, each of the first connections **306c, 306d** that are located in the centre of the first substrate **302** is also provided with a first adhesive material **308c, 308d** around and along its height. In other words, a first adhesive material **306c, 306d** are fabricated around and along the height of the first connection **308c, 308d**.

Similarly, the second substrate **304** is provided with UBM portions in its centre. In the second embodiment, the centrelines of the UBM portions **310a, 310b, 310c, 310d** are aligned with the centrelines of each of the corresponding first connections **306a, 306b, 306c, 306d** on the first substrate **302**.

Referring to Fig. 4B, the arrangement **412** shows the first substrate **302**, with the first connections **306a, 306b, 306c, 306d** extending from one side of the first substrate **302** bonded to the corresponding UBM portions **310a, 310b, 310c, 310d** on the second substrate **304** after step **204**. During step **204**, the first adhesive material **308a**, **308b, 308c**, **308d** and the first connections **306a, 306b, 306c, 306d** are bonded to the second substrate **304**. In an embodiment, the first adhesive material **308a**, **308b, 308c**, **308d** and the first connections **306a, 306b, 306c, 306d** are first bonded together before subsequently bonded to the second substrate **304**. Advantageously, the method for bonding a first substrate **302** and a second substrate **304** as presented avoids the formation of the solder bridge **106c**. The method of bonding as presented alleviates concerns on formation of the solder bridge **106c**, and facilitates higher density of connections with fine pitches.

Figs. 5A and 5B show cross-sectional diagrams illustrating the first and the second substrates prior to and after being bonded in accordance with a third embodiment of the present invention.

Referring to Fig. 5A, the arrangement **500** shows a first substrate **302**, an at least one first connection **306a, 306b** extending from one side of the first substrate **302** and a first adhesive material **308a**, **308b** around and along a height of the at least one first connection **306a, 306b**. Fig. 5A also shows a second substrate **304**, an at least one second connection **506a, 506b** extending from one side of the second substrate **304** and a second adhesive material **508a**, **508b** around and along a height of the at least one second connection **506a, 506b**.

In the third embodiment, there is at least one second connection **506a** extending from one side of the second substrate **304**. A second adhesive material **508a** is fabricated around and along the at least one second connection **506a**. The first and the second adhesive material **308a, 508a** may be a cylindrical structure around and along the first and the second connection **306a,**

506a respectively. In other embodiments, there may be more than one first and second connection **306a, 506a**. As shown in Fig. 5A, there are first connections **306a, 306b, 306c** extending from the one side of the first substrate **302**. The first connections **306a, 306b, 306c** may be spaced apart from one another at an equal distance or a different distance. In an embodiment, as shown in Fig. 5A, the first adhesive material **308a**, **308b** is provided around and along the height of the first connections **306a, 306b** that are at the peripheral of the first substrate **302**. In other words, the first connections that are located in the centre of the first substrate **302** will not be provided an adhesive material. One such example is first connection **306c**.

As shown in Fig. 5A, the second adhesive material **508a**, **508b** is provided around and along the height of the second connections **506a, 506b** that are at the peripheral of the second substrate **304**. In other words, the second connections that are located in the centre of the second substrate **304** will not be provided the second adhesive material. One such example is first connection **506c**. In an embodiment, as shown in Fig. 5A, the second connections **506a, 506b, 506c** are evenly spaced apart on the second substrate **304**, wherein centrelines of the second connections **506a, 506b, 506c** are aligned with centrelines of the corresponding first connections **306a, 306b, 306c** on the first substrate **302**.

Referring to Fig. 5B, the arrangement **512** shows the first substrate **302**, with the first connections **306a, 306b** extending from one side of the first substrate **302** bonded to the second connections **506a, 506b** extending from one side of the second substrate **304**. The first adhesive material **308a**, **308b** and the first connections **306a, 306b** are bonded to the second adhesive material **508a**, **508b** and the second connections **506a, 506b**. In an embodiment, the first adhesive material **308a**, **308b** are first bonded to the corresponding first connections **306a, 306b** before being bonded to the second substrate **304**. The second adhesive material **508a, 508b** is also first bonded to the corresponding second connections **506a, 506b** before being bonded to the first substrate **302** and the first adhesive material **308a**, **308b**.

In the third embodiment, the at least one second connections **506a, 506b, 506c** can be fabricated using electrochemical plating. The at least one second connections **506a, 506b, 506c** can comprise a material selected from but not limited to a group comprising copper, gold, aluminum, tin and indium. The second adhesive material **508a**, **508b** can be fabricated using an electroless deposition technique (e.g. electroless plating), and the second adhesive thickness is in a range of 100nm to 2µm. In other embodiments, the second adhesive thickness may not be

limited to the typical range of 100nm to 2µm, and can be varied accordingly. The second adhesive material **508a**, **508b** comprises a material selected from a group comprising tin, indium and a polymer material suitable for fabricating around and along the at least one second connections **506a, 506b**. In an embodiment, the material comprised in the second adhesive material **508a** may be the same or different from the material comprised in the first adhesive material **308a**. In another embodiment, as shown in Fig. 5A, the first adhesive thickness of the first adhesive material **308a**, **308b** is less than the second adhesive thickness of the second adhesive material **508a**, **508b**. In other embodiments, the first adhesive thickness of the first adhesive material **308a**, **308b** may be of the same or greater thickness as the second adhesive thickness of the second adhesive material **508a**, **508b.**

Figs. 6A and 6B show cross-sectional diagrams illustrating the first and the second substrates prior to and after being bonded in accordance with a fourth embodiment of the present invention.

Referring to Fig. 6A, the arrangement **600** shows a first substrate **302**, an at least one first connection **306a, 306b, 306c, 306d** extending from one side of the first substrate **302** and a first adhesive material **308a**, **308b, 308c, 308d** around and along a height of the at least one first connection **306a, 306b, 306c, 306d.** Fig. 6A also shows a second substrate **304**, an at least one second connection **506a, 506b, 506c, 506d** extending from one side of the second substrate **304** and a second adhesive material **508a**, **508b, 508c**, **508d** around and along a height of the at least one second connection **506a, 506b, 506c, 506d**.

The first connections in the fourth embodiment are similar to the first connections in the second embodiment. That is, each of the first connections **306c, 306d** that are located in the centre of the first substrate **302** is also provided with a first adhesive material **306c, 306d**. In the fourth embodiment, the second substrate **304** is provided with the second connections **506c, 506d** in the centre. Each of these second connections **506c, 506d** that are provided in the centre of the second substrate **304** are provided with a second adhesive material **508c**, **508d**.

Referring to Fig. 6B, the arrangement **612** shows the first substrate **302**, with the first connections **306a, 306b, 306c, 306d** extending from one side of the first substrate **302** bonded to the corresponding second connections **506a, 506b, 506c, 506d** extending from one side of the second substrate **304**. The first adhesive material **308a**, **308b, 308c, 308d** and the first connections **306a, 306b, 306c, 306d** are bonded to the second adhesive material **508a**, **508b, 508c**, **508d** and the second connections **506a, 506b, 506c, 506d**. In an embodiment, the first

adhesive material **308a**, **308b, 308c, 308d** are first bonded to the corresponding first connections **306a, 306b, 306c, 306d** before being bonded to the second substrate **304**. The second adhesive material **508a, 508b, 508c, 508d** is also first bonded to the corresponding second connections **506a, 506b, 506c, 506d** before being bonded to the first substrate **302** and the first adhesive material **308a**, **308b, 308c, 308d**.

Figs. 7A to 7C show cross-sectional and plan views of the first and the second substrates in accordance with embodiments of the present invention.

Referring to Fig. 7A, a cross-sectional view and a plan view of an arrangement **700** are shown. The arrangement **700** comprises a first substrate **302**, an at least one first connection **306a, 306b** extending from one side of the first substrate **302** and a first adhesive material **308a**, **308b** around and along a height of the at least one first connection **306a, 306b**. In an embodiment, as shown in the plan view of Fig. 7A, the first connections **306a, 306b** are spaced apart from one another at equal distances in both horizontal and vertical directions. In another embodiment, the first connections **306a, 306b** may be spaced apart at different distances in one or two of the horizontal and vertical directions. As shown in Fig. 7A, the first adhesive material **308a**, **308b** is fabricated around and along the first connections **306a, 306b** in step **202** as described in the above. In other words, the first adhesive material is fabricated around and along all of the first connections extending from one side of the first substrate **302**. The first adhesive material **308a**, **308b** may be a cylindrical structure around and along the first connections **306a, 306b**. In other embodiments, the arrangement **700** can be used when the distance, otherwise known as pitch, between the adjacent connections are between 10µm to 20µm. An adhesive thickness of 1µm is used for the first adhesive material when the pitch is between 10µm to 20µm. In yet another embodiment, the arrangement **700** can be used when the pitch are beyond or below the range of 10µm to 20µm, with the adhesive thickness of the first adhesive material suitably adjusted.

Referring to Fig. 7B, a cross-sectional view and a plan view of an arrangement **702** is shown. The arrangement **702** comprises a first substrate **302**, an at least one first connection **306a, 306b, 306c** extending from one side of the first substrate **302** and a first adhesive material **308a**, **308b, 308c** around and along a height of the at least one first connection **306a, 306b, 306c**. In an embodiment, as shown in the plan view of Fig. 7B, the first connections **306a, 306b**, **306c** are spaced apart from one another at equal distances in both horizontal and vertical directions. In another embodiment, the first connections **306a, 306b, 306c** may be spaced apart at different distances in one or two of the horizontal and vertical directions. As shown in Fig. 7B,

the first adhesive material **308a**, **308b, 308c** is fabricated around and along alternate first connections **306a, 306b**, **306c** in both horizontal and vertical directions in step **202** as described in the above. The first adhesive material **308a**, **308b, 308c** may be a cylindrical structure around and along the first connections **306a, 306b**, **306c**. In other embodiments, the arrangement **702** can be used when the pitch between the adjacent connections are between 5µm to 10µm. An adhesive thickness of 0.5µm is used for the first adhesive material when the pitch is between 5µm to 10µm. In yet another embodiment, the arrangement **702** can be used when the pitch are beyond or below the range of 5µm to 10µm, with the adhesive thickness of the first adhesive material suitably adjusted.

Referring to Fig. 7C, a cross-sectional view and a plan view of an arrangement **704** is shown. The arrangement **704** comprises a first substrate **302**, an at least one first connection **306a, 306b** extending from one side of the first substrate **302** and a first adhesive material **308a**, **308b** around and along a height of the at least one first connection **306a, 306b**. In an embodiment, as shown in the plan view of Fig. 7C, the first connections **306a, 306b** are spaced apart at equal distances in both horizontal and vertical directions. In another embodiment, the first connections may be distributed at different intervals along both horizontal and vertical directions. As shown in Fig. 7C, the first adhesive material **308a**, **308b** is fabricated around and along the first connections **306a, 306b** that are at the corners of the first substrate **302** in step **202** as described in the above. The first adhesive material **308a**, **308b** may be a cylindrical structure around and along the first connections **306a, 306b**. In other embodiments, the arrangement **704** can be used when the pitch between the adjacent connections are less than 5µm. An adhesive thickness of 0.5µm is used for the first adhesive material. In yet another embodiment, the arrangement **704** can be used when the pitch are beyond 5µm, with the adhesive thickness of the first adhesive material adjusted suitably.

Fig. 8 shows a flowchart illustrating the method for fabricating the first substrate used in the first, second, third and fourth embodiments.

With reference to Fig. 8, the method for fabricating the first substrate **302** used in the first, second, a third and fourth embodiments is illustrated. The method comprises, preparing a first substrate **302** for fabrication of at least one first connection **306a** in step **802**, fabricating at least one first connection **306a** on the first substrate **302** in step **804**; preparing the first substrate **302** with at least one first connection **306a** for fabrication of adhesive material **308a** around and along the height of the at least one first connection **306a** in step **806**; fabricating the first

adhesive material **308a** around and along the height of at least one first connection **306a** in step **808**; and preparing the first substrate **302** having at least one first connection **306a** extending from one side of the first substrate **302** for bonding in step **810**.

In an embodiment, the step **802** of preparing the first substrate **302** for fabrication of the at least one first connection **306a** comprises fabricating a seed layer on the first substrate **302**. Examples of the material for the seed layer includes among other things, a material selected from but not limited to a group comprising copper, gold, aluminum, tin and indium. In an embodiment, the step **802** also further comprises fabricating a first photoresist layer on the seed layer and applying a pattern on the first photoresist layer. The first patterned photoresist layer covers the seed layer but includes at least one void which exposes the seed layer beneath to enable formation of the at least one first connection **306a**.

In an embodiment, the step **804** of fabricating the at least one first connection **306a** on the first substrate **302** comprises electrochemical plating the at least one first connection **306a** on the seed layer exposed by the first patterned photoresist layer. Examples of the material for the seed layer includes among other things, a material selected from but not limited to a group comprising copper, gold, aluminum, tin and indium. In an embodiment, the material used in the seed layer is similar to the material used in the at least one first connection **306a**.

In a first embodiment, the step **806** of preparing the first substrate **302** with at least one first connection **306a** for fabrication of the first adhesive material **308a** around and along the height of the at least one first connection **306a** comprises removing the first photoresist layer to expose the seed layer fabricated on the first substrate **302**. Step **806** further comprises removing the seed layer fabricated on the first substrate **302** to expose the first substrate **302** and the at least one first connection **306a** extending from the first substrate **302**. In an embodiment, after step **806**, the step **808** of fabricating the first adhesive material **308a** around and along the height of at least one first connection **306a** comprises electroless plating the first adhesive material **308a** on the at least one first connection **306a**. In the embodiment, the step **806** comprises immersing the at least one first connection **306a** fully in a chemical solution for electroless plating to occur. The immersion process requires duration of few minutes, and a range of adhesive thickness of the first adhesive material **308a** can be fabricated on the at least one first connection **306a**. In another embodiment, the step **810** of preparing the first substrate **302** having at least one first connection **306a** extending from one side of the first substrate **302** for bonding comprises fabricating a second photoresist layer on the first substrate **302** to a height that is above and

beyond the height of the at least one first connection **306a** and the adhesive material **308a** on the at least one first connection **306a**. The second photoresist layer acts as a dummy film to support the at least one first connection **306a** during a surface planarization process. The surface planarization process is a process of smoothing surfaces with a combination of chemical and mechanical forces. The surface planarization process strips away a layer of the dummy film, the at least one first connection **306a** and the first adhesive material **308a** to expose the at least one first connection **306a**, and form the adhesive material **308a** around and along the height of the at least one first connection **306a**. In an embodiment, the step **810** further comprises removing the dummy film, to form the first substrate **302**, with the at least one first connection **306a** extending from the first substrate **302**, and the first adhesive material **308a** around and along the height of at least one first connection **306a**.

In a second embodiment, the step **806** of preparing the first substrate **302** with at least one first connection **306a** for fabrication of the first adhesive material **308a** around and along the height of the at least one first connection **306a** comprises removing the photoresist layer to expose the seed layer fabricated on the first substrate **302**. Step **806** also comprises removing the seed layer fabricated on the first substrate **302** to expose the first substrate **302** and the at least one first connection **306a** extending from the first substrate **302**. Step **806** further comprises fabricating a second photoresist layer on the exposed seed layer and the least one first connection **306a**. The second photoresist layer is fabricated to a height above and beyond the height of the at least one first connection **306a**. The second photoresist layer is subsequently patterned. In embodiments of the present invention, the patterning comprises removing a thickness of the second photoresist layer around and along the height of the at least one first connection **306a** to form exposed at least one first connection **306a.** In an embodiment, the patterning may include removing the second photoresist layer around and along the at least one first connection **306a** that are at the corner of the first substrate **302.** In yet another embodiment, the patterning may include removing the second photoresist layer around and along alternate rows and columns of the at least one first connection **306a**. In an embodiment, after step **806**, the step **808** of fabricating the first adhesive material **308a** on the at least one first connection **306a** comprises electroless plating the first adhesive material **308a** on the exposed at least first connection **306a**. In an embodiment, the step **806** comprises immersing the at least one first connection **306a** fully in a chemical solution for electroless plating to occur. The first adhesive material **308a** will be fabricated on the exposed at least first connection **306a**. The immersion process requires duration of few minutes, and a range of adhesive thickness of the first

adhesive material **308a** can be fabricated on the exposed at least one first connection **306a**. In an embodiment, the step **810** comprises a surface planarization process. The surface planarization process is performed after fabricating the first adhesive material **308a** on the exposed at least first connection **306a**. The surface planarization process strips away a thickness of the second photoresist layer, the at least one first connection **306a** and the first adhesive material **308a** to expose the at least one first connection **306a**. In an embodiment, the step **810** further comprises removing the dummy film, to form the first substrate **302**, with the at least one first connection **306a** extending from the first substrate **302**, and the first adhesive material **308a** around and along the height of at least one first connection **306a**.

In embodiments of the invention, the first adhesive material **308a** and the at least one first connection **306a** are bonded to the second substrate in a step similar to step **204**.

Figs. 9A to 9W show cross-sectional diagrams illustrating embodiments of the method described in Fig. 8.

Referring to Fig. 9A, a metal material **902** is provided on the substrate **302**. The metal material **902** is planar to the substrate **302**. Examples of the metal material **902**, includes among other things, a material selected from but not limited to a group comprising copper, gold, aluminum, tin and indium. The metal material **902** is so provided on the substrate **302** to serve as a seed layer to enable formation of the at least one connection structure **306** on the substrate **302** as described in step **802**.

Referring to Fig. 9B, a first patterned photoresist layer **908** formed in the step **802** is provided on the metal material **902**. The first patterned photoresist layer **908** covers the metal material **902** and includes at least one void **906** that exposes the metal material **902** beneath to provide for the formation of the at least one first connection **306a**.

Referring to Fig. 9C, the at least one connection **306a** is provided within the at least one void **906** in the first patterned photoresist layer **908.** In an embodiment, the at least one connection **306a** is formed in step **804** through electrochemical plating. The at least one connection **306a** is deposited on the metal material **902** and occupies the whole of the at least one void **906**. Due to the nature of the electrochemical plating process, the crown of the at least one connection **306a** may be uneven.

Referring to Fig. 9D, the first patterned photoresist layer **908** is removed as described in step **806** to expose portions of the metal material **902**. The resulting structure includes the at least one connection **306a** which will also be exposed.

Referring to Fig. 9E, the metal material **902** is removed as described in step **806** to expose the substrate **302** and portions of the at least one connection **306a**. After removal of metal material **902** there are various ways to fabricate the adhesive material **308a.** One way is to provide a second patterned photoresist layer **918** on the substrate **302**; more information will be described in Fig. 9M below.

Another way of fabricating the adhesive material **308a** is shown in Fig. 9F. Referring to Fig. 9F, the at least one connection **306a** is fully immersed in the chemical solution **904** in a manner described in step **808,** and the adhesive material **308a** is provided on the at least one connection **306a** that is exposed to the chemical solution **904**.

Following Fig. 9F, Fig. 9G shows a second photoresist layer **908** provided on the substrate **302.** The second photoresist layer **908** envelops the at least one connection **306a**, with the adhesive material **308a** to support the at least one connection **306a** during the surface planarization process as described in step **810**.

Referring to Fig. 9H, the surface planarized second photoresist layer **908**, with the at least one connection **306a** and the adhesive material **308a** on the substrate **302** is provided. Fig. 9H shows the substrate **302** after the process of surface planarization as described in step **810** has been performed, where a thickness of the second photoresist layer **908** is stripped away in step **806** together with a thickness of the at least one connection **306a** and the adhesive material **308a** to expose the at least one connection **306a.**

Referring to Fig. 9I, the layer of the second photoresist layer **908** as shown in Fig. 9H is removed in step **810.** Hydrogen plasma **910** is used to remove impurities on the exposed surfaces of the at least one first connection **306a, 306b, 306c, 306d**. In other words, the hydrogen plasma **910** is used to remove impurities on surfaces of the at least one first connection **306a, 306b, 306c, 306d** that are not covered by the adhesive material **308a, 308b, 308c, 308d**.

Thus, Figs. 9F-9I shows one method of fabricating the adhesive material **308a** and preparing the first substrate **302** for bonding to the second substrate **304**. The following Figs. 9J-9L show how the first substrate **302** (as prepared by the process shown in Figs. 9F-9I) may be bonded to

various arrangements of the second substrate **304** using a flip-chip technique described in step **204**.

Fig. 9J provides one example of bonding the first substrate **302** and the second substrate **304.** A bonding force **912** is provided on the first substrate **302** to bond the at least one first connection **306a**, the first adhesive material **308a** and the second substrate **304** as described in step **204**. In Fig. 9J, the first substrate **302** comprises at least one first connection **306a** and the second substrate **304** comprises at least one UBM portion **310a**.

Fig. 9K provides another example of bonding the first substrate **302** and the second substrate **304.** A bonding force **912** is provided on the first substrate **302** to bond the at least one first connection **306a**, the first adhesive material **308a** and the second substrate **304** as described in step **204**. In Fig. 9K, the second substrate **304** comprises at least one second connection **506a.** The second adhesive material **508a** is provided around and along the height of the at least one second connection **506a.**

Fig. 9L provides yet another example of bonding the first substrate **302** and the second substrate **304.** A bonding force **912** is provided on the substrate **302** to bond the first substrate and the second substrate **304** in a step similar to step **204**. In Fig. 9L, the first substrate **302** comprises at least one UBM portion **310a** and the second substrate **304** comprises at least one connection **306a** extending from one side of the second substrate **304**. The adhesive material **308a** is provided around and along the height of the connection **306a.**

As mentioned in the above, there are various ways to fabricate the adhesive material **308a** on the at least one connection **306a** of the substrate **302** shown in Fig. 9E. Figs. 9M-9Q describe an alternative method different from that shown in Figs. 9F-9I.

Referring to Fig. 9M, a second patterned photoresist layer **918** is provided on the substrate **302** shown in Fig. 9E. In other words, it is possible to provide the second patterned photoresist layer **918** without having to perform the steps described in Figs. 9F-9I. In Fig. 9M, a thickness around and along the height of the at least one connection **306a** is removed to form a gap **903**. The gap **903** is provided to expose the at least one connection **306a** for fabrication of the adhesive material **308a**. In one embodiment, the second photoresist layer **918** may be patterned to expose only at least one connection **306a** at the corner of the substrate **302**. Alternatively, the second photoresist layer **918** may be patterned to provide gap **903** around and along alternate rows and columns of the at least one first connection **306a**.

Following Fig. 9M, Fig. 9N shows the substrate **302** provided in a chemical solution **904** for fabrication of the adhesive material **308a** as described in step **808**. The at least one connection **306a** is fully immersed in the chemical solution **904**, and the adhesive material **308a** is provided on the at least one connection **306a** that are exposed to the chemical solution **904**. In other words, the adhesive material **308a** is provided on the at least one connection **306a** positioned within the gap **903** within the second patterned photoresist layer **918**. That is, the adhesive material **308a** is not deposited on the at least one connection **306a** that is enveloped within the second patterned photoresist layer **918**.

Fig. 9O shows the second photoresist layer **918** provided around the at least one connection **306a**, and the adhesive material **308a** on the at least one connection **306a** located at the peripheral of the substrate **302**. The second photoresist layer **918** serves to support the at least one connection **306a** during the surface planarization process as described in step **810**.

Fig. 9P show the substrate **302** after surface planarization of step **810** has been performed, where a thickness of the second photoresist layer **918** is stripped away together with a thickness of the at least one connection **306a** and the adhesive material **308a** to expose the at least one connection **306a.**

Referring to Fig. 9Q, the second photoresist layer **918** shown in Fig. 9P is removed as described in step **810.** Hydrogen plasma **910** is subsequently used to remove impurities on the exposed surfaces of the at least one first connection **306a, 306b** to prepare for bonding the substrate **302,** the first adhesive material **308a, 308b** and the second substrate **304.**

Thus, Figs. 9M-9Q show an alternate method of fabricating the adhesive material **308a** and preparing the first substrate **302** for bonding to the second substrate **304**. The following Figs. 9R-9T show how the first substrate **302** (as prepared by the process shown in Figs. 9M-9Q) may be bonded to various arrangements of the second substrate **304** using a flip-chip technique described in step **204**.

Fig. 9R provides one example of bonding the first substrate **302** and the second substrate **304.** A bonding force **912** is provided on the first substrate **302** to bond the at least one first connection **306a**, the first adhesive material **308a** and the second substrate **304** as described in step **204**. In Fig. 9R, the first substrate **302** comprises at least one first connection **306a** and the second substrate **304** comprises at least one UBM portion **310a.** The first adhesive material

308a is provided around and along the height of the at least one first connections **306a** that are at the peripheral of the first substrate **302.**

Fig. 9S provides another example of bonding the first substrate **302** and the second substrate **304**. A bonding force **912** is provided on the substrate **302** to bond the first substrate and the second substrate **304** in a step similar to step **204**. The first adhesive material **308a** and the second adhesive material **508a** are provided respectively around and along the height of the at least one first and second connections **306a, 506a** that are at the peripheral of the first and second substrates **302, 304.**

Fig. 9T provides yet example of bonding the first substrate **302** and the second substrate **304.** In Fig. 9T, the first substrate **302** comprises at least one UBM portion **310a** and the second substrate **304** comprises at least one connection **306a** extending from one side of the second substrate **304**. The adhesive material **308a** is provided around and along the height of the connection **306a.** A bonding force **912** is provided on the substrate **302** to bond the first substrate and the second substrate **304** in a step similar to step **204**.

Figs. 9J-9L and Figs. 9R-9T show the first substrate **302** being bonded to various arrangements of the second substrate **304** using a flip-chip technique described in step **204**. The assembly of at least one first substrate **302** and second substrate **304** shown in Figs. 9J-9L and Figs. 9R-9T is subsequently placed in a global wafer bonder, wherein the step **204** of bonding the first connection, the first adhesive material and the single second substrate is performed using a global bonder technique. Figs 9U-9W show the various arrangements of the first and second substrate **302, 304** being bonded in the global wafer bonder.

Fig. 9U shows a first example of the first and second substrate **302a, 302b, 304** being bonded in the global wafer bonder. A global bonding force **914** is provided on the first substrates **302a, 302b** to bond the first substrates **302a, 302b** with the single common second substrate **304**. The at least one first connection **306a** extending from the first substrates **302a, 302b**, the first adhesive material **308a** and the UBM portions **310a** on the single common second substrate **304** are being bonded. Formic acid gas **916** is channeled through the at least one connection **306a** to remove impurities present on the exposed surfaces of the at least one connection **306a**.

Fig. 9V shows a second example of the first and second substrate **302a, 302b, 304** being bonded in the global wafer bonder. A global bonding force **914** is provided on the first substrates **302a, 302b** to bond the first substrates **302a, 302b** with the single common second substrate

304. The at least one first connection **306a,** the at least one second connection **506a** extending from the first and second substrates **302a, 302b**, **304** and the first and the second adhesive material **308a, 508a** are being bonded. Formic acid gas **916** is channeled through the at least one connection **306a, 506a** to remove impurities present on the exposed surfaces of the at least one first and second connection **306a, 506a**.

Fig. 9W shows a third example of the first and second substrate **302a, 302b, 304** being bonded in the global wafer bonder. Similar to Fig. 9U and Fig. 9V, a global bonding force **914** is provided on the first substrates **302a, 302b** to bond the first substrates **302a, 302b** with the single common second substrate **304**. Formic acid gas **916** is channeled through the at least one connection **306a** to remove impurities on surfaces that may not be adequately enveloped by the adhesive material **308a**.

Thus it can be seen that a method of bonding the first substrate and the second substrate in accordance with the present embodiments have the advantages of improved alignment, higher mechanical strength, better electrical conductivity, greater device reliability and higher density of connections with fine pitches.. While exemplary embodiments have been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist.

It should further be appreciated that the exemplary embodiments are only examples, and are not intended to limit the scope, applicability, operation, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention, it being understood that various changes may be made in the function and arrangement of elements and method of operation described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

CLAIMS

1. A method for bonding a first substrate and a second substrate, the first substrate having at least one first connection extending from one side of the first substrate and the second substrate including at least one under bump metallization (UBM) portion wherein the at least one UBM portion has a broader width across the second substrate than a width of the first connection across the first substrate, the method comprising:

fabricating a first adhesive material only around and along a height of the at least one first connection;.

aligning centerlines of the at least one first connection and a corresponding one of the at least one UBM portion of the second substrate and bonding the at least one first connection, the first adhesive material, and the corresponding one of the at least one UBM portion of the second substrate using a flip chip bonding technique; and

thereafter permanently bonding the at least one first connection, the first adhesive material, and the corresponding one of the at least one UBM portion of the second substrate using a global bonder technique.

2. A method for bonding a first substrate and a second substrate, the first substrate having at least one first connection extending from one side of the first substrate and the second substrate having at least one second connection extending from one side of the second substrate , the method comprising:

fabricating a first adhesive material only around and along a height of the at least one first connection;

fabricating a second adhesive material only around and along a height of the at least one second connection;

aligning centerlines of the at least one first connection and a corresponding one of the at least one second connection and bonding the at least one first connection, the first adhesive material, the corresponding one of the at least one second connection, and the second adhesive material using a flip chip technique; and

thereafter permanently bonding the at least one first connection, the first adhesive material, the corresponding one of the at least one second connection of the second substrate, and the second adhesive material using a global bonder technique.

3. A method according to claim 1, further comprising:

fabricating the at least one first connection on one side of the first substrate.

4. The method according to claim 1, wherein the step of fabricating the first adhesive material comprises:

fabricating a first adhesive thickness of the first adhesive material, the first adhesive thickness being substantially uniform along the height of the at least one first connection.

5. A method according to claim 2, further comprising:

fabricating the at least one second connection on one side of the second substrate.

6. The method according to claim 2, wherein the step of fabricating the second adhesive material comprises:

fabricating a second adhesive thickness of the second adhesive material, the second adhesive thickness being substantially uniform along the height of the second connection.

7. The method according to claim 4, wherein the first adhesive thickness is in a range of 100nm to 2μm.

8. The method according to claim 6, wherein the second adhesive thickness is in a range of 100nm to 2μm.

9. The method according to claim 1, wherein the at least one first connection comprises a material selected from a group comprising copper, gold, aluminum, tin and indium.

10. The method according to claim 2, wherein the at least one second connection comprises a material selected from a group comprising copper, gold, aluminum, tin and indium.

11. The method according to claim 1, wherein the first adhesive material comprises a material selected from a group comprising tin, indium and a polymer material suitable for fabricating around and along the at least one first connection.

12. The method according to claim 2, wherein the second adhesive material comprises a material selected from a group comprising tin, indium and a polymer material suitable for fabricating around and along the at least one second connection.

13. The method according to claim 1, wherein the at least one UBM portion comprises a material selected from a group comprising copper, gold, aluminum, tin and indium.

14. The method according to claim 2, wherein the step of fabricating the first adhesive material and the second adhesive material is performed using an electroless deposition technique.

15. The method according to claim 12, wherein the material comprised in the second adhesive material is the same as a material comprised in the first adhesive material.

16. A method according to claim 1, wherein the step of aligning and bonding the at least one first connection, the first adhesive material, and the corresponding one of the at least one UBM portion of the second substrate using the flip chip technique comprises heating the first and the second substrates to a melting temperature of the first adhesive material when the first adhesive material is a metal.

17. A method according to claim 1, wherein the step of aligning and bonding the at least one first connection, the first adhesive material, and the corresponding one of the at least one UBM portion of the second substrate using the flip chip technique comprises heating the first and the second substrates to a lowest melt-viscosity temperature after B stage when the first adhesive material is a thermoset polymer.

18. A method according to claim 1, wherein the step of aligning and bonding the at least one first connection, the first adhesive material, and the corresponding one of the at least one UBM

portion of the second substrate using the flip chip technique comprises heating the first and the second substrates to a low melt-viscosity temperature of less than 200 degree Celsius when the first adhesive material is a thermoplastic polymer.

19. A method according to claim 2, wherein the step of aligning and bonding the at least one first connection, the first adhesive material, the corresponding one of the at least one second connection, and the second adhesive material comprises heating the first and the second substrates to a melting temperature of the first and second adhesive materials when the first and second adhesive materials are metals.

20. A method according to claim 2, wherein the step of aligning and bonding the at least one first connection, the first adhesive material, the corresponding one of the at least one second connection, and the second adhesive material comprises heating the first and the second substrates to a lowest melt-viscosity temperature after B stage when the first and second adhesive materials are a thermoset polymer.

21. A method according to claim 2, wherein the step of aligning and bonding the at least one first connection, the first adhesive material, the corresponding one of the at least one second connection, and the second adhesive material comprises heating the first and the second substrates to a low melt-viscosity temperature of less than 200 degree Celsius when the first and second adhesive materials are a thermoplastic polymer.

22. A method according to claim 2, wherein a width of the at least one first connection across the first substrate is substantially equivalent to a width of the at least one second connection across the second substrate.