Method and Device for Permanent Bonding of Wafers, as well as Cutting Tool

Specification

This invention pertains to a method for bonding a first bond surface of a first solid substrate that consists of a first material to a second bond surface of a second solid substrate that consists of a second material~~, in accordance with Claim 1,~~ as well as a corresponding device ~~in accordance with Claim 7~~ and a cutting tool ~~in accordance with Claim 9~~.

The purpose of permanent or irreversible bonding of solid substrates is to produce as strong a bond as possible and especially an irreversible bond, i.e., a high bonding force between the two contact surfaces of the solid substrates. For this purpose there exist in the prior art various approaches and production methods, especially the welding of the bond or the creation of a diffusion bond between the surfaces at elevated temperatures.

All kinds of materials, but primarily metals and/or ceramics, are permanently bonded. One of the most important permanent bonding systems is a metal-metal system. In recent years Cu-Cu systems have been the primary systems gaining in popularity. The development of 3-D structures specifically requires in most cases the joining of different functional layers. This joining being done created more and more often using so-called TSVs (Through Silicon Vias). Ensuring contact between these TSVs is very often done by means of copper contact points. At the time of the bonding, full-fledged, functional structures, for example, microchips, are very often already present at one or more surfaces of the solid substrates. Since different materials with different thermal expansion coefficients are used in the microchips, a rise in temperature during bonding is not desirable. Such an elevation of temperature can lead to thermal expansion and thus to thermal stresses that can destroy the parts of the microchip or its vicinity.

the production of a completely new structure over the boundary surface between two metal surfaces that are in contact.

In this case the formation of a new structure is preferably done by recrystallization. Recrystallization is defined as the production of a new structure by means of grain growth. The prerequisites for such grain growth include high degrees of deformation that increase the dislocation density of a material and thus bring the material into an energetically metastable state; when a critical temperature is exceeded, this leads to new grain formation. In heavy industry massive transformation processes such as rolling, forging, deep drawing, twisting, shearing, etc. are primarily used to achieve high degrees of dislocation.

Such massive transformation processes with which the above-mentioned metastable dislocation-rich microstructure can be created at low temperature cannot be used in the semiconductor industry because of the very thin substrates with extremely fine structures and the thin, fragile wafers. Neither the structures nor the wafers can or should be subjected to massive transformation since they will be destroyed thereby.

~~The object~~Embodiments of this invention ~~is therefore to~~ propose a method and a device/a cutting tool with which the bonding of two solid substrates can be done in a manner that is more gentle and more effective for the substrates and any structures on the substrates.

~~This object is achieved with the features of Claims 1, 7, and 9. Advantageous developments to the invention are indicated in the dependent claims.~~

According to a first aspect of the present invention, there is provided a method for bonding a first bond surface of a first solid substrate consisting of a first material to a second bond surface of a second solid substrate consisting of a second material, said method comprising the steps of: working one of a first bond surface and a second bond surface with a cutting tool to

create a metastable structure in at least a near-surface area and to produce a reduced surface roughness of less than 100 nm, bringing the first solid substrate into contact with the second solid substrate at the bond surfaces, and exposing the solid substrates that are in contact to a temperature sufficient to form a permanent bond, said permanent bond being at least primarily produced by recrystallization at the bond surfaces down to a recrystallization depth R that is greater than the surface roughness O of the bond surfaces with a bond temperature TB that exceeds the recrystallization temperature.

According to a second aspect of the present invention, there is provided a device for bonding a first bond surface of a first solid substrate consisting of a first material to a second bond surface of a second solid substrate consisting of a second material, said device comprising: a cutting tool for working one of the first and the second bond surfaces to create a metastable structure in at least a near-surface area and a reduced surface roughness of less than 100 nm, and a sample holder for receiving at least one of the first and the second solid substrates, the sample holder configured to heat and/or cool the solid substrates(s) to a predetermined temperature after the substrate(s) are in contact to form a permanent bond that is at least primarily produced by recrystallization at the bond surfaces down to a recrystallization depth R that exceeds the surface roughness O of the bond surfaces with a bond temperature T_B that is greater than a recrystallization temperature.

~~The~~Embodiments of the invention also includes all combinations consisting of at least two features indicated in the specification, the claims, and/or the figures. In the case of the value ranges indicated, values lying within the limits presented are also to be regarded as disclosed as boundary values and can be claimed in any combination.

The basic idea as per embodiments of this invention is to planarize at least one of the two bond surfaces and preferably both bond surfaces before they are brought into contact, in such a way that the surface roughness O of the bond surface(s) is minimized in order to weld together/ bond the base surfaces optimally after they are brought into contact. In this connection provision is especially made for eliminating chemical-mechanical polishing (CMP) processes. Moreover, according to embodiments of the invention a metastable microstructure is produced at the bond surface in order to obtain a high displacement density and/or an amorphous layer at the bond surface. The high displacement density and/or the amorphous layer promotes and/or accelerates the recrystallization process. In this process a smooth surface is provided in particular (reduction of surface roughness).

In addition, near-surface amorphous areas are provided in order to ensure better bonding of the two surfaces. The production of amorphous materials in industry is mainly done by vapor deposition of a material onto cooled substrates, by shooting ions or irradiation, by extremely powerful mechanical deformation, etc. ~~The~~Embodiments of the invention disclosed here discloses a way of creating already existing near-surface areas with high displacement densities and/or amorphous areas.

The planarization and production of the metastable structure are preferably done by means of a cutting method.

Solid substrates made of the following materials are suitable as solid substrates according to embodiments of the invention:

In order to explain the application of the idea as per embodiments of the invention to structures in the micro-range and/or the nano-range, an explanation will first be given of general physical, chemical, and materials-science principles. When the term tool is used hereinafter, said term generally refers to the tool that is capable of striking a workpiece with a speed v at a certain temperature T. This means impact stress on the workpiece. The tool is preferably a standardized tool, for example, a Charpy notched-bar impact testing machine (DIN EN 10045-1). The workpiece is preferably a standard sample. Figures 3a and 3b schematically depict the effect of tool speed (Figure 3a) and temperature (Figure 3b) on cleavage fracture strength (T_f) and ductile fracture strength (G_f) in the case of bulk metals. The diagrams are schematic representations of these two physical properties. Since the numerical values differ for different materials, no absolute numerical values are given. In Figure 3a the dependency of the cleavage fracture strength and ductile fracture strength of the material is presented as function of tool speed.

Cleavage fracture strength T_f is the resistance that the material puts up against a force that attempts to sever the material without plastic deformation, i.e., in an ideal brittle manner. Ductile fracture strength G_f is the resistance that the material puts up against a force, more specifically a thrust force, that attempts to deform the material plastically. The mechanisms of plastic deformation in this case are primarily the mechanical plastification mechanisms of dislocation motion and dislocation production and the formation of crystallographic twins. The distinction between cleavage fracture strength and ductile fracture strength cannot be made completely based on the material. Thus, it is entirely possible for even ductile materials to exhibit brittle fracture behavior if they have embedded intermetallic phases or if unfavorable stresses conditions prevail because of the sample geometry. Moreover, the impact conditions of tools and sample temperature play decisive roles. Figures 3a and 3b show schematic plots of

cleavage fracture strength and ductile fracture strength as a function of temperature and tool speed for metals. In Figure 3a it is clear that at low tool speeds below a critical speed v_k which is empirically determined in each case for the material, (especially with allowance for thickness), ductile fracture strength G_f has lower values than cleavage fracture strength T_f. Accordingly, at tool speeds below the critical speed v_k the material will fracture more readily by deformation fracture (i.e., ductile fracture) than by cleavage fracture. Above the critical speed v_k, the values for cleavage fracture strength T_f lie below those for ductile fracture strength G_f. Tools that strike the material at speeds above the critical speed v_k will cause the material to fracture in a brittle manner, i.e., by cleavage fracture. From Figure 3a it is clear that ductile fracture strength G_f is heavily dependent on tool speed v_k, while cleavage fracture strength T_f varies hardly at all with tool speed. Cleavage fracture strength and ductile fracture strength additionally depend on the temperature of the material (Figure 3b). At temperatures above the critical temperature T_k material failure occurs primarily due to ductile fracture, while, by contrast, below the critical temperature T_k material failure occurs primarily due to brittle fracture (i.e., cleavage fracture). According to embodiments of the invention, "freezing" of the dislocations thus takes place at low temperatures. Dislocation motion as a material-physical process is explicitly dependent on temperature. The lower the temperature, the lower the dislocation mobility and the more difficult it will be to move the dislocations of the solid substrates. Figures 3a and 3b show that in general a metal fractures in a more brittle manner, the higher the tool speed and the lower the temperature. In order to categorize different materials according to their fracture behavior, the experimentally determined notched-bar impact work K that it takes to fracture the material is plotted as a function of temperature (Figure 3c). In this way a notched bar impact work-temperature diagram is obtained which, depending on the material in question, has an explicit drop-off in notched-bar

other, to bring the near-surface area into a metastable state that promotes and/or accelerates bonding to other surfaces of other structures.

In order for recrystallization to occur, according to embodiments of the invention two conditions are to be met cumulatively.

First, a highly deformed metal has to be heated to above the recrystallization temperature. Tin, for example, recrystallizes at approximately 0°C, zinc at approximately 20°C, aluminum at approximately 100°C, copper at approximately 270°C, iron at approximately 450°C, and tungsten at approximately 1200°C. In general it must be assumed that the actual recrystallization temperatures will lie above or below these values. A decisive factor for recrystallization temperature is contamination by alloying additives. Thus, for example, the recrystallization temperature of 99.999% copper lies at 120°C, but the recrystallization temperature of electrolytically deposited copper, which by nature is rather impure, lies at approximately 200°C. The deposition of copper by electrolysis is always associated with organic additives, ions, and impurities. Copper deposited by CVD and/or PVD processes is, by contrast, of high purity.

The second condition for recrystallization is an energetically metastable state. According to embodiments of the invention, this state is produced by a high dislocation density and/or an amorphous-crystalline structure and/or a quasi-crystalline structure. An amorphous matrix is preferably provided in which partially crystalline phases and/or quasi-crystalline phases are present, most preferably microcrystals and/or nanocrystals with a high dislocation density. Any combination of crystals, quasi-crystals, and amorphous structural components in any volume ratio is also conceivable. In order to make the rest of the text clearer, crystalline-amorphous structures will be primarily addressed.

It is known that so-called "size effects" can radically alter the physical-chemical behavior of materials. The recrystallization of copper, especially for very small dimensions, can take place even below the above-mentioned minimum recrystallization temperature of 120°C. Thus, high-purity materials with microstructures or nanostructures whose surfaces are worked by high speed tools at the temperatures provided produce, according to embodiments of the invention, more efficient recrystallization at lower temperatures than do corresponding bulk materials.

According to embodiments of the invention, it especially advantageous if, as soon as possible after the first working (and optionally the second working), especially within two hours, preferably within 30 minutes, even more preferably within 10 minutes, and ideally within 5 minutes, the solid substrates are brought into contact. This measure ensures that any undesired reactions such as oxidation of the functional layer or the surfaces of the solid substrates are minimized.

The bond surfaces according to embodiments of the invention are worked to a surface roughness O with a quadratic roughness (R_q) of less than 1 μm, preferably less than 100 nm, most preferably less than 10 nm, and even more especially less than 1 nm. These empirical values are determined by Atomic Force Microscopy (AFM).

Another ~~aspect~~embodiment of the invention consists of the formation of a seamless transition between the two solid substrates to be bonded. A seamless transition is defined as a polycrystalline structure that extends, with no interruption in the grain structure, from one side of the bonded wafer to the other. The creation of such a seamless transition is done especially by recrystallization under the conditions of the above-described parameters that are empirically related in particular to the materials of the solid substrates and their dimensions. Recrystallization is the formation of a new structure caused by a high dislocation density and a temperature which has been empirically determined according to embodiments of the invention by grain growth.

Because of the high dislocation density provided for according to embodiments of the invention, the structure is in a metastable state. This metastable state is created by overlapping strain fields of the dislocations. Below the recrystallization temperature thermal motion is not sufficient to cause the dislocations of the dislocation network to begin sliding by themselves due to the mutually repelling strain fields. The dislocations are quasi-"frozen". If the temperature exceeds the recrystallization temperature, thermal motion is sufficient to reduce the dislocation density by means of dislocation motion. A complete reformation of the structure is associated with the reduction in dislocation density. The effect achieved according to embodiments of the invention consists in the fact that the reformation of the structure takes place beyond the bond interface (which is defined/limited by the surface roughness O) and so causes the interface to disappear virtually completely.

~~Accordingly,~~Disclosed herein is a method according ~~to the invention has, especially in its most general form,~~ comprising the following steps, especially in the following sequence, for bonding a first bond surface of a first solid surface consisting of a first material to a second bond surface of a second solid substrate consisting of a second material:

- working of the first and/or second bond surfaces with a cutting tool to create a metastable structure in at least the area close to the surface and, especially at a speed v_s that lies below a critical speed v_k and a temperature T_s that lies above a critical temperature T_k and preferably with simultaneous or subsequent planarization to a quadratic roughness (R_q) of less than 1 μm, preferably less than 100 nm, most preferably less than 10 nm, and most especially less than 1 nm,
- bringing the first solid substrate and the second solid substrate into contact at the bond surfaces, and

- exposing the solid substrates in contact to temperature in order to form a permanent bond, created at least primarily by recrystallization, at the bond surfaces in each case down to a recrystallization depth R that is greater than the surface roughness O of the bond surfaces with a bond temperature T_B that exceeds the recrystallization temperature.

~~A corresponding~~ Disclosed herein is a device ~~according to the invention has, especially in its most general embodiment,~~ comprising the following features:

- a cutting tool to work the first and/or second bond surfaces to create a metastable structure in at least the area near the surface, especially at a speed v_s that lies below a critical speed v_k and a temperature T_s that lies above a critical temperature T_k and does so down to surface roughness O of less than 1 μm, preferably less than 100 nm, most preferably less than 10 nm, and most especially less than 1 nm,
- means for bringing the first solid substrate into contact with the second solid substrate at the bond surfaces, and
- means for exposing the solid substrates in contact to temperature, for the purpose of forming a permanent bond created at least primarily by recrystallization at the bond surfaces in each case down to a recrystallization depth R that is greater than the surface roughness O of the bond surfaces with a bond temperature T_B that exceeds the recrystallization temperature.

~~A~~Disclosed herein is a cutting tool ~~according to the invention is~~ designed for working the first and/or second bond surface at a speed v_s that lies below the critical speed v_k and a temperature T_s that lies above a critical temperature T_k and does so down to a surface roughness O of less than 1 μm, preferably less than 100 nm, most preferably less than 10 nm, and most especially less than 1 nm.

cleavage fracture as brittle fracture). In the case of intercrystalline cleavage fracture, the crack runs along the grain boundaries of a grain. In the case of transcrystalline cleavage fracture, the crack runs transversely through the grain. If it should emerge from the empirical data that the material is fracturing due to intercrystalline fracture, resulting in an unfavorable surface roughness, i.e., a high surface roughness, then the parameters according to embodiments of the invention have to be modified in such a way that surface roughness is minimized. Contrary to embodiments of the invention that is explicitly disclosed here, this state can also very easily result from ductile fracture alone. It should be mentioned, however, that the microstructure of the materials used has grains preferably in the nanometer range, and therefore even in the case of intercrystalline cleavage fracture there will be roughness only in the nanometer range. In particular, the (mean) grain diameter will then be the upper boundary for this (mean) roughness. If the structure should have grains in the micrometer range, then in any case transcrystalline cleavage fracture is desired. Mention should be made here, for example, but not on exclusive basis, of intergranular precipitations, intermetallic phases within the grain, oriented microstructure elements that can deflect cracks, etc. In general, it can be stated that a grain will fracture preferably along the grain boundary when the strength between the grains is less than that of the atoms within a grain.

~~The~~Embodiments of the invention therefore relate~~s~~ to a method by which the recrystallization of a material (the material of the solid substrates) is carried out at comparatively low temperature in the near-surface areas of the bond surface through the creation of a metastable energy state in the structure. In this way two bond surfaces that are brought into contact with one another are permanently and seamlessly joined to one another with a comparatively very low surface roughness O. A metastable energy state is preferably created only in near-surface areas of the bond surfaces. Here a cutting tool, consisting especially of multiple tools, is used that is/are

capable of establishing a certain microstructure at the bond surface by means of frequency, cutting speed, tool geometry, and/or cutting edge insertion angle. In this case it is especially advantageous, according to embodiments of the invention, if the tool parameters and ambient parameters are selected in such a way that the area near the surface and the bond surfaces have an elevated dislocation density after the tool passes through.

After recrystallization, the structure is preferably as coarse-grained as possible. A course-grained structure has very low thermal resistance and, in particular, very low electrical resistance. Thus, such coarse-grained structures, which are preferably even monocrystalline over the interface, are especially suitable for electrically conductive connections. Since the industry will use the method according to embodiments of the invention preferably, but not exclusively, for the production of interconnects, as electrically conductive connections, as low an electrical resistance as possible and thus as coarse-grained a structure as possible are desired in most cases. For components that are interconnected by the method according to embodiments of the invention and are intended to have only a mechanically stabilizing effect, in particular a thermo-mechanically stabilizing effect, then on the contrary a fine-grained structure is preferred since such a structure has a higher fatigue strength, especially in the presence of alternating thermal loads.

In an advantageous embodiment of the invention, the tool parameters and environmental parameters are selected in such a way that, after the first working, i.e., after the tool passes, the bond surface and the area near the surface consist of an amorphous layer in which crystalline areas are provided that preferably have a very high dislocation density. The thickness of the amorphous layer is determined in particular by the (empirically established) tool speed.

Another, elementary ~~aspect~~embodiment of the invention is the recrystallization beyond the contact plane/beyond the near-surface layer of contact (in particular, in the area of surface roughness O).

According to embodiments of the invention, this is achieved and optimized by setting the surface roughness O to be comparatively low, namely by means of the working with the cutting tool. By adjusting the speed of the tool and the temperature in a targeted manner, surface roughness O can be minimized. In the case of most materials, the minimum surface roughness O is associated with a high tool speed and a low temperature since cleavage-fracture surfaces are smoother than surfaces that have undergone a plastic deformation process. While from the standpoint of physics the lower surface roughness does not change anything with regard to crystallization, i.e., the modification of the structure, the lower surface roughness does, however, allow the newly formed grains to bridge the contact plane more easily since there are more contact points owing to the lower surface roughness.

The recrystallization temperatures are dependent on the material used for the solid substrates, and this is especially dependent on the dislocation density of the material. For the purposes of this specification, 50% of the melting point of the material is adopted as the recrystallization temperature (homologous temperature of 0.5). According to embodiments of the invention it is conceivable to influence the recrystallization temperature through the targeted addition of additives, especially alloying elements, or targeted contamination, and preferably to use high-purity metals to reduce it to a minimum.

The empirical determination of material-specific parameters can be done especially by notched-bar impact strength measurement on bulk materials. Furthermore, the empirical determination of parameters according to embodiments of the invention can be done by means of the actual execution and by means of test series with the device according to embodiments of the invention. This is especially preferred because the transfer of standard values of bulk materials for the parameters according to embodiments of the invention to thin substrates is not easily possible, at least not directly.

Moreover, according to embodiments of the invention it is advantageous ~~in one embodiment of the invention~~ to carry out the step of working of the first and/or second bond surfaces in a first module, while the step of bringing them into contact, aligning them, and temperature exposure of the solid substrates that are in contact is done in a separate, second module (physically separate from the first module).

By way of example, but not limiting, Figure 4 shows in sketch and greatly simplified form a top view of a possible tool holder with cutting tools; said tool holder rotates around its axis and is pushed by a forward feed over the wafer to be worked. One skilled in the art is best acquainted with these kinds of tools or tools that work in a similar fashion.

According to embodiments of the invention, a sample holder is provided that can be appropriately actively heated and/or cooled in order to bring the wafer to be worked to the desired temperature. It is also disclosed that the two wafers can/must be aligned with respect to one another after the treatment process according to the invention.

Additional advantages, features, and particulars of the invention are given in the following description of preferred example embodiments as well as in the drawings. Here:

Figure 1a shows a process step according to the invention for working a solid substrate with a cutting tool according to the invention;

Figure 1b shows a bond surface worked according to the invention with a near-surface layer that has an elevated dislocation density;

Figure 1c shows a bond surface worked according to the invention with a near-surface amorphous layer;

Figure 1d shows a bond surface worked according to the invention with a near-surface amorphous layer that has an elevated dislocation density;

CLAIMS

1. Method for bonding a first bond surface of a first solid substrate consisting of a first material to a second bond surface of a second solid substrate consisting of a second material, said method comprising the steps of:

working one of a first bond surface and a second bond surface with a cutting tool to create a metastable structure in at least a near-surface area and to produce a reduced surface roughness of less than 100 nm,

bringing the first solid substrate into contact with the second solid substrate at the bond surfaces, and

exposing the solid substrates that are in contact to a temperature sufficient to form a permanent bond, said permanent bond being at least primarily produced by recrystallization at the bond surfaces down to a recrystallization depth R that is greater than the surface roughness O of the bond surfaces with a bond temperature T_B that exceeds the recrystallization temperature.

2. Method in accordance with Claim 1, in which the first and second materials are identical.

3. Method in accordance with claim 1, in which the first and/or second materials are metals.

4. Method in accordance with claims 1, 2 or 3 wherein the formation of the permanent bond takes place at a bond temperature T_B that is greater than a critical temperature T_k.

5. Method in accordance with claims 1, 2 or 3 wherein the working with the cutting tool is done in such a way that an amorphous layer and/or a layer of elevated dislocation density is formed at the first and/or second bond surface.

6. Method in accordance with claims 1, 2 or 3 wherein after the first working is done and before contact is made, a second working of said one of the first and second bond surfaces with a second tool is carried out at a speed v_o that exceeds a critical speed v_k and at a temperature T_o that is below a critical temperature T_k in order to reduce the surface roughness O to less than 100 nm.

7. Method in accordance with claim 1, wherein said working step produces a reduced surface roughness of less than 10 nm.

8. Method in accordance with claim 1, wherein said working step produces a reduced surface roughness of less than 1 nm.

9. Method in accordance with claim 1, wherein said working step produces a reduced surface roughness of less than 0.1 nm.

10. Device for bonding a first bond surface of a first solid substrate consisting of a first material to a second bond surface of a second solid substrate consisting of a second material, said device comprising:

a cutting tool for working one of the first and the second bond surfaces to create a metastable structure in at least a near-surface area and a reduced surface roughness of less than 100 nm, and

a sample holder for receiving at least one of the first and the second solid substrates, the sample holder configured to heat and/or cool the solid substrates(s) to a predetermined temperature after the substrate(s) are in contact to form a permanent bond that is at least primarily produced by recrystallization at the bond surfaces down to a recrystallization depth R that exceeds the surface roughness O of the bond surfaces with a bond temperature T_B that is greater than a recrystallization temperature.

11. Device in accordance with Claim 10, in which the cutting tool can be adjusted in such a way that a second working is carried out at a speed v_o that exceeds a critical speed v_k at a temperature T_o that is below a critical temperature T_k, in order to reduce the surface roughness O to less than 100 nm.

Claims:

1. Method for bonding a first bond surface of a first solid substrate consisting of a first material to a second bond surface of a second solid substrate consisting of a second material, said method comprising the steps of:

working one of a first bond surface and a second bond surface with a cutting tool to create a metastable structure in at least a near-surface area and to produce a reduced surface roughness of less than 100 nm,

bringing the first solid substrate into contact with the second solid substrate at the bond surfaces, and

exposing the solid substrates that are in contact to a temperature sufficient to form a permanent bond, said permanent bond being at least primarily produced by recrystallization at the bond surfaces down to a recrystallization depth R that is greater than the surface roughness O of the bond surfaces with a bond temperature T_B that exceeds the recrystallization temperature.

2. Method in accordance with Claim 1, in which the first and second materials are identical.

3. Method in accordance with claim 1, in which the first and/or second materials are metals.

4. Method in accordance with claims 1, 2 or 3 wherein the formation of the permanent bond takes place at a bond temperature T_B that is greater than a critical temperature T_k.

5. Method in accordance with claims 1, 2 or 3 wherein the working with the cutting tool is done in such a way that an amorphous layer and/or a layer of elevated dislocation density is formed at the first and/or second bond surface.

6. Method in accordance with claims 1, 2 or 3 wherein after the first working is done and before contact is made, a second working of said one of the first and second bond surfaces with a second tool is carried out at a speed v_o that exceeds a critical speed v_k, especially and at a

temperature T_o that is below a critical temperature T_k in order to reduce the surface roughness O to less than 100 nm, preferably less than 10 nm.

7. Method in accordance with claim 1, wherein said working step produces a reduced surface roughness of less than 10 nm.

8. Method in accordance with claim 1, wherein said working step produces a reduced surface roughness of less than 1 nm.

9. Method in accordance with claim 1, wherein said working step produces a reduced surface roughness of less than 0.1 nm.

10. Device for bonding a first bond surface of a first solid substrate consisting of a first material to a second bond surface of a second solid substrate consisting of a second material, said device comprising:

a cutting tool for working one of the first and the second bond surfaces to create a metastable structure in at least a near-surface area and a reduced surface roughness of less than 100 nm, and

a sample holder for receiving at least one of the first and the second solid substrates, the sample holder configured to heat and/or cool the solid substrates to a predetermined temperature after the substrate are in contact to form a permanent bond that is at least primarily produced by recrystallization at the bond surfaces down to a recrystallization depth R that exceeds the surface roughness O of the bond surfaces with a bond temperature T_B that is greater than a recrystallization temperature.

11. Device in accordance with Claim 10, in which the cutting tool can be adjusted in such a way that a second working is carried out at a speed v_o that exceeds a critical speed v_k, at a temperature T_o that is below a critical temperature T_k, in order to reduce the surface roughness O to less than 100 nm.

12. Method in accordance with claim 6, wherein said cutting tool and said second tool are the same tool.

13. Method in accordance with claim 6, wherein the surface roughness O is reduced to less than 10 nm.

14. Method in accordance with claim 6, wherein the surface roughness O is reduced to less than 1 nm.

15. Method in accordance with claim 6, wherein the surface roughness O is reduced to less than 0.1 nm.

16. Device in accordance with claim 11, wherein the surface roughness O is reduced to less than 10 nm.

17. Device in accordance with claim 11, wherein the surface roughness O is reduced to less than 1 nm.

18. Device in accordance with claim 11, wherein the surface roughness O is reduced to less than 0.1 nm.