Device and Method for Bonding Substrates

The present invention relates to a device for creating an electrically conductive direct bond between a bonding side of a first substrate and a bonding side of a second substrate and a method.

Especially when bonding metallic or metallized substrates, substrates with metallic surfaces, semiconductor substrates, or compound semiconductor substrates, the oxidation of the bonding sides of the substrates to be bonded plays a significant role, as it impedes the bonding process. The oxide prevents or reduces the formation of a mechanically and/or electrically valuable contact. Notably associated with this is, due to longer heating and cooling times, a deterioration in throughput; and, the higher the temperature is or must be during bonding, the larger the influences of expansion owing to temperature differentials are on the alignment or adjustment accuracy of the substrates relative to one another. Furthermore, certain MEMS- and/or semiconductor assemblies, for example, such as microchips or memory chips, do not allow high process temperatures.

In the state of the art, mainly wet etching processes are used for removing oxides that form on the above-mentioned substrates and consequently prevent, or at least impede, an optimum bonding of multiple substrates through a bond process. In the wet etching processes, hydrofluoric acid or hydrofluoric acid-containing mixtures are predominantly used. After reduction of the oxide, a surface – terminated by hydrogen atoms - emerges. These hydrophobic surfaces are suitable for producing a so-called pre-bond. If the two wafers are, however, to become permanently connected to each other, the wafer stack must be heat-treated at elevated temperatures, so that the hydrogen that is produced through the reduction process and terminates the surface of the substrate is removed from the bond interface, and a permanent connection

between the two substrate surfaces, especially silicon surfaces, can form. The substrate stack is heat-treated after the surfaces make contact. Silicon wafers are, for example, heat-treated at a temperature of approximately 700°C in order to ensure such a permanent connection. The methods of the art serve especially to produce multi-layer metal, semiconductor, glass, or ceramic bonds. An especially important application relates to production of photovoltaic multi-layer cells and photonic crystals, especially photonic crystals made of silicon.

One of the major limitations in producing multi-layer cells is the incompatibility of the lattice structures of the individual semiconductor materials with regard to their size and shape. In the production of individual layers through direct epitaxial growth of the layers, this leads to defects in the semiconductor layer brought about by this process. These defects compromise the quality of the produced layer and especially the efficiency that can be achieved in converting light into electric energy. This efficiency is also referred to as quantum efficiency and defines, for solar cells, the ratio of the charge carriers, usable by the photo process, to the quantity of absorbed photons of a particular wavelength. From this in practice, arise constraints with respect to the following parameters:

a) Number of feasible active layers in the structure. This is, due to the difficulty described above, limited to two, or a maximum three layers.

b) Optimization of the individual layers with regard to an optimum wavelength range. In practice, it is not possible today to optimize the individual layers completely freely with regard to the optimum wavelength range and associated conversion characteristics for the conversion from light into electric energy, as compromises must always be made in regard to compatibility of lattice structures.

c) Use of better materials: for certain wavelengths it would be desirable to use silicon or germanium, for example, as these materials would allow for an ideal compromise between efficiency and cost. The use of these materials, however, is often not possible, because the lattice structures are not sufficiently compatible with the other structures used in the cell.

An oxide treatment, specifically oxide removal, before a subsequent bonding process, is often carried out using hydrofluoric acid. In the process, contamination of the surface and especially regrowth of the oxide may occur after oxide removal.

A further problem in this regard is that a variable waiting period between oxide removal and further treatment of the substrate leads to a variable process result of the bonded substrate stack.

A further disadvantage of previous methods is that etching processes must be tailored to the oxide to be etched. As a result, different etching chemicals are required for different semiconductor materials in certain circumstances.

Furthermore, the process requirements with regard to wait time until treatment, kind of process environment conditions (for example, inert atmosphere, free from O2 and, optionally, also free from water) are, in certain circumstances, also different depending upon material. For this reason, a bonding system for bonding different substrates, composed of different materials, can wind up being quite complex. Additionally, due to the different requirements imposed by various materials, a considerable process development effort can arise as soon as new materials are to be introduced into manufacture.

Physical processes, in addition to the already-mentioned chemical processes, represent another means for oxide removal. One of the most important physical processes for oxide removal

is sputtering. Sputtering is defined as the removal of atoms on the surface of a substrate by collision processes of ionized atoms of sputter gas that are ionized and are accelerated by electric and/or magnetic fields.

Sputtering, however, is disadvantageous in that the process inherently generates particles; this is in the nature of the process of removing material from a surface by means of a physical process. This material can be deposited in all manner of places in the process chamber and can either be precipitated, through sublimation, from these places onto the substrate to be bonded or can be directly resublimed back onto the substrate. These particles are obstructive to an optimum – that is, void-free – bond result. In addition, sputtering processes require very high ion energies in order to be able to remove matter from the surface of the substrate. This leads to ions being partially implanted in the substrate, which damages the layer near the surface. This damaged layer can be several nm thick, typically even 5 to 10 nm or more. This damage can negatively affect the characteristics of the bond connection in regards to electric and optical parameters, with the result that this damage is undesirable and presents a problem in practice.

Another fundamental problem in manufacturing multi-layer cells is heat-treatment, which is typical for many processes. Heat-treating is done between 100 °C and 700 °C. At such high temperatures, the materials used are mechanically heavily stressed. In the presence of high temperature differentials, mechanical strain is determined by, above all, thermal stresses. The thermal stresses are dependent on the thermal expansion coefficient and temperature differential. If materials cannot expand freely together because they are welded together along a bond interface, a difference in the thermal expansion coefficients in the presence of a temperature differential results in correspondingly high thermal stress. Because the choice of material is quite

often determined by other boundary conditions, thermal stresses can only be avoided when the temperature differentials within the process steps are as small as possible.

It should be mentioned that the material combinations with which the bonding process should offer the greatest advantage (as an integration of materials with different lattice parameters and/or different thermal expansion coefficients should follow) are least compatible with a heat-treatment process because it is mostly here that the greatest differences with regard to thermal expansion occur.

Embodiments of the present invention disclose a device and a method for bonding with which the bonding process can be carried out more efficiently and qualitatively more valuably.

According to an aspect of the present invention, there is provided a method for producing a direct bond between a bonding side of a first substrate and a bonding side of a second substrate in a workspace, wherein the method includes: a) modifying at least one of the bonding sides of the first substrate or the second substrate in a plasma chamber and/or a bonding/plasma chamber effected by a control device using parameters to adjust the thickness of the damaged layer, the density of the damage, and the species or dose of implanted ions, b) subsequently bonding the bonding side of the first substrate with the bonding side of the second substrate in the bonding chamber or the bonding/plasma chamber.

The scope of the invention includes all combinations of at least two features given in the description, the claims, and/or the figures. With the given value ranges, values that lie inside of the boundaries mentioned should also be revealed as limits and should be claimable in any combination.