Method for Permanent Connection of Two Metal Surfaces

Description

The invention relates to a method for the production of a permanent connection between two metal surfaces.

The production of permanent, electrically conductive, metallic connections between two metal surfaces is gaining increasing importance in the semiconductor industry. Primarily for new types of packaging technologies in the area of so-called "3D integrated devices or ICs (3D IC)," metallic bond connections between two functional planes play a decisive role. In this case, first active or passive circuits are manufactured on two independent substrates, and the latter are permanently connected to one another in a bonding step, and the electrical contacts are established. This connection step can be accomplished either by connecting two wafers (wafer to wafer - W2W), by connecting one or more chips with a wafer (chip xo wafer - C2W), or by connecting one or more chips with a chip (chip to chip - C2C) method. In the case of these connection methods, direct connections between two connecting surfaces are of great interest, whereby both surfaces consist of the same material (metal) to a large extent. Here, methods that, to a large extent, do not require additional materials in this connection plane are quite especially preferred. In this connection, copper (Cu) or aluminum (Al) or gold (Au) is commonly used as metallization. It should be clarified, however, that embodiments of this invention basically also operates in interaction with other metals, and the metal selection is based predominantly on requirements of chip structures and pre-conditioning steps. Therefore, different metals are also to be regarded as embodiments of the invention. In addition, the method can also be used for so-called "hybrid bond interfaces."[1] These hybrid interfaces consist of a suitable combination of metal contact surfaces, which are surrounded by non-metallic regions. In this case, the non-metallic regions are configured in such a way that in an individual connecting step, both the metallic contact as well as contacts between the non-metallic regions can be produced. At this time, these connections, which are free of foreign materials, in particular of foreign metals, are produced by a so-called diffusion-bond method. Here, the contact surfaces are oriented toward one another and are brought into contact. The contact surfaces are pretreated by means of suitable methods (for example, "Chemical Mechanical Polishing," or, in short, "CMP") in such a way that they are very flat, and they have a slight surface roughness. The contact surfaces are then pressed together in a suitable device (for

example, a wafer bonder) and are heated at the same time to a freely selectable process temperature. Here, it may also prove advantageous if this takes place in an optimized atmosphere, such as, for example, a vacuum (e.g., < I mbar, preferably < 1-3 mbar) or in a reducing atmosphere, in particular an atmosphere with a high content (> 1%, preferably > 3%, even better > 5%, and ideally > 9%) on hydrogen (H2). Under these process conditions, a so-called diffusion bond is now produced between the two metal surfaces. Here, in the case of eutectic metal compositions, metal atoms or molecules diffuse back and forth between the two surfaces and thus establish a permanent, metallically conducting and mechanically extremely stable connection between the surfaces. Often, in this case, the connection is of a quality that makes detection of the original contact surfaces in the metal structure impossible, Rather, the connection is shown as a homogeneous metal structure, which now extends beyond the original contact surface. One factor, which greatly limits the use of this technology today, is the temperature that is relatively high in most cases, which is necessary to produce the connection and in particular to make the diffusion possible, in many cases, this temperature is higher than 300°C$_S$ in many cases higher than 350°C, typically 380 to 400°C, and in certain cases even up to 450 or 500°C higher than the temperature that can be tolerated by the components (typically < 260°C, in many cases < 230°C, for certain components < 200°C, and in certain cases < 180 or even < 150°C) and therefore prevents or limits the use of this method. Embodiments of this invention now deal with this problem since it makes possible a method in which the necessary process temperature is reduced dramatically.

These metallic connections are now to be referred to below in this document as "authentic bond connections." In this case, bond connections are always meant in which a connection is produced between two metallic contact surfaces, consisting of a metal A, without the use of foreign material installed permanently in the connection, in particular a foreign metal B, which has a different elementary composition.

As already described above, the methods may exist at this time are limited by the necessary process temperature to make the diffusion process possible. In principle, it can be asserted that diffusion processes are actions that depend on multiple factors. However, it is such that the process at lower temperature proceeds more slowly. In practice, however, this is a problem, since this would limit the economic efficiency of such processes, or would make very drawn-out (> 1 h) processes uneconomical. Therefore, the diffusion bonding processes are not applied between the same contact surfaces. As an alternative, in this case, solder joints or the most

widely varied manifestations of eutectic connections and so-called intermetalfie compound connection applications are used. As examples, solder joints based on lead/tin solder, copper-silver-tin solder, indium-based solders or else gold-tin or gold-silicon or aluminum-germanium, as well as copper-tin (intermetallic compound Cu3Sn) can be cited here. The disadvantage of these methods lies in problems of both manufacturing logistics and technology. In many cases, these bond connections are to be produced in an area of manufacturing where only a certain metallization (e.g., Cu) is established and qualified. In this case, it would be an immense additional expense, m addition to this metallization, to build and also to qualify' the infrastructure for another metallization. From the technological aspect, eutectic connections are to be considered critical with respect to the long-term stability. Certain connections are extremely brittle, and mechanical fatigue phenomena, i.a., can result. In addition, for certain metallizations, very narrow tolerances with respect to the mixing ratio are observed to guarantee the desired properties (e.g., melt temperature, mechanical and electrical properties) of the eutectic connection. In addition, diffusion effects in connection with eutectic connections can cause problems. Thus, for example, it would be a serious problem if tin were to diffuse from one interface between two copper contact surfaces through the entire copper contact and were to reach the underlying barrier layer between the copper contact and the underlying layer. Because of the altered metal composition, this would lead to the mechanical deiamination of the copper in this interface and thus result in a mechanical defect of the component, which could occur only after several years in the field. These are effects that can occur in this form only with microstructures, since here, very thin layers are used in which such effects can only play a role.

Embodiments of this invention disclose a method with which a reduced process temperature and/or a reduced process time can be achieved in metallic bond connections.

According to an aspect of the present invention, there is provided a method for production of a permanent, electrically conductive connection between a first metal surface of a first substrate and a second metal surface of a second substrate, the method including: conditioning the first and second metal surfaces by producing surface defects such that when connecting the metal surfaces a permanent, electrically conductive bond is produced at least primarily by substitution diffusion between metallic ions and/or metal atoms of the two metal surfaces, aligning and bonding the first and second metal surfaces, whereby a temperature treatment is applied such that a reorganization of structure of a near-surface layer of the first and second metal surfaces takes place

Also, all combinations that consist of at least two of the features that are indicated in the description, the claims and/or the figures fall within the scope of the invention. In the indicated ranges of values, values that He within the above-mentioned limits are also disclosed as boundary values and can be claimed in any combination.

Embodiments of this invention now present methods and processes by means of which the bond temperature for authentic bond connections can be reduced dramatically, and this thus makes possible the use of connections, which do not require foreign metal, for a broad area of use. An additional use of embodiments of this invention is also the acceleration of the process, which can be achieved in the case of ideal, selected process parameters and which increases the economic efficiency of the process.

Diffusion can be divided in general into substitutional and interstitial diffusion.

In the substitution diffusion, the diffusion jumps of the individual atom take place along each point in the grid, on which other atoms could be located. As a result, such a diffusion jump can actually take place, if necessary, at the position to which an atom would jump but no other atom can be located (exceptions exist: direct atom exchange mechanisms, which are discussed scientifically but are not yet detected; if they exist, they occur so rarely in comparison to the other atom exchange mechanisms that they can be disregarded). The position at which no atom is located is called a void. The void is to occupy a fundamentally important aspect in the further description of the patent.

In interstitial diffusion, smaller atoms diffuse within the lattice holes of a crystal. Since we are primarily dealing with homoatomic diffusion in this patent, interstitial diffusion is not further considered.

Hydrogen, which diffuses in the lattice holes of the Si crystal grid, would be an example of interstitial diffusion. In comparison to Si, hydrogen is "small,"' such that it has space in the lattice holes.

According to embodiments of the invention, only the substitution diffusion is suitable for the case of homoatomic diffusion of the same metal species.

In addition, surfaces, grain boundaries and volume diffusion can be distinguished. Atoms