inseto	Wafer Bonding Methods	
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- SCOPE: This document provides an overview of the different wafer bonding methods used in semiconductor manufacturing.

Wafer bonding refers to the attachment of two or more substrates or wafers to one another through a range of physical and chemical processes. Wafer bonding is used in a variety of technologies such as MEMS device fabrication, where sensor components are encapsulated within the application.

Other areas of application are in three-dimensional integration, advanced packaging technologies and CIS manufacturing. Within wafer bonding there are two main groupings, temporary bonding and permanent bonding, both of which play a key part in the technologies that facilitate three-dimensional integration.

The main techniques used in wafer bonding are:

- Adhesive
- Anodic
- Eutectic
- Fusion
- Glass Frit
- Metal Diffusion
- Hybrid
- Solid liquid inter-diffusion (SLID)

Adhesive bonding

Adhesive bonding utilises a range of polymers and adhesives to attach the wafers to one another. These polymers include epoxies, dry films, BCB, polyimides and UV curable compounds. Adhesive bonding is widely utilised throughout the microelectronic and MEMS manufacture industry as it is a simple robust and often low cost solution. A major advantage for their use is the comparatively low temperature for protecting sensitive components allowing compatibility with standard integrated circuit materials and processes.

Other advantages include the ability to join different types and materials of substrate together and insensitivity to surface topography. Additionally adhesive bonding can be used for both permanent and temporary wafer bonding. In an adhesive bond it is the polymer adhesive that bears the force needed to hold the two surfaces together and also distributes this force evenly across the substrate surfaces to avoid localised any stresses across the join.

Anodic bonding

Anodic bonding involves encapsulating components on a wafer within a glass layer. Anodic bonding allows the glass wafer to be bonded to the surface of a silicon wafer or other metal substrate without introducing an additional intermediate layer. Anodic bonding, sometimes referred to as field assisted bonding or electrostatic sealing, uses an external electric field to form the bond at the silicon/glass interface.

The anodic bond can be extended to three layers (glass-silicon-glass) through a process called triple-stack bonding. Here the layers are simultaneously bonded, enhancing both functionality and yield. To achieve a high quality anodic bond it is important to have clean planar wafer surfaces with a low surface roughness (<10 nm). Bond strength and quality can be further increased through the use of glass materials with a high number of alkali ions present such as borosilicate glass.

Eutectic bonding

Eutectic wafer bonding takes advantage of the special properties of eutectic metals. Similar to soldering alloys, eutectic metals melt at low temperatures, below the melting point of the substrates to be boned. This property of eutectic metals allows planar surfaces to be achieved at the bonded interface.

The most established eutectic bond system is between silicon and gold and is a well-established process for producing hermetic seals at low temperatures. In order to control reflow of the eutectic material, eutectic bonding requires precise dosing of the bonding force and even temperature distribution across the bonded stack. This helps to reduce any residual stresses within the bond that can lead to failure after excessive thermal cycling.

Fusion bonding

Fusion bonding refers to spontaneous adhesion of two planar substrates without the addition of any intermediate layer. This is also referred to as direct bonding and is a long established technique in the MEMS and semiconductor industry. There are a number of approaches to use fusion bonding to bond together silicon wafers; the common two methods are hydrophobic processing and hydrophilic processing.

In both cases, plasma pre-treatment of the surfaces significantly lowers the thermal requirements of the bond. This allows for some substrates to be bonded at room temperature. The plasma treatment generates an extremely clean that is free from any organic contamination. In hydrophilic bonding the prepared substrates are then covered with a thin layer of water and placed into contact. The bonding then takes place between the chemisorbed water. This bonding takes place at low temperatures or at room temperature. The bonded wafer stack is then annealed at elevated temperatures up to 1100°C.

In hydrophobic bonding the plasma pre-treated surface is given a coating to promote the formation of Si-F bonds It is then the van-der-Waals forces between the silicon, hydrogen and fluorine atoms present. As with hydrophilic bonding the wafer stack must be annealed at higher temperatures to complete the bond. Lower temperature bonding is possible for both processes but requires more complex pre-processing steps to ensure strong and uniform bond forms.

Glass frit bonding

Glass frit bonding, also known as glass soldering or seal glass bonding, is a bonding technique which uses an intermediate glass layer. A standard process involves screen-printing or spin-coating on glass frit layers onto the bonding surfaces. The two substrates are then brought into contact and heated until the glass frit transforms from a glassy paste into a glass layer. With an external pressure applied the glass fuses and bonds the desired substrates together. On cooling, a mechanically stable bond results. A variety of glass frits have been developed to lower the bonding temperature and also match the coefficient of thermal expansion (CTE) of the substrate materials.

Metal diffusion bonding

Metal diffusion bonding, sometimes referred to as thermo-compression bonding, uses two metals such as, Cu-Cu, Al-Al, Au-Au, to bond the substrates together. The metal diffusion bond is achieved by bringing the two metals into atomic contact and applying heat and force simultaneously. The bond is stuck together through the diffusion of metal ions from one substrate to the other. The use of metal diffusion allows two wafers to be bonded both mechanically and electrically in a single step. The technique is required for bonding in 3D applications such as 3D stacking

Hybrid bonding

Hybrid bonding is a bonding process that combines fusion bonding and metal diffusion bonding into a single process. The technique is based on a thermo-compression bond of two metallic layers with an integrated fusion bond.

In this process, a substrate with metal pads such as copper contacts and a dielectric layer can be bonded in a single process. First the dielectric is bonded at low temperatures using fusion or direct bonding process. When this is annealed at higher temperatures a metal diffusion bond occurs. The main application of the hybrid bond process is in advanced three-dimensional device stacking applications as well as CMOS image sensors.

SLID

SLID bonding (solid-liquid inter-diffusion) is based on the diffusion and mixture of different metals and ceramics. SLID bonding is also known as transient liquid phase diffusion bonding (TLPDB) and is used in a number of industries from microelectronics to the aerospace industry.

The underlying principle of SLID bonding is that at the interface between the two substrates to be bonded the materials diffuse across the boundary and change the composition of the interface locally. This change occurs in such a way that the interface can melt before the bulk of the bond material. The liquid interface then inter-diffuses resulting in a shift of the melting temperature and a solidification of the alloy at the bonding interface. The melting temperature of the alloy after bonding is very much higher than the bonding temperature and so solid bond is formed joining the two substrates together. This technique has seen much use in high temperature applications where a stable and uniform bond is required.