H-8-1(Invited)

Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp1200-1201

Low temperature bonding for 3D integration

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1. Introduction

Advanced methods for low temperature bonding are rerviewed and discussed in terms of the concept of the surface activation and the future outlook of their development in 3D integration. Currently, various techniques are used for interconnection and bonding, which include oxide bonding, anodic bonding, glass frit bonding, soldering, eutectic bonding, metal difusion bonding, ultrasonic bonding, adhesive joint and so on. However, high temperature required in these bonding process is one of the major bottlenecks of the conventional methods because of the degradation of the device reliability and manufacturing yield especially in the heterogenious integration consisting of dissimiar materials. The surface activated bonding(SAB) method has attracted an increasing interest due to its simple process flow, no need of additional materials for bonding, and the compatibility with CMOS technology [1].

2. Bonding methods

The conventional bonding methods and proposed surface activated bonding are compared in Fig. 1. These methods are classified as contact bonding methods, because they are used also for wafer bonding where no adhesive are used and physical contact between wafers are the prerequisite condition for bonding. The classical wafer bonding based on hydrophilic bonding requires in general high-temperature annealing ranging 800~1000ºC. Plasma activation using oxygen is a widely adopted solution for decreasing the annealing temperature lower than 400°C. However, the bond strength without annealing is still low and it is hardly to be adopted to bond metal surfaces directly. The process complexity of plasma activation followed by chemical cleaning is undesirable to MEMS packaging applications such as for preserving life cell species. Therefore, a room temperature wafer bonding method with simple processes is preferred.

We have proposed a modified method for room temperature bonding requiring neither annealing nor wet chemical cleaning processes in which a sequential processing of O_2 plasma treatment accompanied by N_2 radical or containing fluorine plama. This method is effective for bonding of Si and glass wafers, and the bonding is carried out at room temperature withi showing very strong bond strength close to the bulk-fracture toufhness of silicon.

On the other hand, the concept of the SAB is very straightforward, based on the fact that the atomically clean metal surfaces are so active as to form chemical bonds betwee them in contct even at room temperature. In this method, the two mating surfaces are activated by argon fast atom beam (Ar-FAB), or low energy Ar-ion beam bombardment, or plasma pretreatment in an ultra-high vacuum (UHV) background, which removes contaminant and absorbtion layers from the surfaces. It is expected that surface atoms are so energetically unstable and reactive to form chemical bond with the atoms on the other surface spontaneously even at room temperature. The reactivity is of course depending on the nature of the materials mated and their conbination. Si wafer bonding in UHV, whereas the local deformation of contact area in atomic level plays an essential role for achievement of ultimate contact between two surfaces.

A disadvantage of SAB was laid in its difficulties to bond ionic materials to each other, which include glass, sapphire and silicon dioxide. The reason of the incapability of SAB for ionic materials is still not clear but it was assumed that ionic materials surface is spontaneously polarized at different levels by means of ion beam bombardment which is use for surface activation prior to the bonding. In order to get rid of these difficulties, a new approaches for the modified SAB were developed. It is called "Bonding via nano-adhesion layer". In this approach, the wafers are bonded after activation with a modified hollow cathode Ar-low energy ion source capable of sputter cleaning and depositing Fe simultaneously on the wafers. Probably Fe thin layer or clusters shield the surface polarity of the ionic materials and therefore the wafers are bonded very strongly.

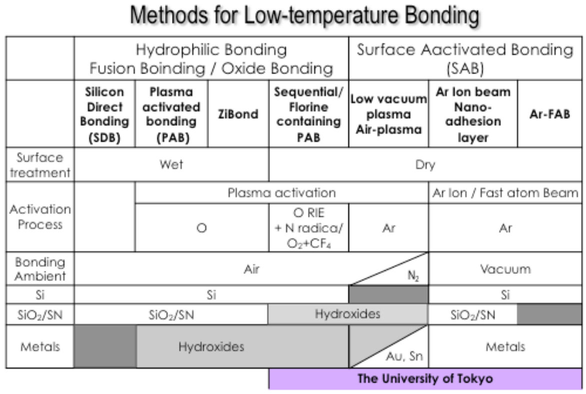

Fig. 1. Classification of the low temperature bonding methods.

3. A Roadmap of microbonding for 3D integration

A japanese consortium, Institute of Advanced Microsystem Intgration (IMSI), which was founded in 1998 in tend to promote R&D for next generation packaging technology by cooperation with academia. They published a roadmap of microbonding for 3D integration as Fig. 2. The key statements are that we would need a solid metal bonding for the bonding pitch below 20 μm, the room temperature bonding below 10 μm pitch, and bumpless interconnect structure below 5 μm pitch. The concept of bumpless interconnect is described in Fig. 3, and a demonstration of Cu-Cu direct bonding at room temperature for the interconnect of 6 μm pitch using SAB method is given in Fig. 4.

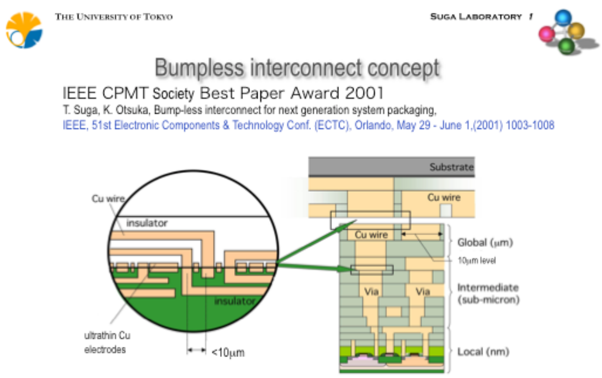

Fig. 2. Concept of bumpless interconnect, 2001 IEEE ECTC

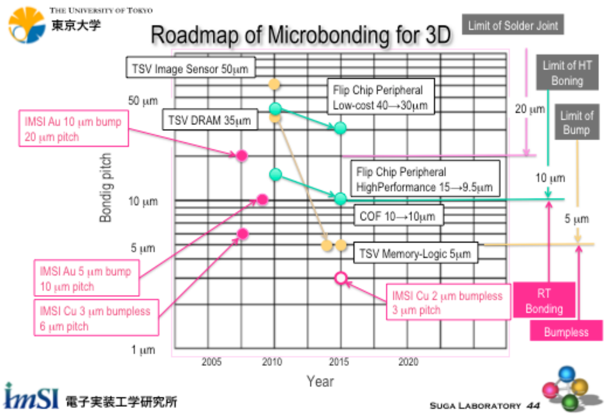

Fig. 3. Roadmap of microbonding for 3D integration by IMSI (2010).

build-up layer of high-density printed circuit board. Wafer bonding using SAB has also been put into mass production for certain sensor devices.

The possibility of the application of SAB in the ambient air was demonstrated on Au bump-Au substrate, AnSn bump-Au substrate, and SnAg bump-Au substrate, which are rather insensitive to oxidation. It was found that even a plasma treatment in low vacuum can activate such metal surfaces, removing the surface contaminations, and under certain circumstances, they can be bonded at temperature

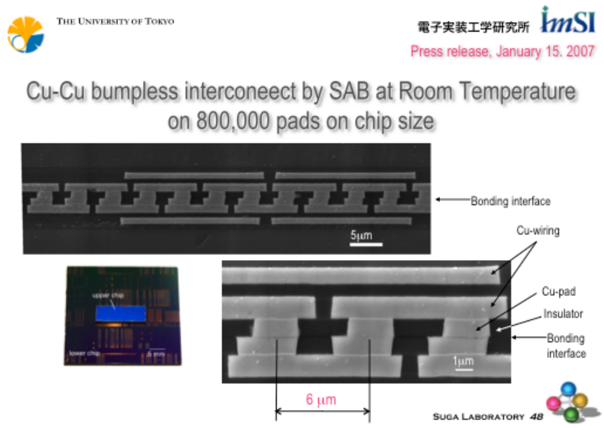

Fig. 4. Cu bumpless interconnects of 6 μm pitch bonded by SAB at room temperature.

lower than 150˚C. The contact pressure, the adjustment of the parallelism between chip and the substrate, and the surface roughness of the bump are critical factors for achievement of the bonding. Cu-Cu direct bonding was also possible in air when very careful treatment of the surface roughness and surface activation, forming thick hydro-oxide or thin oxide film at the interface depending on the conditions of the atmosphere. They might be reduced by anealing or failed by mechanical contact resulting in atomic contact with low electrical regisitance. The mechanism of the bonding in air is still uncler but migh be closely related to the interaction of the activated surface with water in ambient gas, providing a bridge to the hydrophilic bonding of semiconductor wafers.

Our recent work showed also bonding Si-Si can be done in Nitrogen atmosphere just after Ar beam irradiation. It depends again on a precise control of the water contents in the backgournd vacuum before Ar beam irradiation.

4. Concluding remarks

Introduction of the surface activation process is a consequence if one considers the nature of the solid surface to be bonded, and technologically a low temperature process is needed. The bonding process is not a single physical process but combined with inhomogeneity of the interface structures and properties. It is the reason why a precise control of the interface will be necessary to develop the conventional bonding process to an innovative technology.

Acknowledgements

We would like to express sincere thanks to the Institute for advance Micro-System Integration (IMSI) Japan for their financial support.

References

[1] T. Suga, *Technical Digest of 2nd International IEEE Workshop on Low Temperature Bonding for 3D Integration, Hongo, Japan, January 19-20,* (1999)