Low temperature Cu-Cu thermo-compression bonding for advanced micro-system packaging

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ABSTRACT

Low-temperature wafer-level Copper (Cu)-Copper (Cu) thermo-compression bonding has been an attractive choice in terms of its compatibility for microelectronics metallization and its lower cost. To achieve Low temperature Cu-Cu thermo compression bonding, copper oxide should be removed on the surface of the metal. In this paper, the effectiveness of the acetic acid pretreatment for removal of copper oxide before bonding is analysed. The thermo compression bonding is carried out at 250^{0}C for 1 hr followed by 30 min annealing. Further to find the quality of bonding, different characterization techniques are carried out such as dicing of wafers, bond strength test, and SEM analysis.

1. Introduction

The three-dimensional (3D) integration a plausible choice as the next generation of microsystem manufacturing technology. (3D) integration in a system-in-a-package implementation is increasingly using in computer, communication and consumer applications [1]. 3-D integration has advantages of small form factor, high performance, and high function density factor. 3DIC integration is typically achieved using various stacking options like Wafer-on-Wafer, Chip-on-Chip,and Chip-on-Wafer. Wafer-level 3D integration is to stack several thinned wafers by wayof Cu-Cu bonding. 3D integration of ICs using bump-lessCu-Cu bonding is an attractive choice because in a single step it will give both electrical conductivity and mechanical strength for multilayer stack. Metallic bonding also allows through silicon via (TSV) formation before bonding and vertical connection is established during bonding [2]. The copper is a mainly CMOS material [3]. Among the different bonding technologies, Cu-Cu bonding which is achieved using thermo-compression bonding at low temperature via parallel application of heat and pressure presents outstanding advantage. Cu readily gets oxidised when it exposed to air or oxygen ambient atmosphere. The quality of the bonding completely depends upon the interdiffusion of Cu atoms and grain growth across the bonding interface [4]. Where oxide layer acts as a barrier of inter diffusion. So before bonding of wafers the Cu oxide should be removed.

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Researchers have reported different ways to avoid Cu oxidation, Asisa Kumar Panigrahi et.al proposed a technique Cu -Cu Thermo-compression Bonding with Ti Passivation [5] but where Ti is also easily gets oxidised. C.S Tan et.al proposed a technique low-temperature Cu-Cu thermo-compression bonding by temporary surface passivation using a self-assembled monolayer of alkane-thiol [6] which protects the copper surface from oxidation. But this method is expensive and time consuming. Kim et .al proposed a technique Room temperature Cu–Cu direct bonding using surface activated bonding method [7] but this process consumes more time. K.N Chen proposed a chemical pre-treatment by using HCl acid [8] but it doesn't get desired bond strength.

In this paper, the effect of acetic acid pre-treatment of wafers before bonding is presented and results are analysed.

2. Experimental Protocol

2.1 Methodology

The thermo-compression bonding process flow is shown in Fig.1

The wafer used in this work is6-inch P-Type Si wafer. General cleaning (Acetone-IPADI water) was used for cleaning the wafers and dried with nitrogen. After the cleaning, a thin Titanium (Ti) layer is deposited followed by, 300 nm of Copper (Cu) by using a sputtering system as shown in Fig 2. Ti layer below the Cu acts as an adhesive layer between Si and Cu.

After sputtering of a thin metallayer, a wafer is diced into 25mmx25mm sized sample pieces. Again, the general cleaning of those diced pieces is carried out to remove the impurities present on the surface of the metal layer. Diced samples are treated with diluted acetic acid (95% Deionised water and 5% acetic acid) for 5 min at different temperatures 35^0C and 45^0C.

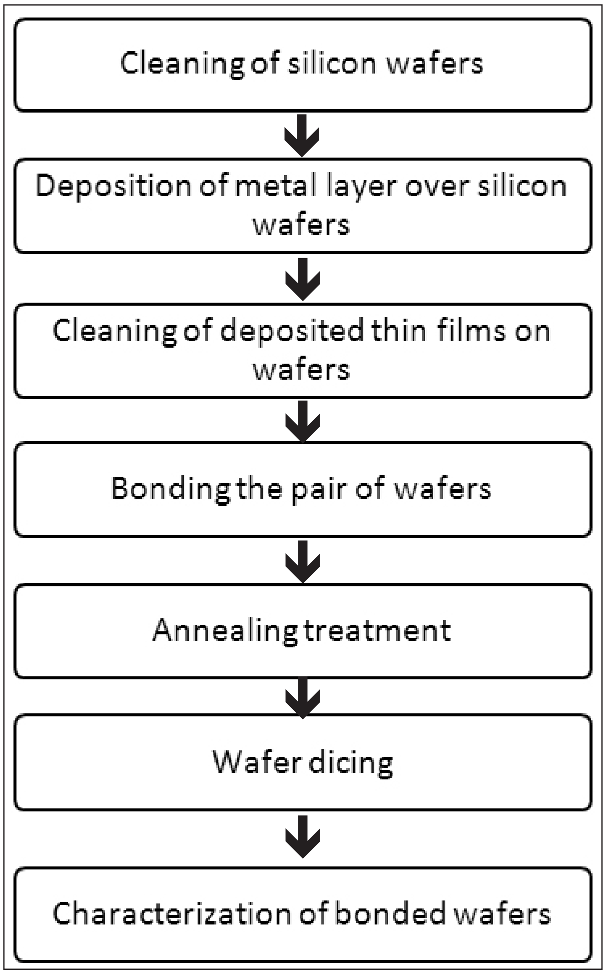

Fig. 1. Thermo-compression process flow chart.

Wafer bonding experiments are carried out in a wafer bonder model (Swiss Microtec SB Gen2) machine by keeping the acetic acid-treated samples face to face on the bond. The thermo-compression process is shown in fig 3. Then the wafers were heated up to 250^0C with a ramp rate of 20^0C with a chamber pressure of $1x10^{-3}$ torr. Once the temperature reached 250^0C, 1500m bar bonding pressure is applied for one hour followed by 30 minutes annealing under vacuum. Then the bonded samples were taken out from the bond chamber after cooling it down. Various characterizations are carried out to study the quality of the bonding.

3. Results and Discussions

Copper gets easily oxidised when it exposed to air or oxygen-ambient atmosphere. To stop further oxidisation the sample pieces are stored

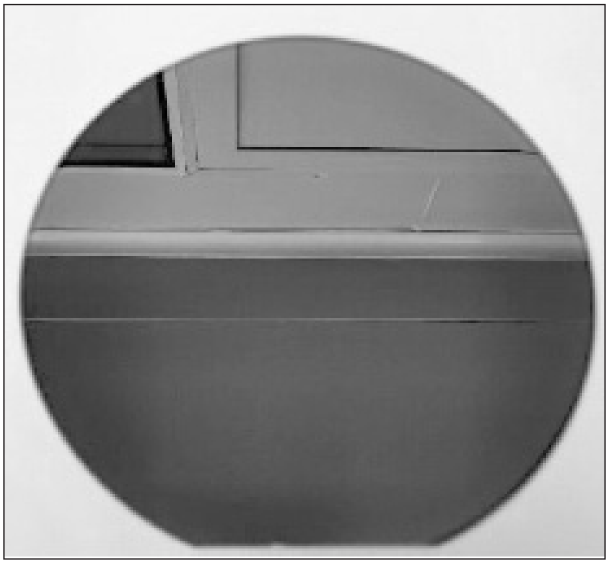

Fig. 2. Thin-film metal deposited 6-inch silicon wafer.

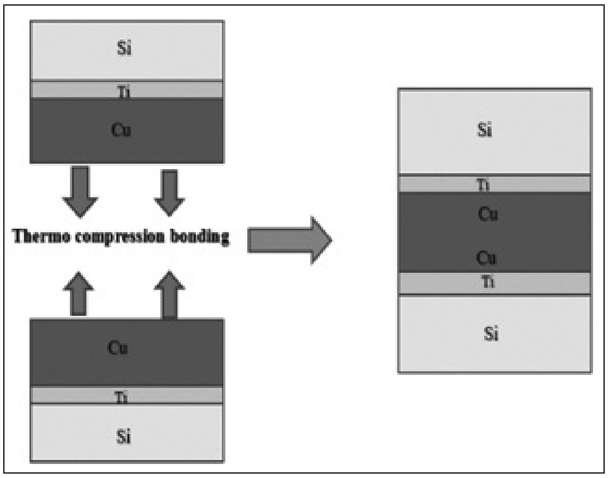

Fig. 3. Schematic diagram of thermo-compression bonding.

in a desiccator and a vacuum is created in the desiccator. The bonding strength completely depends upon the surface roughness and the thin copper oxide layer present on the Cu surface. To reduce the copper oxide layer, the samples are treated with acetic acid. the effectiveness of acetic acid was analysed by treating the samples with pre chemical acetic treatment at different temperatures 35^{0}C and 40^{0}C for 5 min. The etching process will be accelerated at higher temperatures. If the temperature is very high the copper surface will etch more, so optimum temperature selection is required. After chemical pre-treatment, the samples are dried up with Nitrogen gas to remove the impurities and to get clean surface and thermo-compression bonding is performed. The chemical equation is used to remove the copper oxide is

$$CuO + 2CH_3COOH \rightarrow Cu(CH_3COO)_2 + H_2O$$
$$Cu_2O + 4CH_3COOH \rightarrow 2Cu(CH_3COO)_2 + H_2O + H_2$$

In order to evaluate the bonding quality firstly the dicing should be carried out and followed by shear test. The SEM analysis is required to detect the gaps throughout the bonded interface layer so that the quality of the bonding can be understand.

3.1 Dicing of wafers

After thermo-compression bonding, the first step to perform is the dicing of bonded samples. The samples are diced into 10mmx10mm sized multiple pieces by using diamond blade cutting in a DAD3240 Disco Automatic Dicing saw machine as shown in Fig.4. So that proper cross-section with a good surface finish will get and further characterizations like bond test, SEM analysis will be carried out. During dicing the diamond blade will run with desired RPM and moves towards the sample. At this step, the minimum bond strength can be concluded. If the bonded samples are able to withstand with the dicing force by without debonding then it can conclude that the samples got minimum bond strength, if the samples are debonded during dicing then it can conclude the samples are not properly bonded.

In this experiment both the different bonded samples are diced into 10mmx10mm size and samples are didn’t debonded. So can be concluded that both samples got the minimum bonding strength.

Fig. 4. Bonded and diced sample.

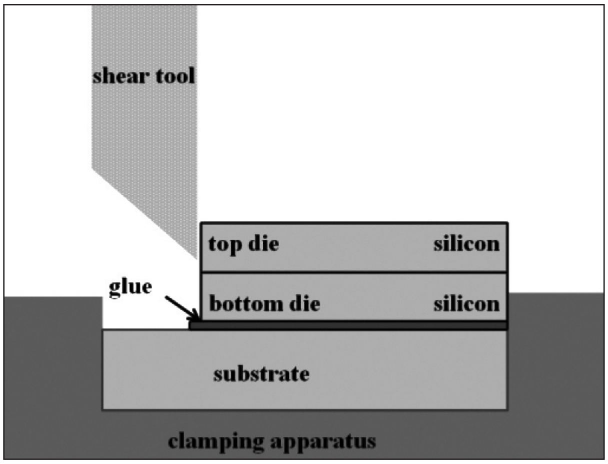

Fig. 5. Diagram for a bond testing process.

3.2 Bond strength test

The bond test is performed by using a bond tester machine. before testing the samples, the diced 10mmx10mm samples are attached to the flat substrate by using EPOXY Technology as shown in figure 5. The bonding interface must able to withstand the external force. The die shear force is applied to calculate the shear strength. The load should be applied on the top wafer horizontally and load will increase gradually till the fracture is observed. At the point fracture starts the load should be noted and shear strength should be calculated.

$$Shear\ stress = \frac{Force}{Cross\ sectional\ area}$$

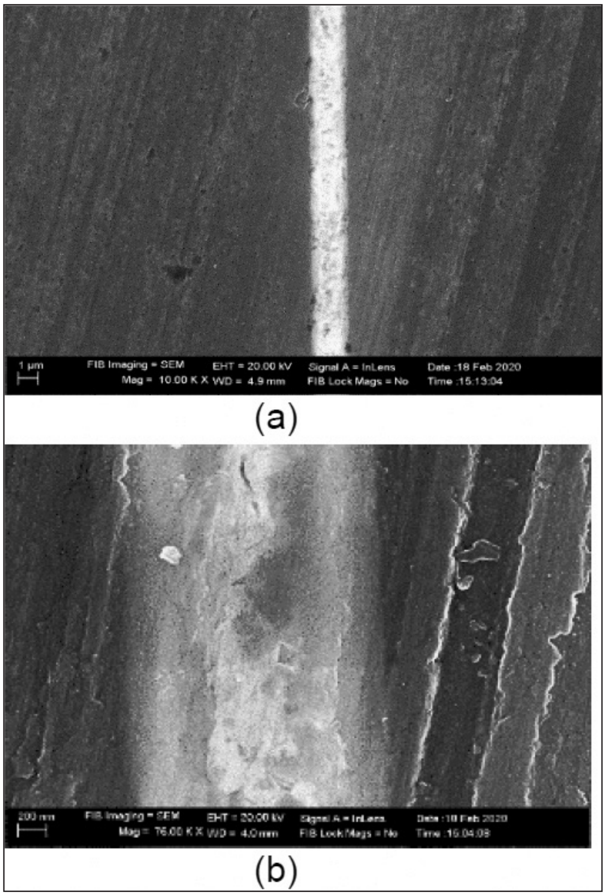

Fig. 6. Cross-sectional SEM images of Acetic acid treated sample at 35^0C and bonded (a)10 KX magnification (b)75 KX magnification.

In this experiment, the bond strength of the acetic treated sample at 35^0C withstand the load of about 53.84 kgf and the bonding strength is 81.2 Mpa, the fracture observed in between the bonding interface. For the acetic treated sample at 40^0C the load exceeded the testing range and load about 70.39kgf with bond strength 106 Mpa and no fracture is observed. The shear strength got in these experiments are comparable with the literature which indicates good bonding strength.

3.3 Scanning Electroscopic Microscopy (SEM) analysis

The SEM analysis is carried out at the cross-sectional area of the diced bonded samples. from Fig.6 and 7 both the bonded samples are not showing any intermediate layer at the bonding interface. This indicates proper interdiffusion of Cu atoms throughout the interface is taken place and the original interface line is disappeared. So that the good bonding is achieved. SEM images of bonded samples are shown in fig.6 and 7.

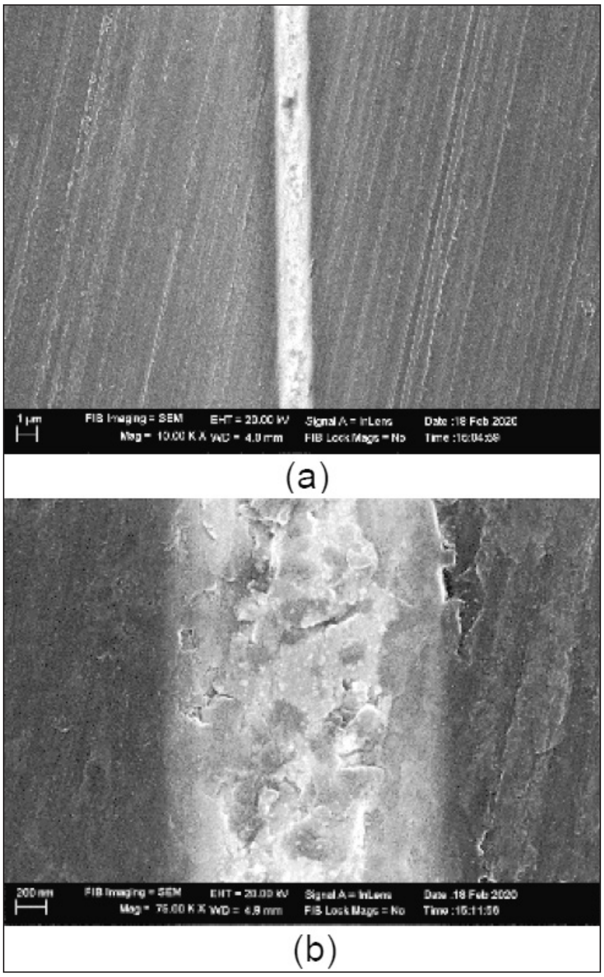

Fig. 7. Cross-sectional SEM images of Acetic acid-treated sample at 40^0C and bonded (a)10 KX magnification (b)75 KX magnification.

4. Conclusions

The effectiveness of the acetic acid is analysed by treating the samples with acetic acid at different temperatures 35^0C and 40^0C for 5 min. Different characterization techniques are carried out such as dicing of wafers, bond test, and SEM analysis. The desired bond strength 106 Mpa is achieved by treating the samples at 40^0C for 5 min and low-temperature thermo compression bonding is achieved at 250^0C.

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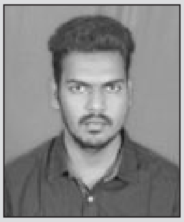

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