Low temperature anodic bonding process with silicon-gold-glass interface for wafer level packaging applications

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KEYWORDS

Die Shear,
Stud Pull,
Anodic Bond,
Ohmic Contact.

ABSTRACT

In this paper, anodic bonding technique at low temperatures with Si-Au-Glass interface has been demonstrated. Also, the techniques to overcome the challenges like gold diffusion/spreading and non-ohmic contacts has been demonstrated. The bond strengths of the anodic bond process is verified through die shear and stud pull tests and observed a good quality bond strength which is better than 10 times in die shear test and 20 times in stud pull test when compared with MIL-Standards.

1. Introduction

This Wafer bonding is a crucial technology for device integration in various areas of micro-electromechanical systems (MEMS), microelectronics and optoelectronics [1]. Fabrication of micro-transducers and Microsystems is made possible through various silicon wafer bonding techniques. Wallis and Pomerantz in 1969 first introduced Anodic bonding technique, which can produce strong bond [2]. Anodic bonding can function for the establishment of a hermetic and mechanically solid bond between glass and semiconductor wafers [3–6]. Merits like low bonding temperature, quick response, and good sealing performance are the reasons for choosing anodic bonding. Anodic Bonding is also referred as field assisted glass-silicon sealing or electrostatic bonding at elevated temperatures. Exclusive of intermediate layer, anodic bonding is a technique that can produce hermetic sealing between silicon and glass substrates. Borosilicate glass with high alkali ion concentration is a necessity for this process [7]. In anodic bonding, the substrates are heated to a typical temperature of 400–450°C. A typical voltage of 400–1200 V is applied to the wafer pair to be bonded [8]. In this paper, low temperature anodic bonding techniques, challenges and their results will be discussed in the subsequent sections.

2. Motivation

Aim is to have a glass wafer which is having gold pattern and appropriate silicon wafer having MEMS device structure. These two wafers are intended to have anodic bonding without affecting the gold layer. In many devices, where anodic bonding with gold interface is present, we have observed issues like gold diffusion, alloying and non-ohmic contact problems. Goodness of the wafer bond is evaluated by measuring the shear and stud pull strengths as well as the integrity of ohmic contact behavior of gold to the silicon after bonding. In this work, low temperature bonding technique is presented through which above-mentioned issues are mitigated.

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3. Procedure

Six-inch Glass wafer and Silicon wafers are chosen for experimentation. Glass wafer (Pyrex 7440) and P type silicon wafer with a thickness of 1 mm and 675micron respectively are chosen. Glass wafer is patterned with gold pads, this process is achieved through coating, exposure and development of liftoff resist/photo resist as per standard lithography techniques and made a pattern of gold pads using e-beam gold deposition (1µm) and acetone lift off. The dimensions of Gold pads are 3X3 mm^2 with a pitch of 10mm as per the Fig 1.

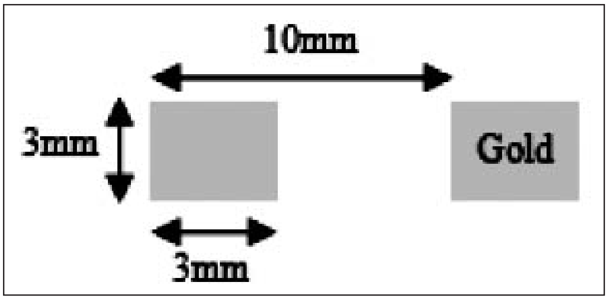

Fig. 1. Gold pads dimensions and pitch.

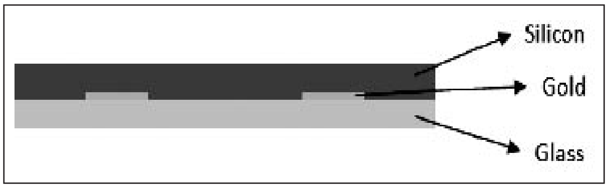

Fig. 2. Cross sectional diagram of bonded wafer.

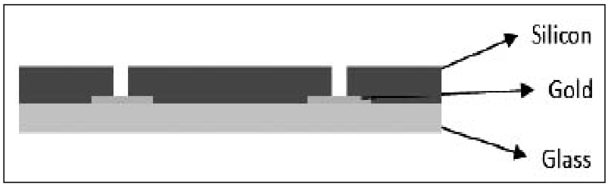

Fig. 3. Cross sectional diagram of bonded wafer with DRIE holes for probing.

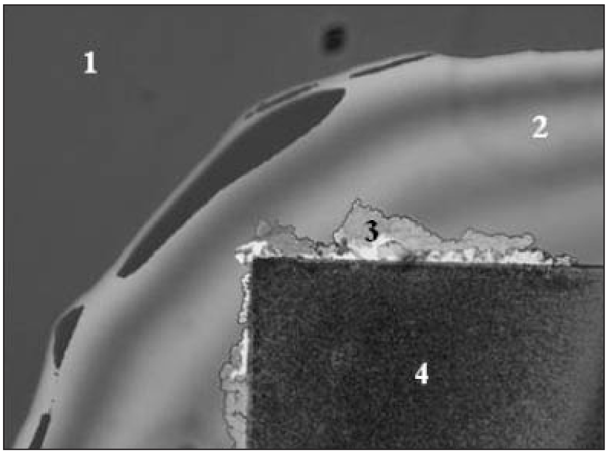

Fig. 4. Different areas of anodic bonding.

Silicon and glass wafer with gold pads are pre-treated with H_2SO_4+H_2O_2 (3:1) prior to anodic bonding. Suss bond aligner is used for wafer bonding process. Typically for anodic bonding we use 390ºC and 1000V for better bond strength results. A schematic for post-bonded structure is shown in Fig.2.

In order to know the ohmic contact nature of the gold pads, Silicon samples are heavily doped on the surface and holes are made in back side of the silicon with DRIE. These holes are used for probing and testing. The cross section of the through Si holes are shown in Fig.3.

4. Results

4.1 Gold spreading improvement

The low temperature anodic bonding experiments are started with 390ºC standard temperature, then with 340ºC recipe which improved the gold spreading and diffusion problems and finally with 320ºC recipe where we found the best results. The detailed bonding recipe for the above-mentioned recipes are shown in Table 1.

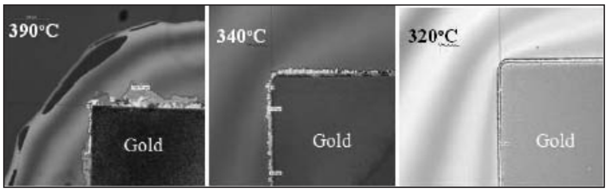

Fig. 5. Gold spread comparison at temperatures 390°C, 340°C and 320°C.

Table 1
Recipe used for anodic bonding.

Temperature	Vacuum	Time	Voltage
390°C/340°C /320°C	1E-4 mbar	Until fall of 2%Imax	1000V

Table 2
Comparison of gold spreading and fringe length in between 3 recipes.

Anodic Bonding	@390°C	@340°C	@320°C
Length of Gold Spreading (max)	132µm	11µm	4µm
Fringe length	585µm	580µm	501µm

Where Imax is the peak current during the bonding which is produced due to alkali elements present in the glass. Gold spreading, diffusion or alloying issues are more predominant at higher temperatures. In Fig.4. shows the post bonded structure of gold bonds. Here, 390ºC temperature recipe is used. There are 4 main important areas to be noted from Fig.4. They are 1. Bonded area, 2. Fringe area (may be partially bonded area), 3. Gold spreading and 4. Gold pad.

Fringe area, i.e., may be partially bonded which is due to the undulations created by gold interface. As gold alloying temperature is 363°C, the gold spreading can be because of the higher temperatures. Hence, lower temperatures of 340°C and 320°C is experimented for bonding. Compared to 390°C bonding recipe, 340°C has improved in gold spreading and in 320°C recipe gold spreading is negligible. Comparison of microscopic images of gold spreading between different temperatures is shown below in Fig. 5 and Table.2.

The dimension values of gold spreading and fringe areas are tabulated and compared in the Table 3. The readings are taken from the microscopic images.

4.2 Shear and pull strengths of 10X10 mm^2 dies

To determine the bond strength of the three processes, we have treated the samples with bond shear and stud pull tests. The samples were symmetrically diced into uniform squares of size 10X10mm^2, in such a way excluding the middle gold square for 10X10 mm^2 as shown in Fig. 6. So, bond area is 91mm^2 (or 0.1410 in^2). The test results of die shear strength are as per the Table.3. The table explains the epoxy to which the die is attached, has lifted off during the die shear test which implies the die strength is superior. Two samples from each process condition is are tested and named (a & b). According to MIL standards MIL 883E method 2019.5, bond area >64X10^{-4} in^2 should have a minimum strength of 2.5Kgf. As evident from Table 3, shear strength values of our samples are at least 40X higher than the required MIL standards and suggests good bond quality. The die images after shear test are shown in Fig.6. On the back side of the die the rough surface is the epoxy, which has been lifted off during die shear strength process shown in Fig.6.

Similarly, for the stud pull test, the dies are attached to epoxy on both sides. Later on, the pull test is performed on the die. The results of stud pull test are mentioned in Table. 4.

Here, although the die was broken, the Silicon glass bond did not get separated. In Fig. 7. first image is the stud attached to the die after stud pull test and second image is the residues of epoxy on the die attach. Here, in stud pull test also good quality of bond strength is achieved. Physical analysis of post tested samples in both stud pull and shear strengths tests. indicates that die attach epoxy is weaker than the anodic bond. Hence, the epoxy lifted off in both the cases.

4.3 Shear and pull strengths of 5X5 mm^2 dies

In the above experiments for 10X10mm^2 dies, we found a very good quality bond strength. In order to find out the limits of the bond strengths the die size has been decreased to 5X5mm^2. So the bond area would become 16mm^2 (0.0248 in^2) which is excluding the gold pad area. Die shear strength tests are conducted on these samples. The results of die shear are shown in Table.5.

From Table.5. we can see the shear strength is around 23 Kgf. As mentioned earlier the MIL-STD-883E, method 2019.2 states bond area >64X10^{-4} in^2 should have a minimum strength of 2.5Kgf.

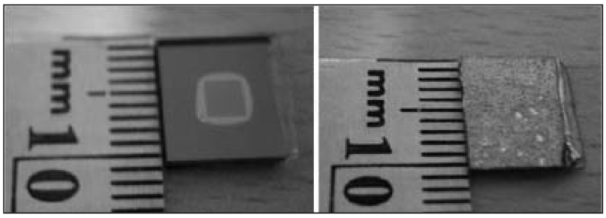

Fig. 6. Die state after shear strength test.

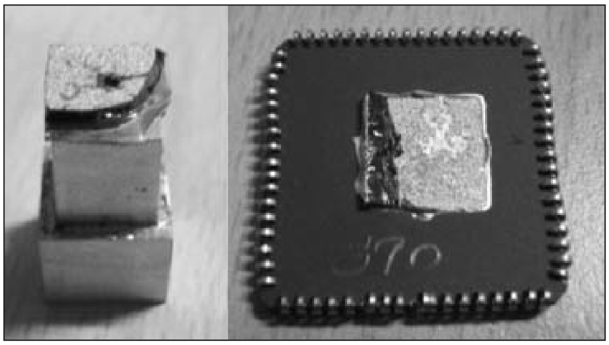

Fig. 7. Die state after stud pull strength test.

Table 3
Comparison of Die shear strength for 10X10 mm^2.

Temperature	Die Shear Strength(Kgf)
320°C	>115
340°C	>107
390°C	>108

Table 4
Stud pull strength of 10X10 mm^2 dies.

Anodic Temp.	Stud pull Strength (Kgf)
390°C	>33.8
340°C	>24
320°C	>30.3

Table 5
Shear strength of 5X5 mm^2 dies.

Sample	Temp	Shear Strength in Kgf
1(a)	320°C	23.04
1(b)	320°C	24.03
2(a)	340°C	23.44
2(b)	340°C	17.35
3(a)	390°C	23.44
3(b)	390°C	24.42

Table 6
Stud pull strength of 5X5 mm^2 dies.

Sample	Temp	Stud pull strength in Kgf
1(a)	320ºC	4.62
1(b)	320ºC	4.74
2(a)	340ºC	3.36
2(b)	340ºC	5.24

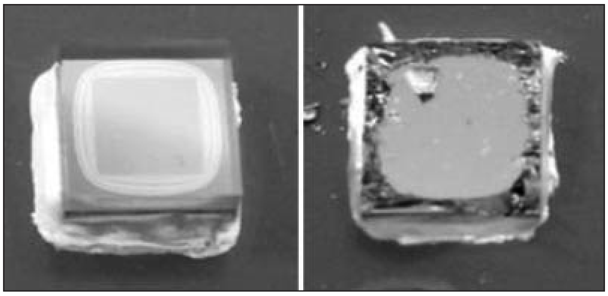

Fig. 8. Die state before and after the shear strength test.

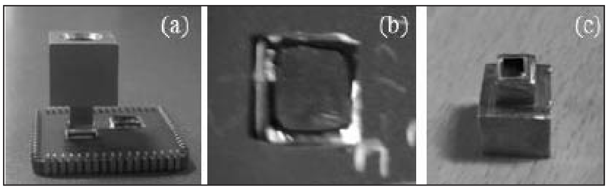

Fig. 9. (a) Before stud pull test (b) Silicon surface after stud pull (c) Glass surface after stud pull test.

Fig. 10. Bond strength test equipment.

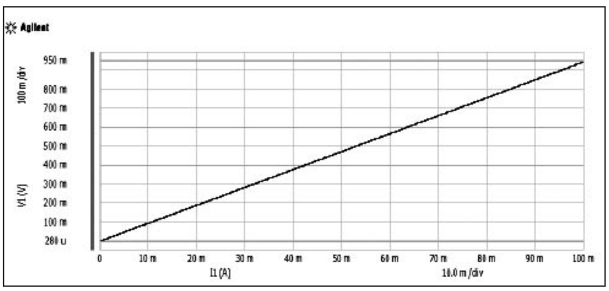

Fig. 11. I-V characteristics of the dies.

So, we have achieved around 10 times better bond strength than MIL-Standards. Similarly, for 5X5 mm^2 die, stud pull test is performed and following results are achieved as in Table.6.

According to the MIL-STD-883, method 2027, bond area of 16mm^2. i.e., 0.0248 in^2 the minimum bond strength should be 0.167Kgf for 1X. Our case, is in compliance with 1X because as per MIL-STD 1X case will be applicable as there is an evidence of attachment at the interface at the die attach medium. So, going with 1X case, the stud pull strength is more than 20 times better to the MIL-STD. This shows the good quality of the bond even at smaller bond areas.

The evidence of bond attachment in stud pull test for 5X5 mm^2 die is shown in Fig. 9(b). the bond strength test like shear and stud pull are measured with tool "ROYCE 650 bond test manager" which is shown in Fig.10.

4.4 Ohmic contact test

For the ohmic contact test, Silicon wafers are implanted with phosphorus at dose 7E15 and energy of 70KeV and 1mm X 1mm DRIE through holes are made for probing as mentioned in procedure section in Fig.3. Remaining operations of bonding are identical. Bonding at 390ºC has low yield of ohmic nature. Whereas for 320ºC, the yield of ohmic nature has increased. Most of the dies with ohmic nature, has linear I-V characteristics. Fig.11. shows the linear characteristics of I-V graph when current forced from 0 to 100mA.

5. Conclusion

In summary, anodic bonding at different low temperatures like 340ºC and 320ºC are experimented and found improvement in the problems like Gold spreading, diffusion and non-ohmic contacts. Also, these anodic bonding recipes are characterized through bond strengths test like stud pull and die shear tests. For 10X10mm^2 dies, bond strength is extremely good, even in bond tests the epoxy has lifted off but the anodic bond is intact. To check the limits of the bond strength, a smaller die size of 5X5 mm^2 is made and found shear strength is 10 times and stud pull test is 20 times better than MIL standards which shows a good quality bond strength.

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7. References

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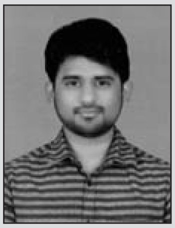

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