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Study on the Glass Silicon Anodic Direct Bonding Parameters

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Abstract

By MEMS packaging test platform for bonding process of bonding temperature and bonding time, and test silicon specifications experimental study. Experimental results indicate that when the bonding voltage of 1200V, bonding temperature of 445^{0}C to 455^{0}C, bonding time is 60s, the void fraction is less than 5%. Glass and silicon wafer bonding quality can achieve the best. The experimental results in order to improve the glass silicon bonding quality provide the basis.

***Keywords**: Glass-Si bonding, MEMS, Encapsulation, Void fraction*

1 Introduction

Micro Electro Mechanical System (MEMS) is a micro mechanical element, micro-sensor, micro-actuator, signal processing and control circuit integrated in one of the micro system. Direct bonding technology is between two wafers without an intermediate layer, using anodic bonding manner directly bonded [1]. Silicon and glass is the most commonly used material is directly bonded with a low reaction temperature and high bonding strength advantages. Glass and silicon direct anodic bonding is an important step in the process of micro sensor package. Package quality affects directly the performance and the reliability of the sensor.

Void fraction is one of the important parameters to characterize the glass silicon anodic bonding quality. The definition of void ratio: empty area did not occur bonded percentage of the total area of the wafer on test interface. The expression as

$$V_{\mathrm{w}} = S_V / S_W \tag{1-1}$$

In the expression, V_{m} is Void fraction. S_{v} is the total area of voids, S_W is The total area of silicon.

There are many main factors that influence the anodic bonding quality. Generally believe that, Bonding temperature controlled at 300-500^{0}C more appropriate. In this temperature range, the conductivity of the sodium ions have sufficient migration rate. More than 500^{0C}, it will result in a silicon microelectronic process certain materials (such as aluminum) failure and incompatibility with other micromachining. The recommended applying a voltage is between 200V-1200V in general, the range is wide, depending on the specific glass material properties and the selected bond temperature to decide. With the increase of applied voltage, the migration rate of conductive ions increases, the time required to attain equilibrium is shortened, namely complete bonding time reduction. When the bonding temperature exceeds 300^{0}C, due to the thermal expansion coefficient of the glass and silicon will vary, the higher the temperature, the greater the change. While the bonding temperature is too high, not only cause large residual stress, resulting in the glass itself burst, seriously affect the rate of bond synthetic products, thereby increasing its packaging costs, but also leads to the structure and properties of the existing parts is changed, and even to produce deformation, makes the bonding quality decreased. While the bonding temperature is too low, bonding strength and low efficiency step down, the bonding surface bubbles and voids are also difficult to reduce or eliminate. Therefore,

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the bonding temperature has a great influence on the quality of the bonding. Under the premise of quality assurance bond, lower bonding temperature is important.

2. Test Program

2.1. Test Equipment

MEMS package test platform is mainly used for packaging materials clean dry environment. The main structure includes Tray feeding mechanism; manipulator automated handling module; furnace combination; trays clamping motion mechanism; microscopy; Trays out of the feeding mechanism etc.

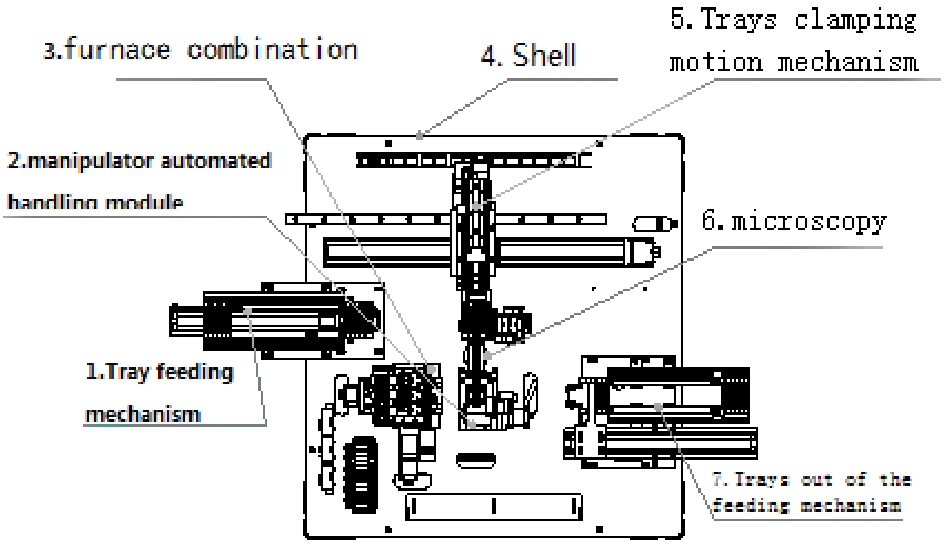

Figure 1. Structure diagram of MEMS package test

2.2. Test Material

Basic performance BF33 glass

Excellent transparency, low fluorescence intensity and high ultraviolet and infrared transmittance

1) Extremely low coefficient of expansion, thermal shock resistance and long-term working temperature up to 450^0C.

2) Excellent chemical stability, have a high degree of corrosion resistance to water, acids, alkalis, and organic substances

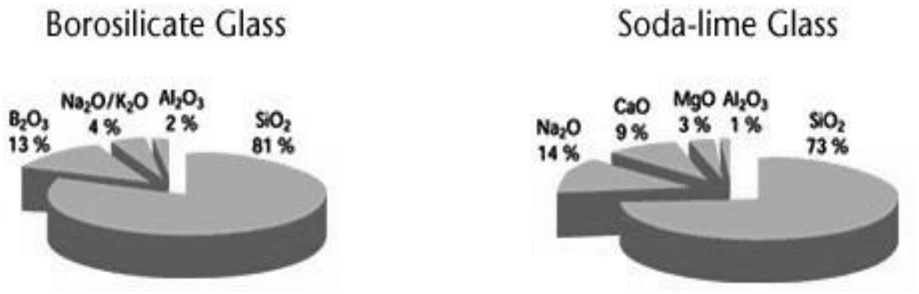

Figure 2. Soda-lime glass and borosilicate glass composition comparison chart

Table 1. BF33 Glass Technical Parameters

Technical parameters	values
Density （25^{0C}）	$2.2g/cm^2$
Coefficient of expansion (ISO 7991)	$3.25*10^{-6k-1}$
Transmittance	91%
Softening Point	820^{0C}
Short-term use	550^{0C}
Long-term use≧10h	450^{0C}
Index of refraction （587.6nm）	1.47140
Knoop hardness	480

In this paper, a square monocrystalline silicon thickness of 0.5mm, a side length of 4mm, resistivity of 0.01-1 (Ω • cm) and a thickness of 2mm, a diameter of 10mm BF33 annular glass. Normal circumstances, the silicon wafer surface have oxide layer, and dust and other magazines, before bonding the silicon wafer and the glass must be cleaned with alcohol.

2.3. Test Procedure

1）Start the software and initialize; 2）Press the "heating" button and wait for the heating to a predetermined temperature; 3）put glass and silicon into the feed tray; 4）Click "Start", the system automatically starts the handling and bonding; 5）Observing the test results，Calculate the porosity. Complete test with different parameters.

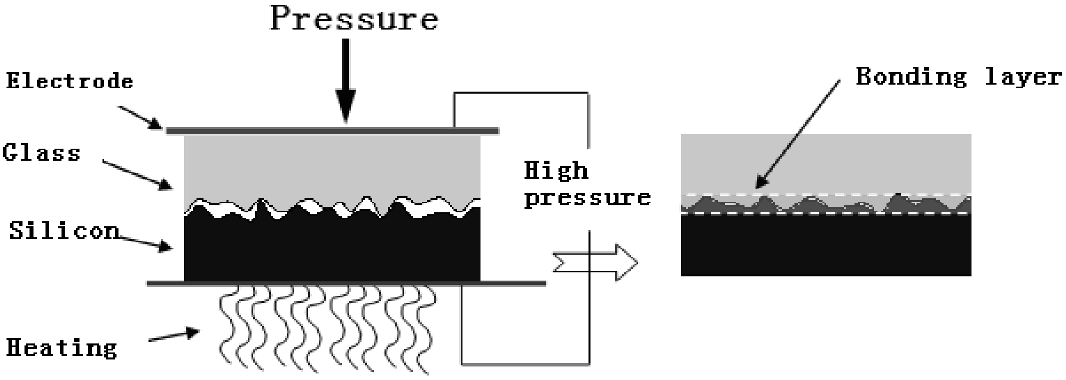

Figure 3. Schematic diagram of bonding principle

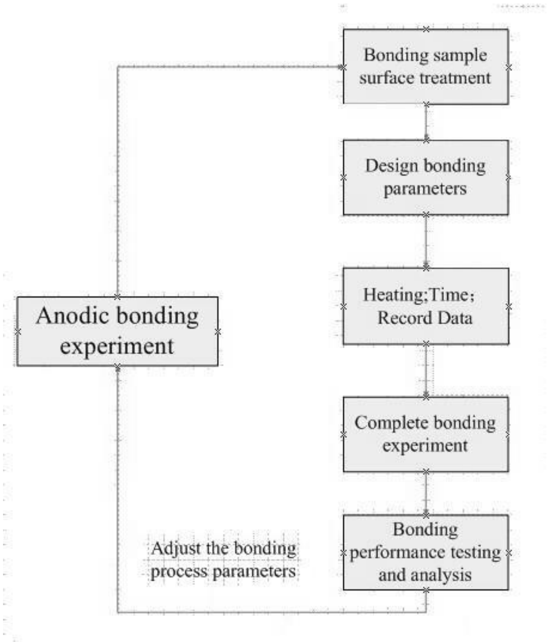

Figure 4. Fabrication process of MEMS package test

3. Analysis of Test Results

3.1. Effect of Bonding Temperature on Bonding Current and Bonding Quality

Glass wafer bonding temperature is generally chosen between 300-500^{0}C, and applied a DC high voltage (approximately 1000V). The range of heating temperature is large. In order to explore the optimal bonding temperature, setting this experiment bonding temperature is 395^{0}C--485^{0}C, and through the Hall sensor installed in the furnace, detected bonding temperature, voltage, current. After the bonding is completed, the glass and the wafer is separated, bonding conditions were observed with a microscope, and calculated the void fraction.

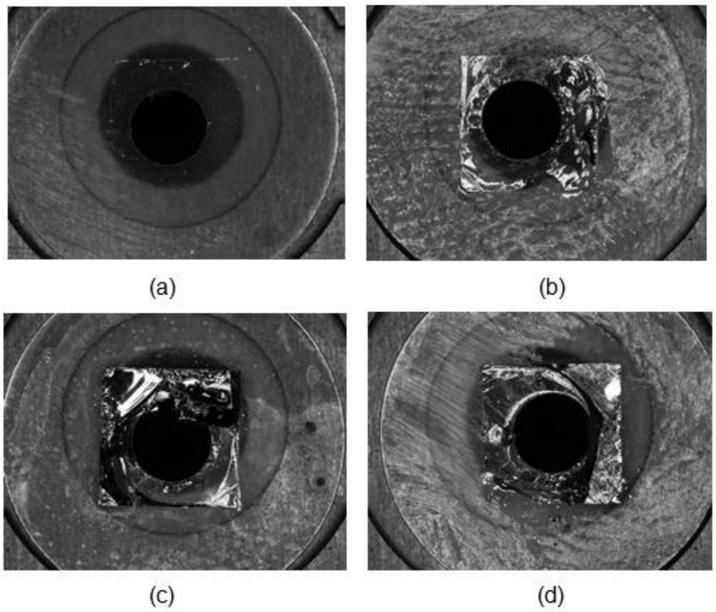

Figure 5. Microscope diagram of glass surface bonding

Figure a, b, c, d was observed by microscope bonding results for the bonding voltage 1200V, bonding temperatures of 395-405^{0}C, 425-435^{0}C, 455-465^{0}C, 465-475^{0}C, the bonding time is 60S. The damaged area and the residual silicon area of Glass surface in those figure is occurrence of bonded area. The glass surface without damage area is no occurrence of bonded area. According to the calculation formula of void fraction (1-1), bonded to the void ratio was calculated at different temperatures, and the results in the following table.

Table 2. Bonding void fraction of 395^{0}C-485^{0}C temperature

Sample	Specification	Pressure	Time	Temperature	Voltage	Void fraction
1	4X4X0.5	1N	60s	395-405^{0}C	1200V	≧95%
2	4X4X0.5	1N	60s	405-415^{0}C	1200V	79.17%
3	4X4X0.5	1N	60s	415-425^{0}C	1200V	43.75%
4	4X4X0.5	1N	60s	425-435^{0}C	1200V	33.33%
5	4X4X0.5	1N	60s	435-445^{0}C	1200V	16.67%
6	4X4X0.5	1N	60s	445-455^{0}C	1200V	≦5%
7	4X4X0.5	1N	60s	455-465^{0}C	1200V	≦5%
8	4X4X0.5	1N	60s	465-475^{0}C	1200V	≦5%
9	4X4X0.5	1N	60s	475-485^{0}C	1200V	≦5%

The experiments indicate that the void ratio would be gradually increased as the temperature gradually decreases. At 445-455^{0}C, the porosity reached 5% or less. (It show that the bonded area has reached more than 95%, the bonding quality is very good). As the temperature continues to rise, the void ratio remains below 5%.

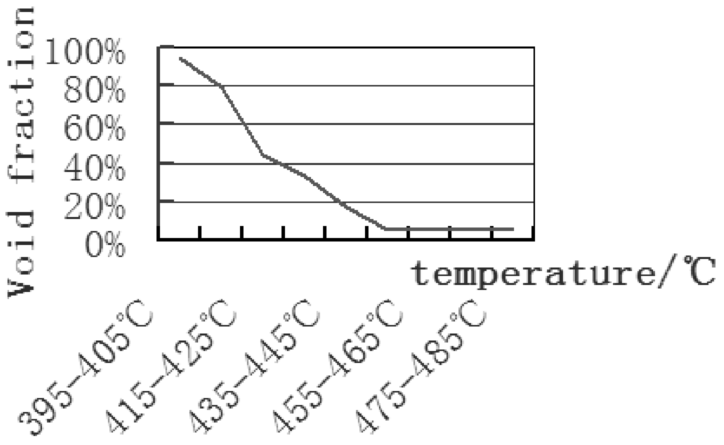

Figure 6. Distribution diagram of 395^{0}C-485^{0}C temperature bonding void fraction

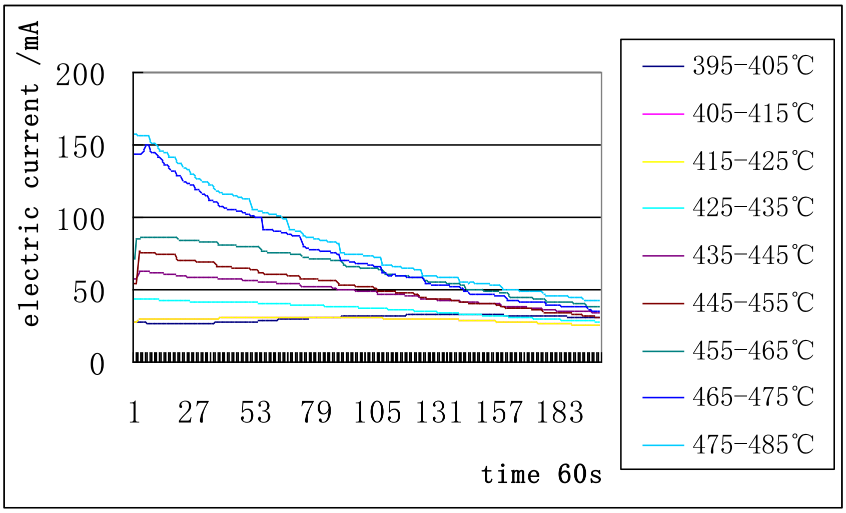

Figure 7. Distribution diagram of 395^0C-485^0C temperature bonding electric current

Observation of the bonding current distribution at different temperatures, as the temperature increases, the higher the temperature the greater the initial current bond. When bonding begins, the current changes, but eventually dropped to about 20-40mA, surface bonding is completed. By analyzing the porosity ≦ 5% of the current data discovery, improve quality requires a minimum of stability current 70mA, bonding quality will be increased.

3.2. Effect of the Bonding Material Specifications for Bonding Quality

Since the bonding of silicon and glass used in the specifications are very small, restricted package structure, bonding the silicon wafer size also have an impact on the quality of the package.In order to explore the relationship between material specifications for porosity, different sizes of silicon wafers were bonded to the test, the test results in the following table.

Table 3. Bonding void fraction of different specifications of silicon wafer

Sample	Specification	Pressure	Time	Temperature	Voltage	Void fraction
1	8mm^2	1N	60s	445-455^{0}C	1200V	50%
2	6.5mm^2	1N	60s	445-455^{0}C	1200V	66.67%
3	6mm^2	1N	60s	445-455^{0}C	1200V	83.33%
4	4.5mm^2	1N	60s	445-455^{0}C	1200V	≧95%

As can be seen from the table 3, the size of bonding silicon wafer so closely related to void fraction. When the silicon-bonded area gradually decreases, the void fraction increases, the bonding quality decreased. Because the pressure plate area for applying the bonding pressure is far greater than the silicon area, when the silicon area is 4.5mm, void ratio as high as 95%, the bonding quality is low.

3.3. Effect of Bonding Time for Bonding Quality

In order to study the influence of bonding time on the bonding results, set the bond voltage 1200V, the temperature of 445-455^{0}C, the contrast test of bonding time 20s, 30s, 40s, 50s, 60s, 120s, 180s. From the void fraction distribution curve can be seen from the table 4, bonding time is larger than 60s, bonding voids ratio is less than 5%, the bonding quality is better. Therefore, in order to improve the bonding efficiency, reduce the bonding energy consumption, bonding time is generally controlled at 60s.

Table 4. Bonding void fraction of 20s-180s

Sample	Specification	Pressure	Time	Temperature	Voltage	Void fraction
1	4X4X0.5	1N	20s	445-455^{0}C	1200V	18.75%
2	4X4X0.5	1N	30s	445-455^{0}C	1200V	8.33%
3	4X4X0.5	1N	40s	445-455^{0}C	1200V	7.29%
4	4X4X0.5	1N	50s	445-455^{0}C	1200V	6.25%
5	4X4X0.5	1N	60s	445-455^{0}C	1200V	≦5%
6	4X4X0.5	1N	120s	445-455^{0}C	1200V	≦5%
7	4X4X0.5	1N	180s	445-455^{0}C	1200V	≦5%

5. Conclusions

Tests showed that the use of MEMS package test platform can improve the accuracy of the manipulation of the packaging process, the accurate control of the bonding temperature, bonding time, and the pulse voltage. Quality bonding depends on the bonding temperature, material specifications, bonding time, and craftsmanship. Tests showed that the applied voltage of 1200V, the bonding time is 60s; the bonding temperature of 445-485^{0}C, the void fraction of 5% or less can achieve good bonding quality. The silicon wafer has bonding specifications smaller, the greater of the void fraction. Bond length of time has little effect on the bonding quality. After reaching the minimum stable current bond, bonded completed within time soon. Through theoretical analysis and experimental research confirms that control bonding temperature and bonding time can improve the efficiency of industrial production.

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