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Bonding Heating Control Based on PID

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Bonding Heating Control Based on PID

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Abstract. In the process of chip production, the bonding machine, as the post-process of chip manufacturing, is a key process to determine the chip productivity and quality. The process of wafer bonding usually involves heating silicon wafer, glass backing and other materials to a certain temperature in a vacuum environment, applying a certain pressure, and bonding for a certain period of time. In the bonding process, the time to heat the material to the specified temperature accounts for about 20% of the whole bonding process. Therefore, shortening the heating time has a great effect on improving the yield. In addition, in the process of heating and pressure, improving the heating stability, reducing the temperature oscillation, can reduce the material deformation and improve the bonding accuracy. In this paper, the intelligent temperature control system based on PID is adopted to control and adjust the bonding heating in real time, so as to shorten the heating time, reduce heating control oscillation, improve the heating effect, and improve the yield and yield.

1. Introduction

Wafer is the carrier used in the production of integrated circuits. Its shape is round, so it is called Wafer. Since the birth of the first integrated circuit in 1958, silicon technology has dominated the production of integrated circuits. Silicon wafers are the basic materials for making semiconductor chips. With the continuous improvement of integrated circuit requirements, Other semiconductor materials are also increasingly being used, such as germanium, gallium arsenide, silicon carbide. Bonding can bond two or more materials (or structures) into a whole, which is an indispensable important link in the semiconductor manufacturing process[1]. Wafer direct bonding allows polished semiconductor wafers to be bonded together without the use of a binder.

Under certain conditions, two wafers with smooth and clean surfaces can bond with each other through chemical bonds on the surface without being restricted by the lattice and orientation of the two kinds of wafer materials. This technique is called wafer bonding technology. There are great degrees of freedom to combine new materials by bonding techniques. Therefore, it is widely used in the fields of microelectronic circuits, sensors, power devices, micromachining, optoelectronic devices, insulating silicon wafers (SOI) and so on. Wafer bonding has become a technology that can be used to make many important optoelectronic devices.

Wafer bonding is an important process in 3d fabrication of semiconductor devices. Regardless of the type of wafer bonding, the main steps of wafer bonding include surface treatment (cleaning, activation), wafer alignment, and final wafer bonding. Through these technological steps, individual single crystal circles are aligned and then bonded together to achieve their three-dimensional structure. Bonding is not only an encapsulation technology in microsystem technology, but also an organic component in 3d device manufacturing. It can be used in both front and back process of device manufacturing. The main bonding applications are wafer and wafer bonding and wafer and glass backing bonding. This paper focuses on the research on the bonding temperature control of silicon and silicon.

2. Silicon - silicon bonding at room temperature under vacuum environment

The birth of ultra-high vacuum bonding dates back to the 1970s. When NASA conducted experiments in space, it unexpectedly found adhesion between bare metal surfaces in the ultra-high vacuum environment. It is well known that when silicon wafers are exposed to the atmosphere, its surface will instantly produce several angstroms thick natural oxide film. Once the oxide film on the surface of the silicon wafer is removed in an ultra-high vacuum environment, the clean polished surface of the wafer is then brought into close enough contact. The intermolecular force (van der Waals force or hydrogen bond) between adjacent material interfaces further narrows the distance between the two surface atoms, so that the interface directly forms a covalent bond.

In 1995, professor Gosele's research group at the Max Planck institute in Germany systematically explored the bonding process between silicon and silicon wafers in the ultra-high vacuum environment. The principle of the bonding process is shown in figure 1[2]. The surface treatment process is the same as the hydrophobic bond method. First, silicon wafers are immersed in hydrofluoric acid to remove the natural oxidation layer on the surface. The surface becomes hydrophobic by covering it with a hydrosilane bond. The two thin crystal circles are pre-bonded at room temperature. Then the bonded wafer was transferred to the ultra-high vacuum cavity, the pressure inside the cavity was reduced to 3×10^{-7} Pa. Through the manipulator to separate the bonding of two wafers (hydrophobic bonding strength at room temperature is very low), then raise the temperature of cavity in the body to 300 ~ 800℃. The residual oxidation film on the surface was decomposed and the hydrogen adsorbed on the surface was desorbed until the oxidation film and hydrogen adsorbed on the silicon surface were completely removed, then the cavity was cooled to room temperature. Finally, the two wafers are bonded again through a vacuum mechanical control device, and the bonding process at room temperature is completed without any external force or annealing. The bonding strength can reach 2.0 J/m^2. It can be seen from the transmission electron microscope image of the bonding interface that there is no amorphous intermediate layer at the Si-Si bonding interface, the atoms are arranged neatly [3-5]. This method is also suitable for Si - GaAs and Si - InP bonding.

In the bonding process, the time to heat the material to the specified temperature accounts for about 20% of the whole bonding process. Therefore, shortening the heating time has a great impact on the mentioned yield. In addition, in the process of heating and pressure, improving the heating stability and reducing the temperature oscillation, can reduce the material deformation and improve the bonding accuracy.

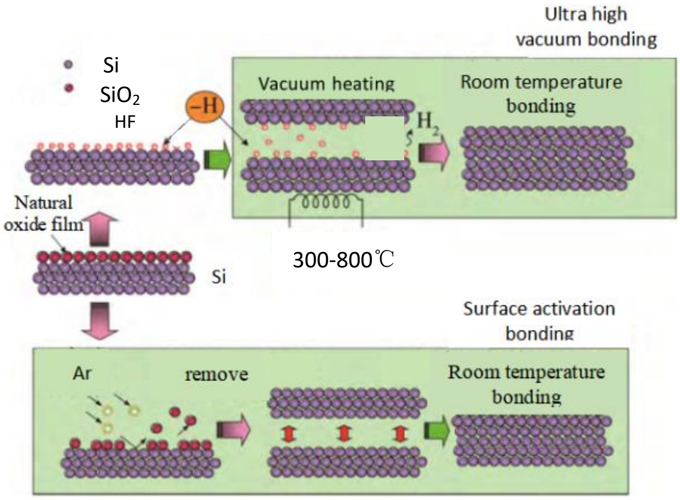

Figure 1. Principle of room temperature bonding in vacuum

IOP Conf. Series: Materials Science and Engineering **563** (2019) 042074 doi:10.1088/1757-899X/563/4/042074

3. PID control principle

In engineering practice, the most widely used regulator control law is proportional, integral, differential control, referred to as PID control, also known as PID regulation. PID controller with its simple structure, good stability, reliable work, easy to adjust to become one of the main industrial control technology.

PID controller parameter setting is the core of control system design. PID controller parameter tuning methods can be summarized into two categories: One is the method of theoretical calculation and setting. It is mainly based on the mathematical model of the system, through theoretical calculation to determine the parameters of the controller. The calculated data obtained by this method may not be directly applicable. It must also be adjusted and modified through engineering practice. Second is the engineering setting method. This method mainly relies on engineering experience and is directly carried out in the test of the control system, the method is simple and easy to master. It is widely used in Engineering practice[6].

PID general calculation and simulation control rules are shown in equation(1):

$$u(t) = K_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}] \quad (1)$$

In the formula: $u(t)$is the output of the controller; $e(t)$is the deviation. That is the difference between the set value and the feedback value; K_p is the amplification factor of the controller. That is proportional gain; T_i is the integral constant of the controller; T_d is the differential time constant of the controller. The expression G(s) of PID control transfer function is:

$$G(s) = K_P + \frac{K_P}{T_i s} + K_p T_d S \quad (2)$$

The proportional coefficient K_P reflects the quick response of the control system and has the characteristics of timely adjustment. The output of proportional control is proportional to the size of the error. The larger the error is, the larger the output will be. If there is no error, the output will be zero. Therefore, the proportional control cannot completely eliminate the error, and the system always has control margin. Excessive proportional coefficient will make the system produce larger overshoot and generate oscillation[11].

The characteristic of integral control is that the output of the regulator does not change until the deviation is eliminated. Therefore, integral control can eliminate the residual difference.

Differential control can reduce the overshoot, overcome the oscillation, improve the stability of the system, accelerate the dynamic response speed and reduce the adjustment time, thus improving the dynamic performance of the system[12].

Proportional integral control not only eliminates the steady-state error of system output when there is only proportional control, but also overcomes the disadvantage of slow response of integral control regulator. However, the proportional integral control has hysteresis and slow response speed, and severe overshoot may produce oscillation. Proportional and differential control can make the control effect of restraining error equal to zero or even negative in advance, so as to avoid serious overshoot of controlled quantity. Therefore, it can improve the dynamic characteristics in the regulation process [13,14].

Therefore, PID control is a reasonable control system. It introduces integral control on the basis of proportional control, which can eliminate the residual difference. Then the differential control is added to improve the stability of the system. This can effectively improve the static and dynamic performance of the system. It is suitable for the occasions with large hysteresis and high control requirements. As proposed in this paper, the bonding heating temperature regulation control can reduce heating control oscillation and improve heating effect. Moreover, the power of the heating rate stage can be adjusted to provide more process parameters for the bonding process.

4. Bonding heating control method

The bonding heating control device is provided with a heating controller, two heating devices and two heating driving devices. The heating device is provided with a heater and at least two temperature sensors. The heating controller is used to realize the measurement of each temperature sensor in the two heating devices. The heating drive device is used to drive the heater to work[7,8]. Among them, two heating devices can heat silicon or glass respectively, and work independently of each other at the same time,which can save heating time and improve heating efficiency [9,10].

The bonding heating control in the experiment is mainly divided into three steps. Firstly, the heating controller measures the temperature of the temperature sensor in the heating device and outputs the PWM openness of the heater in the heating device. Then, the heating drive device drives the heater to work according to the PWM openness output of the heating controller. Finally, the heater in the heating device heats and pressurizes the silicon or glass sheet. Fig. 2 shows the PWM flow chart of the bonding heating control.

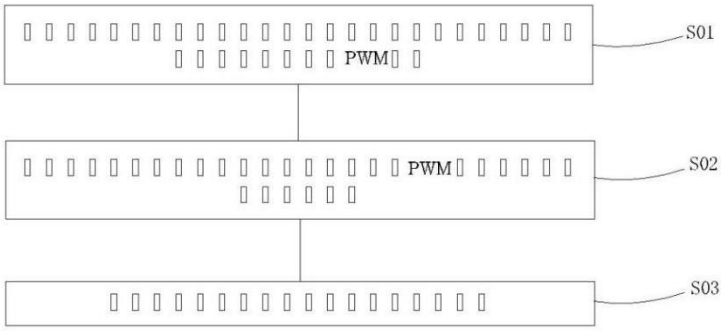

Figure. 2 PWM flow chart of bonding heating control

During the whole bonding heating process, the heating process of the heater is divided into three stages according to the deviation between the temperature of the heater and the actual required temperature: rate heating stage t1, temperature coarse adjustment stage t2 and temperature fine adjustment stage t3. As shown in figure 3.

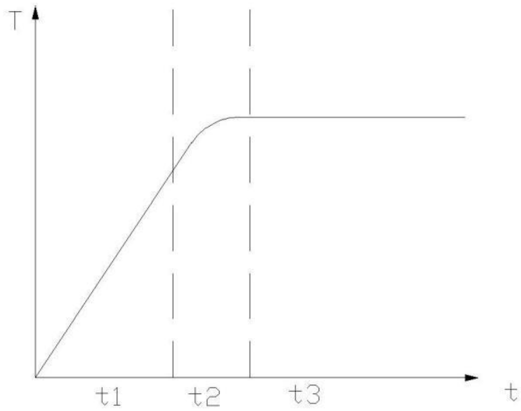

Figure. 3 three stages of bonding heating

In the rate heating stage t1, the ratio kpv of the set value sv of heating rate ramp and heater PWM opening was calculated according to the experiment, which was used as the constant setting of bonding heating control.

$$sv = ramp \times kpv \tag{3}$$

In the temperature coarse adjustment stage t2, PID control algorithm is adopted.The PID parameter and the set value of heater PWM opening sv limit range are taken as the constant setting of the bonding heating control.

In the temperature fine adjustment stage t3, PID control algorithm is adopted.The PID parameter and the set value of heater PWM opening sv limit range are taken as the constant setting of the bonding heating control.

Through rapid heating in the rate heating stage, the heating time is shortened and the yield is improved. At the same time, the heating control oscillation effect is reduced and the heating effect is improved through the temperature coarse adjustment stage and the temperature fine adjustment stage. Moreover, the power of the heating rate stage can be adjusted to provide more process parameters for the

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bonding process [15].

The heating control algorithm used in the experiment is shown in figure 4. After the heater starts heating, the first choice is to judge whether it is in the rate heating stage t1. If it is in the rate heating stage t1, kpv parameters can be obtained from the bonding heating control device constant. Calculate sv value according to sv=ramp* kpv. The heating and driving device drives the heater to work according to the sv value, and then determines whether to close the heating; If it is not in the rate heating stage t1, then judge whether it is in the temperature coarse adjustment stage t2. If so, the PID1 parameter is obtained from the constant of the bonding heating control device, and the sv value is calculated according to the PID control algorithm. The heating and driving device drives the heater to work according to the sv value, and then determines whether to close the heating; If the temperature is not in the rough adjustment stage t2, then judge whether the temperature is in the fine adjustment stage t3. If it is in the temperature fine adjustment stage t2, PID2 parameter is obtained from the constant of the bonding heating control device, and the sv value is calculated according to the PID control algorithm. The heating and driving device drives the heater to work according to the sv value, and then determines whether to close the heating; If the temperature is not in the fine adjustment stage t3, it is directly determined whether the heating needs to be turned off. If the heating needs to be turned off, the heating should be directly turned off. If the heating cannot be turned off, it is re-determined whether it is in the rate heating phase t1 until the heating is finally turned off.

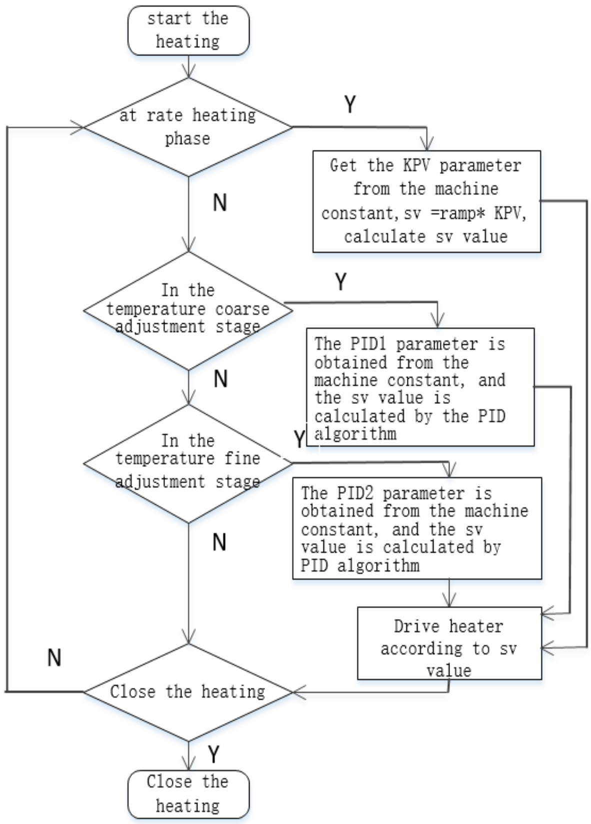

Figure. 4 heating control algorithm flow

5. Conclusion

This paper introduces the chemical principle of direct silicon-silicon bonding in vacuum environment. The PID control algorithm is mainly introduced. The PID algorithm is used to adjust the bonding temperature in the bonding heating and pressure process to improve the heating stability and reduce the temperature oscillation, so as to reduce the material deformation and improve the bonding accuracy. These are of great practical significance to improve the yield and yield of the whole bond.

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