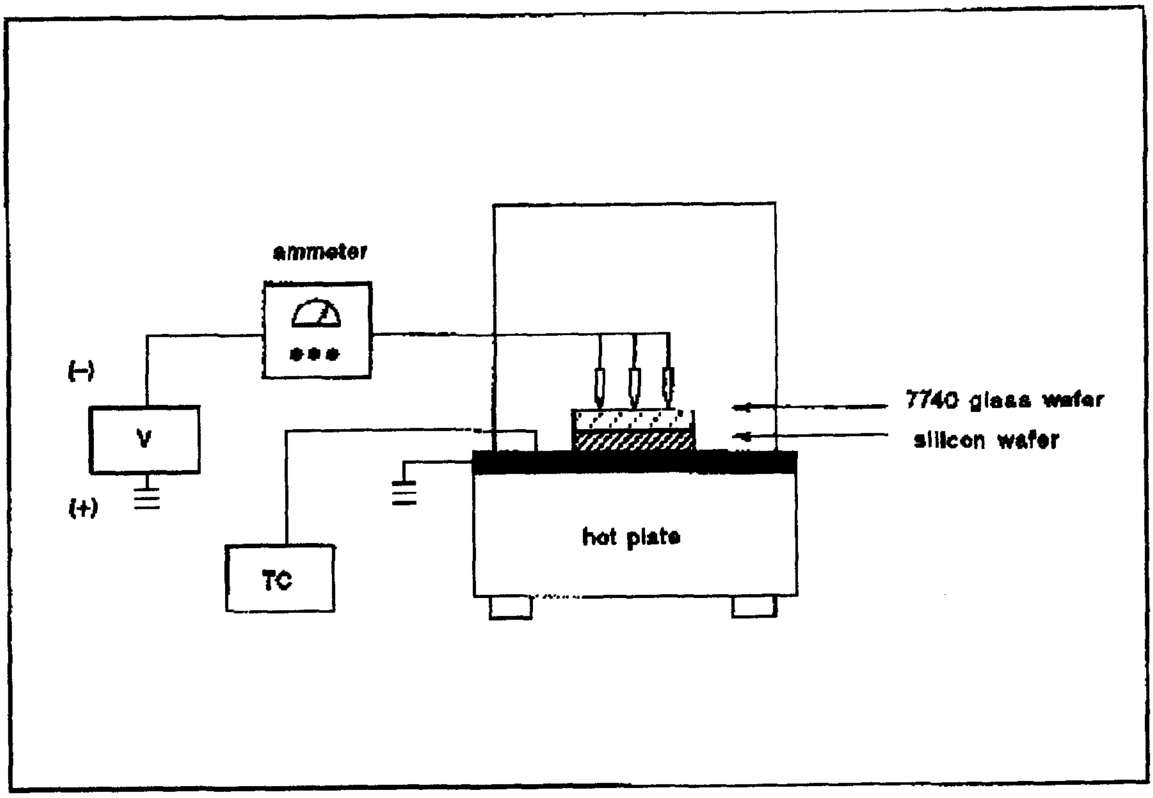
ANODIC BONDING



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Abstract

This paper presents our efforts in anodic bonding, anodic bonding process and anodic bonder. We are going to try to design simple and suitable anodic bond equipment. Firstly, we found out several different bonding ways, such as direct bonding, intermediate bonding and anodic bonding, and then we studied the theory of anodic bonding and tried to investigate the several important anodic bonding processes. Several process parameters: bonding temperature, voltages, bonding time, vacuum condition, flatness, pressure are considered. Compared with these parameters, we get the best anodic bonding process. According to the process are needed, we choose the bonding temperature and the voltage applied ranging from 400℃to 500℃and 1000V to 1500 V. So far, we knew several processes of the anodic bonding, such as Si-Si; Glass-Glass; Si-Glass and so on. Based on this, we master the different parameters can be used in the different process. All of these are introduced in the following.

Introduction

Wafer bonding is one of the most powerful processing techniques used in the fabrication and packaging of MEMS devices. Different approaches are currently in use: direct bonding, intermediate layer bonding, and anodic bonding.

Anodic bonding is probably the most versatile bonding process that can be used to permanently bond two wafers or two substrates. It is considered the workhorse of MEMS packaging and accounts for the majority of all packing application. It is also quite common in MOEMS (optical MEMS). Anodic bonding was first discovered and performed in 1969.Since then it has been established as a standard process in MEMS technology.

Direct bonding became widespread during the 1990s .{1}The technique is based on the principle that hydrophilic surfaces created by wet chemistry or plasma activation will immediately bond upon contact via van der Waals attractions between adsorbed water groups.{2}

Intermediate bonding (indirect bonding) uses an intermediate layer to create a bond between two wafers. Several different polymers have been used as intermediate materials for adhesive bonding including polyimides, epoxies, thermoplast adhesives and photoresists.

Chapter 1. Bonding

Wafer bonding has increasingly become a key technology for materialsintegration in various areas of microelectromechanical systems (MEMS), microelectronics, and optoelectronics. It is also widely used for vacuum packaging, hermetic sealing and encapsulation.

To bond wafers or substrates together, numerous techniques have been developed. These techniques can be categorized into direct bonding, intermediate layer bonding, and anodic bonding. (Figure1).

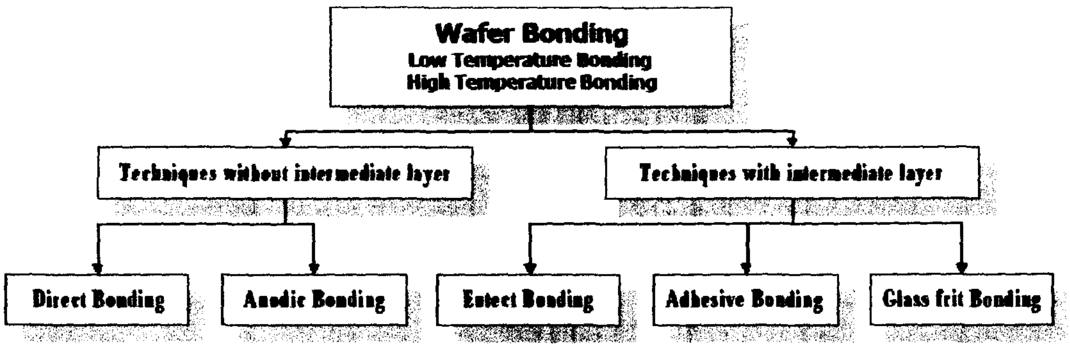


Fig.1 Overview to wafer bonding techniques

But now some anodic bonding process using a layer deposited by electron beam evaporation.

1.1 Direct bonding {3}

Direct bonding can make permanent bonding between different materials with out adhesive. Polished surfaces are contacted and heated to form bonding.

1.1.1 Fusion bonding

Fusion bonding is a kind of direct bonding. It is one of the three methods available for joining composite and dissimilar materials. Fusion bonding offers a number of advantages over traditional joining techniques and it is anticipated that its use will increase dramatically in the future because of the rise in the use of thermoplastic matrix composites and the growing necessity for recyclability of engineering assemblies. Fusion Bonding of Polymer Composites provides an in-depth understanding of the physical mechanisms involved in the fusion bonding process, covering such topics as:

1. Heat transfer in fusion bonding
2. Modeling thermal degradation
3. Consolidation mechanisms
4. Crystallization kinetics
5. Processing-microstructure-property relationship
6. Full-scale fusion bonding
7. Fusion bonding of thermosetting composite/thermoplastic composite and metal/thermoplastic joints

1.1.2 Mechanical fastening bonding {4}

Mechanical fastening bonding is one of the oldest and most commons joining methods. Bolts, screws, and nuts are common fasteners for machine component and structures, which are likely to be taken apart for maintenance, ease of transportation, and various other reasons. Rivets are semi permanent or permanent fasteners used in buildings, bridges, and transportation equipment. A wide variety of other fasteners and fastening techniques are available for numerous permanent or semi permanent applications.

1.2 Intermediate layers {5}

A wide range of bonding processes using various intermediate layers has been used for MEMS fabrication. Techniques include:

- **1.2.1 <u>Glass frit bonding</u>**
- **1.2.2 <u>Thermocompression bonding</u>**
- **1.2.3 <u>Solder bonding</u>**
- **1.2.4 <u>Adhesive bonding</u>**
- **1.2.5 <u>Eutectic bonding</u>**

1.2.1 Glass frit bonding

Low melting point glasses have been used in industry for many decades for forming hermetic seals. The process is typically carried out in the temperature range 400 -650 °C and contact pressures of $\sim 10^5$Pa. The thermal expansion coefficient of the glass is normally chosen to be between the two values for the wafers being bonded and a wide range of sealing glasses is commercially available.

The glass layer can be applied as a performance, spin-on, screen print, sputtered film, etc and patterned to define sealing areas.

1.2.2 Thermo compression bonding

Thermo compression bonding is simply the joining of two surfaces via the welding of a layer of soft metals on each surface. The most common metal for MEMS applications is gold, with a suitable adhesion layer. Moderate temperatures (~300°C) and pressures (10^6MPa) are needed.

The technique offers very low out gassing and therefore is attractive for the sealing of evacuated cavities.

1.2.3 Solder bonding

The solder bonding process works by reflowing low melting point metals to form a seal. Typical metals are Au-Sn, Cu - Sn and Pb -Sn. The metals can be applied by various thin film deposition techniques. The reflow process means that method is not recommended where accurate alignment is needed and, as is the case with thermocompression bonding, the metallic nature of the bond makes it incompatible with the inclusion of metal tracks for interfacing with sealed device. The technique differs from thermocompression bonding in that the metallic intermediate layer needs to be melted for solder bonding. The solder technique is tolerant to particles and is most widely for electrical contacts (e.g. flip chip bonding).

1.2.4 Adhesive bonding

Various adhesives (epoxies, silicones, photoresists, polyimides, etc.) can be used to form wafer bonds. In-situ alignment can be used with this technique but like other processes that rely on some flow in the intermediate layer, alignment accuracy is compromised. The adhesive can be applied by spinning, spraying etc., and the process normally requires some heat (typically between room temperature and

400°C depending on the adhesive being used) and pressure. The technique is tolerant to particles and is useful when the wafers have a severe temperature limitation.

1.2.5 Eutectic Bonding

The eutectic temperature of a two-component system corresponds to the lowest melting point composition of the two components. This property can be exploited to form bonding between two wafers by coating one of the wafers with one component of the system and the other wafer with the second component. When the wafers are heated and brought into contact, diffusion occurs at the interface and alloys are formed. The eutectic composition alloy at the interface has a lower melting point than the materials either side of it, and hence the melting is restricted to a thin layer. It is this melted eutectic layer that forms the bond.

1.3 Anodic bonding

Anodic bonding is being widely used for bonding glass substrate to other conductive materials due to its good bond quality. It can serve as a hermetic and mechanical connection between glass- and metal-substrates or a connection between glass and semiconductor substrates.

In anodic bonding, the substrates are typically heated to a temperature between 400 °C and 500°C. A voltage of 1000 to 1500 V is usually applied to the glass and the other substrates to be bonded. Bonding in vacuum environment possible, as well as aligned anodic bonding.

Anodic bonding possibilities:

- Silicon/silicon
- Glass/glass

- Glass/silicon
- Glass/SOI (silicon-on-insulator)
- Glass/ SOI/ Glass
- Glass/silicon/glass
- Glass/Metal
- Etc.

Method	Temp. (°C)	Volts (V)	Roughness (nm rms)	Precise Gaps	Hermetic Seal	Vacuum
Anodic Bonding	300 – 500	~ 500	20	Y	Y	~ 10 Torr
Glass Frit	400 – 500			N	Y	~ 10 Torr
Au-Si Eutectic	363			N	Y	< 10^{-3} Torr
Adhesives	RT – 200			N	N	N
Thermocompression	100 – 250			N	Y	< 10^{-3} Torr
Solder	300 – 450			N	Y	< 10^{-3} Torr
Direct Bonding	1000		0.5 – 1	Y	Y	~ 10 Torr

Table 1 wafer bonding comparison

We talked about all kinds of bonding, now we have to focus on anodic bonding.

Direct bonding, intermediate layer bonding, and anodic bonding have their own advantages and disadvantages. But anodic bonding is most popular and widely .it has found many applications in the field of MST, MEMS or microengineering. These include the fabrication of pressure sensors, accelerometers, micropumps and other fluid handling devices. The process is also used for first order packaging of silicon microstuctures to isolate package induced stresses. By having the sensitive microstructure bonded to a relatively thick (~1mm) glass base the device can be mounted on PCB's and other substrates having a thermal expansion mismatch with silicon. In this manner, the high stress regions, which would have occurred in the silicon microstructure, instead occur in the glass. And we also can see many benefits of anodic bonding {5}

- Low bonding temperature giving more design flexibility
- Thermally matched stress free bond; stable mechanical dimensions with temperature
- Flat assembly
- No measurable flow of the glass occurs, hence enabling sealing around previously machined grooves, cavities etc. without any loss of dimensional tolerances
- Since glass is an electrical insulator, parasitic capacitances are kept extremely small
- Hermetic seals. The sealing process can readily be performed in vacuum, allowing hermetically sealed reference cavities to be formed (or the sealing in of special gas mixtures)
- Glass transparency at optical wavelengths enables simple, but highly accurate, alignment of pre-patterned glass and silicon wafers. This transparency can also be exploited via optical addressing, and to 'see' inside micro-fluidic devices
- High yield process. Tolerant to particle contamination and wafer warp (the electrostatic field generates a high clamping force which overcomes these surface irregularities)
- Low cost wafer scale process for first order packaging can be done at chip

level if required

- Multi-layer stacks allow an easy route to complex 3-D microstructures

- High strength bond - higher than the fracture strength of glass.

Chapter 2. The anodic bonding process

Abstract: In normal situation, the requirement of anodic bonding is the wafer surfaces to be bonded must be smooth and flat .in this chapter, we are going to give more details about Glass-Glass, Glass-Si, Glass-Metal processes.

Anodic bonding is a method of hermetically and permanently joining glass to silicon without the use of adhesives. The silicon and glass wafers are heated to a temperature (typically in the range 400~500℃ depending on the glass type) at which the alkali-metal ions in the glass become mobile. The components are brought into contract and a high voltage applied across them. This causes the alkali cat ions to migrate from the interface resulting in a depletion layer with high electric field strength. The resulting electrostatic attraction brings the silicon and glass into intimate contact. Further current flow of the oxygen anions from the glass to the silicon results in an anodic reaction at the interface and the result is that the glass becomes bonded to the silicon with a permanent chemical bond.

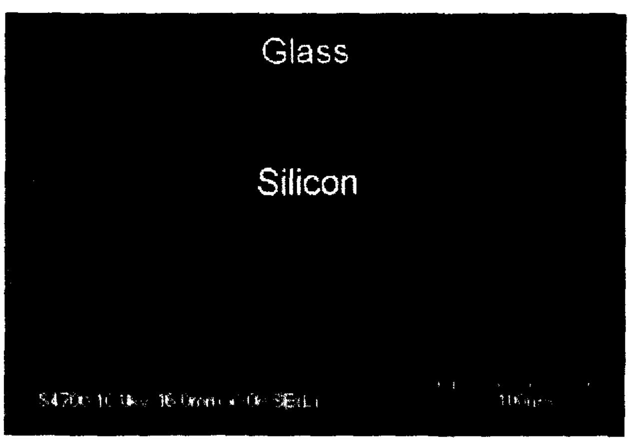


Fig.2 Glass-Silicon sandwich

Anodic bonding is a cost-effective method for wafer-level assembly of MEMS. MEMS packaging is a multidisciplinary field where both the assembly and integration process have to be considered. To continue the miniaturization of microelectronics, efforts have to be made towards increased packaging density substrates and minimized area engaged by passive components. {6}

Anodic bonding is commonly used for joining glass to silicon for micromechanical applications. The utility of anodic bonding arises from the low process temperature, since the glass and silicon surface preserving grooves in either the glass or silicon, which allows formation of devices such as pressure transducer. The physical processes occurring during bonding are of importance in determining the surface conditions required and the process conditions (temperature, voltage, and time) required forming a permanent, high quality bond.

2.1 Si-Glass {7}

The procedure for electrostatic bonding is as follows (**Si-Glass**): The glass and silicon wafers are placed in contact with one another and heated on a hot plate in the range of 250°C to 450° C. The upper limit of this temperature range is determined by the softening point of the glass used. Then a voltage potential of 600 to 1000 volts is applied to the glass/silicon arrangement so that the glass is negative with respect to the silicon wafer. The combination of the elevated temperature and high voltage potential because the positive mobile ions in the glass to drift to the negative electrode, resulting in a thin space charge layer that develops between the glass and silicon. Once the two samples are in intimate contact, the full DC potential is dropped across the space charge region and a high electric field develops that pulls oxygen out of the glass and creates a thin oxide layer between the glass and silicon. This creates an irreversible chemical bond between the two wafers. An important thing to keep in mind is that ideally no external pressure is required to form the bond. In practice, a slight amount of pressure is typically used. The process does not change the physical condition of the glass or the silicon wafer, retaining the patterned design. Based on the si-glass anodic bonding process, the people develop the new materials in the bonding processes, such as si with glass with si, glass+si with glass+si, and so on. The follow figure shows you how much configurations in the anodic multitasks bonding.

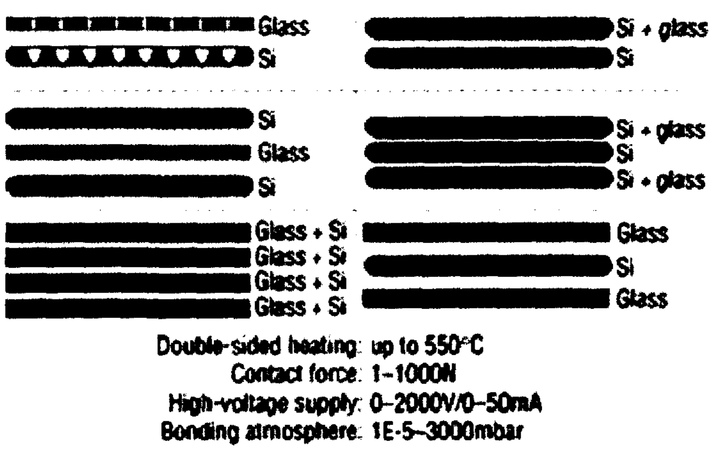


Fig .3 Configurations for anodic multitask bonding

2.2 Glass-Glass {8}

Glass-Glass wafer bonding has not been investigated extensively. However, Glass-Glass bonding has useful applications in bio-MEMS, microfluidic, displays and other areas due to the unique property of glass materials. In this work, glass-to-glass wafer bonding with the assistance of a nano-scale amorphous and hydrogen free silicon film has been performed.

The glass wafers are the commonly used 4-inch Pyrex 7740 borosilicate glass wafers. The surface roughness of the glass wafers, Ra, is less than 15 Å, and the flatness is better than 5 μm. The thickness of the glass wafer is about 500 μm. An amorphous and hydrogen free silicon thin film was deposited onto the glass substrates using a DC magnetron sputtering system (Unaxis LLSEVO). To achieve a hydrogen-free film, the base pressure of chamber was pumped down to 5×10^{-5} Pa. A high-purity 99.99% silicon planar target was mounted at a distance of 10 cm from the substrate and Ar was used as the sputtering gas. The gas flow rate was typically 100 sccm (standard cubic centimeter per minute), and the pressure was about 0.2 Pa. The target power density was in the range of 1.1 to 1.5 W/cm^2. By controlling the deposition time, a film thickness of about 100 nm was obtained, as measured by an ellipsometer (J.A. WOOLLAM Co., HS-190™).

2.3 Glass-Metal {9}

The formation of anodic bonds is satisfactorily explained by oxidation of the metal surface into the glass. Sufficient charge transfer occurs to allow the oxidation and the observation of charge neutrality in the depletion layer indicates that oxygen ions are delivered to the anode in the case of silicon anodes. Electrostatic attraction is important when the parts are not initially brought in intimate contact by an applied pressure. Joule heating of the depletion layer is not required for bonding to occur, and is inconsistent with minimal filling of surface topography on silicon anodes.

Chapter 3. Physical parameters of anodic bonding process and resulting effect

Abstract: The physical parameters affect bonding quality directly. We are going to discuss about physical parameters which are important.

Anodic bonding necessitates stringent cleanliness and flatness of the surfaces to be bonded and requires a high annealing temperature to achieve reliable bond quality. The influencing parameters on the bonding quality include the bonding temperature, the applied voltage, the pressure, the bonding time and vacuum level, etc. However, the temperature and the voltage play the most important role in anodic bonding process.

3.1 Physical parameters of anodic bonding process

3.1.1 Pressure {6}

In most applications, bonding must be carried out in reduced pressure of ultra-pure inert gases. But under atmospheric pressure, almost perfect junctions are feasible using the proposed system and procedures.Fig.4 shows the proposed system. And in the procedures, the most critical step is the of cleaning the surfaces to be bonded. At atmospheric pressure, the temperatures are almost equal to that of the heating plate. An important thing to keep in mind is that ideally no external pressure is required to form the bond. In practice, a slight amount of pressure is typically used. The process does not change the physical condition of the glass or the silicon wafer, retaining the patterned design.

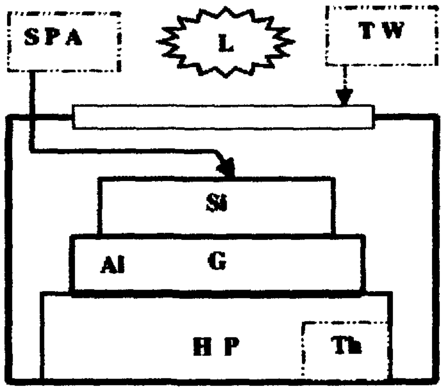


Fig.4 Disposition of the elements in the bonding chamber (HP: hot plate, Th: thermocouple, G: glass wafer, Al: aluminium layer, Si: silicon wafer, L: electric lamp, SPA: single point anode, TW: transparent window).

3.1.2 Vacuum {6}

Vacuum is not an important parameter of the anodic bonding process. Mostly, one uses the atmospheric pressure conditions. But if under vacuum, it will form the less dense populations of several sized voids. The use of an aluminum layer deposited on the wafer surface in contact with the heating plate and another wafer heating by an electric lamp improve significantly the population characteristics. For example, if at 100Pa, these modifications limit the decrease in the minimum bond density to 22% if the potential difference equals 250V and to 13% at 750V. So it means if bond density is high, than the voids will become less, and opposite, the voids will become more and more. In terms of mechanical strength and production yield, results were observed under vacuum at different temperatures.

3.1.3 Voltage & Temperature {9}

The temperature is the dominant factor to affect the electrostatic force which would cause the firm contact of two wafer surfaces facilitating the bonding reaction to occur.

The voltage is also significant for the control of the maximum electrostatic force. When a voltage is applied, the power source charges this special capacitor. It is worth to note that during charging, the electrons in bonding wafer move toward the positive electrode and the holes move in opposite direction and accumulate on the inner surface of wafer near the other wafer in a very short time. On the other hand, at the driving of electric force due to applied voltage, the mobile positive alkali ions in wafer diffuse toward the cathode and neutralize with the electrons from the power source, and leave the negative oxygen ions in the body of the wafer. So the voltage is the one of the most important parameters in the bonding process.

A higher applied voltage is expected to increase the mobility of the Na^+ ions. A higher voltage produces a higher electric field. The higher electric field will increase the drift velocity of the sodium ions. Higher voltage will also accelerate the detachment of the sodium ions from the lattice matrix, and contribute to the concentration of free sodium ions. This is the likely reason for the higher current and the longer time required to establish the equilibrium state Therefore, a higher applied voltage can generate more free sodium ions, and subsequently, contributes to a larger electrostatic force.

High temperatures caused high current and result in good bond quality. At high temperatures, more ions decompose from Na_2O and K_2O to migrate to the cathode. The equilibrium state is easily obtained and the transition period is shorter. (The detail of voltage see chapter 4)

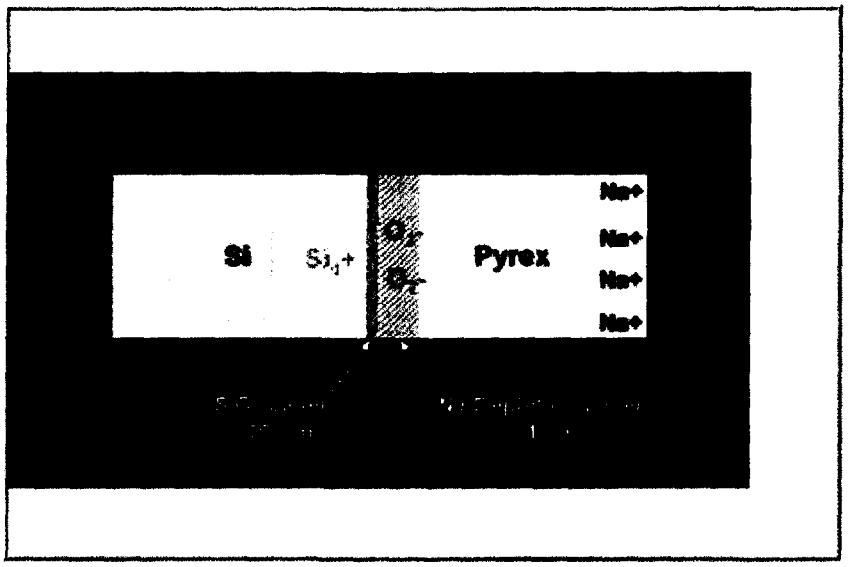


Fig .5 Schematic showing the joining of silicon wafer and Pyrex in Anodic bonding

Except the above we discuss, we found the thermal expansion coefficient also has relationship with the temperature. The follow picture can explain this relationship:

Anodic Bonding Temperature

- **Bonding temperature > 280°C --> Si under tension**
- **Bonding temperature < 280°C --> Si under**

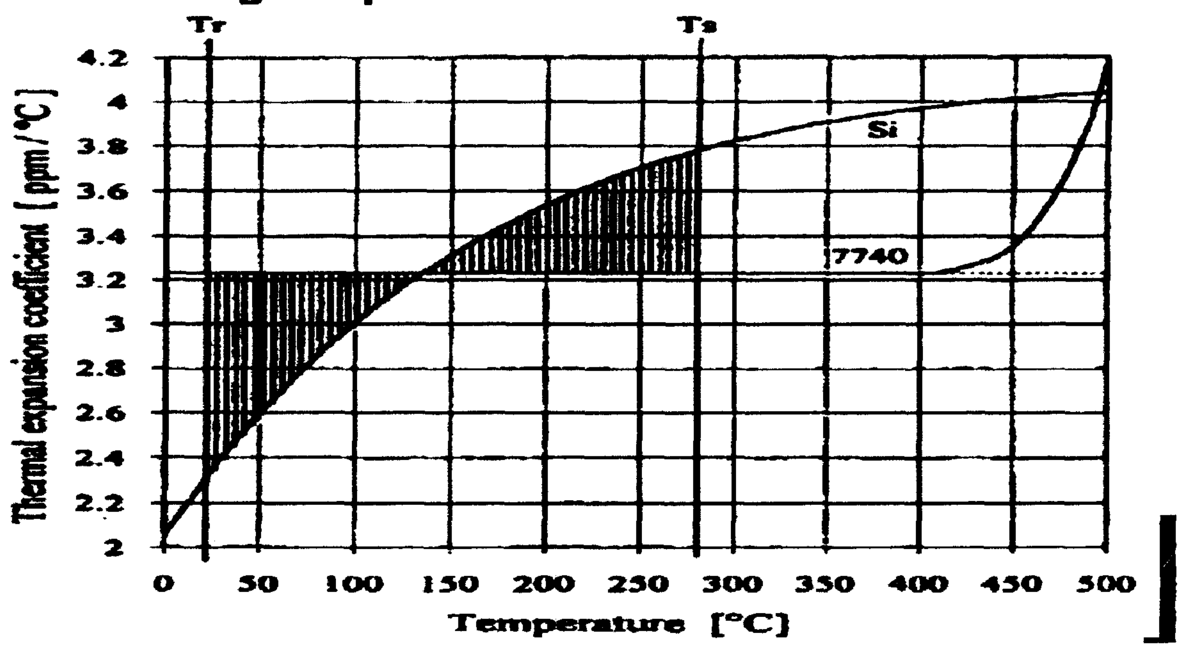


Fig .6 The relationship between thermal expansion coefficient and temperature

3.1.4 Flatness & Roughness {10}

The bonding strength largely depends on the flatness of the surfaces. Two factors are very important for Surface flatness:

1. Wafer deformation.

2. Depend on bonding energy. (1)

(1)For any particular chemical bond, say the covalent bond between hydrogen and oxygen, the amount of energy it takes to break that bond is exactly the same as the amount of energy released when the bond is formed. This value is called the **bonding energy**.

Flatness and cleanliness of the surfaces are critical to a successful bond. In the process, a local surface roughness of 5-7 angstroms was sufficient for the bonding force to pull the surfaces together.

3.1.5 Current {9}

Current, temperature and voltage relate each other. And these parameters are important for bonding. Higher bonding temperatures and voltages will yield higher bond quality. We can see this in the below. (Fig.7)

Anodic bonding takes place immediately on the application of the external voltage. At the start of the bonding process, the value of the current is high but falls rapidly, especially for high bonding temperatures. In Glass-Glass bonding process, we can see high temperatures generate high ion mobility in the glass substrate. As the temperature is raised, the conductivity of glass increases exponentially. A rapid build up of the space charge occurs at the interface, giving rise to electrostatic forces, which brings the two wafers into intimate contact. Therefore, high temperatures cause high current (Fig. 7(a)) and result in good bond quality. At high temperatures, more ions decompose from Na_2O and K_2O to migrate to the cathode. The equilibrium state is easily obtained and the transition period is shorter.

A higher applied voltage is expected to increase the mobility of the Na^+ ions. A higher voltage produces a higher electric field. The higher electric field will increase the drift velocity of the sodium ions. Higher voltage will also accelerate the detachment of the sodium ions from the lattice matrix, and contribute to the concentration of free sodium ions. This is the likely reason for the higher current and the longer time required to establish the equilibrium state (Fig.7 (b)). Therefore, a higher applied voltage can generate more free sodium ions, and subsequently, contributes to a larger electrostatic force.

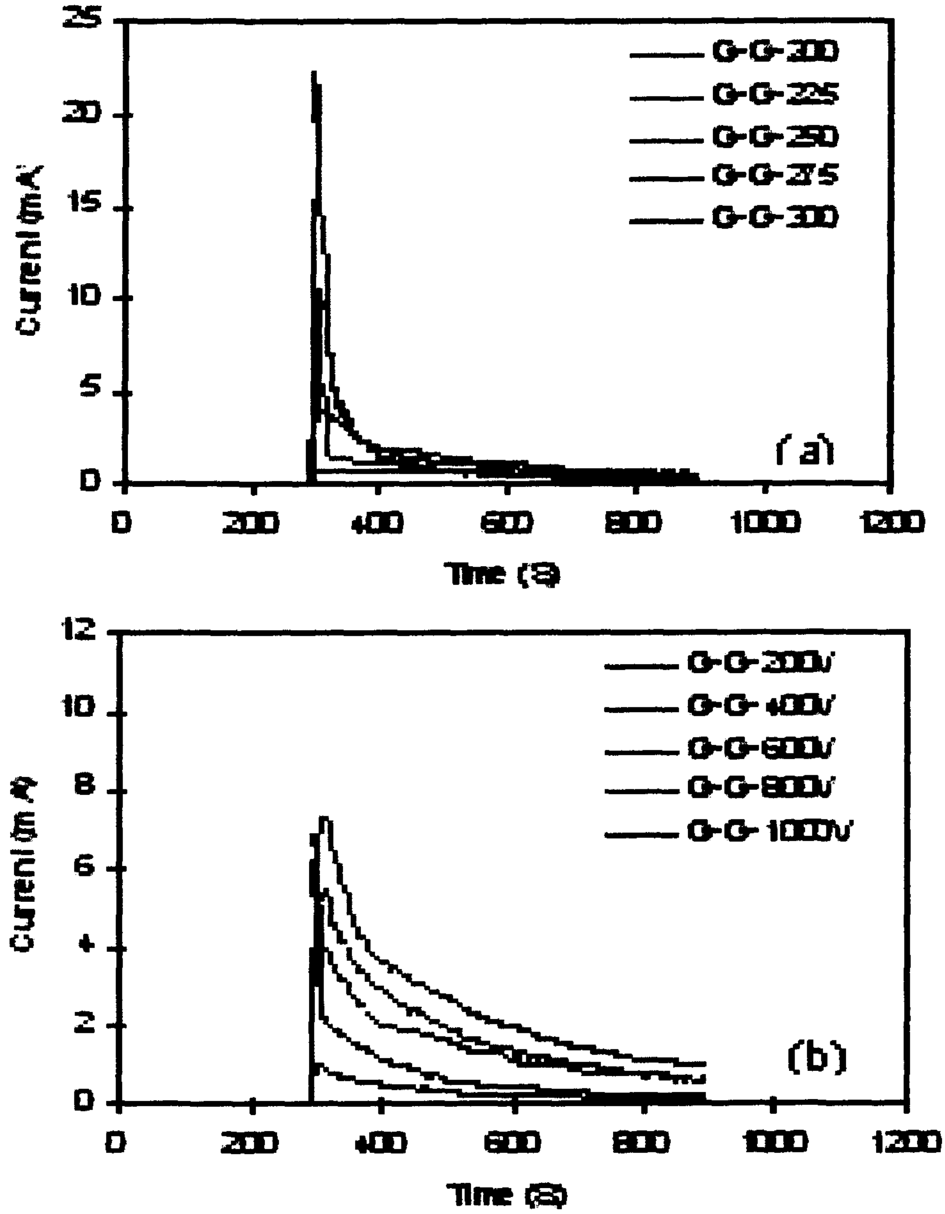


Fig.7 The current-time relationship under different temperatures at voltage of 600 V (a) and under different voltages at temperature of 250°C. Force is 200 N and vacuum is 1 Pa.

3.1.6 Polarity {10}

There are the two setup configurations: negative polarity configuration and positive polarity configuration.

The negative polarity configuration is Pyrex on top; it has a longer bonding time and better bond quality than the positive polarity configuration, which is Pyrex on bottom. It is thought that the difference between the two step ups is the way the electrical field is generated.

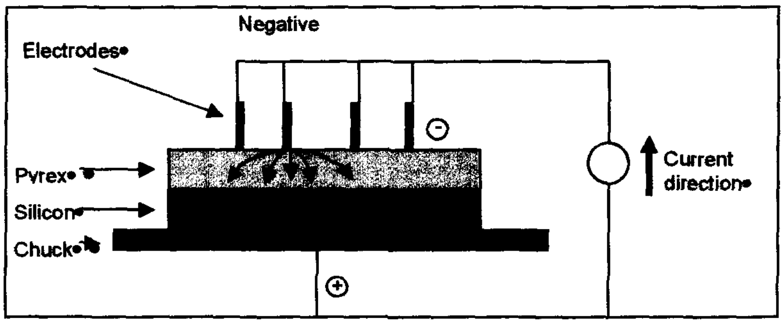
In the negative polarity setup, the electrical field is generated through an electrode at a point contact. The field strength decreases as the distance from the electrode increases. Thus the bonding is formed first at the contact point of the electrode, then propagate outwards. This bonding formation minimizes trapped voids across the wafer surface.

In the positive polarity setup, the current travels through the wafer chuck first rather than through the electrodes. It creates a uniform electron field across the wafer. A bond is formed simultaneously across the wafer, rather than propagating from a single point. The allowance for a shorter bonding time is required. However, it has the tendency of trapping voids in -the interface. This results in lower bond quality than the previous configuration.

Normally, the polarity is only considered when glass and si bond

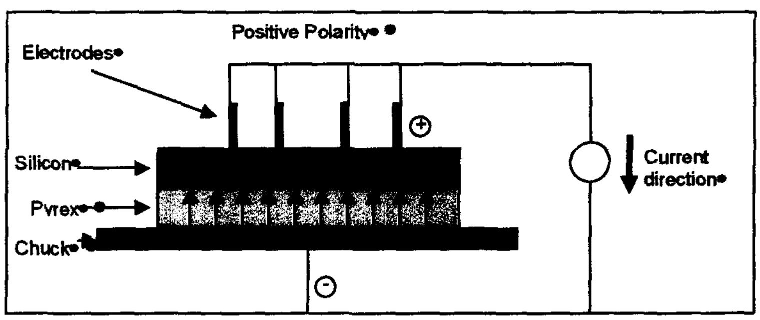
together. So we just discuss glass-si and si-glass this situation.

1. with glass – silicon configuration (**negative polarity**)



(a)

2. With Silicon – glass configuration (**positive polarity**)



(b)

Fig .8 The polarity configurations (a) is negative polarity. (b) is positive polarity.

3.2 Resulting Effect

3.2.1 Bond Strength {9}

The bond strength is an important factor for bond quality and reliability. High bond strength indicates that a good bond has been formed.

Fig8 shows the bond strength versus bonding temperature and voltage. The tensile strength of the bonded pairs is higher than 10 MPa for all the bonding conditions. The bond strength obtained in this study is comparable to that of Si/glass wafers bonded using higher bonding temperatures by other researchers.{9} The bond strength increases with an increase in the bonding temperature.

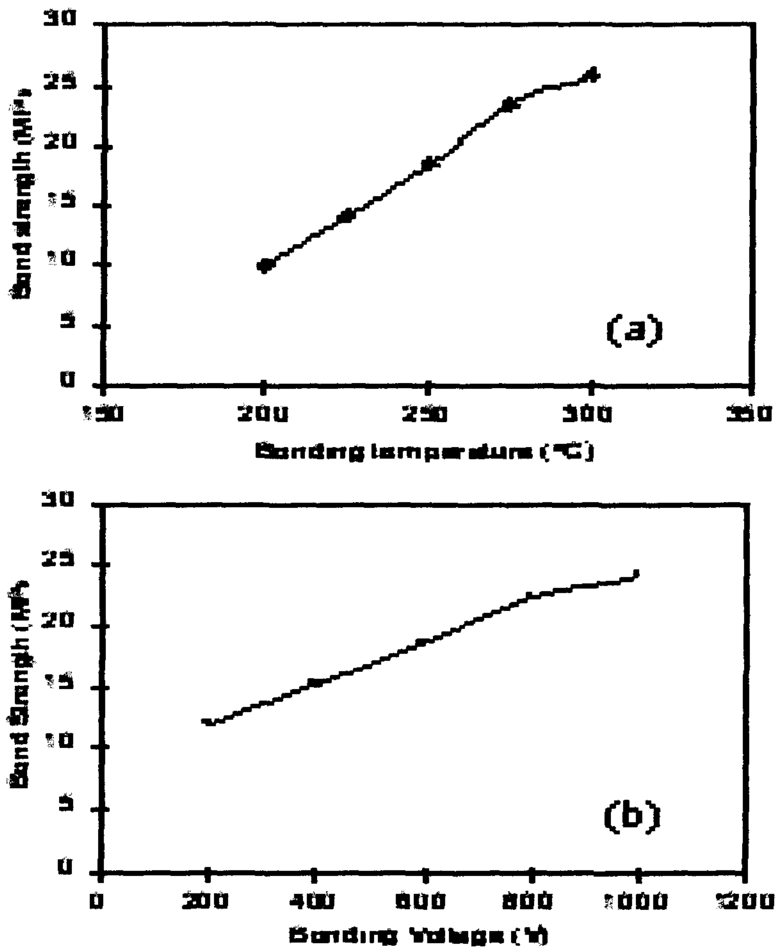


Fig.9 Bond strength (MPa) under different temperatures at voltage of 600 V (a) and under different voltages at temperature of 250°C and (b) Bonding force of 200 N, bonding time of 10 min and vacuum of 1 Pa.

3.2.2 Thermal Residual Stress

The thermal residual stress induced by the low temperature anodic bonding process via the change in the curvature of the wafers. As expected, low temperature bonding largely reduced the induced stress. Normally, all the bonded wafers under different conditions were measured by the researchers. {9}

Chapter 4. Materials Of Bonding

Abstract: There are some materials can be used in bonding. Normally, Si and glass are widely used. Different types of glass are introduced in this chapter.

The anodic bonding of various conductive materials to glass has been realized successfully for the first time in 1969 by Wallis and Pomerantz. {11}They demonstrated that it was possible to irreversibly bond different metals and semiconductors to an ion-containing glass by applying a potential between the two samples and heating them at a relatively low temperature.

As known some typical configurations in anodic bonding process. Such as sodium rich glass (conductive glass) +silicon, any metal(detail in next paragraph), or (silicon dioxide, silicon nitride, polysilicon) on silicon glass, Pyrex 7740, 7070 and soda lime 0080 ,except above those, some special materials can be used ,such as:

1) Foturan square chips.

2) Sodium-borosilicate glass Tempax.

3) Stoichiometric (2)

(2) **Stoichiometry**: In chemistry, stoichiometry is the study of the combination of elements in chemical reactions. The related term stoichiometric is often used in thermodynamic to refer to the "perfect mixture" of a fuel and air. Stoichiometry rests upon the law of definite proportions (i.e., the law of constant proportions) and the law of multiple proportions. In general chemical reactions will combine definite ratios of chemicals. Stoichiometry is often used to balance chemical equations) silicon nitride etc. but in all the case, silicon and Pyrex 7740 is the most commonly used in the field.)

4.1 Glass-Glass {12}

When people use the glass with glass to achieve the anodic bonding process, mostly we use Pyrex 7740 borosilicate wafer with one wafer surface sputtered with a layer of amorphous Si. And when these two wafers are succeeding to bond together using anodic bonding technique at different process parameters such as:

(1). Bonding temperature is ranging from 200 ℃ to 400 ℃.

(2). Voltage applied is ranging from 400V to 1200V.

(3). Bonding duration is from 10 min to 30 min.

(4). Vacuum lever is from 0.1 mbar to 0.001mbar.

Based on the model established, the experimental results were evaluated theoretically by {12}. And it was found that the bonding temperature and voltage has significant effects on the magnitude of the electrostatic force.

4.2 Glass-Metal {13}

The anodic bonding of metal to glass can also be of great interest for sensors encapsulation. The use of metals can increase the robustness of the packaging and eliminate the use of glue. And metals having a coefficient of thermal expansion close to Pyrex, such as invar (64% Fe, 36% Ni), Alloy 42 (58% Fe, 42% Ni) and Kovar (54% Fe, 29% Ni, 17% Co), were investigated by {11}. This metals and titanium to ion-containing glasses, Pyrex (Corning 7740) and Foturan (Schott) glasses was evaluated in terms of samples preparation, bonding parameters, and bonding characteristics. At a bonding temperature below 300 ℃, the stress induced to Pyrex was smaller when the Invar was used; however, a weak bonding was obtained at the lowest bonding temperatures investigated. In comparison with invar and Alloy 42 bonded to Pyrex, Kovar induced a smaller stress for bonding temperatures higher than 350 ℃. For bonding temperatures in between 300 and 350 ℃, a similar value of stress as obtained for Kovar and Alloy 42 bonded to Pyrex as well as a high bonding strength. A post-annealing step at a temperature of and higher than the bonding temperature was shown to decrease the bonding stress and can be used to improve the bonding strength of samples bonded at low temperature. Kovar and Alloy 42 bonded to Pyrex at temperatures of and higher than 250 ℃ were tight to liquid at a pressure of 1.5 bars. In the case of titanium, Pyrex and Foturan were successfully bonded to titanium thin films and sheets. The table 2 is the thermal expansion coefficients of materials used for the anodic bonding of metal to glass, we can see the Pyrex (Corning 7740) and Foturan (Schott) glasses with Respectively a Coefficients of thermal expansion (CTE) close to Si and close to Ti.

Temperature (°C)	Coefficients of thermal expansion (ppm/K)						
	Si	Pyrex	Alloy 42	Kovar	Invar	Foturan	Ti
0–200	3.0	3.1	4.5	5.5	1.7	-	-
0–300	3.3	3.2	4.5	5.1	4.9	8.6	9.5
0–350	3.4	3.2	5.0	-	6.6	-	-
0–400	3.5	3.3	6.0	4.9	7.8	-	-

Table 2 Thermal expansion coefficients of materials used for the anodic bonding of metals to glass

4.2.1 Pyrex and Foturan square chips

Pyrex and Foturan square chips (15mm, 500um thick) were anodically bonded on small metal square plates (40mm diameter, 500um thick) with the aim of investigating by {14} the influence of the surface roughness and of the bonding conditions on the characteristics of metals bonded to glass. The temperatures are varying from 200 to 450 ℃ and voltages from 500V to 1500V. And these samples were cleaned in acetone and isopropanol before bonding them together.

4.2.2 Polished Invar, Kovar and Alloy 42

Polished Invar, Kovar and Alloy 42 were successfully bonded for bonding temperatures also between 200 and 450 ℃, and the voltages also between 500 and 1500V. However, bondings performed at temperatures below 250 ℃ were found to be weak just by manually putting pressure on the samples. The bonding performed to evaluate the bonding characteristics, such as stress, strength and tightness were done at a constant voltage of 1000V.

4.2.3 Anodically bond glasses to titanium {14}

Anodically bond glasses to titanium were performed at temperatures between 300 and 400 ℃. The first attempts to bond Foturan to Ti sheets were performed successfully at 400 ℃ and at a lower voltage of 300-400V. At higher voltages, electrical breakdown occurred in the Foturan and cracks could propagate in the material and black spots be formed. However, the results were hard to reproduce. Bonding Pyrex to Ti sheets was not performed successfully. However Pyrex was bonded with success to a Ti thin film (500nm thick) between 300 and 400 ℃ and 800V. The Ti thin films were deposited by e-beam evaporation on a 525 μm thick Si wafers on which an 80nm thermally dry silicon oxide was grown. So Pyrex to Pyrex plates could be anodically bonded together (300-400 ℃, 800V) using an intermediate Ti thin film deposited on one Pyrex plate. So actully, we talk about anodic bond of glass to titamium was failed in this experiment, and this experiment should belong to intermediate bonding. But in this experiment they are failed, it didn't mean the titamium and Pyrex can not bonded in anodic bonding process, because we also found another experiment they are successful in anodic bonding of titamiun and Pyrex (detail see chapter 5 the table of non-industrial machine)

4.3 Silicon and glass

4.3.1 Silicon and glass (Pyrex 7740) {15}

Anodic bonding between silicon and glass (Pyrex 7740) is a well-know process. The bonding was performed at the temperature range from 250 ℃ to 500 ℃ and voltage range from 400V to 1000V. The high yield process (very tolerant to particle contamination and wafer warp) hermetically and permanently joins glass to silicon producing a thermally match stress, high strength bond without using adhesives.

4.3.2 The sodium-borosilicate glass Tempax (Schott # 8330, almost identical to Pyrex, Corning # 7740) {15}

The sodium-borosilicate glass Tempax (Schott # 8330, almost identical to Pyrex, Corning # 7740) was investigated by {13}; it is widely used in Microsystems technology because its thermal expansion coefficient (3) is close to that of silicon. The temperature of these materials junction is ranging from 200-450 ℃ and the voltage in the range is only 200-500V.

4.4 Stoichiometric silicon nitride to glass (Schott 8330) {16}

Stoichiometric silicon nitride with a thickness of 100nm was deposited at 800 ℃ onto polished Si wafer. The nitride covered wafer was bonded to thick bulk glass substrates (Schott 8330). The bonding was performed at 400 ℃ with a voltage of 800V applied. Bonding time is 15 min.

(3) Thermal expansion coefficient:

The (volume) thermal expansion coefficient α is defined by

$$\alpha \equiv -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_P \quad (1)$$

$$= \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P \quad (2)$$

$$= \frac{\gamma C_V}{K_T V} = \frac{\gamma C_P}{K_S V}, \quad (3)$$

where ρ is the density, T is the temperature, $(\partial\rho/\partial T)_P$ indicates a derivative at constant pressure, V is the volume, γ is the heat capacity ratio, C_V is the heat capacity at constant volume, K_T is the isothermal bulk modulus, C_P is the heat capacity at constant pressure, and K_S is the adiabatic bulk modulus.

4.5 Intermediate layer in anodic bonding

In anodic bonding process field, we also use intermediate layer to success the bonding quality.

4.5.1 Silicon wafer have been anodically bonded to sputtered lithium borosilicate glass layers (Itb 1060) on Silicon {16}

Silicon wafer have been anodically bonded to sputtered lithium borosilicate glass layers (Itb 1060) on Silicon at temperature as low as 150-180 ℃. The bonding voltage level was selected as only 50V so that electric breakdown of the glass layer was avoided reliably. The bonding time resulted from the bonding current curve recorded at same time range from 30 min to 60 min.

And the researcher also found the experimental analysis on the anodic bonding with an evaporated glass layer.

4.5.2 Silicon to silicon anodic bonding process using a glass layer deposited by electron beam evaporation {16}

The researcher found a silicon to silicon anodic bonding process always using a glass layer deposited by electron beam evaporation. The effects on the bonding process were investigated by {16} as a function of the thickness of the glass layer and the concentration of sodium ions in the glass layer and the concentration of sodium ions in the glass layer. The surface roughness of the glass layer decreased with increasing thickness of the glass layer. It was observed that the deposited glass layers of more than 1.5um thickness had very small surface roughness. The performance of the bonding temperature is in the range of 135-240 ℃ with an electrostatic voltage in the range of 35-100V.

4.5.3 Bonding lead zirconate titanate (PZT) ceramics to silicon wafer {17}

Anodic bonding was investigated for bonding lead zirconate titanate (PZT) ceramics to silicon wafer. Sputtered borosilicate glass was used as an intermediate layer. Piezoelectric ceramic lead zirconate titanate Pb (Zr, Ti) O3, or PZT, is one of the most practical materials for converting mechanical energy to electrical energy and vice versa, and is widely used for mechanical sensors, piezoelectric actuators, and ultrasonic transducers. Well-bonded wafers were obtained by applying voltage of 300V at 500 ℃ or 500V at 400 ℃. The bonded area increased while applied voltage was kept constant. The size of the bonded area depended on the resistivity of the ceramics at bonding temperatures. Fig. 10 show relative thermal expansion of the unpolarison and polarized PZT and the unpolarized PLZT.

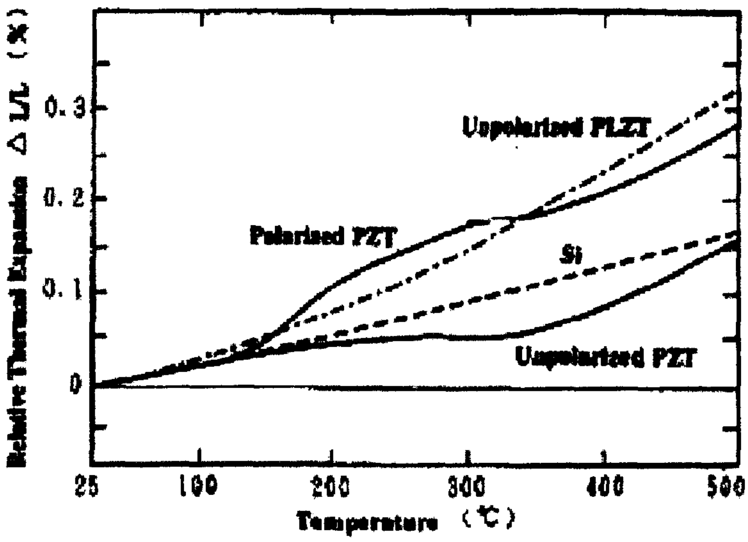


Fig.10 Relative thermal expansions of PZT, PLZT and Si.

The Fig.11 shows the bonding setup the glass layer on the ceramic wafer adn the polished Si surface was placed in contact on the heater plate.

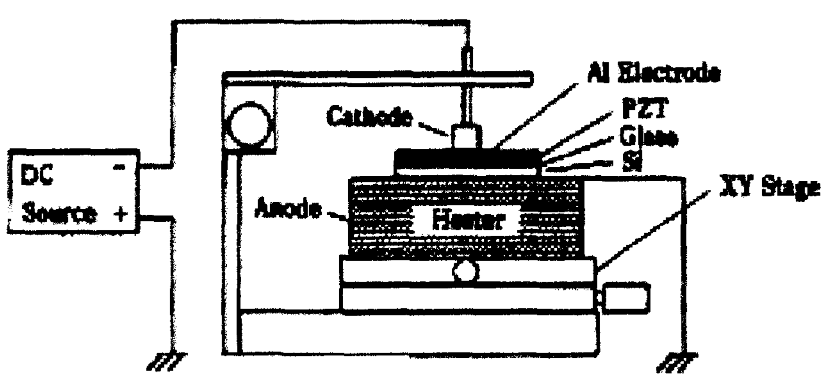


Fig.11 Bonding setup

Fig.12 a, as can be seen the PZT-Si wafer is well bonded and there is neither clear gap nor step at the ceramic-glass and glass-Si boundaries. Fig.12b shows the unpolarized PLZT-Si wafer bonded under the same conditions. Fig.12c is the PLZT and Si are also well bonded, but cracks along the grain bondaries are observed. The cracks reach a distance of 110-130 um form the PLZT-glass bound.

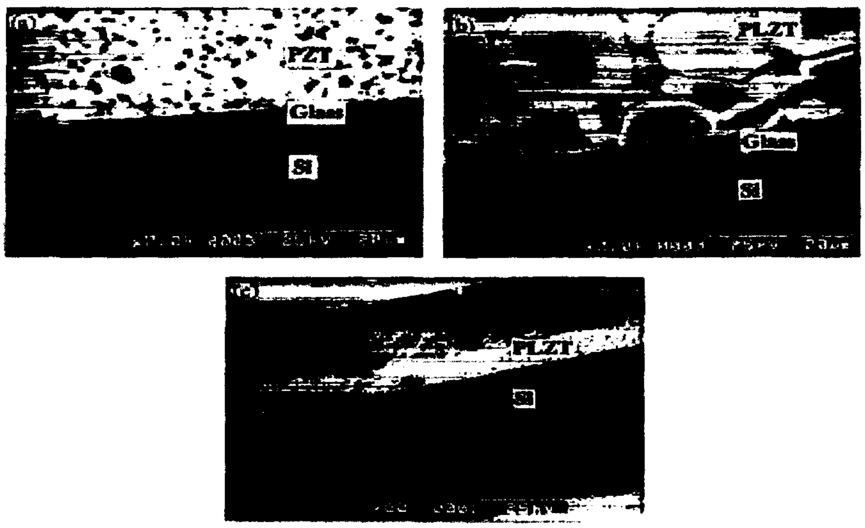


Fig.12 SEM photographs of broken-off sections of bonded wafer: (a) PZT-Si. (b) PLZT-Si (c) overall view of PLZT-Si. The wafers were bonded at 500℃, 300V for 10 min.

Fig.13 shows the photographs of the PZT-Si bonded wafers under different bonding conditions. The white regions in the center are the Al electrodes.

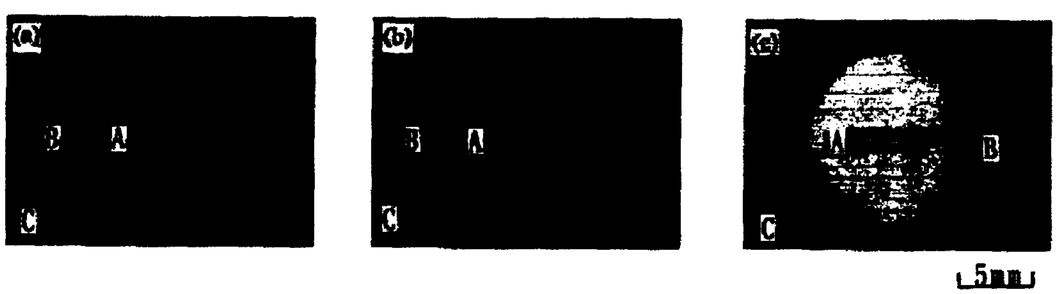


Fig.13 Photographs of PZT-Si wafers bonded under different conditions. (a) 500℃, 300V, 20 min; (b) 400℃, 500V, 200 min; (c) 350℃, 600V, 200 min. The white electrode regions A in the center and the dark regions B around the electrodes are bonded.

The regions marked C are not bonded.

Chapter 5. Industrial & Non-Industrial Machine

Abstract: There are two kind of bonder available: Industrial machine and non industrial-machine. We got several industrial machines information, but the machines are expensive for us. And non-industrial machine also called self-made machine, they always are used by experiment, they are useful and also have good quality and low price. So in this chapter we will compare with industrial machine and non industrial-machine, then we will find a good combination for our self-made machine.

5.1 Industrial machine

5.1.1 AML-WB04 bonder

A feature of the Bonder is that alignment and bonding are performed in-situ in a high vacuum chamber. The wafers are loaded cold and heated in the process chamber. For high accuracy alignment (2–5μm), they are only aligned and brought into contact after the process temperature is reached, thus avoiding differential thermal expansion effects which can compromise alignment.

NB although designed primarily as an Anodic Bonder, the AML-WB04 can also perform Direct silicon - silicon aligned pre-fusion bonding, glass frit, adhesive, Temporary, Solder and eutectic bonding as well as ALIGNED EMBOSSING where the capabilities of the machine in terms of temperature, forces and alignment capability allow.

5.1.2 SB6/8e Substrate Bonder

The SB6/8e is a semi-automatic, computer controlled, stand-alone substrate bonder accommodating up to 6" & 8" wafers.

5.1.3 SWS-100 IRV/IRT bonder

Temporary fixing system of multiple layer circuit boards for anodic bonding. This system is to temporarily fix silicon and glass substrates as part of the fabrication processes of small parts for micromachining, semiconductor pressure sensors, acceleration sensors, etc., before firmly bonding them together through, anodic and direct bonding processes

5.1.4 EVG 501 Wafer Bonder

EVG 501 Universal Bonder 4" & 6" Wafer-to-wafer bonder for anodic bonding (Si to Pyrex, Pyrex to Pyrex) and adhesion bonding of different materials (e.g. SU-8, BCB). The bonding process is fully computer controlled. Bonding recipes can be created and stored. A vacuum system with maintenance-free pump is attached. Bonding can be performed in vacuum, air or Nitrogen atmosphere. The currently available bond tool allows bonding of 4 inch wafers. Alignment of wafers is done with the AL6 mask aligner.

(This industrial machine's specification will see in Appendix)

5.2 Non-industrial machine

We make a table to compare with different parameters of different non industry machine, and then we choose the suitable parameters to make a new machine.

5.2.1 The table of non-industrial machine

	Experiment 1 {16}	Experiment 2 {17}	Experiment 3 {18}	Experiment 4 {19}	Experiment 5	Experiment 6	Experiment 7
Materials	P-Type Silicon and Borosilicate glass	3-4" (silicon and Pyrex glass)	Silicon and borosilicate glass Corning 7740	Titanium and Pyrex glass	Pyrex 7740 glass and silicon	Silicon with sputtered Pyrex thin flim and silicon	Glass and silicon
Power supply	Stanford Research Systems Inc. Model PS310 - 0-1200V						
Hot plate	Thermolyne Hotplate - 40-540°C						
Anode	Cu wire		wafer on a hotplate and wired				
Cathode	5x5" Al Plate		a conductive metal hotplate				
Temperature	540°C	350-450°C	400°C	300°C	400°C	400°C	200°C ~500°C
Voltage	900V ~1250V	200V ~400 V	1000V	Up to 2000V	100V~1200V	20V ~200V	200V ~1000V
Current	1mA						1mA
Pressure		Mbar region (mechanical pumping)		Up to 3mBar	0~2000bar	0~2000 bar	15~250KPa
Vacuum				1×10-4mBar			
Polarity				Negative			

5.3 Defining the problem

From the introduction of anodic bonding until now, we have a lot of information in our mind and finally we can make our own design for anodic bonding process. After all the process we see, we knows the material is the first step for every process, we saw a lot of processes the researchers made before, the mostly they use silicon and Pyrex, because these two materials is the common materials they choose in this field. Because silicon has some advantages in technological properties and physical properties. See the table below:

Technological properties

- Abundant element ~28%
- Simple purification
- Good crystal quality
- Strong & hard material. 7GPa
- Controllable doping
- Good oxide SiO_2
  - Diffusion mask
  - Dense pin-hole free dielectric
  - Good adhesion
  - Surface passivation

Physical properties

- Appropriate bandgap ~1.1eV
  - High breakdown voltage
  - No deep traps
  - Indirect-high carrier lifetime
- Reasonable mobility
  - Electrons 1400cm^2/Vs
  - Holes 500cm^2/Vs

Table 3 The advantages of silicon

And about Pyrex, we will choose the corning 7740 because Pyrex code 7740 glass is a borosilicate composition that is used to provide unique chemical, thermal, mechanical and optical properties. Because of its composition, Pyrex code 7740 brand glass resists attack by all acids except hydrofluoric and hot phosphoric. The low coefficient of thermal expansion of Pyrex code 7740 glass allows it to withstand higher temperatures and temperature excursions than ordinary window glass. It has higher transmission than ordinary soda-lime glass, particularly in the infrared and ultraviolet regions. These properties enable it to provide long service and fulfil requirements which common window glass cannot meet. Pyrex code 7740 can be used as a neutron absorber in poison rods and ranching rings. Tempering 7740 glass enables it to withstand tension stresses of 3000 psi and increases its thermal shock resistance as well. But of course except these two materials, another kind of materials such as Pyrex 7070, soda lime 0080 and Foturan square chips, Sodium-borosilicate glass Tempax, Stoichiometric. Because their parameters are quiet similar with the common materials, so they also can use in the in our bonding process design.

In the anodic bonding process, the most important step is choose the power supply and hotplate, we read the anodic bonding theory and the specification of industrial and self-made machine, then we knew the anodic bonding process need the voltage ranging is 1000V~1500V and the degree ranging is 400℃~500℃. So we found out several power supplies and hotplates and they are suitable to this case.

According to these above, we will design ourselves-made machine in the following chapter.

Chapter 6. Design of Utrecht anodic bonding apparatus

Abstract: Now, we are going to design our-selves made machine. Firstly, the most important thing is that suitable power supply and hot plate. The price needs to be considered.

6.1 Quality table

The first idea of the whole assignment was to make a complete quality table for *anodic bonder,* in order to analyze the Structural and Functional model of the anodic bond equipment, the following steps were undertaken:

1. An analysis of Customer Requirements (CR) and Engineering Characteristics (EC) of the product, and the relations between them (Interaction Table). [1]
2. An analysis of the product structure and the relation between EC, presented above, and the components of the product. [2]

6.1.1 Interaction table

In the table below, a translation of the customer statements which stated above into Engineering Characteristics is presented (an interaction table):

[1] "*Product Design and Development*". Ulrich and Eppinger, Ch. 4 and 5; "*Integrated Product and Process Design and Development*", Magrab. Ch.5

[2] "Integrated Product and Process Design and Development", Magrab. Ch 4.

Engineering Characteristics

Customer Requirements	Current(Ma)	Voltage (V)	Temperature (°C)	Width (cm)	Height (cm)	Depth(cm)	Cost (€)	Mass (kg)	Geometric shape of the model (radius: cm)
Easy to bond	X	X	X						
Safety	X	X	X						
Low cost							X		
Hand able									X
Operate easily	X	X	X						
Small size				X	X	X			
Light weight								X	
Stability	X	X							

Table 4 Customer Requirements – Engineering Characteristics

6.1.2 Analysis of the relationship between EC (Engineering Characteristics) and Components of the product

In order to realized the importance of each component of the product they are related with the Engineering Specification as presented follows:

This chart indicates the importance of component / assembly in the system.

Components

Engineering Characteristics	Hot plate	Power supply	Electrode	Ammeter	TC
Current(Ma)		X			
Voltage (V)	X	X			
Temperature (℃)	X		X		
Width (cm)	X				
Height (cm)	X				
Depth(cm)	X				
Cost (€)	X	X			
Mass (kg)	X	X			
Geometric shape of the model (radius: cm)	X				

Table 5 Engineering Characteristics – Components

Target specification

No.	Product	Customer Needs	Imp.
1.	Anodic bonder	Easy to bond	9
2.	Anodic bonder	Safety	5
3.	Anodic bonder	Low cost	7
4.	Anodic bonder	Hand able	3
5.	Anodic bonder	Operate easily	3
6.	Anodic bonder	Small size	7
7.	Anodic bonder	Stability	7

Table 6 Level of Importance for Function of anodic bonder

Making of level of importance is set between values of 1,3,5,7 and 9, to realize greater differences between specifications, where 9 is the most important and 1 is least important.

We finish this quality table completely. That is to say, we finish the translation from the voice of customer to the voice of designer. From these charts, it is clear to see that hotplate and power supply are very important, in the following; we will identify possible and alternative design solutions of hotplate and power supply.

6.2 Power supply and hotplate

concepts / criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Voltage	D	−	−	s	s	+	+	−	−	−	−	s	−	−	s	−	S	−
Current	A	−	−	−	−		−	−	−	−	−	−	−	s	−		−	−
polarity	T							+	s	s	+		s	+				
Regulation	U					+	+			−				s				
voltage adjustment continuous	M							−				+						
accuracy						+												
Price		+	+	+	+	−	+	+		−			−	−	−	−		
Stability													+	s				
+		1	1	1	1	3	3	2	0	0	1	1	1	1	0	0	0	0
−		2	2	1	1	1	1	3	2	4	2	1	3	2	2	2	1	2
S		0	0	1	1	0	0	0	1	1	0	1	1	3	1	0	1	0

Table7 Evaluation matrix for power supplies

Datum: 0~2000V, 0~60mA, regulation 0.005%, polarity is positive or negative, accuracy is 0.01%, voltage adjustment continuous is 5V steps, price is 500 euro, Stability is ± 0.01% per hour
+: meaning better than, less than, less prone to, easier than, etc., relative to the datum.
−: meaning worse than, more expensive than, more difficult to develop than, more complex than, more prone to, harder than, etc., relative to the datum.
Where any doubt exists as to whether a concept is better or worse than the datum, then use:
S: meaning same as datum

We saw this list of power supplies, the best power supply is considered that number (14) Glassman PS/ER05R60.0-11, because the current is the best of our design. The spec of this power supply you can see in (Appendix III).

concept / criteria	1	2	3	4	5	6	7
temperature	D	–	–	–	+	+	+
Plate size	A	s	–	–	s	–	–
Overall size	T	+	+	–	+	–	–
Voltage	U	+	s	s	s	s	s
Watt	M	+	–	–	+	–	–
+		3	1	0	3	1	1
–		1	3	4	0	3	3
S		1	1	1	2	1	1

Table8 Evaluation matrix for hot plates
Datum: temperature 200~550℃ , plate size is 4"~6" and the overall size is 20Wx20Dx15H, voltage 240V and watt is 0~2000W
+: meaning better than, less than, small than, etc., relative to the datum.
−: meaning worse than, bigger than, more difficult to develop than and harder than, etc., relative to the datum.
S: meaning same as datum.

We will choose (5) model HP66YH, because the size 6"x6" and the degree max 537°C, they are both enough for this process. (The picture shows in Appendix III) and we choose this model also have another season, because the power is 120/240V and 1100W (Appendix III), it's just like a normal electric appliance, so we don't have to find a special socket for it.

After these, we will make some detail decisions, such as the anode, the cathode, the polarity and electrode and so on.

Normally, we use the 32 elements of the Product Design Specification to make our quality table complete. We studied this method from the book named TOTAL DESIGN written by Stuart Pugh.

6.3 PDS (Product Design Specification)

PDS (Product Design Specification) plays important roles in the process of designing a new product. The PDS is essential in all fields of design activity from architecture to shipbuilding, electronics to mechanical engineering. A PDS *must* be comprehensive and unambiguous. And at the end of the design activity, the design of the product must be in 'balance' with the PDS, even though the PDS may have changed on the way through.

There are 32 elements of the product design specifications. They are as following:

(1) Performance
(2) Environment
(3) Life in service
(4) Maintenance
(5) Target product cost
(6) Competition
(7) Shipping
(8) Packing
(9) Quality
(10) Manufacturing facility
(11) Size
(12) Weight
(13) Aesthetics, appearance and finish
(14) Materials
(15) Product life span

(16) Standards and specification

(17) Ergonomics

(18) Customer

(19) Quality and reliability

(20) Shelf life (storage)

(21) Processes

(22) Time-scales

(23) Testing

(24) Safety

(25) Company constraints

(26) Market constraints

(27) Patents, literature and product data

(28) Political and social implications

(29) Legal

(30) Installation

(31) Documentation

(32) Disposal

6.4 The selection from the PDS

We select 9 important elements we consider from those 32 elements of PDS and add them into our prior quality table. They are as following.

(1) Performance

(2) Environment

(3) Target product cost

(4) Competition

(5) Size

(6) Weight

(7) Product life span

(8) Quality and reliability

(9) Safety

In our opinions, those 9 elements are very important and necessary in every design activity. And those 9 elements play important roles for each other. In our opinions, the quality and reliability affect the safety. And the quality and reliability are influenced by the maintenance. Those 8 elements affect the competition of the products. When a company or a design group wants to design a new product, they have to think about those aspects so as to make their products perfect.

Now, we will analyze these 9 elements individually.

- Performance:

The performance demanded or likely to be demanded should be fully defined; for our anodic bonding process, how fast, how often and the rate of working, these thing we have to think before our design. I thought we will use the machine every single day at least 10 hours. The transient response has to be so fast like <1 second.

- Environment:

All aspects of the product's likely environment should be considered and investigated:

1. Temperature range: in our process, the temperature range will be a quite important part, because we need a high temperature to succeed the operation. The temperature range is 400℃~500℃.
2. Pressure range: this part not really important in our process, but if we want to have a good result for our bonding process, then we are going to choose a pressure range, the range will be between 5×10^{-5} mbar and 2×10^{-6} mbar.

3. Dirty or dusty: we will find the easy way to clean it, after the machine is cool down, then we can just use water to clean the hotplate surface and the electrode.

- Target product cost:

Target product costs should be established from the outset and checked against existing or like products. So after we compare with competitor's products, we will choose some of parts we can buy and the others we will try to make by ourselves.

- Competition

In the market, the strong competition exists among those manufacturers. All of them want their own products to be the main stream and the most popular one in the market. They hope their products are the must-buy goods of the customers. That is to say, they want themselves to be the winner in the competitions. How can they get the good position in the market? They depend on their own products to be the winner. So from the time they had a good idea to design a type products to the day they started the program to design it, the competition is the essential and necessary aspect they must think about. We have said before that they depend on their own products to be the winner. It means that as a designer, he has to design something by some new concepts or by some creative approaches.

In this case, the product is the anodic bonder which can bond two wafers together. We focus on the new improvement that is to get high quality bond, bonding strong. As a designer, we collect those information from the main customers in the market and internet, and then convert them into a new concept for our new products. Here, we regard the suggestion from the information as a new concept and according to it to improve our product. We are sure that our type of the anodic bonder has strong competition in the market and can attract most of the customers.

So the competition is very important for a new product. It determines the position is good or bad in the market. It determines the success or failure of a product. That is why we add this element

- Size:

Size constraints should be specified initially. So in our mind, because we think it's have to be easy way to do the process in the lab, so the size should be not large, so we decided the size is less than 50cm(L)X50cm(W)X30cm(H).

- Weight:

Allied to size, weight is important when it comes to handling the product on the shop during manufacture, in transit and so on. So the total weight of the product should less than 30 kilos.

- Materials:

The choice of materials for a particular product design is invariably left to design team. In our process, the materials is quite important, we have to choose the materials suitable to our operation. The maximum temperature, the heat transfer, and corrosion resist of the materials and so on, we all have to think about it. So the materials should be specified.

- Product life span:

Some indication of the life of a product as a marketable entity should be sought. Of course we want to our production remain in the marketing for as long as possible, but the product life span is reducing rapidly, so our product is separate, than it can not be easy change for every part.

- Quality and reliability

The people concerned in the market including the customer, the designer, the design group or the whole company must pay enough attention to the quality and reliability of the product. In fact, the quality and reliability determines the fate of a product. It is the most important element in the whole 32 elements of the product design specifications.

If the designers want their product to be in a good position

In the market, they should spend plenty of time in getting to the requirements of the products to meet the customer demand. But they are the most difficult aspects to quantify in absolute terms, although statistical data from company product precedents are helpful here. And the company must ensure adequate feedback of any failure analysis to the design team.

Here, the quality and reliability also play important roles in designing or improving our jack. For example, if the anodic bonder is broken suddenly because of the poor quality and reliability during the process that the wafers are bonding, it is too dangerous for the people and is damaged to the equipment. Of course, nobody wants it happens. That is why we focus on this element. So improving the quality and the reliability is main aim and task for the designers.

- Safety

The safety aspects of proposed design and its place in the market must be considered. But in our process, because our process is special, so the safety is really important and every single part we need to think over for the safety protection.

Until now, we have finished the analysis about those 9 elements we select from the product design specifications .We think those 9 elements are quite important for ourselves anodic bonder.

6.5 Planning and designing a appropriate structure which includes drawings

6.5.1 Gathering Information

According to the non-industrial machine experiment 1, finally, we built the following environments:

- The anode is Cu wire and the cathode is 6x6"Al plates.

- The polarity is the negative polarity configuration, because in Chapter 3.1.6 we talk about the negative polarity configuration can get the better bond quality than the positive polarity configuration.
- Bonding environment: under atmospheric pressure conditions, because this is the easy way to do the bonding process without special apparatus for vacuum. But the bonding quality is not so perfect. (So if we want to get the better bonding quality, then we can choose under vacuum, or process gas. Vacuum Chamber: Vacuum: $>5x10^{-5}$ mbar and $<2\ x10^{-6}$ mbar)
- Wafer size in mostly process, they all choose the 4"~6" wafer, so we will have the same decision.

We see in the industrial machines, they almost use the star shaped electrode in their process, but we saw the article {22}, the researchers use multiple point electrodes in a spiral arrangement, because then they not only can solve the gas-trapping problem but also reduce the bonding time in anodic bonding.

6.5.2 Design method:

Electrode: a conductor that delivers electricity into a cell without necessarily entering into the cell reaction. Also, a system in which a conductor is in contact with a mixture of oxidized and reduced forms of some chemical species.

We choose the material for the electrode is Poly (P-Phenylene)-Based Carbon, because the PPP-based carbon electrode can obtain by heat treatment at 700℃ and this material is economic cost and high endurance.

Firstly, we will introduce the some possible arrangement of electrodes matrix. We can see in fig.13, there are several different arrangements of electrodes matrix. To design those electrodes matrix, each point electrode that forms electric field is assumed the same as a planar electrode. In order to distribute the force of the electrode uniformly over all point electrodes, a spring is installed for each electrode to guarantee each of the point electrodes to contact the glass wafer with equal pressure. The heater and the anode electrode plate can be installed properly to let average heat transfer to the wafer. With the above hardware arrangement, it is practical to assume every point electrode can make the same bonding region, and the bonding region can extend at a same speed outwardly.

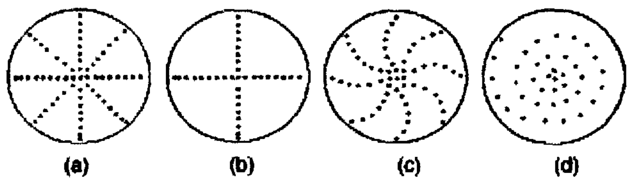
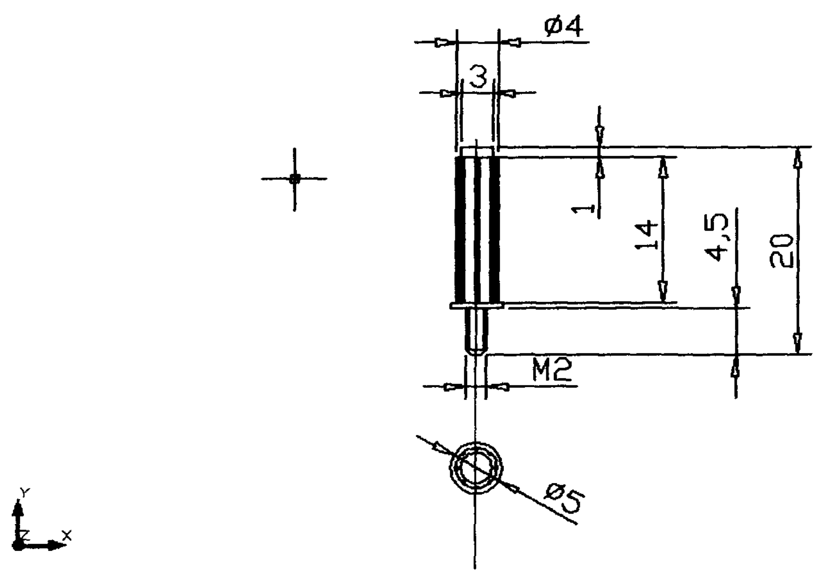


Fig.14 Different arrangement of electrodes matrix

With these assumptions, we now can discuss the bonding effects with those different electrodes matrix. The electrodes (a) in fig.13, which are arranged in terms of radiation, the gas can be expelled out from the exit of the fan-shaped. However, because the edge of wafer directly contacts the air, the free oxygen from air helps the anodic bonding to occur. So the bonding time of the wafer edge is faster than other position of the wafer, it may trap gas. The electrodes (b) expand the fan-shaped area to solve the problem of the electrode (a), but expand they are also make the bonding time last longer. If choosing electrode (c), it may solve the problem of the electrode (b), but still it can not solve the problem of electrode (a). For solving the problems of the electrodes (a) and (b), using non symmetrical way to arrange point electrode may be a good idea. Electrode (d) is nonsymmetrical way to arrange point electrode, this spriral type of electrodes will build a spiral-unbound pathway during bonding, and the gas within the interface can get away through this spiral unbonded pathway. At last the spiral unbound region will disappear from center to edge, and then the bonding is accomplished. Consequently the type of electrode (d) is the best choice in this study.

6.6 Creating a Prototype



For the electrode, we use the tolerance is +/- 0.003, because for the accuracy this is enough, and for the technology if the requirement is higher than this, It will be hard to make it.

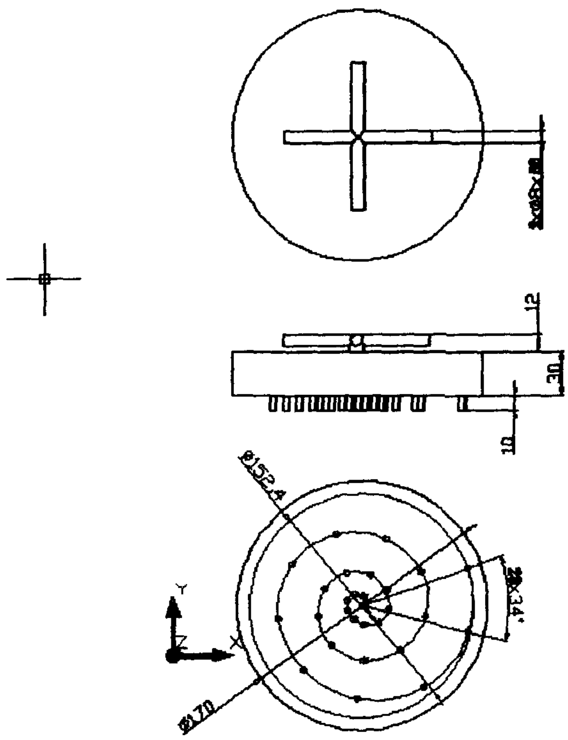
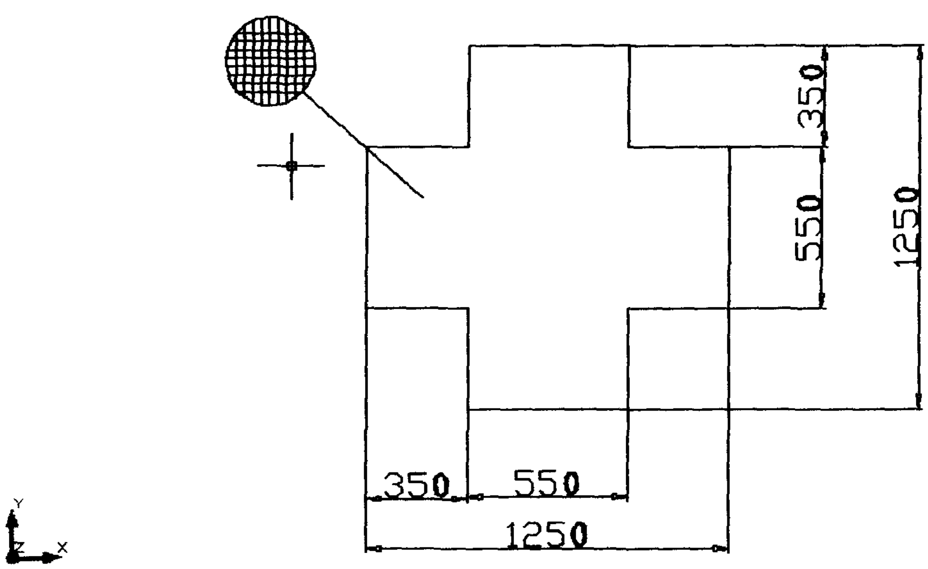
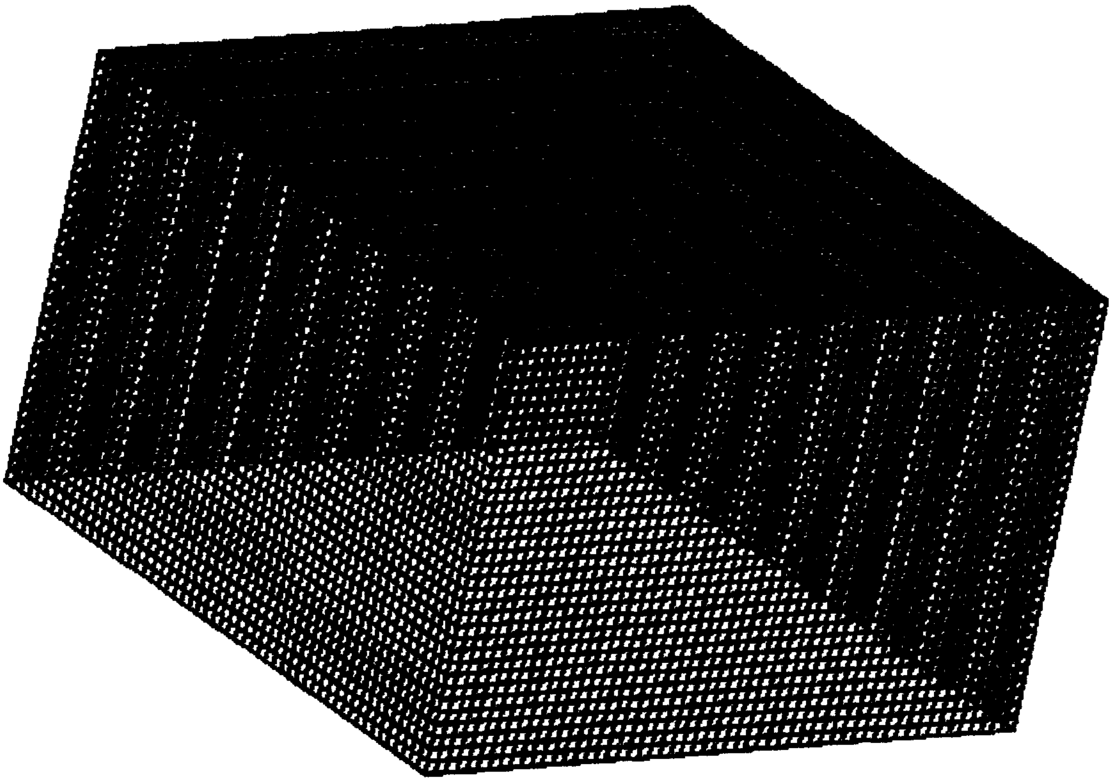


Fig.15. the drawing of electrode





The safety cover 55cm(L)X55cm(W)X35cm(H)

Finally, we design an anodic bonder concept (Fig 16.)

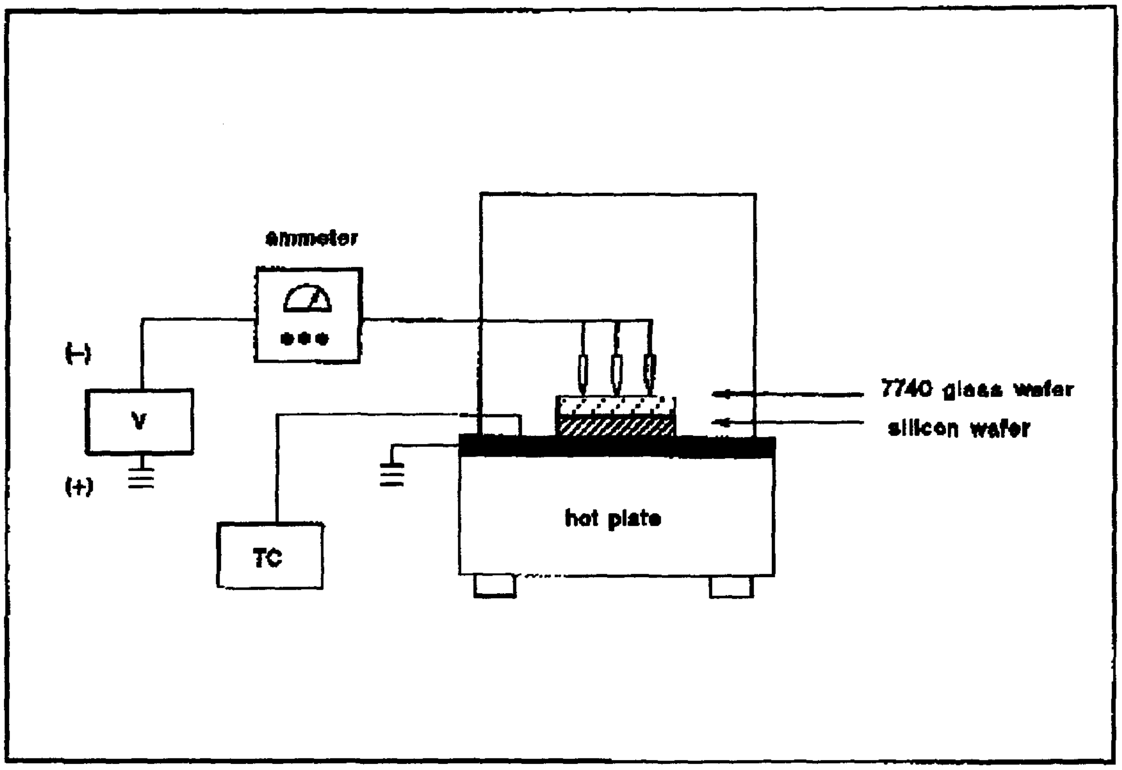


Fig.16 Apparatus used for electrostatic bonding

TC = thermocouple for measuring plate temperature

V = voltage supply

Ammeter = Extech digital multimeter (measuring current)

6.7 Safety of bonding process

We already mentioned safety above now we say it again, because it really important. In our anodic bonding process, the safety is a more important in others, because in this process, the requirement of temperature and the voltage is quiet high, so the safety becomes necessary.

Our design is step by step, firstly, for the power supply, we choose the power supply to buy, so it's become easy to solve the problem, the power supply self has the safety protection, it has automatic current regulation protects against all overloads, including arcs and short circuits. Fuses, surge-limiting resistors, and low-energy components provide ultimate protection.

Then the hot plate, we also choose to buy one, so it's not difficult any more, and we are choose the materials is stainless steel, because max temp is 815 ℃. Uniformity, heat transfer, corrosion resist and wear resist are very good, release is just fair. But t for the safety it has own protection already.

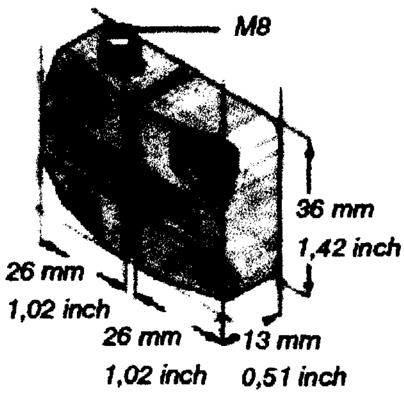
We will make the electrode for our self, so the safety problem we will also solve for ourselves

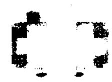
, so we decide to put a ammeter and a voltmeter in our process, because ammeter is an instrument for measuring the electric current in amperes in a branch of an electric circuit, and voltmeter can measure the change in voltage between two points in an electric circuit and therefore must be connected in parallel with the portion of the circuit on which the measurement is made. Because we choose the ammeter and voltmeter in our process, then we can always know how it's going on there, and we can control the voltage and current. And before the ac outlet we still set a fuse there, because in case the voltage and current so high, then they can stop before it becomes a big damage. And because the voltage is so high, so we choose the high voltage wires, the type is (WHV) 16-2KV-W, 2000V 16 AWG tinned stranded (19/29), Polyrad (white) jacket .045"OD. 2500' spools.

Last step is for our life safety, because when they make bonding together, the degree will become so high, and it not is careful, it will hurt the person who is doing the process, so we make a cover for the experiment, we use the stainless steel to make a length 55cm; width 55cm and high 35cm cover. Then people can not touch it directly.

In the process, because the temperature and voltage are so high, so it's so dangerous, so we decide to make a safety switch on the cover.

Safety switches PSENmag and PSENcode, safety switches PSENmech and optoelectronic protective equipment PSENopt provide effective personal security and industrial safety in automated production and logistics processes. PSENmech ensure that an open safety gate or unsafe position is detected and the machine stopped. They can be used for finger, hand and body protection.

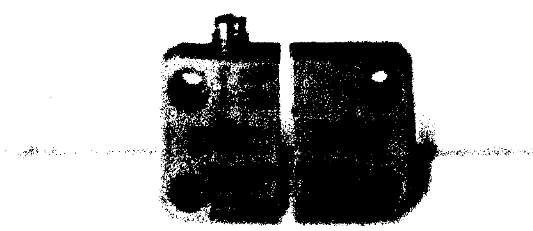




6 mm

PSEN 1.1p-20, PSEN 1.1-20

3 mm



PSEN 1.1p-10, PSEN 1.1-10

Chapter 7. Experiment

Abstract: It is time to build our-selves anodic bonder, we have enough information to design a model

7.1 Prepare for experiment

This experiment can be succeed or not, the clean wafer is very important, so we must remove all foreign matter from the surface of the silicon wafers (dirt, scum, silicon dust, etc.) prior to processing. This procedure entails the use of two solutions which contain hydrogen peroxide (H_2O_2) to remove residual organic, ionic and metallic contamination left behind by the conventional solvent and HF cleaning procedure.

So there are three conditions that must be satisfied for this technique to work.

1) The glass must be slightly conductive at the bonding temperature.

2) The glass and silicon/metal must typically have a surface roughness of less than 2μms rms.

3) The glass and silicon/metal should have closely matched coefficients of thermal expansion

Although there are so many kinds of materials can be bond together, during our experiment, we choose glass (Corning7740) and silicon these two wafers. Because of we believe these wafers can be easier to bond together, and get high quality.

Anodic bonding is the process of bonding silicon to glass at a relatively low temperature through the combined use of heat and electrostatic forces. The wafer is placed top down onto a conducting surface on a hotplate and wired as an anode. A peace of borosilicate glass such as Corning 7740, which has a thermal coefficient of expansion equal to silicon, is place on top of the silicon wafer without oxide obstructions. A voltage of around 1000v and a temperature of 400°C are applied to the glass and wafer to complete the bonding process.

Now, we are going to start, and we use the anodic bonded (Fig.15)

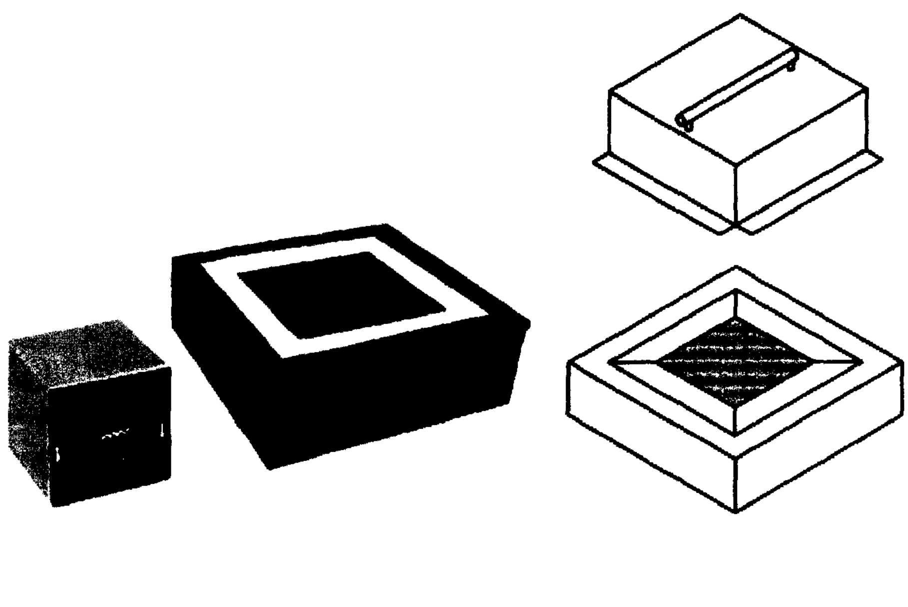
7.2 Equipment :{ 23}

7.2.1 Supplies:

Glassman High Voltage Power supply

Hot Plate

Model	Plate	Overall Size	Power	Max Temp
HP66YX	6 x 6"	18W x 18D x 6"H	1.8 KW	1500F (815C)*



Multimeter for monitoring current

7.2.2 Materials

Hydrogen Peroxide, H_2O_2

7740 Glass Wafer

Silicon Wafer

We have to do this thing, Use extreme caution when performing this experiment. The hot plate is at a very high temperature and the voltage used is extremely high. Both are potentially hazardous.

7.3 Lab Procedures:

1. Perform all parts of the initial wafer clean on the Corning 7740 glass sample except for the HF section. Remember, HF etches glass.

2. Place the silicon wafer, followed by the glass wafer onto the hot plate. If the samples were cleaned properly in step 1, a fringe pattern will be evident between the samples.

3. Move the probe tip into contact with the glass and silicon wafer sandwich, positioning it onto the center of the glass.

4. Check the contact between electrodes and wafer sandwich, in order to let the electrode contact adequately with wafer sandwich, we firstly unscrew the electrode from the top board and turn on the power supply little bit, let the surface of electrode really touch the wafer surface, then we can screw up the electrode. One by one, we check all the electrodes contact with wafer sandwich like this.

5. Heat the hot plate to 450° C. Refer to the settings posted on the side of the temperature controller for expected hot plate temperature.

6. Turn on the voltage supply. Slowly ramp the voltage up to 1000V.

7. Observe the current using a digital multimeter. A drastic current drop was observed in the first minute of the bonding experiments, which is due to the surge of Na+ ions drifted to the cathode. The current reaches a steady state at a longer time.

8. Watch what happens to the silicon-glass sandwich as the voltage is increased. The required bonding time drops significantly as the applied voltage increases from 100 to 1000V .this can be explained with respect to the bonding mechanism discussed. At an elevated temperature, Na+ ions in the glass become so mobile that they are attracted toward the cathode as a result of the applied voltage.

   The bond strength is an important factor for bond quality and reliability. A high bond strength indicates that a good bond has been formed. The bond strength versus bonding temperature and voltage.

9. Turn off the hot plate, but leave the voltage on for about ten minutes. Then turn off the power supply.

10. Allow the hot plate to cool to 100°C and then slowly remove the bonded wafers.

11. Do the report.

7.4 Interface integrity

After anodic bonding, the bonded pair will be checked, put the bonded wafers under different temperatures, voltages, bonding time (10 min) and vacuum (1 Pa.)At low bonding temperatures (say, 200°C), more and larger voids are found at the interface. With increased bonding temperature, the number of voids and the void size decrease noticeably. When the bonding temperature is higher than 400°C and the voltage is higher than 800 volts, no voids are found. The bonding temperature and the voltage have a significant influence on the voids. The unbonded area or voids are mainly attributed to gas entrapment between the mating surfaces of the two wafers. No voids arise from particle contamination, thus indicating that the cleaning procedure is effective.

Final Conclusion:

This report let us we know Anodic bonding is a well developed bonding technology for silicon to borosilicate glasses. However, the desire exists to extend the technique to other materials, and to allow for the bonding of etched wafers. An experimental program is underway to investigate the possibilities of achieving this goal. Through this study, it is hoped that a more comprehensive understanding of the bonding technique will be developed.

Appendix Ⅰ:

(1) AML-WB04 bonder

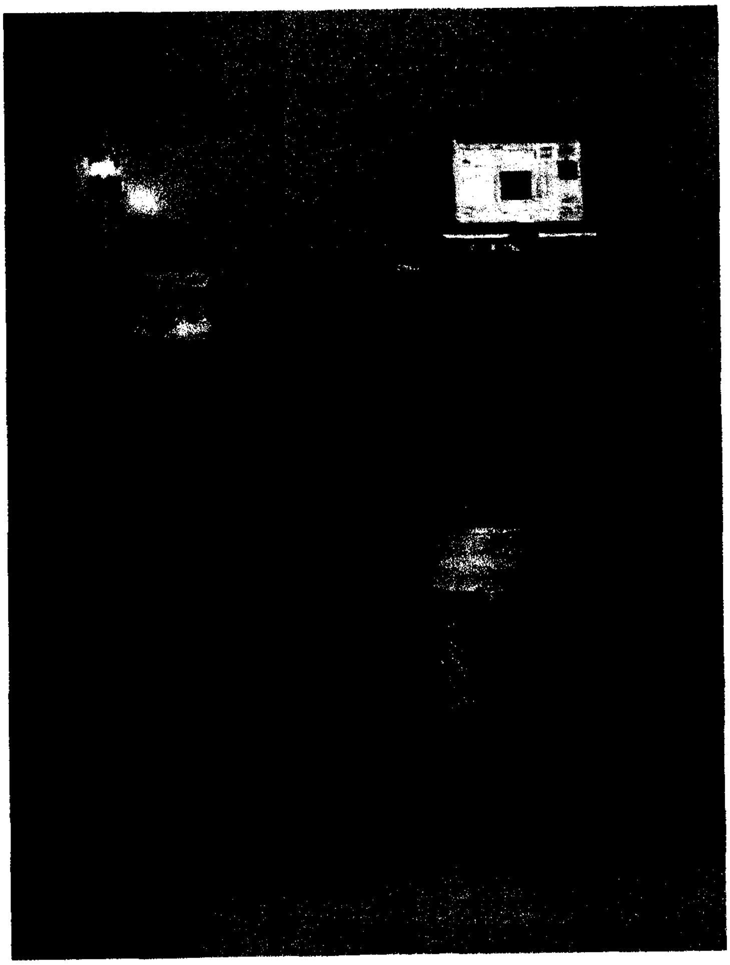


Fig.17AML-WB04 bonder

Bonding environment:

Vacuum or process gas

Vacuum Chamber:

Vacuum: $< 2 \times 10^{-6}$ mBar

Spare port (KF16)

Vacuum System:

Fully automated Turbo pumping station

Wafer sizes:

3", 4", 5", 6" & 8" wafers Standard Platens: Min. glass thickness for aligned anodic bonding: 0.4 mm (unbevelled) Maximum overall thickness of wafers to be bonded is 10mm.

Temperature:

Both Upper and Lower Platens heated up to 560°C, adjustable in 1°C steps. (High temperature 600°C operation is available as an option.)

Heating & Cooling rates are programmable

Temperature uniformity: +/- 2°C at 400°C for 4" wafers & +/- 3.5°C for 6" wafers

Anodic Bond cycle time is ~ 20 mins for std. Silicon to 7740 glass at 360 °C.

Electrodes:

Upper & lower full size planar platens:

High Voltage Supply:

0-2.5kV DC, up to 40mA

Constant current or constant voltage operation.

Required services:

3 * IEC socket - 13A 230V AC Power supply + safety earth bonding point. (110V option available)

Dry Nitrogen & Compressed Air lines pressure □ 0.5 Bar, □ 4.5 Bar gauge. Hose adapter: 8mm (OD) tube, push coupling

1 Gas exhaust G1/8" male thread

(2) **SB6/8e Substrate Bonder**

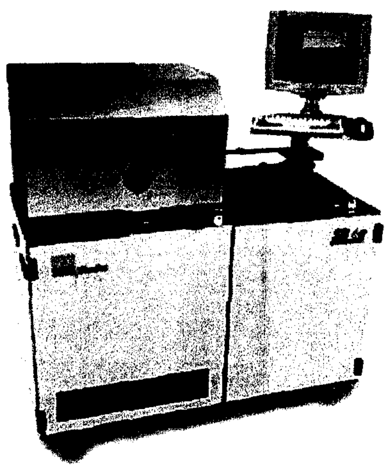


Fig.18 SB6/8e Substrate Bonder

Voltage:

Bonding Voltage: Upto 2000 Volts

Temperature:

Bonding Temperature: Upto 580°C

Optional Low Temperature Bond Module for increased bonding strength already at annealing temperatures of 200°C

Wafer size:

For all types of wafers and substrates up to 200mm diameter, stack thickness up to 6mm (larger thickness of request).

Electrode:

Star Shaped Electrode

Vacuum:

Vacuum/evacuation time: 5 X 10^{-5} mbar/10 min.

(3) SWS-100 IRV/IRT bonder

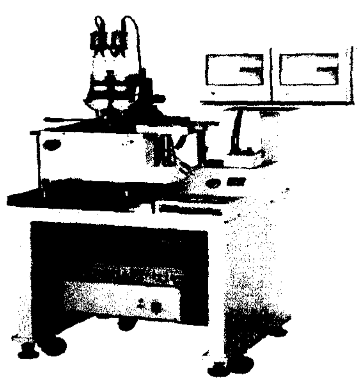


Fig.19 SWS-100 IRV/IRT bonder

Wafer size:

Φ 4 inches Thickness 0.4mm-1.0 mm

(4) **EVG 501 Wafer Bonder**

Fig.20EVG 501 Wafer Bonder

Temperature:

550 °C

Typical Application:

Bonding silicon and quartz wafers

Wafer size:

4" wafers, 4" glass (tooling is available for 6 inch wafers)

Specimen:

100 mm substrates

Main characteristics:

Bonding plan parallel substrates

Bonding voltage:

0-1200 V/ 50mA

Pressure:

Up to 3, 4 KN

Facilities:

Bonding under vacuum and controlled ambient

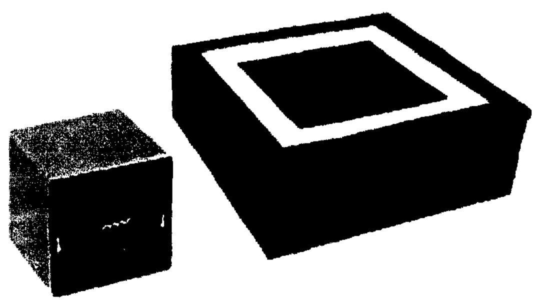
Appendix II :

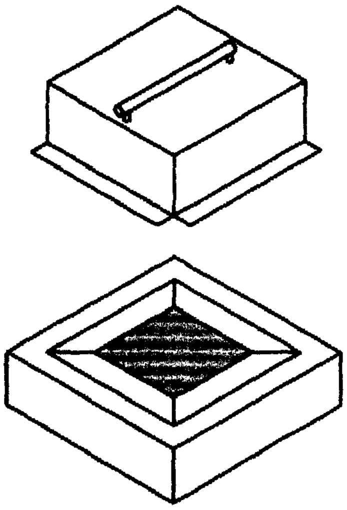
Specs for power supplies

	SINGLE OUTPUT DC LAB POWER SUPPLIES (listed by output voltage rating)	Price Us$
ISCO 493	0-1000V, 0-400mA (200mA @ 1000V)Constant voltage, current or power mode Electrophoresis power supply	390
Keithley 240	0-1200V, 10mA Constant voltage, 10V resolution. Reversiable polarity.	290
ISCO 494	0-2000V, 0-200mA (100mA @ 2000V)Constant voltage, current or power mode Electrophoresis power supply	390
Kepco APH2000	0-2000V, 0-10mA Power supply-Amplfier. Constant voltage or constant current mode of operation	350
SRS PS325	0-2500V, 25Wt, 1V resolution, 0.001% regulation, 0.05% accuracy	650
HP 6110A	0-3000V DC, 6mA Set any voltage from 0-3000V with 20mV resolution, 0.001% regulation	450
NE Scientific RQE-5001	0-5000V DC, 10mA, reversable polarity, voltage adjustment continuous or in 10V steps.	300
Agilent / HP 6110A	Precision HV Power Supply 3000V/6mA	Call
Agilent / HP 6515A	HV Power Supply 1600V/5mA	550
Bertan 205A-01R	High Voltage Power Supply 1kV/30mA	Call
Fluke 412B	0-2000 V High Voltage Power Supply	Call
Fluke 415B	High Voltage Power Supply 3kV/ 30mA	1295

Glassman PS/ER05R60.0-11	HV Power Supply 5kV / 60 mA	1495
Keithley 247	High Voltage Power Supply 2kV/6mA	895
Physik Instrumente P-198	Stablized 3 Channel Voltage Source 1kV	650
Spellman SL2PN60	Power Supply 0-2kV / 30 mA	Call
Voltronics BAM-6-5.5	High Voltage DC Power Supply 6 kV /5.5 mA	Call

Specs for High Temperature Hot Plates





Model	Plate	Overall Size	Power	Max Temp
HP66YH	6 X 6"	12W X 12D X 5"H	120/240V, 1100W	1000F (537C)
HP99YH	9 X 9"	18W X 18D X 5"H	240V, 2600W	1000F (537C)
HP1212YH	12 X 12"	24W X 24 D X 5"H	240V,4600W	1000F (537C)
HP66YX	6 x 6"	18W x 18D x 6"H	240V, 1800W	1500F (815C)*
HP99YX	9 X 9"	21W x 21D x 6"H	240V, 3500W	1500F (815C)*
HP1212YX	12 x 12"	24W x 24D x 6"H	240V, 6000W	1500F (815C)*

*Maximum temperature *with* hood. Maximum *without* hood is 1211F (654C)

Chart of Plate Material Characteristics

MATERIAL	max temp	uniformity	heat transfer	corrosion resist	release	wear resist
Anodized aluminum	700F-371C	very good	very good	good	good	good
Steel,unfinished	1500F-815C	fair	good	poor	fair	very good
Steel,hard chrome	900F-482C	fair	good	good	fair	very good
Stainless steel	1500F-815C	fair	good	very good	fair	very good
Ceramic coat or solid	1500F-815C	very good	very good	very good	fair	very good
Reinforced Teflon coat	550F-287C	good	good	very good	very good	good

Appendix III

PS/ER05R60.0-11 **HV Power Supply 5kV / 60 mA**

Features

Air Insulated. As in all standard Glassman power supplies, the ER Series features "air" as the primary dielectric medium. No oil or encapsulation to impede serviceability or increase weight.

Constant Voltage/Constant Current Operation. Automatic crossover from voltage or current regulated mode dependent on the load conditions.

Low Ripple. Better than 0.02% of rated voltage at full load.

Tight Regulation. Voltage regulation better than 0.005% line or load: current regulation better than 0.05% from short circuit to rated voltage.

Fast Transient Response. Less than 3 milliseconds for a 50% load transient.

Front Panel Controls (Analog and Digital Versions). Ten-turn voltage and current controls with locking vernier dials. AC power ON/OFF and high voltage enable switches.

Remote Control Facilities. As standard, all ER Series power supplies provide output voltage and current program/monitor terminals, TTL high voltage enable/disable, safety interlock terminals, and a +10 volt reference source.

Small Size and Weight. ER Series power supplies consume only 3.5" of vertical panel height. Total weight is 18 pounds.

Warranty. Standard power supplies are warranted for three years; OEM and modified power supplies are warranted for one year. A formal warranty statement is available.

Specifications

(From 5% to 100% rated voltage. All units operate down to zero output with very slight degradation of performance.)

Input: 105-125 V RMS, 48-63 Hz single phase, <6 A. Connector per IEC 320 with mating line cord.

Efficiency: Typically 85% at full load.

Output: Continuous, stable adjustment, from 0 to rated voltage or current by panel mounted 10-turn potentiometers with 0.05% resolution, or by external 0 + 10V signals is provided. Linearity is <1% of rated. Accuracy is 1% of rated + 1% of setting. Repeatability is <0.1% of rated.

Stored Energy: 20 kV model, 1.5 joules; 60 kV model, <4 joules.

Voltage Regulation: <0.005% +1mV/mA, line and load.

Ripple: <0.02% RMS of rated voltage +0.5V at full load; models 1.5kV and lower, 400mV (500mV Japan).

Current Regulation: <0.05% from short circuit to rated voltage at any set current.

Voltage Monitor: 0 to +10 V DC for zero to rated current. Accuracy, 1% of reading + .1% of rated voltage.

Current Monitor: 0 to + 10 V DC for zero to rated current. Accuracy, 1% of reading + .05% of rated current.

Stability: 0.01% per hour after 1/2 hour warm-up, 0.05% per 8 hours.

Voltage Rise/Decay Time Constant: Typically 50 ms rise or decay time constant (300 ms for 75 kV model) using HV (on/off) or remote voltage control with 75% resistive load.

Temperature Coefficient: 0.01%/°C.

Ambient Temperature: -20 to +40°C operating, -40 to +85°C storage.

Polarity: Positive, negative, or reversible with respect to chassis ground.

Protection: Automatic current regulation protects against all overloads, including arcs and short circuits. Fuses, surge-limiting resistors, and low-energy components provide ultimate protection.

Accessories: Detachable 8-foot shielded HV cable (see Model Chart for cable type) and 6 foot detachable line cord provided.

Remote Controls: Common, +10 V reference, interlock, current monitor, current program, voltage monitor, voltage program, TTL, and ground, provided on a rear panel mounted terminal block.

External Interlock: Open off, closed on. Normally latching except for blank front panel version where it is non-latching.

HV Enable/Disable: 0-1.5 V off, 2.5-15 V on.

Options

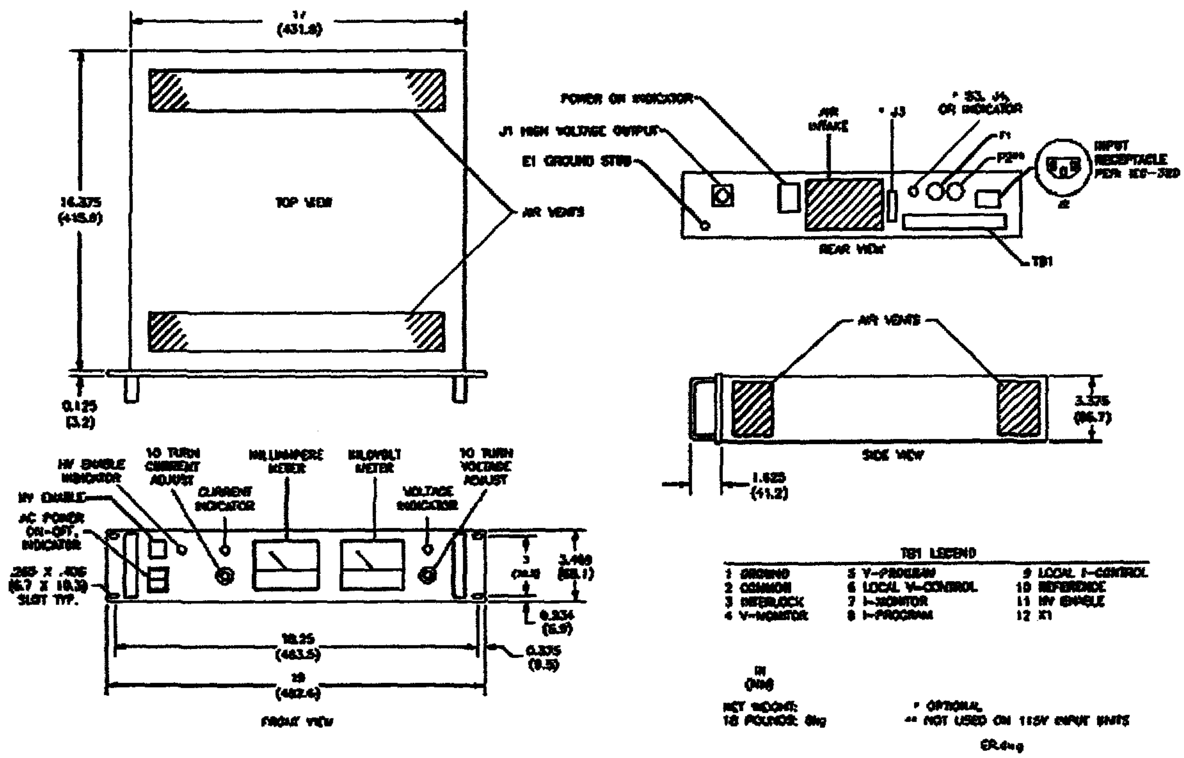
Symbol	Description
100	100 V input, rated 90-110 V RMS, 48-63 Hz.
220	220 V input, rated 200-264 V R MS, 48-63 Hz.
400	48-420 Hz, available on standard model and options 100 and 220.
DM	3-1/2 digit LCD panel meters.
NC	Blank front panel (power switch only).
CT	Current trip. Power supply trips off when the load current reaches the programmed level. This option has a rear panel switch that selects either "trip" operation or current limiting.
ZR	Zero start interlock. Voltage control must be at zero before accepting an enable signal.
SS	Slow start ramp of up to 30 seconds available. Specify time.
GE9	RS-232 control and monitor.

Models

Click on the model number below to request a quote and for complete ordering part number.

Reversible Polarity Only		ER1R300	0-1kV	0-300mA	RG-59
		ER1.5R200	0-1.5kV	0-200mA	RG-59
		ER2R150	0-2kV	0-150mA	RG-59
		ER3R100	0-3kV	0-100mA	RG-59
		ER5R60	0-5kV	0-60mA	RG-59
		ER6R50	0-6kV	0-50mA	RG-58
ER10P30	ER10N30	ER10R30	0-10kV	0-30mA	RG-8U
ER15P20	ER15N20	ER15R20	0-15kV	0-20mA	RG-8U
ER20P15	ER20N15	ER20R15	0-20kV	0-15mA	RG-8U
ER25P12	ER25N12	ER25R12	0-25kV	0-12mA	RG-8U
ER30P10	ER30N10	ER30R10	0-30kV	0-10mA	RG-8U
ER40P7.5	ER40N7.5	ER40R7.5	0-40kV	0-7.5mA	RG-8U
ER50P6	ER50N6	ER50R6	0-50kV	0-6mA	RG-8U
ER60P5	ER60N5	ER60R5	0-60kV	0-5mA	RG-8U
ER75P4	ER75N4	ER75R4	0-75kV	0-4mA	DS2124

Outline Drawing



Reference:

(1)Bonding via intermediate layers

Applied Microengineering Ltd (AML)

173 Curie Avenue, Didcot, Oxon, OX11 0QG, United Kingdom

Tel: +44 (0)1235 833934 Fax: +44 (0)1235 833935 e-mail: aml@aml.co.uk

(2)This Homepage supervise by student of Quality Control and InstrumentationUnversiti Sains Malaysia, 1999. For question or comment regarding this page, contact Nienick@Hotmail.com

(3) Printed glass for anodic bonding-a packaging concept for MEMS and system on a chip

Leif bergstedt and katrin person, the imego institute, Aschebergsgatan 46, SE-411 33 Goteborg, Sweden, phone: 46 31 7501800, fax: 46 31 7501801, e-mail: leif.bergstedt@imego.com

(4)Silicon glass anodic bonding under partial vacuum conditions: problems and solutions

Gabriel blasquez, Patrick favoro

CNRS-LAAS, 7 Avenue Roche, 31077 Toulouse Cedex 04, France

(5) Influence of bonding parameters on electrostatic force in anodic wafer bonding

G..Y.Li, L.Wang

School of materials Engineering, Nanyang Technological University, Singapore 639798, Singapore

Institute of material research and engineering, Singapore

(6) Mechanisms of anodic bonding of silicon to Pyrex glass

Kevin B.Albaugh Paul E. Cade

IBM General Technology Division Essex Junction, VT 05452

Don H. Rasmussen

Department of Chemical Engineering

Clarkson University

Potsdam, NY 13676

(7) (9) Bonding properties of metals anodically bonded to glass

Danick Briand, Patrick weber, Nicolaas F. de Rooij

Institute of Microtechnology, university of Neuchatel, Rue Jaquet-Droz 1, P.O. box 3, CH-2007 Neuchatel, Switzerland

(8) Modeling of Electrostatic Force for Glass-to-Glass Anodic Bonding

S.M.L Nai, J.Wei, and C.K.Wong

(10) Anodic bonding joins silicon wafers glass

Product news received on 24 March 2000 from Applied Micreongineering

(11) In situ investigation of ion drift processes in glass during anodic bonding

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(12) low-temperature anodic bonding to silicon nitride

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(13) low-temperature anodic bonding of silicon to silicon wafers by means of intermediate glass layers

A.Gerlash, D.Maas, D.Seidel, H.Bartuch, S.Schundau, K.Kaschlik

(14) Experimental analysis on the anodic bonding with an evaporated glass layer

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(15) Anodic bonding of lead zirconate titanate ceramics to silicon with intermediate glass layer

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(16) WTC Microfab Lab - Authorized User Equipment Menu

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(17) http://micronova.tkk.fi/equipment/anodic_bonder.html Anodic bonder

(18) mitghmr.spd.louisville.edu/course2000/exp8_2000.html Experiment Eight Anodic Bonding and Film Deposition by Sputtering

(19) Titanium MEMS: Anodic Bonding of Titanium to Pyrex Glass Faculty Lab: Noel MacDonald

Lab Mentor: Yanting Zhang Group Members: Dan Aubrey Warren Hoplins Jesus Roman Deizely Santana

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(21) W.H. Ko, J.T. Suminto and G.J. Yeh, "Bonding techniques for microsensors", Micromachining and Micropackaging for Transducers, Elsevier, Amsterdam, (1985).
(22). Improvement of bonding time and quality of anodic bonding using the spiral arrangement of multiple pointel extrudes Jung-Tang Huang, Hsueh-Ah Yang
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(23) Reviewed by Dr. Walsh on 8-6-97