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ANODIC BONDING OF SILICON AND GLASS FOR BENTMONOCHROMATOR

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Abstract

Anodic bonding technology is a method which mainly by the aid of the electric field and temperature for connecting two materials such as glass-glass or glass-silicon wafer substrate by forming covalent bonding. The bent monochromator used in the synchrotron radiation which was made by high quality silicon wafer bonded onto concave cylindrical shape Pyrex glass base. In the past, it is made by gluing. The anodic bonding method for fabricating the bent monochromator which has more advantages than bonding by glue, such as tight bonging, non-intermediate, and simple process. This paper describes the detailed manufacturing processes and testing results.

INTRODUCTION

Synchrotron radiation possesses a wide range of wavelengths; it must be converted into a single wavelength of light before it is used in the experiment. One such method for obtaining a single wavelength is to use a perfect single crystal (E.g., silicon or germanium). Based on Bragg's law, $n\lambda = 2d \sin(\theta)$; if an x-ray is incident onto a crystal surface, where λ is the wavelength of the x-ray, d is the spacing between the crystal layers, θ is the incident angle, and n is an integer, the incident beam will be diffracted in such a way that the spectral component will be along the direction that satisfies Bragg's law. The law explains the link between an x-ray light shooting into a crystal surface and its subsequent reflection. Thus, the photon energy (wavelength) can be selected by the crystal and Bragg angle.

The bent monochromator is composed of a concave cylindrical-shaped Pyrex substrate and a flat surface silicon wafer. Previously, these were manufactured by bonding the silicon wafer and the precision concave Pyrex with high-temperature glue, as illustrated in Fig. 1. However, this bonding method was insufficient to ensure the quality of the combination between the silicon wafer and the concave substrate and hampered its performance. To improve the performance and quality of the bent monochromator, we fabricated it via anodic bonding technology; this is an important bonding technique used in the silicon industry and is commonly used for joining glass and silicon. In addition to facilitating the bonding between two solids without a medium layer like glue, its benefits include tight bonging, non-intermediate, and simple processes. [1-5]

This method primarily involves using high temperature to provide glass energy, activating and dissociating the sodium oxide (Na_2O) in the glass into oxygen (O_2-) and sodium ($Na+$) ions. At this time, an appropriate voltage is applied to both ends of the silicon wafer and glass substrate,

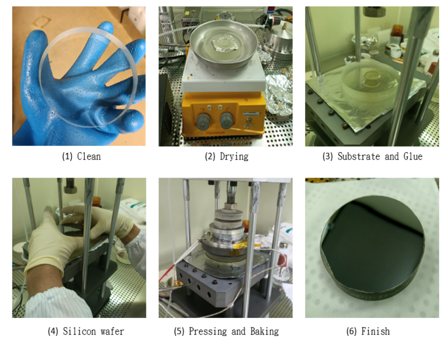

Figure 1: The behavioural mechanism of Anodic bonding.

which causes the positively charged Na+ ions in the glass to migrate toward the cathode and the negatively-charged O_2- ions in the glass to migrate toward the silicon and glass substrate bonding surface. The negatively-charged space in the region between the silicon–glass interface, which produces a large electrostatic field, repels the O_2- ions toward the silicon surface and then the irreversible chemical bond interacts, following which the stable Si–O–Si bonds acts as a SiO_2 layer in the interface between the wafer and the substrate. Figure 2 illustrates the behavioural mechanism of anodic bonding. The main bonding theory can be expressed using the two equations below.

Cathode: $4Na^{+} + 4e^{-} \rightarrow 4Na$
Anode: $Si + 2O_2^{-} \rightarrow SiO_2 + 4e^{-}$

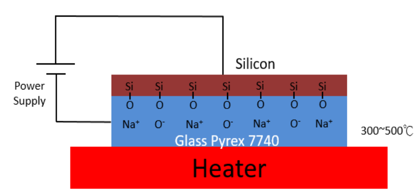

Figure 2: The behavioural mechanism of Anodic bonding.

This paper aims to present a review of anodic bonding technology to bond Pyrex glass and silicon wafers in the manufacturing of a bent monochromator.

EXPERIMENTAL

The detailed procedure of the bent monochromator will be described in the following section.

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1. Silicon wafer preparation

Anodic bonding is performed on n-type silicon wafers obtained from an ingot produced using the float zone technique. Two different types of crystal axes are employed in this experiment <111> and <331>. Their diameter is 4 inches, thickness is 525 ± 25 µm, surfaces are double-sided polished to optical quality (λ/4), and the wafer is cut to obtain the required size of 38 × 80 mm.

2. Concave Pyrex substrate preparation

The 7740 Pyrex glass of concave cylindrical substrate are chosen because the thermal expansion coefficient is near to silicon, and then optically polished to λ/4. The length is 80mm, the width is 37.5mm, and the thickness is 9.5 mm. The radius of curvature of concave cylindrical is 1.5m according to the required spec.

3. Convex die preparation

To ensure that the two blanks touch at the center, the convex die should have a radius that is∽1% smaller than the concave substrate. Invar iron as a convex die material has been chosen for its uniquely low coefficient of thermal expansion. The length is 85 mm, the width is 37.5 mm, and the thickness is 9.5 mm, which is slightly greater than the thickness of the substrate.

4. Pressing system

The anodic bonding pressing system is developed using four portions, including a pressing tool, temperature controller, power supplier, and monitoring system, as shown in Fig. 3.

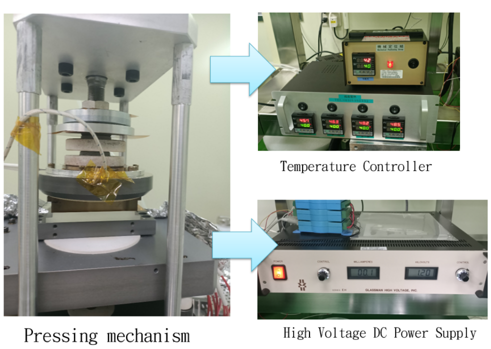

Figure 3: Pressing system.

The pressing tool provides uniform pressure between the silicon wafer and a Pyrex substrate via a pneumatic cylinder. Two heaters on either side of the programmable control provide a uniform temperature. An insulating ceramic of a lower-heating plate in the center is used to heat the Pyrex substrate. The convex die is heated using an upper-heating plate. The silicon wafer and Pyrex substrate are uniformly heated to avoid thermal breakage. Furthermore, the high-voltage DC power supplier supplies a uniform electric field between the silicon wafer and the Pyrex substrate. During the anodic bonding process, a monitoring system records the experiment conditions, including the heating procedure, voltage, and current variation.

5. Anodic bonding setup

(1) First, clean the silicon wafer and Pyrex substrate and inspect the surface for dust particles on the bonding interface.
(2) Position the Pyrex substrate on the lower-heating plate and place the silicon wafer on the concave Pyrex substrate. This operation should be completed as quickly as possible to mitigate the presence of dust particles.
(3) Place the conducting material (anode) on top of the silicon wafer; the size of the conducting material is slightly larger than the silicon wafer. Next, place the kapton and the convex cylindrical die on top of the anode.
(4) The pressing tool's cylinder begins to operate and is pressed against the substrate under appropriate and uniform pressure via a convex cylindrical die. The air pressure of the cylinder in this experiment was 0.6 bar. Figure 4 is a schematic diagram of the experiment.

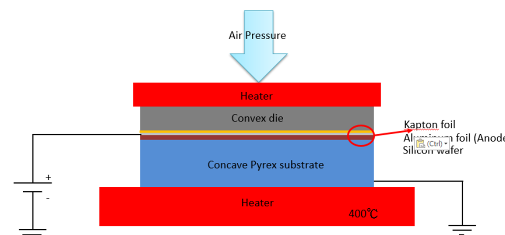

Figure 4: Schematic diagram of the experiment.

(5) The ensemble was installed in a pressing tool and heated up to ≈400°C. While the temperature is stable, turn on the power supply and gradually apply a positive high voltage (1650–1800 V) to the system for 2–3 h. Finally, cool the system to room temperature to complete the fabrication process.

RESULTS AND DISCUSSION

The parameters used in the experiment of anodic bonding silicon wafers and Pyrex glass substrates, including pressing force, electrode materials, DC voltage, and so on, as well as the improvement of bonding interface defects, detailed description, and test results are as follows:

Pressing Force Test

The Load Cell (stress sensor) was used to test the mechanism's pressing force and to determine a more appropriate pressing force to avoid damage to the silicon wafer during the bonding process. Figure 5 depicts the relationship between the inlet pressure and the acting force of the pneumatic cylinder. The influence of the pressing force on the silicon wafer was also tested. When the pneumatic cylinder's air inlet pressure exceeds 0.8 bar (the force of the pneumatic cylinder is approximately 260 N), the likelihood

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of crack formation on the silicon wafer increases. As a result, this experiment uses a 0.6 bar air pressure to ensure no damage to the silicon wafers.

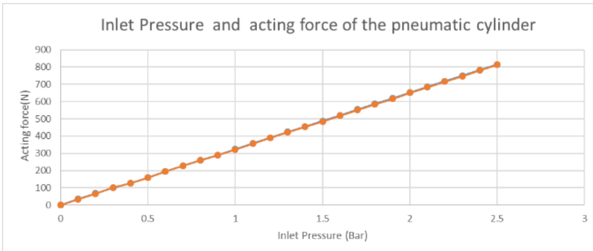

Figure 5: The relationship between the inlet pressure and the acting force of the pneumatic cylinder.

Electrode Material

Two different materials were tested as electrodes in this experiment (copper and aluminum). Although copper has better conductivity than aluminum, it oxidizes at a high temperature of 400°C, which would cause contamination on the wafer surface, as revealed in Fig. 6. Thus, aluminum foil was selected as the electrode material.

Figure 6: After anodic bonding, copper and aluminium electrode.

DC voltage value and bonding time

Anodic bonding utilizes high temperature to activate the Na_2O inside the glass and dissociate it into oxygen (O_2-) ions and sodium (Na+) ions, following which an appropriate voltage is applied to both ends of the silicon wafer and the glass substrate. Negatively-charged O_2- ions in the glass are affected by the electric field and migrate toward the bonding surface where they react with Si to form a SiO_2 layer.

The positively charged Na+ ions in the glass are drawn to the glass surface of the cathode by the negative charge, where they react with the moisture in the air to gradually form a white layer of sodium hydroxide (NaOH) on the glass surface. When the applied voltage exceeds 1800 V, there is more NaOH on the glass surface of the cathode, as shown in Fig. 7, if the voltage is too low, the bonding will be incomplete. Thus, a voltage of 1700 V is used in the experiment.

When the temperature reaches 400°C, a high-voltage DC supply is applied to the system. The current value will gradually decrease over time, approaching zero after 2–3 h. Zero current implies that the high-voltage anodic bonding

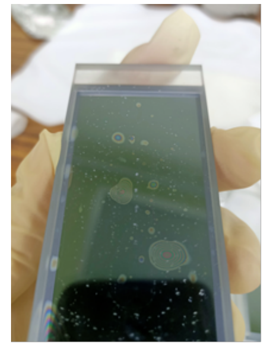

Figure 7: Excess NaOH on the glass surface.

has been completed. Figure 8 depicts the change in the current value throughout the process; the applied voltage is 1700 V and the temperature is 400°C.

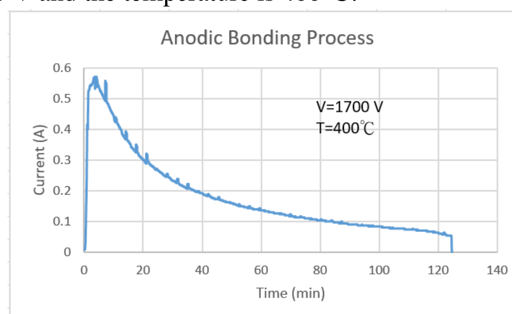

Figure 8: The change of current value.

Results of Anodic Bonding

After heating to 400°C and supplying a voltage of 1700 V, wait approximately 2 h until the current approaches zero before turning off the power and allowing the system to cool. Figure 9 shows the finished product.

Figure 9: Bent monochromator.

CONCLUSION

Anodic bonding is an important bonding technology in semiconductor process technology. Its main feature involves the bonding of silicon wafers and Pyrex glass via covalent bonding without the use of glue. In the past, the bent monochromator was manufactured using high-temperature glue to bond the silicon wafer and the Pyrex glass. To complete the bonding process, this paper employs a self-designed anodic bonding mechanism that uniformly pressurizes the workpiece, heats it, and supplies DC voltage. We hope that future studies will provide a more accurate method to manufacture bent monochromators.

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