The electrostatic-alloy bonding technique used in MEMS

Abstract Electrostatic-alloy bonding of silicon wafer with glass deposited by Au to form Si/Au-glass water, and bonding of Si/Au-glass with silicon wafer were researched during fabrication of pressure sensors. The silicon wafer and glass wafer with an Au film resistor were bonded by electrostatic bonding, and then Si-Au alloy bonding was formed by annealing at 400°C for 2 h. The air sealability of the cavity after bonding was finally tested using the N₂ filling method. The results indicate that large bond strength was obtained at the bonding interface. This process was used in fabricating a pressure sensor with a sandwich structure. The results indicate that the sensor presented better performances and that the bonding techniques can be used in MEMS packaging.

Keywords bonding, electrostatic-alloy bonding, pressure sensors, microelectromechanical systems (MEMS)

MEMS (Microelectromechanical systems) micro sensors, actuators and microsystems usually use Si and glass as their substrate material. Bonding of glass/Si, Si/Si, glass/glass are key technologies in building a MEMS microstructure. There is no need for any bond in Si/glass static bonding, which aims to bond Si and glass firmly. This technology has been used as a normative process in the fabrication of pressure sensors and adopted broadly in developing other MEMS microstructures. In the following condition it will be difficult for Si/metal-glass to bond: when we need to lead out a metal down-lead from Si/glass interface in a complicated MEMS microstructure, especially when metal down-lead is on the same side of the glass, a step will appear on the interface. Besides, the bonding of a Si/metal-glass/Si multilayer structure is a difficult problem in the technology of MEMS bonding.

We research the bonding technology of complicated structures in Si/Au-glass and Si/Au-glass/Si when we try to develop a sensor package with a self-testing function. The sensor packaged with this technique has the following advantages: the interface is airproof, firm and has a self-testing function.

1 Structure of the pressure sensor

Figure 1 shows the structure of a pressure sensor, which has the self-testing function. The chips of this pressure sensor adopt a polysilicon structure. We put four polysilicon strain resistance on the appointed location of the pressure-sensitivity film in order to build a Wheatstone bridge used as the pressure-sensitivity component; we put a heater on one side of the glass and make a cutoff to the press cavity by airproof bonding the Si/glass. Then we build a gas-drive-pressure self-testing component, which can help us implement the function of self-testing the pressure.

When we apply an electric power on the thermistor, the gas in the cutoff to press cavity will expand after absorbing heat, which will create a pressure on the pressure-sensitivity film. Then, the polysilicon bridge will produce a self-testing signal, and the sensor puts up pressure self-testing.

2 Analysis of the bonding of sensor cut off to press cavity

Static bonding, also named anode bonding, can bond glass
with movable Na⁺ and Si together without any bond. Figure 2 shows the static bonding principle. At 300–400°C and 700–1 000 V, the Na⁺ in the glass will move towards the cathode direction and form an exhaust layer for the Si and glass interface. The breadth of this exhaust layer will be several µm. Si and glass will be attached closely by the strong Coulomb force produced by the opposite charge on the exhaust layer (carrying minus charge) and Si (carrying positive charge), which will make the current density reach its maximum instantly. At the same time, a Si-O bond created on the Si/glass interface will be created. When Si/glass bonding is fast, the pressure cavity is formed.

In the self-test pressure sensor shown in Fig. 1, we make a metal film resistance heater on the glass. The metal down-lead of this heater has to pass through the bonding interface of Si/glass creating a step around the metal down-lead where the glass and Si do not get in contact. It will be hard for this area to bond under static bonding. Besides, the interface of the Si/metal down-lead also cannot form a chemical bond under the static bonding effect. Thus, the airproof cut off to the press cavity of the sensor cannot be created only by static bonding.

In order to solve the problem of the down-lead step in the Si/glass bonding interface, we intend to use a higher bonding temperature and voltage to get a tiny distortion by softening the glass, controlling the thickness of the metal film in a certain range, and making the glass and Si around the step contact to finish the static bonding.

We will use metal film as the metal heater on the glass. Shown as the Au-Si phase diagram, Au-Si can melt to an alloy at 363±2°C, which means that Si/Au are likely to bond at a lower temperature near that of static bonding. Compared with Au/glass, Ti/glass can bond better. So, we choose a Ti-Au double deck film as the heating resistor.

To carry out Au/Si alloy bonding, we first bring the surface of the Au/Si in contact closely by pressing on them. Secondly we insulate them under a temperature of at least 363°C for a period of time. During this, the Si on the interface will diffuse towards the Au. The diffusion will continue until the alloy condition is satisfied and the alloy bond is formed through the interface.

Therefore, the heater of the self-testing sensor is made of Au film resistance and its self-testing cut off to press cavity is packaged by electrostatic-alloy bonding.

### 3 Electrostatic-alloy bonding experiment

Deposition of the Ti-Au film in vacuum evaporation on the 7740 glass is done first and the conglutinate layer of Ti will have a thickness of 500 Å while Au will adopt a different thickness and lithography resistance bar. Follow the contrast experiment in Al film resistance. Before bonding, decay the surface of Si with the HF and make sure there is no oxidation layer.

We use HG-1 anodic boning machine developed by Harbin Institute of Technology (H.I.T) MEMS Center to achieve bonding. Static bonding of Si/glass is done first and then Si/Au alloy bonding follows.

After bonding, we use nitrogen to press the vacuum and check the method for leaks to test the obturation of the cutoff to press cavity. Firstly, we put the sample into a leak detection equipment produced by North Wireless No.1 Factory and keep it under a condition of $3 \times 10^5$ Pa by filling in N₂ for 40 min. Secondly, we deflate the gas, take out the sensor chip and put it into a vessel with grain alcohol immediately. We need to keep the liquid at 1–2 cm higher than the surface of the sensor in order to observe whether there are any bladders created. If there are no bladders, we will put this vessel into a low air pressure platform covered with a vacuum cover and take out the gas until the vacuum degree reaches $0.2 \times 10^5$ Pa in order to detect leaks. The result of the bonding and leak detection are shown in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Au/µm</th>
<th>Static bonding</th>
<th>Alloy bonding</th>
<th>Leak detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
<td>800 V, 380°C</td>
<td>Step edge without bonding</td>
<td>Big air bubble, leak</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>1 000 V, 420°C</td>
<td>Step edge without bonding</td>
<td>Air bubble, leak</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>Small unbonding section</td>
<td>400°C, 2 h</td>
<td>No air bubble, airproof</td>
</tr>
<tr>
<td>4</td>
<td>0.3</td>
<td>Step edge with bonding</td>
<td>400°C, 2 h</td>
<td>Small air bubble, leak</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>Step edge with bonding</td>
<td>400°C, 2 h</td>
<td>Small air bubble, leak</td>
</tr>
<tr>
<td>6</td>
<td>0.8</td>
<td>Step edge with gap</td>
<td>400°C, 2 h</td>
<td>Small air bubble, leak</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
<td>Step edge with bonding</td>
<td>400°C, 2 h</td>
<td>Small air bubble, leak</td>
</tr>
</tbody>
</table>

![Fig. 2 principle fig of static bonding](image-url)