Analysis of Anodic Bonding and Packaging Effects in Micro Sensors

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ABSTRACT

Anodic bonding is quite popular in making micro-sensors since it can bond sodium-rich glass to silicon or virtually any metals with good adhesion strength in lower temperature. It is well known that this process will introduce thermal strain due to different coefficients of thermal expansion between silicon (or other metal) and glass. Yet its effects have not been well studied. After anodic bonding, either adhesive or solder joint is usually used to attach the bonded sensors to plastics or other materials. The packaging strategy will definitely influence the performance of sensors too. The effects and interactions in the process of anodic bonding and die attachment will be studied in this paper. Models based on finite element method are proposed to describe the relationship among them. The simulation results match experimental results quite well. Based on this model, the major influential factors are also studied systematically.

Keywords: anodic bonding, sensor, packaging

1 INTRODUCTION

If a high voltage (around 400-1500V) is added to help bond the glass and silicon based sensor, the required bonding temperature can be lowered to around 400 °C. This process is usually called anodic bonding. It is quite popular in making micro-sensors since it can bond sodium-rich glass to silicon or other metals with good adhesion strength in lower temperature than using thermal bonding. This process is widely used to help make 3D structure, create hermetic environment or help reduce the outside packaging influences. However, it will still introduce thermal strain, which is caused by different coefficients of thermal expansion between silicon (or other metal) and glass, and its effects have not been well studied yet.

After anodic bonding, either adhesive or solder joint is usually used to attach the bonded glass to engineering plastics or other materials. The packaging strategy will determine the amount of stress induced in packaging brought to the sensor and definitely influence the performance of sensors, too. Therefore, the above effects and interactions between anodic bonding, and packaging are very important for the performance of sensor and will be studied in this paper.

To study the anodic bonding effects, piezoresistive type pressure sensors are used as samples and their zero pressure offsets are measured before and after anodic bonding, respectively. Since the stress variations can not be easily measured, the zero pressure offsets are used here. Zero pressure offset is a function of stress gendered in piezoresistors and is useful for studying the interactions between each process. For example, the thermal strain induced by anodic bonding leads to an eight to twelve mV shift of the zero pressure offset. A finite element model is then created to obtain the stress status change due to anodic bonding and to calculate the corresponding offset drift. In order to calculate the voltage changes from thermal strain and pressure, linear assumptions and submodeling techniques of ANSYS are used here. It is found that the simulated offset drifts match the results of the real sensors quite well. Based on the above model, parametric studies on offset drifts induced from anodic bonding are also done. The dominant parameters on drift seem to be contact areas between silicon and Pyrex glass and the thickness of Pyrex glass.

Next, the interactions between anodic bonding and die attachment are also investigated. The zero pressure offsets of piezoresistive type pressure sensors are again measured. This time the sensors are bonded first and later attached to engineering plastics by using RTV. Another drift in opposite direction is shown. In order to understand the process, a new finite element model is created to obtain the stress status caused by anodic bonding and die attachment, respectively. The corresponding offset drifts are also calculated. This model must be able to consider the previous anodic bonding effect with the addition of new elements (RTV and plastics) and give us the equivalent offset drift. Therefore, the element birth/death and submodeling techniques of ANSYS are used to do the tricks. The simulated results match quite well with measured data. Further analysis and study are done based on this model. It shows that the Young's modulus of RTV (or other adhesives) is the main decisive factor. Apparently, the thermal strain stemming from the different coefficients of thermal expansion between silicon and glass is released by the softness of adhesives.

2 ANODIC BONDING

Thirty years ago, Wallis and Powerantz [1] first discovered that if an electric field is added between a metal as anode and a glass as cathode, a strong adhesion strength can be obtained with a lower temperature than using thermal bonding. This process is usually known as anodic bonding or electrostatic bonding. Compared to thermal bonding, anodic bonding has the advantage of lower process temperature and less stringent requirement for surface quality. The bonding of Si-glass is hermetic and the strength is even higher than the substrate [2]. The creation of a SiO_2 layer between Si-glass interface is believed to be the main reason for the strong bonding. The bonding mechanism is usually explained from an electrochemical viewpoint. At elevated temperature, the migration of sodium toward the cathode makes a high electric field in the interface and pulls the glass and Si into intimate contact. The high temperature helps to create the covalent bond between the interface. A schematic of anodic bonding set-up is as shown in Figure 1.

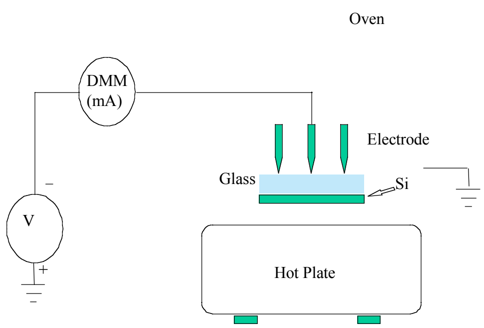

Figure 1. Anodic bonding set-up

To study the anodic bonding effects, piezoresistive type pressure sensors are used as samples and their zero pressure offsets are measured before and after anodic bonding, respectively. The pressure sensors are made by bonding silicon sensor and Pyrex 7740 glass together. The bonding control parameters are temperature (350-430 °C), bias voltage (600-1500V) and time (up to 60 minutes). To inspect the bonding results, probing station is used to test zero-pressure offset before and after anodic bonding, respectively.

3 FINITE ELEMENT ANALYSIS

Though, a thin plate theory was developed long time ago for rectangular or square type plate and is used for basic analysis of diaphragm type pressure sensor, it is good only when the deflection is small compared with thickness of diaphragm. Therefore, the real application is limited. To study the effects caused by bonding glass to the sensor, the thermal strain and glass structure must be also considered. Finite element analysis is obviously the best candidate to serve this purpose. Since the dimension of resistors is too small compared with the dimension of die, a meaningful mesh will need a very large database and long calculation time. Meanwhile, large deformation asks for nonlinear calculation techniques and stringent convergence criteria [3].

To study the anodic bonding phenomena, the stress contributed by pressure and thermal strain due to the differences of coefficients of thermal expansion between the silicon and glass must be considered at the same time. In addition to input problems, the boundary conditions for each input are also different. Since such system is very complicated, steps are taken to simplify the analysis. First, the induced system responses from stress change due to pressure difference and thermal strain are assumed to be linear. That means the system is assumed to be linear. Also, the corresponding boundary conditions are set accordingly and are also assumed to make no differences.

To meet all the requirements, the submodeling technique provided in ANSYS [4], which requires less storage space and still provides needed mesh size, is used. The submodeling process requires to create a new small model out of the original model (that's why it is called submodel) and read in the boundary conditions of cutting edge within previous larger model. With two different inputs and boundary conditions, an automated procedure coded in ANSYS macro language is also developed to assist in studying different structure parameters. The model parameters are listed in Table 1.

die spec.	2.5*2.5*0.415 mm
diaphragm spec.	1.35*1.35*.015 mm
etch angle	54.7 °
wafer orientation	(1 0 0) n-type silicon
resistor orientation	<1 1 0> p-type silicon
material	anisotropic silicon
model size	1/4 die
temperature	400-25 _
element type	Solid 64 [4]
mesh method	Mapped Mesh [4]

Table 1 Parameters used in model

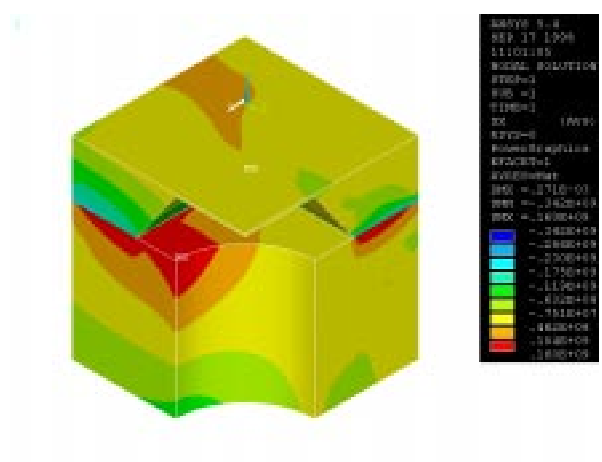

Figure 2: Stress distributions after anodic bonding

The diaphragms in our sample pressure sensors are square type and only one quarter of die is needed to do the analysis due to the symmetry. Figure 2 shows one of stress distribution results, σ_x, on a one-fourth sensor model. The stress distribution, σ_x and σ_y, are symmetrically on the center of edge with same signs.

4 OUTPUT VOLTAGE

Resistors are with finite length and usually located in the high stress gradient areas to maximize their outputs. Based on finite element analysis, summation method is used to calculate the equivalent stress result.

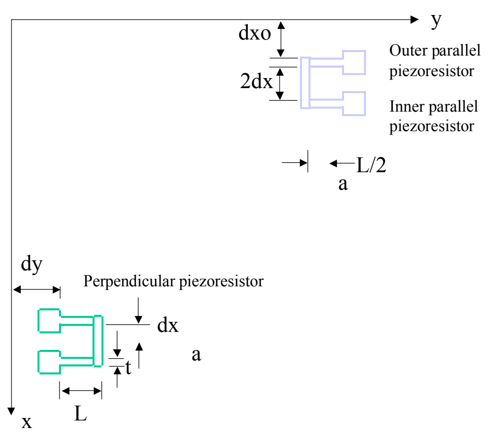

Figure 3: The positions of piezoresistors in 1/4 square diaphragm

From Figure 3, we know that the resistors are located near the edge of diaphragm and very sensitive. The resistor dimensions, resistor locations and their distances away from the edges are chosen as output control parameters. If the width of diaphragm is 2a and the thickness is h, then the stress of outer parallel resistor can be described as

$$\sigma_{x,plo} = \frac{\int_{\delta y+a-L/2}^{\delta y+a}\int_{\delta x+dxo}^{\delta x+dxo+t} \sigma_x \Delta x \Delta y}{Lt/2} \qquad (1)$$

$$\sigma_{y,plo} = \frac{\int_{\delta x+dxo}^{\delta x+dxo+t}\int_{\delta y+a-L/2}^{\delta y+a} \sigma_y \Delta y \Delta x}{Lt/2} \qquad (2)$$

where $\sigma_{x,plo}$ and $\sigma_{y,plo}$ represent the equivalent stress of outer parallel resistor in x axis and y axis, respectively, and δx and δy are the distance from the edge of die to that of diaphragm. The equivalent stress of other resistors can be obtained similarly.

If nonlinear piezoresistive relation [5] is considered, the resistance change can be expressed as

$$\frac{\Delta R}{R} = \sum_{i=1}^{n} (C_{li}\sigma_l^i + C_{ti}\sigma_t^i) \qquad (3)$$

where σ_{li} and σ_{ti} are the ith-oder transverse and longitudinal piezoresistive coefficients. In general, a third-order polynomial approximation is good enough.

If a Wheatstone bridge circuit is used to obtain the output voltage, the sensitivity, s, calculated based on the above information will be

$$s = \left(\frac{1}{2}\frac{\Delta R}{R}_{pl} - \frac{1}{2}\frac{\Delta R}{R}_{pp}\right) \qquad (4)$$

where $(\Delta R/R)_{pl}$ and $(\Delta R/R)_{pp}$ represent the change rate of resistance in parallel resistors and perpendicular resistors respectively.

Then the corresponding device output, V, can be estimated as

$$V = sI_c R_c \qquad (5)$$

where I_c is device current and R_c is device resistance. When the both sides of the diaphragm are under normal 1 atm pressure, the output is called zero-pressure offset.

From the above equations, the offset drift from the sample sensors after anodic bonding is calculated to be around 10 mV (from the original –0.08 to 10.23mV) and is very close to the statistical results (usually also shifts around 10 mV).

Based on the above analysis strategies, parametric studies on offsets from anodic bonding are also done. The results are shown in Figure 4. The dominant parameters on offset seem to be the contact areas between silicon and Pyrex glass and the thickness of Pyrex glass

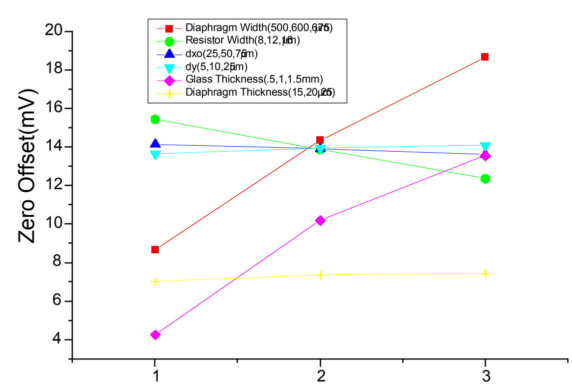

Figure 4: Offset after anodic bonding

5 DIE ATTACHMENT

As stated before, the packaging will introduce extra stress/strain and change the final sensor performance. To study the interactions between anodic bonding and die attachment, the zero pressure offsets of piezoresistive type pressure sensors are again measured. This time the sensors are bonded by anodic bonding first and later are attached to engineering plastics by using RTV. Another drift in opposite direction is seen. In order to understand the process, another finite element model is created to obtain the stress status caused by anodic bonding and die attachment. To make this model behave like real sensors, this model must be able to consider the original anodic bonding effect and then the effects with the addition of new elements (RTV and plastics). The equivalent offset drifts, of course, must be also shown. To solve this difficult problem, the element birth/death and submodeling techniques of ANSYS are used to do the tricks.

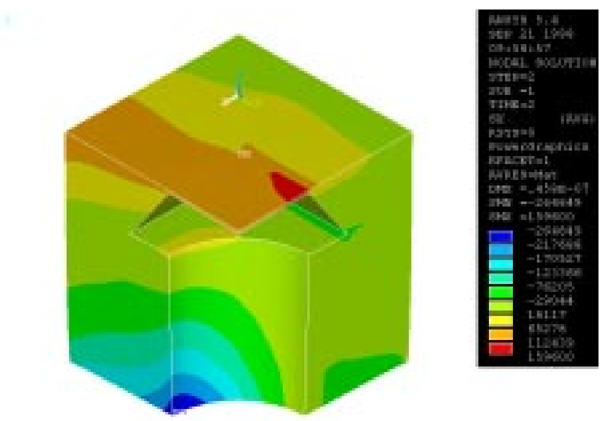

Figure 5: Stress distributions after bonding and die attachment

The simulated result is shown in Figure 5 and the calculated voltage output matches quite well with measured data. Further analysis and parametric study are done based on this model. It shows that the Young's modulus of RTV (or other adhesives) is the major decisive factor and the result is as shown in Figure 6. Apparently, the thermal strain stemming from the different coefficients of thermal expansion between silicon and glass is released by the softness of adhesives.

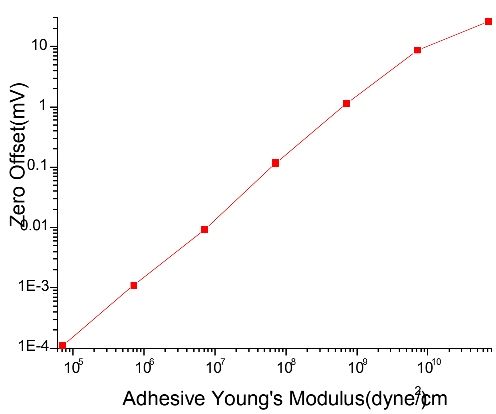

Figure 6: Offset after die attachment

6 SUMMARY

In this study, interactions among anodic bonding and die attachment and their effects are explored and well understood. The results and experience should help design and make a better micro-sensor.

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