Pressure-Indicating Film Characterization of Wafer-to-Wafer Bonding

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Wafer-to-wafer bonding has become an enabling semiconductor technology in industries such as 3D packaging, MEMS, MOEMS, and SOI. In a typical wafer bonding process, two flat substrates are permanently joined (bonded) to one another by applying precise combinations of physical pressure, temperature, and/or voltage (Figure 1). Each of the above factors is set depending on the substrate materials being bonded, and the control of these parameters is crucial to a successful, high-quality, high-uniformity manufacturing process.

Of the three major parameters in a bond recipe, voltage and temperature are readily measurable within a wafer bonding chamber using common electronics and thermocouples. Pressure, on the other hand, is measured in the tool as the total amount of force exerted over the pressure column. This measured force is then used to calculate the average pressure, assuming perfectly flat pressure plates.

In practice, the pressure plates are often non-ideal, or they may have degraded over time. This leads to potential pressure variations which would not be detected with control software alone. Such poor distribution of pressure can lead to unbonded wafer areas, cracked wafers, or even premature wear of the pressure plates.

The significance of a uniform applied pressure in a bonding process depends largely on the specific materials being bonded. For example, in an anodic bonding process, silicon is bonded to glass (typically Pyrex®) by applying a large electric field (e.g. 1000V) at elevated temperatures (e.g>300 C). At such temperatures, sodium impurities in the bulk of the normally insulating glass becomes mobile (Figure 2), thus making the glass much more conductive. When a high voltage is applied to the anode (hence the name anodic bond) in this state, the sodium ions move towards the anode, leaving oxygen ions at the bond interface. The reaction between silicon and oxygen then forms a very strong SiO2 bond.

What is relevant to our discussion is the fact that the applied voltage also creates a very large electrostatic force on the bond stack, which assists with the bonding process. Because the magnitude of the electrostatic pressure is generally sufficient for a full bond, physically applied pressure is neither critical nor required for this type of bond process.

However, in an eutectic/ thermocompression bonding process, two arbitrary substrates are bonded together using thin intermediate films that are often metallic alloys (Fig. 1-3). A common bond metal for silicon is Au-Si eutectic bond with a eutectic temperature of 363°C. In this bond, the silicon surface is placed in contact with Au deposited on the other substrate, and the stack is brought in contact to a temperature just beyond the eutectic point for a short time to allow the alloy to form.

Temperature control is obviously a critical parameter here, but it is not the focus of this discussion. Given a fixed temperature, if too much pressure is applied, the eutectic alloy could "spill out" into unwanted regions and cause short circuits. Conversely, too little pressure would typically result in weakly bonded or unbonded regions. And in practice, both spill outs and unbonded regions are often found on the very same pair of substrates due to pressure and/or temperature non-uniformities. Therefore, the characterization of applied pressure

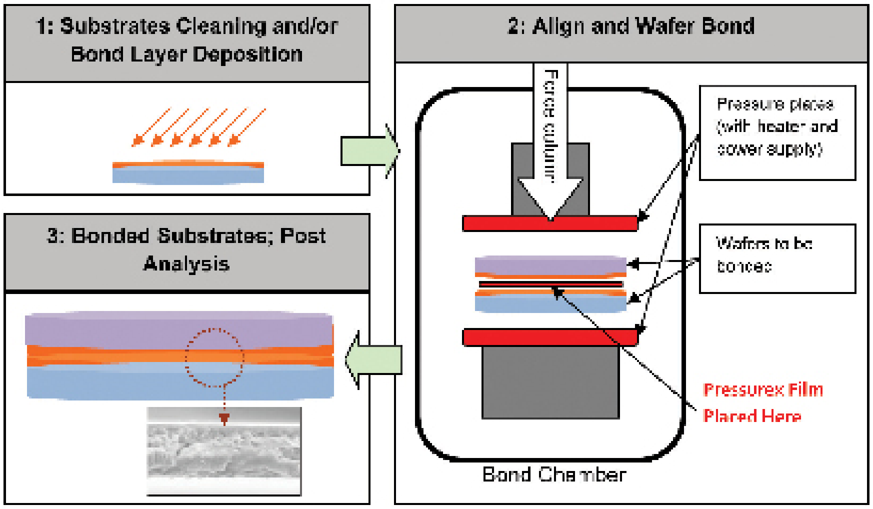


Figure 1: Wafer bonding process illustration.

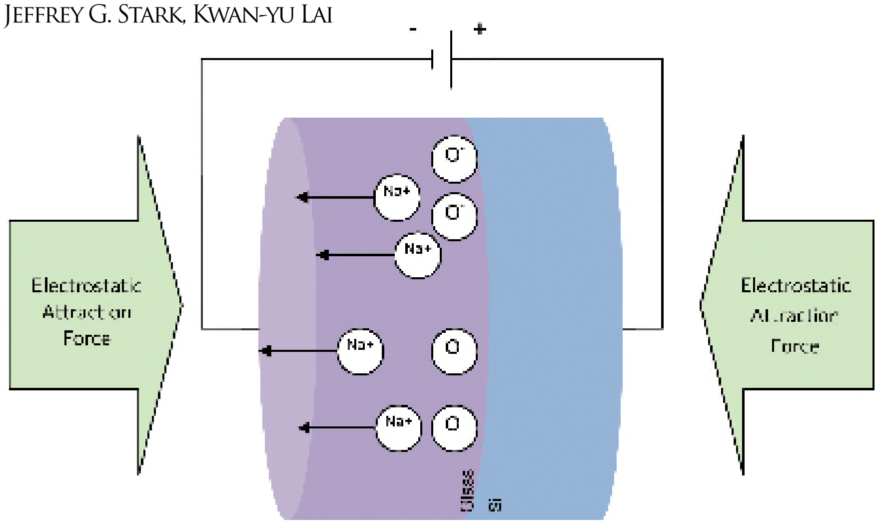


Figure 2. Anodic bonding process illustration

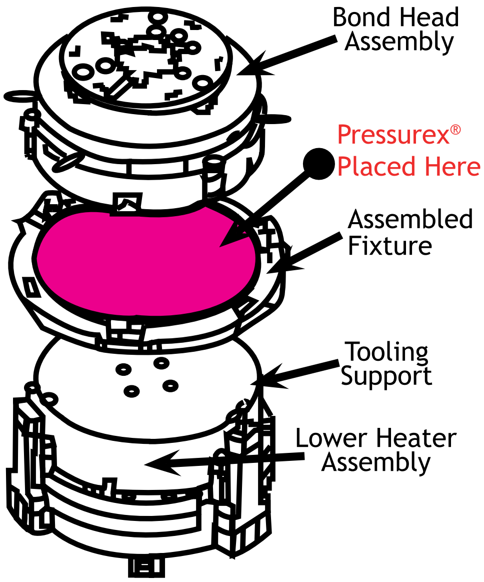


Figure 3. Magnified image of a wafer bonding fixture shows Pressurex sensor film in place

would be an important aspect of such bond processes to achieve a high yielding bond.

Pressurex® film, developed by Sensor Products Inc., is one of the most direct and economical ways to detect and correct such pressure variations. The thin flexible film measures pressure from 2 - 43,200 PSI (0.14 - 3,000 kg/cm2).

Pressurex® is a Mylar based film that contains a layer of tiny microcapsules. The application of force upon the film causes the microcapsules to rupture, producing an instantaneous and permanent high resolution "topographical" image of pressure variation across the contact area.

When placed between contacting surfaces of a wafer bonding fixture, it instantly and permanently changes color directly proportional to the amount of pressure applied. The precise pressure magnitude is easily determined by comparing color variation results to a color correlation chart (conceptually similar to interpreting Litmus paper).

The film's thickness is 4 or 8 mils, which enables it to conform to tight spaces. It is ideal for invasive intolerant environments and tight spaces not accessible to conventional electronic transducers.

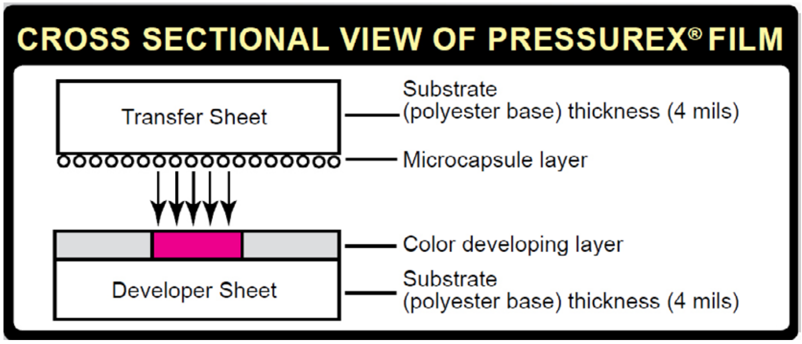
By running a bond recipe, with the pressure set to 4 bar on an appropriate grade of pressure film, a direct imprint is formed. Figure 4a shows an image of Pressurex Micro® sensor film 2-20 PSI (0.14 - 1.4 kg/cm2) taken from a 6" diameter bonding tool with poor pressure uniformity. Analyzing the pressure distribution with the Topaq Tactile Force Analysis System®, this image is transformed into a color coded pressure map in Figure 4b, revealing a donut shaped high pressure ring (>10 bar) with relatively little pressure applied at the center. The line scan [Figure 4c] further elaborates these pressure inconsistencies.

A series of adjustments to the pressure column of the bond tool were then made, and the pressure uniformity was checked each time by running the same bond recipe on the same range of pressure film. The resulting series of images are shown in Figure 5, which confirms that the adjustments have been made and the actual pressure is more uniform. Note that after the adjustments, the pressure film analysis shows an offset from the intended recipe pressure of 4. By using properly calibrated pressure film, the offset can be corrected. Similarly, it can also be used to match processes across multiple bond tools.

In addition to troubleshooting the pressure distribution, the same pressure film can be used as a tool performance log in manufacturing practices such as six-sigma statistical process monitoring. Cost savings will inure to users of pressure indicating film through decreased scrap rate and increased time efficiency. There are also specific benefits that are distinct to each type of bonding application:

1. Metal Eutectic Bonding

Key benefits provided: Prevents the eutectic alloy from spilling out into unwanted regions and causing short circuits which given a fixed temperature can occur if too much pressure is applied. Conversely, minimize weak bonded or un-bonded regions which can occur if too little pressure is applied. The pressure



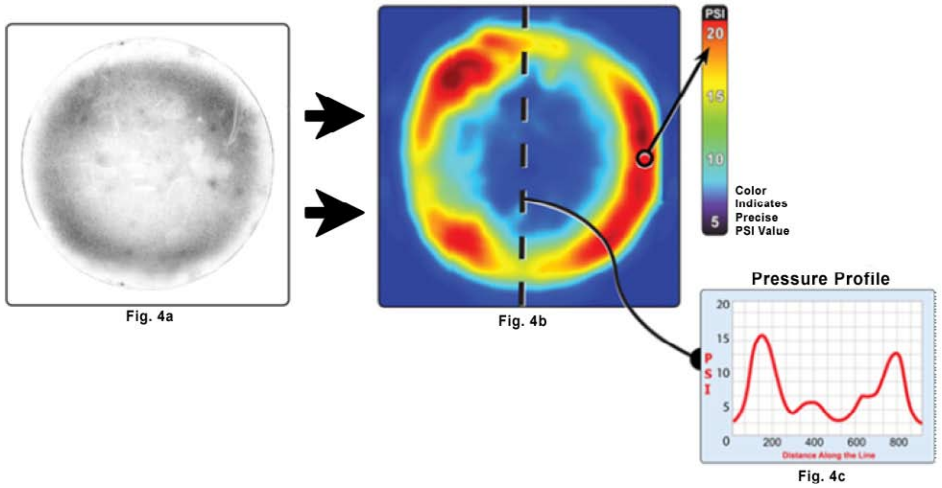


Fig. 4a

Fig. 4b

Fig. 4c

Figure 4. Bond tool images show pressure inconsistencies.

film reveals both the magnitude and distribution of pressure across the bonding platen and part minimizing the potential of too much or too little pressure.

Film grade recommended: Ultra low (28 to 85 PSIi)

2. Anodic Bonding

Key benefit provided: Reveals whether the top and bottom plates are in uniform contact.

Film grade recommended: Ultra low 28-85PSI(2-6kg/cm2)

3. Fusion Bonding

Key benefit provided: Minimizes trapped air pockets in between the bonded substrates which on certain applications can be caused by non-uniform applied pressure.

Film grade recommended: Ultra low 28-85PSI(2-6kg/cm2)

4. Metal Diffusion Bonding

Key benefit provided: Greatly minimize un-bonded wafer sections since the wafer won't bond at all if the forces are too low.

Film grade recommended: Super low 70-350PSI(5-25kg/cm2)

5. Glass Frit Bonding

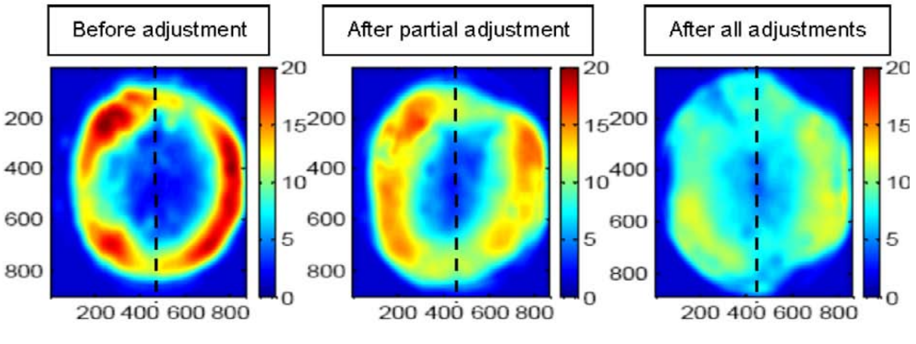
Key benefit provided: Ensures hermetic seal is formed around the device which will not occur if pressure is too low. Prevent the glass frit from flowing into the device area which can occur if pressure is too high.

Film grade recommended: Ultra low 28-85PSI(2-6kg/cm2)

6. Polymer Adhesive Bonding

Key benefit provided: Minimizes voids caused by polymer thickness non-uniformity. While this is not a direct problem related to the amount of pressure, pressure non-uniformity can exacerbate the problem.

Film grade recommended: Ultra low 28-85PSI(2-6kg/cm2)



Before adjustment

After partial adjustment

After all adjustments

Figure 5. Bond tool images show improvement to the pressure uniformity as captured by Pressurex Pressure Indicating Film.

Conclusion

In summary, Pressurex® is a quick and direct research tool that provides a snapshot of the pressure distribution of a bond tool at room temperature. Through calibrated post analysis, it also provides a method to compare processes and tools in manufacturing.

About Micralyne Inc.

Micralyne is one of the largest independent MEMS foundries in the world. As a MEMS industry innovator and leader, Micralyne has a reputation of offering unparalleled MEMS product development and commercial volume MEMS manufacturing. With core competencies in MEMS micromachining, thin film deposition, and MEMS assembly & test capabilities, Micralyne develops and manufactures MEMS technology for the communications, energy, life sciences, and transportation markets. http://wvw. micralyne.com

About Sensor Products Inc.

Headquartered in New Jersey, USA, and established in 1990, Sensor Products Inc. is a world leader in the manufacture and distribution of tactile pressure indicating solutions. Their customized and off-the-shelf products are installed within all of the Fortune 500 industrial companies as well as thousands of smaller manufacturing firms. Their sensors are used in applications as diverse as tire testing to semiconductor manufacturing and from R&D labs to space missions. Additionally, Sensor Products Inc. provides in-house and on-site stress and pressure mapping analysis and consulting, as well as a variety of regional technical seminars. http://www.sensorprod.com

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