Comprehensive Study on Polymer Based Chip-to/chip Bonding for Gas Sensor Application

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Abstract

In sensor application, there is a need to bond a silicon or glass die on another sensor die to form either the enclosed cavity for the sensor or to form a heterogeneous integration of two different devices. Chip to chip bonding can be applied either by polymer material such as die attach epoxy or solder material, or using hermetic method with frit glass material [1]. One of the attractive polymer material is the photosensitive polyimide (PSPI) [2]. In applications, PSPI is being applied as re-distribution layer for the package. Good adhesion to RDL is required for PSPI with low temperature curable nature [3]. PSPI can be patterned to form the cavity structure on the sensor device.

The study presented in this paper is to investigate the bonding joint of chip by chip using PSPI adhesive film "X". One of the challenges of adopting PSPI is that it must maintain good adhesion between the bonded interfaces. As such, comprehensive DOE run is carried out to obtain the most optimized parameters for the sample/chip die attachment onto substrate. The bonded samples are able to pass the die shear strength criteria and withstand the wire bonding process without delamination.

1. Introduction

There is a widespread use of polyimides in the manufacturing of electronic devices and being increasingly used in the diverse areas of information technology and electronics. The research for developing PSPI has been increased, hence using photoresists for patterning polyimides is unnecessary and the number of steps in fabrication of electronic devices has been reduced. In the future, the development of technology using PSPI is expected to contribute in the significant role of manufacturing photonic devices.

PSPI is being used in a photonic gas sensor device as an adhesive for bonding between the photonic substrates and emitter/detector chips. In this studies, glass and Si dies are used to bond unto a Si substrate printed with PSPI by using different bonding force at different temperature of the chuck table and temperature of the bond head using a Pick and Place tool. The bonded samples are subjected to curing at temperature of 200°C for 2 hours using oven. Die shear strength will be further study and discuss.

2. Test Vehicle Design

Comprehensive study on the bonding quality is conducted using glass and silicon die. The glass die is for adhesive inspection and the Si die is for die shear test. The size of the glass die A is of 2.3mm x 3.1mm x 1.1mm, and glass die B with the size of 2.6mm x 3.2mm x1.1mm. The silicon die A with the size of 2.3mm x 3.1mm x 0.73mm, and Si die B with the size of 2.6mm x 3.1mm x 0.73mm. Figure 1 showed both the glass and silicon die. Glass die A or glass die B will be bonded onto the PSPI patterned on Si substrate as shown in Figure 2. Table 1 summaries the different test vehicles used in the bonding study. Figure 3 show the bonded samples that is ready for either visual inspection or die shear test.

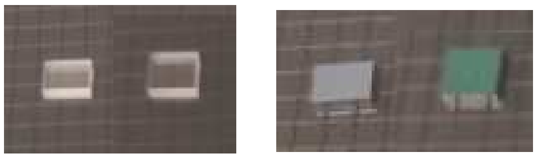


Figure 1: (a) Glass Die; (b) Silicon Die

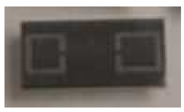


Figure 2: PSPI Coated Substrate

Table 1: Details of die types and dimensions

Bonding Configuration	Chip's Material	Chip's Size	Substrate's Material
A	Glass	2.3mm x 3.1mm x 1.1mm	Si
	Si	2.3mm x 3.1mm x 0.73mm	
B	Glass	2.6mm x 3.2mm x1.1mm	
	Si	2.6mm x 3.1mm x 0.73mm	

Figure 3: Bonded Glass/Die on PSPI Coated Substrate

3. Experimental Methods

Plasma treatment on the surface is a known method of improving the adhesion between the bonded surface. An experiment is done to verify any impact to the contact angle and the bonding adhesion strength before implementing the plasma treatment on further study on the bonding parameters. The samples were subjected to Ar plasma before bonding with chuck temperature set at 130C, bond force of 4kgf for duration of 20sec. With Ar plasma cleaning treatment on the die surface, the contact angle drops significantly from 28 degrees to 8 degrees as shown in Figure 4 and 5 respectively. The bonded sample with and without plasma treated is subjected to shear test and the result is tabulated in Table 2. Shear force increases for bonded samples with plasma treatment. As such, all samples will be treated with plasma treatment before the bonding study.

Table 2: Die Shear Results (With and without Ar Cleaning)

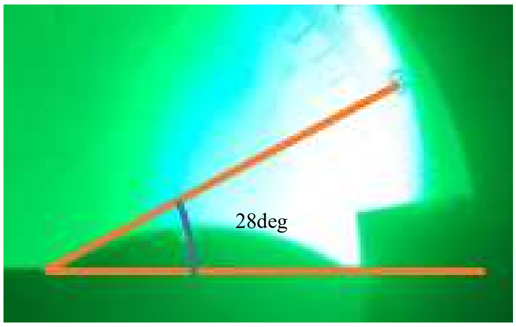
Without Plasma		With Plasma	
Config A Avg Shear Force (gf)	Config B Avg Shear Force (gf)	Config A Avg Shear Force (gf)	Config B Avg Shear Force (gf)
709.5	1230	1267	1747

Detail DOE run with different force, time, and temperature has been carried out to determine the most optimized process that yield higher shear strength. Table 3 tabulates the DOE details. The dies are treated with 10 minutes of Argon (Ar) plasma cleaning prior to bonding. After bonding, the packages are then sent to cured at 200°C for 2 hours, followed by die shear test. The die shear strength should meet the specification as stated in MIL-STD-88, method 2019. By applying final optimized bonding parameters, the chips are bonded and formed the sample (Figure 3) ready for the next step of PCB die attachment. Figure 6 illustrated the full wire bond package with the sample bonded on PSPI coated substrate which is attached to PCB. The test vehicle used is a 1900um x 10080um x 775um thick Si substrate with coated PSPI on each end as shown in Figure 7.

Visual inspection of the coated PSPI via bonded glass die was done using optical microscope. The gap between the die and substrate will be measured. The shear tool height is set 2/3 of the Si and glass die height as shown in Figure 8.

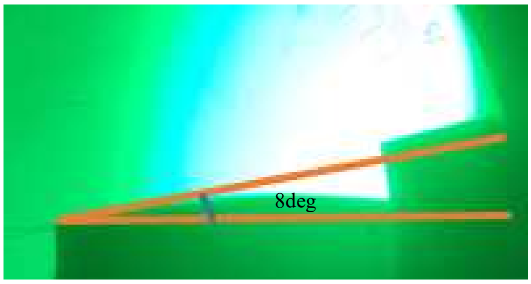
Table 3: Information of the DOE Plan

DOE Run	Chuck Temperature (°C)	Bond Force (kgf)	Bond Time (sec)	Bond Temperature (Celsius)
1	130	1	20	115
2	130	2	20	115
3	130	4	10	115
4	130	4	20	115
5	130	4	20	Room Temperature
6	130	5.5	10	Room Temperature
7	130	5.5	20	Room Temperature
8	130	5.5	10	115
9	130	5.5	20	115
10	130	6	10	Room Temperature
11	130	6	20	Room Temperature



The contact angle is at 28 degrees.

Figure 4: Contact Angle Measurement Before Ar Plasma Clean



The contact angle is at 8 degrees.

Figure 5: Contact Angle Measurement After Ar Plasma Clean

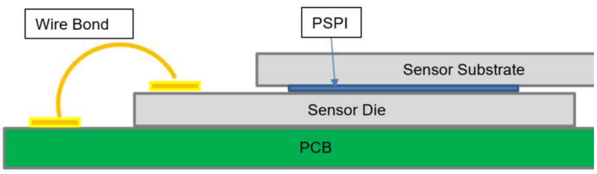


Figure 6: Schematic Drawing Bonded Sample on PCB with Wire Bond

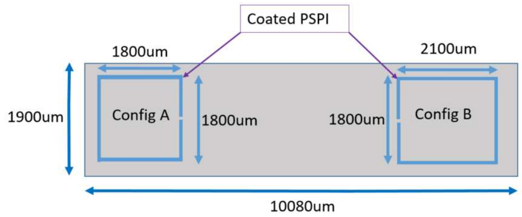


Figure 7: Si Substrate with coated PSPI Schematic Diagram

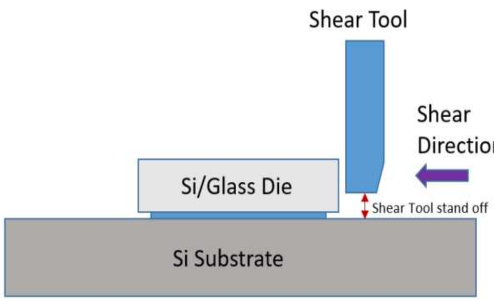


Figure 8: Die Shear Test Schematic Diagram

4. Results

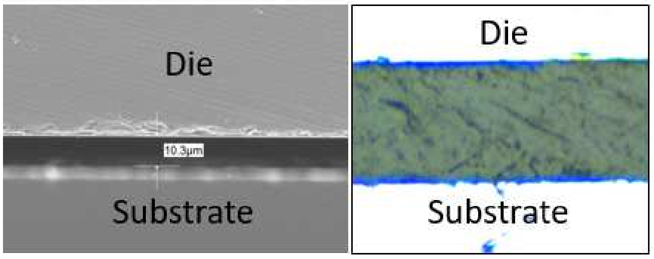


Figure 9: Cross Section Images

The cross section image for bonded area are taken using Nikon Microscope. Optical images for bonded glass die on coated PSPI substrate are taken using Nikon Microscope. Figure 10 showed the images of the bonded samples for DOE 1 to 6. Figure 11 showed the images of the bonded samples for DOE 7 to 11. Uniform spreading of the PSPI material on the bonded interface were observed.

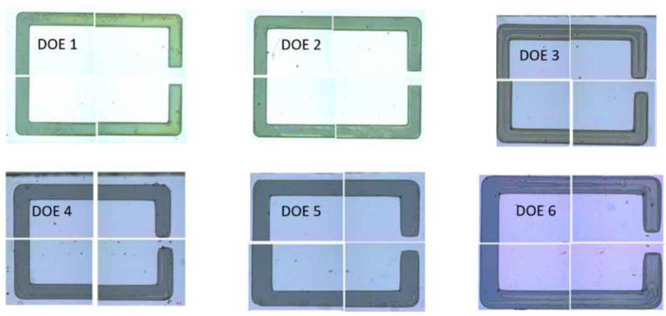


Figure 10: Optical Images of Bonded samples for DOE 1 to 6

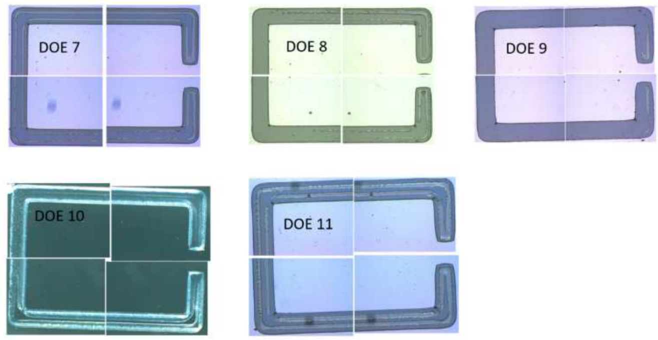


Figure 11: Optical Images of Bonded samples for DOE 7 to 11

Shear test was conducted on the bonded samples. Figure 12 showed the images of the shear tested samples for DOE 1 to 6. Figure 13 showed the images of the shear tested samples for DOE 7 to 11. Interfacial failures were observed for all DOE runs.

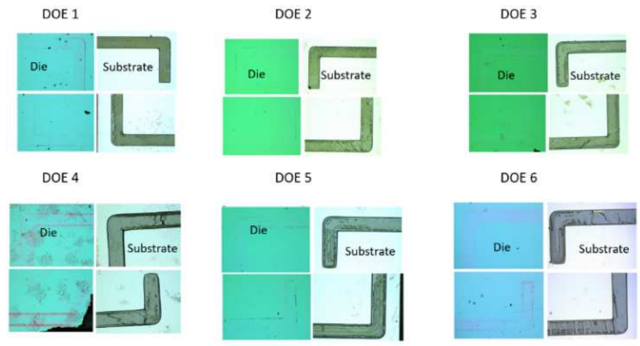


Figure 12: Optical Images of shear test for DOE 1 to 6

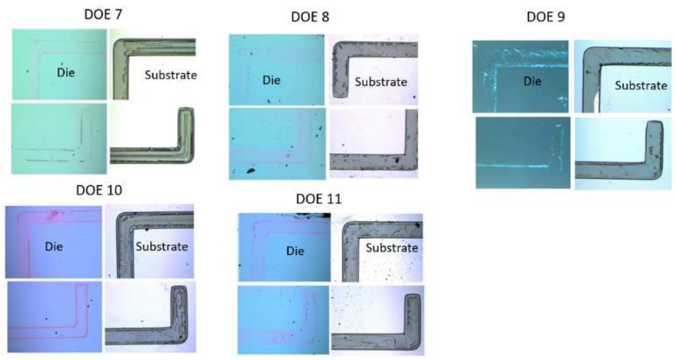


Figure 13: Optical Images of shear test for DOE 7 to 11

5. Die Shear Strength Analysis

The die shear strength should meet the specification as stated in MIL-STD-88H, method 2019. The surface area of the coated PSPI for Config A and Config B are calculated as following;

Config A: 20 x 10^-4 inch sq
Config B: 22 x 10^-4 inch sq

The die strength for Config A and Config B are determined based on the die area by using the graph as shown in Graph 1. Thus, the minimum force required for Config A is 800 gram and Config B is 900 grams. The results for die shear strength have been tabulated with average shear force as shown in Table 4. Chart 1 & 2 illustrated the average shear test force for each DOE run for confi A & B respectively.

DOE 9 with the elevated bond temperature and longer bonding duration exhibited the highest die hear strength results. DOE 1, 2 , 6 and 10 failed the minimum shear strength requirement.

Graph 1: Minimum Force versus Die Attach Area

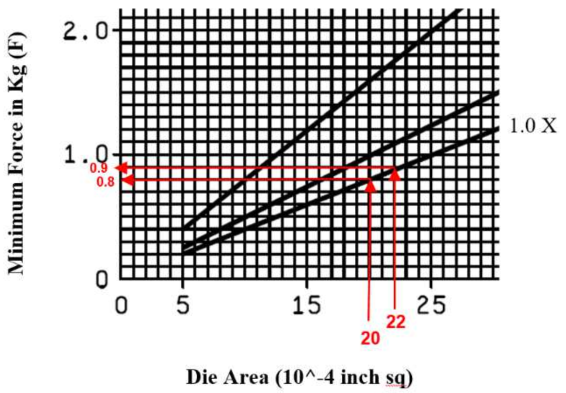


Table 4: Die Shear & Gap Height Results

DOE Run	Config A Avg Shear Force (gf)	Config B Avg Shear Force (gf)	Config A Avg Gap Height (um)	Config A Avg Gap Height (um)
1	326.6	367.9	14.1	14
2	4274.3	338.8	13	11.3
3	9591	4584	13.25	15.1
4	7055	8016	16.38	15.76
5	1267	1747	10.9	10.4
6	598.4	4314	17.9	18.7
7	646.2	3476.9	16.7	16.3
8	8941	9183.9	12.8	17.8
9	13698	8643.6	13.8	14
10	359	538.5	17.18	21.6
11	1454	1309.7	18.8	18.3

Chart 1: Shear Test Result for Config A

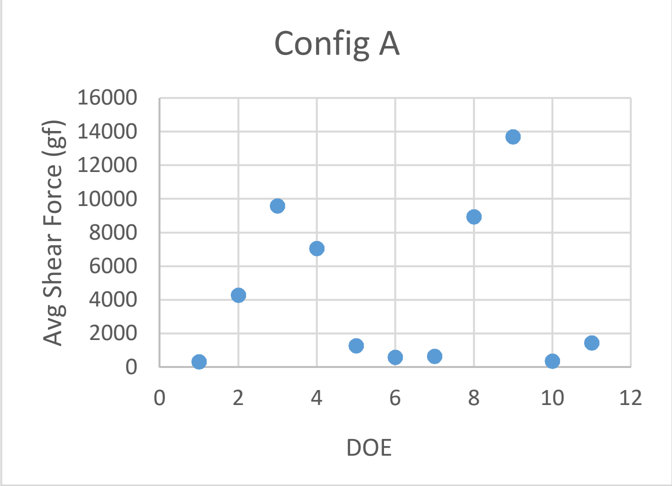
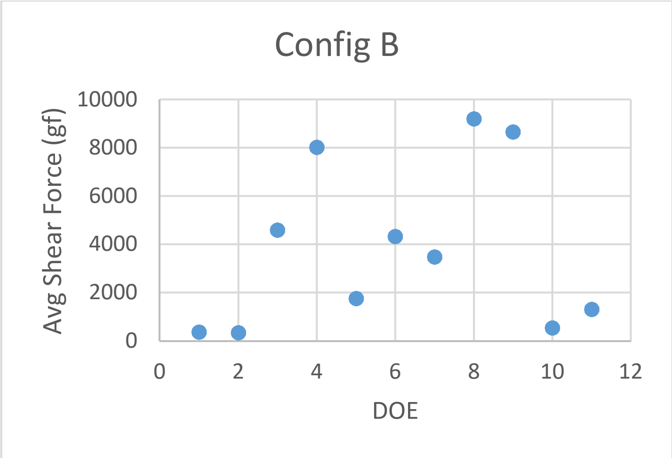


Chart 2: Shear Test Result for Config B



6. Conclusions

Comprehensive Study on Polymer Based Chip-to/chip Bonding for Gas Sensor Application had been conducted with the following findings

- Bonding force at 2kgf and below is not strong enough to get achieve the minimum force required.
- Ar plasma cleaning treatment increased the shear force.
- Parameters of DOE 5 is chosen for bonding actual device as it manage to achieve die shear force requirements without excessive bonding force and without bond temperature. Also without bond temperature, the device will not be subjected to excessive heat treatment.
- Parameters of DOE 5 is applied for actual device and it is able to withstand the wire bonding process without delamination.

7. Acknowledgements

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