Thermosonic Gold to Gold Intermetallic Advantages for CSP Packaging

By

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Abstract

Flip chip thermosonic back end assembly method is a low cost clean gold to gold interconnection method. The advancement of flip chip thermosonic process for CSP packaging of HBLED and CMOS image sensors is occurring due to the precision intermetallic clean interconnection properties and ability to provide a small form factor packaging to consumer products. This paper will investigate thermosonic metal to metal interconnection process for these high growth assembly markets.

Thermosonic bonding uses a micro weld interconnection die attach method at lower bonding temperature (150°C). The thermosonic metal to metal interconnection method is lead free and the process does not use flux or solder alloys. Thermosonic flip chip die attach process uses a robust individual die "scrubbing" process which reduces assembly steps and eliminates the mass reflow oven used commonly in C4 solder process.

The metal to metal interconnection method provides excellent thermal performance for HBLEDs which require the T_j peak temperature to be controlled to maximize device MTBF and overall color temperature performance. The uses of metal to metal interconnection method provide superior thermal performance when compared to solder alloys.

The metal to metal interconnection method provides high precision with low particle generation for high performance bonding of CMOS image die using a low-k dielectric wafer. The line spacing for the substrate is 50 μm / 50 μm. Stud bumping machines have a ball placement accuracy of +/- 2.5μm. Thermosonic GGI die bonders have a mounting accuracy of +/-7 μm.

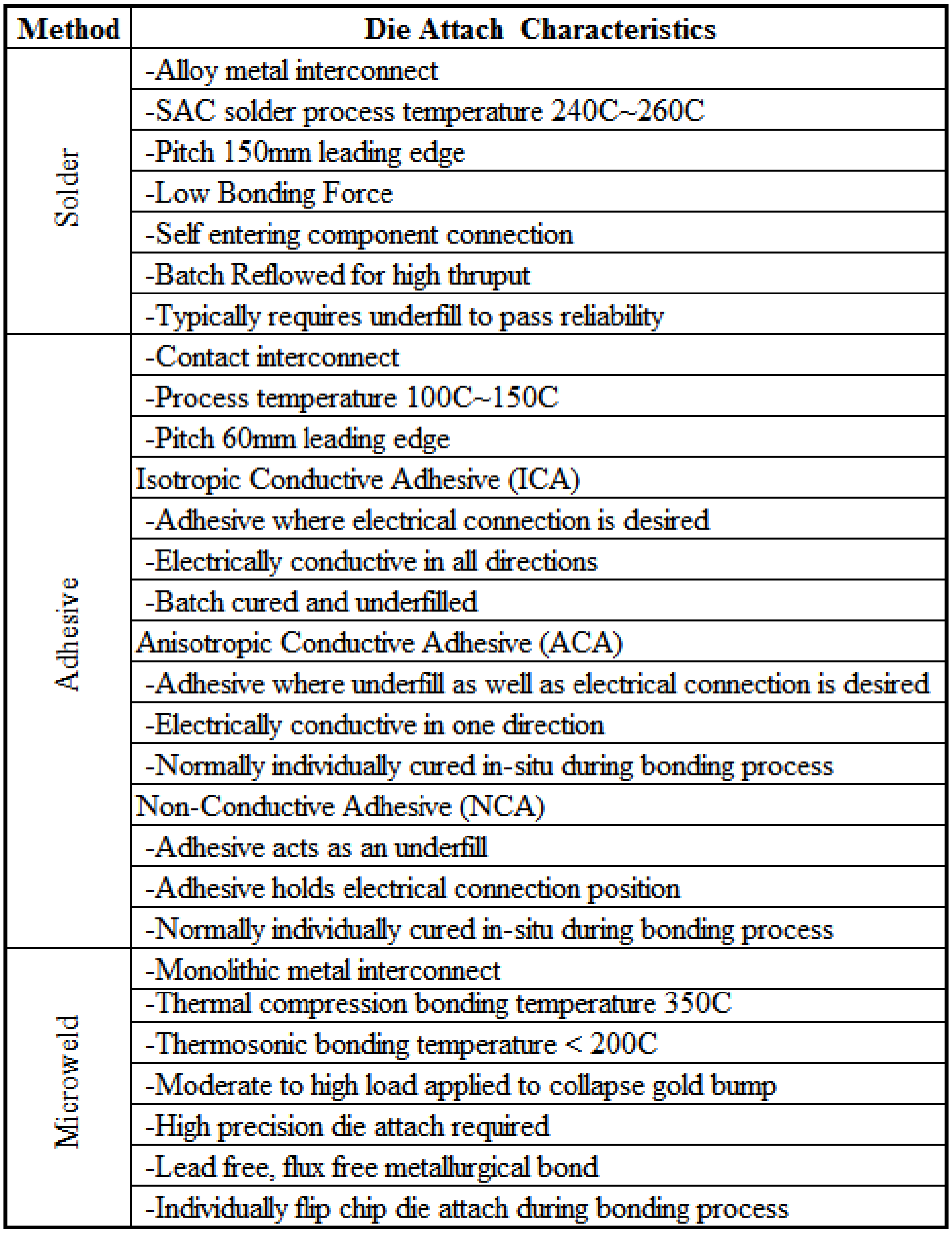
Thermosonic bonding has fast process bonding times of < 500 msec which is important productivity factor in cost sensitive cell phone camera and flash modules.

Keywords: thermosonic flip chip, interconnect, clean, low-k dielectric

Introduction

Flip chip processes methods can use solder, adhesive, or microweld techniques (Table 1). This paper will focus on gold to gold (GGI) thermosonic microweld interconnection method. The flip chip thermosonic GGI process is similar to wire bonding, in that is uses a thermosonic bonding technique. In the case of thermosonic GGI flip chip bonding the gold bumps are simultaneously bonded to the substrate.

In thermosonic GGI flip chip bonding traditional perimeter gold wire bonds are replaced with array gold stud bumps using array gold stud bumping process it is possible to reduce the die packaging geometry by 70%. In the case of thermosonic bonding substrate line spacing of 50 µm / 50 µm are used in production with 30 µm / 30 µm required by 2012.



Method	Die Attach Characteristics
Solder	-Alloy metal interconnect
	-SAC solder process temperature 240C~260C
	-Pitch 150mm leading edge
	-Low Bonding Force
	-Self entering component connection
	-Batch Reflowed for high thruput
	-Typically requires underfill to pass reliability
Adhesive	-Contact interconnect
	-Process temperature 100C~150C
	-Pitch 60mm leading edge
	Isotropic Conductive Adhesive (ICA)
	-Adhesive where electrical connection is desired
	-Electrically conductive in all directions
	-Batch cured and underfilled
	Anisotropic Conductive Adhesive (ACA)
	-Adhesive where underfill as well as electrical connection is desired
	-Electrically conductive in one direction
	-Normally individually cured in-situ during bonding process
	Non-Conductive Adhesive (NCA)
	-Adhesive acts as an underfill
	-Adhesive holds electrical connection position
	-Normally individually cured in-situ during bonding process
Microweld	-Monolithic metal interconnect
	-Thermal compression bonding temperature 350C
	-Thermosonic bonding temperature < 200C
	-Moderate to high load applied to collapse gold bump
	-High precision die attach required
	-Lead free, flux free metallurgical bond
	-Individually flip chip die attach during bonding process

Table 1

GGI CSP Package Interconnect Low Cost Flip chip thermosonic GGI process uses a rigid interposer such as ceramic, silicon, FR4 or BT (figure 1). Precision gold stud bumping machines provide stud bump diameters from 55µm to 120µm. The stud bump height is typically 35 µm to 75µm. Stud bumps can be applied to the die or the substrate. The preferred stacked stud bump profile for thermosonic CMOS die bonding is shown in figure 2. The stacked bump increases the gap to facilitate underfill process.

Electroless gold nickel plated gold bumps can also be used for thermosonic bonding process. The plated gold stud bumps typically have a thickness of 25 µm. A cost comparison of the different bumping processes is listed in the table 2.

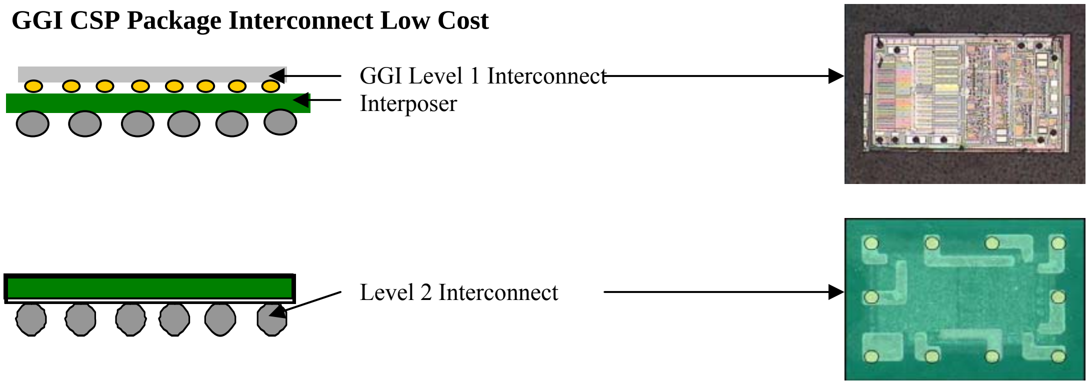


Figure 1

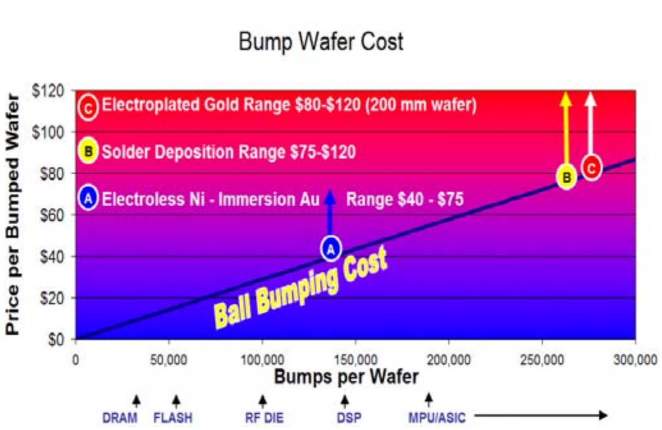


Table 2

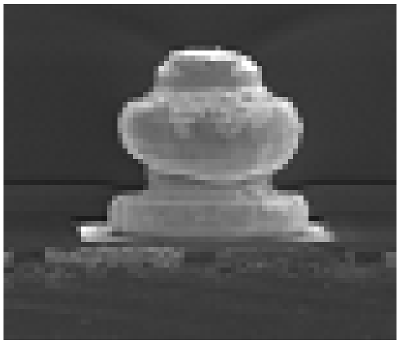
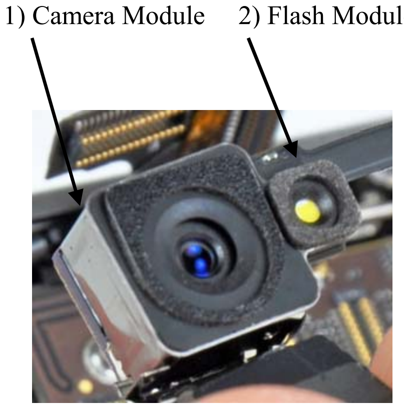


Figure 2 (Stacked Au Stud Bump)

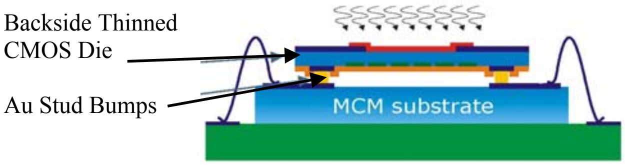
Cell Phone Camera and Flash Module Using GGI Flip Chip Process Cell phones require compact sensor design with high performance. The cell phone camera market specification improved from 2 megapixels to 5 megapixel (picture 1) and 30 lux @2M flash both uses available GGI flip chip interconnect (figure 3). The sensor uses backside illumination (BSI) which improves performance at low light. A low profile camera module with flash module can now be packaged into smart phones.

Camera Module and Flash Module



Picture 1

CMOS Sensor GGI Interconnect



Flash HBLED GGI Interconnect

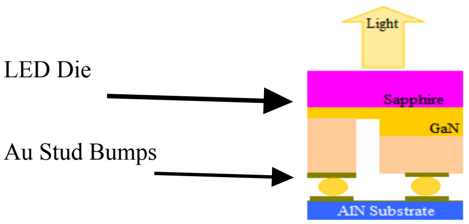
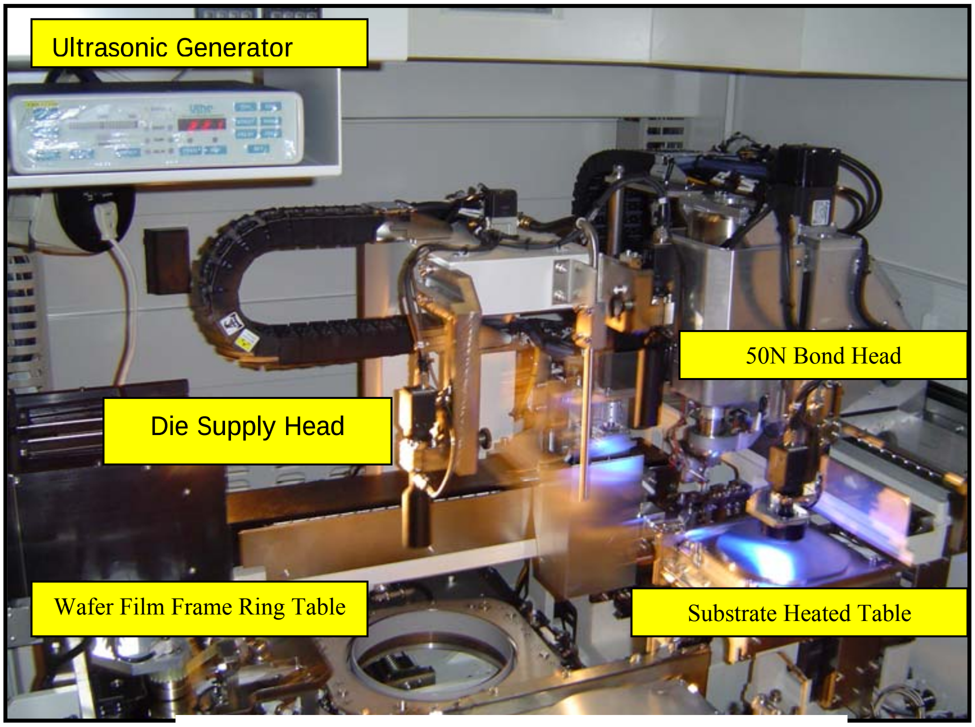


Figure 3

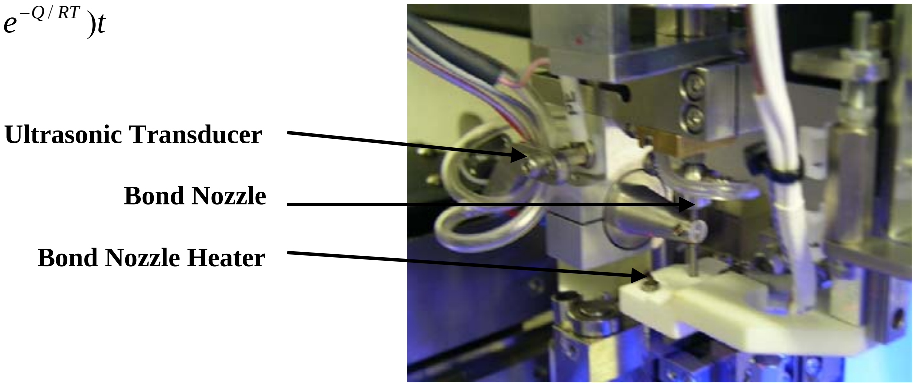


Picture 2 Thermosonic Machine Configuration

CMOS and HBLED GGI Flip Chip Thermosonic Machine Configuration The low inertia bond head of the bonder uses a voice coil motor that provides fast linear feedback response of less than 5msec. The VCM load head can be programmed from 1~50N with .01N resolution (picture 2). The bond profile should have the following features: 1) Programmable load <1N per bump, 2)Precise height control (Z axis) with feedback, 3)Low inertia bond head with minimum friction forces, 4)9 watt capability transducer, 5) 200C maximum bond nozzle heating 6) 200C maximum substrate table heating 7) Class 100 operation 8) Short bond profile <500msec.

GGI Thermosonic Bonding Process In thermosonic flip chip bonding process the diffusion of atoms across the bond interface is the primary weld mechanism of stud bumps. Typically 70% of the activation energy comes from ultrasonic power and the balance is from heated die and substrate. Ultrasonic process can form bonds with much less energy because it is distributed more efficiently. Using Fick's law the thickness of the diffusion layer is described by $X = \sqrt{(D_o e^{-Q/RT})t}$

Q is the activation energy required to initiate diffusion. The energy input into the bond interface is provided by kinetic energy (ultrasonic) and thermal energy (heat). The collapse of the stud bump (deformation) provides intimate contact at the bond interface and allows a larger area where atoms can diffuse through. The scrubbing motion of the ultrasonic tip cleans the surface bond while transferring energy to the joint.



GGI Thermosonic Bonding Process In thermosonic bonding the transducer is operated at its resonant frequency of 62 KHz. The impedance of transducer is ~20 ohms. It is important that the impedance remain constant during the bonding process. The relationship between ultrasonic power and nozzle tip amplitude (vibration displacement) is shown (Table 3). As power increase amplitude increases proportionally. The bond profile for most die attach application uses ultrasonic power less than 3 watts (3.5 µm amplitude). If the ultrasonic power is too high (above 3 watts) a decrease of bump positioning precision can occur. The phenomenon includes die slippage and skewing due to bump rotation.

Power W	Amplitude µm
0.1	0.65
0.2	0.86
0.3	1.08
0.4	1.25
0.5	1.42
0.6	1.53
0.7	1.65
0.8	1.76
0.9	1.84
1	1.97
1.1	2.06
1.2	2.16
1.3	2.26
1.4	2.37
1.5	2.4
1.6	2.5
1.7	2.59
1.8	2.64
1.9	2.69
2	2.8
2.1	2.84
2.2	2.9
2.3	2.96
2.4	3.03
2.5	3.08

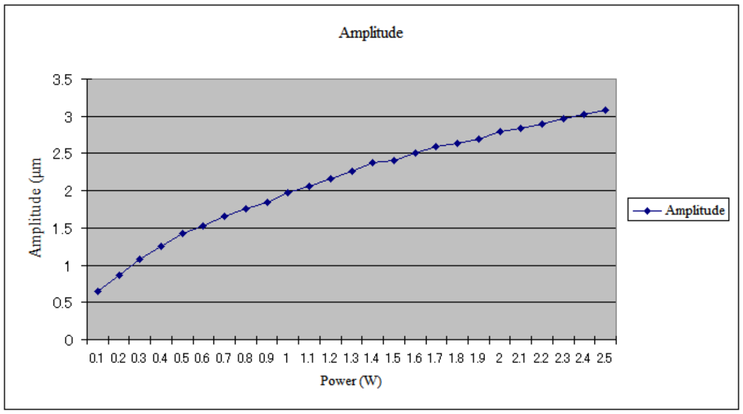
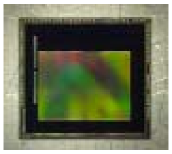
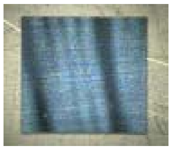


Table 3

CMOS Image Sensor Materials

Front **Figure 5** Substrate: 50mm x 110mm; Die: 6.7mm2 **Back**





Bump Measurements and Geometry

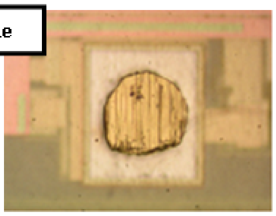
	Bump Height		Bump Diameter		Neck Diameter		Mode	Strength (g)
48 bumps	Height	Base	X	Y	X	Y		
MAX	52	38	58	58	32	33		38.2
MIN	51	37	56	57	32	31		30.0
AVE	**51.5**	**37.8**	**57**	**57.5**	**32**	**32**	B、C	**33.2**

Table 4

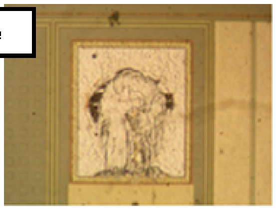
Bump (SEM Picture)

Bump (Top View)

B Mode



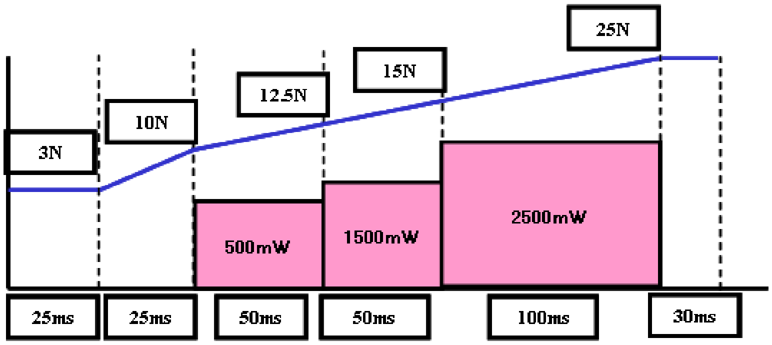
C Mode



Bond Profile

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 5
Time (ms)	25	25	50	50	100	30
Load(N)	3	10	12.5	15	25	25
US Setting (%)			5	10	15	

Substrate : 150℃
Nozzle : 200℃



Die Shear : 1833 grams

Table 5

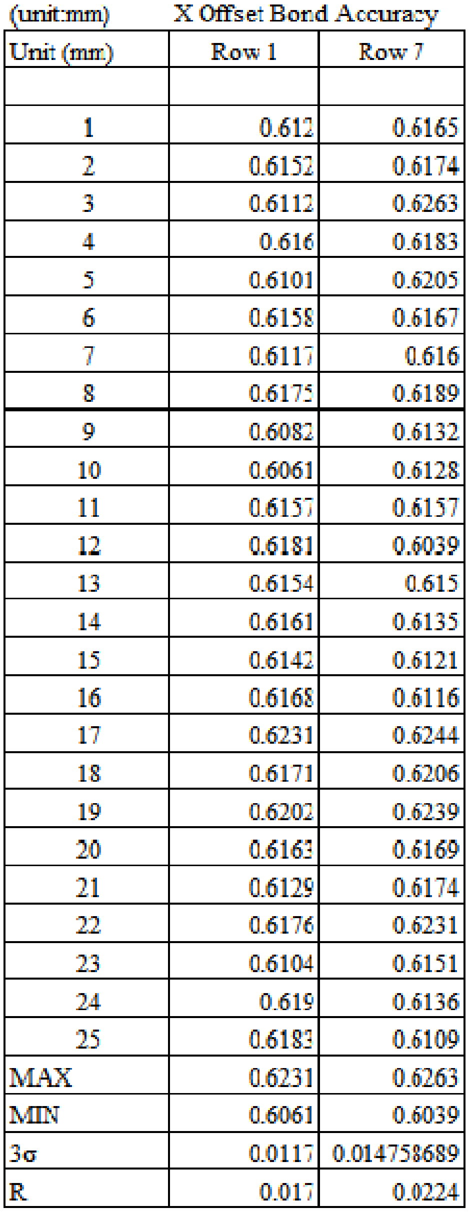
Bond Profile The test CMOS material consisted of a 50mm x 110mm substrate, 6.7mm2 T=0.18mm die with 48 stacked bumps (figure 5). The stacked bumps were ball sheared to determine mode and strength (g) (Table 4). The ball shear of 33 grams equates to estimated die shear strength of 1593 g (33g x 48 bumps) with 100% die bump transfer. The thermosonic bonding profile time was 280 msec with a peak load of 25N with die heating of 200 deg C and substrate heating of 150 deg C. The peak ultrasonic power was 2.5 watts (Table 5) The short bonding time is desired to achieve high productivity. The 5 step bond profile used in this test achieved die shear strength of 1833 grams. Using nominal ultrasonic power in the bonding profile allows good bond accuracy to be achieved.

Bond Accuracy Data

bond accuracy within +/- 20µm@3sigma

Y offset Bond Accuracy

Unit: mm	Row 1	Row 7
	L3	L3
1	-0.1962	-0.1951
2	-0.2007	-0.2004
3	-0.1997	-0.204
4	-0.2006	-0.2051
5	-0.1983	-0.2077
6	-0.2027	-0.2099
7	-0.2014	-0.207
8	-0.196	-0.2053
9	-0.2016	-0.2091
10	-0.198	-0.2083
11	-0.2019	-0.2098
12	-0.1942	-0.2079
13	-0.2027	-0.2106
14	-0.1961	-0.2065
15	-0.1957	-0.2136
16	-0.1964	-0.2036
17	-0.2004	-0.2031
18	-0.1993	-0.1982
19	-0.1996	-0.2004
20	-0.197	-0.1971
21	-0.1985	-0.2048
22	-0.1981	-0.2051
23	-0.1962	-0.2083
24	-0.195	-0.2015
25	-0.1957	-0.2029
MAX	-0.1942	-0.1951
MIN	-0.2027	-0.2136
3σ	0.007676	0.0134898
R	0.0085	0.0185



(unit:mm) X Offset Bond Accuracy

Unit (mm)	Row 1	Row 7
1	0.612	0.6165
2	0.6152	0.6174
3	0.6112	0.6263
4	0.616	0.6183
5	0.6101	0.6205
6	0.6158	0.6167
7	0.6117	0.616
8	0.6175	0.6189
9	0.6082	0.6132
10	0.6061	0.6128
11	0.6157	0.6157
12	0.6181	0.6039
13	0.6154	0.615
14	0.6161	0.6135
15	0.6142	0.6121
16	0.6168	0.6116
17	0.6231	0.6244
18	0.6171	0.6206
19	0.6202	0.6239
20	0.6163	0.6169
21	0.6129	0.6174
22	0.6176	0.6231
23	0.6104	0.6151
24	0.619	0.6136
25	0.6183	0.6109
MAX	0.6231	0.6263
MIN	0.6061	0.6039
3σ	0.0117	0.014758689
R	0.017	0.0224

Table 6

Thermosonic Bond Accuracy Ultrasonic energy effects bond accuracy. Data was collected by using offset data (Table 6) and the machine substrate camera.

Particle Data

Thermosonic bonding the machine operation is done in accordance to class 100 clean level. The CMOS image sensor is sensitive to particle contamination The clean level specification is Class 100 (particles <2.0 microns). The ultrasonic bonder uses a hepa filter and ionizer to maintain machine clean room operation. The clean room performance is verified using a particle measuring system at the die supply, carrier table, and wafer table. Typical particle measurements are shown in table 7.

sample	at supply head	at carrier table	at wafer table
1	100	100	100

Table 7 Particle Data

Bond Shear Strength and Bump Transfer The shear strength and bump transfer can be correlated to the bond profile. Factors such as load, heat, ultrasonic power, and cycle time affect die shear strength and bump transfer. In the course of this evaluation 14 different bond profiles where: time, ultrasonic power, load, and heat were varied in the bond profile. The general guide line is 0.8N of load per bump with 0.1 watt of ultrasonic per bump.

Normally the user will evaluate several bond profiles in order to meet their specifications for die bond shear strength and bump transfer. Die shear testing is a quick evaluation that can be done at the machine factory site. The factory tests include die shear measurement, microscope and IR inspection. The user must do cross section and thermo mechanical stress testing at their facility since these tests involves significant time.

Since thermosonic bonding is a micro weld process the first step in any bond process study is to clean the substrate and die of any particles, contamination or residue using argon plasma.

Conclusion

Thermosonic die attach has been used primarily for cell phone device back end assembly.

Thermosonic GGI bonding is expanding rapidly for GGI CSP packaging of cell phone modules. Flip chip thermosonic bonder high productivity die attach is achieved through simultaneous bump bonding. Excellent shear forces of over 35 grams per bump were achieved for fine bump pitch devices (57 µm). The GGI process uses solid phase welding die attachment process, which provides excellent electrical coupling, and low resistance for high performance interconnect packaging. The GGI process uses a monolithic metal bond without the fatigue characteristics associated solder alloy bump die attach.

Low cost organic substrates are already in production using the GGI process since bond temperatures are typically less than <200 ^{o}C.

Thermosonic GGI flip packaging is a low cost proven assembly method for high performance cell phone devices.

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