

Thermosonic Gold to Gold Flip Chip Bonding for Small Die High Density Interconnect

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Abstract

In this study the thermosonic flip chip bonding profile consisting of temperature, load, ultrasonic power, and time was investigated for small die attach. The study results show that temperature changes impact the bonding lattice which include elastic modulus, and tensile strength which results in different die shear strengths. In this study the heating was restricted to the bond tool tip to minimize

temperature changes to the piezo transducer. Temperature changes will impact the impedance and dissipative ultrasonic energy of the piezo system. The study shows that thermosonic flip chip bonding parameters are influenced mutually. This study can help demine the flip chip bonding criteria and optimization using thermosonic GGI process.

Key words: Flip Chip Thermosonic Bonding, GGI (Gold to Gold Interconnect), Die Shear Strength, Ultrasonic Energy

Introduction

Thermosonic GGI flip chip bonding is one of the back-end methods for device electrical packaging interconnect.

Flip Chip device packaging is a growing interconnection method which includes: intermetallic bonding solder reflow; GGI thermosonic and thermocompression bonding; and adhesive bonding. The main feature of flip chip bonding is multiball bonding at one time using a die specific bonding profile. In wire bonding the interconnect is done sequentially using a wire bond profile.

In flip chip thermosonic GGI bonding process the main process parameters include: 1) Ultrasonic Power, 2) Temperature, 3) Load, 4) Time. The temperature is a critical factor that influences the bonding quality and ultrasonic transmission. The temperature will impact the substrate material and die if it is too high. If the temperature is too low incomplete bonding will occur.

Flip Chip Thermosonic GGI Bonding Process

Thermosonic GGI flip chip die bonding is a process where a gold stud bump and the gold layer on a substrate are intermetallically joined using a bond profile consisting of: ultrasonic power, heat, load, and time. The horn configuration for thermosonic flip chip die attach is similar in configuration to a gold wire bonding system (Fig 1). A phase locked 62 KHz generator supplies power to piezoelectric transducer. For this study an overhang tapered horn

Other influence factors for thermosonic bonding include quality of the gold stud bump (bump strength and geometry), cleanness of die and substrate (removal of organic and inorganic contamination).

Thermosonic GGI flip chip die assembly method uses a low cost gold stud bumping process. In most cases the die aluminum pad is gold stud bumped using a gold stud bumping process machine. The substrate finish consists of a gold layer with a nickel barrier over a conductor layer (ENIG).

High precision GGI die assembly can be accomplished using gold bump diameters between 50 μ m ~120 μ m. The thermosonic GGI flip chip die assembly method allows area array of bump pads on the die surface rather than wire bond die perimeter pads. The GGI flip chip method allows final device package size to be reduced 50% to 70% compared to gold wire bonding assembly process. Table 1 shows the merits of each flip chip bonding process.

with a heated tungsten carbide bond tool that is matched to a 1mm die size was used.

The ultrasonic piezo transducer converts electrical energy into mechanical oscillation waves. The axial oscillation from the piezoelectric transducer is transmitted and amplified by the tapered horn. The wave is converted to flexural oscillation in the bonding tool which is transmitted to the die. The bond tool tip and substrate material is heated using a

Flip Chip Thermosonic GGI Bonding Process

method to minimize electrical performance changes to the piezo transducer.

Using a flip chip thermosonic bond profile the ultrasonic energy, heat, load over time allows the

atoms between the gold stud bump and gold layer on the substrate to diffuse and form a strong intermetallic bond at the atomic level. This second intermetallic bond between the stud bump and substrate gold layer occurs with the reorganization of the atomic lattice at the interface level.

Table 1 Flip Chip Methods

Comparison of Different Flip Chip Die Assembly Methods
Back End Process

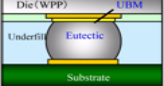
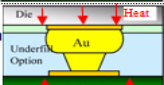
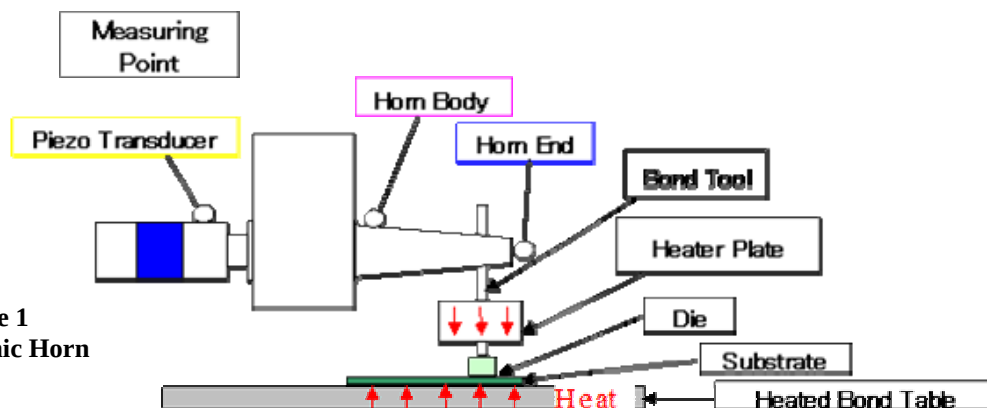
Die Attach Assembly Method	Bump to Pad Interconnect	Typical Process Time	Features
C4 Using Mass Reflow Oven 	Intermetallic	Die Attach Process 1 second Reflow Cycle > 2 minutes Peak Reflow < 30 seconds	1) Mature Process 2) Used for high I/O applications 3) Pad Distribution is Required 4) High Cost of Solder Bumping 5) Typical Pitches >150 μm
C4 Using Thermal Compression Bond Head with Heating 	Intermetallic	Die Attach Process 1 second Bond Head Heating cycle 7~10 seconds	1) Mature Process 2) Used for high I/O applications >1500 3) Pad Distribution is Required 4) High Cost of Solder Bumping 5) Typical Pitches >150 μm
Antistrophic Conductive Film (ACF) 	Contact	Die Attach Process 1 second Bond Head Heating Cycle 7~10 seconds	1) Specialized Process 2) Used for LCD Panel Assembly 3) Typical Pitches >60 μm 4) Contact Joint Resistance >x3 of intermetallic interconnect resistance 5) Usage Trending Down
Nonconductive Paste (NCP) 	Contact	Die Attach Process 1 second Bond Head Heating Cycle 7~10 seconds	1) Specialized Process 2) Alternative Process to ACF 3) Contact Joint Resistance >x3 of intermetallic interconnect resistance 4) Usage Increasing for RF Devices 5) Ganged Head D/A Option Available
Eutectic (ESC) 	Intermetallic	Die Attach Process 1 second Bonding Cycle Time < 2 seconds	1) Mature Process 2) Typical Pitches >50 μm 3) Alternative Process to ACF 4) Ganged Head D/A Option Available 5) Lead Free Process Available
Gold to Gold (GGI) Thermocompression 	Monometallic	Die Attach Process 2 seconds Bond Head Heating Cycle 5~10 seconds	1) Specialized Process for Die <25mm ² 2) Used for I/O applications <750 3) Typical Pitches >25 μm 4) Die Attach Temp <450°C 5) Used for Cell Phone Display Drivers
Gold to Gold (GGI) Thermosonic 	Monometallic	Die Attach Process 1 second Bond Head Die Attach <500 milliseconds	1) Specialized Process for Small Die 2) Used for I/O applications <100 3) Typical Pitches > 80 μm 4) Die Attach temp < 200°C 5) Variant Process to Gold Wire Bonding

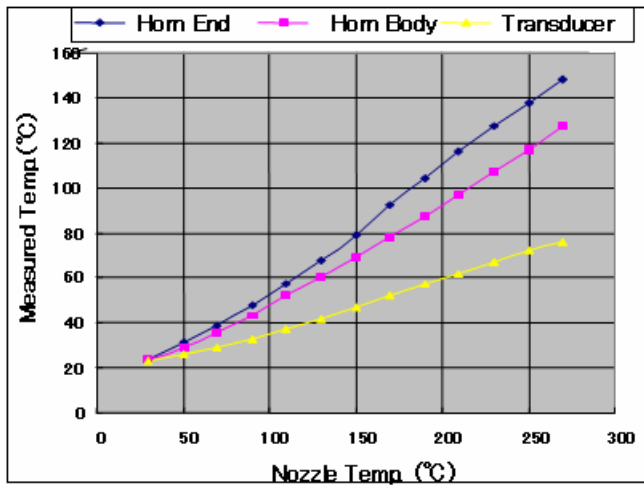
Figure 1
Thermosonic Horn



Experimental

The thermosonic horn temperature, frequency, and impedance characteristics were characterized using direct measurements. The purpose was to make certain that the piezo transducer electrical properties remained constant during bond tool heating up to 275°C.

The bond tool temperature is varied from 25°C to 275°C in order to measure the temperature at three different locations (Horn end, Horn Body, and Transducer). The transducer temperature was



Temperature Measurements use a K-type Thermocoupler At different locations on the Horn

Figure 2

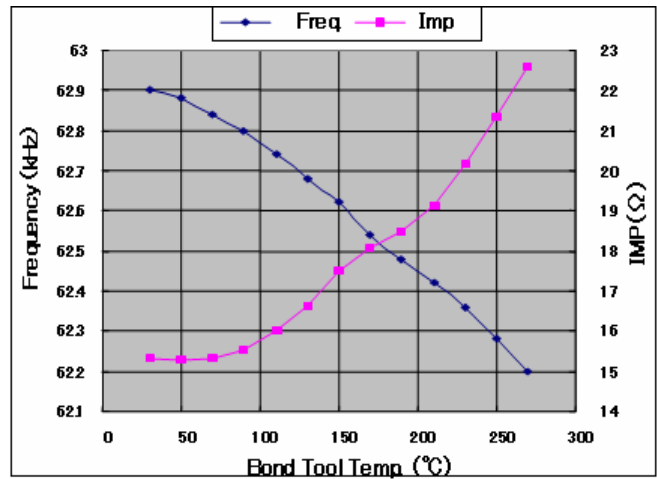
The horn design is based upon finite element method to calculate the resonant frequency and oscillation mode, and to predict the horn dynamic performance. Ideally the horn is designed to oscillate in a purely longitudinal mode at the frequency with uniform output amplitude. This is to avoid “die cratering” during thermosonic bonding due to vertical oscillation.

Use of a low impedance horn design allows efficient use of ultrasonic power. The amount of ultrasonic power can be reduced to achieve good thermosonic die bonding. Finally the impedance must be constant under different loads and ultrasonic power levels (Figure 5). Changes in the impedance value in production would not allow consistent thermosonic flip chip die bonding.

Bond tool /substrate heating provided consistent die bonding results in the temperature range of 125°C to 175°C. Bond tool /substrate heating aids in the removal of inorganic contamination and improves gold bump transfer. The higher bond tool /substrate temperature improves

not to exceed 100°C operation temperature (Figure 2). The bond table heating does not have any impact on the piezo transducer at temperature less than 275°C.

The Bond tool impedance and frequency response was measured while varying the bond tool temperature between 25°C to 275°C. The operating frequency varied between 62 KHz and 63 KHz, and the Impedance was to be less than 25 ohms Figure 3.



Horn Impedance vs. Bond Tool Temperature

Figure 3

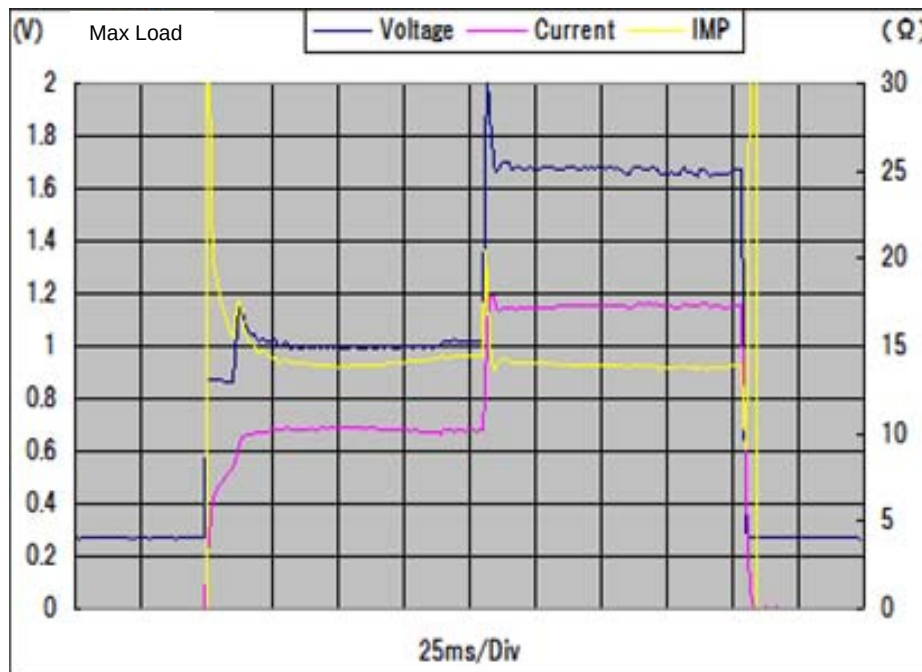
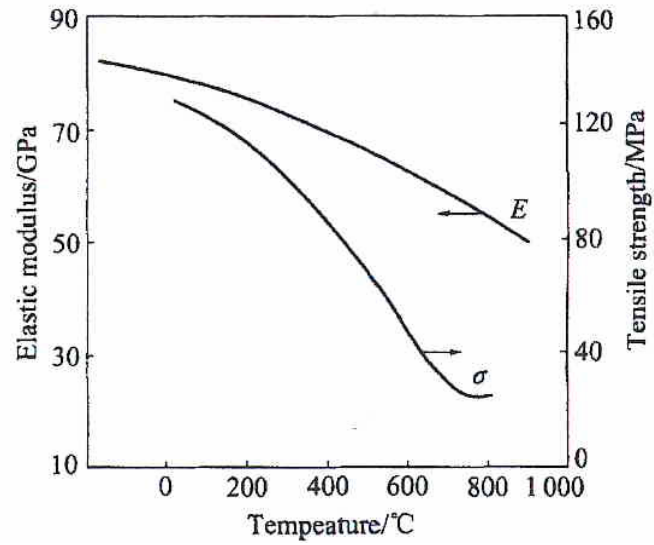
productivity by reducing thermosonic bonding cycle time. Bond tool / substrate heating soften the gold metal material and accelerated the diffusion process between the gold stud bump and the substrate gold layer.

The atom diffusion coefficient expression $D = D_0 \exp(-Q/RT)$, where D_0 is the diffusion coefficient and Q is the diffusion activation energy. The gold atoms will tend to diffuse to each other with increasing temperature. In addition, increasing temperature will soften gold and accelerate the diffusion process. Figure 4 shows relationship among elastic modulus (E), tensile strength (σ) of gold and temperature. As temperature increases tensile strength and elastic modulus decreases for gold.

At high temperatures, the gold atoms diffuse to each other to quickly to break thru oxidation films at 62 KHz oscillation frequency. In this case cavities can result in the bonding interface causing low die shear strength.

Experimental

Figure 4
Relationship among elastic modulus (E), tensile strength (σ) of gold and temperature



- 1) Ultrasonic Power at Max Load
- 2) Applied Ultrasonic Power of 0.75 watt and 2 watts
- 3) Impedance constant for Different Ultrasonic Power Levels

Figure 5
Thermosonic Horn Bond Tool FEM Impedance Analysis Maximum Load
At Different Ultrasonic Power Levels

Thermosonic Bond Parameters

A 1mm die was select for this study with a known bond profile without bond tool tip heating (Figure 6). Bond Tool heating of 175°C was used in this study and five different bond parameters with varying load, ultrasonic power and time. In Thermosonic flip chip bonding it is desirable to

minimize stress to the die. If bonding time, ultrasonic power, or applied load forces can be reduced this would be an advantage to the user to reduce die bonding cycle time and improve total machine cycle time.

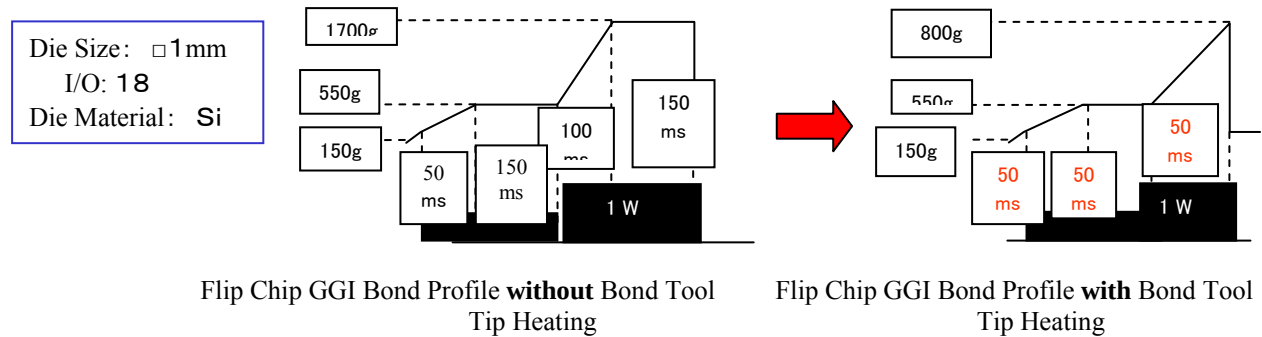


Figure 6

Thermosonic flip chip GGI die bonding is a variant process to gold wire bonding. The gold wire hook is replaced by a gold study bump. Because GGI is a precision die attach method, argon plasma cleaning of materials is used to remove any organic and inorganic contamination. The gold stud bumping

and GGI die attach equipment are typically installed in a class 10,000 clean room. The stud bump height is controlled to +/- 2.5 µm. The Typical stud bump height is 60 µm.

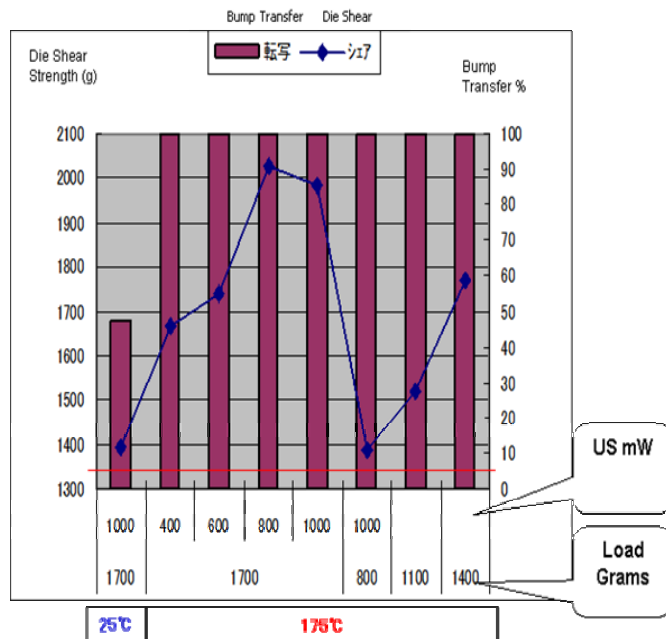


Figure 7

A known good bond profile without bond tool heating (bond tool temperature 25°C) for a 1mm die was selected. This bond profile met the user specifications for die shear and bump transfer.

Bond Tool heating of 175°C was added to the bond profile. Five different bond profiles were studied and die shear and bump transfer results were compared to the bond profile without bond tool heating die shear and bump transfer results (Figure 7).

Measurement of Die Shear Strength and Bump Transfer

For thermosonic flip chip die bonding process a die shear tester is used to measure the die shear strength (Figure 10). A microscope is used to inspect the bump transfer (inspection of sheared bump material on die and substrate).

The parameter setup for die shear testing is different from ball shear testing. The die shear test speed is

slower and the shear height is performed close to the substrate surface. The die shear parameters are shown in Figure 9 for the Dage 4000. Figure 10 shows the position of the substrate with die on the Dage 4000 table. The shear tool width is the same as the die width of 1mm.

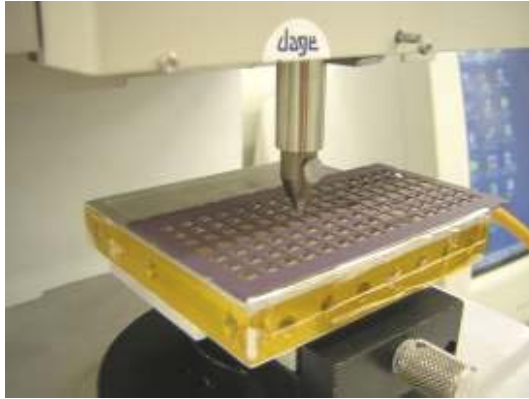


Figure 8: Dage Die Shear Test Table Position

Parameter	TDK Settings
Test Speed:	50 mm/S
Land Speed	100 mm/S
Shear Height	0 mm
Over Travel	100 mm

Figure 9: Dage 4000 Die Shear Parameters

Figure 10: Dage 4000 Die Shear Table (Die Shear Test)

Die Shear Mil-STD-883



Courtesy of Dage Inc.

Figure 11: Visual Inspect of Die Sheared Material Using a Microscope

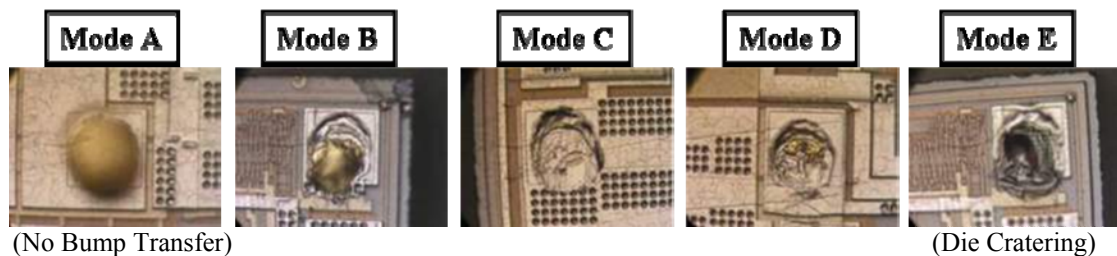


Figure 11: Visual Inspect of Die Sheared Material Using a Microscope

For this study the shear mode required was mode B, 50% bump transfer (Figure 11). 50% of the bump sheared material is found on the die and substrate. The bump transfer specification is

dependent on the bond characteristics required by the user in order to pass their reliability testing and whether or not there is down stream process using heat $>100^{\circ}\text{C}$ such as molding or underfill operations. If additional heat is applied downstream gold diffusion will continue in the process changing the mode characteristics.

Conclusion

Thermosonic GGI process is a high precision interconnect method for small die flip chip die attach. The addition of die /substrate heating provides several advantages to the user. In this study process time can be reduced by up to 30%. Bump transfer and die shear strength was improved by 45% using the same no heating bond profile parameters for load and ultrasonic power. Another option bond profile option to the user is to reduce stress to the die by reducing heated bond profile applied load by 50% to achieve the same bump transfer and die shear as the no heated bond profile.

It is important to avoid too low or too high of temperature which can result in poor flip chip die bonding. The best die bonding results were using a heating temperature of 175°C in this study. The advantages were found both with organic and inorganic substrates. Thermosonic GGI process is a lead /flux free process precision die attach with process bond accuracy of $\pm 10\mu\text{m}$. Thermosonic GGI flip chip process is a back end process suited for mobile, option, and sensor device packaging where device profile and electrical performance is critical.

References

- Tummala R. R., Microelectronics Packaging Handbook, New York: McGraw-Hill 2001.
- M.Kawahara, "Process Guidelines of Flip Chip Mounting Technology", JEITA Publication, ETR 7010, June 2003.
- T. Miyakoshi, Ultrasonic Bonding Guidelines for 100 bump devices". January 2005.
- A. Dohya, "Environmental and Endurance Test Methods for Bare Die Mounting". June 2002.