Ultrasonic Bonding in semiconductor industry – The fast and clean process

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Abstract (Preliminary Summary)

Ultrasonic die bonding is an innovative and efficient technique increasingly utilized in the semiconductor industry for the assembly of microelectronic components. This method leverages high-frequency ultrasonic vibrations to create strong, reliable bonds between semiconductor dies and substrates, significantly reducing thermal stress compared to traditional bonding methods. The advantages of ultrasonic die bonding include rapid processing times, enhanced mechanical strength, and the ability to bond dissimilar materials, making it particularly suitable for advanced applications such as power devices, RF components, MEMS, and LED packaging. Despite its numerous benefits, challenges such as equipment costs, process optimization, and material compatibility remain. Ongoing research and development efforts aim to address these issues, paving the way for broader adoption and integration of ultrasonic die bonding in automated manufacturing processes.

Introduction

Ultrasonic die bonding is an advanced packaging technology widely used in the semiconductor industry to attach semiconductor dies to substrates or packages. This paper provides a comprehensive overview of the ultrasonic die bonding process, its mechanisms, advantages, challenges, and applications in modern semiconductor manufacturing.

The demand for smaller, faster, and more efficient electronic devices has driven innovations in semiconductor packaging technologies. Ultrasonic die bonding has emerged as a preferred method when using heat sensitive dies or due to its ability to create strong, reliable bonds with minimal thermal stress.

Flip-chip bonding is a solderless die-to-die bonding technology for area-array connections (Figure 1). The approach is applied to join an array of gold bumps at the bottom of an ICs (Figure 2), onto gold-plated pads on a substrate. It is a simple, clean, and dry assembly process using, generally, the thermo-compression bonding method [2]. The pure thermo-compression bonding typically requires interfacial temperatures of the order of >300°C [2,3]. This temperature can damage packaging materials, laminates and some sensitive microchips [4]. This next level bonding solution is very advantageous in the flip-chip bonding because the interface temperature and the bonding force, typically, can be much lower; between 100 and 160°C and 20 and 50g/ bump, respectively [2].

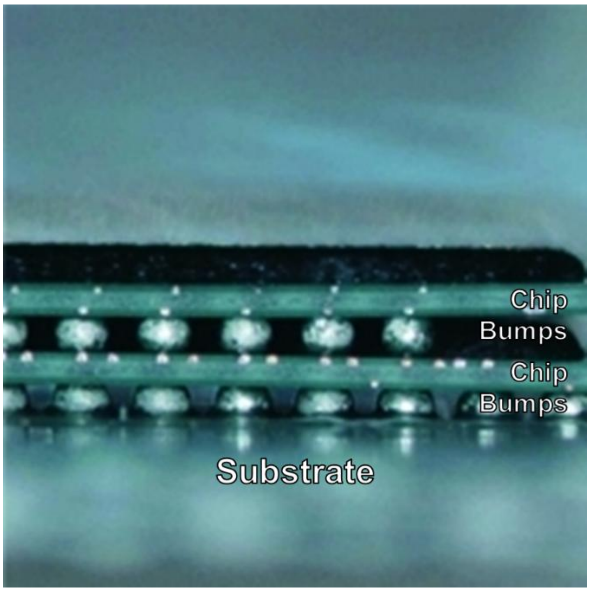

Figure 1: A semiconductor fabrication using the flip-chip die bonding to stack the chips on each other

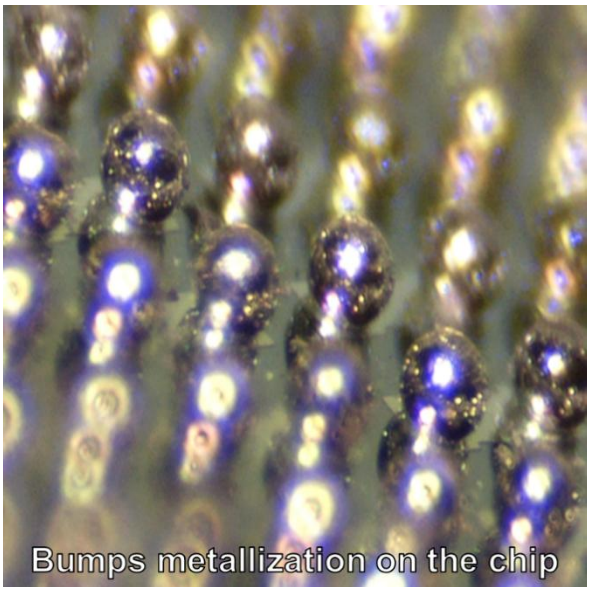

Figure 2: Au stud bumps metallized on the chip's surface

Ultrasonic (U/S) bonding Process

Ultrasonic die bonding utilizes high-frequency ultrasonic vibrations (typically in the range of 20 kHz to 70 kHz) to generate localized heating at the interface between the die and the substrate. The process involves the following steps:

The surfaces of the die and substrate are cleaned and prepared to ensure optimal bonding conditions. The process starts with the substrate sitting on a heated or non-heated stage. The chip is held by a vacuum pickup tool (Figure 3), which must be designed and suitable for the U/S bonding application, *i.e.*, Die Collet. After aligning the die to the substrate by TRESKY Pattern Recognition System, the die is placed onto the substrate, and a controlled amount of pressure is applied. Ultrasonic energy is introduced, causing the surfaces to vibrate. This vibration disrupts the surface oxides and contaminants, allowing for atomic-level contact. The U/S parameters, *i.e.*, power, time, and delay time are adjustable in the TRESKY software (Figure 4). The combination of pressure and ultrasonic energy leads to the formation of a solid-state bond as the materials undergo plastic deformation and diffusion.

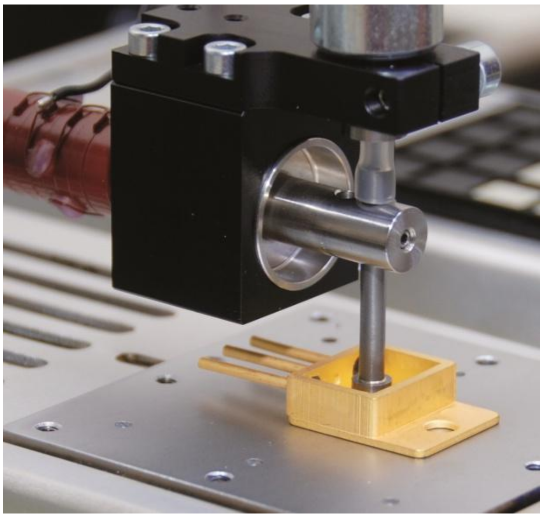

Figure 3: U/S process setup in a TRESKY Die Bonder machine

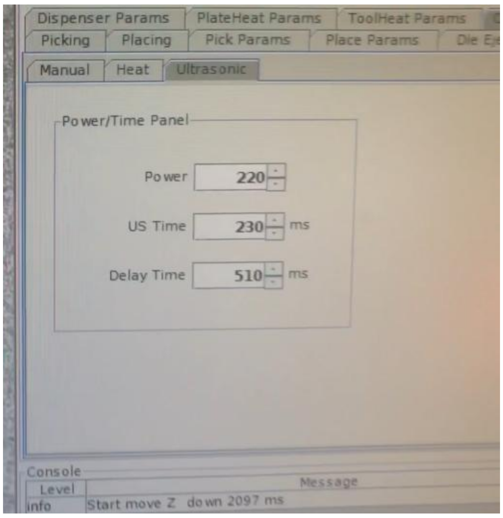

Figure 4: The TRESKY Die Bonder software shows the U/S parameter setting

Co-planarity and parallelism of Die Collet with respect to the substrate is a very important parameter to achieve a good bonding result. Misalignment can produce uneven force distribution which creates an established joint on side A but an insufficient connection on side B (Figure 5). TRESKY´s Vertical Technology guarantees stable and accurate co-planarity and parallelism over the whole Z-axis stroke. In combination with the force control, an excellent bonding result is achieved on every height (Figure 6).

<u>Typical U/S parameters:</u>

Heated stage (substrate):	100°C to 160°C
Ultrasonic power:	100 to 200mW/ bump
Bond force:	20 to 50g/ bump

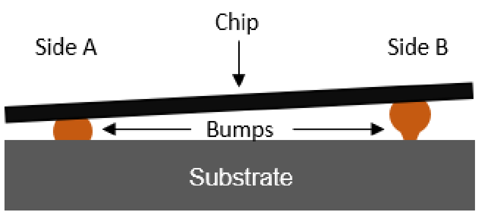

Figure 5: Insufficient connection due to the misalignment

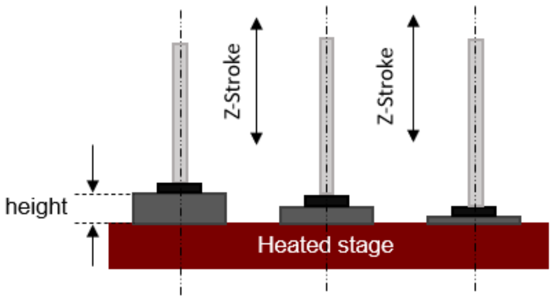

Figure 6: Stable and accurate co-planarity and parallelism over the whole Z-axis stroke of TRESKY Vertical Technology

Influence of bond parameters to the process

Force, time, temperature, U/S power, and U/S time are parameters that have a great influence on the U/S process and can be programmed individually on TRESKY systems. Generally, higher setting than the optimized parameters lead to more collapsed bump area and higher strength of the connection. However, when increasing these parameters, it is important to recognize the risk of an electric short circuit between adjacent bumps as well as possible breakage of the chip (Figure 7-9).

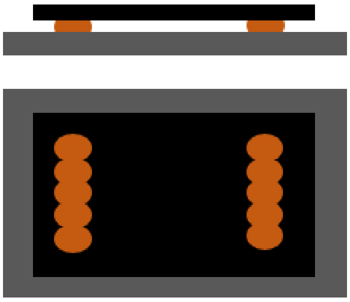

Figure 7: Parameters too high – short between bumps

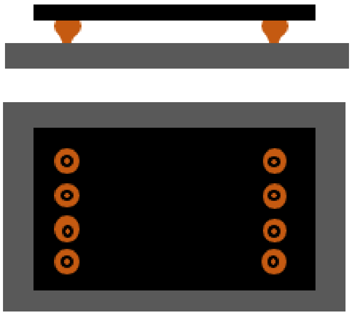

Figure 8: Parameters too low – insufficient connection

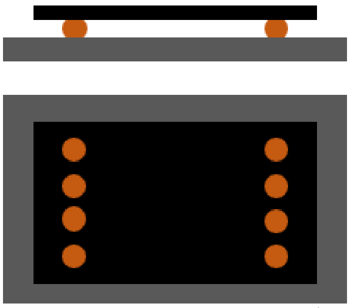

Figure 9: Parameters optimized – good connection

U/S Die-Collets

The cycled Die Collet movement during US process, a sensitive chip's surface, and heat transfer are at least 3 factors showing a Die Collet is compatible for U/S bonding. As the US power is applied during TSB, the transducer vibrates, so that the Die Collet will move in X and Y directions for a few microns distance and in a very short time (Figure 10). This movement is cycled in the kilohertz frequency range. Because the Die Collet grips the chip along the chip's edges, the chip will follow the Die Collet vibration, which occurs within a 10 thousand times below than 1 second and at the same time it is pressed by the bond head with a given bond pressure. Further, this grip is also advantageous because there will be no mechanical contact on the chip's surface that will not damage the structures (Figure 11). Moreover, there will be only very small contact area between the chip and the Die Collet (along the chip's edges) that a very low heat will be transferred into the Die Collet, in other words, most of the heat of the bond temperature from the heated stage will be accumulated between the chip and the substrate, thus, the thermal energy will be dissipated within the bumps and the pads on the substrate.

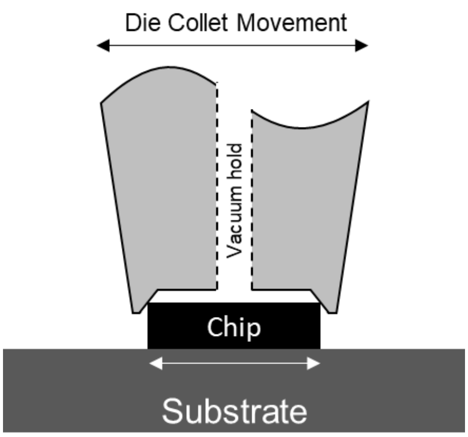

Figure 10: Allow the ultrasonic action

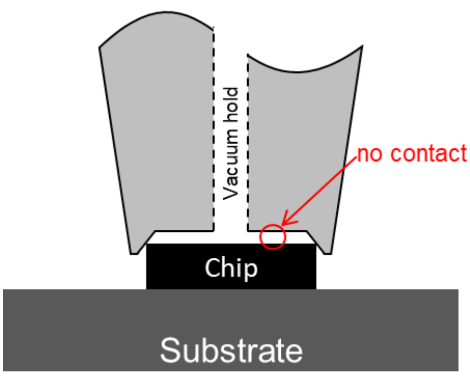

Figure 11: No physical contact with sensitive chip surface allowed

Advantages of Ultrasonic Die Bonding

Ultrasonic die bonding offers several advantages that make it an attractive alternative in the semiconductor industry over traditional bonding methods. Here are some key benefits:

1. Low Thermal Stress:
The process generates minimal heat, reducing the risk of thermal damage to sensitive semiconductor materials and ensuring the integrity of the components.

2. Fast Bonding Times:
Ultrasonic die bonding can achieve bonding in a matter of milliseconds, significantly increasing production efficiency and throughput.

3. Strong Mechanical Bonds:
The technology creates robust and reliable connections, which are essential for the performance and longevity of semiconductor devices.

4. Ability to Bond Dissimilar Materials (Hybrid):
Ultrasonic die bonding can effectively join different materials, allowing for greater design flexibility and the integration of various components.

5. Reduced Need for Adhesives:
The process often eliminates or minimizes the use of adhesives, which can simplify manufacturing and reduce potential contamination issues.

6. High Precision and Control:
The ultrasonic bonding process allows for precise control over the bonding parameters, leading to consistent and repeatable results.

7. Compatibility with Automated Processes:
Ultrasonic die bonding can be easily integrated into automated manufacturing systems, enhancing overall production efficiency.

8. Environmentally Friendly:
The process typically requires fewer chemicals and materials compared to traditional bonding methods, making it a more sustainable option.

9. Scalability:
Ultrasonic die bonding can be adapted for various scales of production, from small batches to high-volume manufacturing.

10. Versatility:
The bonding technology is applicable to a wide range of semiconductor devices, including power electronics, RF components, MEMS, and LEDs, making it suitable for diverse applications.

These advantages contribute to the growing adoption of ultrasonic die bonding in the semiconductor industry, as manufacturers seek to improve performance, efficiency, and reliability in their products.

State of the art

Recent advancements in ultrasonic die bonding technology have significantly enhanced its process control and repeatability, positioning it as a compelling alternative to traditional bonding methods such as thermocompression and adhesive bonding. These improvements stem from innovations in ultrasonic equipment, including better transducer designs, advanced control algorithms, and real-time monitoring systems that allow for precise adjustments during the bonding process. This level of control ensures consistent bond quality, which is crucial for high-reliability applications in the semiconductor industry.

One of the standout features of ultrasonic die bonding is its ability to create strong, durable bonds at lower temperatures compared to conventional methods. This characteristic is particularly advantageous for advanced packaging applications, where many semiconductor materials exhibit thermal sensitivity. By minimizing thermal exposure, ultrasonic die bonding helps prevent damage to delicate components, such as organic substrates and sensitive semiconductor materials, thereby maintaining their performance and reliability.

Moreover, ultrasonic die bonding facilitates the integration of a wide range of materials, including silicon, gallium nitride (GaN), and other compound semiconductors. This versatility is essential in the context of modern semiconductor technologies, which increasingly require the combination of different materials to achieve desired electrical and thermal properties. For instance, GaN is often used in high-power and high-frequency applications due to its superior performance characteristics, and ultrasonic die bonding allows for effective integration with silicon-based components.

The ability to bond dissimilar materials (Hybrid) not only broadens the applicability of ultrasonic die bonding across various semiconductor technologies but also enables the development of more complex and efficient device architectures. This includes advancements in 3D packaging, where multiple dies can be stacked and interconnected, enhancing performance while reducing the overall footprint of electronic devices.

Conclusion

Ultrasonic bonding is an innovative bonding solution that TRESKY provides, specifically designed for semiconductor packaging. This technology employs ultrasonic (U/S) power in conjunction with the Die Collet design to create robust joints between semiconductor chips and their substrates.

One of the standout features of ultrasonic bonding is its ability to operate at low bonding temperatures and pressures. This characteristic is particularly beneficial in semiconductor applications, as it reduces thermal stress on the materials involved, thereby preserving their integrity and performance.

In addition to the bonding process itself, TRESKY's pick & place systems enhance the overall effectiveness of the bonding operation. These systems are engineered to maintain excellent co-planarity and parallelism along the Z-axis stroke, which is crucial for ensuring the straightness and alignment of the ultrasonic-bonded chips. This precision is important for the reliability and functionality of the final semiconductor products.

Ultrasonic die bonding represents a significant advancement in semiconductor packaging technology, offering several advantages, including rapid bonding times and the formation of strong mechanical joints. These benefits contribute to improved manufacturing efficiency and product performance.

While there are still challenges to overcome in the widespread implementation of this technology, ongoing research and development efforts are expected to address these issues. As the semiconductor industry continues to evolve, ultrasonic die bonding is anticipated to play a pivotal role in meeting the increasing demands for smaller, faster, and more efficient electronic devices.

In summary, TRESKY's ultrasonic bonding technology not only enhances the bonding process in semiconductor fabrication but also aligns with the industry's future needs, making it a crucial component in the development of advanced electronic devices.

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