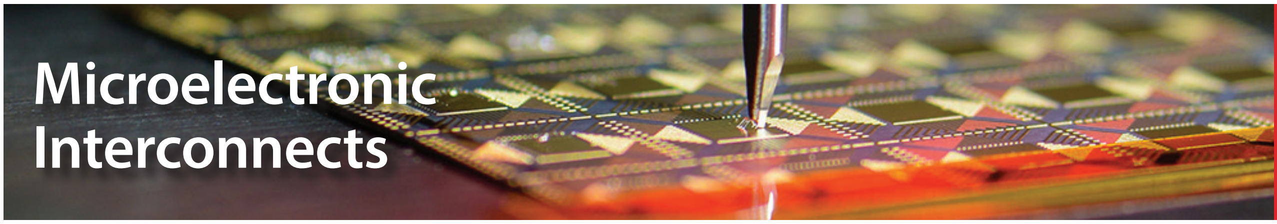

Microelectronic Interconnects

SILICON Heartland
SMART MICROSYSTEMS™

Developing Robust Interconnects for Microelectronic Assemblies

Mara Rice
SMART Microsystems Ltd.

THE MICROELECTRONIC INDUSTRY IS rapidly growing. Every day new applications, next-generation materials, and state of the art information gathering sensors are being created. Each new device must be packaged and electrically connected to the outside world. A robust and reliable interconnect is critical to the success and function of every integrated circuit, sensor, and device. Advanced technologies, new manufacturing techniques, and novel materials come with unique challenges when it comes to making robust and reliable interconnects. Custom packaging, unusual part geometry, and unconventional material limitations can make a usually reliable interconnect process difficult to develop. Despite these obstacles, well understood processes like gold ball bonding and aluminum wedge bonding, as well as emerging technologies like isotropic and anisotropic conductive adhesives can be successfully implemented with extensive process development.

More than 90% of the 15 trillion interconnects are manufactured by wire bonding, and ball bonding is the predominant method of making these interconnects. A combination of heat, ultrasonic energy, and force is used to form a cold fusion weld between the gold wire and the material of the desired bond location. Gold is preferred for its mechanical thermal properties and low chemical reactivity. Gold wires can be easily bonded to many materials and will not likely corrode in harsh environments. Gold will not oxidize at high temperatures and has a lower thermal coefficient of expansion than copper and aluminum. Gold ball bonding is frequently the interconnect method of choice for many sensors, including photodiodes. Some photodiodes are used in high-temperature applications and may be required to sustain temperatures as high as 200˚C during operation. Because of this, gold ball bonding is often used in photodiodes.

The photodiode application, like many others, presents many unique wire bonding process challenges owing to the unique application of the device. The first challenge is fixturing. Before wire bonding development can begin, a custom fixture must be designed to securely hold the parts and maintain temperature during thermosonic bonding. Gold ball bonding requires that parts be held in a stationary position, with a fixed orientation, perpendicular to the bonding tool. The fixture must be able to withstand elevated bonding temperatures, hold the part securely, not add any unintended stress to the part, and not interfere with bond head movement. In some cases, the photodiode has a unique package designed so that the die is thermally insulated. This presents further challenges when designing a fixture. To ensure the part is fully heated to the desired temperature, a fixture is designed to conduct heat and maintain the desired temperature through the package and to the wire bond pads.

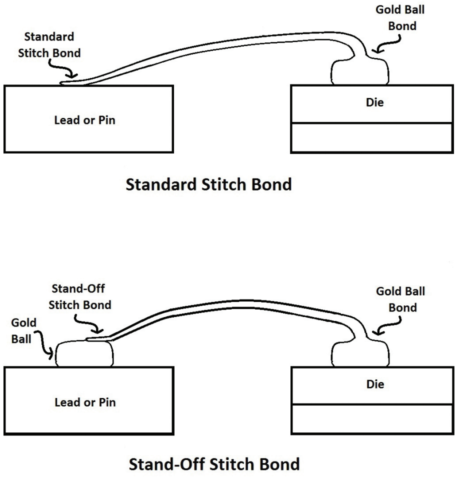

Figure 1. Diagram showing the difference between a SSB and a standard stitch bond.

Once fixturing has been resolved, wire bond development can begin. This involves development of a robust weld through a design-of-experiments (DOE) for critical bond parameter selection and optimization while meeting the package limitation for wire loop geometry. The photodiode can contain some unique geometry that can present product limitations over life. If wires are too long or tall they can interfere with the package, become deformed with heat or vibration, or become shorted. By understanding loop geometry and bond head movement, proper looping can be determined.

Loop geometry is not the only challenge presented by a photodiode's unique package design. The machined surfaces on the pins are not always an entirely favorable bonding surface. These surfaces can be courser and less planar than a typical semiconductor finish on account of previous processes upstream in the assembly. The machined surfaces are where the wire bonds terminate. The termination end of the gold ball bond is called the stitch (also referred to as the crescent) bond. Just like the ball, the stitch bond requires a thick, even, and smooth plating to make a reliable bond. To overcome the surface defects a stand-off stitch bond (SSB) is used instead of a standard stitch bond (see Figure 1 for a comparison). To make a SSB, a gold ball is first bonded to the pins or leads, where the bond will terminate. This gold ball has a larger surface area and contains more gold than a standard stitch bond. Because of this, the gold ball bonds more readily and more securely to the imperfect surfaces. Once the gold balls have been placed the gold wire bond is made as usual, with the stitch bond welding to the top of the gold ball rather than directly to the pins or leads. The ball offers a large, thick, and smooth surface to which the stitch bond can be welded. This is a more reliable and robust bond for non-semiconductor grade surfaces, which can be used in high-reliability applications.

Aluminum wedge bonding is another popular interconnect technique. Unlike gold wire, aluminum does not need to be bonded at an elevated temperature. With the use of force and ultrasonic energy, aluminum can be welded to Al or some dissimilar metals at room temperature (see Figure 2 for image of bond head and work surface). This method is especially useful for temperature-sensitive parts. Because of the low-temperature capabilities of aluminum wedge bonding, it is selected as the interconnect method for many applications, such as MEMS optical sensors. MEMS optical sensors are sometimes connected to a flex circuit and they can be extremely sensitive to both heat and electrostatic discharge (ESD). These unique characteristics present another set of challenges.

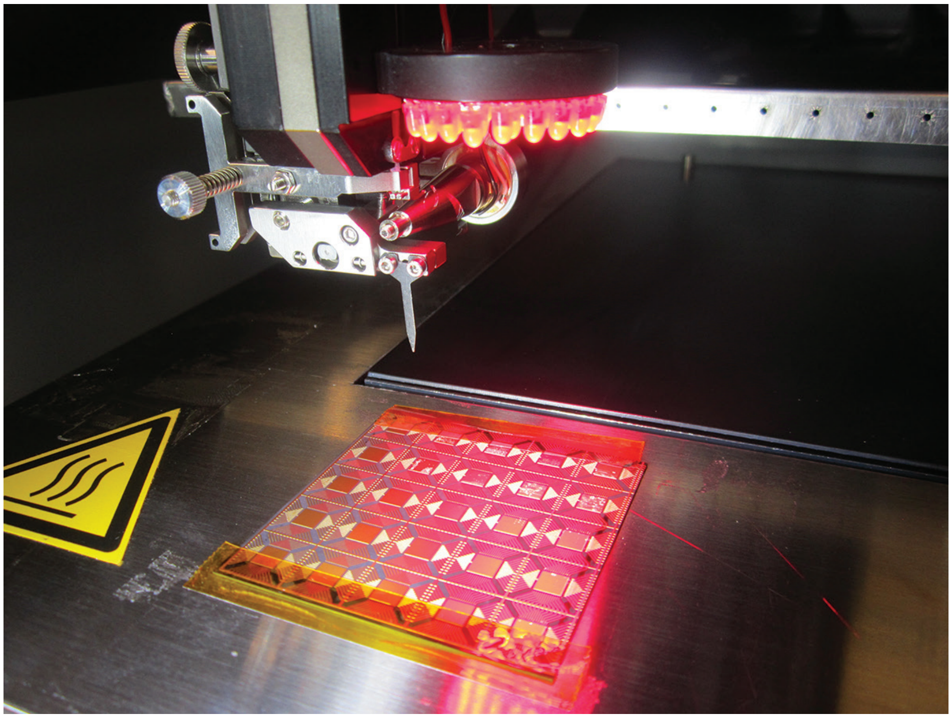

Figure 2. Aluminum wedge bond head with test coupon on work surface.

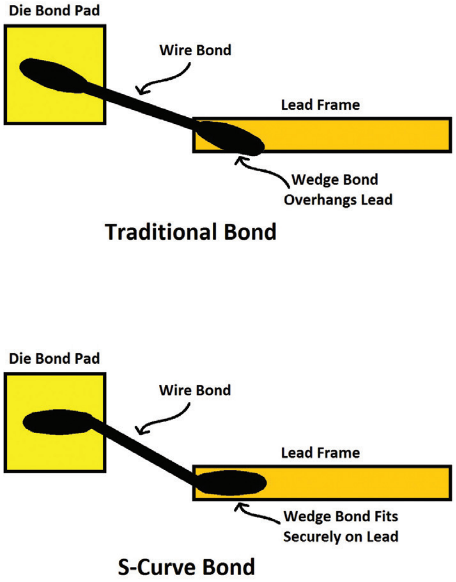

Figure 3. Diagram showing an S-curve bond shape.

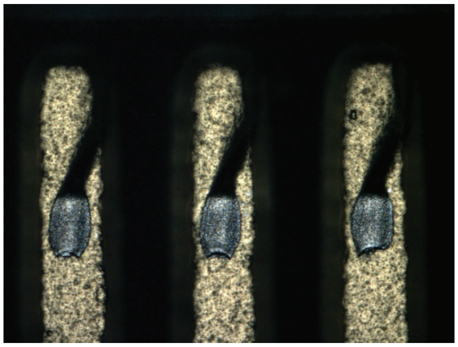

Figure 4. Image of S-curve wire bonds with 125µm pitch.

Once again, fixturing is always critical. Much like with gold ball bonding, the parts need to be secured in a fixed location, in an established orientation, and on a plane perpendicular to the bond tool. A common obstacle with a flex circuit is that it does not tend to lie perfectly flat. This creates undesired opportunity for the flex to shift during bonding. This movement can put an unwanted force on the die creating either die movement, die tilt, or die cracking while the part is in the fixture. A combination of set screws to secure the die and vacuum to secure the flex circuit can achieve necessary part perpendicularity and stability during bonding while removing the threat of unnecessary stress on the die. A slight variation between die attach and bond line thickness on each part can allow for some die movement in the fixture. This movement can disrupt wire bonding. The problem can be solved by placing a thin compliant support material beneath the die during bonding. This compliant material supports the die and reduces movement during wire bonding. Fixtures are initially designed on a solid modeling computer program. They are then rapid prototyped in SLA plastic to check fit, form, and function. Once the design has been verified, the fixture is approved and precision-machined out of aluminum.

MEMS optical sensors can be extremely ESD sensitive (e.g., <100V). Often time these are devices designed to be actuated electrostatically. As a result, every step of the process must by ESD-compliant. Special caution is taken during process development, handling, storage, and shipping. Every surface these parts touch must be checked and grounded before coming in contact with the parts. This requires careful consideration when developing the handling system used for the parts—for example, the fixtures used on the wire bonding equipment, trays used at inspection stations, and the protocol for how the parts get transferred during the process. Because of the extreme sensitivity of the parts, great caution must be used at all times when dealing with ESD-sensitive parts in order to avoid unwanted yield loss.

Once fixturing has been verified and ESD sensitivity has been guarded against, wire bonding development can begin. It is common that wire bond process development is not straight forward. With the increased demand for more interconnects in a smaller space leads and bond pads on PCB can become extremely dense. Depositing metallization with small and dense features can result in non-ideal surfaces. Sometimes leads can be tilted non-planar to the fixture. Often when this occurs no two parts are the same, with each lead tilted to a varying degree with metallization deposited to varying thicknesses. This makes developing a reliable and repeatable bond process difficult. By increasing the search height and decreasing the touchdown speed the wire bonder can compensate for the varying heights of the leads. Utilizing a combination of angled bonding and s-curves, lead tilt is accounted for and a robust aluminum wedge bonding process can be developed (see Figures 3 and 4).

The increasing demand for advanced applications of sensors has led to a surge in new technologies. Often times these new technologies use novel (sometimes referred to as next-generation) materials. Novel materials that are used to functionalize next-generation MEMS sensors need to be integrated with semiconductor and microelectronic manufacturing processes. These novel materials can have unique material properties that are extremely useful in the sensor, but often come with strict process limitations. For example, a sensor used in new medical imaging technology may use a die made out of one such next-generation material. Next-generation materials typically require extensive development and can become very costly. These materials can also be is extremely brittle (more brittle than Si), temperature sensitive, and sensitive to chemical exposure. Some materials cannot withstand the force needed for wedge bonding or the heat (and force) needed for ball bonding. These sensors need to connect to a PCB, but wire bond interconnects often can damage the sensor.

Because wire bonding is often not a viable option, bond pads can be engineered to be on the backside of the die to allow for a direct attach to the PCB. More stable materials can then undergo a flip-chip thermal compression process. Unfortunately, thermal compression requires both heat and force that may damage novel materials that are too brittle. Temperature-resistant and less costly materials could be interconnected using a solder reflow process. The heat of a reflow process can damage the heat-sensitive materials and does not allow for rework. To protect the novel material from heat and stress, a new flip-chip interconnect method can be developed. The pads on the PCB can be bumped with gold balls. Each ball is then coined to increase surface area and create bump height consistency (Figures 5 and 6). An isotropic conductive adhesive (ICA) can be dispensed on top of each coin. The adhesive can run over the sides of the coins as needed, but should not come in contact with any other adhesive covered coin. The die can be placed on the adhesive covered coins. It is aligned so that the adhesive covered coins contact the bond pads on the die and establish interconnects between the die and the PCB. The PCB provides passivation between each pad, coin, and adhesive glob. Insulated interconnects are formed as a result.

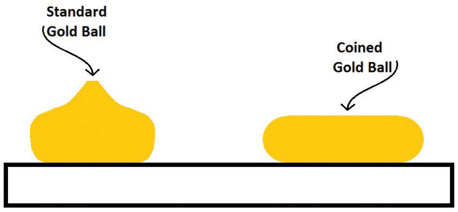

Figure 5. Diagram showing the difference in geometry between a coined and an un-coined bump.

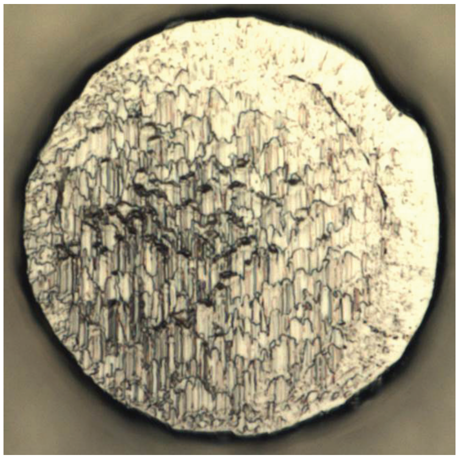

Figure 6. Photo of a coined gold bump.

The ICA has a low-temperature cure (less than 80˚C) so heat is never applied to the next-generation material. Only a slight force is required to attach the die to the conductive adhesive, which protects a brittle die from compression forces and stress damage. The adhesive acts as a semi-compliant material and compensates for any non-planarity between the coins and the die. It also compensates for any coefficient of thermal expansion mismatch between the PCB and novel material, further protecting the brittle material from stress.

The novel material and die itself are very expensive, therefore it is crucial that rework is possible. Because of the high-value added nature of the components, scraping a working die as a result of a misalignment, electrical short, or other interconnect failure is not an option. The conductive adhesive allows for the die to be repositioned or remove after it has been attached without sustaining damage. This is an important cost-saving process element. It allows for the new interconnect process to be fully developed at the lowest cost possible. Additionally, this method provides working prototypes without sacrificing thorough and deliberate testing and development.

Summary

These exciting advancements in the microelectronic industry are not without challenges. New applications and next-generation materials provide vast new opportunities for integrated circuits, sensors, and state-of-the-art manufacturing techniques. Creating robust and reliable interconnects for these new technologies presents a series of new obstacles. Despite this, problems encountered as a result of custom packaging, unique geometry, and unusual material limitations can be overcome. Using a combination of well understood processes (such as wire bonding), emerging technologies (such as isotropic conductive adhesive), and creative thinking, reliable interconnect processes can be developed for any new technology. Robust interconnects are crucial for the function and success of all new microelectronic technologies. Interconnect methods are adapting and advancing with the changing market. The cutting edge breakthroughs in the semiconductor market, combined with advanced interconnects processes, will continue to fuel growth and expand the microelectronic assembly landscape.

Mara Hirz is a process and manufacturing Engineer at SMART Microsystems in Elyria, OH. She has experience in wire bonding, die attach, testing, inspection, and analysis. Her current role includes process development and project management where she leads technical teams to success in developing assembly processes for new products on time and in budget. Mara received a BS in Mechanical Engineering from Cleveland State University with concentrations in thermodynamics, and is currently working towards her Masters. Email: mara@smartmicrosystems.com