Wire Bonding in Optoelectronics

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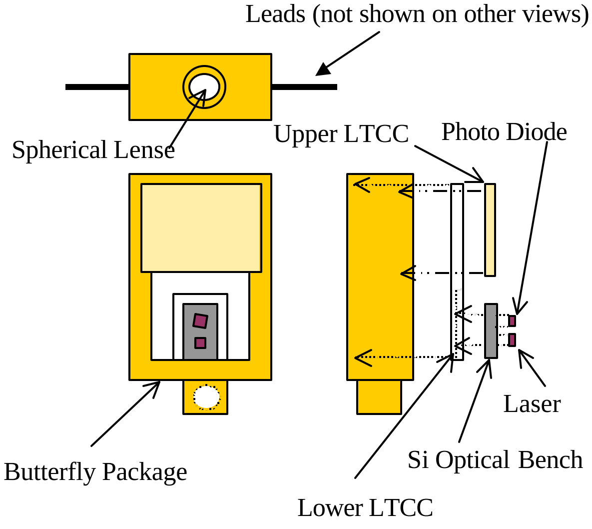
Introduction

Optoelectronic packages are classic hybrids with some new opto-mechanical variations. Although the most technically challenging tasks that they present are their very precise assembly placement requirements, resulting from the alignment and coupling requirements of the optical components and the light path, they also challenge the wire bonding process. Some of the variations that challenge wire bonding are:

- Multiple surface metallizations within the same package.
- Large bonding height differential.
- Low bonding temperatures.

Figure 1. Butterfly Package with Height of Bonding Surfaces



Height of Bonding Surfaces[mm]	
Thermo Electric Cooler	-0.7
Lower LTCC	0
Si Optical Bench	0.9
Pkg Wall L1	1
Pkg Wall L2	2.7
Upper LTCC	3.3

Wire bonding Optoelectronic Packages

Figure 1 shows some of the components within an optoelectronic package and their heights with respect to the base LTCC. The range of height, in this example 4mm between the lowest and the highest components in the package (largest actual wire bonding height differential is 3.3mm) is unusually large. Figure 2 shows the combinations of surfaces that might be wire bonded within the package. In addition there are often wire bonds between different locations on the same surface. The large number of surfaces, each with separate optimum bonding parameters, and large height differential make these packages difficult to bond.

Bonding the ball on the LTCC surface can often improve yield and reliability. Because the ball is soft, newly solidified and clean, it bonds to the thick film gold surface of the LTCC readily. Second bonds on the soft LTCC surface often have low yield. The soft thick film of the LTCC often does not provide enough mechanical resistance for the wire to deform and bond during second bond. Instead the wire is pushed undeformed into the LTCC thick film, forming a low strength poorly welded connection. The LTCC surface area is large and allows bonding large diameter ball bonds. Since most optoelectronic packages have low lead counts and do not require fine pitch bonding, larger ball bonds provide benefits by having a larger weld cross-section with higher strength and should be used when required.

Figure 2. Wire Bonding Surface Combinations

	Upper Bonding Surface				
Lower Bonding Surface	**LTCC 1**	**Si Optical Bench**	**Package Wall Level 1**	**Package Wall Level 2**	**LTCC 2**
TEC	√				
LTCC 1	■	√	√		√
Si Optical Bench	■	■	√		
Pkg Wall L1	■	■	■		√
Pkg Wall L2	■	■	■	■	√

Wedge Bonding vs Ball Bonding

There are two commercial wire bonding variations, ball bonding and wedge bonding[1]. Both processes use ultrasonic energy to enhance welding (co-deformation of the wire and substrate to produce an intermetallic joint). In the case of gold wire bonding both methods use elevated (100^{0}-220^{0}C) temperature processes, although wedge bonding is normally performed at slightly lower (25^{0}-50^{0}C) temperature than required by ball bonding. Figure 3 provides a chart comparing the two processes. Although ball bonding is normally faster, and more commonly used, wedge bonding has some distinct advantages (looping, bonding temperature, and contamination sensitivity) for optoelectronic packages.

Figure 3. Wire Bond Method

Ball Bond

- Faster
- Any Direction from Ball
- Less Aggressive
- Most Common Process (availability)

Wedge Bond

- Finest Pitch
- Less sensitive to surface contamination
- Low profile, controlled wire length loops
- Lower Bonding Temperature

DOEs For Optoelectronic Packaging

Process optimization poses additional difficulties when components are valuable as are some newly developed optoelectronic devices. Small lot sizes, short runs, and lack of available components all make optimization, with statistically meaningful sample sizes, a challenge. DOEs are necessary to understand the complex bonding conditions. Several excellent experimental designs that require only a few samples are available. The Taguchi L-9 design requires only 9 samples to test 4 variables at 3 levels each. The 2^{4-1} fractional factorial design is also effective when only a few samples are available. This design tests 4 variables at 2 levels each with 8 samples. Adding center points to these designs allows testing of curvature in the response surface with only a few extra samples. Saturated designs that are frugal with expensive samples are available in many commercial DOE software packages. The E-Chip package is a noteworthy example.

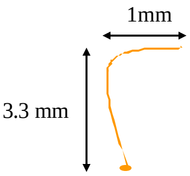
When there are many types of metallizations within the same package, as is the case with optoelectronic devices, it is important to consider each metallization separately. Multi-variate response surface experiments, with each metallization type grouped to find a separate optimum, are required to optimize the process. Concurrent DOEs for each of the metallizations can easily be run by assigning each to a separate wire group (available in the software of automatic bonders) and changing parameters for each group separately according to the DOE plan. Additionally, analysis of the measured responses must also be separated. Experimenting in this manner allows separate optimization of bonding parameters for each metallization, and a better optimum response than would be achieved if all of the wires were bonded with the same parameters.

Loop Shape

Looping algorithms for automatic wire bonders have not been fully developed for optoelectronic packages. Figure 1 shows a chart of actual heights of some components within a package. In some cases wire bond loop profiles are required having as much as 3.3 mm vertical height differential. Figure 4 is a sketch of a loop between the two LTCC surfaces in Figure 1. Programming loops for this application, with the profiles available on commercial wire bonders, is difficult. Wire bonder manufacturers need to develop easily controlled and programmed loop profiles as they have for other common package types**.** This will enable process engineers to focus on the desired loop shape, rather than on profiles that were designed for other products requiring different shapes and that lack the control necessary for this application.

Figure 4. Wire Bond to Upper LTCC

- Range of bonding heights is very large (4mm in a single package). Requires programmable focal height for good PRS
- Needs new loop shapes
- Only a few wires carry high frequency signals. The length and height (shape) of the high frequency wires is critical.



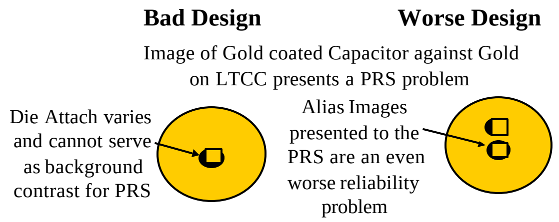
In IC ball bonding the wire normally descends from the ball bond to the second bond on a lower elevation surface. Optoelectronic packages often have wires that ascend from the ball bond to the second bond. The ascendant shape shown in Figure 4 provides higher yield and reliability than the descendant shape.

Deep Access and Pattern Recognition

The extreme range of height differential (as much as 4-5 mm) within an optoelectronic package requires deep access equipment and tooling. In order to accurately and repeatably locate and bond components whose surfaces are at different heights, the Pattern Recognition (PRS) System must have a clearly focused image. Programmable focal height offers this clear image over the required height range and is a mandatory requirement for optoelectronic packages.

Automatic wire bonders need unique vertical and horizontal edges with good contrast for defect free pattern recognition. Optoelectronic devices often have multiple levels of gold coated components placed close together. Finding a cubic, gold coated capacitor against the gold background on a LTCC is a challenge when there are several capacitors in the same field of view (alias images). Good design rules for package manufacturability are required to ensure high yields, otherwise PRS failures and alias images will result in yield loss.

Figure 5. Pattern Recognition Problems



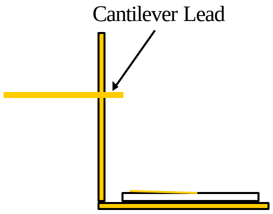
Pattern Recognition Systems need good contrast between dark and light edges in both the X & Y directions

Special bonding tools are also required for some optoelectronic devices because the height of the package walls may interfere mechanically with the bonder. Interference may come from the underside of the ultrasonic horn, wire clamps, capillary or wedge shank. These mechanical issues often have a detrimental effect on process capability and if possible should be avoided by design. Grinding and shaving capillaries and wedges to allow deeper access and close proximity to the package walls is sometimes necessary but always risky, costly and decreases yield.

Second Bond Issues

Cantilever leads (leads protruding through the package wall like diving boards), can vibrate and attenuate ultrasonic energy. It has been shown that if the natural vibration frequency of the lead is greater than half the ultrasonic bonding frequency, the lead will resonate and will not bond [2]. Shorter cantilevers and stiffer beam cross-sections can improve the bonding process. The first bond of a wedge bond is capable of bonding closer to the package wall, and often is more reliable than a ball bond in this type application.

Figure 6. Cantilever Leads are Difficult to Bond



- Bonding close to Package Wall Requires Bottle neck capillary
- Thin Leads can Resonate during ultrasonic bonding. Resonance attenuates ultrasonic energy required for bonding.
- Bottleneck capillaries are more fragile and have shorter life than standard capillary designs.

Wire bonding occurs at the end of the assembly process after the lowest melting temperature solder alloy has already reflowed, therefore bonding temperature is limited (often as low as 130^0C). Allowing optical components to reflow a second time would compromise their placement accuracy, lowering reliability. Individual components within the package (upper level LTCC substrates and cantilever leads) can often be below 100^0C. The quality of the crescent bond (the second bond in the thermosonic ball bond process) is challenged by low temperature bonding because the mechanism for bond formation is diffusion and these conditions do not enhance diffusion. A solution to this problem is the use of high frequency ultrasonic generators and plasma cleaning. Plasma cleaning will increase the wire bond pull strength significantly and often allow high yield manufacturing where otherwise unacceptable process yields would be experienced.

Ribbon Bonding - A Variation of Ultrasonic Wedge Bonding

High frequency components are often interconnected with ribbon bonds (thermosonic wedge-wedge bonding using flattened wire with a rectangular cross section). Ribbon wire provides better high frequency electrical performance than round wire, while conductance is higher[3]. Mutual inductance and cross talk between adjacent ribbons is lower.

Ribbon bonding requires a dedicated wire bonder designed for this application. Bonding parameters (ultrasonic power and bond force) required to bond a thin ribbon are significantly lower than for the equivalent diameter round wire. Stiffness of the thin ribbon cross section is also significantly lower than for the round counterpart, allowing ribbon to bend and form a loop with less force than equivalent round wire. Lower ultrasonic power and bond force combined with easier bending and loop formation are better for bonding fragile high frequency dice that are often made from brittle materials (GaAs, $LiNb_3$).

Conclusions

Assembly of optoelectronic packages presents new process engineering challenges. Good design guidelines, DOEs, and process capability studies are required to establish robust manufacturing processes. .

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