TP04PUB284

TECHNICAL PAPER

Wire Bonding Challenges in Optoelectronics Packaging

author(s)

JIANBIAO PAN, PHD
California Polytechnic State University
San Luis Obispo, California

PATRICE FRAUD
NPOS Consulting
Los Angeles, California

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terms

Wire Bonding
Optoelectronics Packaging
Ball Bonding
Wedge Bonding

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Wire Bonding Challenges in Optoelectronics Packaging

Jianbiao Pan, Ph.D.
Assistant Professor
Department of Industrial & Manufacturing Engineering
California Polytechnic State University
San Luis Obispo, CA 93407
Phone: (805) 756-2540
Email: pan@calpoly.edu

Patrice Fraud
Sr. Technical Consultant
NPOS Consulting
2225 S. Beverly Glen Blvd.
Suite 104
Log Angeles, CA 90064
Phone: (310) 441-9857
Email: pfraud@attglobal.net

Abstract

Wire bonding has been used in integrated circuit (IC) packaging for many years. However, there are many challenges in wire bonding for optoelectronics packaging. These challenges include bonding on sensitive devices such as Lithium Niobate and Indium Phosphide, bonding over cavity, bonding over cantilevel leads, and bonding temperature limitations. The optoelectronics package design brings another challenge, which requires wire bonding to have deep access capability.

In this paper, the wire bonding technologies are reviewed, and ball bonding and wedge bonding are compared. The variables that affect the wire bonding process are then discussed. Finally the challenges of wire bonding in optoelectronics packaging are presented in details.

Keyword: Wire bonding, optoelectronics packaging, ball bonding, wedge bonding

Introduction

Wire bonding has been the dominant method of electrical interconnection between the integrated circuit (IC) and the package. The interconnections to 95% of semiconductor chips use the ultrasonic or thermo-sonic technique at a frequency ranging from 60 to 120 KHz.

Wire bonding is also a common method of optoelectronics packaging. The differences between conventional IC packaging and optoelectronics packaging are: 1) conventional IC packaging deals with electrical signal only while optoelectronics packaging deals with electrical signal as well as optical signal; 2) conventional IC packaging mainly uses ball bonding technique while optoelectronics packaging commonly uses wedge bonding or ribbon bonding because wedge/ribbon bonding offers deep access, fine pitch and better high frequency performance.

Optoelectronics packaging brings new challenges to wire bonding. These challenges include bonding on sensitive devices such as Lithium Niobate and Indium Phosphide, bonding over cavity, bonding over cantilevel leads, and bonding temperature limitations. The optoelectronics package design brings another challenge, which requires wire bonding to have deep access capability. This paper presents the challenges of wire bonding in optoelectronics packaging after an overview of wire bonding technologies is given and wire bonding process variables are discussed.

Wire Bonding Technologies

Wire bonding is a solid state welding process, where two metallic materials are in intimate contact, and the rate of metallic interdiffusion is a function of temperature, force, ultrasonic power, and time. There are three wire bonding technologies: thermo-compression bonding, thermo-sonic bonding, and ultrasonic bonding.

Thermo-compression is performed using heat and force to deform the wire and make bonds. The main process parameters are time, temperature, and bonding force. Based on a diffusion welding theory [1], the diffusion reactions progress exponentially with temperature. So small increases in temperature can improve bond process significantly. In general, thermo-compression requires high temperature (normally above 300°C), and long bonding time to make bonds. That high temperature can damage some sensitive ICs. In addition, the process is very sensitive to bonding surface contaminants. That is why the technology is seldom used now.

Thermo-sonic bonding is performed using a heat, force, and ultrasonic power to bond a gold (Au) wire to either an Au or an aluminum (Al) surface on a substrate. Heat is applied by placing the package on a heated stage. Some bonders also have heated tool, which can improve the wire bonding performance. Force is applied by pressing the bonding tool into the wire to force it in contact with the substrate surface. Ultrasonic energy is applied by vibrating the bonding tool while it is in contact with the wire. Thermo-sonic process is typically used for Au wire/ribbon.

Ultrasonic bonding is done at room temperature and performed by a combination of force and ultrasonic power. The pressur used in ultrasonic bonding and thermo-sonic bonding is much lower, and welding time is shorter than for thermo-compression bonding. Though Au wires to Au pads bonds can be made by ultrasonic bonding, ultrasonic bonding is primarily used for Al wires on either Au or Al pads, and has been the dominant technique for large-diameter Al wire in power electronics device applications. The comparisons of these three wire bonding technologies are shown in Table 1.

Table 1. Wire Bonding Technologies

Wire bonding	Thermo-compression	Thermo-sonic	Ultrasonic
Ultrasonic Power	No	Yes	Yes
Bonding force	High	Low	Low
Temperature	High (300~500°C)	Middle (120~220°C)	Low (room temperature)
Bonding time	Long	Short	Short
Wire Material	Au	Au	Au, Al
Pad material	Au, Al	Au, Al	Au, Al
Contamination	Strongly affected	Middle	Middle

Ball Bonding vs. Wedge Bonding

There are two types of wire bonds: ball-wedge bonding and wedge-wedge bonding. The ball bonding and wedge bonding processes are described in references [2, 3, and 4]. Today, more than 95 percent of all wire bonds in electrical packaging are performed with gold ball bonding [2, 3]. That is because ball bonding is much faster than wedge bonding. Ball bonding requires only three axes of movement (X Y Z) while wedge bonding requires four axes of movement (X Y Z θ). In ball bonding, only gold (Au) wire can be used while gold and aluminum (Al) wires are used commonly in wedge bonding. This is because Al wire will oxidize during the electronic flame off (EFO) process to form the ball. Note that high-volume copper (Cu) wire ball bonding process is under development now [8]. To avoid Cu wire being oxidized during the ball formation, the EFO process is performed into inert gas environment. The comparisons of ball bonding and wedge bonding are shown in Table 2.

Though wedge bonding is slower than ball bonding, wedge bonding offers many benefits, for example, deep access, fine pitch, and low and short loops. That is why wedge bonding has been used extensively in microwave and optoelectronics applications.

Table 2. Comparison of Ball Bonding and Wedge Bonding

Applications	Ball bonding	Wedge bonding
Bonding Techniques	Thermo-compression (T/C) Thermo-sonic (T/S)	Thermo-sonic (T/S) Ultrasonic (U/S)
Temperature	T/C-- >300°C T/S-- 120°C to 220°C	Al wire—U/S at room temperature; Au wire—T/S 120°C to 220°C.
Wire size	Small (<75μm)	Any size wire or ribbon
Pad size	Large (3 ~ 5 times of wire diameter)	Smaller pad size than a ball bond. Good for the microwave application. The pad size = 2-3 times of wire diameter (could be =1.2 times of ribbon width)
Pad material	Au, Al	Au, Al
Wire material	Au	Au, Al
Speed	Fast (10 wires/sec)	Relatively slow (4 wires/sec)

Variables that Affect the Wire Bonding Process

This session focuses on wedge bonding process only. The components of a wedge bonding process include the wedge, the wire or ribbon, the substrate, the wire bonder, and the process parameters. The detailed variables of the above five components that influence the wedge bonding process are summarized in Figure 1.

Effect of Wedge

Wedge material is typically Titanium Carbide or Ceramics for gold wires or ribbons. A titanium carbide wedge is cheaper and easier to manufacture than a ceramics wedge. For aluminum wires, Cemented Tungsten Carbide is commonly used wedge material. Cemented Tungsten Carbide wedge can be contaminated with gold easily and results in excessive tool degradation, tool wear and premature tool replacement. That is why cemented tungsten carbide wedge is not good for Au wires.

In ultrasonic bonding and thermo-sonic bonding, it is important for the wedge to transmit the ultrasonic power to the interface between wire and bonding pad. That requires a good wedge foot design. For a gold wire with a diameter larger than 1 mil, a cross groove on wedge foot is required to achieve a good bond. The extra mechanical 'gripping' action of the cross groove gives the tool/wire interface a higher ultrasonic coupling energy to the bond surface. For an Au wire with a diameter less than 0.8mil, a flat face is commonly used. Aluminum wire application commonly requires a concave foot design.

With the move toward further miniaturizing of packages, foot size of a wedge has shrunk. Back in the 1990s, the basic rule was the foot size set to 2.5 times of the wire diameter. Today due to the shrinkage of chip size and high density of I/Os, the foot size of the wedge is commonly set to 1.5 to 2 times of the wire size.

Effect of Wire/Ribbon

The common wire material of thermo-sonic bonding is gold and of ultrasonic bonding is aluminum. Gold wire/ribbon to a gold bond pad is extremely reliable because the bond is not subject to interface corrosion, intermetallic formation, or other bond-degrading conditions. Gold wire welds best with heat although cold ultrasonic Au-Au wire bonds can be made.

In thermo-sonic bonding, a wire with 99.99% to 99.999% of Au, usually ranging from 0.7mil (18μm) to 1.3mil (33μm) in diameter is used. 1 x 4 mil (25μm thick by 100μm wide) Au ribbon is common for high frequency application. Two main wire properties are percent of elongation and tensile strength. In general, a hard wire/ribbon gives higher pull strength and consistent loop and tail length formation. A soft wire/ribbon is preferred when the device is sensitive to ultrasonic stress. Experience indicates that soft ribbon with elongation of 8-13% needs low force and low ultrasonic power and hard ribbon with elongation between 1-4% needs large force and large ultrasonic power to achieve a good bond.

Effect of Substrate

The parameters of the bond pad include pad metallization, gold or aluminum metallized surface thickness, pad cleanliness, and whether the pad is well supported. Pan, et. al [7] compared chromium-gold (Cr/Au) and titanium- titanium nitride-platinum-gold (Ti/TiN/Pt/Au) metallization on wire/ribbon bondability. The thickness of the gold layer also played a critical role in bondability. Minimum gold thickness requirements for wire/ribbon bonding are 40 microinches or 1 μm. A thicker gold layer will have a favorable effect on bondability.

It is very important to keep the bond pad from contamination. Contaminations on bond pads will degrade the bondability and reliability of wire bonds. UV Ozone cleaning and plasma cleaning are two effective methods to remove organic contaminations.

The bond surface should be well supported during bonding to make a high quality bond. Bonding on not well supported surfaces such as cantilever pins, ultrasonic power will attenuate.

Effect of Bonding Process Variables

Bonding process variables include ultrasonic power, bonding force, bonding time, and temperature. Design of experiments method is commonly used to determine the proper process settings to ensure that all bonds are made.

To find the optimum bonding settings is not an easy job because there are interactions between process variables. A high quality bond can be characterized as high pull strength (or shear strength in ball bonding) and consistent tail length. Possible failure modes are non-stick, foot-lift, and heel-break. Non-stick means that no bonds can be made. Foot-lift means that the whole bond lifts during destructive testing, while heel-break means that the wire broke at heel during a destructive test and the foot of the wire still remains at the bond pad.

The heel-break is a preferred failure mode. Experiences indicate that there is a strong relationship between pull strength and wire deformation as shown in Figure 2. Because of the relationship, some wire bonder manufacturers developed on-line bond process control based on the measurement of deformation. Note that the relationship can be invalidated if strong contamination exists at the bond interface.

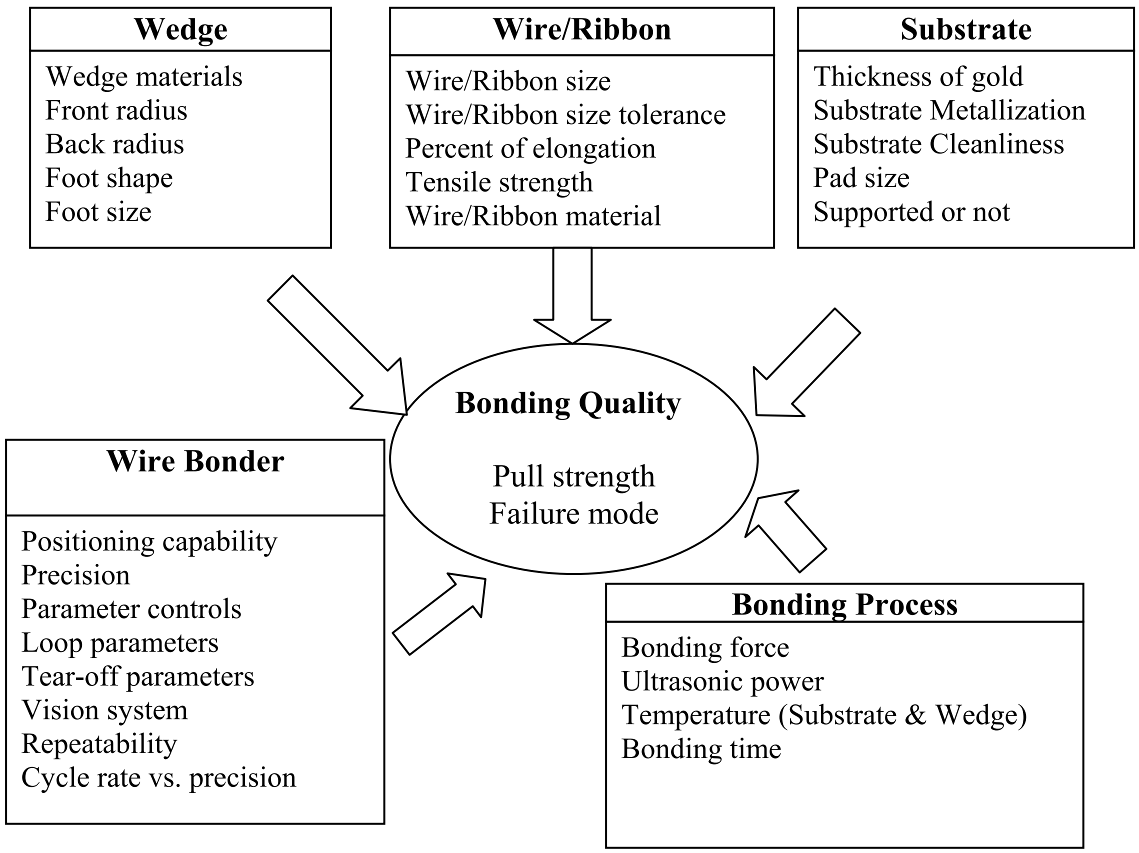

Figure 1. Factors that Influence the Wedge Bonding Process

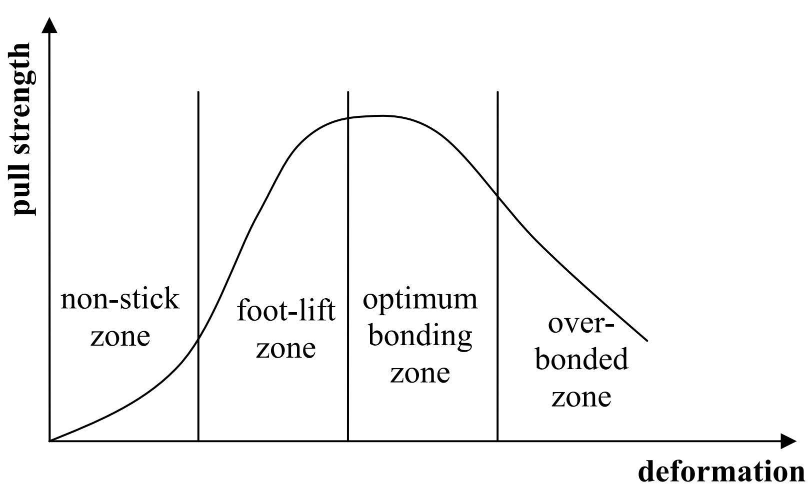

Figure 2. Relationship between Pull Strength and Wire Deformation

Challenges of Wire/Ribbon Bonding in Optoelectronics Packaging

As described previously, wedge bonding is commonly used in optoelectronics packaging. Ribbon bonding is a special case of wedge bonding and has been used as interconnection for optoelectronics application because of its lower impedance and lower inductance.

Though wire bonding has been used in integrated circuit (IC) packaging for many years, there are many challenges in wire bonding for optoelectronics packaging. These challenges include bonding on sensitive devices such as Lithium Niobate (LiNbO3) and Indium Phosphide, bonding over cavity, and bonding over cantilevel leads.

Bonding Temperature Limitations

Some of optoelectronic devices such as Lithinum Niobate ($LiNbO_3$) are very sensitive to stress so that epoxy with low glass transition temperature was selected to mount $LiNbO_3$ die on a package. As a material, Lithium Niobate is both piezoelectric and pyroeletric. These unfortunate properties produce excessive amounts of surface charges on the die when it is quickly raised in temperature. Both the epoxy used in the application and the $LiNbO_3$ properties tend to limit maximum bonding temperature up to about 150°C.

Some optoelectronics devices are assembled with a hierarchy of solders to mount components to the package. Many optical devices require precise placement, so no second time solder reflow is allowed after assembled. Since wire bonding process is performed after a series of component mount processes, the bonding temperature cannot exceed the lowest reflow temperature of solder alloys. These restrictions on how high the package temperature may be raised make the wire/ribbon bonding difficult [6].

Bonding Substrate Limitation

The second challenge is bonding to a substrate that is not attached rigidly. For example, cantilevel leads are commonly used in optoelectronic packages. Bonding on cantilevel leads is a challenge because the leads can vibrate and attenuate ultrasonic energy. In addition, the cantilevel leads are assembled to the package first, and then plated with Ni and Au. Since the whole package is plated with Au, the Au thickness is limited on these cantilevel leads to lower the package costs. The thin Au thickness makes wire bonding difficult.

In another case, some optoelectronic package was designed having cavities under the ribbon bonding areas. The cavities are for optoelectronic functions such as the co-planer design of the package RF launch areas. These cavities tend to defeat the ultrasonics used in the wire bonding process.

Packaging Design Limitation

Many optoelectronic packages are designed as “butterfly” shape. Electrical interconnections are from the cantilevel leads to the die pads mounted inside the package. The height difference between the cantilevel leads and the die pads are large, which requires the wire bonder to have deep access capability.

Different from IC packaging, which the first bond is on the die pad and the second bond is on the package, typical wire bonding in optoelectronic packaging has the first bond on the cantilevel leads and the second bond on the die. This is because the bond pads on the cantilevel leads are very close to the package walls as shown in Figure 3. To avoid interference between the wedge and the package wall, the first bond is normally placed on the leads.

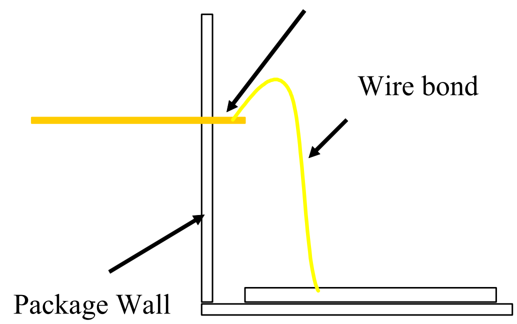

Figure 3. Sketch of Wire Bond between the Cantilevel Lead and the Die Pad

Conclusions

The optoelectronics industry is driving the wire bonding technology toward new challenging. The challenge is to achieve quality product and robust process for optoelectronics application at the IC industrial standard with a yield less than 25 ppm defect. This requires process development effort in optimizing the wire bonding process using statistical methodologies. It is also a challenge for the suppliers of wire, wedge and equipment.

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Biography

Dr. Jianbiao (John) Pan is an assistant professor in the Department of Industrial and Manufacturing Engineering at California Polytechnic State University, San Luis Obispo. After he received a Ph.D. degree from Lehigh University, Bethlehem, PA in 2000, Pan joined the optoelectronics center at Lucent Technologies/Agere Systems as a member of the technical staff. While at Lucent, he developed and implemented package manufacturing and assembly processes for the 10G, 20G, and 40G Lithium Niobate modulator, polarization controller, tunable laser, and 40G receiver. Pan's research interests have been concentrated in lead-free soldering, electronics packaging, optoelectronics packaging, surface mount assembly, hybrid microelectronics, and computer aided manufacturing. Pan has been an SME advisor on electronics manufacturing, and served on the National Technical Committee for the International Microelectronics and Packaging Society (IMAPS). He is a recipient of 2004 M. Eugene Merchant Outstanding Young Manufacturing Engineer Award from the SME.

Patrice Fraud founded NPOS Consulting in 2001, coming from F&K Delvotec Inc., where he was North American Field Service and Application Engineering Mgr. He joined F&K Delvotec, Gmbh. (Germany) in 1996 and joined F&K Delvotec, Inc. in 1997, the new local Head quarter located in California. Prior to that, he held a management position at Kulicke & Soffa at their local branch in Europe, directing customer support and developing applications for high-speed wire bonding and dicing processes. He has broad experience in managing all aspects of Process & product development from conception through production. Patrice has over 20 years experience of associations with the Assembly and microelectronic industry. He earned a BSEE from Paris V Science University (France).