

Practical Considerations for PowerRibbon® Bonding of Hybrid Packages

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Abstract

PowerRibbon® development started at Orthodyne in 2000 and was first used in mass production in 2004. Today, PowerRibbon® is a robust process used in a variety of applications around the world, including automotive power modules for popular hybrid cars. Production experience has proven the performance, cost and productivity advantages of ribbon, and in today's market, it is a valuable tool for maximizing competitiveness. This paper is an overview of the steps needed to implement a PowerRibbon® production process.

Keywords: PowerRibbon®, ribbon bonding, Aluminum, power hybrid

Introduction

The PowerRibbon® process currently bonds Aluminum ribbon in sizes from 500 x 100 to 2000 x 300 microns (20 x 4 to 80 x 12 mils). The essential similarity of the PowerRibbon® ultrasonic bonding process to the long-established and well-understood large-diameter Aluminum wire bonding process means that surface metallizations and die types that are successfully bonded with wire can be bonded with ribbon, including power MOSFETs and IGBTs.

Inspection methods and failure modes for ribbon are similar to round wire and can often be evaluated with the same measurement systems. Automated wire bonders can be converted to ribbon and the retraining of operators and technicians is minimal.

A wide range of ribbon sizes makes the process useful for a wide range of applications, including applications with very high current requirements.

Ribbon bonding is environmentally-friendly and can bond solar modules [1] and other applications that are typically soldered.

The low loops and high currents possible with ribbon make it the preferred interconnect for many discrete power packages [2]. Ribbon is suitable for small, thin packages with severe constraints on loop height, such as SO-8 or PQFN [3], and for larger high-current packages, such as DPAK or TO-220.

This paper will focus on PowerRibbon® in hybrid power modules, where exceptional performance and reliability under harsh operating conditions is a common requirement.

PowerRibbon® in Hybrids

PowerRibbon® is particularly exciting for power hybrid applications because it is the first new high-current-capacity interconnect process to reach volume production in many years.

Ribbon is a cost-effective way to achieve a higher level of electrical performance and reliability than is possible with Aluminum wire bonding. In some applications, ribbon's improved performance in package profile, current spreading, thermal management or switching frequency may be important factors.

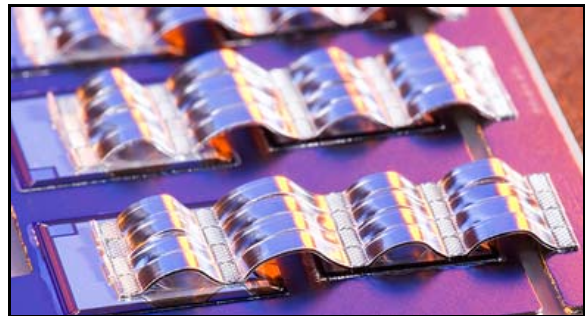


Figure 1. High-current PowerRibbon® bonds on a hybrid substrate.

Reliability test results for PowerRibbon® have been as good as, or better than round wire [4]. PowerRibbon® performance in vibration testing is excellent, which could be a deciding factor in favor of ribbon for some applications where the high current capacity of ribbon is not required.

Table 1. Constant-Voltage Interconnect Resistance Equivalence for Ribbon and Wires of Equal Length

Al Ribbon (mils)		Number of Parallel Aluminum Wires for the Same DC Current Capacity									
Width	Thickness	4 mils	5 mils	8 mils	10 mils	12 mils	14 mils	15 mils	16 mils	18 mils	20 mils
30	3	7.2	4.6	1.8	1.1	0.8	0.6	0.5	0.4	0.4	0.3
30	6	14.3	9.2	3.6	2.3	1.6	1.2	1.0	0.9	0.7	0.6
40	4	12.7	8.1	3.2	2.0	1.4	1.0	0.9	0.8	0.6	0.5
40	6	19.1	12.2	4.8	3.1	2.1	1.6	1.4	1.2	0.9	0.8
40	8	25.5	16.3	6.4	4.1	2.8	2.1	1.8	1.6	1.3	1.0
50	8	31.8	20.4	8.0	5.1	3.5	2.6	2.3	2.0	1.6	1.3
60	6	28.6	18.3	7.2	4.6	3.2	2.3	2.0	1.8	1.4	1.1
60	8	38.2	24.4	9.5	6.1	4.2	3.1	2.7	2.4	1.9	1.5
80	6	38.2	24.4	9.5	6.1	4.2	3.1	2.7	2.4	1.9	1.5
80	8	50.9	32.6	12.7	8.1	5.7	4.2	3.6	3.2	2.5	2.0
80	10	63.7	40.7	15.9	10.2	7.1	5.2	4.5	4.0	3.1	2.5
80	12	76.4	48.9	19.1	12.2	8.5	6.2	5.4	4.8	3.8	3.1

Ribbon has more current capacity per interconnect than wire, which means fewer bonds and greater equipment throughput. Ribbon decouples current capacity from the interconnect thickness for flatter loops in thin packages [5]. The combination of performance improvement, productivity, flexibility, and cost savings makes ribbon the interconnect of choice for many applications.

The steps needed for a successful ribbon bonding application are not complex. Whether transitioning from wire to ribbon, or designing a new hybrid, the steps are similar.

Selecting Ribbon Size

Tables are available for the current capacities of ribbon and the equivalence of ribbon to wires of different materials and lengths. Table 1 shows the equivalence of a ribbon to aluminum wires in a range of sizes. For example: one 80 x 12 mil ribbon is equivalent to 4.8 wires that are 16 mils in diameter.

Factors that can affect ribbon size selection include: bond pad or lead size, thermal management, current crowding, $R_{DS(ON)}$, impedance, loop length, loop shape, package height, and device operating environment.

Current capacity is often the deciding factor in ribbon size selection, but the size of bond pads or leads may limit the possible ribbon size. A variety of PowerRibbon® bondtool designs are available to meet different bond pad or lead constraints.

Requirements for low $R_{DS(ON)}$, reduced current crowding on a die, or thermal management

may require a larger ribbon. Looping requirements for stitch bonds may limit the thickness of ribbon. Package height is not usually a factor that limits the thickness of ribbon for hybrids but is often a factor in discrete power semiconductor packages.

Device Layout for Looping

Looping considerations affect hybrid design differently for ribbon than for large-diameter aluminum wire. For more consistent ribbon looping and less stress on the heels of bonds, optimize the position and orientation of bond pads and leads so that bonds are at 'natural' angles relative to the loops.

Bonds that are not at 'natural' angles are said to be at 'forced' angles. Forced angles may occur because the process program for the bonder has a manually-programmed angle for a bond, or because a ribbon with more than two bonds has bonds that are not in a straight line, as shown in Figure 2.

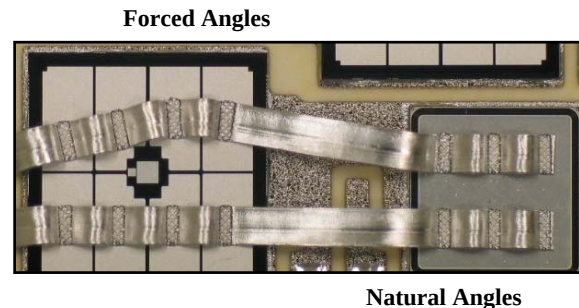


Figure 2. A hybrid with both natural and forced angle bonds.

A wire-bonded application with large forced angles may require repositioning of the die or substrate traces, depending on the size of the ribbon.

As the angle of a ribbon bond increases away from the natural bond angle, the possibility of looping variation or damage to bond heels increases. Wide, thick ribbon with low loops and a short distance between bonds can only tolerate small forced angles.

The relative height of bond surfaces can affect the maximum-allowable forced angle, for instance: from a die up to a pin or lead. It may be necessary to simulate the device layout and perform trial bonding to verify whether a looping and forced angle choice is robust enough for production.

Bond Surface Stability

Another aspect of hybrid package design for ribbon bonding is the stability of the bond surfaces. As in large-diameter wire bonding, clean and well-supported bond surfaces are essential to good ribbon bonds.

Bond force and ultrasonic energy is distributed over the entire ribbon bond area throughout bonding and so, in some cases, ribbon bonds may have lower localized forces than wire bonds, but the total force and ultrasonic energy applied to a ribbon bond is usually higher than the force and energy applied to a wire bond.

Voids under dice or substrates are likely to cause variation in ribbon bonding or damage to the bonded surface. Pins that flex or resonate may cause poorly-formed ribbon bonds. Mold locks for pins in plastic packages can insure adequate support to stabilize the pin during bonding. An alternate transducer frequency may reduce resonance in some applications.

Appropriate hybrid package design and low variation in manufacturing processes upstream from the bonder will insure consistent ribbon bonding results.

Bondtool Selection

Bondtool selection can affect, or be affected by, device layout and package constraints. Many aspects of the PowerRibbon® bondtool geometry combine to provide consistent, strong bonds.

Bondtool selection will depend on the width, thickness, and type of ribbon. In some cases, special foot designs are used to allow bonding on narrow leads or to provide stronger heels for difficult loop shapes. Figure 3 shows a bond produced by a short-foot tool.

The bondtool design will determine the size of the bonded area and the way in which the

intermetallic bond develops during the bonding process. This will affect the current density and distributed resistance, as well as the long-term reliability of the bond.

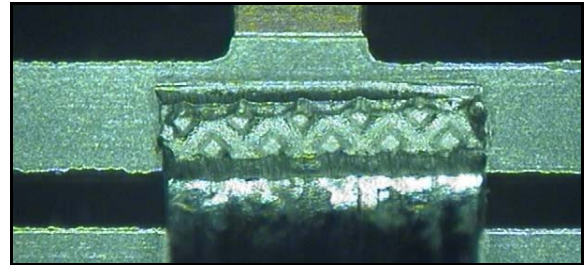


Figure 3. The ribbon bond from a short-foot bondtool fits on a narrow lead.

Ribbon Material Selection

Most PowerRibbon® applications now in production use corrosion-resistant mono-metallic Aluminum ribbon. New types of high-performance ribbon, such as bi-metallic ribbon, are in development to meet a wider range of performance requirements.

An increasing number of vendors offer ribbon suitable for PowerRibbon® bonding. Competition has significantly reduced prices and expanded the opportunities for ribbon applications. Orthodyne provides a specification for the dimensional tolerances of ribbon to insure that looping and bonding variation is minimized.

Process Programming

Programming ribbon process programs is essentially identical to programming Aluminum wedge process programs.

Usually, values for ribbon bond parameters will be higher than for wire, but the ribbon bonds respond to parameter adjustments in same way as wire bonds. A designed experiment (DOE) to establish bond parameters is not always required but is recommended for process optimization.

Examine the heels of the ribbon bonds and avoid weakening them by over-bonding or excessive bending during loop formation. Use shear and pull test to verify bond force, bond time, and ultrasonic power parameters.

Measuring Ribbon Bonds

Measuring ribbon bond characteristics is similar to measuring wire bonds, though there are important differences in the techniques and there is one ribbon measurement that does not exist for wire bonds: 'remaining thickness' [6].

Not all measurement methods are practical or possible for all ribbon applications. The ribbon and the bonds are so strong that some measurements are very challenging!

Shear test is the best measure of bond adhesion and provides information about the bond contact area. Ribbon shear test requires appropriate equipment and fixturing methods to get consistent data. Factors for successful ribbon shear test include:

- The shear tester has a highly rigid structure.
- A shear tool designed for ribbon is used.
- The device to be sheared is firmly held.
- The shear plane is parallel to the bond plane.
- The bond is sheared from the front, not side.

The test equipment shear height resolution and accuracy is critical to reliable and repeatable results.

Thick ribbons with short loops may require that the ribbon is cut at mid-span before shearing, so the shear is not affected by ribbon stiffness or the next bond. Shear test may not be possible for a hybrid package that does not have sufficient access for the shear tool. Package pins may not have enough support to keep a pin rigid during shear test.

Pull test for ribbon is primarily a measure of heel strength and the most common failure mode for ribbon pull test is heel breaks – a mid-span break is less common. Bond lifts only occur if there is a significant problem with the bond process, perhaps gross contamination.

It is possible for the ribbon to be stronger than the pull hook, especially with hooks designed to get under low loops. A peel test module for a pull tester can evaluate low-loop ribbons.

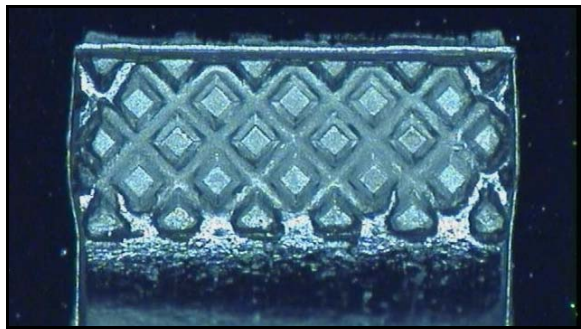


Figure 4. A well-formed ribbon bond has a clearly-defined waffle pattern, small heel groove and no excessive side bulge.

Visual inspection is a valuable tool for production monitoring of a ribbon bonding process. Common inspection criteria include: an even, well-formed waffle pattern, no excessive deformation or

cracks at the heel, a consistent tail length with a clean cut, and consistent loop shapes. Figure 4 is a bond that meets this inspection criteria and Figure 5 is a bond that shows evidence of over-deformation.

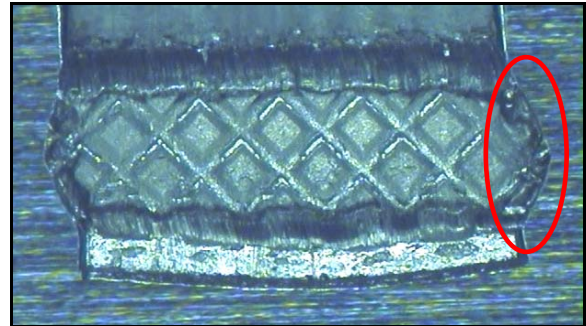


Figure 5. An over-deformed ribbon bond is indicated by bulges at the sides of the bond and a deep heel groove.

A ribbon bond with a well-formed waffle pattern and no signs of over-deformation or heel cracks is very likely to be a good bond.

‘Remaining thickness’ is a measurement technique used at Orthodyne that has been valuable for development of the PowerRibbon® process and bondtools.

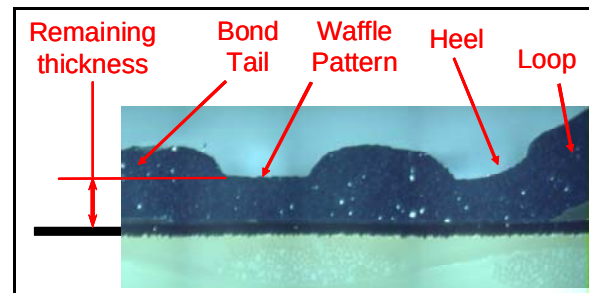


Figure 6. A ribbon cross-section illustrates the ‘remaining thickness’ measurement.

Remaining thickness measurement can be done destructively by cross-sectioning a bond or non-destructively with a highly-accurate laser displacement meter or measuring microscope. While not a requirement for development or support of a ribbon application, remaining thickness is a metric that is in use at some production facilities as a non-destructive bond evaluation tool.

A less accurate, but also useful measurement of deformation is produced by the ribbon bonder during the process of bonding and can be displayed or data-logged.

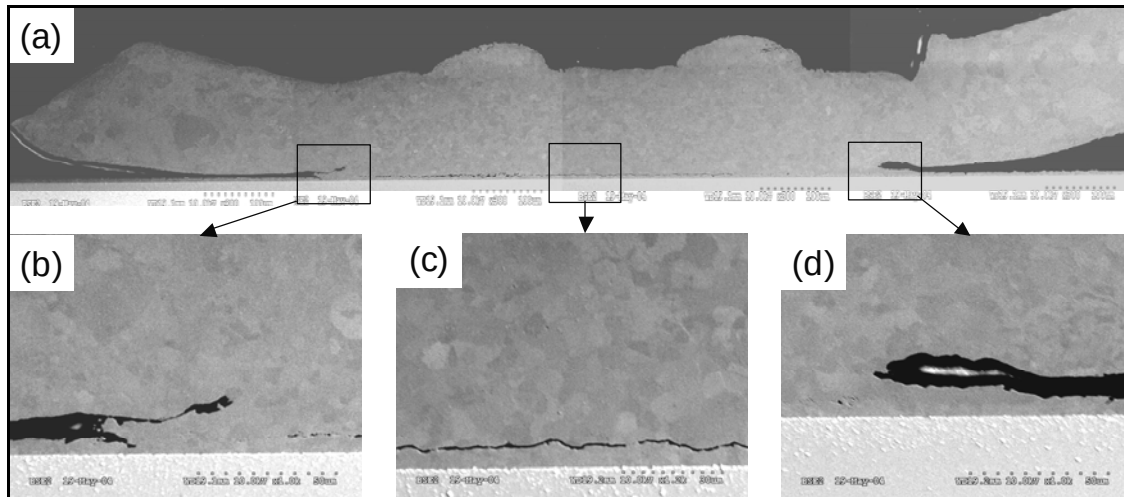


Figure 7. Cross-section of a ribbon bond after temperature cycling that shows crack propagation similar to an Aluminum wedge bond.

Qualification Testing

When a process program is creating strong bonds and acceptable loops, the process is ready for qualification testing.

A strong bond heel and good intermetallic mixing of the ribbon with the bonded surface are keys to ribbon bond reliability. Five years of qualification testing have shown that a well-formed PowerRibbon® bond consistently performs as well as, or better than Aluminum wire. Aluminum wedge bonds are recognized as a highly-reliable interconnect and test results show that PowerRibbon® bonds are even better than wedge bonds for maintaining electrical contact after cycling [7].

PowerRibbon® has excellent performance in vibration testing, which can be a deciding factor for choosing ribbon in applications where the other advantages of ribbon are not significant factors.

The failure modes for ribbon during temperature and power cycle testing are similar to large-diameter Aluminum wedge bonds. Figure 7 shows stress-induced cracks that propagated from the outer edge of the bonded area and expanded until failure occurred, which is the same failure mechanism seen in wedge bonds.

Test results show that the larger area of a ribbon bond may allow it to survive this kind of failure mechanism longer than wire bonds.

Minimize Process Variation

A few general guidelines will help to keep a ribbon process stable.

As with all types of bonding, variation in upstream processes can be a significant source of variation in ribbon bonding. If upstream processes are in control, then it is easier to keep the ribbon

bonding process in control. SPC tools can detect variation and out-of-control processes.

Excessive die tilt can cause non-uniform bonding across the width of a ribbon bond. Excessive die tilt while bonding wide, thin ribbon may cause die damage or reliability problems.

Clean bonding surfaces are important for strong bonds. Die or substrate mounting may leave residues that contaminate bond surfaces.

At the ribbon bonder, repeatable fixturing and clamping is especially important, due to the high forces and ultrasonic power used to create ribbon bonds.

Clean bondtools regularly to insure that the ribbon bond heel is not weakened by over-deformation caused by aluminum buildup.

Summary

PowerRibbon® has matured to a robust production process that has performance, productivity, and cost advantages for many hybrid applications. Ribbon is an incremental technology enhancement available to power hybrid designers and has minimal impact on production facilities. The procedures and tools for ribbon process creation and control are field-proven in applications worldwide. The steps to creation of a ribbon process for hybrids are:

- Select the ribbon size.
- Optimize the device layout and design.
- Select the bondtool and the ribbon material.
- Create the process program.
- Measure the bond characteristics.
- Perform qualification testing.
- Minimize process variation.

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