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The Ribbon Revolution: Break the Bonding Bottleneck

Introduction

Semiconductor and microelectronic device markets demand ever smaller, lighter, often higher-power products — with high reliability and long-lasting performance. These characteristics drive the choice of *electrical interconnects* bonded from chip to substrate, or from chip to chip. The microelectronics packaging industry traditionally uses *wire bonds*.

However, a newer technology — *bond ribbon* — is quietly revolutionizing the field. It surpasses the reliability and performance of heavy wire bonds for numerous high-power applications.

Gold ribbon is employed for a small number of specialized uses, although its material expense can be high. But *aluminum* ribbon is gaining popularity as the superior solution for a wide range of high-power devices.

This paper outlines some important wire bonding considerations, contrasted with key advantages and design engineering trade-offs of aluminum bond ribbon interconnects.

The Bonding Bottleneck

Many large-volume printed circuit board (PCB) manufacturers use capital-intensive *wave soldering* and/or *solder paste reflow* technologies for component interconnections. However, within individual semiconductor components, a common way to attach the miniature device to its external packaging is wire bonding.

Wire bonds exhibit comparatively low cost, and ease of bonding with ultrasonic wedge bonders. Although wire bonding is done one connection at a time, bonding equipment can rapidly place and bond the fine wire into position at a very high rate. Historically, the introduction of larger bonders also allowed for heavy wire bonds that carry higher voltage/currents. This enabled wire bonding to be employed in making power component (e.g., diode) connections. Used for decades, it has long been the industry standard.

However, wire bonds can exhibit several drawbacks in certain uses.

First, most higher-power applications require multiple heavy wire bonds: often *as many as ten bonds per connection*. And the more wire bonds used, the more operational steps involved. So wire bonding can become a significant throughput bottleneck within the manufacturing process.

The need for multiple wire bonds leads directly to another, often critical problem. More wire bonds create more connection points to the chip. Each is a potential failure site due to movement or fatigue / work hardening, caused by factors such as thermal stress from on/off cycling — especially in high-power (and thus high-heat) devices. Result: more opportunities for failure of the electronics package, and often the whole device.

In addition, multiple bonds may conceal developing problems. When one wire breaks, it is typically not immediately detectable. But the fault often stealthily propagates, as the remaining wires connected to the chip overheat, and each bond fails in turn.

This propensity to break is increased by the relatively fragile configuration of a wire bond. In manufacturing, the attachment made by the thermosonic bonder crushes the already thin wire, flattening it out at the bond site and considerably reducing its vertical cross section. This deformation renders the wire even more easily breakable.

Finally, especially with provision for strain relief, wire bonds tend to exhibit relatively high profiles, looping up between chip and substrate or chip and chip. This may present a space problem that negatively impacts industry efforts to minimize chip height for ever more miniaturized devices.

The Ribbon Revolution

A newer technology is gaining attention in the microelectronics world. Interconnects composed of *aluminum ribbon* are functionally quite similar to wire. In fact, this type of bond ribbon is essentially flat wire, with a rectangular cross section.

Wire remains the right choice for many applications where ribbon is not suitable. However, ribbon displays clear advantages over wire in many other cases. For applications including most high-power devices, bond ribbon is becoming the new standard choice of interconnection solution.

In the past, bond ribbon was often produced by taking an aluminum rod, rolling it to create a flat strip, slitting to width, and then cutting the result to the desired length. However, this method was found to produce undesirable features such as sharp edges and burrs that might impair processing and/or degrade electrical characteristics. Most advanced manufacturers now instead start with an aluminum wire. They draw it to size, roll it flat, anneal it, and spool it for handling. Bond ribbon thus produced has rounded edges and no burrs, and is easy to handle.

Gold bond ribbon began to be used for interconnects by the 1990s. Aluminum ribbon for microelectronics package bonding emerged in the mid-2000s, driven by customer demand for lower-profile (and less expensive) ribbon. Today, the vast majority of ribbon used for interconnects has a 99.99% aluminum composition, though in a few applications, gold ribbon brings benefits sufficient to outweigh its higher cost.

High-purity ribbon is ideally used for applications requiring high reliability and high power. A key reason: due to its larger cross section, ribbon requires fewer bonds to attain the same levels of power handling. For example, *a single 40 mil X 4 mil (0.04 in X 0.004 in) aluminum ribbon can replace up to ten heavy 5 mil (0.005 in) diameter wires*.

In addition, bond ribbon presents an optimal combination of high electrical and thermal conductivity with low cost and high density.

PCBs using ribbon interconnects are becoming ever more popular in a wide range of higher-power applications and varied industries. In microwave technology, gold ribbon is the material of choice. For aluminum ribbon, notable applications include:

- Medical devices
- Optical communications
- Automotive
- Aviation
- Marine
- Electric vehicles (especially newer types such as busses and semitrucks)
- Power electronics
- Batteries (especially for electric vehicles and handheld equipment)
- Commercial energy grids

Superior Electrical Characteristics

Given a bonding wire's relatively small size and round shape, it can be difficult to get every wire in optimum metallurgical contact with the substrate. Poor contact can lead to unexpected impedance, and increased potential for overheating at any given bond site.

With ribbon's broad, flat cross section, it's easy to obtain a consistent, controllable, predictable bond to ensure consistent electrical performance.

As well as contributing to better functionality throughout the service life of the device, this wide area of contact confers an initial benefit during the bonding process itself. The ultrasonic bonding energy transfers more easily through the wide ribbon to the substrate, for optimum bond success.

Another advantage: when current is passed through a round wire, it can create a troublesome amount of electromagnetic interference (EMI). Acting as an unintended antenna, the wire transmits or receives unwanted radio frequency [RF] energy due to its unfavorable aspect ratio. This parasitic "noise" degrades the quality of signal transmission, possibly interfering with device functionality. And the greater the current, the greater the EMI noise.

By contrast, a bond ribbon's low, flat profile presents a more favorable aspect ratio, dramatically reducing noise. This is a significant advantage, particularly in exceptionally noisy high-voltage applications.

Improved Heat Handling

Higher-power devices are infamous for "running hot." And the more power they use, the more heat they generate. Unfortunately, higher temperature inside a microelectronics device can negatively impact its reliability. Further, while continued high heat is bad, on/off thermal cycling with frequent component expansion/contraction can often be significantly worse.

Thermal stress-induced mechanical creep is a leading cause of circuit and device failure.

Compared to wire, the flat shape of bond ribbon allows for faster, more efficient heat dissipation. Ribbon presents a wider surface area, so thermal concentration is naturally dissipated, and the larger mass attenuates the thermal cycling effect. This contributes to more efficient heat dispersal for the entire package.

Bond ribbon's superior heat handling is especially critical in high-powered applications. It can contribute considerably to more reliable performance and longer service life.

High Reliability

As discussed, an important reason that ribbon interconnects are more dependable than wire is because they require fewer bonds, and thus present fewer points of potential failure. However, there are other, equally simple mechanical factors that make ribbon the winner in any reliability contest.

With its wide cross section, a ribbon demonstrates greater tensile strength than an individual wire.

The stress relief built into a bond ribbon profile can better absorb a degree of movement due to factors such as thermal stressing.

And in the manufacturing process, the bond head causes relatively minor deformation of the (already flat) ribbon. Finally, the head forms two stripes across the entire width of the ribbon, for solid contact with the substrate and little chance of breakage.

Better Throughput

In many applications, ribbon provides substantially greater manufacturing process throughput than is possible when using wire interconnects.

Again, ribbon involves fewer bonds than wire. Where a typical heavy wire bond configuration might demand 10 bonds, a ribbon making the same electrical connection needs only 2 bonds. So considerably less manufacturing time, cost, and effort must be devoted to bonding interconnects.

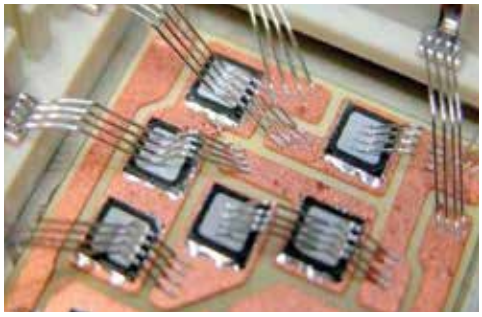
In addition, the aluminum ribbon bonding process requires no preheating of the substrate. Due to the low melting point of aluminum, the bond is achieved at relatively low temperature. Bond ribbon also makes it unnecessary to use a protective atmosphere or perform surface pre-cleaning. Aluminum forms a natural oxide layer that's easily bonded through, and actually assists in "scrubbing" the bond site.

In one typical case, a manufacturer making high-power laser diodes was anticipating the need to ramp up production. The facility's planners expected to purchase and install more bonding equipment to meet this demand. Instead, they made the switch from wire bonds to bond ribbons — to achieve fewer steps required with significantly fewer bonds. Time scheduled for the bonding process per module was reduced from 2 hours down to 40 minutes!

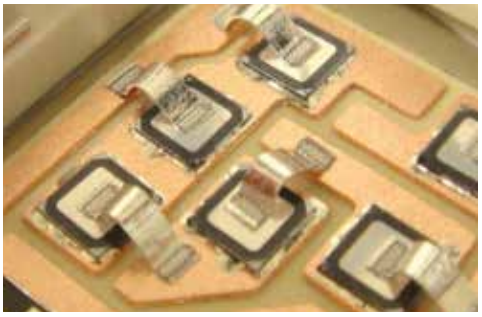
Lower Profile

Without the same necessity for strain relief, a bond ribbon presents a significantly lower profile than a wire bond. The ribbon simply doesn't loop as high as a wire. And the ribbon itself exhibits a smaller vertical cross section. (Although the ribbon's horizontal cross section is obviously wider, this increases the connection area underneath, and makes it more resistant to stress than a narrower wire bond.)

Wire bond



Ribbon bond



Together, these characteristics enable the creation of a thinner, more compact package — ideal for the space-saving device miniaturization demands of today (and tomorrow).

Ribbon Requirements

Note that since ribbon exhibits a significantly larger surface area than traditional wire formats, the force and power required to accomplish bonding are greater. Power dies must be designed to accommodate ribbon's more extensive real estate, and to withstand the requisite higher force and power.

However, these capabilities are often already built into a PCB manufacturer's existing power dies, since multiple heavy wire bonds are already being used. Also, high-power components can better handle higher bonding energy requirements. They are designed for high current and elevated operating temperature, and so can easily endure a more rigorous bonding process.

Finally, a ribbon bond head must be added to the wire bonding machine. Such heads are readily sourced from the machine manufacturer. Bonding tools — available from many suppliers — for various ribbon sizes are used with the bond head.

The Future of Ribbon

The use of bond ribbon interconnects has been projected to increase sharply in the next few years, as its benefits become more widely recognized.

One current hotspot of ribbon adoption: testing equipment applications. Here the industry is witnessing increasing use of both gold and aluminum ribbon material.

These applications and others often require much smaller cross-sectional sizes than ever before. In fact, advanced gold bond ribbons can now be produced with dimensions of only 0.001 inch wide by 0.00025 inch thick!

Aluminum bond interconnects also are being used in a growing array of sizes, including fairly small dimensions to fit ever smaller devices. Additionally, although aluminum ribbon is ideal for use in the rapidly increasing number of higher-power devices, it's also being applied to interconnect microelectronics in lower-power applications. These trends should continue, and intensify.

Common Aluminum Ribbon Available Today			
Composition	**Dimensions (mils)**	**Tensile Strength (gm)**	**Elongation (%)**
99.99% Aluminum + 50 ppm Ni	30 x 3	250 – 350	15 – 25
	40 x 4	400 – 550	10 – 30
	50 x 5	1000 – 1500	20 – 35
	40 x 6	700 – 1100	20 – 35
	60 x 6	1300 – 1700	20 – 35
	80 x 6	1800 – 2200	20 – 35
	50 x 8	1500 – 2000	20 – 35
	60 x 8	2000 – 2500	20 – 35
	80 x 8	2300 – 2800	20 – 35
	60 x 10	2200 – 2600	25 – 40
	80 x 10	2700 – 3400	25 – 40
	80 x 12	3300-4000	25 – 45

Conclusion

Wire bonds are an established industry standard in microelectronics packaging. However, they have some clear disadvantages. For many applications that require higher reliability or higher power, aluminum bond ribbon has emerged as the interconnect of choice.

Note that ribbon suppliers are not all created equal. Manufacture of high-quality bond ribbon requires extensive knowledge of the metals involved, as well as high-end, specialized equipment — plus, of course, the know-how necessary to utilize this equipment. An exceptional supplier must demonstrate precise control over initial materials, wire sizes, ribbon rolling techniques, gauging, annealing, and spooling.

Users should make sure any prospective supplier can meet these criteria — and furnish references to ribbon bond projects successfully completed.

About COINING

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For people who demand precision, flexibility, and speed, COINING is the market leader in custom alloys, microstampings and solder preforms. COINING also offers specialized bonding wire, precision thermal management materials, and hermetic solutions. In fact, we're the largest solder preform manufacturer in the world. With a broad range of products, the most extensive library of preform dies in the industry - about 15,000 different tools - and our very own COINING labs to make custom alloys, we can move faster to market than our competition.

About AMETEK

AMETEK Specialty Metal Products consists of six leading manufacturers of advanced metal products based in the USA and UK: Fine Tubes, Superior Tube, AMETEK Eighty Four, COINING, Hamilton Precision Metals, and AMETEK Wallingford.

Our extensive product range includes thermal management materials, metal tubes, strip, shaped wire, clad plate, powder, bonding wire and ribbon, solder preforms, and bond pads.

From powering aircrafts and space rockets, to advancing medical care, and accelerating the transition to renewable energy – our precision materials enable technological innovations.

AMETEK Specialty Metal Products is a business of AMETEK Inc., a leading global provider of industrial technology solutions serving a diverse set of attractive niche markets.

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