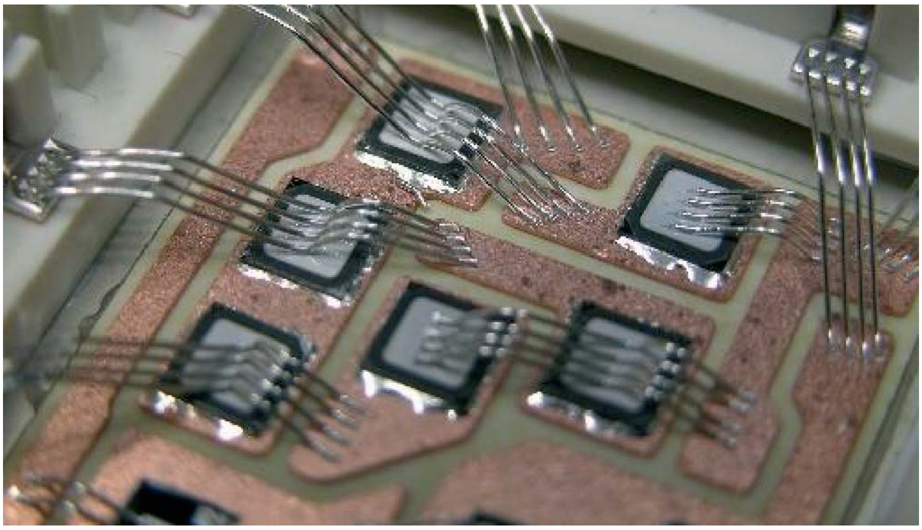
More Performance at Lower Cost – Heavy Aluminium Ribbon Bonding

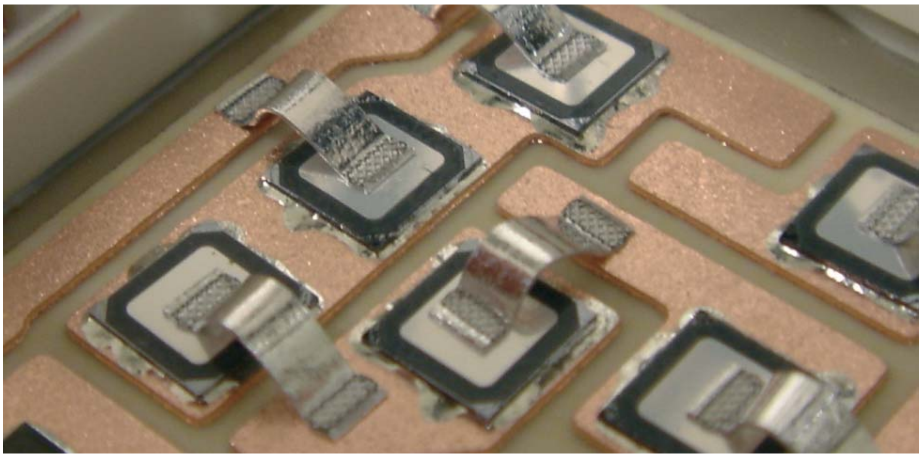
Lower cost through higher productivity – while improving quality

Heavy wire bonding has been used in volume production for many years with a wire thickness of up to 500 µm or so. This is why for high currents, e.g. in power modules, multiple wires and stitch bonds have been required. The parallel wires and serial bonds have the disadvantage of reducing bonder throughput sharply and so increasing the cost of bonding. For this reason, aluminium ribbons with a large cross section equivalent to several wires have long been a goal of bonding specialists, and recently this wish has come closer to being fulfilled.



Today, a ribbon format of 2000 µm width and 200 µm µm thickness (80 mil by 8 mil) has been established as a de-facto standard. It offers a cross section of 0,4 mmÇ which is slightly more than twice that of a heavy wire of 500 µm (cross section 0,196 mmÇ). A second version of 300 µm thickness, correspondingly, can replace three such wires.

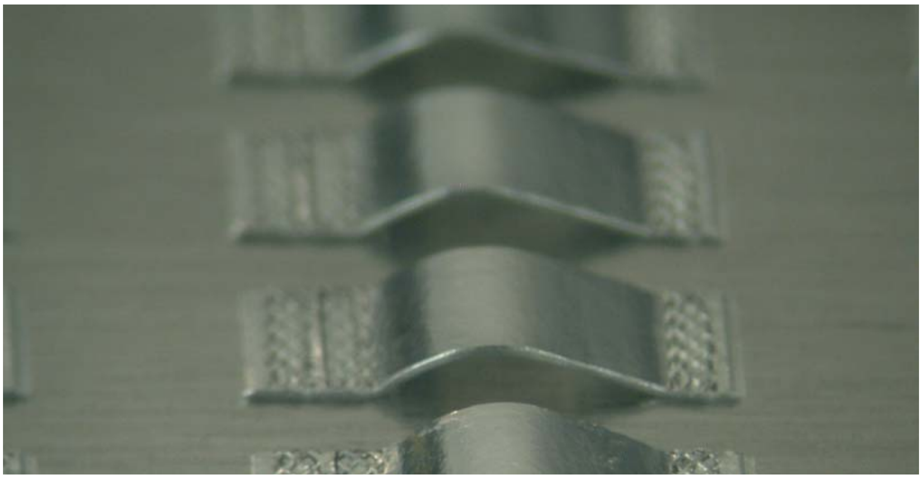
A typical power module employs 3 Al wires of 400 µm for each chip, covering a width on the chip of at least 2,5 mm . A standard 2000x200 µm heavy ribbon offers a slightly larger cross section of 0,4 mmÇ while taking up less width at around 2 mm. Bond times stay much the same at 300 ms per bond (600 ms per wire) and so the bonder will have about three times the productivity with ribbon, compared to using wire.

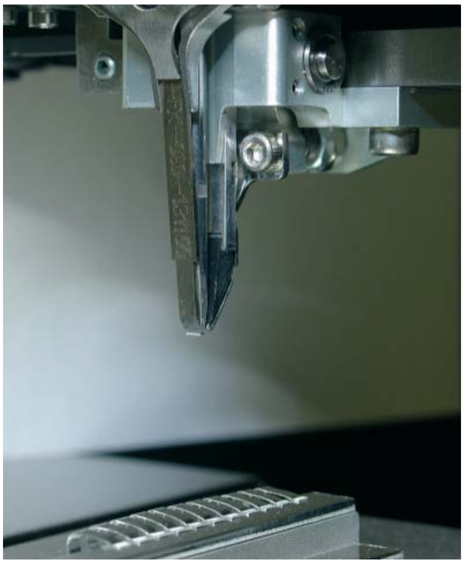


Beyond the higher throughput, the larger cross-section combined with a flat geometry provides some technological advantages:

- superior coverage of the bondpad due to little spread of the bondfoot
- flat geometry allows lower loops
- less damage in the heel of ribbon, compared to heavy wire
- stitch-bonds are even easier to perform than on wire

For a given loop geometry the heel damage, especially for reverse bonding, is considerably lower than for an equivalent heavy wire. Therefore Heavy Aluminium Ribbon Bonding (HARB) can make connections across unusually high steps with short bonds, which in turn permits highly attractive geometries when bonding in special hybrid packages. Furthermore, stitch-bonding requires lower heights in the looping curve which reduces again the heel damage; and lastly, the vibration resonances of a ribbon bond are very different in the vertical and lateral directions, which makes a ribbon bond much more immune against external vibrations.





The basic bond processes between wire- and ribbon-bonding are so similar that standard heavy wire bonders can be used, usually by a conversion kit to HARB . The only requirement is that ultrasonic power and bond force can handle the higher demands of ribbon. Bond tools for HARB have no V groove. Instead there is a flat tool foot of defined length which usually has a surface structure in a cassette pattern of defined size and depth. More detailed research is aimed at whether the cassette walls should be inclined at 45° or at 90° and what the optimum depth in relation to the ribbon thickness should be. Contrary to early development bond wedges, no special ribbon guide is needed inside the tool, such as a rectangular opening, to hold the wire under the wedge. This function can easily be taken care of by a ribbon guide which is largely identical to the one used for heavy wire bonding.

Very often, an additional ribbon clamp is included either in the ribbon guide or at a different position somewhere in the bond head. Its purpose is to fix the ribbon in place during tear-off after cutting. This improves the stability of the bonding process but experience shows that for standard loop geometries it is dispensable.

A sufficiently wide bond tool can be used to bond ribbons of varying width. This is, in principle, also true for different thicknesses, but the cassette patterning of the tool foot which was discussed above ought to vary with the ribbon thickness, and therefore it is customary to use different tools for different ribbons.

The cutting knife has to fulfil more exacting demands for ribbons than for heavy wires, because the ribbon’s larger cross section mandates larger cutting forces and, hence, stiffer cutting blades as well as a perfectly adapted geometry.

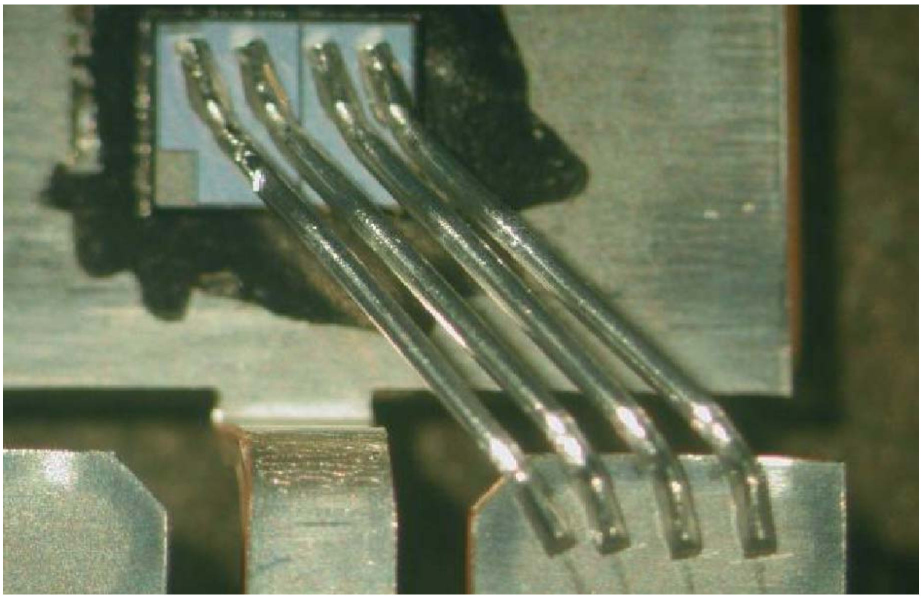
HARB works at much higher ultrasonic energies and therefore is much more demanding as regards clamping of the work piece. Vacuum hold-downs, which can frequently be used for flat-bottomed substrates, are usually not reliable enough and have to be augmented or replaced by mechanical clamping fixtures.

Differences in HARB

Most differences between the two bonding processes are simply explained by the larger metal cross section which has to be deformed during bonding.

As mentioned already, cutting the ribbon requires more force than for wire, and the cutting edge has to be precisely in line with the bond pad plane. This is even more important if cutting is to be done on the chip. Given a cutting length of up to 3 mm (assuming a 3 mm ribbon is used, as would be desirable), even a modestly wedge-shaped solder or glue bed will cause a noticeable variation across the cutting area, which in turn will make it more difficult to tear the rest of the ribbon cleanly, and therefore will make the whole process less stable. On the other hand, it may be surprising to learn that, overall, the cutting process for ribbons is rather simpler to control than for standard heavy wire. This is because the cutting resistance of a ribbon increases from top to bottom with the metal volume being displaced and so prevents accidentally cutting all the way through the ribbon. In contrast, the cross section of a heavy wire increases from top to bottom at first, and then decreases. Therefore heavy wire is more susceptible to accidental overcut.

A substantial limitation of HARB concerns bonding in difficult spatial conditions where wire bonding has the extra option of bonding “around the corner”, or in S-shape. Clearly this is impossible for ribbons, and so some types of leadframes cannot be bonded advantageously with HARB, especially where for reasons of simplicity a standard leadframe type has been used with several wires squeezed into a given T-post . In the future, specialized leadframe designs will be required for this; they will offer the extra advantage of thinner form factors after molding because of the lower loop geometry of the ribbon.



For very-high-current applications, i.e. several wires in parallel, it is a frequent practice to add one or more extra wires which are not actually required electrically. In case of a single-wire failure they can keep the component functioning. Compared to this, HARB is an all-or-none technology because usually there is no space for a second ribbon on the bond pad.

Short-term trends and hurdles due to long-term features

As might have become clear so far, there is enormous interest in the HARB technology and at the same time very little practical experience with it. The main reason – apart from the usual development hurdles – is the longterm behavior of bonded components. The main worry today focuses on the bondpad metallization on the chip. Here, several problem areas converge:

- required ultrasonic power increases with increasing bond cross section, as does the bond force
- power chips are becoming ever thinner to conduct heat more efficiently to the substrate
- there are, as yet, no power chips or bonding surfaces optimized for HARB because of today's low market volume
- damage can be invisible (also to the standard analytical methods) but cause long-term failures

The ultrasonic energy required for bonding increases with the cross section of the bond material and also with the length of the bond since the US energy has to deform this entire Aluminium volume. Further, it increases with the area covered by the bond, i.e. the welding area (ribbon width times bond length). For the ribbon dimensions which are economically attractive at more than 2mm length and 300 µm width, these energies are at least three times higher than for a 500 µm wire, and this also implies that there are no practical data which could meaningfully be extrapolated.
What could also be detrimental to long-term stability is the fact that a ribbon bond almost by definition covers a large part of the bondable chip metallization with Aluminium which has a large thermal expansion coefficient of 24 ppm/K. The bulk Silicon of the chip, by contrast, only expands at a TEC of 2,5 ppm/K. This large thermal mismatch is well known and poses considerable risk of cracks in the vicinity of the interface, especially if the parts are run at frequent thermal cycling. In automotive applications this is, of course, the rule and not the exception. Heavy wires, on the other hand, cover several smaller bond islands so the effect may be less pronounced there. However, it is entirely thinkable that a chip soldered to the substrate and bonded by HARB is held in a sort of sandwich with higher TEC above and below and therefore is not as badly stressed.

A further point of discussion at the present time concerns whether it is more damaging to the chip surface to make one large bond at high energy or several bonds in series with lower individual energies, as in today's wire bonding with multiple wires. Again, it is possible that the denting effect of the individual heavy wire bonds (given that the contact area of a wire is narrow at the beginning of the bond and then widens during bonding) is more detrimental than the large-are flat contact with the ribbon. As before, the experimental base is simply not large enough today to make clear statements.

What's next?

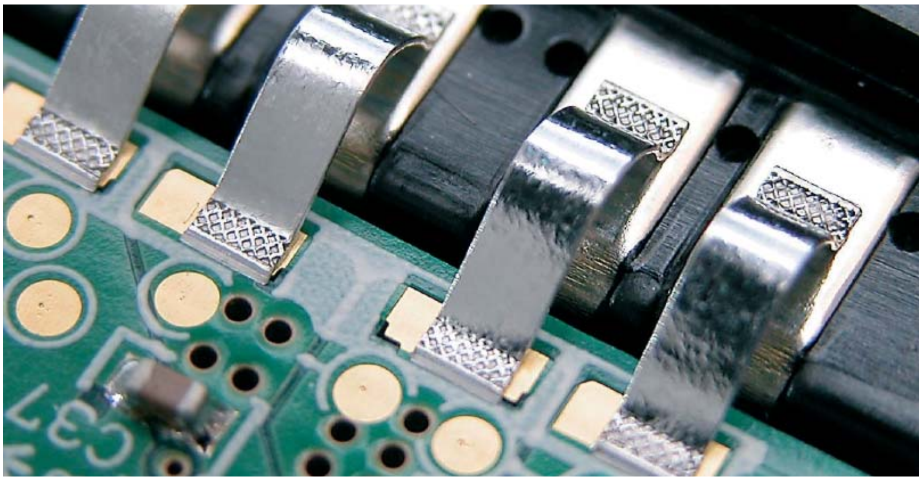
The new HARB technology is so attractive that practically every manufacturer or consumer of power semiconductors is making trial experiments. The most urgent further development today concern, at least for Europe and USA, issues of measurement and test. Most pressing is the need to define standards for pull-testing and shear-testing, as regards recommended shear heights and shear directions along the bond or across, and also standards for evaluation the shear break patterns.

The ribbons are at the threshold of defined standard dimensions. At the moment, only the dominating heavy-wire manufactures offer heavy aluminium ribbon, and the small volumes sold today are far from optimized and low-cost production methods. To illustrate this point, the ribbons are usually made from Al wire of the corresponding cross section which is then cold-rolled to the desired thickness, instead of cutting them from sheet metal at the correct thickness. A special post-rolling treatment is sometimes added also. All of this is responsible for ribbon prices far above the comparable wires, but it is reasonable to expect that this will come down rapidly as the volumes grow. This will have to happen anyway or the advantage from higher machine productivity will be lost by higher material cost.

Promising first steps

As a consequence of the hurdles discussed above, not many components are on the market today which are bonded by HARB. The simplest, and hence most promising, applications might be where a PCB or hybrid substrate is connected to the power connections of a package, such as that shown in fig 7 . Here, no Silicon chips have to be bonded and therefore this is an ideal arena to collect practical experience.

In addition it is very helpful that conversion kits for HARB are also available for semi-automatic wire bonders. This helps sample bonding work because one does not have to face the high investment for a fully automatic bonder; nor is it necessary to block a production machine with R&D samples. It is to be expected that this will help reduce the crucial Time to Market for new products, and may smooth the development path for this attractive technology and its enormous potential.



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