# Ribbon Bonding for High Frequency Applications

# Advantages of Ribbon and the Impact on the Microwave Market

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*Abstract* — Due to increasing frequencies in all fields of information technology, ribbon bonding is gaining more widespread attention from designers of applications which were traditionally bonded with round wire and ball bonders. This presentation will review the advantages of ribbon bonding over round wire and the impact for the microwave market.

*Index Terms* — ribbon, wedge-bonding, wire-bonding, skin effect, crosstalk, loop stability, bond stacking.

#### I. INTRODUCTION

Interconnecting semiconductors with ribbon rather than round wire has been popular in high frequency electronics for a long time. Surprisingly there are still countless applications bonded traditionally with round wires and ball bonders even so the electrical performance of the product could benefit from ribbon bonding technology. Reasons for this hesitation to adopt ribbon technology can be found in the machine supplier market. Fully automatic ribbon bonders with sufficient specification properties to win by cost of ownership have only been available for a few years. All those applications which could also be bonded with round wire and ball bonders were waiting for the right equipment technology to come forward even if traditional wire bonding was a compromise on the product performance.

The steep increase in the gold price and the continuous demand for gold in the electronics manufacturing market is adding significance to the choice of semiconductor interconnection. Ribbon bonding technology allows reducing the cross section area of the gold bond while maintaining or increasing the surface area at the same time. Some high frequency electronic packages could be changed from 2 mil round wire to  $\frac{1}{2}$  mil x 3 mil ribbon and be produced at lower material cost (less gold volume) with the same electrical performance (same surface area per bond). The development of the gold prices can be expected to make such a change even more attractive in the future.

### II. ADVANTAGES OF THE ELECTRICAL PROPERTIES OF RIBBON BONDS VERSUS WIRE BONDS AT HIGH FREQUENCIES

The most common reason for using ribbon bonds in high frequency applications is the so called <u>skin effect</u>. Each free electron represents a negative electric charge that naturally separates from other negative electric charges, scattering the

free electrons evenly across the conductor. The wire itself however, is surrounded by a magnetic field which is dependent on the direction of current flow. If the conductor carries a high frequency signal, the self-induction caused by this magnetic field leads to increasing separation pressure from within to the outer surface of the conductor (see Fig.1). The tendency of all free electrons to move along the surface ("skin") of the conductor leads to a reduction in effective cross section area and thus to an increase in effective resistance [1]. For gold and copper, the skin depth available for free electron movement is less than a micron at a frequency of 10 GHz [2]. The resulting reduced electrical performance of the connected semiconductors causes the final product to have less power efficiency at higher frequencies.



Fig. 1. Skin effect compared on a round wire and a ribbon.

The advantage of ribbon over round wire is the relatively large surface area in proportion to the cross section area. Fig.1 shows a ribbon with a side relation of 5:1 compared to a round wire. The more extreme this relation (the wider and thinner the ribbon), the less effect the frequency has on the effective resistance resulting in greater power efficiency of ribbon bonded products. Compared to a 2 mil round wire, a  $\frac{1}{2} \times 6$  mil ribbon has more than twice the surface area with nearly the same cross section area. Since a majority of the free electrons are near the surface area anyway, the resistance caused by the skin effect does not have such a drastic impact in the ribbon as it does in the round wire.

Apart from the skin effect there is yet another problem with wire bonds at high frequencies. <u>Crosstalk</u> is the term for signals in one wire inducing interfering signals into neighboring wires when each wire starts to behave like an antenna. The parasitic capacity of this wire-antenna may be neglected in lower frequency ranges, where the emitted

signals can not bridge the gap to the next wire but in the GHz range the wires really start exchanging signals. Again the geometry of the ribbon helps in this case. A ribbon bonded application exchanges less crosstalk than the same application bonded with round wire [2]. This benefit will lead to better signal quality of high frequency devices and less electrical noise on the supply or ground contacts, an obvious plus for satellite or wireless technology, where bundled high frequency information carries signals of voice, radio or television transmission.

# III. MECHANICAL AND OTHER GEOMETRICAL ADVANTAGES OF RIBBON BONDS VERSUS ROUND WIRE BONDS

Further advantages for the package design result from the ribbons flat top surface, which can enable stacking several ribbon bonds on top of each other. Stacked bonds are often used in high frequency applications for redundant grounding. Stacking round wires is a less robust process when the bonded wires are placed at different angles, because the round wire on top tends to "roll off" the bottom wire during deformation. The flatter ribbon avoids this complication and allows reliable bond stacking even under 45° angles. Examples from the field of high frequency electronics where this would allow improvements to the performance, design and manufacturability of existing HF circuits are given in Fig.2.

An X-strap is often desired for connecting a Schottky diode with a very high operating frequency. This design feature should create even distribution of electrical charges and eliminate the crosstalk between the wires and their neighborhood. 4 or even 6 equally spread loops going off the diode would be ideal, however the small and fragile bondpad on top of the diode seems to make this impossible. Where round wires would tend to "roll off" and therefore only allow manual bonding with all associated disadvantages, ribbons can be stacked at angles even in automatic mode.

The other example of a design feature demanding angled stacked bonds is a HF package in radial package design with a central common ground point. By tying all surrounding ground leads or die bonding pads to exactly the same grounding point charges can not build up in one location of a board. The formation of unintended capacitors by the leads can be compensated most effectively if a common grounding point is used. In a small enough package multiple grounding connections will only fit on a compound bond. Often this is done in manual wire bonding processes to allow operator intervention as the wires roll off the stack. Automatic ribbon bonding has the potential to replace such manual processes because stacking the ribbons at an angle is possible in automatic bonding.



Fig. 2. X-strap for Schottky diode and common ground point around HF channel in a radial package design.

Another advantage of ribbon over round wire bonding is the better mechanical loop stability of ribbon bonds which can achieve lower loop angles and lower loop heights than round wire bonds. In particular, if the loops are very long in relation to the wire diameter, gravitational pull on the loop sets a limit for loop stability. For round wires the side to side stability of long loops is usually the limiting factor. If the electronic package is exposed to strong accelerations in the application, the wires may have to withstand multiple G-forces in any direction of acceleration. A long, low loop could tip over sideways when a certain acceleration threshold is exceeded. This effect is called "loop sway". Depending on the relation of ribbon width to thickness, the mechanical resistance against loop sway is greater by orders of magnitude in a ribbon loop compared to a round wire loop with the same profile. Additionally, long loops with round wire tend to bend in the middle (loop sagging) if the loop profile is kept at a minimum. The mechanical stress distribution in a ribbon allows lower profiles for long loops before loop sagging occurs [3].



Fig. 3. Example of low long ribbon loops.

The loops shown in Fig.3 are approx. 80mil long and provide an extremely low, yet reliable gap over ground. The ribbon used in this example is 1x3mil. Achieving a comparable loop geometry with round gold wire is at least challenging, with a ball bonder this is virtually impossible because loop sagging would occur at the end of the loop.

For the product, the loop stability discussed above means higher reliability because the mechanical and thermal stress that a product sees during its lifetime will apply pull forces on the loops in any direction. Superior product reliability at high acceleration explains why airborne and space applications were the forerunners in the packaging industry to demand ribbon connections over wire bonds. Some recently introduced electronic devices, such as sensors and recording boxes in automobiles and airplanes are expected to continue to function after a high speed impact. This is one reason manufacturers are adopting ribbon bonding more and more.

In some applications, the compact geometric dimensions of the deformed ribbon, which is only slightly wider than the undeformed ribbon, can help to make best use of the available bondpad area. This becomes especially clear when a single ribbon can replace multiple round wire bonds in applications with a relatively high power per I/O. In addition to the ribbon's current-carrying capability, which can be adjusted by altering either its width or thickness, the <u>contact area</u> underneath the bond may play an important role on a high power device. Examples where these arguments apply can be found in the solar power market, where certain types of solar cells are connected to the substrate by ribbon rather than round wire bonds.



Fig. 4. Contact area underneath multiple ball bonds or round wire wedge bonds compared to a single ribbon bond.

The contact area, indicated in blue in Fig.4, is continuous only for a single bond per pad. Multiple wires terminating on the same pad lead to a non-continuous contact area in which the high current can enter the semiconductor. This may result in local differences in heat dissipation and electric field strength. High power / high current semiconductors can be expected to tolerate greater currents if the pad area is covered by a large continuous welding area rather than multiple spot like contacts. The amount of wires fitting on a pad is limited by the geometry of the bond tool (wedge or capillary) and by the deformation of the wire. If a single ribbon can be used instead of multiple wires, the geometry of the bond tool does not matter as long as the distance to the next pad, or pitch, is large enough. The effect of deformation can be virtually ignored when ribbon is used since ribbon width increases much less by deformation than wire width. In absolute figures this depends on the ribbon dimensions and the relationship between width and thickness.

As an example, a typical deformed ball bond is about 3 times the wire diameter, a typical deformed wedge bond is about 1.4 times the wire diameter and a typical deformed ribbon is just 1.1 times the ribbon width if the width is at least 3 times the thickness [3]. The explanation for this lies in the lower vertical deformation required to bond the ribbon and in the greater proportion of material displacement occurring in the cross groove and the front and back of the bond foot. The ribbon is in a sense "pre-deformed" by offering a sufficiently large initial contact area for the friction weld even before force and ultrasonic energy are applied to the bond. When bonding round wire, this contact area first has to be created by initial wire deformation.

Taking advantage of the low loop profiles combined with the current carrying capabilities of larger ribbon dimensions has allowed designers of packages with an active optical die surface to apply this technology to combat the <u>shadow effect</u>. The example in Fig.5 explains this with an application where a single ribbon replaces multiple ball-bonded round wires with the same current-carrying capability on a power LED. Bonded wires connecting power LEDs may cast a shadow from light emitted by the LED surface under a shallow angle.



Fig. 5 Wire shadow effect on a ball-bonded power LED compared to a ribbon bonded power LED.

The naturally low lift-off angle and profile of a typical ribbon loop greatly reduces this shadow effect compared to a group of ball-bonded wires that extend vertically above the ball.

This additional light emission increases effective LED luminosity without any change in the LED itself or the power consumption. Any active optical component which could respond to light coming in under a shallow angle can benefit from this effect as much as light emitting components. This could apply to solar cells, CCD chips, displays or laser LEDs.

## IV. REQUIREMENTS FOR RIBBON BONDING

The main requirement for automatic ribbon bonding is the equipment, which must be a <u>wedge-wedge bonder</u> with "deep access" configuration. The <u>deep access</u> bondhead guides the ribbon vertically along the back of the wedge tool and provides either one or two clamping points where it can be clamped during the tear-off movement. This movement describes a controlled relative movement between the bondhead and the table while the clamp is closed. It is often called "table tear" because early versions of ribbon bonding machines used to move the X and Y axes with the table while the bondhead was moving in Z only. Modern automatic wedge-bonders move all axis with the bondhead and therefore allow easy integration of indexers and inline automation concepts.

Important differences between ribbon capable wedge bonders of different makers lie hidden in the bondhead technology. A <u>true vertical wedge tool alignment</u> without any transducer pivot is a huge process advantage for ribbon bonding. It ensures even pressure on the bond tool and avoids heel damage by the back radius digging into the ribbon during overtravel. A very fast touchdown recognition and a stiff bondhead design is needed to avoid force fluctuations at the beginning of bonding. Precise force control and programmable touchdown force and speed are important factors for successful automatic ribbon bonding. Fig.6 shows a "true vertical" deep access bondhead for automatic ribbon bonding.



Fig. 6 Modern deep access bondhead for ribbons up to1 x10mil.

If a deep access wedge bonder is already available the right consumable material has to be selected. Depending on the clamping points of the ribbon in the bondhead a wedge tool has to be selected with either a double flat shank or a vertical feed hole, the latter requiring a clamping point above the transducer. The feed "hole" is actually a rectangular slot and is dimensioned to allow some play for feeding the selected ribbon dimension without dragging. All leading wedge tool manufacturers offer ribbon wedges with a double flat shank style for automatic ribbon bonding. The vertical feed through wedge design is less common for automatic applications but is available from some suppliers because of the demand for manual ribbon bonders. Wedge tools for gold ribbon have to have a tip made of Titanium carbide, ceramics or Osmium. Tungsten carbide wedge tools are chosen for aluminum ribbons. The bondfoot should supply sufficient grip on the ribbon surface by adequate design features such as a cross groove. Larger ribbon dimensions benefit from bondfoot designs featuring spikes, pyramids or waffle-grid patterns which greatly improve ultrasonic coupling.

The ribbon material itself is available from all wire manufacturers in a variety of dimensions. Very few ribbon

gauges can be considered "standard" gauges, which is why the wire manufacturers usually manufacture "on demand". The choice of ribbon gauge has to consider the desired current carrying capability, the available area on the smallest bond pad, the ratio of width to breadth and the amount of ribbon that fits on a standard wire spool. For reasons of the electrical properties discussed in section II a large ratio of ribbon width and breadth is desired. A ratio of 1:10 is common with typical ribbon gauges of  $\frac{1}{2}$  x 5mil or 1x10mil. The downside of using the widest ribbons for volume production is that only a small length (less than 50 ft. for a 10mil wide ribbon) will fit on a single layer spool. In volume production environment the frequent need to replace the spool may become a limiting factor for throughput. As 1x10mil automatic ribbon bonding is adopted more and more by high volume manufacturers in the solar cell market the challenge of fitting more ribbon on a spool is becoming more important to solve. It might take a combined effort of wire and equipment manufacturers to provide a solution, because the feasibility of a simple cross layer winding like for round wire is disputed for ribbon.

#### V. CONCLUSION

Improving the power efficiency of electronic devices is no longer only a matter of economical or ecological awareness, but a requirement in the effort to develop modern products. Power management is the key to improving the battery life of hand-held electronic devices. In addition, reducing the amount of heat generated inside power-efficient products helps reduce the size and weight of the product. Whether hand-held, airborne or flown into space, every electronic part is expected to become smaller, more compact and lightweight; offer more functions and last longer on one battery charge.

A wedge bonder has the flexibility to run either round wire or ribbon of aluminum or gold material. Wire bonder users should consider the technical arguments of ribbon bonding discussed here in relation to their applications, and need to consider a wedge bonder rather than a ball bonder for their next equipment investment. In many cases technical advantages of ribbon bonding lead to greater yield and product performance, resulting in comparable or even lower total cost of ownership. In particular this can occur when the manufacturer opts to change from ball bonding to high end, high speed wedge bonding.

#### REFERENCES

- [1] The "skin-effect" is discussed in detail in numerous publications. For a selected list of references see <u>http://www.answers.com/topic/skin-effect</u> or <u>http://en.wikipedia.org/wiki/Skin effect</u> where the equations for calculating the skin depth are quoted.
- [2] I.W.Qin, P.Reid, R.Werner and D.Doerr of Kulicke & Soffa in their SEMI West 2002 abstract "Automatic Wedge Bonding with Ribbon Wire for High Frequency Applications".
- [3] B.K.Benton of Palomar Technologies Inc, May 2000 in the "Microwave Journal".