Large Diameter Wedge Bonding of Round and Ribbon Wire:

The Future for High-Power, High-Reliability Automotive Electronics

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Summary: ***With automotive modules increasing in cost, field failures cannot be tolerated. Zero defects and optimum long-term reliability are essential for electronics manufacture and performance. Large diameter wire can help in reaching a zero-defect goal.***

Wedge bonding is widely used for interconnection of automotive engine control modules (ECMs) and other under-the-hood devices (see Figure 1). As vehicle electrification becomes more widespread, it will become even more prevalent. Bonding of large ribbon wire, Al, Cu, and Al-clad Cu will become a dominant technology due to the ribbon's large current-carrying capacity, excellent high-frequency conductance, and low inductance. As automotive

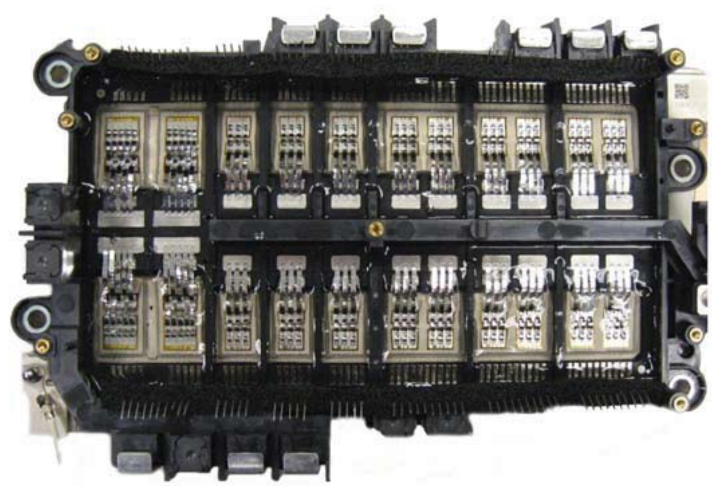

Figure 1: Prius engine control.

modules are expensive, field failures carry huge costs. Zero defects and optimum long-term reliability are essential during electronics manufacture and performance. Large diameter wire will support the goal of zero defects.

Bonding large diameter wire and ribbon requires substantially more energy than bonding fine wire. Ultrasonic generator output can be as high as 50W (Al wire) and 100W (Cu and ribbon) compared to 0.25W for fine wire bonders. Bond parameters are higher, with thicker metallization on leads or on substrates required. Soft-touch contact detection and closed-loop bond force control provide uniform bond deformation and high bond reliability.

For cantilever leads, lead shape and size must accommodate the larger forces and provide a stable surface for bonding. Lead cross-section and exposure length must be mechanically stiff to provide a stable bonding surface without resonating during bonding. If leads resonate, ultrasonic energy will be attenuated, resulting in poor bond quality.

The dynamics of loop formation with heavy wire are very different from that of fine wire. Relative stiffness (deflection under a load) for 20 mil wire is 160,000X that of 1 mil wire (stiffness is proportional to D [1]). During looping, significant forces are applied to both the first bond and to the underlying metallization while bending the wire. Loop profile and trajectory both have an important effect on minimizing those forces.

While looping motions that minimize bond stress effect bond quality, understanding bonding mechanics provides the process engineer with a big advantage in the development of optimized processes. Wedge bonders can bond both ribbon and round wire on the same platform with only a minor changeover. Heavy wire wedge bonders can bond both round bonding wire of up to 20 mils diameter and ribbon up to 80 mils width x 12 mils thick.

Heavy Wire Current-Carrying Capacity

Large diameter aluminum or copper round or ribbon wire are commonly used in electronic interconnection of ECM devices because of the high current required by these components. A 20 mil diameter, 100 mil length, 99.99% Al

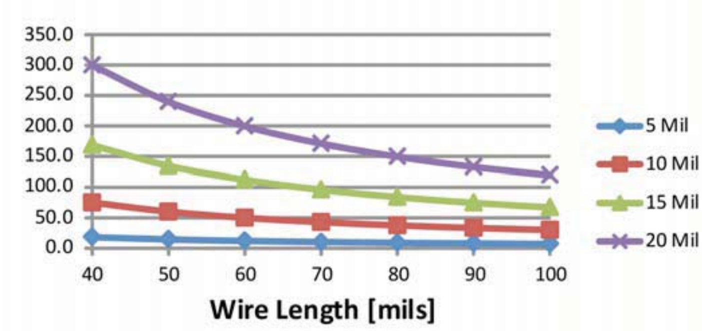

Figure 2: Safe DC current carrying capacity.

round wire can safely carry 120 amps [A]. Safe capacity is a better metric than fusing current, a metric commonly used. Fusing current is the amount of DC current that melts the wire and results in an open circuit; safe capacity is defined by its ability to produce less than a 83°C temperature rise (in air or encapsulated). Figure 2 provides a graph showing safe DC current carrying capacity [amps] as a function of wire diameter and length for large diameter 99.99% Al wire [2]. It applies to DC current and low-frequency alternating current, as current flows through the entire cross-section of the wire for these conditions.

For short ribbons, safe current is the same as a round wire of the same cross-section (D=sqrt(4*w*t/ϖ)). As AC frequency increases, current flow moves by magnetic effects to the wire surface (skin) and is proportional to the wire perimeter (outer 0.5 µm of the surface). Ribbon wire, because the perimeter is larger than round wire of equivalent cross-sectional area, is capable of carrying more high-frequency current. In addition, ribbon wire induction is lower, enabling faster signal propagation. As a result, ribbon bonding is becoming an important alternative for automotive electronics.

As insulated gate bipolar devices (IGBT power modules) carry high currents and have very high switching rates, they are increasingly ribbon bonded. Heavy ribbon not only carries the high currents required, but also helps transfer heat out of the IGBT. Ribbon as large as 12 mils thick x 80 mils (in Al, Cu-clad, Al, and Cu) can be bonded with a heavy wire bonder. As we move toward vehicle electrification, with much higher energy demands for power storage in banks of parallel connected batteries, ribbon bonding will be the leading-edge interconnec-

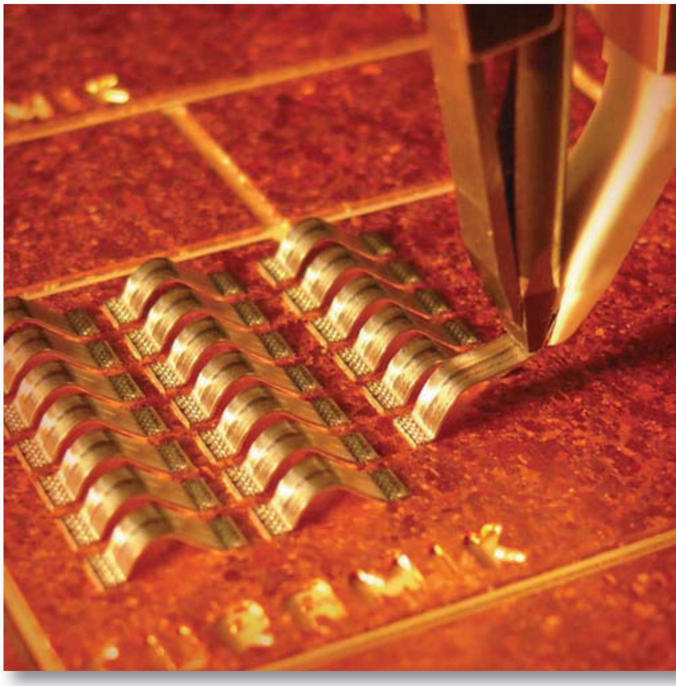

Figure 3: Copper ribbon bonds.

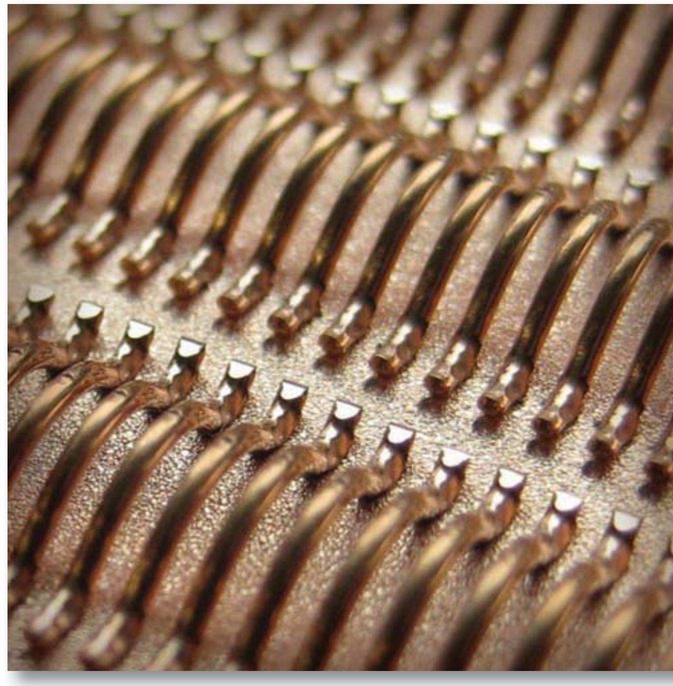

Figure 4: V groove.

tion technology. Figure 3 depicts wedge bonding with large ribbon.

Wedge and Active Cutter Configuration

Heavy wire wedge tools are configured differently than fine wire wedges because, after forming second bond, the wire is cut by the "active cutter" located behind the tool. This differs from fine wire wedge bonding where the wire is terminated by either clamp or table tear motions. The active cutter provides a precision depth cut that improves bond reliability, limits impact force, and increases cutter life expectancy. Programming both cutter speed and force provides better control than previously available. When reverse bonding (second bond on the die bond pad), the active cutter is so precise that bonding is accomplished without marking the die surface. The ability to program cut depth as a percentage of the wire diameter enables reverse bonding on sensitive structures.

Using the active cutter, the second bond heel can have a full cross-section, enabling the use of "V" and "U" groove tools (see Figure 4) that capture a large portion of the wire cross-section within the groove, without reducing the area of the second bond heel. The increased cross-section allows bonds to achieve both higher pull strength and higher shear strength than achievable with conventional shaped tools.

Fine wire wedge bonding requires a smaller cross-sectional area (more deformation) behind second bond to reliably terminate the wire.

Process Integrated Quality Control (PIQC™)

High-cost, high-reliability devices used for automotive packages require a much higher level of quality assurance than lower-cost commodity ICs. Automotive packages often carry much higher current and must operate in one of the most difficult environments. Under-the-hood operating conditions are high-stress environments. With the new government initiatives for vehicle electrification, higher currents and more difficult thermal stress will increase already difficult requirements. High long-term reliability and zero defects in manufacturing are required.

Some newer wedge bonders have real-time quality monitoring features that are unavailable on ball bonders. PIQC™ is one such bond quality measurement system that uses multi-variate analysis to determine bond quality and transmit the data to the factory computer system. Tracking of bond quality enables an exact record of each bond to be stored and eliminates bad bonds from entering the system.

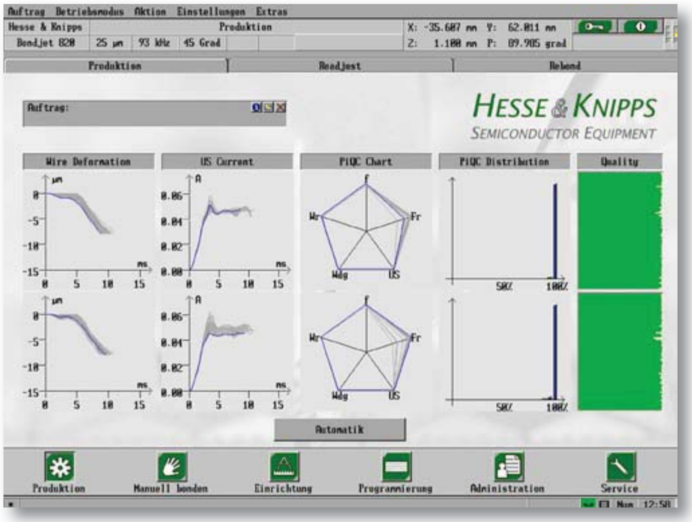

Figure 5: Screen capture of a radar chart.

PIQC™ incorporates a patented sensor, mounted directly on the ultrasonic transducer that captures real-time measurements of friction at the bond interface and amplitude of the tool tip. During bonding, the system monitors and captures both the normal ultrasonic control signals and the unique signals reflected from the bond interface to the PIQC sensor. More than five individual signals are monitored and analyzed using multi-variate analysis including: ultrasonic current, transducer impedance, ultrasonic frequency, tool displacement, and bond interface friction. Each signal is compared to a standard and graded. Different types of defects, such as scratches, contamination, and bonding off-pad, trigger different responses from the indicators. A combination of five response indicators is used to maximize quality discrimination. A quality decision algorithm determines the overall quality grade. Acceptance limits can be specified that will either flag a poorly bonded device or stop the process for operator assistance. The "radar chart" provides a graphic picture of the five signals simultaneously. Figure 5 is a screen capture of some of the quality tools demonstrating the bond uniformity and showing a radar chart.

The process engineer can monitor production operations from his desk and be assured that the process is meeting requirements. Traceability of each device bond record assures that quality is maintained throughout the system and that it is well documented.

Conclusion

Wedge bonding large diameter wire and ribbon provides a highly-flexible, high-reliability process that is widely used for automotive applications. The high volumes and high reliability required by the automotive industry are being met by new, innovative developments such as PIQC, ribbon bonding of larger size wires, copper round and ribbon bonding, and active cutting. Heavy wire wedge bonding will continue to add new capabilities that enable new automotive applications. **SMT**

References

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As a distinguished member of the technical staff for Hesse & Knipps, Inc., Lee Levine provides support for customers with challenging wedge bonding process requirements. In addition, he researches and presents technical papers on various aspects of wedge bonding.

A degreed expert in metallurgy, Levine has more than 30 years of semiconductor materials, manufacturing, and process development experience. The recipient of the IMAPS 1999 John A. Wagnon Technical Achievement Award, he holds four patents and has published over 70 technical papers. His major innovations include copper ball bonding, loop shapes for thin, small outline packages (TSOP and TSSOP, and CSPs) and introduction of DOE, and statistical techniques for a better understanding of the wire bond assembly process.

Levine is founder of Process Solutions Consulting, Inc.; his company currently provides process consulting, yield improvement, SEM, EDS, and metallography services to customers in the microelectronics industry. Levine is also an IMAPS Fellow and has served as IMAPS' vice president of technology. He may be reached at Levine@hesse-knipps.us.