Wire bonding ranks among popular and dominant interconnect technologies due to its reputation for versatility, performance, and reliability. Wire-bond types can be described either by the mechanism for creating the wire bond or the type of bond. Wire-bond mechanisms offer three different methods for imparting the requisite energy to attach a wire to the bond site: thermocompression, ultrasonic, and thermosonic. Two types of bond methods exist: the ball-stitch and the wedge bonds (Table 1).

**Ball-stitch Bonding**
In ball bonding, a capacitive discharge spark melts the tip of the wire and the surface tension of the molten gold forms the ball. This is called the “flame-off” process. The ball is then placed at the target bond site, and ultrasonic energy transmitted by the capillary scrubs the pad surface, creating a metallurgical bond between the ball and pad. In this type of bonding, the capillary does not contact the pad surface. For the second half of the bond, the capillary is moved to the location for the stitch bond. Here, the capillary rests against the pad surface and ultrasonic energy forms the stitch and cuts the wire (Figure 1). The entire sequence of ball-stitch bonding is shown in Figure 2.

**Wedge Bonding**
In wedge bonding, a stub of wire is pressed against the bond pad by the foot of the capillary, applying ultrasonic energy to form the bond between the wire and bond pad. The capillary is then moved to the second bond location and the process is repeated. Once the second bond is completed, the wire is clamped and snapped above the second bond.

The following guidelines are recommended when planning for the use of wire bonds in a package design.

**Wire-bond Connections**
Avoid chip-to-chip connections – Unless electrical performance demands it, wire bonding directly between ICs should be avoided. Creating the stitch bond transmits mechanical energy to the pad, which could lead to micro-cracking in, or under, the pad metallization. Micro-cracks represent a potential reliability risk; therefore, intermediate bond pads should be designed into the substrate.

Don’t cross wires – Bond wires should not cross over one another, other die, or bond pads (Figure 3). Under external mechanical stresses, the unsupported loop of the wire bond could droop and contact a wire directly under it, leading to a short circuit.

Remember: bond pads do matter – Bond pads should be positioned to create the shortest bond wire possible (within provided design rules). The length of the wire bond determines the total impedance, capacitance, and inductance of the connection. Long wire bonds can be detrimental to the overall package performance.

<table>
<thead>
<tr>
<th>Bond Type</th>
<th>Bonding Mechanism</th>
<th>Wire</th>
<th>Temperature</th>
<th>Ultrasonic</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball</td>
<td>Thermosonic</td>
<td>Au</td>
<td>Elevated</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>Wedge</td>
<td>Thermosonic</td>
<td>Au</td>
<td>Elevated</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>Wedge</td>
<td>Ultrasonic</td>
<td>Al</td>
<td>Ambient</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>Ball</td>
<td>Thermocompression</td>
<td>Au</td>
<td>Elevated</td>
<td>No</td>
<td>High</td>
</tr>
</tbody>
</table>

All substrate bond pads should be gold-plated to a minimum thickness of 0.76 µm, otherwise the mechanical energy of the scrubbing process can result in the wire penetrating the pad and damaging underlying structures.

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The back-end process

Selecting the Wire
The choice of wire diameter depends on the wire bond pitch, current carrying capacity, and cost. 1-mil diameter gold wire is a common choice, and has a resistance of 1.17 mΩ per mil of length, and a burn-out current of approximately 0.7 Å, depending on wire length, heatsinking, etc. Typical inductance attributable to a 1-mil bond wire is 25 pH per mil length, but varies depending upon bond wire height. Aluminum wire is almost exclusively used in wedge-bonding applications, because the high propensity of Al to oxidize requires ball bonding with Al wires to be performed in an inert atmosphere.

Bond Placement
In the package design process, it is important to consider bond placement relative to other components—a consideration that will increase as package sizes decrease and layout densities increase. When wire bonds are to be placed in close proximity to tall components, clearance (X) required by the bonding tool and tolerances for both die placement and bond accuracy must be considered. Figure 4 illustrates a situation when a 0.01-in. capillary tip is used for ball-stitch bonding and a reasonable value of X is 0.01 in. > ¼ of the component height (B2).

In a stitch bond, the actual bond area is offset from the capillary centerline. Therefore, clearance must include additional tolerance, equal to half the capillary tip diameter to ensure proper clearance. Thus, for a 0.01-in. tip capillary, Y should be 0.005 in. > X.

Another solution is to use wedge bonding, in which the bonding tool has a vertical front face. Unfortunately, as a semi-automatic process, wedge bonding is slower—and therefore more costly—than ball-stitch bonding.

Bond Placement – Lids and Glob-top
Figure 4 shows the requirements for wire-bond placement in proximity to lid-attach locations and glob-top dam and fill. The placement requirements account for the tolerances in lid dimensions and placement accuracy. In the case of glob-top dam and fill, the placement is dictated by the amount of settling in the glob-top dam material during curing.

Pad Sizing and Spacing
Table 2 provides guidelines for designing pads on the substrate and specifying pad sizes on die. The dimensions...
Failure Mechanisms & Evaluation Methods

Common defects or failures that can occur in wire bonds fall under three categories based on the underlying cause. If the bonding force is too high, die-surface cratering or peeling of pad metallization may occur. Conversely, if the bonding force is too low, the bonds may not stick to the pad. Contaminated bond pads or uneven pad surfaces may also keep them from sticking. Wire breakage during the bonding process is usually a result of imperfections (nicks, scratches, or kinks) in the wire.

Evaluating Wire Bonds

Wire bond strength and acceptability of wire-bonded parts can be evaluated using either a destructive pull test (DPT) or a non-destructive pull test (NDPT). The most commonly accepted standards for these tests are MIL-STD-883, Method 2011.7 Bond Strength and MIL-STD-883, Method 2023.5, respectively. These standards describe the sample sizes for each type of test and accept/reject criteria for different wire and bonding types. Acceptance criteria are based on the strength and wire break location during destructive bond pull tests. Of eight wire breakage locations listed in MIL-STD-883, Method 2011.7, only breaks occurring over the mid-span of the wire are acceptable (Location 2 in Figure 5).

Additional methods for evaluating wire bonds include visual inspection and ball shear strength. Visual inspection identifies damaged wire bonds, misplaced or lifted bonds, and bonds that might be shorting against other bonds or components. Ball-shear testing determines wire bond-to-pad adhesion.

Wire-bond reliability is usually tested by subjecting bonded parts to standard mechanical shock and vibration tests, temperature cycling or shock, and damp heat. Wire-bond stability is evaluated by comparing the destructive pull test of the wire bonds after reliability testing against a control sample.

Conclusion

With due care, wire bonding can be accomplished on a variety of substrates, ranging from PCBs to multi-layer and thick-film ceramics to flexible circuits. While other technologies like flip chip may allow for reduction in overall package dimensions, wire bonding’s track record of versatility, performance, and reliability keep it a viable technology in the design and manufacture of electronic components. Additionally, wire bonding equipment manufacturers and semiconductor assembly houses continue to push this interconnect technology. Recent advances in ultra-fine-pitch wire bonding allow for package-size reduction while providing higher interconnect densities. Following the criteria outlined here, designers can use wire bonding to provide a robust and reliable interconnect in most electronics applications.

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### TABLE 2. Typical substrate and IC pad dimensions.

<table>
<thead>
<tr>
<th>Description of Spacing</th>
<th>Typical Values: 0.001-in. Wire</th>
<th>Typical Values: 0.0007-in. Wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire length, minimum</td>
<td>0.040 in.</td>
<td>0.030 in.</td>
</tr>
<tr>
<td>Wire length, maximum</td>
<td>0.100 in.</td>
<td>0.075 in.</td>
</tr>
<tr>
<td>Loop height clearance above die</td>
<td>0.015 in.</td>
<td>0.015 in.</td>
</tr>
<tr>
<td>Die pad: min. available circle (ball)</td>
<td>0.004 in.</td>
<td>0.003 in.</td>
</tr>
<tr>
<td>Die pad: min. available circle (wedge)</td>
<td>0.0025 in.</td>
<td>0.002 in.</td>
</tr>
<tr>
<td>Substrate pad: 1 bond</td>
<td>0.010 × 0.008 in.</td>
<td>0.010 × 0.008 in.</td>
</tr>
<tr>
<td>Substrate pad: 2 bonds</td>
<td>0.010 × 0.010 in.</td>
<td>0.010 × 0.010 in.</td>
</tr>
<tr>
<td>Die</td>
<td>0.003 in.</td>
<td>0.003 in.</td>
</tr>
</tbody>
</table>

**FIGURE 5. Wire bond failure locations and descriptions.**
About Maxtek

Maxtek, a Tektronix company, is a proven custom microelectronics company providing a complete range of design, assembly and test services to equipment manufacturers. With 35 years of experience serving the measurement, military and medical markets, Maxtek works as an extension of our customers’ teams to resolve the most demanding packaging challenges.

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