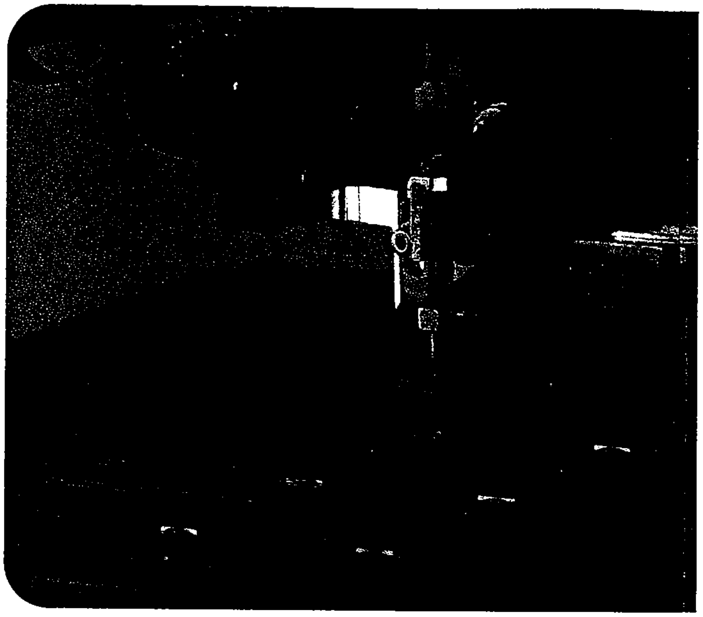
ADVANCED PACKAGING'S
Step by Step

Wire bonding, a low-temperature welding process, continues to dominate semiconductor interconnection. New technologies, such as copper wire and wafer metallization, promise increased flexibility and performance.

Wire bonding



BY LEE LEVINE

Wire bonding continues to dominate semiconductor interconnection, accounting for more than 90 percent of all leads assembled to packages in 1999. The worldwide lead count for integrated circuit (IC) interconnections is expected to double to more than 9 trillion by 2003.[1]

There are currently two wire-bonding techniques: gold ball bonding, which lays claim to more than 95 percent of the total wire bonded lead count, and gold or aluminum wedge bonding. Applications involving copper ball and wedge bonding are expected to increase as copper wafer metallization becomes more prevalent during the next two years.[2]

The Ultrasonic Bonding Mechanism

In the simplest terms, wire bonding is a low-temperature welding process. Ultrasonic energy, applied through a bonding tool (called a capillary or wedge), increases the dislocation density of the wire and bond site, lowering flow stress and the modulus of elasticity while increasing the rate of diffusion. This allows the material to deform easily at much lower stress than would otherwise be required.[3]

As material flow occurs, microscopic slip planes shear across each other. At the surface, this slipping provides new surfaces that are metallurgically clean. Because these clean surfaces on the bond site and wire are in contact, they diffusion weld to each other. Table 1 lists the stages of ultrasonic welding. Higher ultrasonic frequencies increase the strain rate and enable the material to transfer energy from the bonding tool tip through the wire or ball to the bond interface more efficiently.

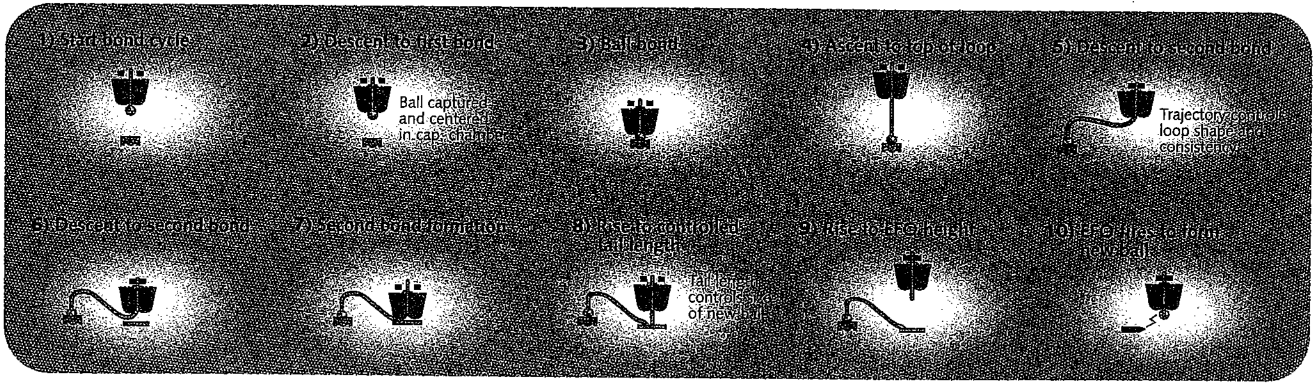


Figure 1. Schematic of the wire, substrate, bonding capillary tip cross section and wire clamps through the important stages of forming a ball bond.

Reprinted from the April 2000 edition of **ADVANCED PACKAGING**

Wire-bonding Equipment

Modern high-speed, automatic wire-bonding equipment has been continuously developed and refined to meet never-ending requirements for small complex devices for computers, electronics, wireless communications and other products. As a result, pad pitches (the distance between the centers of the pads to which the wires are attached) for leading edge devices have decreased from 100 µm just a few years ago to 60 µm and below today. Concurrently, the number of leads per device has increased to as many as 1,000.

Exponential increases in research and development for wire bonders, bonding tools and bonding wire have been required to keep pace with these demanding requirements. In addition, integration of equipment, tools and materials has become critical to the development of robust mass production processes.[3] Table 2 describes the current state-of-the-art capabilities available in automatic ball and wedge bonders.

Ball Bonding Steps

An advantage of ball bonding is that the round cross-section of the capillary enables bending the wire at any angle radiating from the ball, enabling wire placement at any angle with only X-Y motions. The ball bonding process consists of creation of a first (ball) bond on a pad on the die, followed by a second (wedge) bond on the corresponding package lead to form the electrical circuit between the chip and carrier. It can be broken down into the following ten steps, all of which occur in as little as 80 milliseconds.

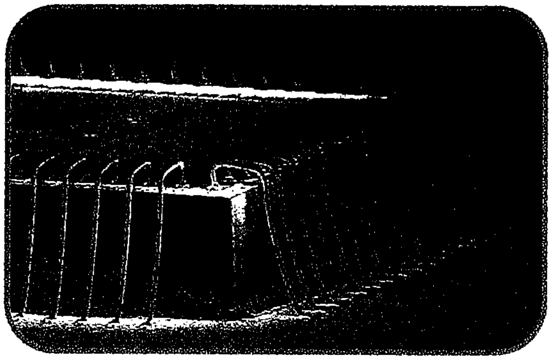


Figure 2. CSP loops created by a ball bonder. Special bends are formed that provide this shape with the second bonds close to the die edge.

Before bonding a package, the bonder's vision system identifies two previously "taught" regions in the pattern of circuitry (eye points) on the top surface of the die. Once the pattern recognition system (PRS) locates the two eye points, the bonder is able to transform the bond locations that were originally taught, correcting them for placement variation in each device. For fine pitch bonding, lead locations are also corrected based on scanning the leads and locating them using the bonder's video lead locator (VLL).

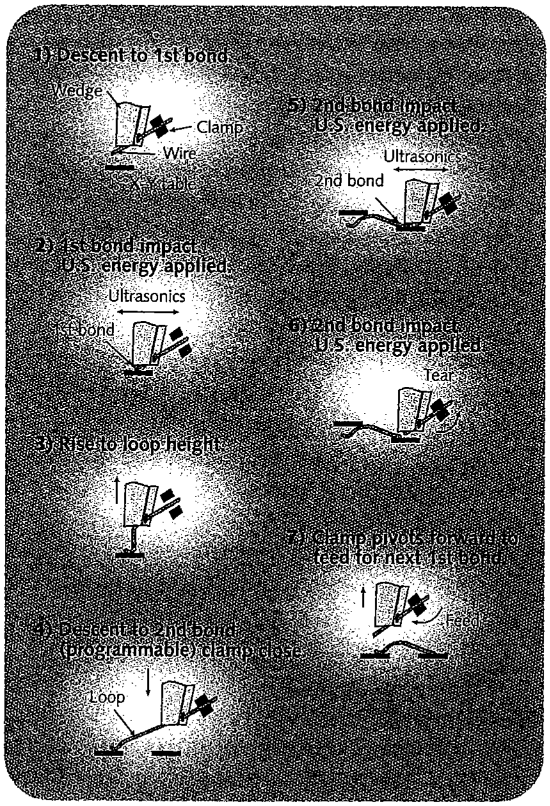


Figure 3. Schematic of 7-step wedge bonding process.

1. The process begins with the capillary and a ball at the end of the wire at reset height. The wire clamps are open, and an air tensioner applies force to seat and center the ball in the conical chamfer of the capillary.

2. The capillary descends to first bond. There are two components to this motion: a high-speed portion and then, close to the work surface, a slower, controlled-velocity descent during which the bonder "senses" contact with the surface. It is not unusual for the height of die or substrate to vary by several mils; therefore, a wire bonder must be capable of sensing touchdown for each bond and cannot rely on previous height data.

3. During creation of the ball bond, ultrasonic energy changes the material properties of the ball and bond pad, allowing easy deformation and bonding.

4. The capillary ascends to the top of the wire loop. Die position variation can change the lengths of each wire within a package. The wire bonder recalculates and adjusts the length of wire required by each loop in the package before it is bonded. During the ascent to top of loop, the required wire length is metered out precisely. At top of loop, the wire clamps close so that no additional wire can enter the loop.

5. During the trajectory, precisely calculated motion algorithms, both on the ascent to top of loop and in descent toward second bond, enable the wire bonder to produce some of the special shapes required by many of today's advanced packages. They include the "worked" loop shape, chip scale package (CSP) loop and ball grid array (BGA) loop.

6. As the bondhead descends, wire protruding from the capillary contacts the surface first. As the capillary continues downward, the wire rolls upward, lifting and shaping the loop near second bond.

7. Two welds are made during second bond formation. First, the capillary face forms and welds a crescent (fishtailed) shape, attaching the wire to the lead. Second, the inner chamfer of the capillary welds the tip of the wire still within the capillary to the substrate (the "tail bond"), providing the attachment that will allow the proper length of wire to be metered for the next ball.