Wire bonding

A review of some fundamentals

BY MIKE GREENELSH

Ongoing demands for higher I/O counts while minimizing board real estate are driving high-density connections between chips and the packages. As a result, lead wire bonding, the most widespread technology for formation of interconnects in semiconductors, has become perhaps the most sophisticated process of all the assembly operations. The proper selection of bonding wire materials has become a critical part of the process.

Over the years, the specification of bonding wire has been somewhat of a moving target. Integrated circuit (IC) manufacturers and the ASTM have adopted many standard specification and test method guidelines. However, many IC designers must make judgement calls about factors affecting wire bonds, such as burnout rate, metal fatigue and current-carrying capacities, because wire bonding parameters are based on what are believed to be typical samples. The complexities involved in bonding interconnects, not to mention uncertainties surrounding their applications, make it a challenge to fit everything into a "typical" range.

Popular Bonding Wire Materials

Generally speaking, the elements most commonly used to make bonding wire are gold and aluminum. Bonding wire is usually specified by its strength, based on the metallurgical characteristics of elongation and breaking load. Both gold and aluminum are strong and ductile, and both also have similar resistance in most environments.

Gold: Gold is used because it is normally inert, is well-suited to the ball bonding process, and demonstrates excellent loop formation and cycle performance. However, in a high heat situation, gold presents problems because it tends to absorb the radiated energy, making it unstable. (This can be a significant problem in aerospace applications.) Gold wire can be stabilized with several different dopants including beryllium and calcium, as well as proprietary materials. Gold wires for ball bonding are normally supplied in the annealed condition to prevent unwanted "break-off" partial annealing that will occur during initial ball formation. The reliability and flexibility of gold wire bonding have made it the most widely used technology in the IC industry.

Aluminum: Small-diameter aluminum wire is commonly used for ultrasonic wedge bonding. Aluminum alloys also provide the advantage of relatively good fatigue resistance. In practice, the lightweight silicon-aluminum alloy has been shown to be quite reliable. Because aluminum is too soft to draw for small wire diameters, an alloying material (normally silicon) must be added to meet necessary breaking load and elongation parameters. Unfortunately, silicon and aluminum do not combine readily, and when heated, silicon alloy particles can cause stress risers, resulting in cracking of the wire. Therefore, the small-diameter aluminum-silicon wire must be heat treated (partially annealed) in such a way as to cause the silicon to disperse evenly before it is drawn. In larger diameters, the metal can be heat treated to stabilize the silicon before the wire is drawn, and then heat treated again in the final draw to get the elongation and break point required. (It may be noted that magnesium-doped aluminum wires have advantages — including better fatigue resistance — compared to silicon-doped wire, but the silicon-doped aluminum has become the standard.)

Other Materials: In addition to gold and aluminum, many IC manufacturers today are opting for copper, palladium-alloy, platinum or silver bonding wire because of the potential for substantial gains in conductivity and therefore circuit speeds. The choice of copper for interconnections requires structures to be encapsulated with a barrier layer (usually with a thin film layer) to achieve the required adhesion, and to protect against diffusion of copper atoms into silicon devices, which will degrade performance. Palladium-doped gold wire is used for ball bonds on IC chips for flip chip applications and ball-in-the-corner interconnects. Platinum wire is sometimes specified for high-temperature semiconductor devices, and silver is an option for high-speed applications because its high electrical conductivity.

Shelf Life Issues

Some companies adopt a discretionary policy of discarding bonding wire after three or six months. The principle here is that they would rather toss out good wire than risk a change in metallurgical properties that could affect the yield of a given machine setup.

Testing has shown that hard, as-drawn wire begins to weaken within six weeks of manufacture. Specifically, the breaking load decreased by between 5 and 15 percent in that period, and then decreased more slowly for the balance of the two-year period of that particular test. However, stress-relieved and annealed wires (both gold and aluminum) stayed within their breaking load specifications for the entire two-year test period.

Test results for elongation have been somewhat more ambiguous. It appears that annealed or stress-relieved wire can be used for up to two years, although elongation may vary slightly.

Metallurgical Fatigue

Metal fatigue issues are usually a result of application details, rather than a specific problem with the wire. Fatigue is the result of repetitive stress, such as the repeated bending of a wire. Recurrent bending can break a wire even though this stress is much lower than is required to fracture it in a single bend or pull.

Device manufacturers are usually cautious about using fans or radiators to cool devices, but thermal cycling in ICs constantly flexes bonded wires, and can therefore produce fatigue failures. During thermal cycles, any undispersed silicon in aluminum-silicon wire may grow and serve as stress risers, making the wire prone to crack and fail. Also, loop height can affect thermal cycling as much as or more than the properties of the wire itself.

Wire Burnout

Burnout is related to metallurgical fatigue, but it results from certain factors causing the current-carrying capacity of wire to be exceeded and fuse the wire. Most of these factors are metallurgical, and they include resistivity, thermal conductivity, temperature coefficient of resistance and melting point. Another major contributor is the length of the wire (the longer the wire, the lower the current needed for burnout.

Recognizing the difficulty in predicting the maximum current a wire can carry and the likely incidence of wire burnout, many designers simply over-specify wire diameter or use multiple wires. In fact, wire burnout is not a common problem in the field.

Elongation and Breaking Load Parameters

There are trade-offs between elongation and breaking load, two fundamental metallurgical characteristics of bonding wire that influence wire specification. Elongation pertains directly to the elasticity of a particular wire, and it is essentially how much a wire can stretch under various stress-strain conditions before plastic deformation (permanent stretching) occurs. Breaking load is the amount of elongation a wire can sustain before the breaking point.

There are instances when an IC manufacturer may want to exceed the normal elongation of a certain type of wire without encountering plastic deformation or compromising breaking strength. This can be accomplished to some extent by slightly annealing or fully annealing the wire.

Wire Quality Factors

There are several factors that contribute to the quality of wire, including intrinsic material properties, processing and design factors.

Metal Purity: Base metals must meet ultra-pure standards. For example, gold has to be at least 99.9999 percent pure (i.e., "four nines" or "4/9"). A higher quality of melting stock results in fewer contaminants such as oxides that could cause fatigue or wire drawing problems.

Shape: If the wire were slightly out of round, it could not pass through the bonding machine capillary and could slip or not run smoothly. Therefore, it is important not to have stress risers in silicon-based alloys, or the silicon "chunks" may cause capillary blockage or compromise bond integrity.

Annealing: Heat treating (annealing) is an important process in making bonding wire. The raw material can be treated, which, in the case of an aluminum-silicon alloy, ensures that the silicon is dispersed properly. After being drawn to its final size, the wire can be annealed again to stabilize the alloy. During this final heat-treating process the wire gets a degree of external protection in the form of a light patina of oxidation, which helps to prevent rapid oxidation.

Handling: Even in 2002, improper handling is a measurable source of wire damage. Something as simple as impacting a wire spool with a fingernail can create significant defects in the wire. It is important to have clear and detailed handling information, as well as training for the operators and other people handling the wire. **AP**

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