

Propagation Mechanism and Metallurgical Characterization of First Bond Brittle Heel Cracks in AlSi Wire

Raymond T. Fitzsimmons
Raytheon Company
528 Boston Post Road
Sudbury, MA 01776

Dr. Henry Chia
American Fine Wire
907 Ravenwood Drive
Selma, AL 36701

ABSTRACT

Bottom die heel cracks in 1.25 mil Al-1% Si wires were found to cause opens and shorts. All the failures were attributed to brittle looking fatigue die heel breaks. This failure mechanism has been traced and reproduced through experimentation and found to be directly caused by the 60KHz ultrasonic energy vibrating the wire behind the tool during the first bond.

These bottom first-bond heel cracks have been observed at multiple suppliers of semiconductors and represent a reliability problem. Bonds with these cracks exhibit low pull strengths (<1.0 gram for annealed wires and <2.0 grams on unannealed wires).

In order to increase the frequency of these brittle cracks, hard AlSi wire was deliberately produced for this study. The frequency of the bottom cracks increased from one in a thousand to eight out of ten wires, when normal wire (19 grams tensile breaking force) was replaced with hard wire (35 grams tensile breaking force).

The wire bonding sequence was partitioned to determine the onset of the crack and its propagation. The magnitude of the cracking is described at five points in the bonding cycle. Results show that the ultrasonic vibration during first bond produces an incipient crack that further propagates during the remainder of the wire bond cycle.

Full metallographic characterization of the wire which included optical as well as scanning electron microscopy was performed in order to investigate the matrix/particle involvement in the failed specimens.

The possible fracture formation and propagation characteristics are described and the specific contribution of the AlSi alloy system is discussed.

I. INTRODUCTION

First bond heel cracks on the

bottom side of 1.25 mil (32 micron meters) diameter Al-1% Silicon wire have been observed at multiple semiconductor assembly houses and are believed to represent a reliability problem. These cracks result in low bond pull strengths (<1.0 gram for annealed wires and <2.0 grams on unannealed wires). All the wires exhibiting cracks exhibit similar morphology at the first bond fracture area after wire pull (Figure 1). The fracture exhibits a shear line in the middle with a severely deformed structure above and below. This is important because low bond pulls and breaks are not routinely observed under the scanning electron microscope for fracture signature and are assumed to be due to mechanical damage. Cracks of this nature were first observed and reported last year at the ECTC Conference⁽¹⁾ and are now believed to occur more often than previously thought.

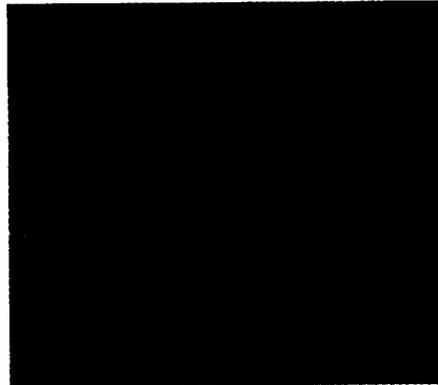


Fig. 1. Die heel crack after wire pull. White arrow shows the shear line. Black arrows indicated the severely deformed areas.

II. EXPERIMENTAL METHOD

Recent studies performed have shown a direct correlation between crack width and the ultrasonic vibration during the first bond. In order to determine the cause of the cracks, Al-1% Silicon wire was deliberately manufactured with low ductility in order to make the material more susceptible to fracturing and thus increase the frequency of the cracks. The wire was cold worked from the cast ingot without intermediate anneals in order to produce a low ductility matrix.

The size and distribution of the silicon particles were not affected by the processing sequence. A high resultant tensile force was obtained due to the high degree of cold work exerted on the aluminum wire. The deliberately produced hard wire was ultrasonically bonded to standard semiconductor die pads and packages. The crack frequency increased from one in one thousand in regular wire to 8 in 10 wires when the normal wire (19 grams breaking load) was replaced with hard wire (35 grams breaking load). A frequency of 80% of the wires with cracks allowed the bonding process and crack propagation to be easily studied. The low ductility wire not only has poor crack resistance and fatigue properties but also requires more power (tool displacement) and time (number of vibrations) to complete the bond, therefore facilitating the incidence of fatigue-like failures.

The bonding sequence is illustrated in Figure 2. The bonder was stopped at five points in the cycle (1,2,3,4,6) and the wire was cut behind the tool. At each of the five points, approximately 20 wires were bonded, and each of the first bond heel areas was photographed at 1500X

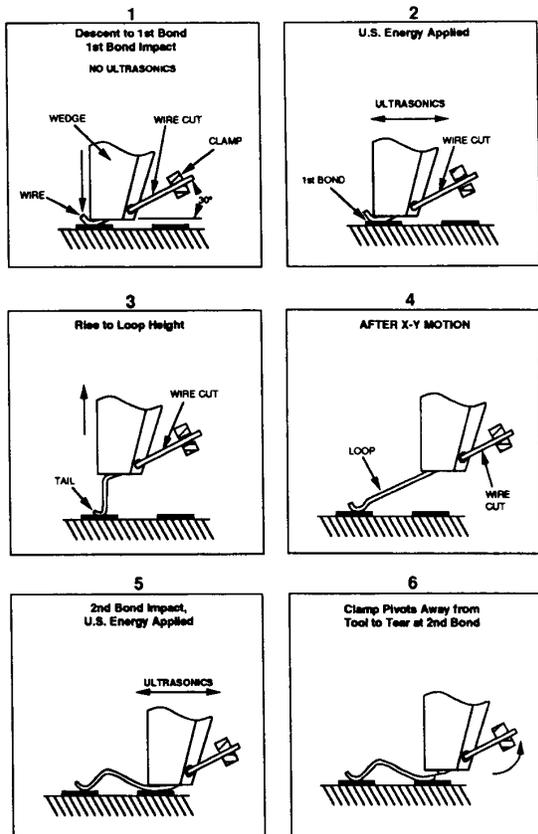


Fig. 2. Wire bonding cycle (Sequence).

using a Scanning Electron Microscope to determine the onset and propagation of the bottom heel cracks formed.

III RESULTS AND DISCUSSION

Crack Formation Manipulation

The wire bonding mechanical sequence was partitioned in order to determine the onset of the crack and its propagation. The magnitude of the cracking is described at five points in the bonding cycle (Figure 2):

- (1) after first impact,
- (2) after the first ultrasonic energy is applied
- (3) at the top of the loop
- (4) at the completion of the loop
- (5) at the completion of the second bond.

Figure 3 shows that no cracks appear after first impact before the ultrasonics have been applied (sequence No. 1). After the first bond, the ultrasonic energy (sequence No. 2) is applied, and cracks appear at the top and bottom of the heel area (as shown by arrows in Figure 4). The incipient cracks further propagate during the rest of the process cycle



Fig. 3. Sequence 1. Die heel area after impact no ultrasonics.



Fig. 4. Sequence 2. Die heel after 1st bond ultrasonics.

Figure 5 shows the cracks again after the tool rises to the top of the loop (sequence No. 3). This motion bends the wire forward about 15° to 30°. After the table moves, the wire bends 90° backward, and the cracks further propagate (sequence No. 4) (as shown by arrows Figure 6). It can be easily observed that after the second bond is complete (sequence No. 6), the cracks are more pronounced. (as shown by arrows Figure 7).



Fig. 5. Sequence 3. Die heel after tool is raised to loop height.

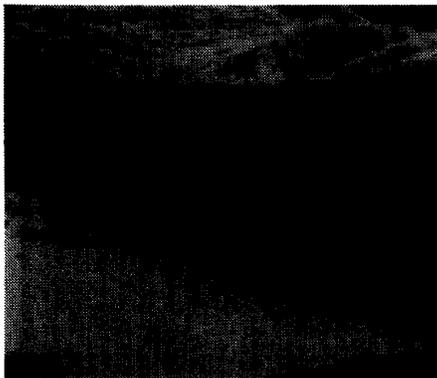


Fig. 6. Sequence 4. Die heel after wire motion.

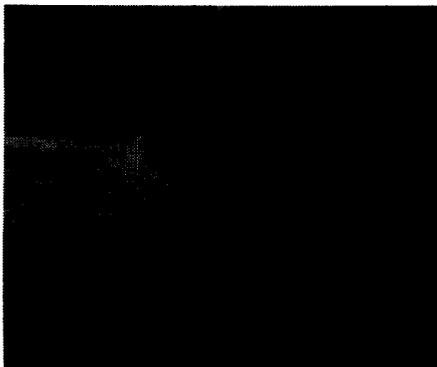


Fig. 7. Sequence 6. Die heel after completed second bond.

In order to have an experimental model for comparison purposes, a wire potted in epoxy was manually bent through 180°. This bending sequence produced a fatigue-type fracture with similarities to the ones obtained in this study. The bending fractured the wire with a central line (shear) (white arrow) but exhibited ductile surfaces on either side (as shown by black arrows) and an elongated surface (Figure 8).



Fig. 8. Hard wire potted in epoxy and fatigued by bending. White arrow central shear line. Black arrows ductile surface.

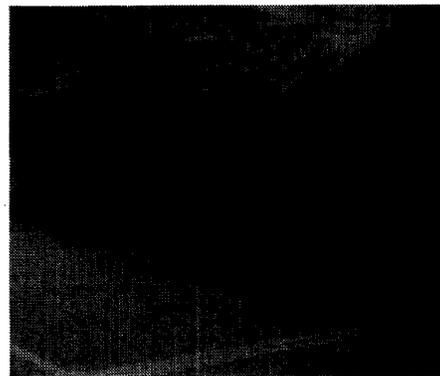


Fig. 9.

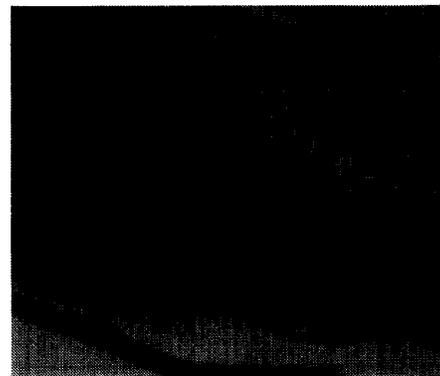


Fig. 9&10. Die heel crack before wire pull. White arrows shows cracks.

Figures 9 and 10 show the cracks before wire pull, and Figure 1 shows the fractured surface after wire pull. The fracture shows a center line where the cracks from the two sides meet (white arrows) and a brittle (the absence of ductility was confirmed since no dimples or microvoid coalescence characteristics were observed) structure above and below (as shown by black arrows) the center line. This indicates that the failure is a high-frequency, low-amplitude fatigue failure and not a high-amplitude, low-frequency fatigue failure as in Figure 8.

Bottom heel cracks occur only sporadically, but when they are observed, they occur in significant numbers. Observation of the hard wire showed that the cracks are formed during the first bond. The actual vibration of the wire behind the tool during first bond has been photographed using an electronic camera in the streak mode (1). Figure 11 shows the vibration to be approximately 10 wire diameters in amplitude and at frequencies varying from 30 to 60 KHz. This vibration is forced vibration and not resonant vibration because the distance between the tool and the clamps can vary, yet the same number of cracks will occur. It was observed that the cracks also were formed with the clamps open.

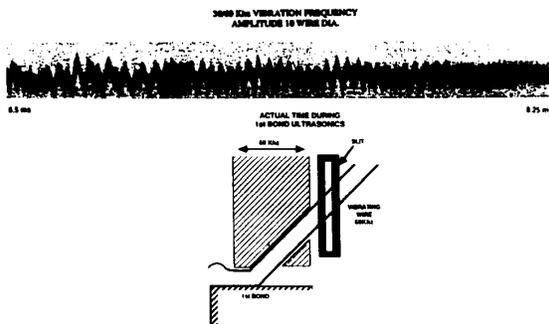


Fig. 11. Vibration on wire at the heel of the first bond during ultrasonics of the first bond.

A simple explanation of the mechanism is that the vibrating wire is pinned at the heel of the first bond creating a fulcrum for the work hardening to start to propagate the cracks. The fractured area (after wire pull) always has a line in the middle of the surface. This is the part of the wire ("hinge") that does not move during wire vibration and that fractures by a shear stress mechanism. The line is always horizontal because the motion of the wire is vertical and it is not allowed to move side to side

because it is contained in the tool hole.

Microscopic Examination

The produced specimens were characterized under the optical metallographic microscope and the Scanning Electron Microscope.

As can be observed in Figure 12, the cracks nucleate perpendicularly to the wire axis first from the bottom and later from the top. The cracks originate in the middle of the bottom and move to the outside as evidenced in the studied cross sections.

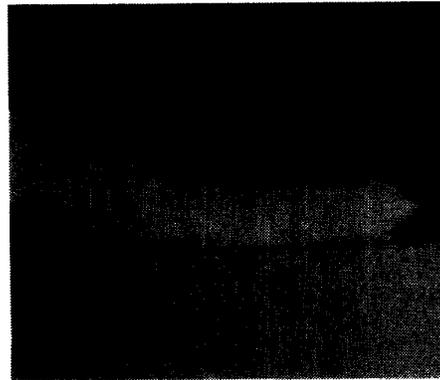


Fig. 12. Cross section of wire bond with normal Si particles.

The fractured area shows no distinct evidence of the classical fatigue striations. This could be due to possible fretting or rubbing of the two separating surfaces as the crack propagates. It is known that fatigue-fracture striations are produced only by plane-strain conditions⁽²⁾. The exact fracture mode of these cracks is not clear, but it certainly must be dependent upon the extent and morphology of the plastic zone at the propagating crack tip. The SEM examination revealed a center line which results from the last portion of the specimen to fracture. This region simulates the central line which is normal to the tension axis and contains small shear lips. It is possible to assume that this behavior could be attributed to "plane-stress" conditions with absence of the common fatigue striation morphology. Since macroscopic fatigue cracks follow planes of high tensile stresses, the mode of stressing and the specimen shape would be the controlling factors on the resulting geometrical features of the fracture surface.

It is important to note that the crack path or its propagation did not appear to be affected by the presence of large second phase particles of silicon. The wire exhibiting the normal, non-resolvable silicon particle distribution (Figure 12) shows a crack propagating perpendicular to the wire axis. A specimen deliberately produced with large second phase primary silicon particles is shown in Figure 13. The crack propagation and path do not appear to be affected by the presence of the large particles. The cracks propagate following the same direction as that of Figure 12. This would indicate that the crack propagation and morphology appear to be strongly dependent on the orientation of stresses acting in the heel portion of the bond and not on the structural features of the wire.

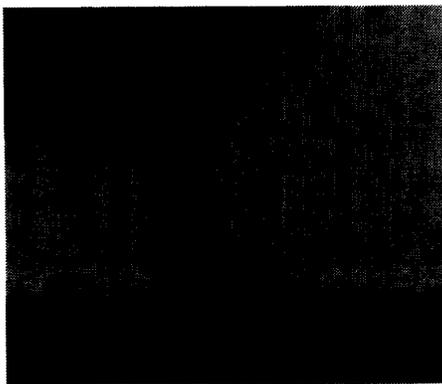


Fig. 13. Cross section of wire bond with deliberately produced large Si particles.

Thorough metallographic examination of all specimens showed that no correlation exists relative to the normal top cracks caused by looping, aluminum oxide accumulation or mechanical surface defects.

IV. CONCLUSIONS

1. The brittle die heel cracks are induced by the ultrasonic tool movement at 60 KHz. This motion in turn vibrates the wire behind the tool during first bond, resulting in a fatigue failure.
2. The cracks are exacerbated by the wire hardness and the remainder of the bonding sequence.
3. The cracks propagate through the matrix and are not affected by the presence of large deliberately produced silicon particles.
4. The excessive wire vibration must be dampened in order to completely eliminate the problem.
5. The use of hard wire and the manipulation of the process by partitioning the ultrasonic wire bonding sequence has proved to be a useful tool in understanding the cause of brittle die heel cracks that have caused opens and shorts.

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