Brittle Cracks Induced in AlSi Wire by the Ultrasonic Bonding Tool Vibration

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Abstract—**Brittle first bond heel breaks in AlSi wire have been observed on 68 lead cerquad flat packs at two assembly houses. These low pull strengths of 0.1–2.5 g (annealed) all have the same appearance. 1500x SEM photographs of the fractured surfaces after pull testing all show a grainy brittle structure above and below a center ductile line (Fig. 5). These brittle heel cracks start at the bottom of the heel and can be observed before wire pull. Bottom brittle first bond cracks have not been reported to date.**

Considerable 60-kHz vibration is consistently present at the first bond heel during the first and second bonding either on the chip or frame [1]. This is the same frequency as the vibration of the ultrasonic tool and is well above the resonant frequency (10–15 kHz) of the wires. This vibration exercises the first bond area and can create the possibility of embrittlement, leading to bottom heel cracks especially with wire with elongations of < 1%. We conclude that die heel damage is induced to a varying degree in every wire, and that any crack on the bottom of a first bond heel is a reliability problem.

Introduction

A SMALL but statistically significant number of die heel breaks in the 0.1–2.5-g range (annealed) were found on 1 1/4 mil Al, 1% Si wire (Fig. 1). These were found on 68 lead cerquad high reliability integrated circuits at two different assembly houses. Pull strengths of 4 to 5 g are normal for these annealed wires. The more brittle the wire (< 1% elongation) the lower the pull strength (0.1–1.0 g). Preanneal pull strengths in the 1.4–4-g range have been observed with large cracks. Preanneal poll strengths of 6.0 g show the start of the cracking. All preanneal first bond breaks < 5 g and postanneal breaks < 3 g should be SEM'd and compared to Fig. 5.

The wires with low bond pull strengths had all passed mil std 883 visual criteria, burn-in (125°C for one week), yet were observed to have varying degrees of die heel cracks after destructive physical analysis (Figs. 2–4). Since most AlSi wire is actually used in the annealed condition (post-seal), it is important to know the annealed strength of the wires.

Bottom die heel cracks had not previously been reported [2]. All of the low pull break areas had a grainy structure and a fine horizontal ductile line through the middle without any apparent elongation (Fig. 5).

All the fracture surfaces of the normal pulls had an overall

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Fig. 1. Worst-case brittle fracture: 0.2-gf die heel break.

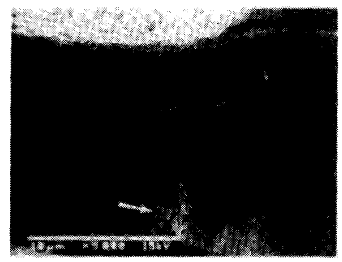

Fig. 2. 0.5-mil crack.

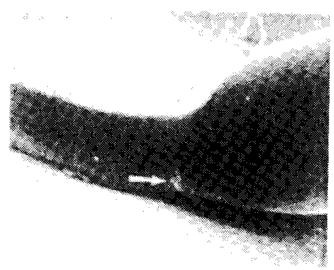

Fig. 3. 0.3-mil crack.

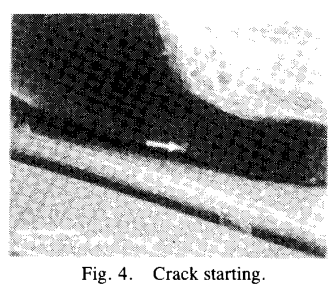

Fig. 4. Crack starting.

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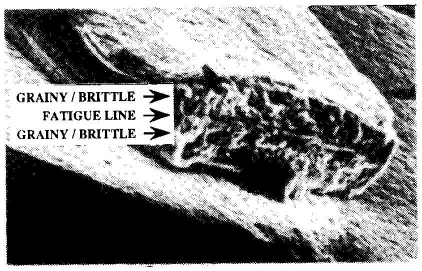


Fig. 5. Brittle die heel break.

Fig. 6. Normal ductile die heel break.

ductile, elongated, and shiny appearance with no center line (Fig. 6).

A. Occurrence of the Problem

At the two manufacturing facilities where these brittle fractures were discovered, the wires with low pull strengths were erroneously explained as failing because of mechanical damage or wire pulling error because of their low occurrence (approximately 1 wire in 10 000). However if one is observed, a careful look at other wires within the lot and surrounding lots will show a significant number of cracked wires (1 in 100).

B. Analysis of Wire Breaks

The wires with low pull strengths (< 2.5 g) were all observed to have the same appearance at the die heel fracture on the first bond. They all had a brittle grainy structure with a thin horizontal middle line (Fig. 5). In contrast, the normal pulls had a shiny ductile surface with good taffy-like elongation (Fig. 6).

SEM analysis of approximately 10 000 first bond heel areas before wire pull revealed varying degrees of brittle looking cracks starting at the bottom of the heel area (see Figs. 1–4). Brittle cracks in this area have never been reported to date. Ductile top heel cracks have always been observed in AlSi ultrasonic wire bonding to varying degrees, but they have not been identified as affecting reliability.

The problem is of importance because it has been associated with 3 different machine models, with wire from 4 different vendors, and has involved approximately 6 bonding wedges. The only way to determine if the problem is present, is to SEM the heel areas looking for the brittle structure on the first bond after wire pull (shown in Fig. 5). In most cases (80%) the problem wires are corner bonds approximately 115 mils long.

II. Experimental Method

A. Reproducing the Fatigue Line

The horizontal line in the middle of the first bond heel fracture area was reproduced by cutting the wire at the second bond area (without bonding) and flexing the wire (at the bond heel) through 90-deg excursions (see Figs. 7–11).

Fig. 7 shows no cracking top or bottom as bonded. This wire was bonded with a very low loop height and low ultrasonics to minimize the typical top heel crack. Fig. 8

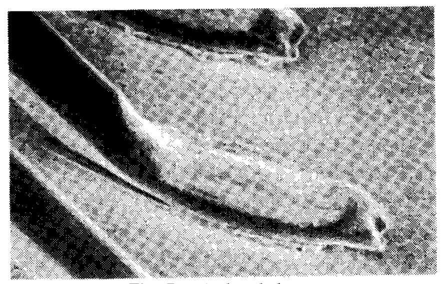


Fig. 7. As bonded.

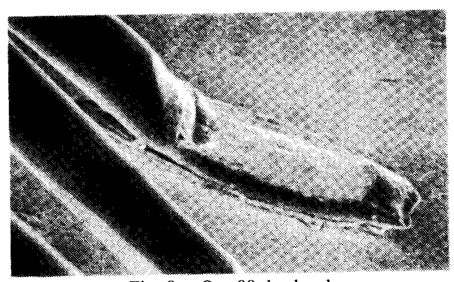


Fig. 8. One 90-deg bend.

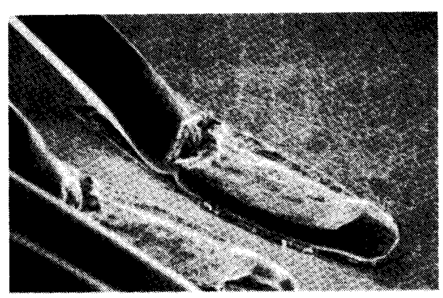


Fig. 9. After the second 90-deg bend.

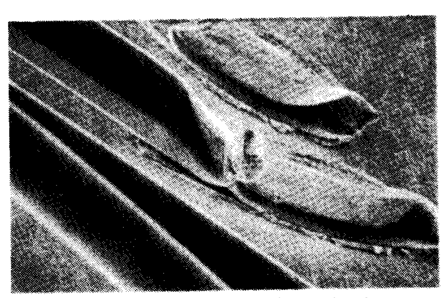


Fig. 10. After the third 90-deg bend.

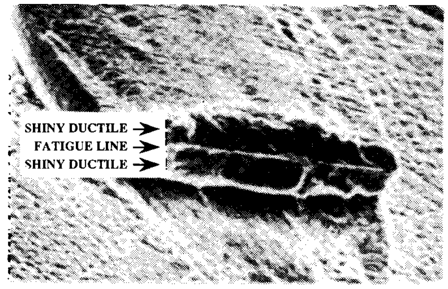


Fig. 11.

shows the typical ductile crack present on AlSi wire in the bond heel area.

This is because under normal bonding conditions, the wire does go through a high amplitude, low frequency excursion during first bond lift off and looping. The second 90-deg bend shows a crack starting at the bottom of the heel (Fig. 9).

The third bend shows the two cracks coming together (Fig. 10) and during the fourth bend the wire broke, leaving a horizontal line through the middle of the first bond fractured area, similar to the problem breaks.

The fractured surface, however, did not have the grainy surface, but was shiny with no elongation. This "paper clip" (breaking of a wire by bending) test suggests that these fractures were a fatigue type failure.

B. Reproducing the Grainy Structure

In order to reproduce the grainy structure and to determine the resonant frequency of the wires, each of the wires in the package was resonated as illustrated in Fig. 12.

A fixed alternating current of 100 MA was passed through the wires over the frequency range of 5–100 kHz. The envelope of mechanical vibrations were observed visually when resonance occurred. Resonant vibrations were found only in the range of approximately 10–15 kHz, depending upon wire length. During the test, several wires fractured, and SEM photographs of their break areas exhibited a grainy fractured surface similar to the structure in the problem wires. These results suggest that low bond pulls were the result of a high frequency, low amplitude fatigue type failure.

Because of the low occurrence and difficulty of reproducing the bottom heel cracks, an experiment was undertaken to determine if ultrasonic bonding energy could cause this type of break on a standard production bonding machine. By physically stopping the tool from compressing the wire during the second bond and applying the ultrasonic energy to the wire, breaks of character similar to the problem fractures occurred. Both the fatigue line and grainy structure were reproduced together with some wires having bottom heel cracks.

III. Photoinstrumentation

The causes of the degradation were investigated experimentally. A high-speed movie taken at 10 000 pictures per second (pps) during second bonding revealed the presence of low amplitude, high frequency wire vibration and "captured" an actual die heel break. To determine the frequency, amplitude and distribution of vibrations along the wires, it was necessary to use an image conversion (IC) camera in the streak recording mode.

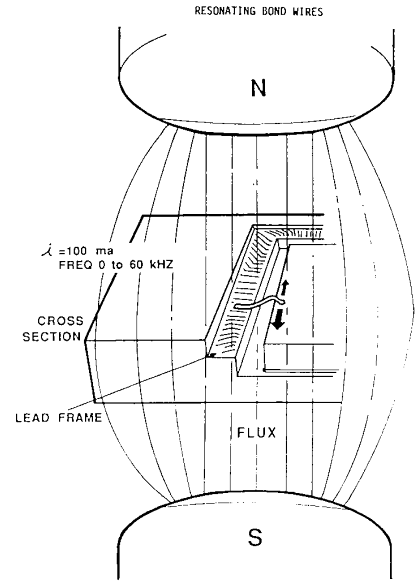


Fig. 12. Material-Al 1% Si. Diameter-0.00125 Height-0.015 in. Length-0.110. Resonance-14 kHz.

The advantage of this electronic camera over a mechanical camera is that there is no inertia at start-up, so that with proper synchronization, the camera is up to speed instantly when the event occurs. The IC camera also is inherently capable of recording at rates far in excess of rotating prism cameras (2×10^6 pps). The camera was synchronized to link the photo record to specific points in time, relative to the application of second bonding energy and to die heel wire breaks when by chance they occurred.

Although photo sequences taken in the framing mode (e.g., movies) are easier for most people to conceptualize, they have long information gaps between successive exposures. Movies require large numbers of frames to be taken at rates which are high compared to the highest mechanical frequency to be resolved. Operation of the IC camera was limited to the streak recording mode which simply produced continuous oscilloscope-like plots of wire movement.

To understand the technique of streak photographic recording, consider that the film in a conventional camera (Fig. 13) "sees" only a single point of interest along the length of the wire through a narrow slit.

The image of the rest of the wire is shielded from view. If the film is moved horizontally across the back of the camera as the wire moves up and down, the continuous exposure record shown will be produced.

Fig. 14 is a schematic diagram illustrating how the image conversion camera makes a streak recording.

The image of the visible element of wire passes through the objective lens and falls onto the photocathode where it liberates electrons. These electrons are accelerated toward a phosphor screen which converts their energy back into a

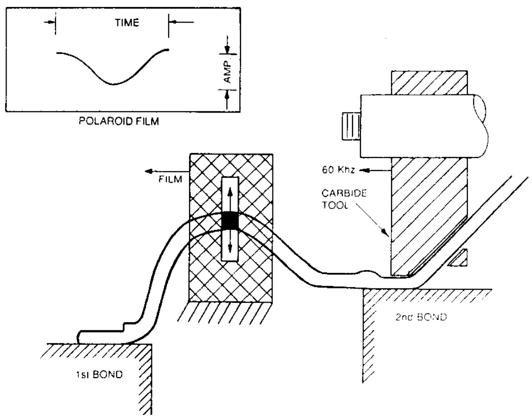


Fig. 13. Streak photography.

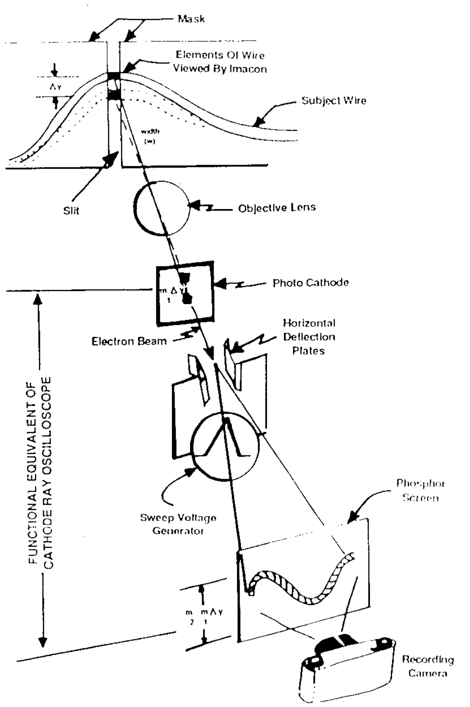


Fig. 14. Streak photography IMACON camera.

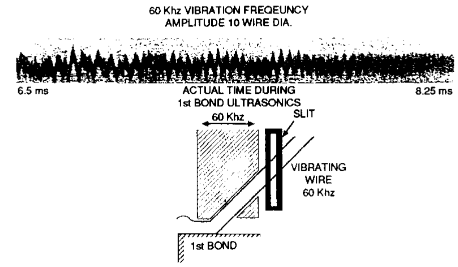


Fig. 15. Vibration on wire at the heel of the first bond during ultrasonics of the first bond.

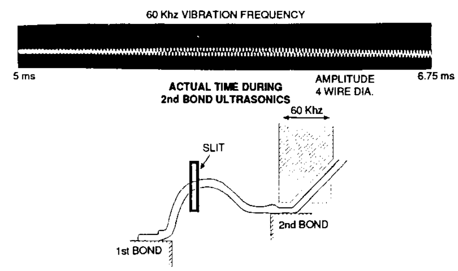


Fig. 16. Vibration on wire near the heel of the first bond as the second bond ultrasonic is being applied.

point of light. A ramp of voltage applied to the deflection plates linearly sweeps the electrons horizontally across the phosphor screen. The electrons will also have vertical motion due to wire vibration. The combined motions "paint" a continuous path on the screen. As with the oscilloscope, this electronic camera may be triggered precisely to "catch" the desired moment during the event (application of ultrasonic energy). Standard film is used to record the result of the single sweep.

A. Electronic Camera

The total optical magnification for the Imacon camera was 32X. A 20X Leitz metallographic objective was employed for its long working distance from the wire (to clear the obstruction of the ceramic package). The length of the streak record (width of the phosphor screen) is 70 mm, and the IC tube has an optical magnification of 2.0. The width of the screen image is, therefore, twice the slit width. The narrowest available slit is 0.001 in (25 μm), or approximately 0.07% of the trace length. This equates to an ability to resolve approximately 140 cycles of 60-kHz vibration at the slowest sweep speed of 100 μs/mm. Resolution of the IC tube is approximately 12 line pairs per millimeter, about 5 times greater than our worst-case requirement. We could readily identify 60-kHz vibrations at extremely low amplitude (approximately 0.001-in peak-to-peak.) at the slowest sweep speed. The highest speed employed was 25 μs/mm.

B. Electronic Camera Results

The streak plot in Fig. 15 illustrates the very high amplitude wire motion (approximately 10 wire diameters) which occurs behind the tool during the application of the first bond ultrasonic energy.

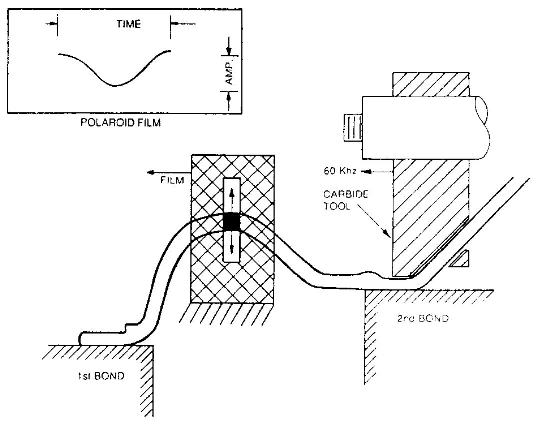
Fig. 16 is illustrative of the 60-kHz vibration having an amplitude of approximately 4 wire diameters in the vertical direction which is observed all along the wire during the second bond.

No vibration nodes were found along the wire. The vibrations can be found quite close to the heel. The vibrations during the first and second bond are considered the major contributing factors in brittled heel breaks.

The record in Fig. 17 illustrates that no 60-kHz energy is present on the wire, or applied to the die heel, when the wire is suitably decoupled from the bond ultrasonics.

IV. Discussion

Low wire bond pulls, and therefore, detected brittle fractures, appear to occur only sporadically, but then in groups



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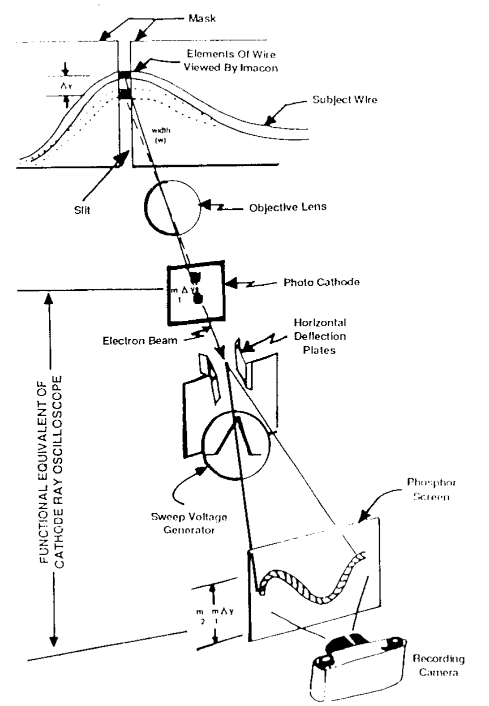

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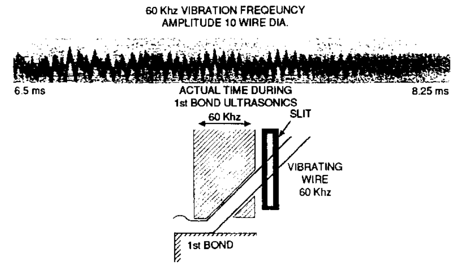

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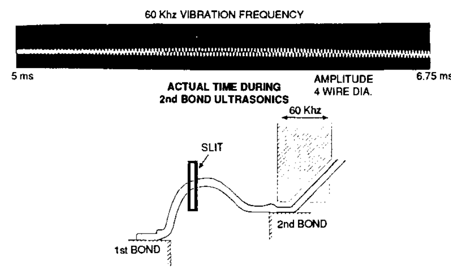

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