Brittle Cracks Induced in AlSi Wire by the Ultrasonic Bonding Tool

BRITTLE CRACKS INDUCED IN AlSi WIRE BY
THE ULTRASONIC BONDING TOOL

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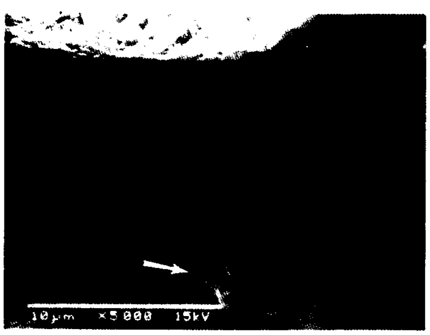
BACKGROUND

A small but statistically significant number of die heel breaks in the 0.1 to 0.3g range were found on 1 1/4 mil Al, 1% Si wire. These were found on 68 lead cerquad high-reliability integrated circuits at two different assembly houses. Pull strengths of four to five grams are normal for these annealed wires.

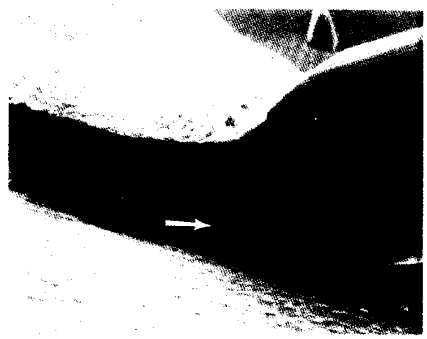
The wires with low bond pull strengths had all passed Mil Std 883 visual criteria, temperature cycling (-65 C to + 175 C), and burn-in (125 C for one week), yet were observed to have varying degrees of die heel cracks after bonding (Figures 1-4).

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

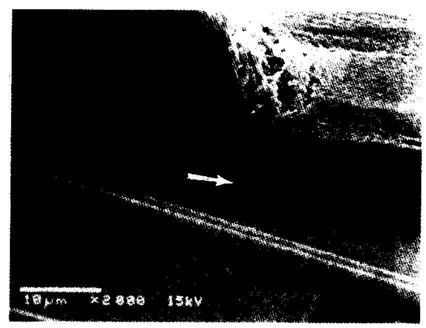
WORST CASE
BRITTLE FRACTURE
0.2 gf DIE HEEL BREAK
FIGURE 1



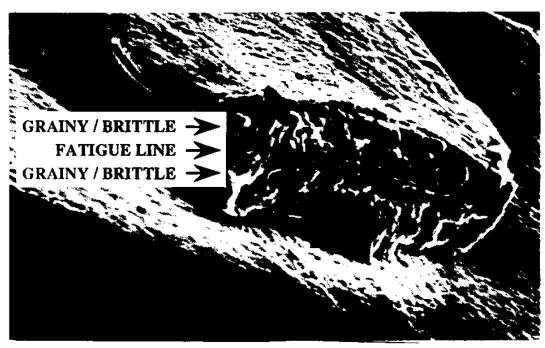
.5 mil CRACK
FIGURE 2



.3 mil CRACK
FIGURE 3



CRACK STARTING
FIGURE 4



BRITTLE DIE HEEL BREAK
FIGURE 5

All the fracture surfaces of the normal pulls had an overall ductile elongated and shiny appearance (Figure 6).

The causes of the degradation were investigated experimentally. A high-speed movie taken at 10,000 pictures-per-second

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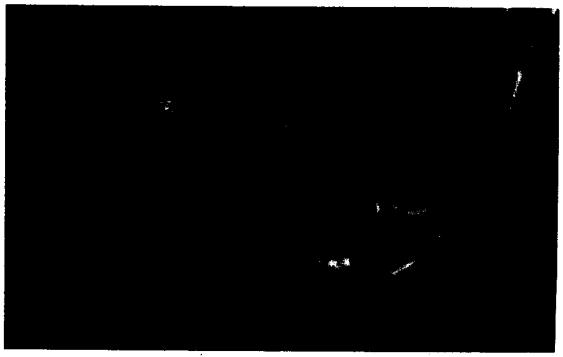


NORMAL DUCTILE DIE HEEL BREAK
FIGURE 6

(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.

Considerable 60 kHz vibration is consistently present at the die heel during second bonding. 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 1st bond area and can create the possibility of embrittlement, leading to heel cracks either visible or hidden. We conclude that die heel damage is induced to a varying degree in every wire, and that any crack on the bottom of a 1st bond heel is a potential reliability problem.

ANALYSIS OF WIRE BREAKS

The wires with low pull strengths (< 1.0 g) were all observed to have the same appearance at the die heel fracture on the 1st bond. They all had a brittle grainy structure with a thin horizontal middle line (Figure 5). In contrast, the normal pulls had a shiny ductile surface with good taffy-like elongation (Figure 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 Figure 1-4). Brittle cracks in this area have never been reported to date. Ductile top heel cracks always have been observed in AlSi ultrasonic wire bonding to varying degrees, but they have not been identified as affecting reliability.

OCCURRENCE OF THE PROBLEM

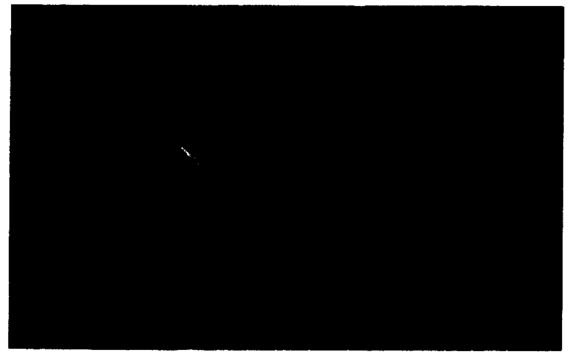
At the two manufacturing facilities where these brittle fractures were discovered, the wires with low pull strengths were erroneously explained as failing because of mechanical damage or wire pulling errors because of their low occurrence (approximately 1 wire in 10,000).

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 Figure 5).

INVESTIGATION

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 degree excursions (see Figure 7-11).



AS BONDED
FIGURE 7

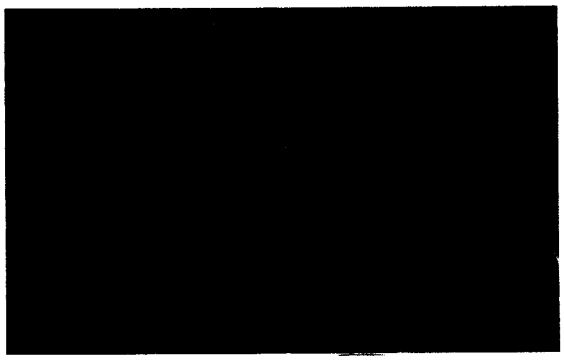
Figure 7 shows no cracking top or bottom as bonded, but Figure 8 shows the typical ductile crack present on AlSi wire in the bond heel area

ONE 90 BEND
FIGURE 8

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 degree bend shows a crack starting at the bottom of the heel (Figure 9).

The third bend shows the two cracks coming together (Figure 10) and during the 4th bend the wire broke, leaving a horizontal line through the middle of the first bond fractured area similar to the problem breaks.

AFTER SECOND 90° BEND
FIGURE 9



AFTER THIRD 90° BEND
FIGURE 10

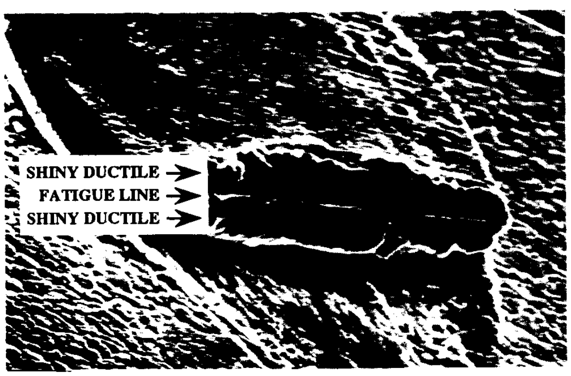


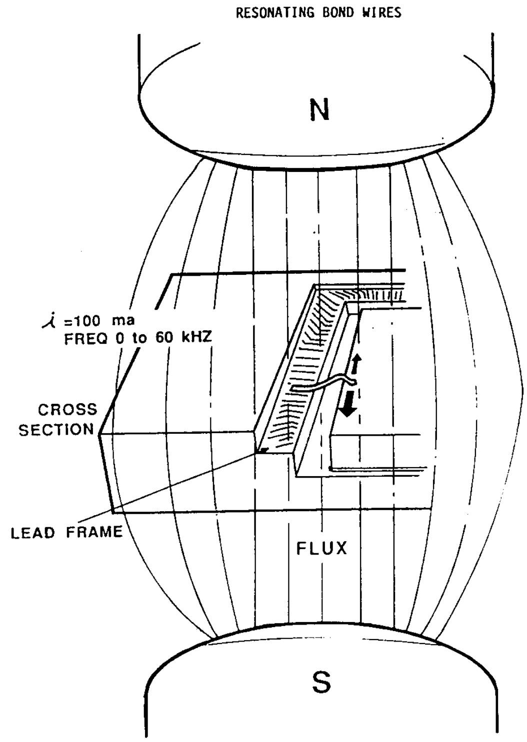
FIGURE 11

The fractured surface, however, did not have the grainy surface, but was shiny with no elongation. This "paper clip test" showed that these fractures were a fatigue type failure.

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 Figure 12.

A fixed alternating current of 100 mA was passed through the wires over the frequency range of 5 to 100 kHz. The envelope



MATERIAL - Al 1% Si
DIAMETER - .00125
HEIGHT - .015"
LENGTH - .110
RESONANCE - 14 KHZ

FIGURE 12

of mechanical vibrations visually were observed when resonance occurred. Resonant vibrations were found only in the range of approximately 14 +/- 2 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 show 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.

PHOTOINSTRUMENTATION

High-speed mechanical movie cameras first were employed at 500 PPS and 10,000 PPS during ultrasonic stimulation. The filming attempted to determine if the problem was resonant or forced vibration which caused the brittle die heel breaks. The amplitude of the vibrating wires was recorded at both rates, but the frequency could not be determined.

In order to satisfactorily resolve the vibrating wire frequency it was necessary to employ an IC camera. 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.

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 (Figure 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.

Figure 14 is a schematic diagram illustrating how the IC 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 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.

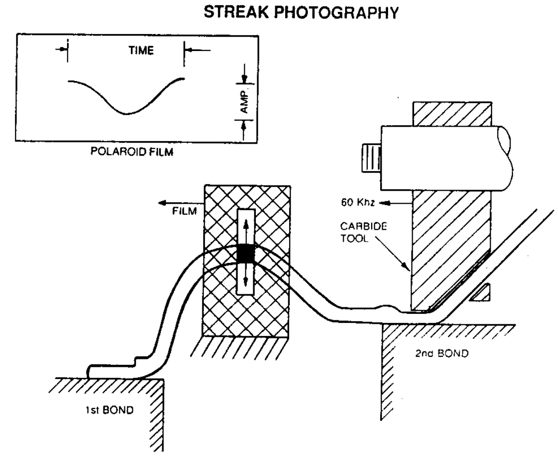


FIGURE 13

STREAK PHOTOGRAPHY IMACON CAMERA

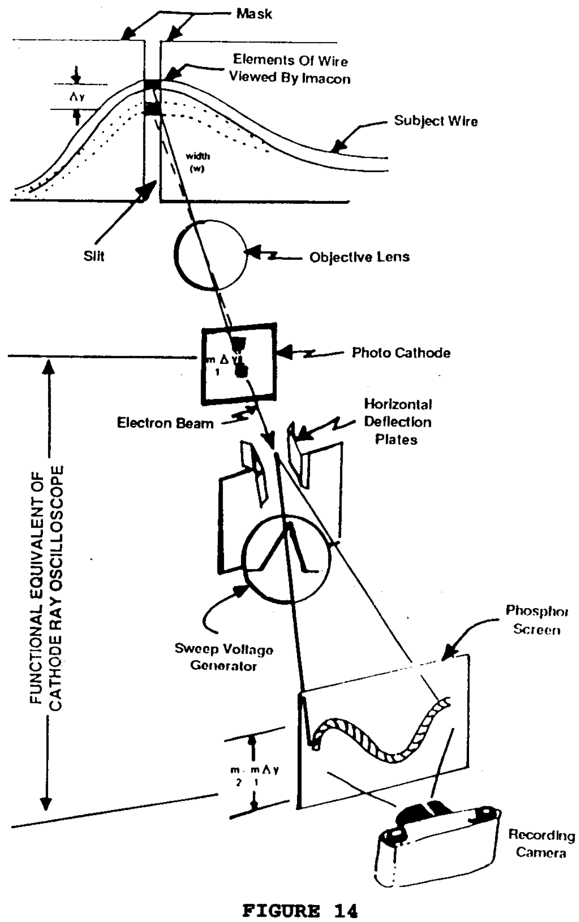


FIGURE 14

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" (25 micrometers), 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 microseconds/mm. Resolution of the IC tube is approximately 12 line-pairs-per mm, about 5 times greater than our worst-case requirement. We could readily identify 60 kHz vibrations at extremely low amplitude (approximately 0.001" peak-to-peak) at the slowest sweep speed. The highest speed employed was 25 microseconds-per-mm.

ELECTRONIC CAMERA RESULTS

The streak plot in Figure 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.

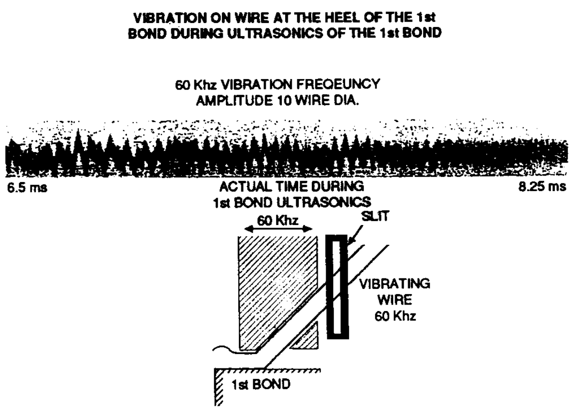


FIGURE 15

Figure 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.

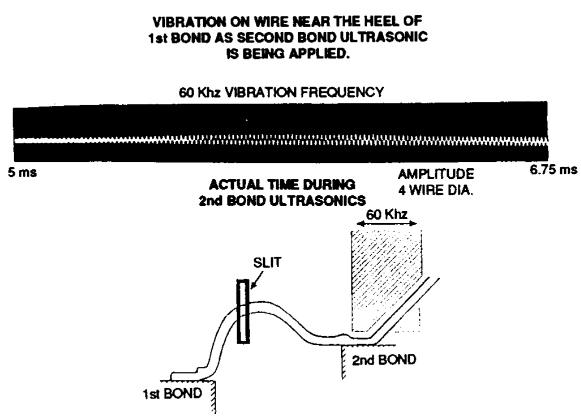


FIGURE 16

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 brittle die heel breaks.

The record in Figure 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.

The wire demonstrates this same decoupling when adjacent wires are bonded, another indication that only 60 kHz during bonding produces the first bond embrittlement.

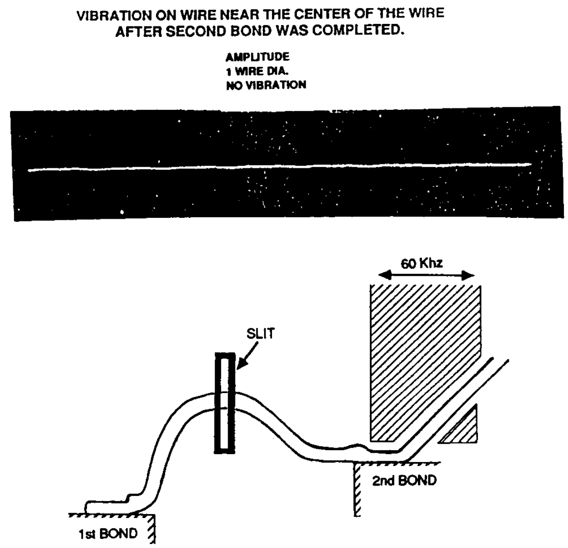


FIGURE 17

DISCUSSION

Low wire bond pulls, and therefore detected brittle fractures, appear to occur only sporadically, but then in groups of significant numbers of units. It is postulated that the low wire bond pull strengths are the result of fatigue at the die heel due to the interaction of bending of the wire during looping and of high frequency, low amplitude ultrasonic vibration during first and second bonding.

The electronic camera showed considerable 60 kHz vibration is present at the die heel during first and second bonding. 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 1st bond area and can create the possibility of embrittlement, leading to hidden heel cracks. It is felt that the considerable 60 kHz energy transmitted from the ultrasonics bond to the die heel makes a major contribution. It produces the requisite vertical wire flexure to account for most of the brittle fracture and for the formation of the "hinge" always found in the SEM photographs. It does NOT appear that the die heel is embrittled during the bonding of adjacent wires.

We conclude that die heel damage is induced by ultrasonic bonding to a varying degree in every wire, and that any crack on the bottom of a 1st bond heel is a potential reliability problem.