IeMRC Annual Conference 2012

“Wire Bonding Integrity Assessment for Combined Extreme Environments”

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Outline

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- Research Focus
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  - Experimental Approach
  - Test Samples & Wire Bonding
  - Wire Bonding Characteristics
  - Experimental Design
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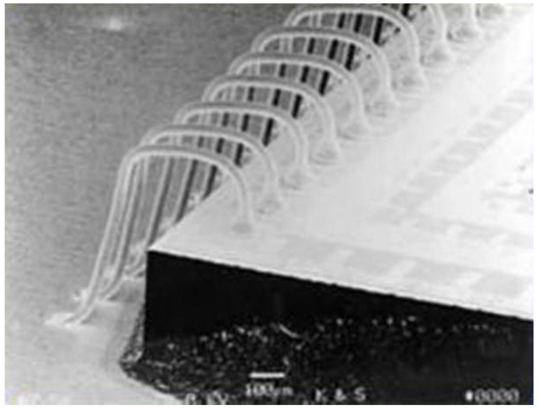
- Acknowledgements

Background

Wire bonding:

- 40 years of reliability background.
- Harsh environment applications raise concerns about reliability under combined extreme loadings.
- New industry requirements



Problem Identification

- **The main concerns in assembly and packaging:**
  - **Low cost**
  - **Small size**
  - **Functional density**
  - **Integration density**
- **Fundamentals of failure under complex and harsh conditions**

Unit to compare	Best	Middle	Worst
Cost	WB	-	FC, TAB
Manufacturability	WB	FC*	TAB**
Flexibility for changes	WB	-	FC, TAB
Reliability	FC	WB, TAB	-
Performance	FC	TAB	WB, TAB

Major Interconnection Technology Comparison[1]

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[1] Harman, G., "Wire bonding in microelectronics – materials, processes, reliability and yield", McGraw-Hill, 2nd Edition, 1997

***Flip Chip**

****Tape-automated bonding**

Research Focus

The effects of combined thermal and vibration loadings on wire bonding performance - the rational:

- **Temperature and vibration are prime causes of failure within electronic circuits.**
- **Research on behaviour of wire bonded devices limited only in normal operation conditions.**
- **Knowledge gap in testing and qualification of electronics under combined harsh conditions.**
- **Wire bonding performance under those combined conditions has not been fully characterised.**

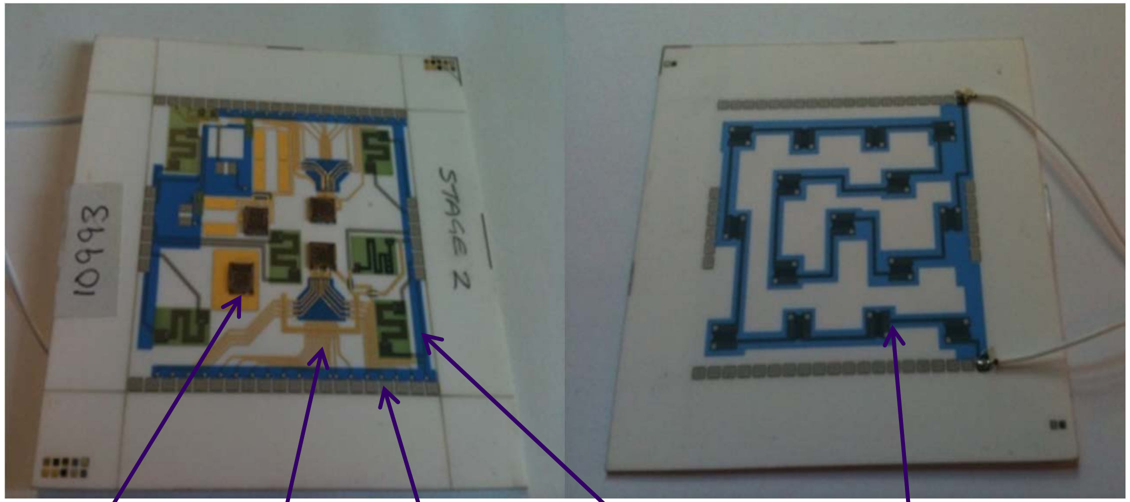
Experimental Approach

- **Investigation of:**
  1. Bond strength & mechanical integrity
  2. Electrical resistivity changes
  3. Microstructural defects induced
  4. Wire orientation role on wire degradation
  5. How loop geometry is affected by the conditions applied

- **Analysis methods:**
  1. Wire pull & ball shear testing
  2. Electrical resistance measurements
  3. Metallographic observation

Test Samples & Wire Bonding

Alumina (Al_20_3) ceramic substrates with interconnected components and embedded heating element



Silicon chips

Heating element

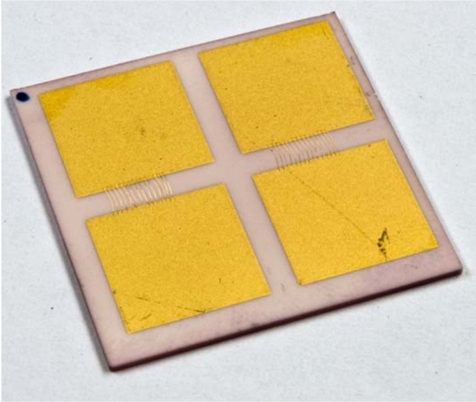
Au thick film conductor tracks

Thick film resistor sensors

Pd-Ag solder connection pads

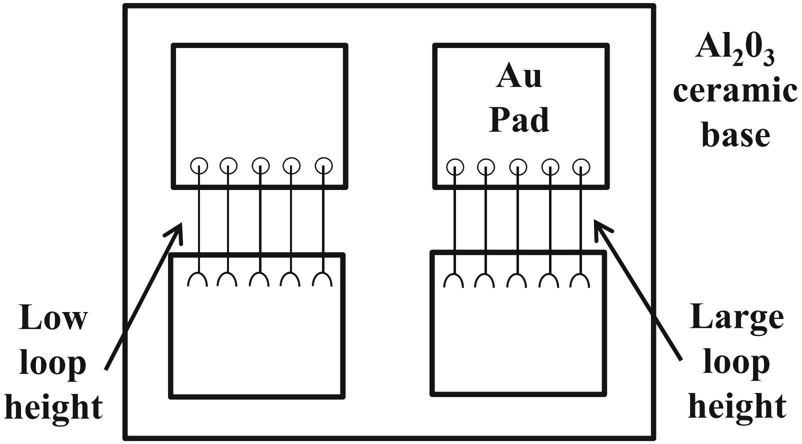
Test Samples & Wire Bonding

Al_2O_3 Ceramic Substrates with Au thick film pads



Wire Bonding:

- Au ball-wedge bonding.
- The gold pads were wire bonded by pairs of two: one pair using low loop height and, one using a larger loop height

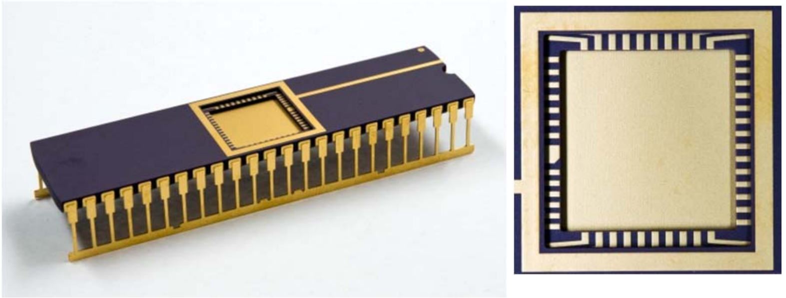


a) *b)*

Schematic representation of the two wire bonding profiles for the a) low loop height and, b) large loop height.

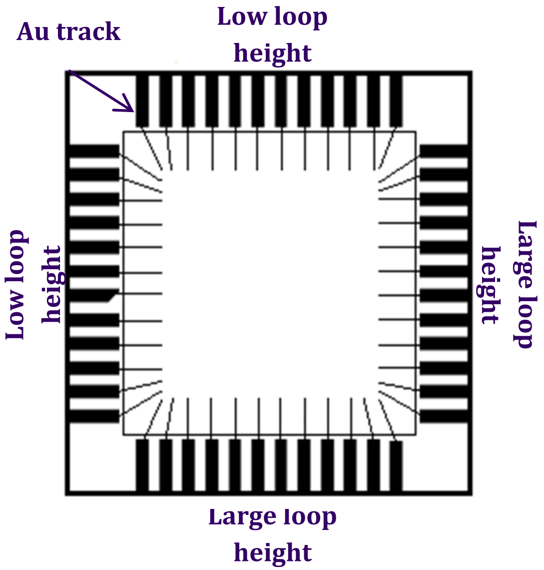
Test Samples & Wire Bonding

48-pin Dual-in-line (DIL) High Temperature Co-fired Ceramic (HTCC)



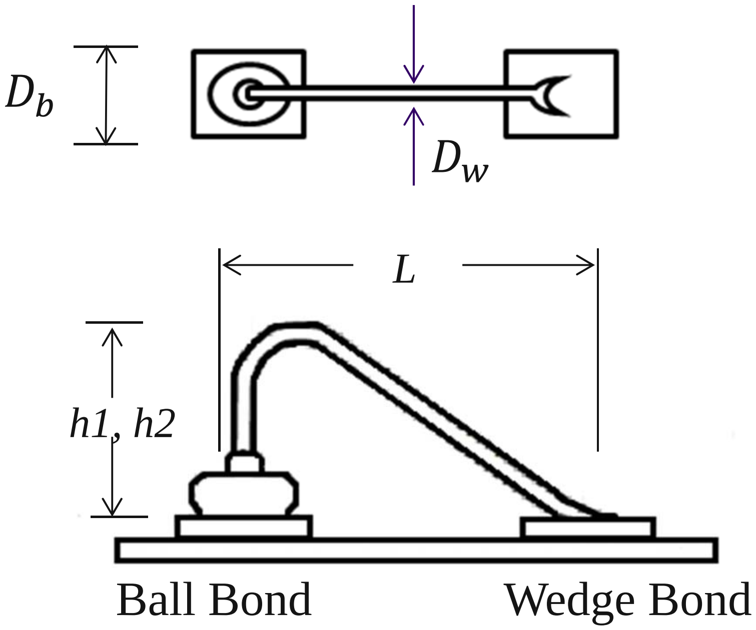
Wire Bonding:

- Au ball-wedge bonding
- Two wire loop heights
- X & Y direction wire bonding to allow testing on two axes at the same time



Schematic representation of the wire bonding profile for the two loop heights

Wire Bonding Characteristics



Schematic representation of the wire bonding structure, a) top view and, b) side view.

Description	
Wire Diameter ()	25 µm
Ball Diameter ()	75 µm
Low Loop (h1)	~200 µm
Large Loop (h2)	~300 µm
Pitch size	300 µm
Distance between ball & wedge bond (L)	2000 - 2300 µm

Wire bonding characteristics

Experimental Design

Phase 1:
Understanding the parameters

TEST 1:

(verification of the testing system)

Stage 1:

Thermal Test ONLY:

Elevated temperature up to 180°C*

Stage 2:

Vibration Test ONLY:

- **Sine fixed frequency at 300Hz**
- **Acceleration at 10g rms**

TEST 2:

(combined thermal & vibration test)

Stage 1:

- **Elevated temperature up to 180°C.**
- **Sine fixed frequency at 500Hz.**
- **Acceleration at 10g rms.**

Stage 2:

- **Elevated temperature up to 180°C.**
- **Sine fixed frequency at 1500Hz.**
- **Acceleration at 20g rms.**

Stage 3:

- **Elevated temperature up to 180°C.**
- **Sine fixed frequency at 2000Hz.**
- **Acceleration at 20g rms.**

***Temperature increase by power input**

Experimental Design

Phase 2: Factorial design

Test replicates and duration:

- **Each test replicated 3 times (one for each axes)**
- **Total duration of each test: 3 hours**

	Process Parameter Level		
Run No.	Temp.	Freq.	Accel.
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	-
7	-	+	+
8	+	+	+

Orthogonal Array and Control Factors Assignment

The design consists of 3 factors each at 2 different levels:

Each level (high (+) and low (-)) of the factors represented as follows:

- **Temperature level: 250°C (+) and 180°C (-)**
- **Frequency level: 2000 Hz (+) and 500 Hz (-)**
- **Acceleration level: 20 G (+) and 10 G (-)**

Experimental Design

Phase 3: ***High temperature-vibration testing based on Aviation Standards***

Stage 1

Temperature exposure at 25°C, 180°C and, 250°C (3 hours)

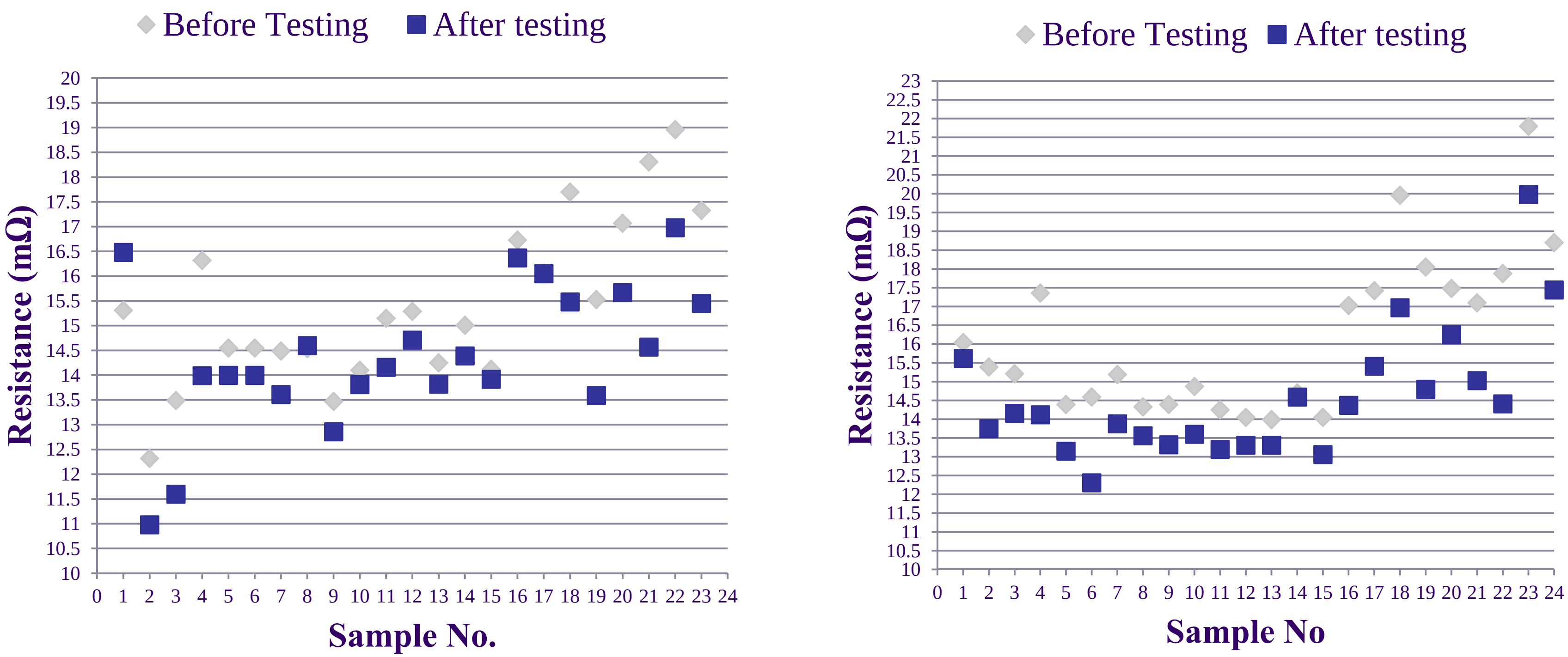
Stage 2

Sinusoidal vibration testing (vibration test procedure for airborne equipment)

Stage 3

Temperature exposure (25°C, 180°C, 250°C) (3 hours) & sinusoidal vibration testing (3 axes)

Electrical Characterization



a) **b)**

Electrical resistance changes for the a) low loop and, b) the large loop wires before (♦) and after (■) testing

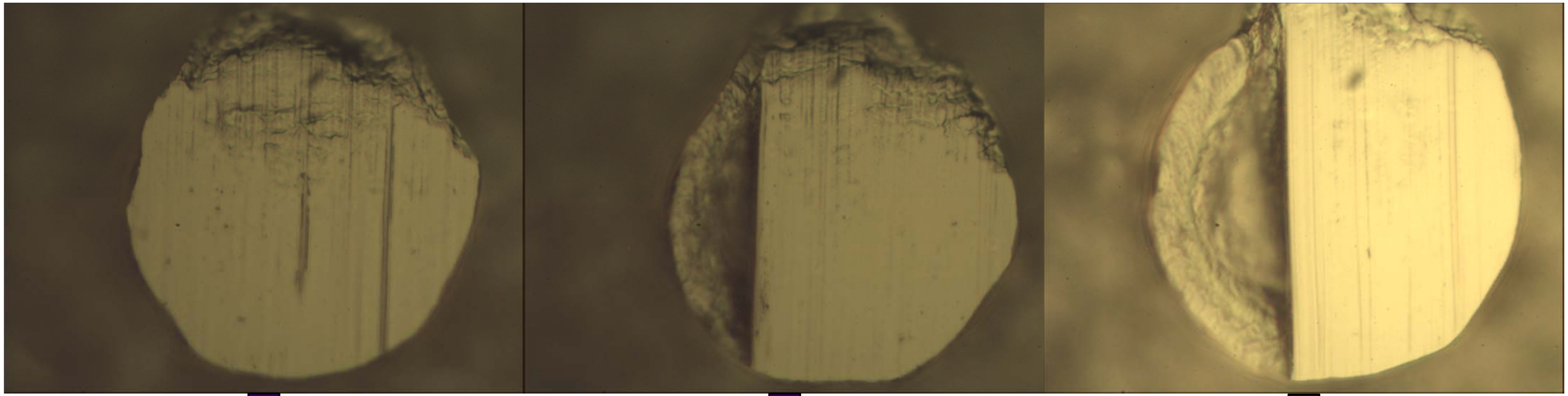
Bond Strength

Wire Orientation on the Vibration System	Ball Bond Shear Failure Load, grms	120°C 500Hz 10grms	250°C 500Hz 10grms	120°C 2000Hz 10grms	250°C 2000Hz 10grms	120°C 500Hz 20grms	250°C 500Hz 20grms	120°C 2000Hz 20grms	250°C 2000Hz 20grms
Y	Mean	48.73	**32.03**	49.61	42.50	49.25	**37.28**	50.46	50.85
	SD	8.63	3.00	10.92	9.87	12.50	15.82	8.32	16.78
X	Mean	50.26	**30.13**	56.92	44.29	47.07	**28.72**	51.06	44.48
	SD	8.08	3.07	2.54	13.74	12.45	6.13	8.78	15.78
Z	Mean	43.61	**41.92**	54.55	40.49	58.16	**32.97**	53.39	44.53
	SD	11.35	9.36	4.66	10.80	2.34	9.38	4.06	14.36
All bonds	Mean	47.38	**34.98**	53.73	42.35	51.76	**32.99**	51.70	46.54
	SD	9.62	7.96	7.30	11.17	10.84	11.20	7.06	15.25

Shear load mean values and standard deviation for bonds after testing – MIL-STD 883H

Metallographic Observations

Observations from failed balls after shear testing



Ball shear	**Ball shear and partial ball lift off**	**Ball shear and partial metallization lift off**
Observed in all cases	**After testing at:** 250°C, 500 Hz, both 10G and 20 G	

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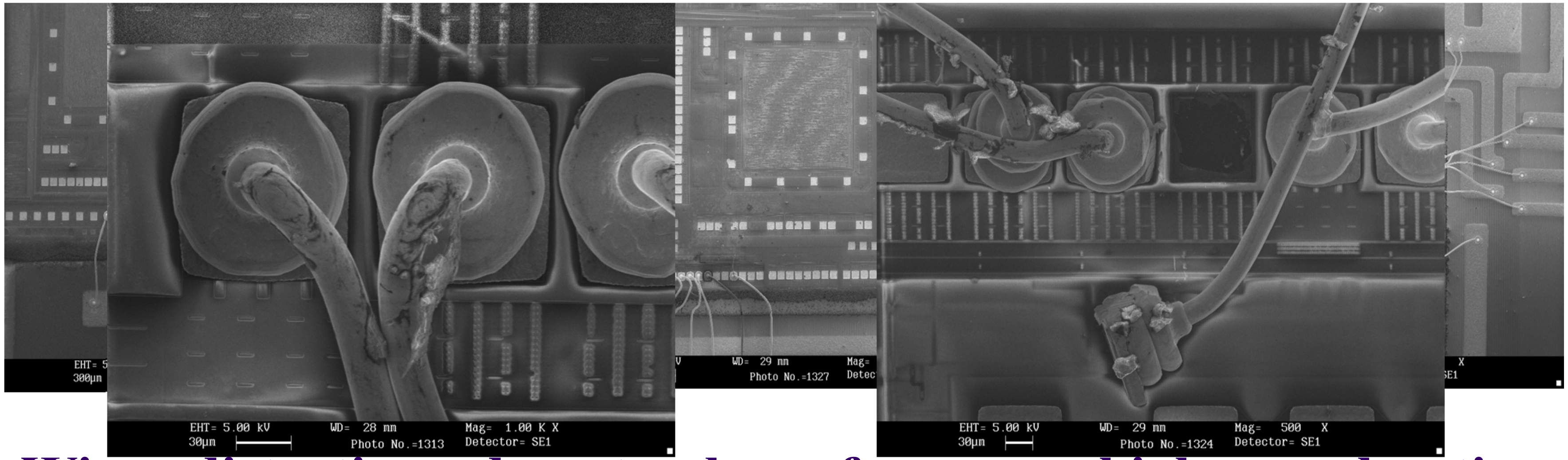
Metallographic Observations

SEM analysis of failed bonds & wires



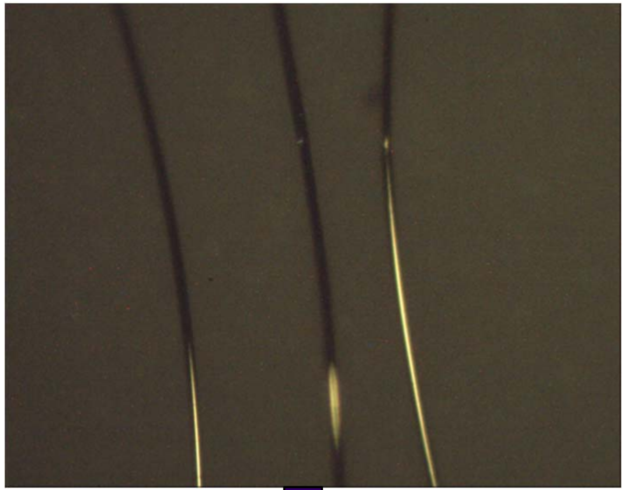
Wire distortion due to low frequency-high acceleration vibration loading combined with high temperature at 250°C

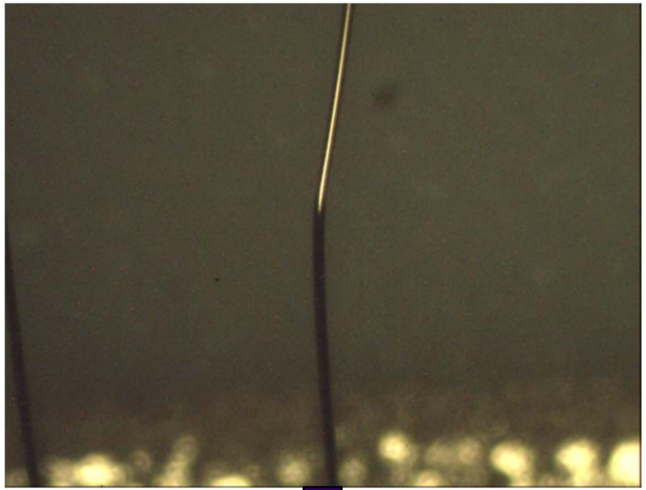
Failure associated with short circuiting

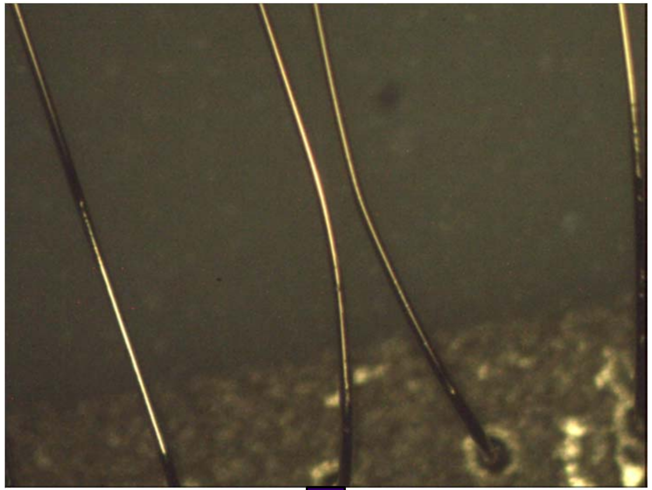
Interconnection failure on the silicon chip

Metallographic Observations

Observations from deformed wires after testing



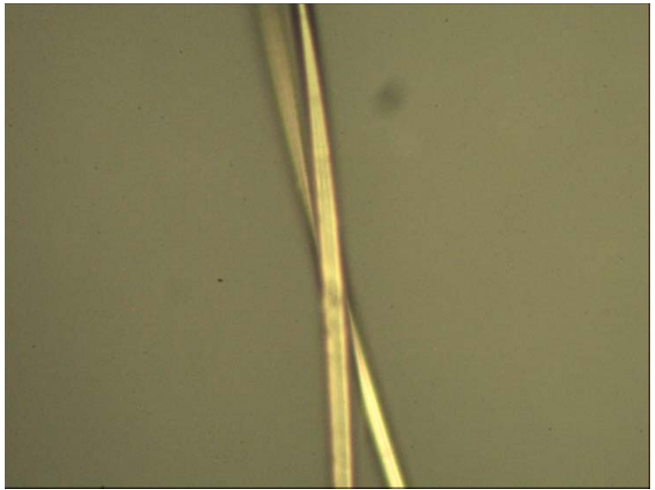




Wires tangled to one direction	**Wire bend**	**Wires tangled sideways**
➢ X axis orientation ➢ 250°C and 120°C ➢ 500 Hz ➢ Both 10G and 20 G	➢ Y axis orientation ➢ 250°C ➢ 500 Hz ➢ 20 G	➢ Z axis orientation ➢ 250°C ➢ 500 Hz ➢ Both 10G and 20 G

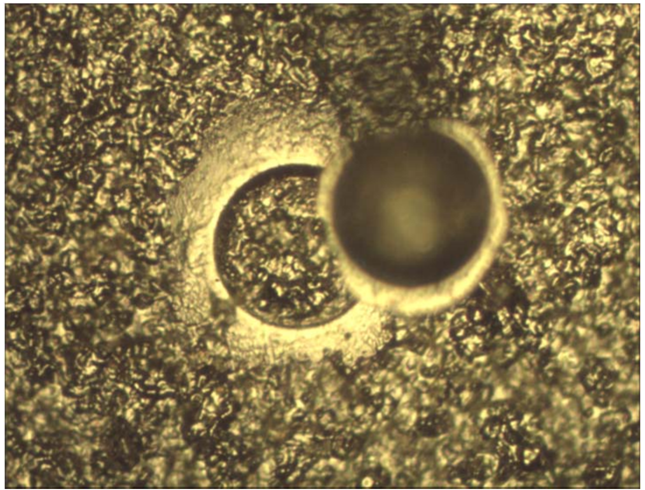
Metallographic Observations

Observations from deformed wires after testing



Short circuit

- X axis orientation
- 250°C
- 500 Hz
- 20 G



Ball lift off

- X & Z axes orientation
- 250°C
- 500 Hz
- Both 10 and 20 G

Conclusions

- **The findings of this study on Au ball bonded devices include:**
  - **An appreciable decrease in the electrical resistance after testing which could be attributed to annealing of the wire.**
  - **The shear force to failure of the ball bonds is reduced after testing particularly at higher temperature and low frequency vibration.**
  - **Distortion of the larger wire loops is more severe when testing at low frequencies.**
  - **The effect of wire orientation in respect to the direction of the vibration should be considered when vibration is involved in the testing regime.**

Conclusions

- Further tests are planned to extend the vibration/temperature regime and also to examine the effect on wire bond pull strengths, where annealing of the wire above the ball bond may result in changes in performance under combined vibration/temperature conditions.

- On real devices, the combined vibration/temperature exposure needs to be extended to generate end of life failure modes, where changes in electrical characteristics can be measured and failure analysis undertaken.

Acknowledgements

- ***GE Aviation Systems*** **(Newmarket, UK) for providing the testing samples and valuable technical guidance.**
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Thank you
Any Questions?

Loughborough University

GE Aviation