Fine Pitch Copper Wire Bonding Process and Materials Study

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Abstract:

Over the years, the maturity of copper wire bonding using (38um and 50um wire diameter) process for mass production mode has demonstrated a great deal of success for standard (non-fine pitch) packages like discrete and power devices having a copper (Cu) bond- aluminum (Al) metallization interface. The advantages of switching from gold (Au) to Cu aside for cost saving reasons, are its higher electrical conductivity characteristics, and its resistant to wire sweeping during molding as Cu has a higher Young's modulus than Au.

In recent months, a great deal of interest from various new package research and development group from the semiconductor industry have included in their future roadmaps directed towards the development of a new copper wire bonding process for fine pitch type of application.

The intent of this study is to establish a basic understanding of its process and materials used as applied to fine pitch type of leadframe and BGA substrate based packages. The study has shown the utilization of advanced wire bonder copper capability, selection of suitable copper wire and capillary design in total synergy to develop a complete process. Furthermore, the study also identifies areas for further development and improvement of Cu wire bonding for fine pitch application.

Introduction:

Two commonly used package types were covered in this study. The two packages were 225 BGA and 100QFP. The main intention is to develop a viable fine pitch copper wire bonding process for these packages. Special emphasis is placed on the second bond. The bonding material of the second bond surface is gold plating over nickel over copper for BGA. The 100QFP has silver spot plating on copper leadframe.

Objective:

To establish a working ultra fine pitch copper wire bonding process for BGA and leadframe package applications.

Physical Characteristics of Copper and Gold Material:

The main advantage of copper wire over gold wire is higher Young Modulus and lower electrical resistivity.

Item	Unit	Copper	Gold
Symbol	-	Cu	Au
Atomic Number	-	29	79
Atomic Weight	-	63.546	196.967
Crystalline Structure	-	fcc	fcc
Lattice Constant	Angstrom	3.6147	4.0785
Melting Point	°C	1083.45	1063.15
Boiling Point	°C	2582	2710
Density	g/cm3	8.93	19.32
Electrical Resistivity	μΩcm	1.69	2.3

Thermal Conductivity	W/mK	394	293
Coefficient of Linear Expansion	10-6/K	16.6	14.2
Tensile Strength	MPa	240	230
Young Modulus	10^{10}N/m2	13.6	8.8
Elongation	%	15.0	4.5

Table of physical characteristics of copper and gold based on 30µm. wire diameter

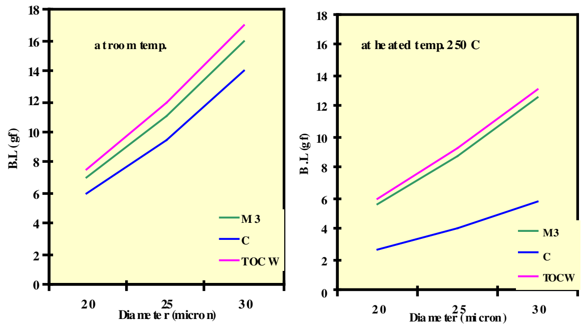
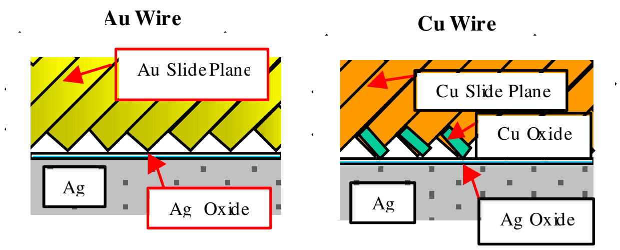


Chart of mechanical properties comparing Cu wire with a range of widely use Au wire types

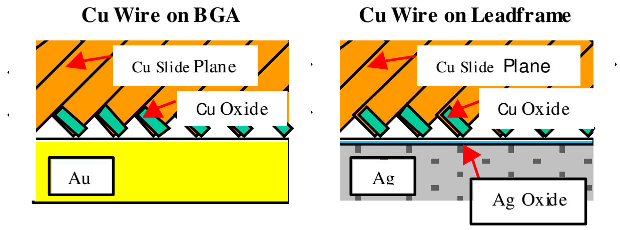
Second Bond Mechanism Comparison Between Copper and Gold:

Gold wire welds readily onto the second bond upon application of force and ultrasonic energy. However this is not the case for copper wire. The copper wire in an unopened sealed spool already has a thin layer of copper oxide on the surface. This copper oxide retards the second bond welding.

This problem is further complicated in fine pitch wire bonding requirements. As the bond pad pitch gets smaller there is very little room for the capillary tip between adjacent bonded wire. As a result the capillary tip has to be reduced to prevent the capillary from touching the adjacent wire. The reduction in the capillary tip reduces the total area available to form a strong stitch.



Stitch Bond comparison between Au wire and Cu wire onto silver plated leadframe



Stitch Bond comparison between Cu wire bonding onto Au plated BGA substrate and Au spot plated leadframe

Copper Wire Bonding Capillary:

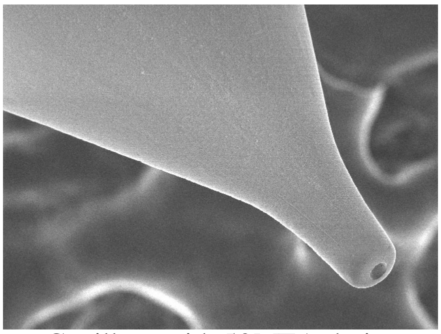
The capillary design selection process for ultra- fine pitch copper wire-bonding application did not encounter much difficulty as it is also dictated by the following- the bond pad pitch (BPP), bond pad opening (BPO), and wire diameter (WD)- basically, the same consideration is applied as in gold wire ultra-fine pitch bonding. Consequently, the capillary geometrical considerations for the copper wire bonding affecting the bonded ball diameter, and stitch are also similar to that of the gold wire- except that proper face angle and outer radius design combination are essential to provide optimum stitch formation and reliability. (See Table below)

● Highly Sensitive ◉ Slightly Sensitive ○ No Effect

Capillary/ Response	H	CD	CA	FA	OR	T
Ball Size	●	●	◉	○	○	○
Ball Shear	◉	●	◉	○	○	○
Stitch Length	○	●	○	○	○	●
Pull Strength	○	◉	○	●	●	●
Pitch Distance	○	○	○	○	○	●
Looping	●	○	○	○	○	○

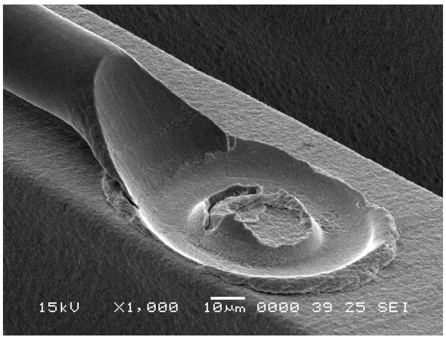
Interaction of the capillary design with respect to the actual bonding response

The 50MTA (main taper angle) design provides the stability in the transfer of ultrasonic energy- to achieve consistent mashed ball diameter, and good stitch formation.



Capillary with 50MTA design

Previous studies of ultra-fine pitch copper wire bonding showed consistency in the mashed ball diameter (MBD) formation is achievable. However, it showed some reliability concerns in the formation of the stitch- as it is barely sticking into the leadframe or substrate. Further increase in the application of the bond power and bond force will create deterioration of the stitch reliability.



Stitch bond with increased bond power and force

With the proper geometrical design combination of capillary's outer radius and face angle and the new feature of the ASM wire bonder's –SBE (stitch bond enhancer), this issue has been addressed and resolved.

Wire Bonder Set up:

A standard wire bonder AB339 retrofitted with a simple copper wire bonding kit was used. The copper bonding kit consisted of a nitrogen nozzle fixture at the FAB (free air ball) formation area and a flow meter for inert gas.

The composition of the pre-mix inert gas used is 95%N2 with 5%H2. This is a commonly available gas from main gas suppliers and is non- explosive. It is below the lower explosive limit of H2. The main purpose is to form an inert gas shroud around the copper tail and the FAB to prevent oxidation prior to bonding. An optimized flow rate of 0.3-0.5 l/min was used.

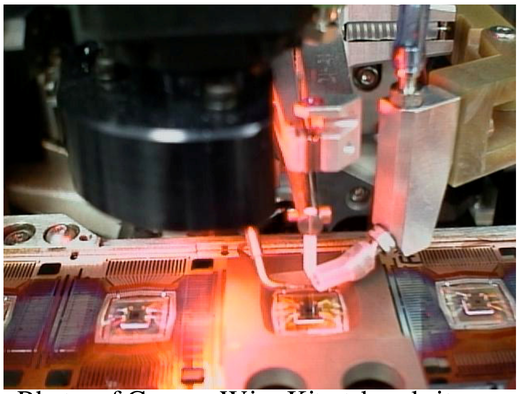


Photo of Copper Wire Kit at bond site on AB339 wire bonder

Materials for 70µm Bond Pad Pitch on BGA:

Test die used is ASM2000 with AlSiCu metallization. BGA substrate used is 225BGA, a commonly available substrate with gold over nickel plating finish. Copper wire used is 1.0 mil copper wire type TOCW from Tanaka with elongation of 6% up and a breaking load of 8-16g. Capillary used is SBNS-30AB-AZM-1/16, H12, CD16, T3.5 from SPT. Transducer used is the standard high frequency 138kHz of AB339.

Both the pre-heat and the bond site temperature was set at 130 deg C. This is significantly below the Tg (glass transition) temperature of BT resin material. Optical microscope, wire pull tester and shear tester used were Hisomet Union, Unitek micropull and Royce 550 respectively.

Results for 70µm Bond Pad Pitch on BGA:

Bond Quality	Min.	Max.	Mean.	Std. Dev.	Sample Size
Ball Size (mil.)	2.18	2.32	2.26	0.025	40
Ball Height (µm)	13.2	15.5	14.3	0.65	40
Loop Height (mil.)	6.15	6.95	6.6	0.25	40
Ball Shear (g.)	23.9	29.9	26.5	1.62	40
Stitch Pull (g.)	4.8	7.6	6.5	0.72	40

Mean Shear gm/mil^2 6.66

SEM Photos of 70µm BPP on BGA:
(See Appendix A)

Materials for 70µm Bond Pad Pitch on Leadframe:

Test die material is the same as those used for BGA. Leadframe used was 100QFP copper leadframe with silver spot plating. The leadframe thickness is 6 mils with spot silver plating. Transducer used is the standard high frequency 138kHz of AB339. Bond temperature used was 240 deg C.

Discussion:

70µm bond pad pitch with a mean stitch pull strength of 6.5g at a low bond temperature of 130 deg C was readily achievable. However low stitch pull strength and 1.8% of NSOL (non stick on lead) was encountered when bonding was made on 100QFP. One possible factor is illustrated in the comparison of stitch

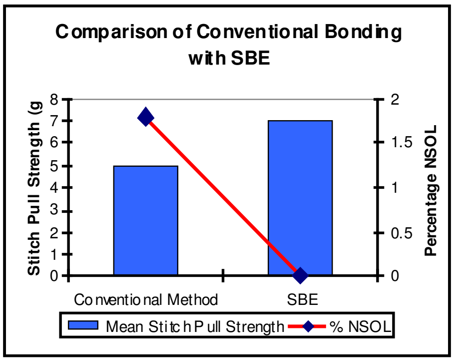
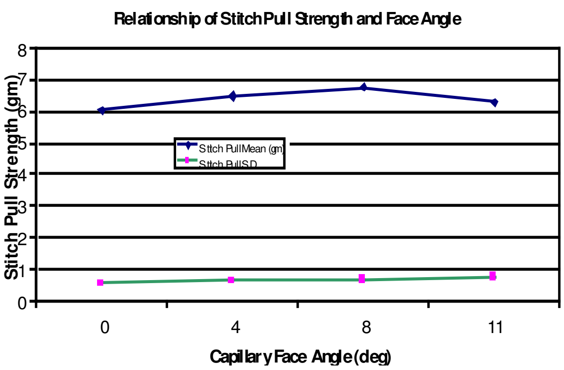


Chart comparing stitch pull results and NSOL with and without SBE

bond mechanism of copper wire onto silver plated leadframe and gold plated BGA substrate.



Relationship of Stitch Pull Strength and Face Angle

The stitch bond on the BGA substrate has to overcome a layer of copper oxide on the copper wire surface prior to bonding. However the stitch bond on QFP Ag spot plated leadframe has to overcome the silver oxide layer in addition to the copper oxide layer.

The SBE (Stitch Bond Enhancer) feature of the wire bonder was used to achieve a much higher stitch pull strength and resolve the occurance of NSOL.

Various FA(face angle) dimension of capillary design type SBN 31AB 50MTA were evaluated to establish the relationship of stitch pull strength with FA. Results obtained were not significantly different as all mean stitch pull strength obtained were above 6 gm.

Results for 70 µm Pad Pitch on Leadframes:

Bond Quality	Min.	Max.	Mean	Std. Dev	Sample Size
Ball Size (mil.)	2.26	2.41	2.34	0.033	40
Ball Thickness (mil.)	0.4	0.6	0.54	0.37	40
Loop Height (mil.)	6.9	7.8	7.52	0.231	40
Ball Shear (g.)	24.5	38.5	31.69	3.11	40
Stitch Pull (g.)	5.2	8.8	6.97	0.73	40
FAB Size (mil.)	1.93	2.1	1.96	0.029	40

Mean Shear gm/mil^2 7.34

SEM Photos of 70µm BPP on Leadframe:
(See Appendix B)

Cross Sections of Cu FAB, Ball Bond and Stitch Bond:
(See Appendix C)

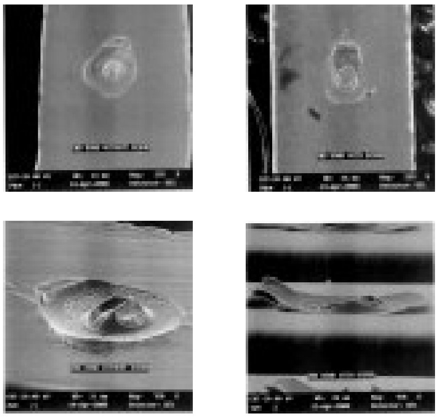
SBE (Stitch Bond Enhancer):

The SBE, a programmable feature of the AB339 wire bonder for second bond stitch pull strength enhancement and improved consistency. This feature includes programmable table displacement cycles, directions, amplitude, time, ultrasonic power and bond force. This feature enables the removal of the copper oxide from the surface of the copper wire prior to bonding onto the package leads or bond fingers.

Stitch Pull Failure Mode:

A comparison of stitch pull failure mode was made. I was found that the stitch bond weld area with the use of SBE is much larger that those bonded wothout the SBE. This resulted in a higher stitch pull strength obtained.

SEM Comparison of Failure Modes:



Without SBE With SBE

Results for 60µm Bond Pad Pitch on Leadframe:

With the positive results obtained from the 70µm BPP on leadframe, the group proceeded to evaluate 60µm BPP on leadframe. The wire bonder set up is the same as for 70µm BPP with the SBE feature enabled. Wire type used was TOCW, diameter of 0.9mil. and elongation of 8 – 16%. Capillary design was SBNF30ZA–AZM – $^{1}/_{16}$ XL, 50MTA, OR 20, FA4.

Bond Quality	Min.	Max.	Mean	Std. Dev	Sample Size
Ball Size (mil.)	1.18	2	1.91	0.047	40
Ball Thickness(mil.)	0.4	0.6	0.45	0.034	40
Ball Shear (g.)	18	26.5	20.29	2.51	40
Stitch Pull (g.)	4.2	6.3	5.24	0.46	40

Conclusion:

The success of ultra fine pitch copper wire bonding process for 70µm and 60µm BPP is based on the following:-

(a) The development of the SBE feature of AB339 wire bonder to provide enhanced stitch capability.

(b) The synergy of copper wire and capillary design used provided the capability needed for the establishment of the process.

Ultra fine pitch with Au wire down to 50µm BPP for mass volume production has already been achieved two years back. With the continuous development of the wire bonder together with the right capillary design and wire type, similar ultra fine pitch capability with copper wire would be achievable in the near future.

Other areas for further development includes copper wire bonding on Cu metallization for ball bond and bare Cu leadframe for stitch bond.

References:

1. ASM Application Laboratory reports on fine pitch copper wire bonding on leadframe and BGA substrate.
2. Ultra Fine Pitch Chip Interconnect Symposium by ASM, SPT, UTHE and Tanaka 1999.
3. Capillary and Process Optimization For 50µm Bond Pad Pitch, Assembly and Packaging Seminar Semicon Singapore 1999.

Acknowledgments:

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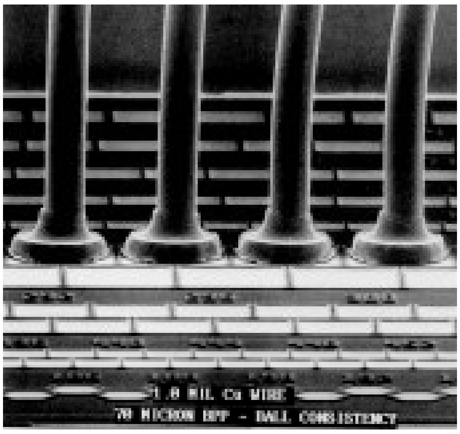
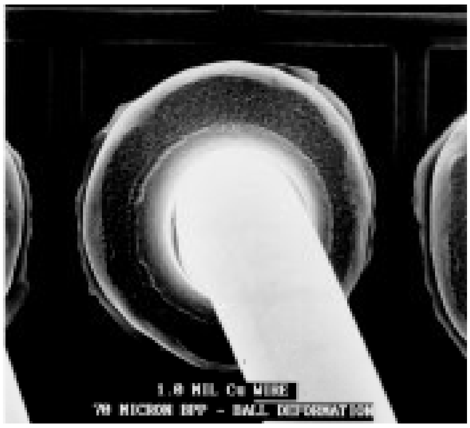
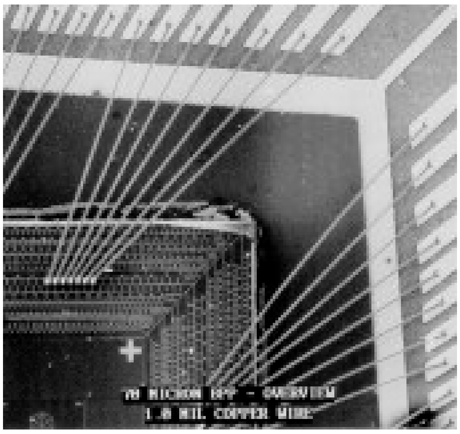
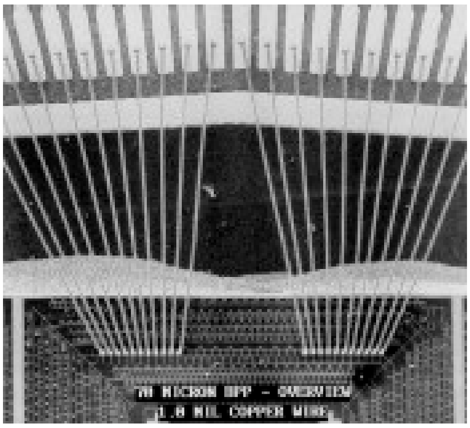
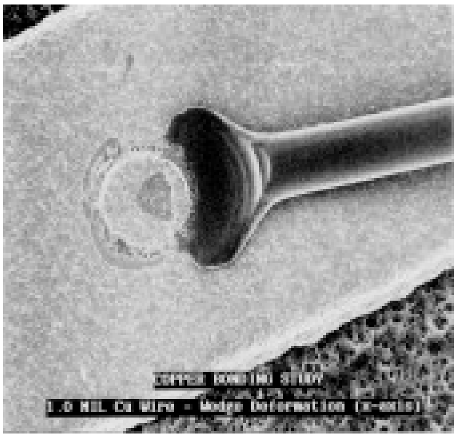
Appendix A – 70μm Bond Pad Pitch on 225BGA

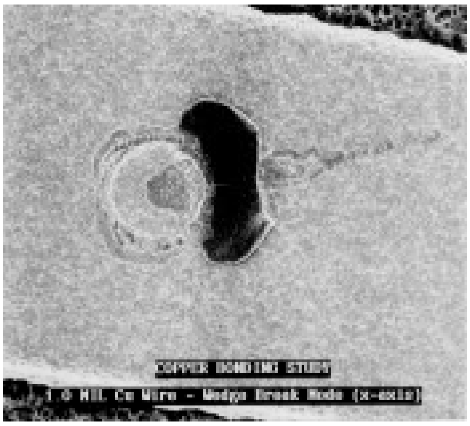




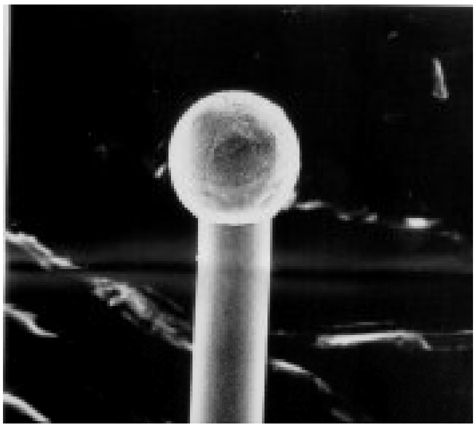


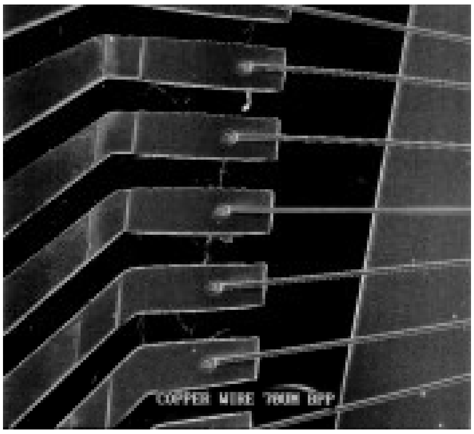


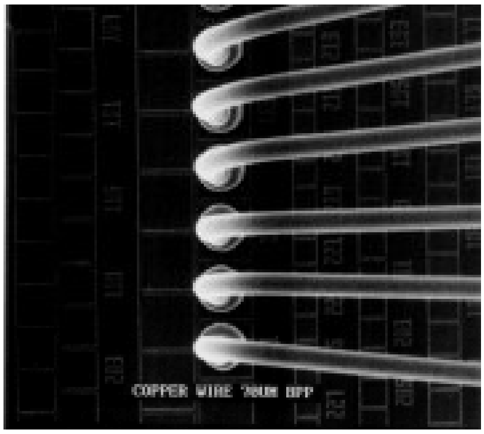


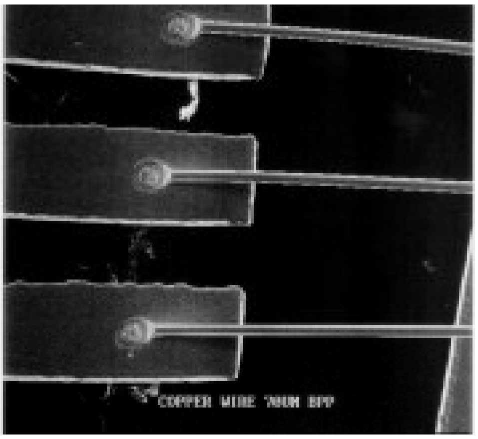


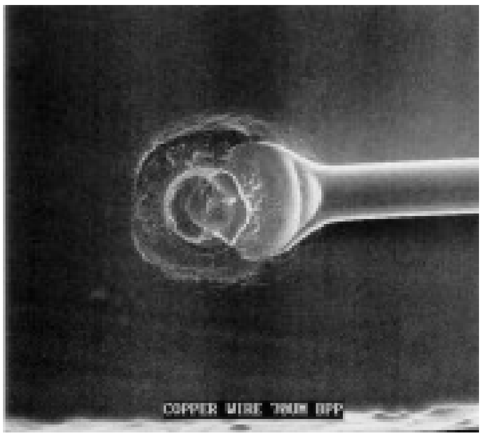
Appendix B - 70µm Bond Pad Pitch on 100QFP

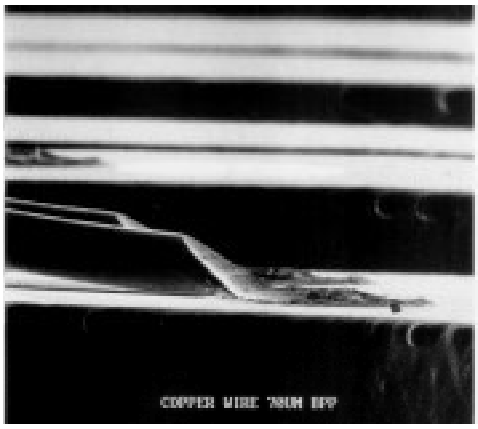


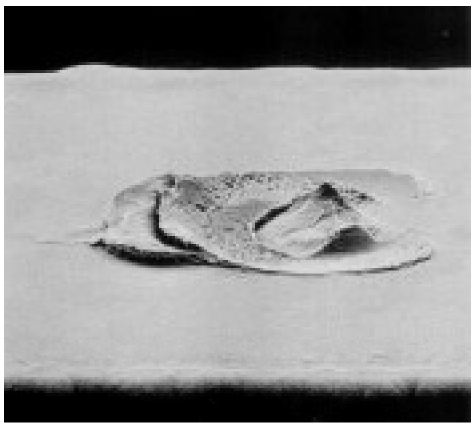












Appendix C - Cross Sections