The Future of Packaging and Cu Wire Bonding Advances

Ivy Qin

Introduction

- Semiconductors have been around for over 70 years
- Packaging is playing a more and more important role, providing low cost high performance solutions.
- Wire bonding technology will continue to be the most popular interconnect method in the foreseeable future.
- Most recently, advances in Cu Wire Bonding enabled wire bonding for advanced nodes devices including 28 and 20 nm, and extended capability to low cost packages such as QFN.
- We are also developing technologies such as thermocompression flip chip to provide cost effective solution for high performance packages.

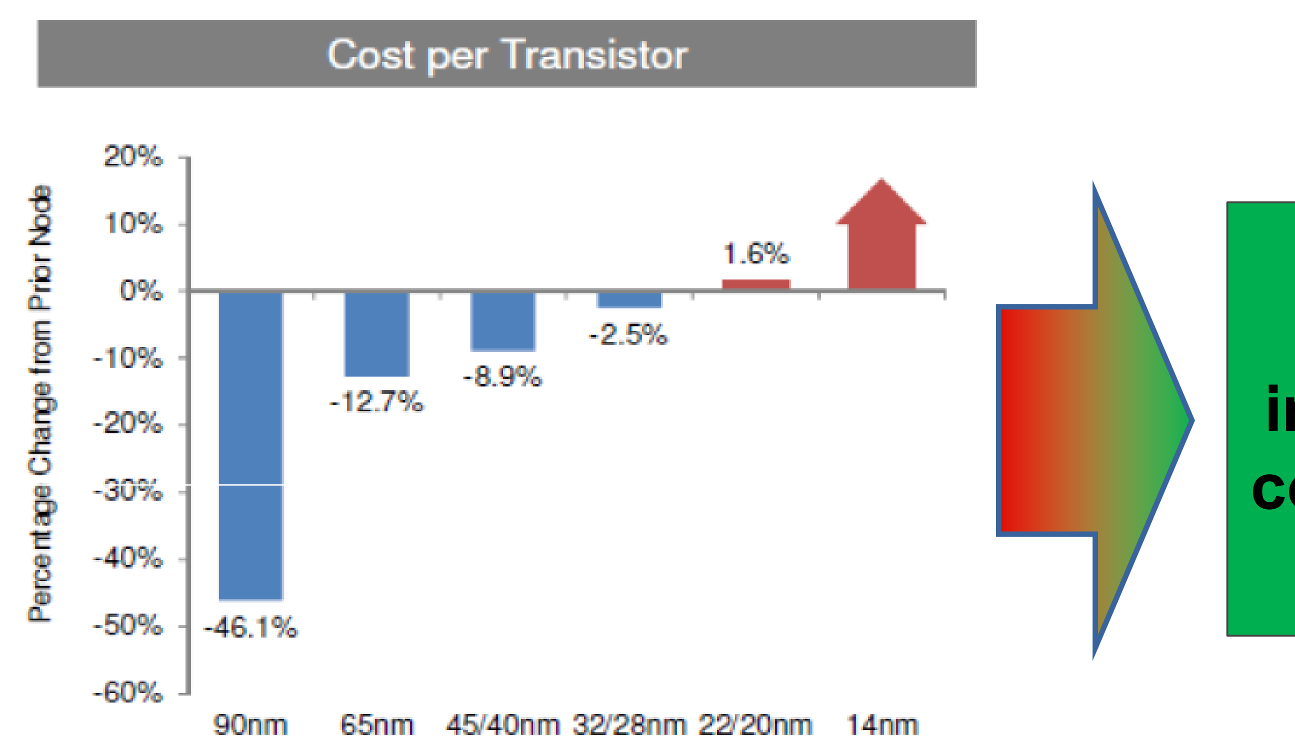
Semiconductor Industry: Cost is King

Major Trends Of The Semiconductor Industry

Cost is King

1. Increasing chip complexity -leads to rising design cost & few new entrants
2. Consumer market is the leading user of semiconductors – leads to greater market volatility & cost sensitivity
3. Increasing manufacturing cost & scale – leads to manufacturing outsourcing
4. Need for innovative solutions & faster payback on the rising cost of R&D – leads to R&D partnerships & collaborations
5. Volatility of Global Economy – leads to careful inventory management to control cost

Slow-down of Moore's Law Drives Advanced Packaging



Performance and efficiency improvements at lower cost through packaging innovation

Packaging Trend

(Bn Units)	2011	2012	2013	2018	CAAGR 2013 – 2018
DIP/SOT	4.3	4.1	4	3.4	-3.2%
SO/TSOP/SOT	78.5	76.8	81.3	90	2.1%
QFP/LCC	18.3	17.5	17	15	-2.5%
QFN	20.5	19.8	27	56	16%
Wire Bond CSP	8.1	7.4	8.4	10.7	5.0%
Stacked CSP	6.7	6.9	8	11	6.6%
BOC for DRAM	13.5	12.5	11	7	-8.6%
Wire Bond BGA	1.1	1	0.9	0.8	-2.3%
COB (Wire Bond)	10.7	11.4	12	15.5	5.3%
Flip Chip CSP	1.3	2.3	3.0	7.4	20%
Flip Chip CSP for DRAM (aka FC BOC)	0.2	0.7	1.4	6.0	32%
Flip Chip BGA/PGA/LGA	1.1	1.1	1.1	1.1	0.0%
DCA Flip Chip	5.5	5.5	5.7	6.5	2.7%
Wafer CSP (FC)	9	9.8	13	28.5	17%
COG	4.6	4.9	5.4	7.6	7.1%
COF	3.3	3.2	3.2	3.5	1.8%
Subtotal Wire Bond	161.7	157.4	169.6	209.2	4.3%
Subtotal Flip Chip	25	27.5	32.8	60.6	13.1%
IC TOTAL	186.7	184.9	202.4	269.8	5.9%

84% is wire bonded

Faster growth in Flip Chip

Source : Prismark

5

Focus – Mobility/Internet

APU/DRAM
Bandwidth

Logic
Cost / Performance

Display
DRAM
NAND Flash
Applications Processor and Multi-Media Processors
Baseband & Transceivers
RF and FEM (PA, Switch, etc.)
Image Sensors (Camera)
Touch Controller
Combo Chip
PMIC
GPS

Memory
Cost / Size

MEMs, CIS,
Support ICs
Cost / Size

Advanced Packages for Bandwidth

DRAM

+

APU

Today	2015/16	Future
Wire Bond	Wire Bond	TSV Stack
C4 FC	Adv FC	TCB Cu Pillar
POP	Advanced POP or Hybrid	3D TSV

10x10 max target, minimum determined by contact grid

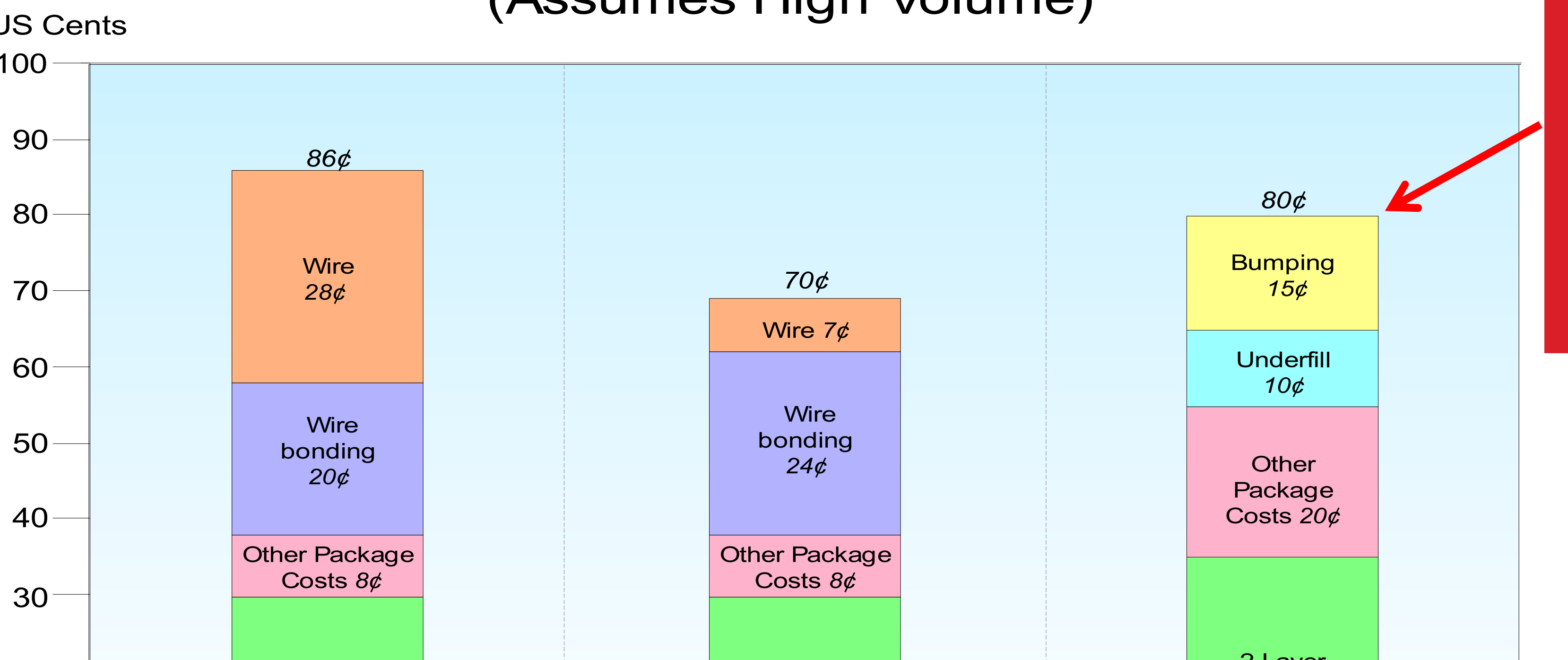
Memory Cube

SoC Die

Baseline 12mm x 12mm BGA Substrate

K&S Advanced Packaging Solution

Package Cost



Add additional cost of creating TSVs and Thermo compression bonding For 3D package

Wire Bonding Evolution

1st wire bond

70 years later

3.0kV 20.4mm x35 SE(L)
1.00mm

Replica of the first transistor
(1947)
Source: Bell Labs

Cu Wire Bonded Device >1000 wires
(2014)
Source: K&S

Ball Bonder Evolution

Relative Productivity

280
240
220
200
180
160
140
120
100
90
80
70

1484
1484XQ
1488 turbo
1488 plus
8020
8028
8028S
Nu-tek
elite
Maxμm
8028PPS
Maxμm plus
ultra
ConnX
ConnX LED
ConnX PLUS
IConn
ProCu IConn
IConn ProCu PLUS

100μm
90μm
80μm
70μm
60μm
50μm
40μm

Bond Pad Pitch

Copper Capability

Automatic Ball Bonder Market Share Trend

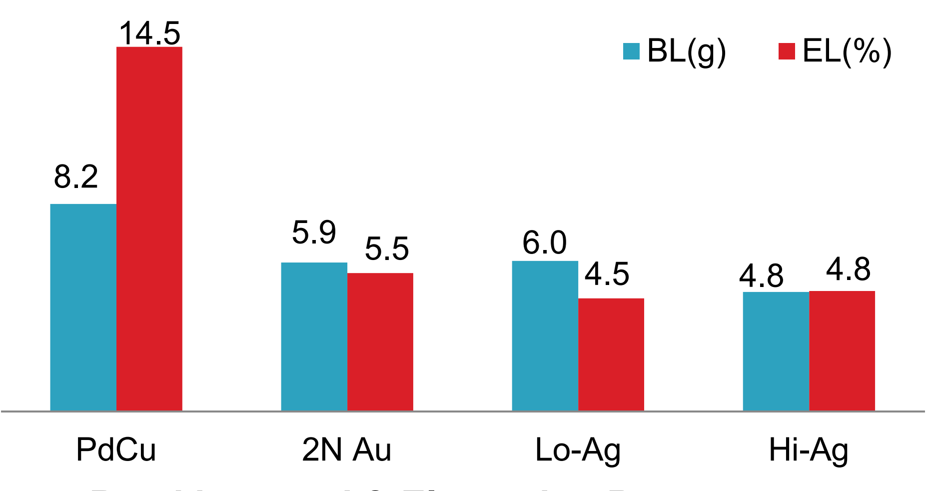
Market Share: 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%

Calendar Year: Q2'07, Q4'07, Q2'08, Q4'08, Q2'09, Q4'09, Q2'10, Q4'10, Q2'11, Q4'11, Q2'12, Q4'12, Q2'13, Q4'13, Q2'14, Q4'14

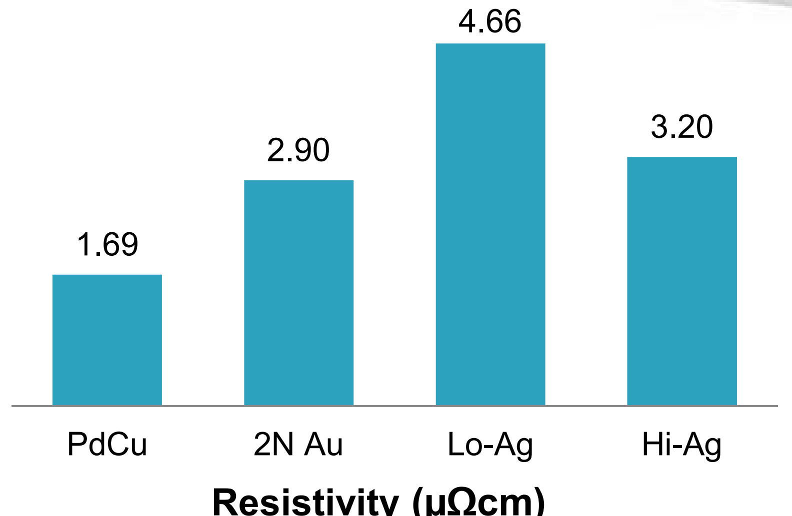
Forecast

K&S — C1 — C2 — Other

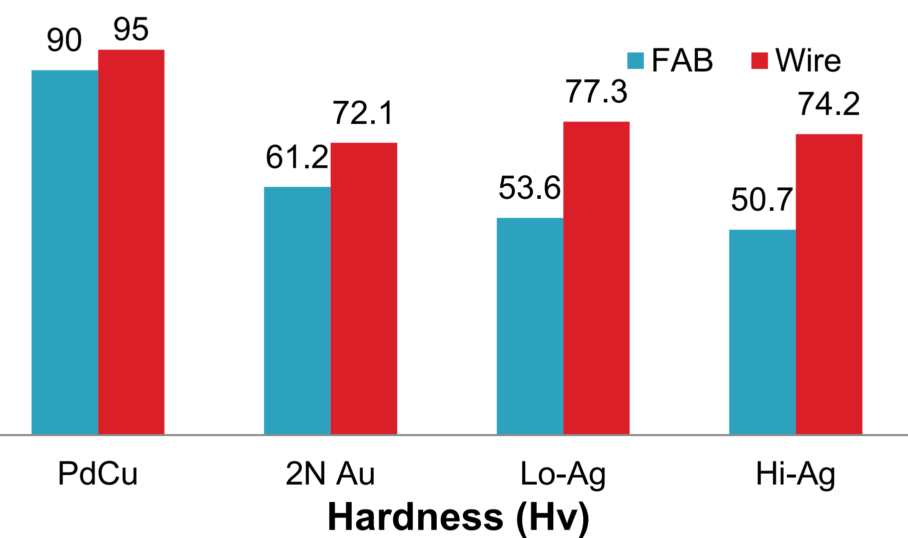
Bonding Wire Comparison



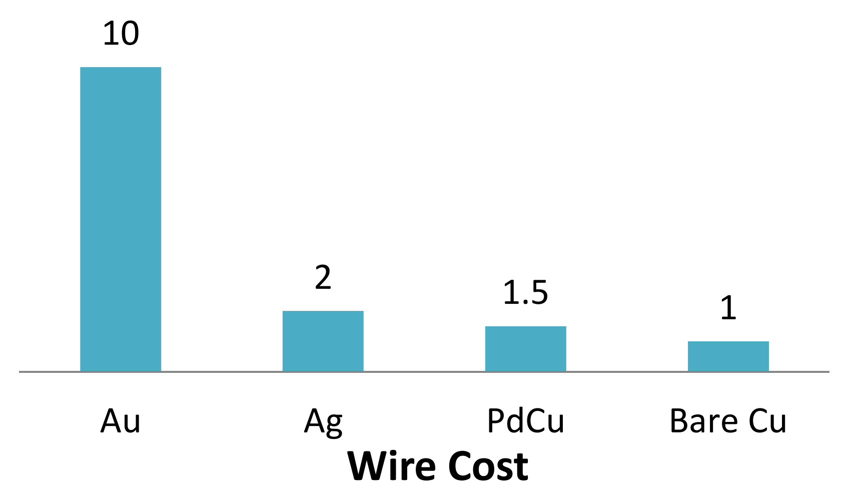
Breaking Load & Elongation Rate



Resistivity (μΩcm)



Hardness (Hv)

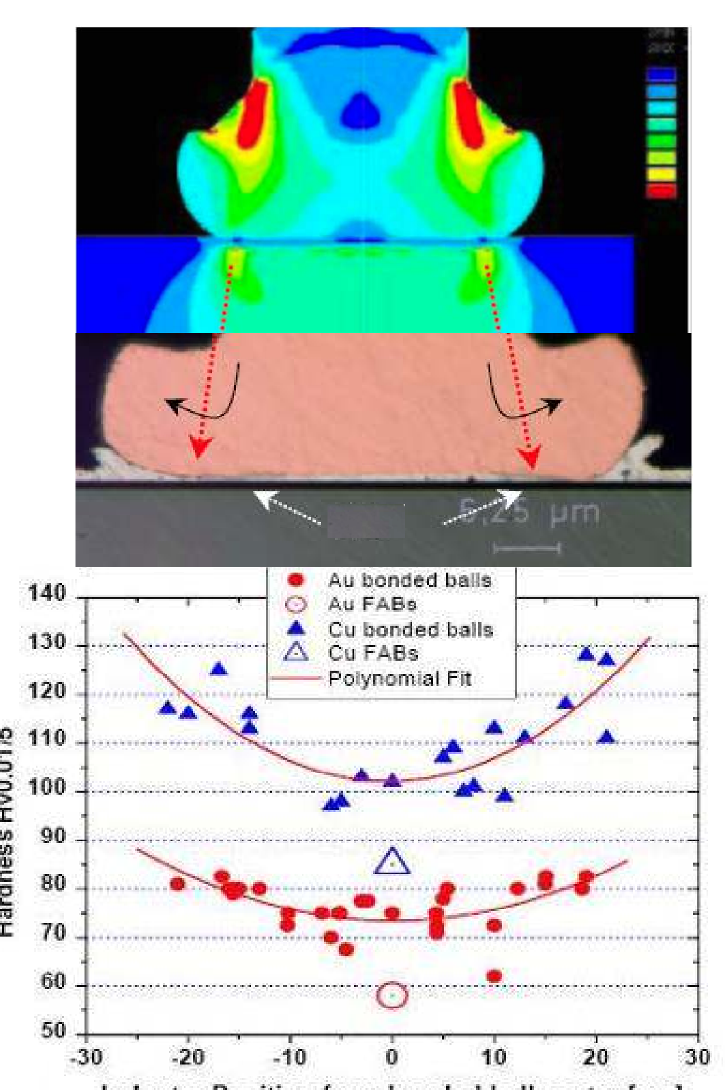


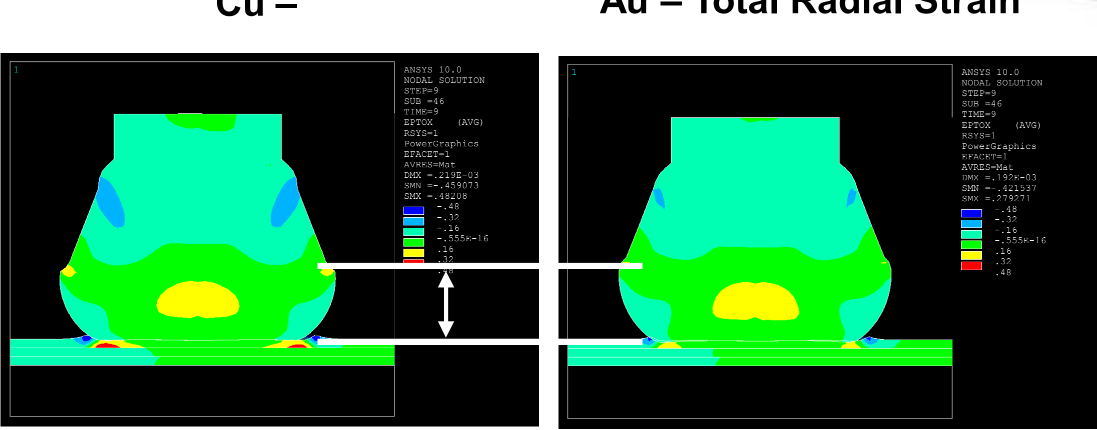
Wire Cost

Advantages of Cu Wire Bonding

- The main advantage of Cu wire bonding is the lower cost.
- It also has higher thermal and electrical conductivity.
- It has higher mechanical strength for better wire bond looping performance which is the key for high I/O count devices.
- Cu IMC growth rate is much slower than Au and Ag. It has improved intermetallic reliability in high temperature application.
- Cu wire bonding is easily adaptable to existing assembly infrastructure.

Cu Wire Bonding Challenges





- Cu oxidizes: it is hard to bond to, high energy is often required to bond Cu. Pad damage (peeling, crack, Al splash) is often an issue.
- Cu is also harder, which aggravates the above issues.

Traditional Cu Wire Bonding Process

- Traditional Cu process window is small comparing to Au.
- Low end is limited by poor bondability (low IMC%, NSOP).
- High end is limited by pad damage (Splash, peeling, crack).

Au

Cu Process Window

IMC — Too Low | Acceptable

Al Splash — Acceptable | Too High

Crack — No Crack | Crack

Pull test failure — Ball Lift | OK | Pad Peeling

Bonding Energy (e.g. USG level)

Complexity in Optimizing Cu Processes

Au $3^3 = 27$ cell matrix: 9 Cell DOE

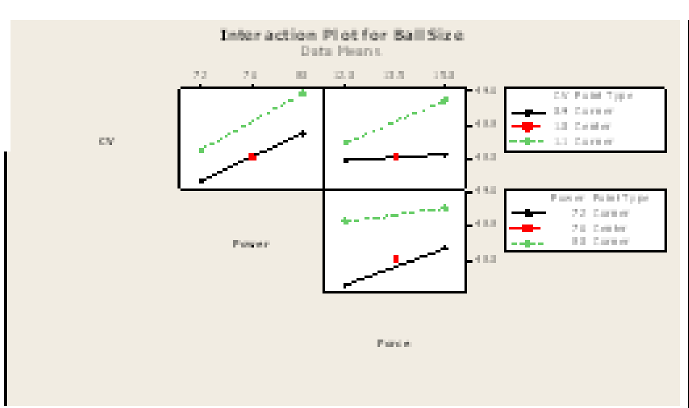
	CV	Power	Force	BST
1	0.9	72	12	21.1
2	1.1	80	15	23.1
3	1	76	13.5	21
4	0.9	72	15	20.2
5	1.1	72	12	20.3
6	1.1	72	15	18.8
7	0.9	80	12	21.2
8	1.1	80	12	20.8
9	0.9	80	15	21.4

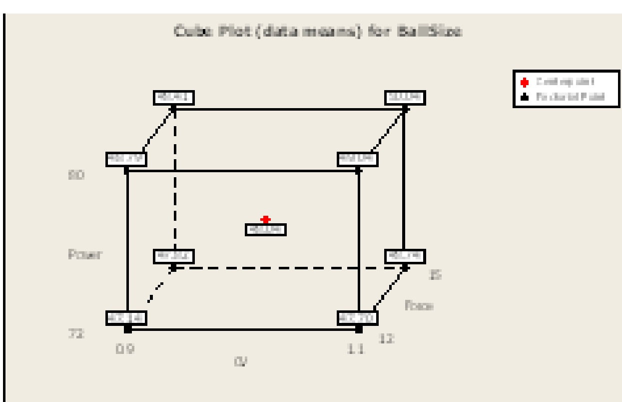
Optimum range

CV : 1.1 F mode (fixed)

Power: 72 ~ 78mA

Force: 12 ~ 14g





Cu:
(3 segments)

Initial Bond

F, P, t

Scrub

F, P, t, scrub

Form Weld

F, P, t

In reality, there are 10 parameters in each phase.

If phases independent 27+64+27=118 cell matrix: 9 + 16 + 9 = 34 cell DOE
if dependent 10^3 = 1000 point matrix: 10^2 = 100 cell DOE

Copper Wire Optimized Bonder

- A robust Cu process is ***more complicated*** than Au
- **ProCu Processes** were developed to address this challenge with a ***Response Based Parameters*** concept
  - ***Auto calculate*** Power/Force/Time based on Target Ball Diameter to deliver ***optimal Cu process***
  - ***Reduce the total number of parameters,*** with ProCu5 process, we only need to fine tune 2-3 adjustments for most applications
- **ProCu Processes** are running in production.
  - Proven to be easier to achieve robust process with ***higher IMC, less Al splash, eliminating crack and peeling***
- We have reached our objectives for Cu wire bonding

as easy and as robust as Au

Classical Process Parameters To ProCu Response Based Parameters

Edit Bond1 Parameters

Group ALL Wire ALL Site ALL

Bond Limits Summary

Min : NA Max : NA

1 Edit ALL

<<< Page 1 (of 2) >>>

2 USG >>>
3 Force >>>
4 Bump/Sec >>>
5 Scrub >>>
6 Misc >>>
7 C/V 0.29 mils/ms
8 Tip 6.50 mils
9 Contact Detect Mode FMode

Done Parameter Set

6 Force Profiling OFF
7 Init'l Force 65.00 grams
8 Init'l Force Time 33 %
9 Force Ramp Time 10 %

Done Parameter Set

7 USG Freq High
8 Init'l USG Time 0 %
9 Init'l USG Level 100 %

Done Parameter Set

7 Tail Position 8.00 mils
8 Release USG 50 mAmps
9 Bump-Lift Detect Thresh 0.00 microns

Done Parameter Set

8 Reference Delay 5.00 ms
9 Min USG Time 15 ms

Done Parameter Set

> 100 Classic 1st Bond Parameters

1 Auto | 2 Manual | 3 Program | 4 Configure | 5 Calibration | 6 Utilities | 7 Diagnostic | 8 Sys Admin

Segmented Bond Parameters

Group ALL Wire ALL Site ALL

Select Wire or Wire Group

Bond Limits Summary

Min : NA Max : NA Units NA Total Time: 1.50

Edit ALL

Bond Selector

<<< Page 1 (of 2) >>>

Parameter	Seg-1	Seg-2	Seg-3	Seg-4	Seg-5	Seg-6	Seg-7	Seg-8	Seg-9	Seg-10
Mode	Force	OFF	Scrub	OFF	OFF	OFF	OFF	OFF	OFF	OFF
USG Current	156.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Force	52.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
USG Ramp Up	0	0	0	0	0	0	0	0	0	0
Force Ramp	0	0	0	0	0	0	0	0	0	0
Scrub Cycles	0	1	1	0	0	0	0	0	0	0
Scrub X Amplitude	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scrub Y Amplitude	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Done

Target Ball Dia is the main input
+
Fine tuning adjustments

Edit Bond1 Parameters

Process Responses

Group ALL Wire ALL Site ALL

Bond Limits Summary

Min : NA Max : NA

1 Edit ALL

Parameter Entry Style ProBond
Loop Type FORWARD
Bond Selector Bond1
Process Type ProCu-5
ProCu-5 Mode Mode-4

2 Wire Diameter 0.60 mils

<<< Page 1 (of 3) >>>

3 Target Ball Diameter 27 microns
4 Bond Strength Adjust 85 %
5 Diameter Adjust 0
6 Height Adjust 0.00 microns
7 Bond USG Adjust 0 mAmps
8 Bond Force Adjust 0.00 grams
9 Diameter Adjust 2 0

Done Parameter Set

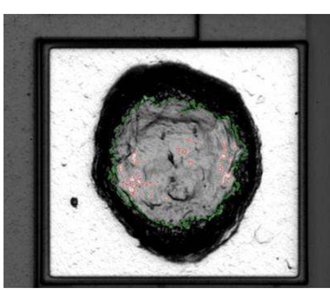
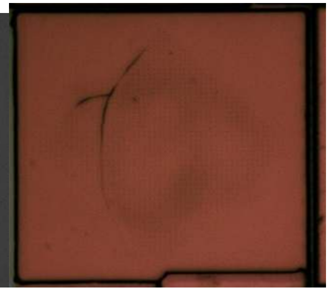
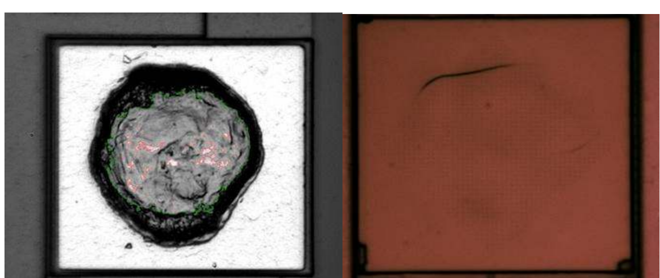
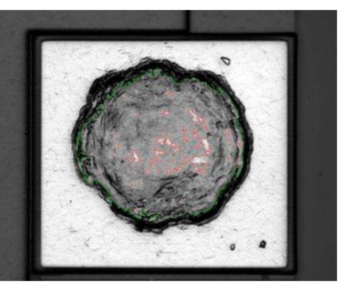
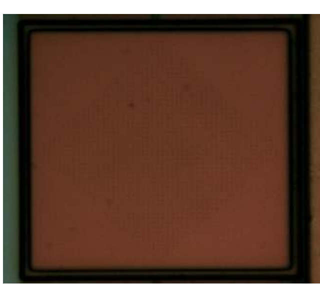
Resolving Pad Crack For Cu Wire Bonding

Process	Ball Dia (um)	Contact Dia (um)	Splash X (um)		Splash Y (um)		Ball Height (um)	IMC%		Pad Crack %
			Avg	Max	Avg	Max		Avg	Min	
Traditional Process on ProCu BSA=85	52.1	41.2	55.0	57.2	62.0	64.5	11.1	93%	90%	27%
Traditional Process on ProCu Plus BSA=85	51.9	42.1	54.1	56.0	61.1	62.3	10.9	93%	91%	9%
ProCu5 on ProCu Plus BSA 85	53.2	46.3	57.5	59.1	54.7	56.8	10.1	93%	89%	0
ProCu5 on ProCu Plus BSA 105	53.0	45.8	57.4	59.5	57.6	58.5	10.3	94%	90%	0

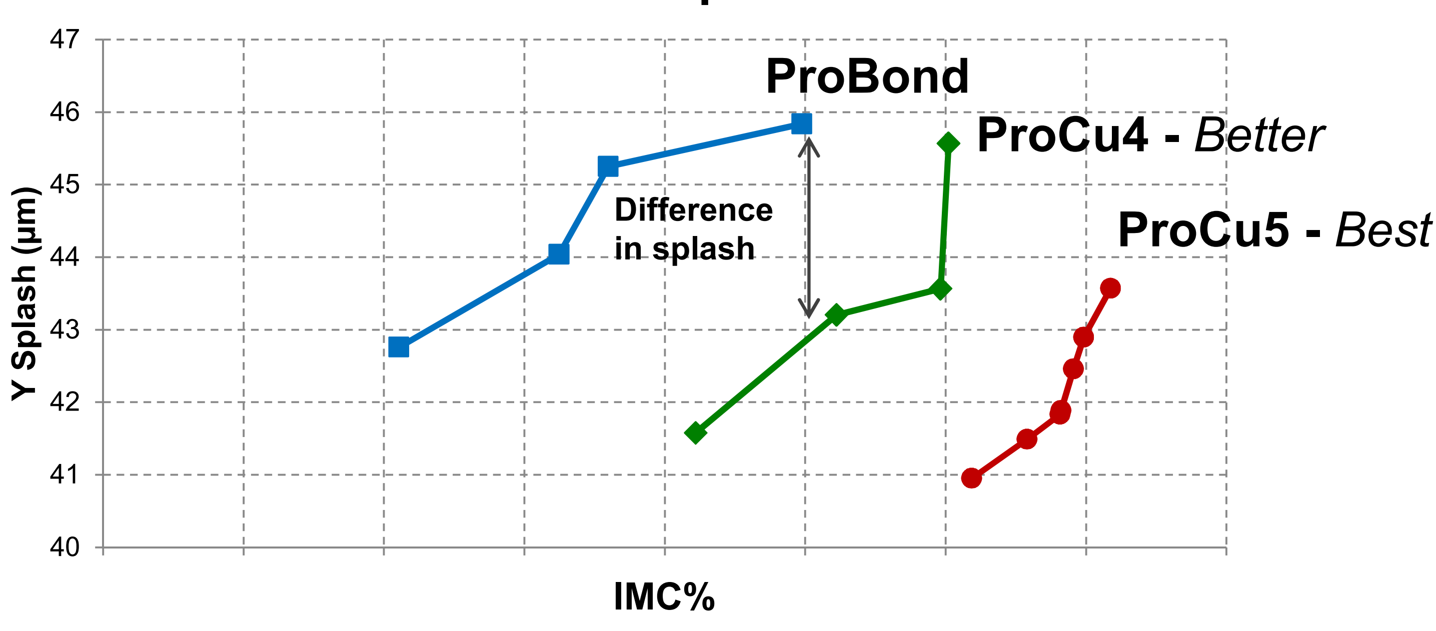
Traditional Process on ProCu

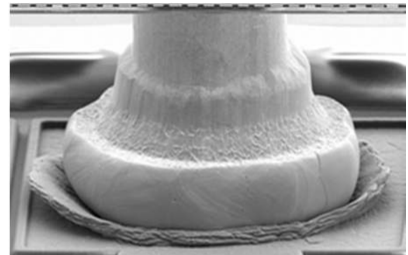
Traditional Process On ProCu Plus

ProCu5 on ProCu Plus

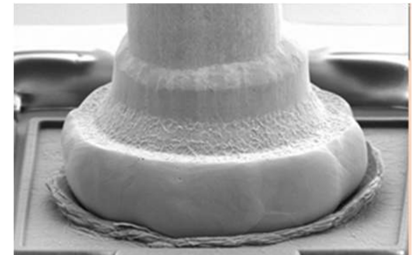






Improving Al Splash and IMC

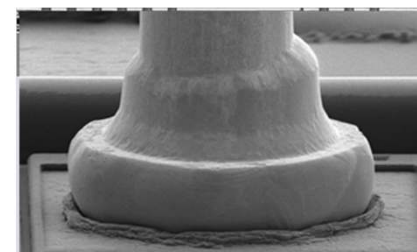




ProBond on ProCu



ProCu4 on ProCu



ProCu5 on ProCu Plus

Fine Pitch Advances – 40um Pitch Process

- 15um wire/40um pitch process is tested as part of our latest equipment verification test. Portable results are achieved across all machines meeting all wire bonding specifications.
- We are fully capable to support 28nm and 20nm wire bonding in high volume production.

MC #	Shear/ Area (gr/mil²)	Ball Dia (um)	Ball Height (um)	Splash (µm)					IMC (%)		Dage Pull (gr)		
				X Avg	X Max	Y Avg	Y Max	XY Avg	Avg	Min	Avg	Min	Lift Peel
Spec	>7	27 ± 1.5	7.5 ± 1.5		<34um		<34um		>85%	>80%		>2.5	0%
MC42331	8.7	27.2	6.8	31.2	32.3	30.1	31.6	30.6	92%	88%	5.4	5.1	0%
MC43231	9.3	27.7	7.0	33.1	33.9	31.7	33.2	32.4	90%	86%	4.7	4.1	0%
MC42440	8.0	28.0	8.3	32.2	33.9	30.4	33.0	31.3	90%	84%	5.0	4.6	0%
MC43294	7.9	27.4	7.4	32.6	33.8	30.8	32.1	31.7	94%	90%	4.8	4.5	0%
MC43047	8.6	27.3	7.0	32.7	33.9	31.9	33.5	32.3	90%	86%	4.7	4.3	0%
Avg	8.5	27.5	7.3	32.4	33.6	31.0	32.7	31.7	91%	87%	4.9	4.5	0.0
Min	7.9	27.2	6.8	31.2	32.3	30.1	31.6	30.6	90%	84%	4.7	4.1	0.0
Max	9.3	28.0	8.3	33.1	33.9	31.9	33.5	32.4	94%	90%	5.4	5.1	0.0

Reliability Study of Fine Pitch Cu Process

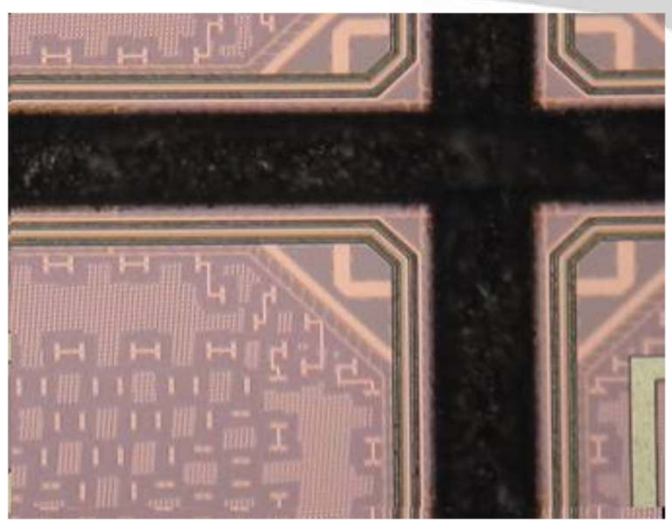
Technology Innovation Solutions ®

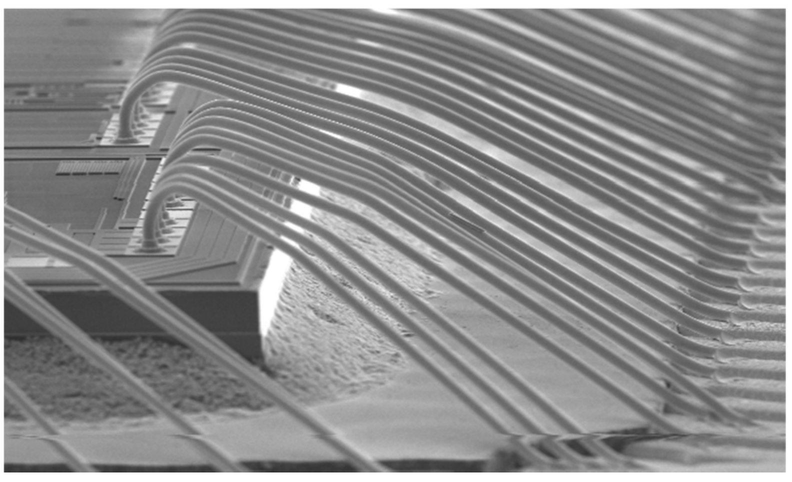
Cell	Wire Dia. [um]	Ball Dia. [um]	Y-Splash. [um]	Shear [g]	Cont. Dia. [um]	IMC [%]	Al remain [%]	HAST 96hr Failure	HAST 168hr Failure	HAST 96hr Failure	HAST 336hr Failure
10	15	29.6	34.8	11.1	24.1	96.2	51.8	8%	16%	0%	0%
11	15	31.5	36.3	12.8	26.9	94.6	52.9	8%	9%	0%	0%
12	15	33.8	38.1	14.1	28.5	93.6	53.6	0%	0%	0%	0%
13	18	37.1	41.2	16.5	30.7	95.0	51.8	0%	0%	0%	0%
14	18	38.9	41.7	17.3	33.0	91.2	53.6	0%	0%	0%	0%
15	18	40.8	44.1	19.2	35.9	91.6	49.1	0%	0%	Did not test	
								Med Grade EMC		**Low Cl, Low Cl + Ion Trapper EMCs**	

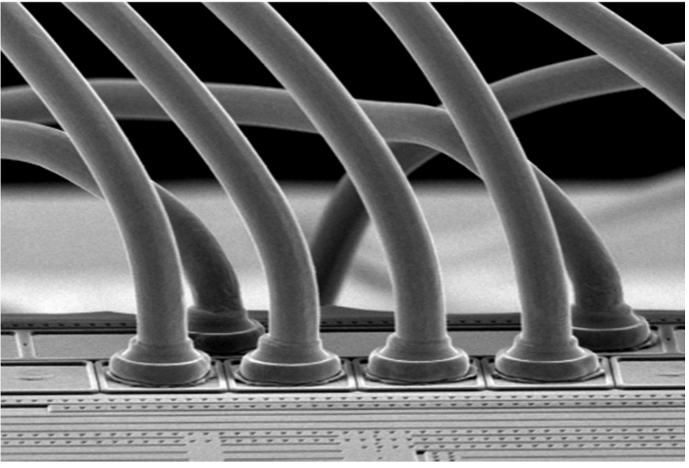
- Smaller bonded ball diameter negatively affects reliability outcome.
- Better molding compounds with low Cl and Ion Trapper can easily pass 336 hour bias HAST reliability test for all cells.
- 30um bonded ball is targeted for 40um pitch application. This shows that reliable 40 um pitch Cu wire bond process is achievable.

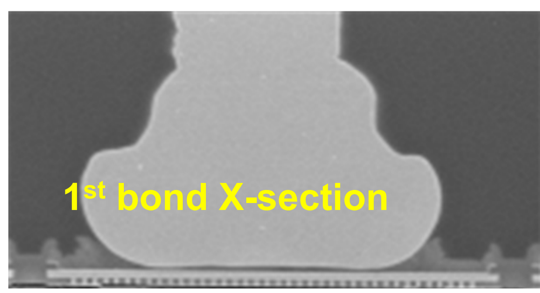
28nm ELK Wafer Status

- Major foundries wafer qualified
- Multiple customer’s device qualification pass
- Multiple customer’s device already production
- MP Avg. yield performance 99.88% since May









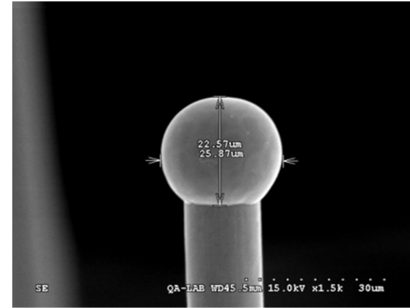
Source: ASE

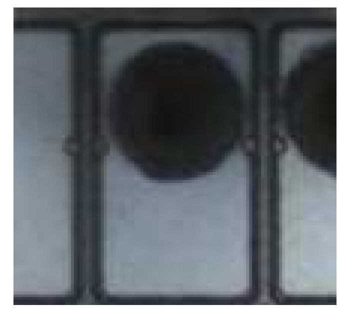
15um Cu Wire Development

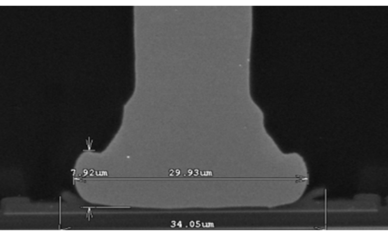
28nm ELK, 35um Bond Pad Opening

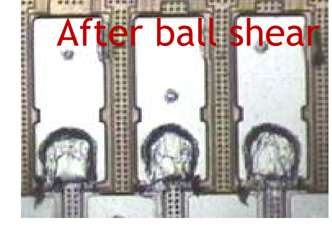
- Device information
  - PKG: PBGA31X31X1.17
  - Lead count: 899L
  - Wafer technology: 28nm ELK
  - BPP/ BPO: 40um / 35 um

- W/B material control
  - 15um Cu_Pd Wire
- W/B Machine control
  - Machine – KNS wire bonder + Cu kit



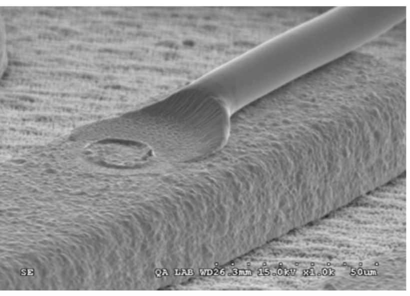


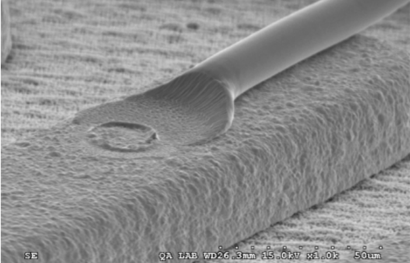


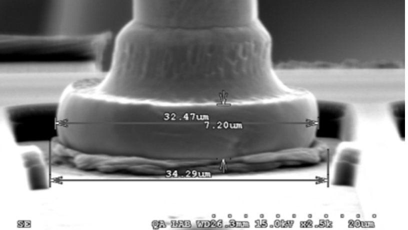


Wire Type	15um Nippon_EX1p			
Ball Size	X	Y	Z	Al Splash
Min	27.70	27.90	6.90	33.30
Max	29.20	29.80	8.40	34.80
Avg	28.39	28.81	7.60	34.06
Std	0.52	0.60	0.50	0.57

Wire Type	15um Nippon_EX1p		
Test	Wire Pull	Stitch Pull	Ball Shear
Min	4.93	3.69	15.35
Max	5.88	4.82	17.24
Avg	5.203	4.417	16.128
Std	0.31	0.367	0.552
Cpk	2.37	2.196	4.909



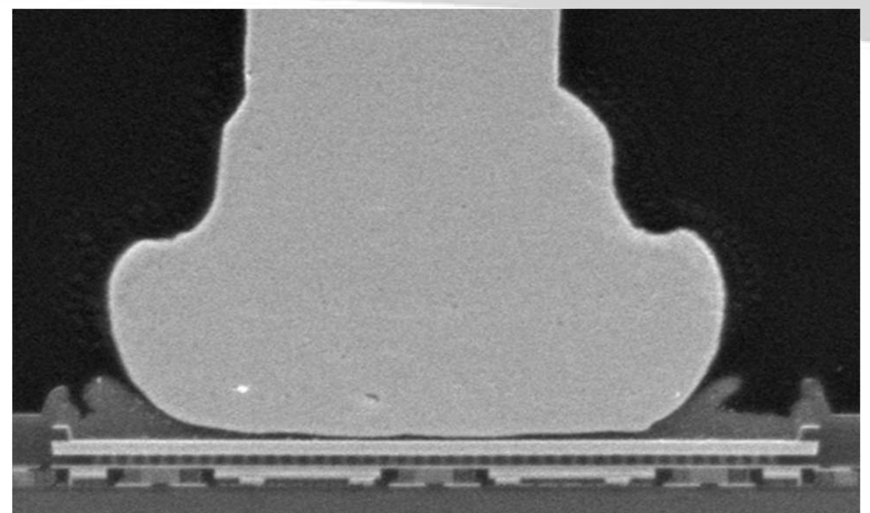


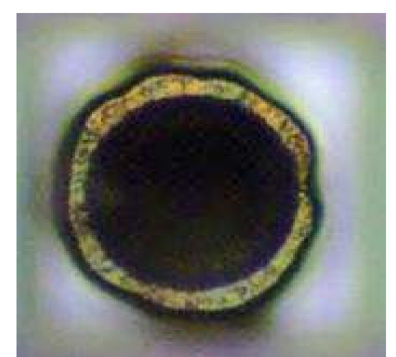


Source ASE

20nm ELK Wafer Development

- Device information
  - Package type : PBGA
  - Package size: 31 x 31mm
  - Lead count: 899L
  - Die size : 7.9 x 7.9mm
  - Bond pad pitch: 45um
  - Bond pad opening: 40um
  - Al layer thickness: 1.4um
  - Pad structure : DS
- W/B control
  - Machine : K&S ProCu Bonder
  - Wire diameter: 18um Cu coating wire
- Status
  - Under Reliability test

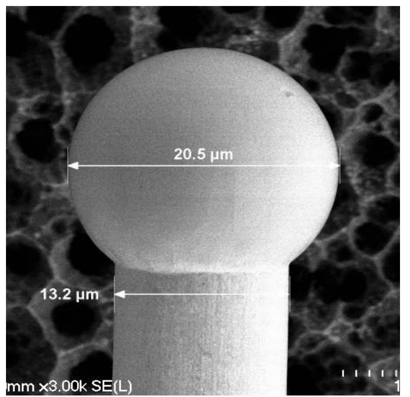


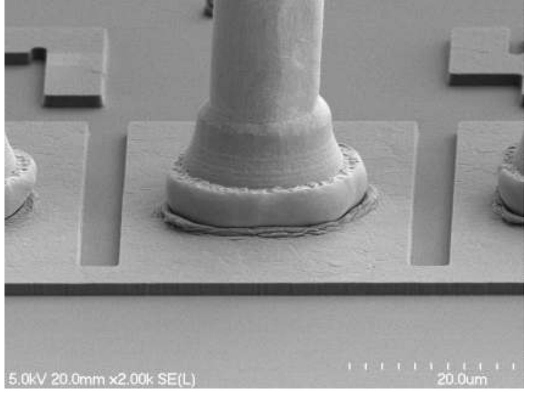


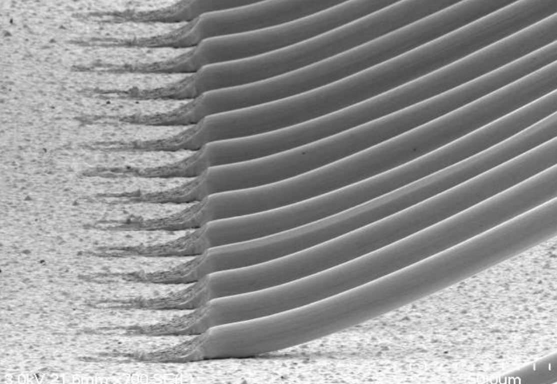
Source: ASE

Cu Wire Fine Pitch Capability 13µm wire / 35um Pitch

	Ball Dia (um)	Ball Height (um)	Shear (g)	X Splash (µm)	Y Splash (µm)	IMC (%)	Contact Dia (µm)	1st bond Pull (g)	2nd Bond Pull (g)
Average	**24.1**	**6.1**	**6.9**	**27.8**	**28.7**	**96%**	**19.9**	**3.8**	**2.7**
Stdev	0.26	0.26	0.34	0.90	0.70	2%	0.30	0.25	0.22
Max	24.6	7.0	7.4	29.5	29.8	98%	20.3	4.2	3.0
Min	23.6	5.5	6.3	25.9	27.6	91%	19.4	3.1	2.3
Range	1.0	1.5	1.1	3.6	2.2	7%	0.9	1.1	0.7





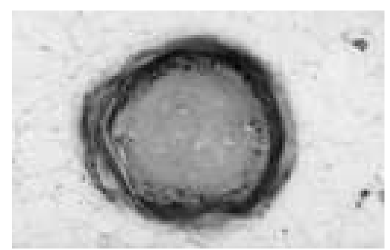


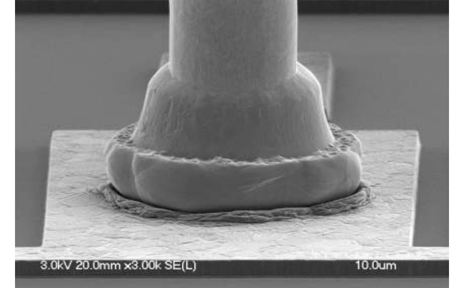
Achieved Good Free Air Ball, 1st bond, 2nd bond and Looping performance

Cu Wire Fine Pitch Process Window

BSA (USG)	Ball Dia (um)	Ball Height (um)	Shear Avg (g)	X Splash Avg (um)	Y Splash Avg (um)	Y Splash Max (um)	IMC Avg (%)	IMC Min (%)	Contact Dia (um)	Pull Avg (g)	Pull Min (g)	Lift	Peels
65	24.3	6.2	6.3	27.8	27.7	29.0	90%	89%	20.0	3.8	3.4	0%	0%
70	24.1	6.1	6.9	28.3	28.7	29.8	92%	91%	19.9	3.8	3.1	0%	0%
75	24.3	6.0	7.2	28.6	29.2	30.0	96%	96%	19.9	3.8	3.2	0%	0%

BSA = 65





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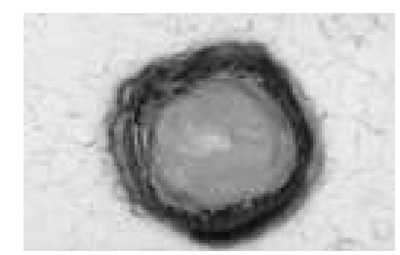

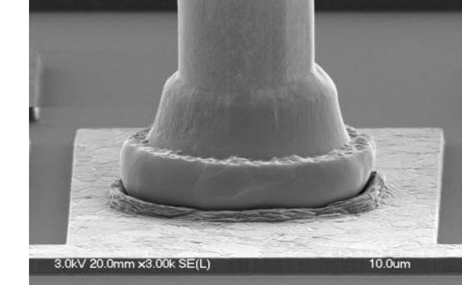

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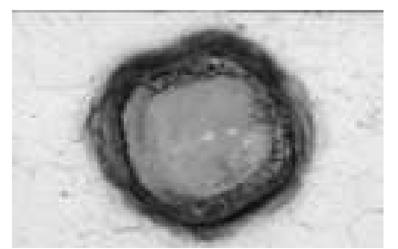
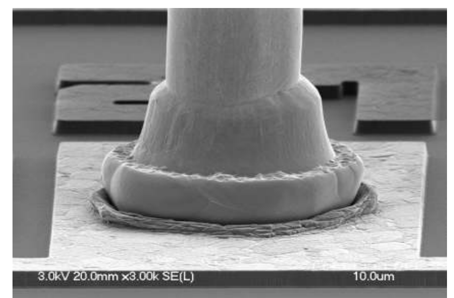




Copper Wire Bond Looping Challenges

- PdCu wire is *stronger* than Au, it has ***better* looping capability** for fine pitch, multi-tier devices
- The Challenge is … **Complexity !**
- Applications have increasing wire counts
- We provided new loop profiles & advanced trajectory control to achieve good results
- ***Many*** wires with ***many*** loop profiles is a teaching and optimization challenge
- We are working to make this task easier

Advanced node Application:
> 500 wires
0.6 – 0.8 mil PdCu wire
Up to 8 layers of loops
wire length up to 200 mils
loop heights up to 400um

K&S AutoOLP

- **AutoOLP™** is a system which **convert** device drawings into wire bonding program (recipes) in minimal time.
- We are adding new capability of 3D loop clearance check.

Setup CAD Drawing → Set Loop Parameters → 3D Display & Clearance Checking → (Satisfied) → Program Generation → Bonder

3D Display & Clearance Checking → (Not Satisfied) → Set Loop Parameters

One By One Group

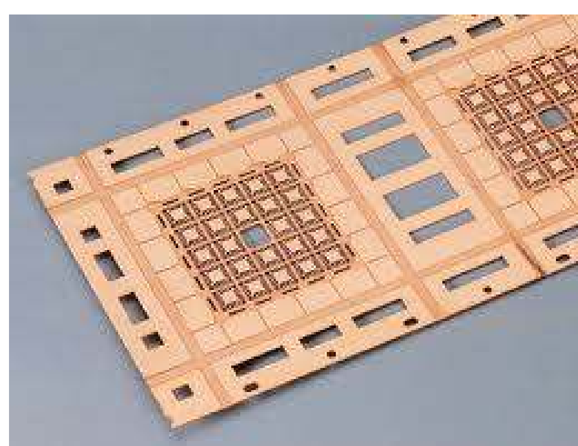
Load Bonder Recipe back to AutoOLP in 3D View

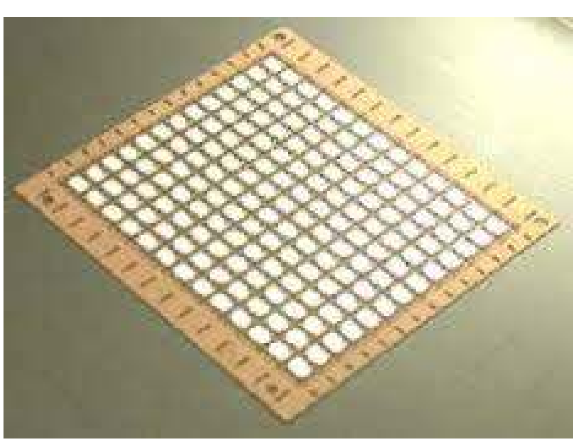
QFN (Quad-Flat pack No-Lead)- the fastest growing wire bond package

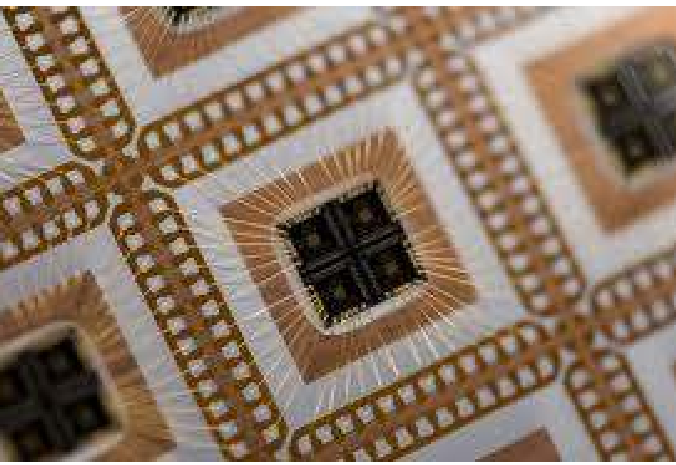
(Bn Units)	2011	2012	2013	2018	CAAGR 2013 – 2018
DIP/SOT	4.3	4.1	4	3.4	-3.2 %
SO/TSOP/SOT	78.5	76.8	81.3	90	2.1%
QFP/LCC	18.3	17.5	17	15	-2.5 %
QFN	20.5	19.8	27	56	16 %
Wire Bond CSP	8.1	7.4	8.4	10.7	5.0 %
Stacked CSP	6.7	6.9	8	11	6.6%
BOC for DRAM	13.5	12.5	11	7	-8.6 %
Wire Bond BGA	1.1	1	0.9	0.8	-2.3 %
COB (Wire Bond)	10.7	11.4	12	15.5	5.3%
Flip Chip CSP	1.3	2.3	3.0	7.4	20 %
Flip Chip CSP for DRAM (aka FC BOC)	0.2	0.7	1.4	6.0	32%
Flip Chip BGA/PGA/LGA	1.1	1.1	1.1	1.1	0.0%
DCA Flip Chip	5.5	5.5	5.7	6.5	2.7%
Wafer CSP (FC)	9	9.8	13	28.5	17 %
COG	4.6	4.9	5.4	7.6	7.1%
COF	3.3	3.2	3.2	3.5	1.8%
Subtotal Wire Bond	161.7	157.4	169.6	209.2	4.3%
Subtotal Flip Chip	25	27.5	32.8	60.6	13.1 %
IC TOTAL	186.7	184.9	202.4	269.8	5.9%

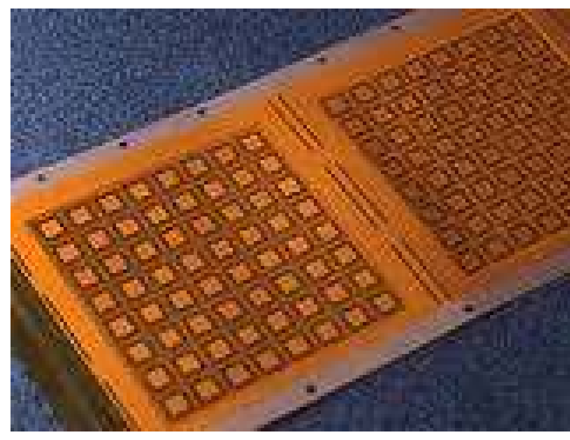
Source : Prismark

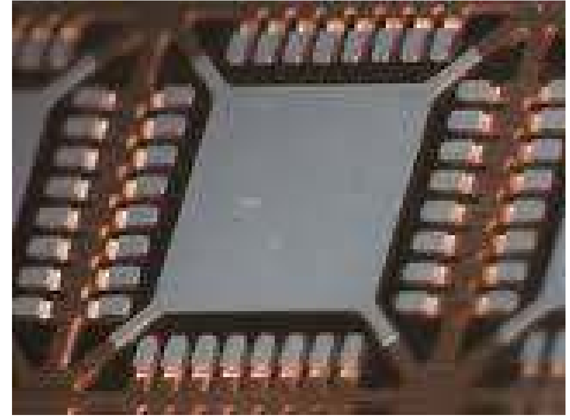
QFN Device Samples





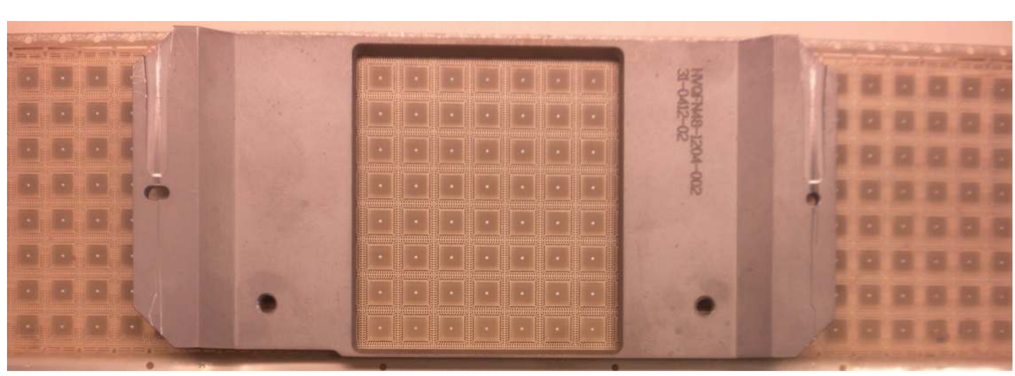


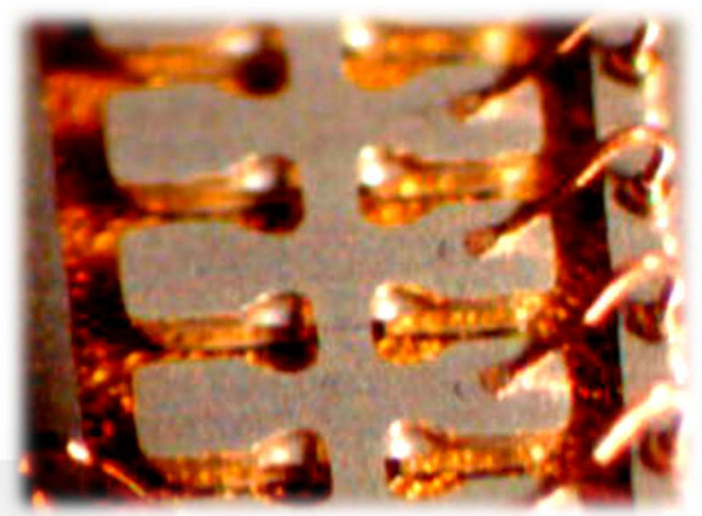




QFN Overview

- The benefits of QFN include low cost, reduced lead inductance, a small "near chip scale" footprint, thin profile and low weight.
- First bond processes are generally not an issue on QFNs
- Second bond can be difficult for several reasons …
  - Effective leadfinger clamping is impossible for most QFN designs
  - Silicone adhesive backing tape provides no anchoring of leadfingers
  - QFN Lead-beams are highly prone to resonate under ultrasonic energy
  - New plating types (PPF, μPPF) and roughened surfaces are less bondable compared to traditional Ag plating





Advances in QFN 2nd Bond – ProStitch Plus Process

- Uses response based parameters
- Provide similarity in the look & feel of interface to ProCu.
- Stitch parameters initialized for processes based on material set information – wire diameter, cap geometry, etc.
- Fine adjustment parameters will optimize the process to account for difference in applications.

App Information(* Required for ProStitch Plus)		
Cap Part Number	Unknown	
Tip Dia*	2.40	mils
Chamfer Dia*	1.00	mils
Outer Radius	0.36	mils
Wire Diameter*	0.70	mils
Die Pad Thickness	0.00	microns
Die Pad Metallization	Unknown	
Lot Number	Unknown	
Misc Comment	Unknown	
Done		

<<< Page 1 (of 2) >>>		
2 Scrub Cycle Boost	Standard	
3 Scrub Cycle Adjust	0	
4 Scrub Force Adjust	0	%
5 Scrub Amplitude Adjust	0	%
6 Scrub Phase	Circular	
7 Scrub Speed Adjust	0	%
8 Peel Reduction	0	%
9 SHTL Reduction	0	%
<<< Page 2 (of 2) >>>		
2 Scrub USG	0	mAmps
3 Deform Adjust	0	%
Done Parameter Set		

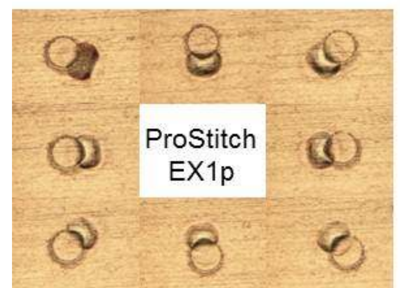
Process Improvement Example

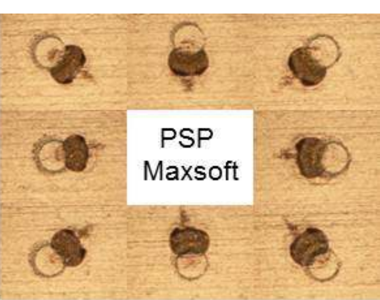
0.8mil Bare Cu and AuPdCu Wire on PPF QFN

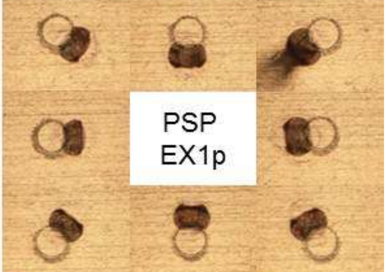
- ProStitch process
  - Maxsoft Bare Cu: 100% NSOL.
  - EX1p AuPdCu: 0% Cu remain and low stitch strength.

- ProStitch Plus process
  - Bare Cu and AuPdCu wire both have good results.

Process type	Traditional Process		ProStitch Plus	
Wire type	Maxsoft	EX1p	Maxsoft	EX1p
NSOL/SHTL	100%NSOL	OK	OK	OK
Peel		OK	OK	OK
Cu remain		Most 0%	100%	100%
Stitch strength avg		4.11	5.60	5.96
Stitch strength min		2.24	4.70	5.16
Stitch strength std		1.04	0.39	0.45
Cpk(lsl=2.5)		0.52	2.65	2.56







Conclusion

- Wire bonding has improved significantly over its technology life
- Advanced in Cu wire bonding pushed envelope for bonding advanced packages and also enables the packaging to be cheaper
- K&S will continue improving our wire bonding technology

  As well as working on other advanced packaging technology to support the future interconnect requirement

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