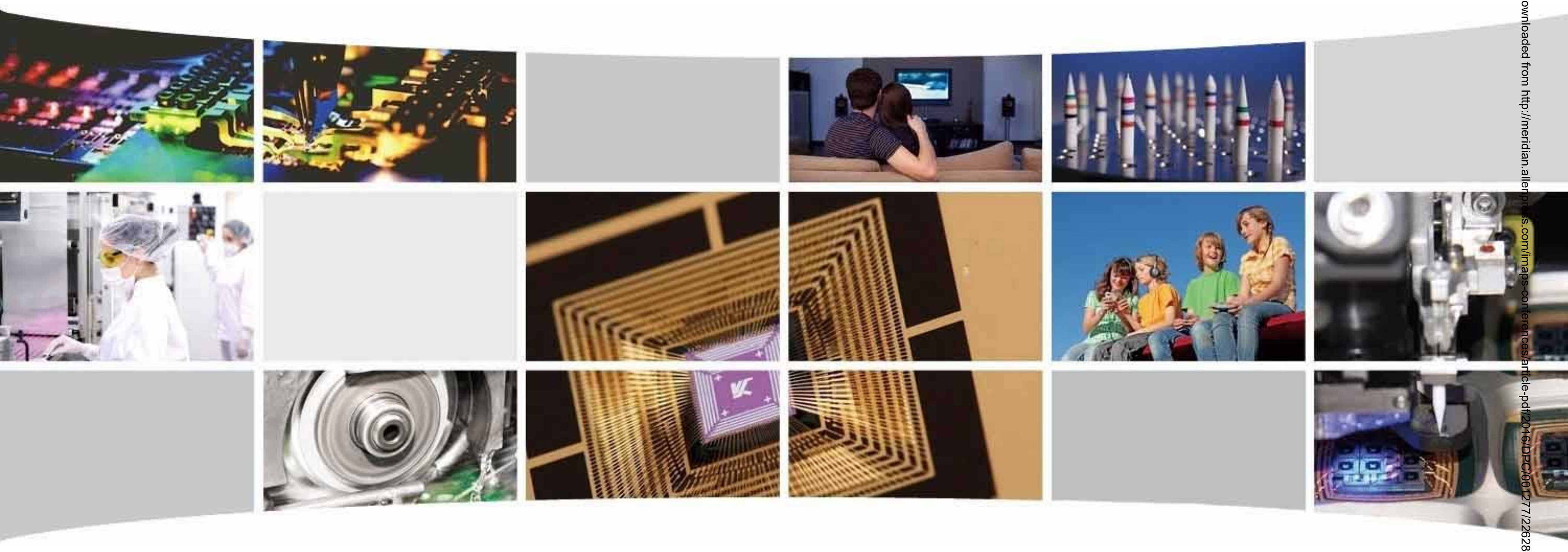

TCB Process Options to Achieve the Lowest Cost

IMAPS Die Packaging Conference
March 2016

Agenda

Technology
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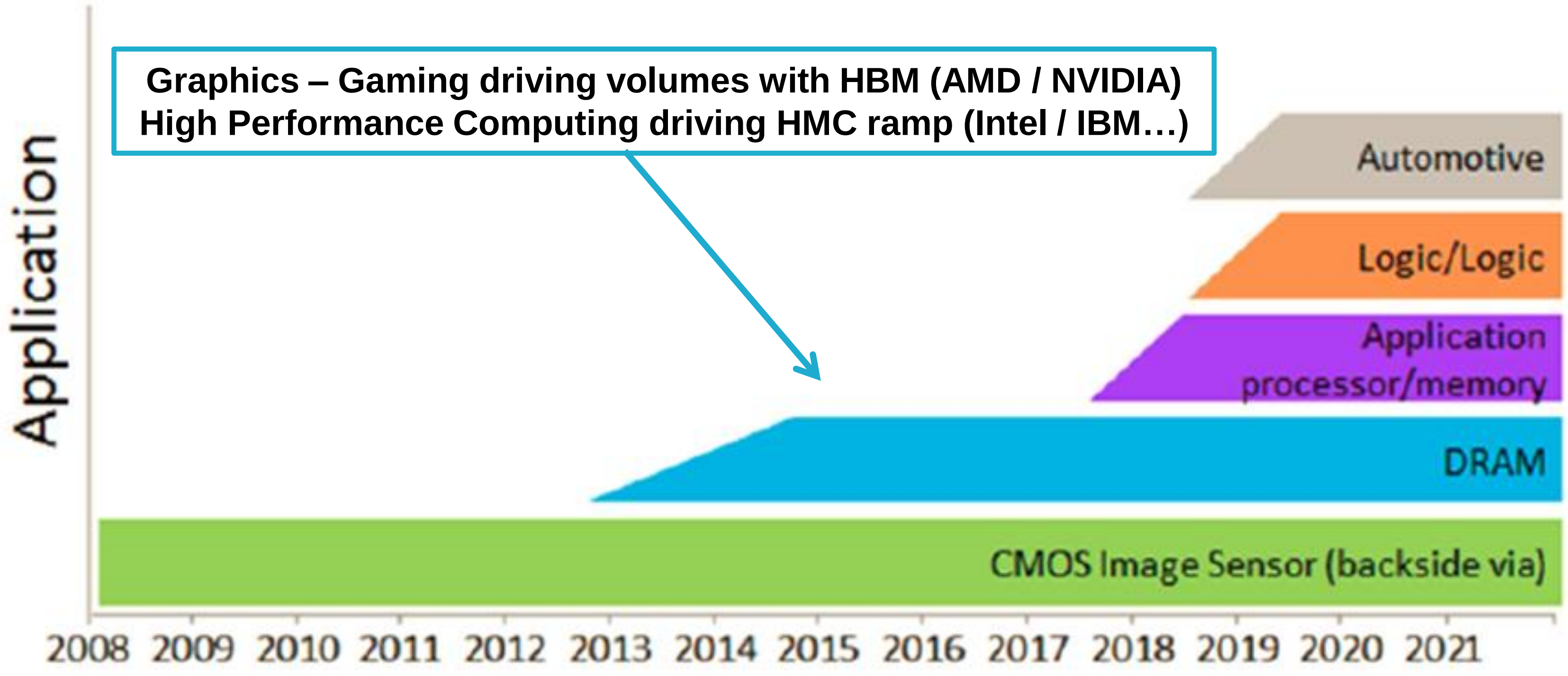
- TCB Market Information
- Drivers of Process Cost
- Types of TCB Processes and Potential UPH
- Methods to Achieve High UPH
    - Equipment design considerations
    - Process step optimization
    - Reduced range temperature cycling
    - TC-NCF process optimization for UPH
    - TC-CUF process optimization for UPH

3D IC with TSV Adoption Timeline



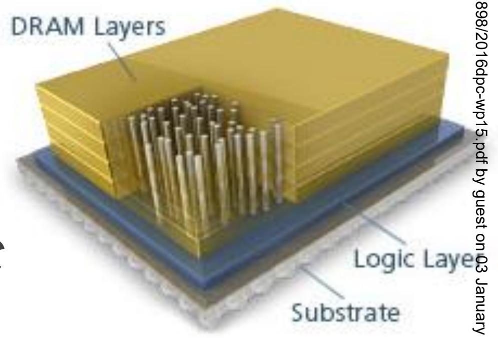
Graphics – Gaming driving volumes with HBM (AMD / NVIDIA)
High Performance Computing driving HMC ramp (Intel / IBM…)

Source: TechSearch International, Inc.

- **Image sensors with backside vias from Toshiba in January 2008, Sony CMOS image sensors + logic**
- **Tezzaron DRAM in 2013, Micron HMC, SK Hynix HBM, Samsung DIMM in 2015**
- **Logic on logic 2019 at the earliest**
- **Automotive (image sensor + logic) for safety reasons**

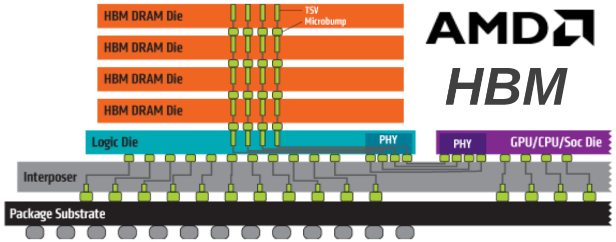
Volume Packages Using Stacked Die

- Stacked memory products are highest volume products assembled using TCB
- ***Hybrid Memory Cubes (HMC)*** are used in high-performance computing
  - High speed serial interface
  - Assembled on laminate with Chip to Substrate (C2S) TC bonders
- ***High Bandwidth Memory (HBM)*** is used primarily for graphics applications
  - JEDEC standard for high density parallel interface
  - HBM1 in volume production
  - HBM2 enabling higher bandwidth is starting
  - Assembled on interposers to enable high-density routing
  - HBM uses Chip-to-Wafer (C2W) TC bonders
  - Potential to move to C2S with EMIB



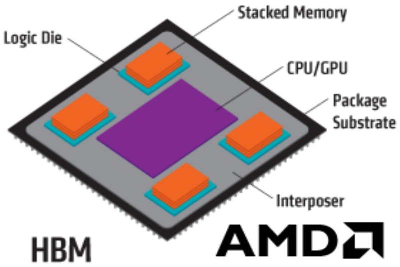
Micron

HMC



AMD

HBM



K&S Semiconductor Assembly Equipment

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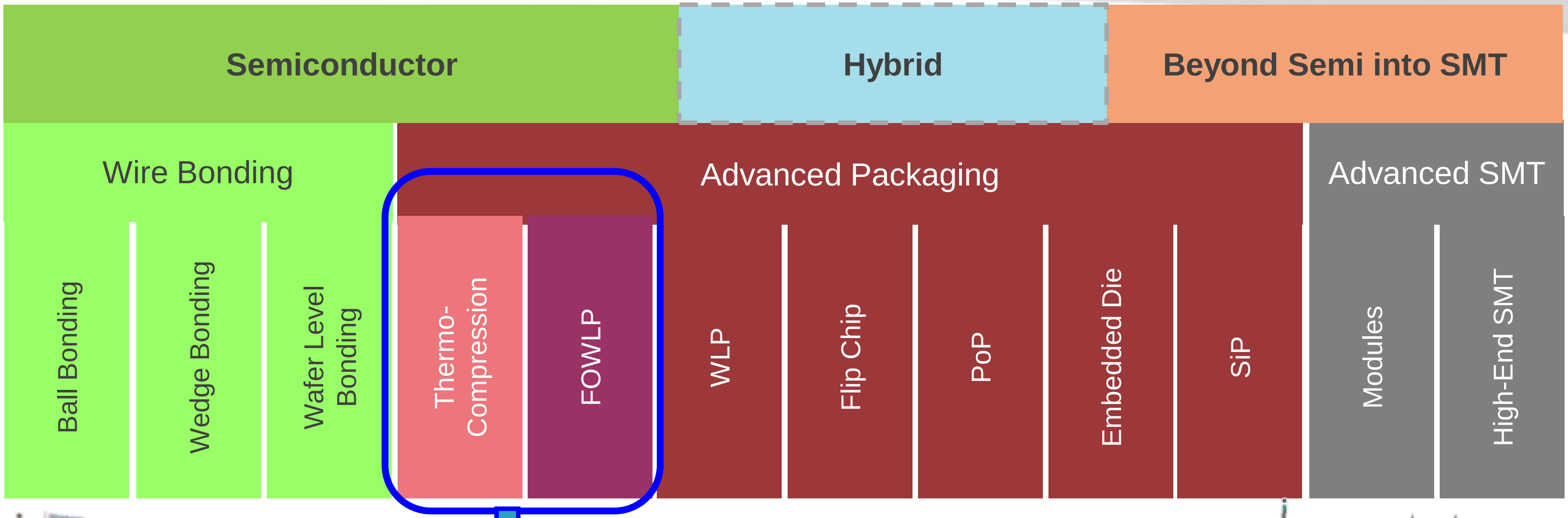

- **Semiconductor**
  - Wire Bonding
    - Ball Bonding
    - Wedge Bonding
    - Wafer Level Bonding
- **Hybrid**
  - Advanced Packaging
    - Thermo-Compression
    - FOWLP
    - WLP
    - Flip Chip
    - PoP
    - Embedded Die
    - SiP
- **Beyond Semi into SMT**
  - Advanced SMT
    - Modules
    - High-End SMT

K&S Offers the Full Range of Semiconductor Assembly Equipment

APAMA^{TM} Thermocompression Bonders

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APAMA C2S TC Bonder

APAMA C2W TC Bonder

- High UPH design of the APAMA TCB platforms enable the lowest unit cost for TCB in both C2S and C2W applications
- Chip to Substrate (C2S APAMA) is targeted at stacked die or single die on laminate *(HMC or HBM with EMIB)*
- Chip to Wafer (C2W APAMA) is targeted at stacked die or single die on wafer *(HBM or 2.5D interposer assembly)*

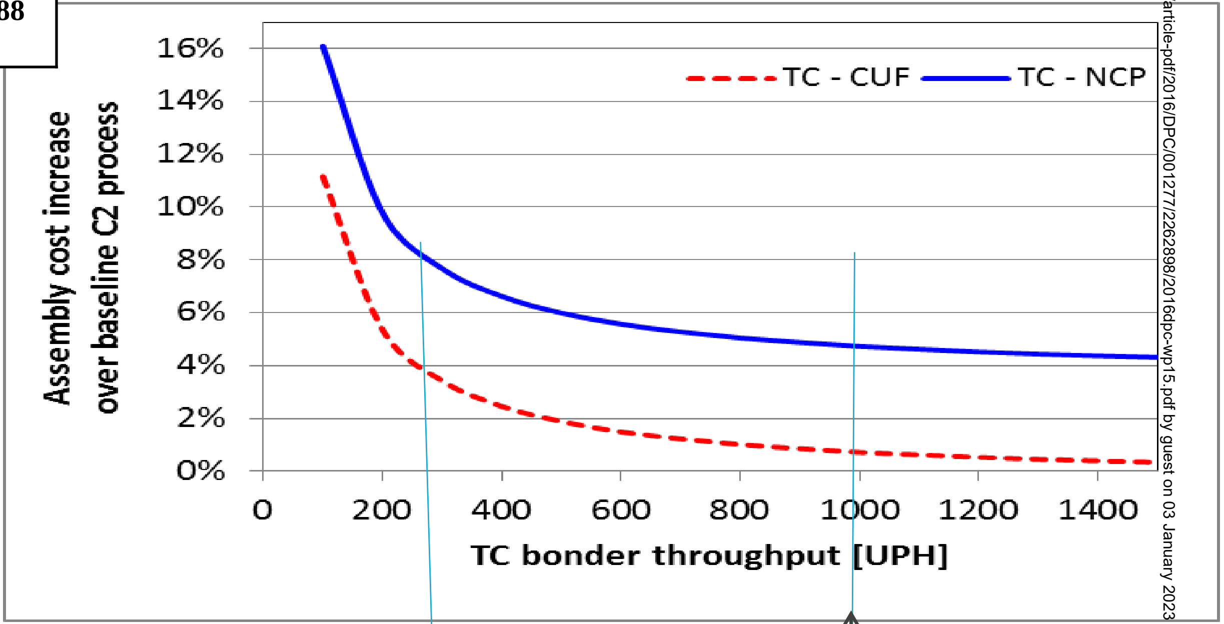
Unit Cost for TCB is Driven by Throughput

	Die	Subst.	C2/TC	Other Assem.	Total
C2 - CUF	11.96	0.58	0.77	4.33	17.64
TC - CUF	11.96	0.58	0.84	4.29	17.67
TC - NCP	11.96	0.58	1.24	4.10	17.88

Savansys Cost Model

- Results show very little difference between mass reflow cost and thermo-compression cost at high UPH
- Higher costs for TC-NCP is due to high materials cost - Material cost will go down during HVM transition

The Cost of TCB is Competitive with Mass Reflow at High UPH



Today's TC Bonders Running in Production

Small cost difference at 1000 UPH

TCB Local Reflow Process Options

Process		Advantages	Disadvantages	UPH
Pre-applied Underfill	Paste (NCP)	• Die is underfilled during TCB • Reduced die stress • Mature process	• Potential tool contamination • Void-free underfill requires dwell • Longer bond times to ensure curing	• Current 1000+ • Future 1500
	Film (NCF)	• Die is underfilled during TCB • Reduced die stress • Less chance for tool contamination than paste • Hot transfer at 150C is now possible for high UPH	• Void-free underfill requires well controlled temperature ramp • Large temperature changes may be required	• Current 1100+ • **Future 2000+**
No Pre-applied Underfill	Dip Flux	• No chance of tool contamination • Very short bonding process times • Low forces even for high bump counts	• Requires flux cleaning • Requires post-bond CUF • More stress on bonds before CUF • Cooling to < 80C at fluxing station	• Current 900+ • Future 1500
	Substrate Flux	• Fluxing process capability demonstrated • Very fast and very limited bond head temp changes per cycle	• Requires flux cleaning • Requires post-bond CUF • More stress on bonds before CUF	• Prototyped 1000+ • **Future 2500+**

High UPH process capability has been demonstrated all processes

What methods are used to achieve high UPH

Methods to Achieve High UPH

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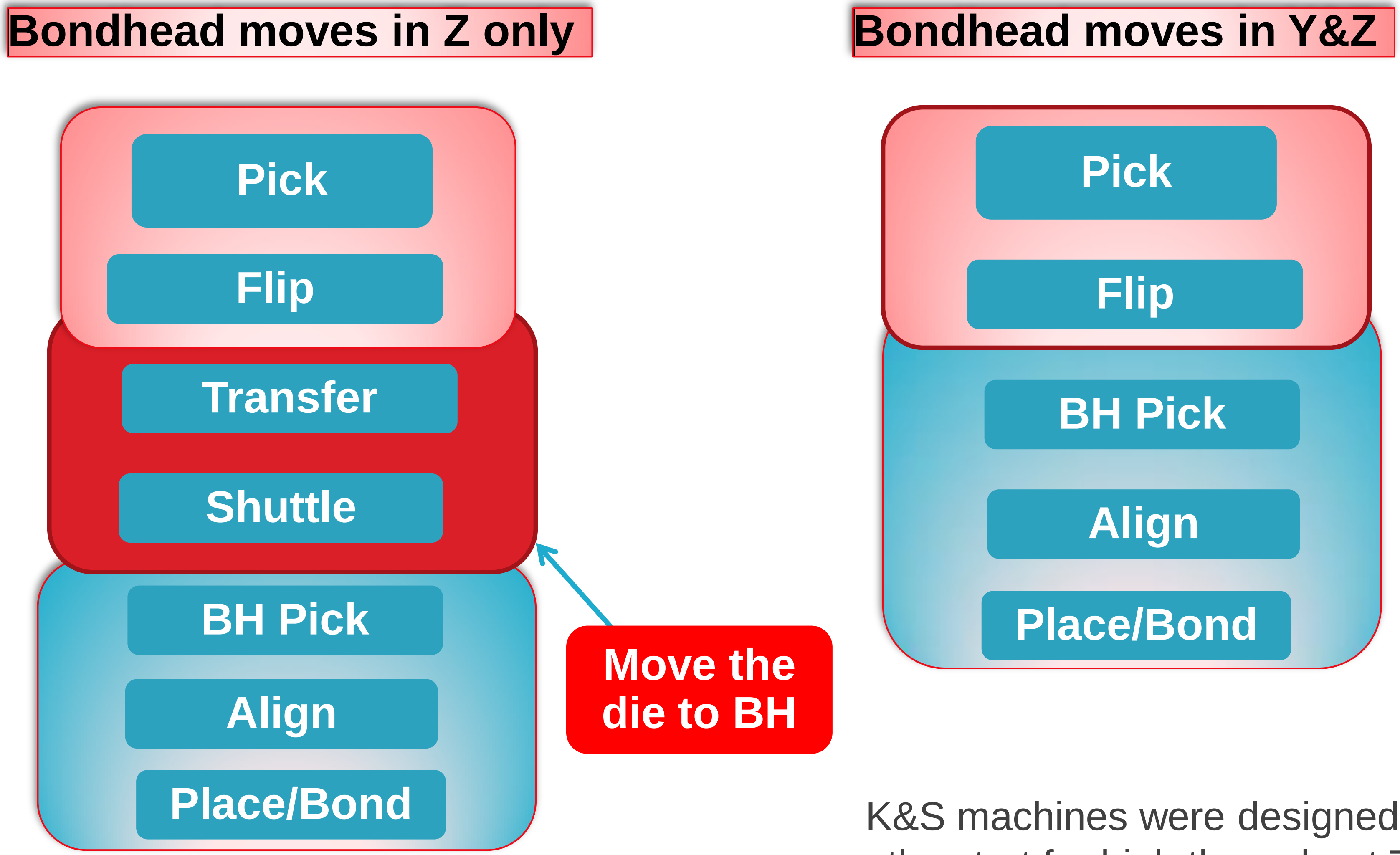
Equipment Architecture Choice
Bonding Sequences of TC Bonders



Bondhead moves in Z only

Pick

Flip

Transfer

Shuttle

BH Pick

Align

Place/Bond

Move the die to BH

Bondhead moves in Y&Z

Pick

Flip

BH Pick

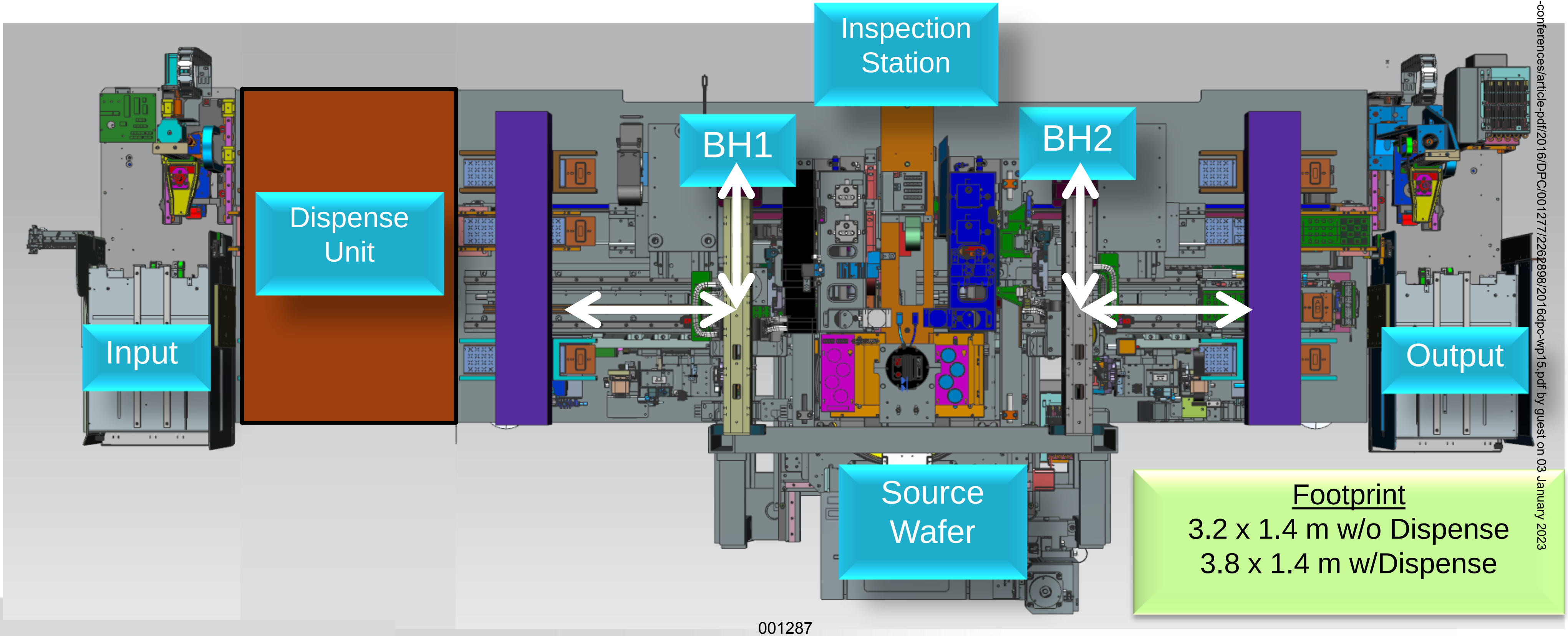
Align

Place/Bond

K&S machines were designed from the start for high throughput TCB

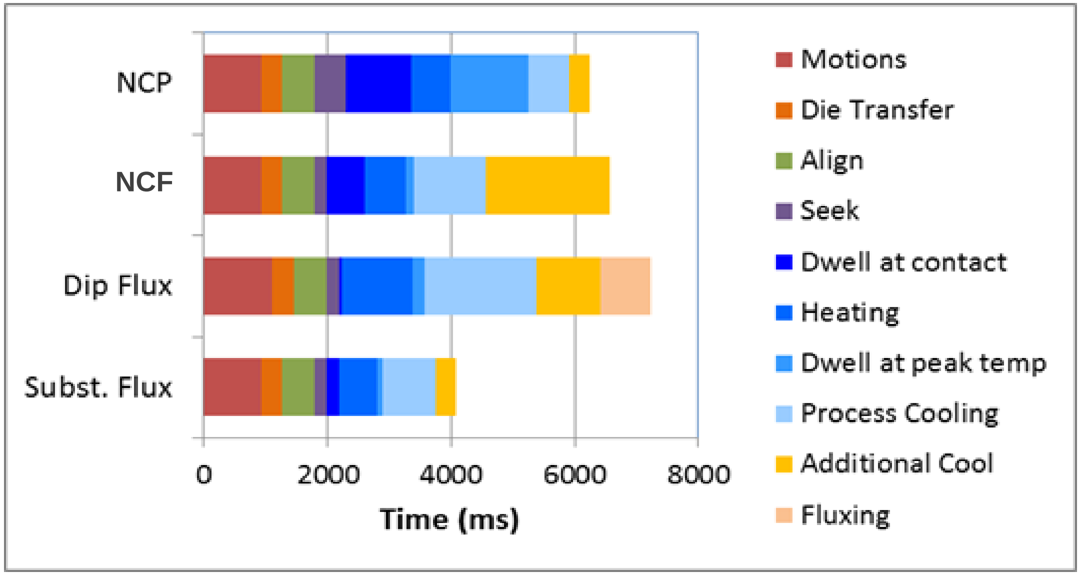
Machine Layout for C2S

- Diagram of C2S layout
- Bondhead moves in Y and Z
- Substrate moves in X



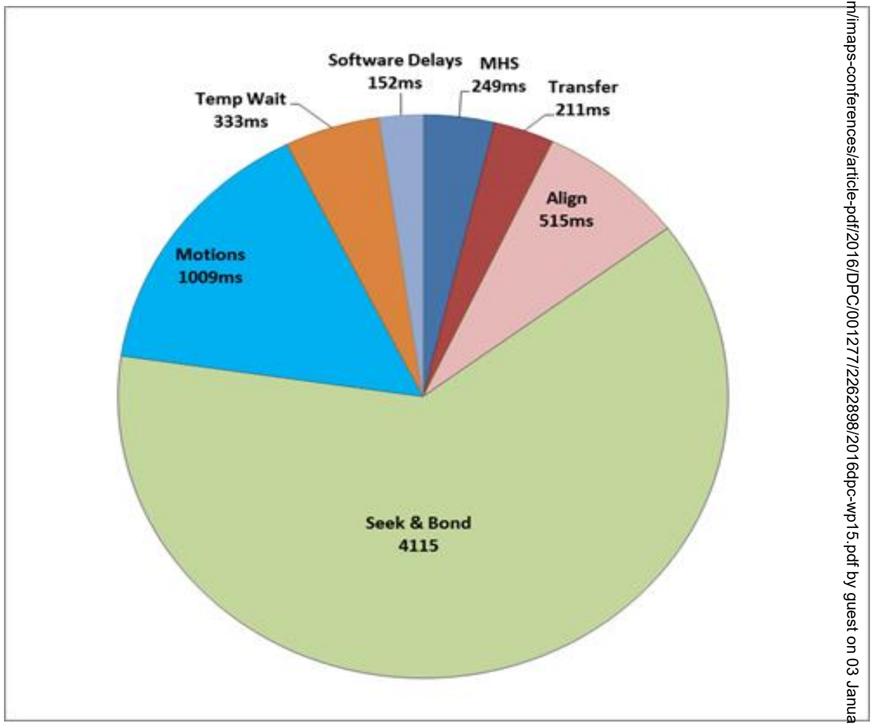
Footprint
3.2 x 1.4 m w/o Dispense
3.8 x 1.4 m w/Dispense

Process Comparison



	NCP	Underfill Film	Dip Flux	Substrate Flux
Bonding	66%	42%	47%	48%
Additional cooling	5%	31%	14%	8%
Die handling & align	29%	27%	39%	44%
Cycle time (sec)	6.3	6.6	7.2	4.1

NCP Process Breakdown



Analyze/Optimize Program Segments

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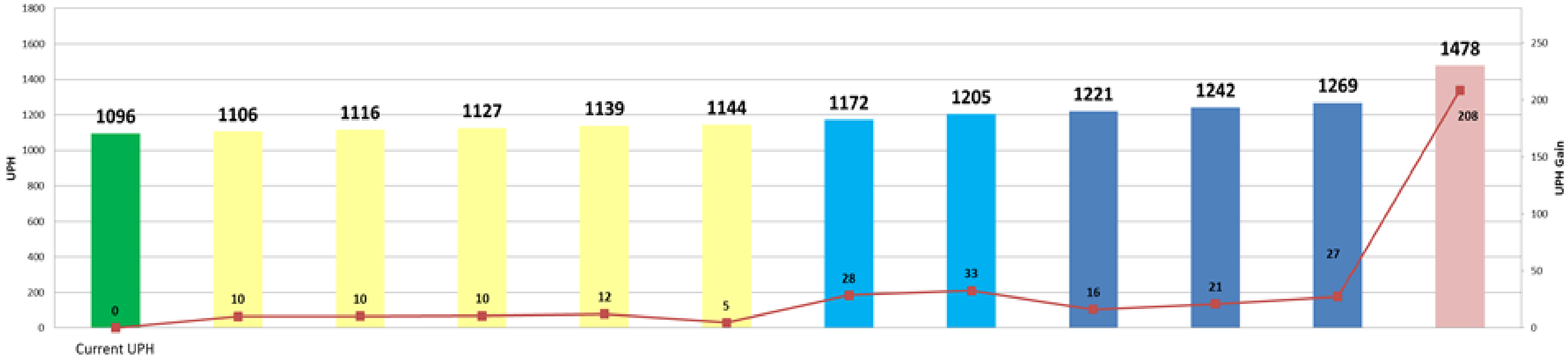
- UPH model is a good predictor of UPH performance
- Walk-up charts can be created to guide UPH optimization
- Variation in performance to the model can be investigated
- Machine logs can identify deviation in the performance and root cause for slower UPH
- *Customer processes can be modeled for UPH before running*



NCP Walk-up Chart Example

UPH Improve Features

Green -- UPH measured on A3 with Software 4.1.0.9

Yellow -- Software Improvement

Blue-- Hardware updates

Pink -- Process Optimization

Validation of Machine Performance

- Machine logs can identify deviation in the projected performance and determine root cause for slower UPH
- Discrepancies in actual performance as compared to the model are analyzed to understand root cause

Bond Process Visualizer

Left - Wafer: Strip: Col:31563346715 Row:31563346715

Zoom: All

From 00:00.000 To 00:14.219

		Channel	Value
○	☑	Temperature	79.98484
○	☑	Z-pos	-43117.032
○	☑	Controller out	1.34692
○	☑	Position error	-2.634
○	☑	Vacuum flow sensor	2.45105
○	☑	Force feedback	0.04238
○	☑	Cooling valve	0
○	☑	Vacuum valve	1
○	☑	Purge valve	1
○	☑	Var node 1	0
●	☑	Var node 15	-1
○	☑	Var node 2	0
○	☑	Var node 9	-44159.10156

☑ x-axis zoom ☑ y-axis zoom

High UPH TC Bonding

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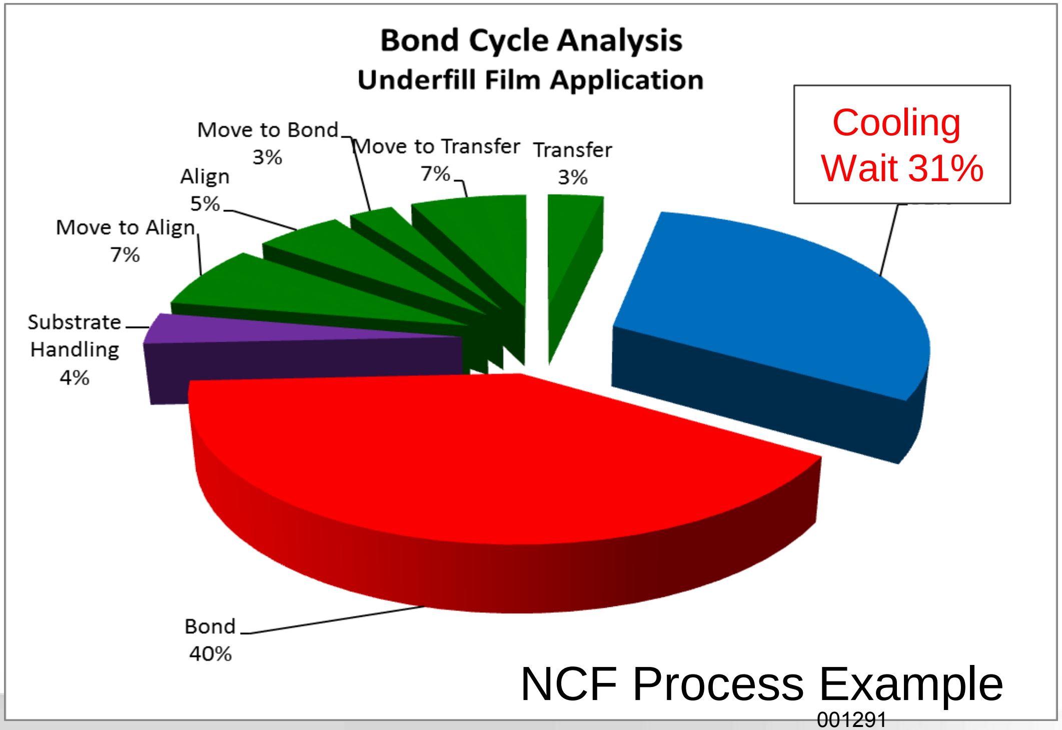
- Equipment design with optimized movement efficiency (29% of cycle)
- Maximize parallel functions in the process whenever possible
- Analyze and optimize each program segment
- *Reduce range of temperature cycling required by the bond head (71% of cycle)*
  - Temperature cycling is required for each die bond cycle
  - Reducing the range greatly improves the process UPH



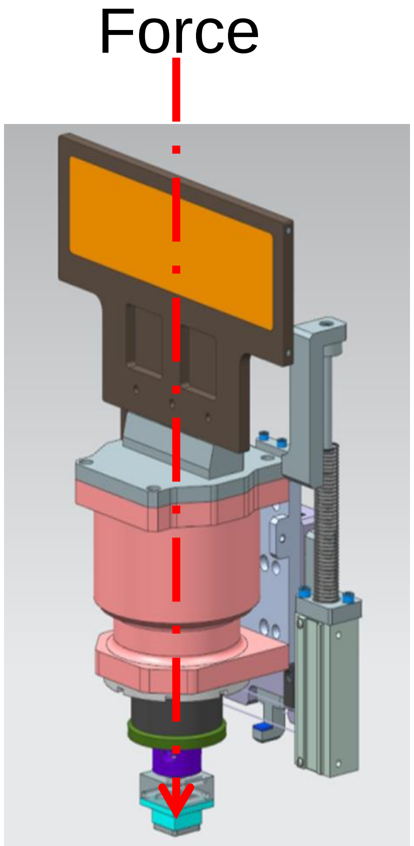
NCF Process Example

- Transfer 3%
- Move to Bond 3%
- Substrate Handling 4%
- Align 5%
- Move to Align 7%
- Move to Transfer 7%
- Cooling 31%
- Heating 40%

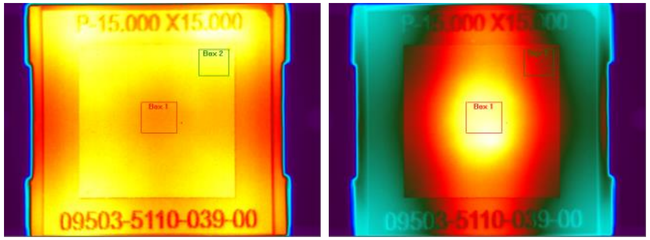
Unique Bondhead Design

Direct Drive Servo Z-Axis, Integrated Y and Z Motion

- Unique architecture with separated X and Y axes
  - Bondhead moves in Y, Z, theta
  - Eliminates handover shuttle required in Z only architectures
- Z voice coil servo replaces leadscrew for improved <u>high speed</u> motion control
- Heating at 350 deg C/sec and cooling at 130 deg C/sec
- Temperature Uniformity during Heating
  - Programmable dynamic uniformity control allows uniformity adjustment during die heating
  - Programmable center to edge temperature gradient available
  - Die with non-uniform pillar distribution can be programmed for more uniform joint temperature



Dual Zone Control for Focusing Heat to Needed Area

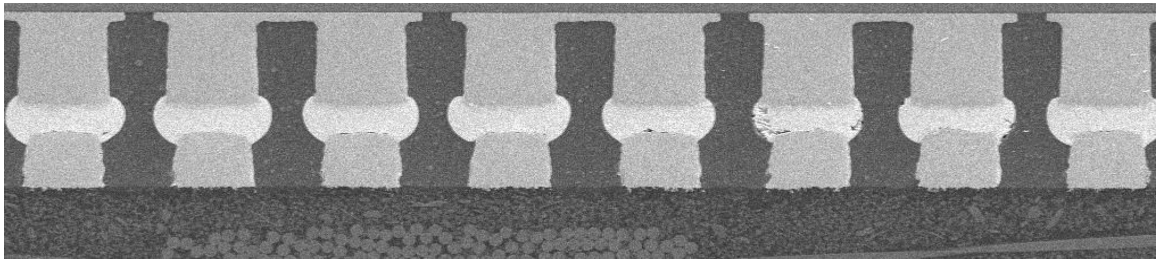


Example of Extreme Center and Edge Balancing

Process Optimization for UPH Improvement

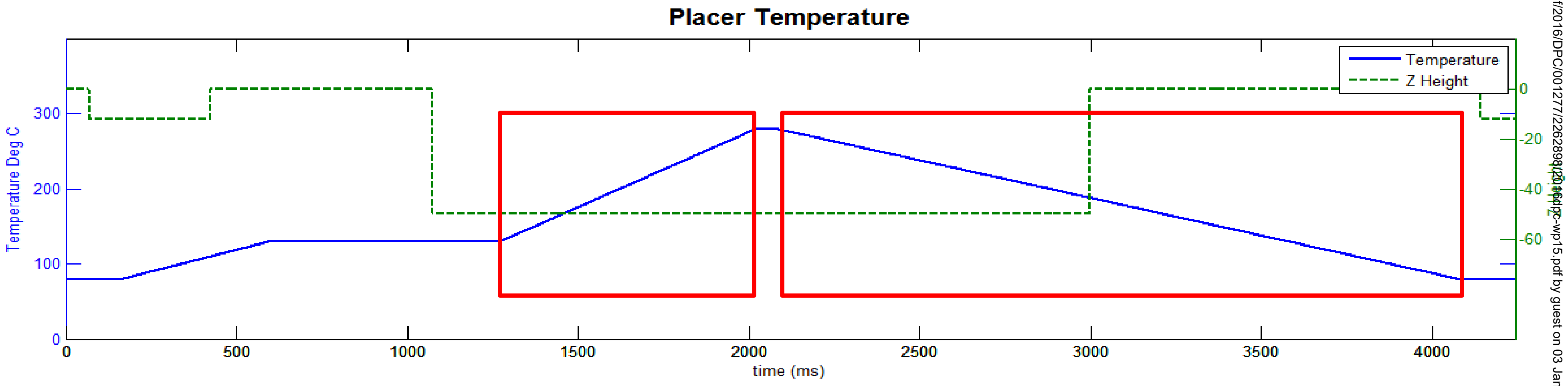
Two key approaches can improve process UPH

- Reduce temperature excursions for the bond head
  - Enable higher die transfer temperature
    - TC-CUF flux dip requires lower bondhead temp
    - TC-NCF needs lower transfer temp to prevent film damage
  - Hot touch down for TC-CUF
- Remove sequential process steps
  - Flux dip process for each die adds time



NCF Cycle with Conventional Die Transfer

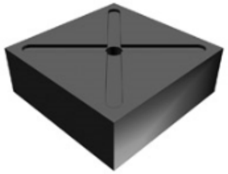
- Transfer temperature of 80^{o}C
- K&S production bonders with advanced bondhead design
    - Fast and linear heating possible (up to 350^{o}C/sec)
    - Slow and non-linear cooling (125^{o}C/sec possible)
    - Conventional TC-NCF process cooling consumes valuable process time



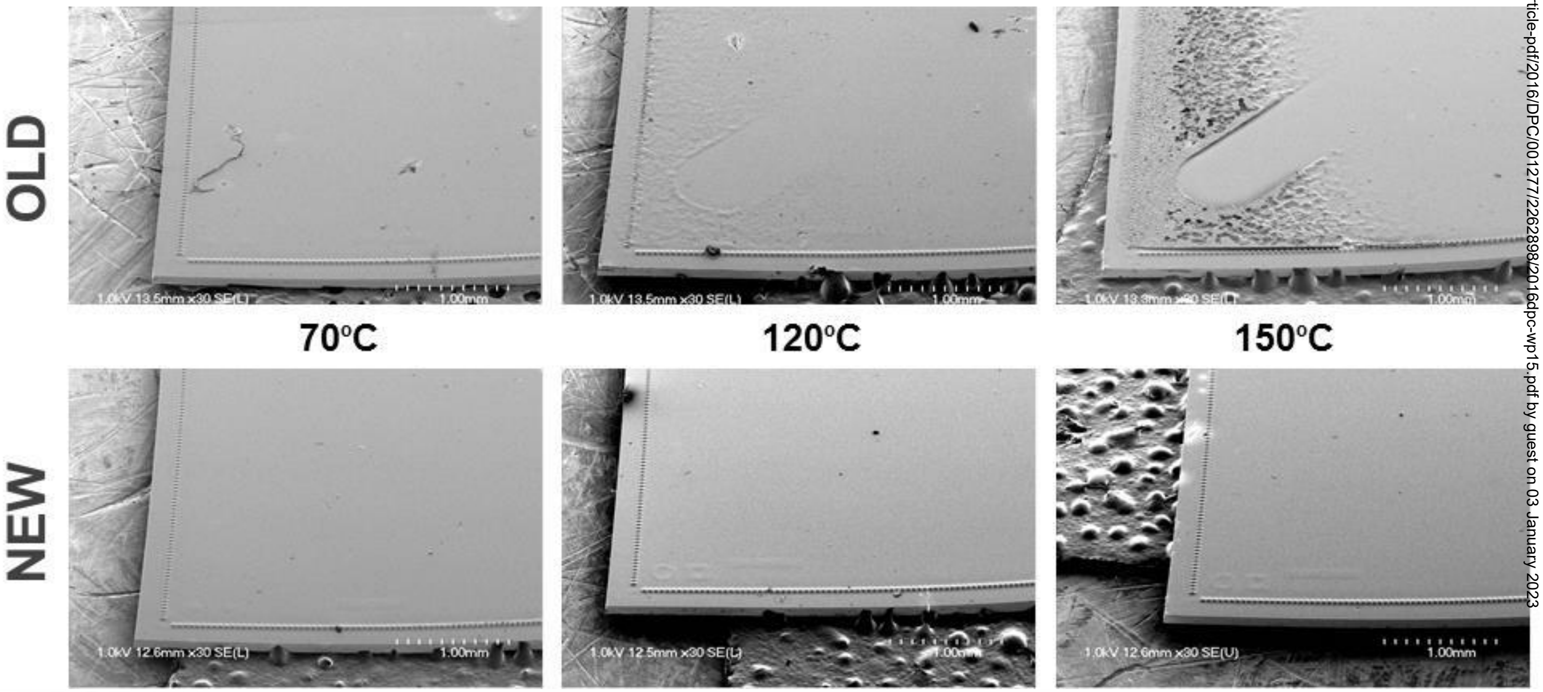
TC-NCF Process Limitations

- NCF has been limited to a die transfer temperature <80ºC to avoid handling damage to the film when it becomes tacky
- New handling techniques developed to allow the NCF to be transferred at 150ºC
- NCF UPH is improved by 500 over the same process with an 80ºC transfer temp
- This improvement enables NCF to become one of the highest throughput options for stacked die TCB or die on interposer processes

Dual Head UPH
80ºC = 1236
150ºC = 1726



Pick Tool



TC-CUF Process UPH Improvement

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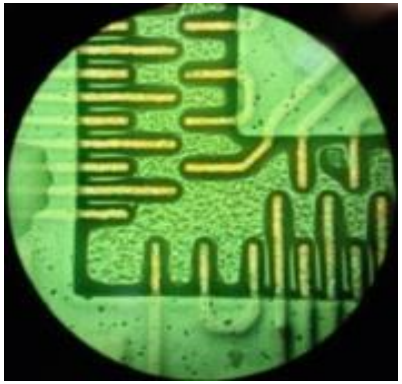
- Dip fluxing of die prior to TCB is a slow process for HVM
  - Die dipping in flux requires temperatures around 80ºC
    - Bond head temperature excursions >200ºC
  - Die dipping process is sequential to pick and bond
    - Adds >500ms to process
  - Demonstrated process with 6.9 sec cycle per unit (~1000 UPH)
- Substrate fluxing is a fast process enabling a breakthrough for TCB
  - Removing die flux dip reduces bond head temperature excursion to ~120ºC
  - Demonstrated a process with 4.8 sec cycle per unit (UPH >1500)
  - Potential to exceed 2500 UPH with higher temperature touch down

- **Two factors improve TC-CUF process UPH**
  - *Removing the sequential flux dip process*
  - *Enabling higher die transfer temperature*

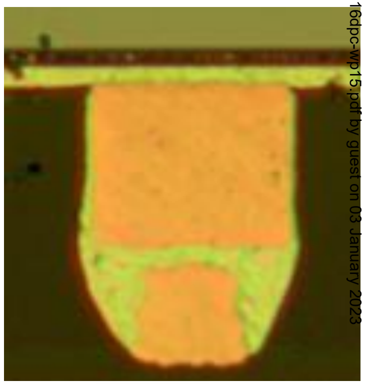
TC-CUF Substrate Flux for UPH Improvement

- Substrate fluxing has been validated using a unique printing method developed by K&S
- Method enables patterned flux printing immediately prior to bonding
- Similar flux volume to that used in a conventional flux dip process
    - Limited flux volume ensures effective flux cleaning after bonding
- Process capability has been verified thorough SEM cross-section and bump metallurgy for several key factors in the process
    - Flux volume applied to the substrate
    - Contact temperature of the die to the substrate
    - Die time at temperature prior to contact
    - Substrate time at temperature prior to bonding

Printed Flux



300ºC Bond Temp



TCB Local Reflow Process Options

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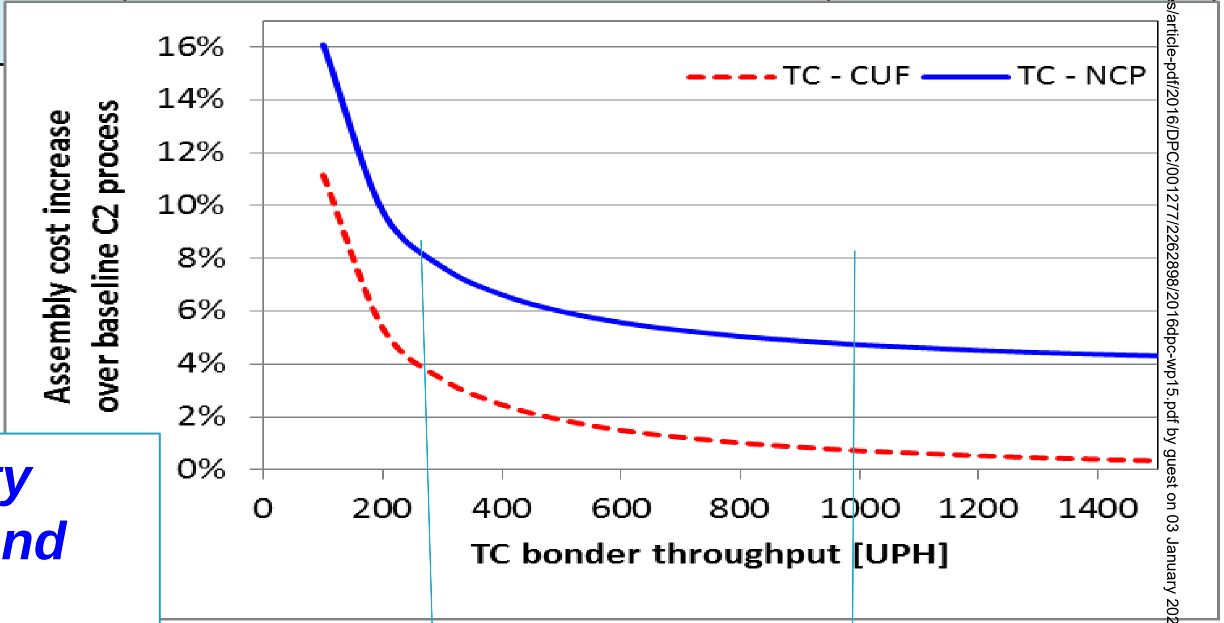
Process		Advantages	Disadvantages	UPH
Pre-applied Underfill	Film (NCF)	• Die is underfilled during TCB • Hot transfer at 150C is now possible for high UPH	• Void-free underfill requires dwell • Large temperature changes required	• Current 1100+ • **Future 2000+**
No Pre-applied Underfill	Substrate Flux	• Fluxing processes demonstrated Very fast and very limited bond head temp changes per cycle	• Requires flux cleaning • Requires post-bond CUF • More stress on bonds before CUF	• Prototyped 1000+ • **Future 2500+**



High UPH Process Capability Demonstrated for both NCF and Substrate Flux Processes

Today's TC Bonders Running in Production

Small cost difference at 1000 UPH

Thermocompression Bonder Specifications

Process Requirements	Specification 2015	Specification 2016 (EOY)
Thin die handling (TSV 10:1) Die thickness	≥ 35 um	≥ 30 um
Fine pitch Cu Pillars Accuracy	± 2.0μ, ±20 mdeg, post bond (3σ) ±1.0μ, ±10 mdeg, glass die (3σ)	± 1.5μ, ±15 mdeg, post bond (3σ) ±1.0μ, ±10 mdeg, glass die (3σ)
Cu Pillar Stacking Planarity	2μ / 10mm	2μ / 20mm
Bondhead Size	26x26mm	38x38mm
High force capability	0.5 to 300N	0.5 to 500N
Process Control Force Accuracy	0.25N or 1% (whichever larger)	0.25N or 1% (whichever larger)
Bond Line Thickness Z-Height Resolution	± 1.0μ (with temperature compensation)	± 1.0μ (with temperature compensation)
Low COO – Productivity	Heat Ramp: 200 C/s	Heat Ramp: 350 C/s
	Cool Rate: 100 C/s	Cool Rate: 150 C/s
	Dry Cycle: <1.5 sec	Dry Cycle: <1.3 sec
	Sprint UPH: 3000 DH	Sprint UPH: 3500 DH
Yield and Metrology	Die crack detection Contamination inspection Post bond overlay	Die crack detection Contamination inspection Post bond overlay

Chip to Substrate Bonder

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Summary

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- K&S has developed the next generation thermocompression bonder to enable cost-effective, high performance packaging
- Methods to Achieve High UPH
  1. Equipment design considerations
  2. Process step optimization methodology
  3. Impact of temperature cycling for each die
  4. Process optimization through reduced temperature range and higher die transfer temperature
     a) TC-NCF process at 2000 UPH
     b) TC-CUF process at 2500 UPH

APAMA™

MORE THAN BONDING

Advanced Packaging with Adaptive Machine Analytics