Die Stacking: Cost and Reliability Implications

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CPMT/SCV Dinner
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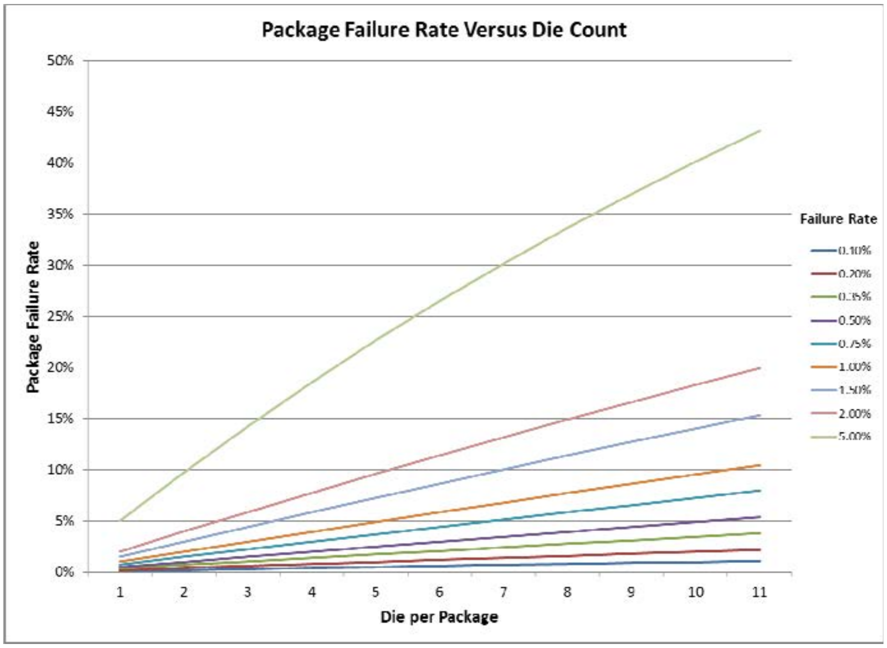
AEHR TEST SYSTEMS

Agenda

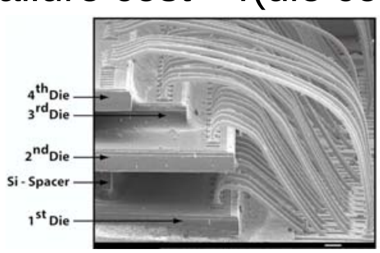
- Reliability Implications of Stacked Die
- Known Good Die (KGD)
- Application case studies re: benefit of Wafer-Level Burn-In (WLBI)
- Automotive case study: Hall-Effect Sensors
- Conclusions



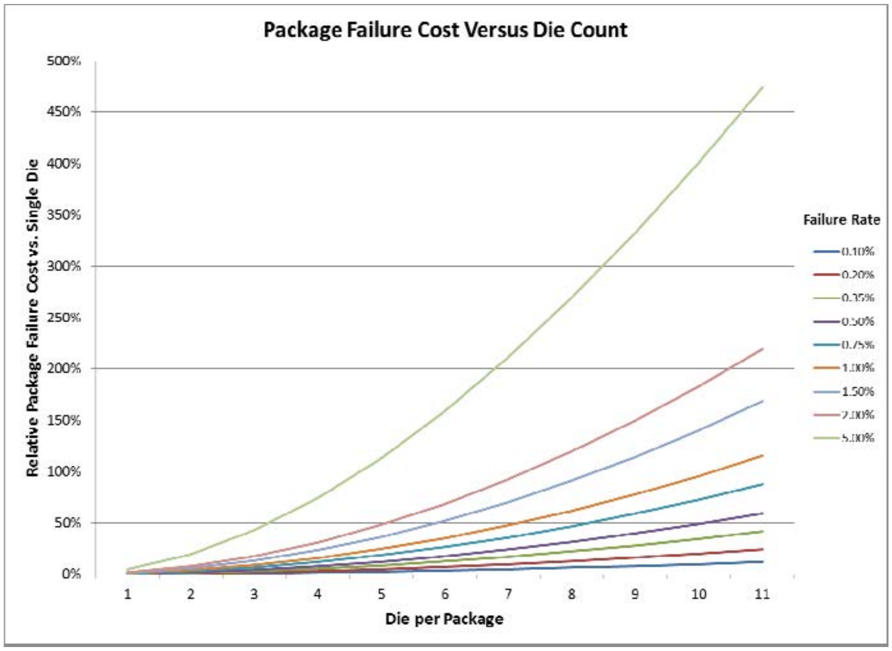
Cost Versus Reliability Tradeoffs for Stacked Die 3

Cost of Failure

- Module failure rate = *f*(die count)
- Module cost = *f*(die count)
- Failure cost =
  (Module failure rate) * (Module cost)
- Failure cost = *f*(die count^2)



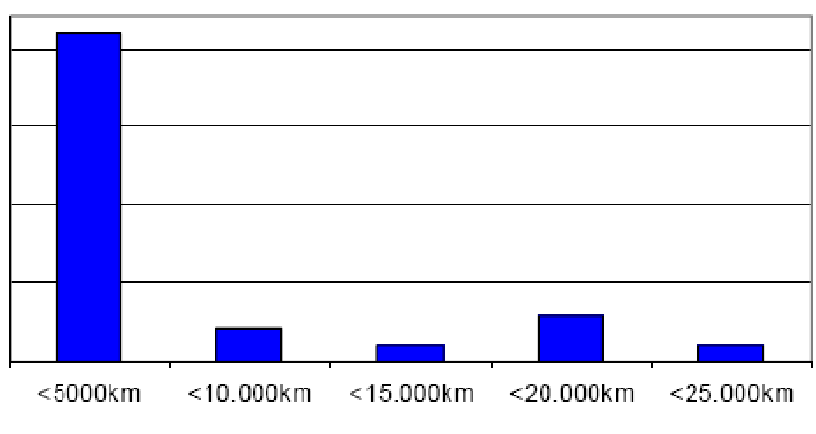
From KGD 2005: Reducing Burn-In Costs for KGD 4



Cost Versus Reliability Tradeoffs for Stacked Die 5

WLBI Motivation

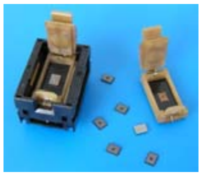
75% of failures occur before 5000km



From BiTS 2009: Wafer-Level Burn-In of Hall-Effect Sensors 6

Known Good Die

- Die which have been fully burned-in to remove infant mortality
- Burn-in options:
  - – Use tester and step across wafer in 1 to "n" steps
    - Cost effective only if using existing equipment
  - – Temporary die packaging
    - Good solution for low volumes
  - – Wafer-Level burn-in
    - Best for high volumes



Cost Versus Reliability Tradeoffs for Stacked Die 7

Application Analysis Objective

- To determine what factors affect the decision whether or not to burn-in a device
- Compare burn-in benefit versus cost across several different applications
- All scenarios assume DRAM type parts for consistency
  - – Analysis applies to all types of devices

Cost Versus Reliability Tradeoffs for Stacked Die 8

Tradeoff Assumptions

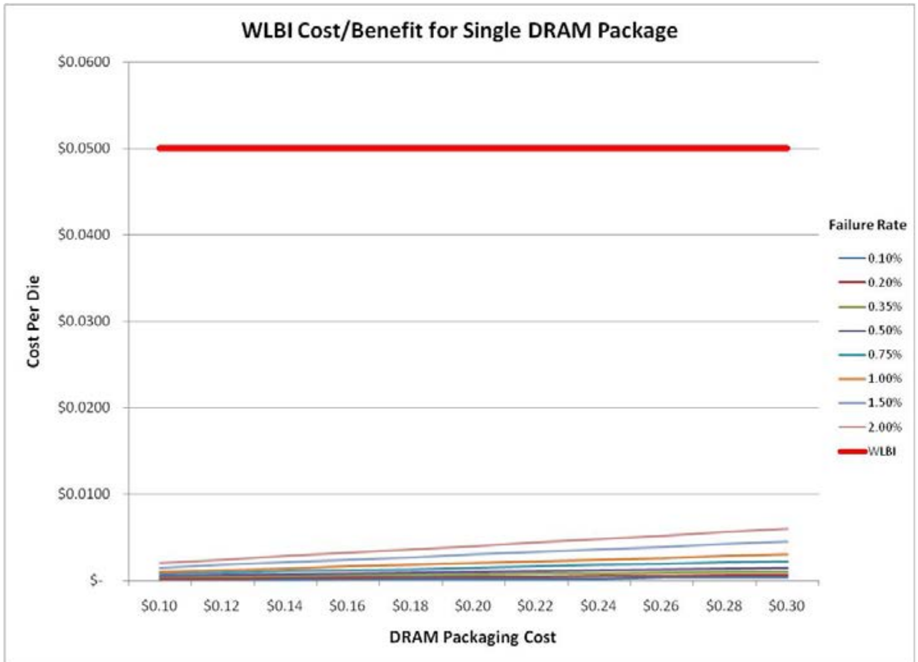
- Leading edge DRAMs estimated as 750 die per wafer and about $2 each
- Other DRAMs estimated as1500 die per wafer and about $1 each
- All failure rates are improvement due to burn-in

  = Non-Burn-In failure rate – Burn-In failure rate
- Wafer-Level Burn-in (WLBI) cost estimated as
  - 5 cents per die for leading edge DRAMs
  - 2.5 cents per die for other DRAMs

Simple DRAM Scenario

- Single, leading edge DRAM die
- Single die, FBGA package
- Model Cost per Die versus
  - WLBI reliability improvement
  - Packaging cost
- Analysis ignores implications of failure

Source: Digikey



Cost Versus Reliability Tradeoffs for Stacked Die 11

Simple DRAM Observations

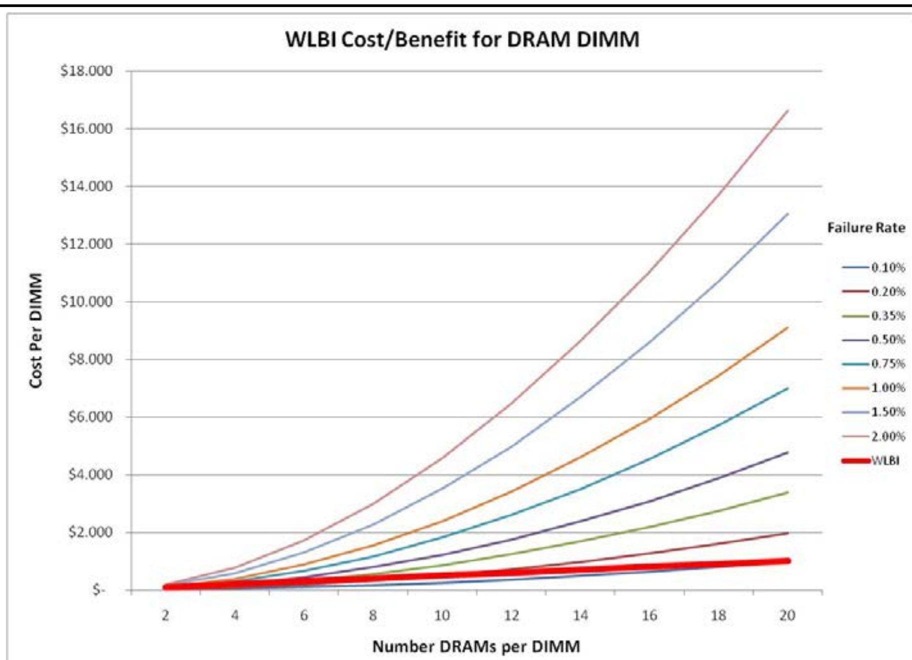
- Failure cost savings are quite small
  - Failing die would have been thrown away
  - Cost savings is in avoiding packaging early failure die
  - WLBI would cost much more than savings
- Other implications of failure would be MUCH higher, but ignored in this analysis
  - Downstream product failures
  - Bad customer relations

Cost Versus Reliability Tradeoffs for Stacked Die 12

DRAM DIMM Scenario

- DRAM DIMM with multiple die
  - – Assumes no post-assembly repair
  - – Failure of a die causes loss of DIMM
  - – WLBI cost estimated as 5 cents/die
- Model Cost per Die versus
  - – WLBI reliability improvement
  - – Number of die per DIMM

Source: Digikey



DRAM DIMM Observations

- Failure costs of DRAM DIMM are much higher due to:
  - Any die failure causes good die to be thrown away, “One bad apple spoils the barrel”
  - Failure cost is related to the square of die count
- WLBI very cost effective in most cases
  - WLBI cost linear with die count
  - More cost-effective as die count increases

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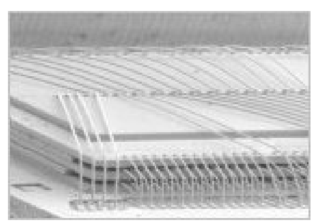
Stacked Die Scenario



Source: STATS ChipPAC

- Stacked package with:
  - $20 microcontroller chip
  - 2 flash die @ $5 each
  - 1 to 10 simple DRAMs @ $1 each
  - $5 packaging cost
- Model Cost per Die versus
  - DRAM WLBI reliability improvement
  - Number of DRAMs in the stack
- Note: only DRAM failures considered

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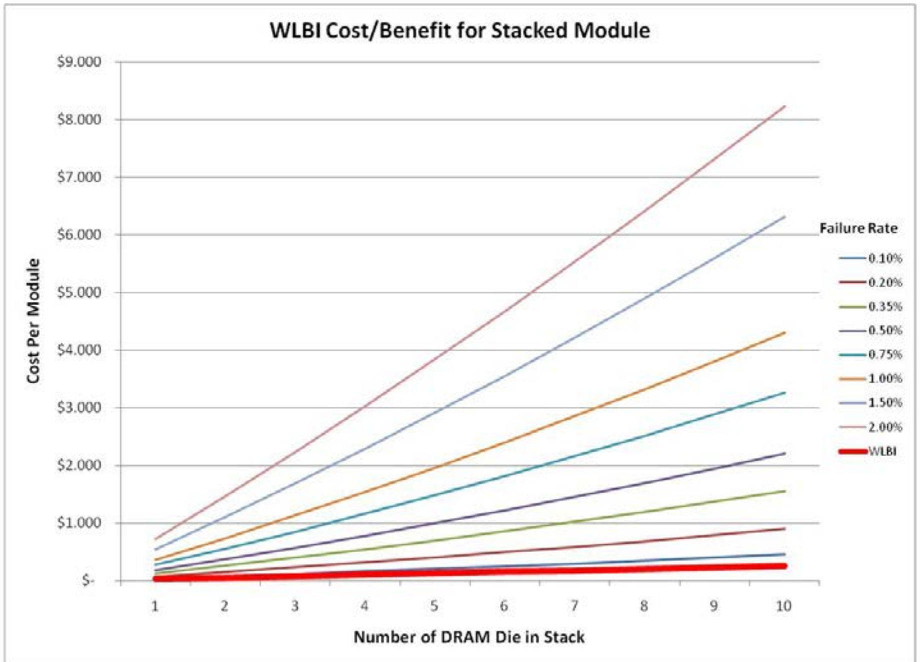

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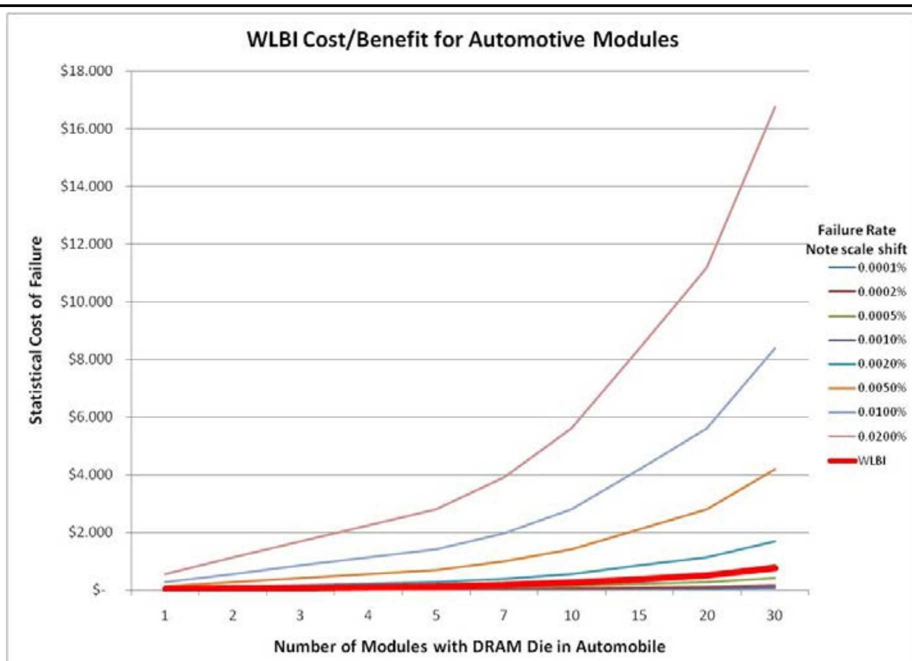
Stacked Module Observations

- Failure costs of stacked module start out much higher due to:
  – Any DRAM die failure causes entire module (including other die) to be lost
- Failure cost is more linear for same reason
- WLBI can be very cost effective
  – Even if DRAMs are a very small fraction of module cost

Cost Versus Reliability Tradeoffs for Stacked Die 18

Automotive Module Scenario

- Simple modules with small DRAM die
- Cost of failure to manufacturer estimated as:
  - $300 warranty repair bill for parts & labor
  - 10% decrease in customer likelihood to buy same brand again
  - Car price for model: $25,000
  - $2800 total cost of failure
- Note major shift in assumed DRAM reliability!



Automotive Observations

- The end application can highly affect the demand for highly reliable KGD
- Even extremely reliable modules may be insufficient
  - Even single digit PPM may be too high
- WLBI very cost effective in most cases
  - Even if DRAMs are a very small fraction of module cost

Application Conclusions

- If any of the following are true, then WLBI is likely to be very cost-effective:
  - Many die in a non-repairable assembly
  - Module contains high valued die
  - If the application has a very high cost of failure
- WLBI effectiveness is typically not dependent upon the die's cost

Automotive Case Study

- Automotive Challenges
- Why Hall-Effect Sensors
- Motivation for WLBI
- Conclusions

Automotive Environment

- Temperature extremes
  – Closed car in summer sunshine
  – Empty car at night in Northern climates
- Vibration
- Abrasive dirt & dust
- Solvents (oil, gasoline, etc.)
- High humidity, Moisture

Hall-Effect Sensors

- Provide sensing of
  - Contact (like a switch)
  - Position (like a potentiometer)
- Sealed
- No abrasive wear
- Simple, highly reliable

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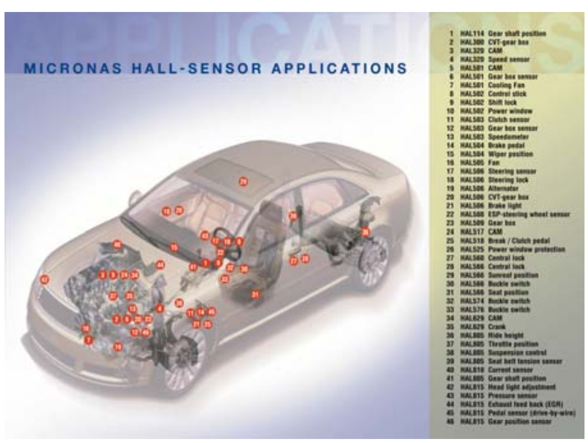
Hall-Effect Sensor Applications



- **Hall-Sensors used in dozens of switch and position applications**
- **Critical: brake switch, speedometer, cooling fan, etc.**
- **Convenience: ride height, suspension control, seat position, etc.**

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WLBI Motivation

Micronas zero ppm program

- Targets:
  - – No failures on customer side
  - – Satisfy automotive quality requirements
  - – Improve continuously
    - Products
    - Production
    - Personnel
    - Processes

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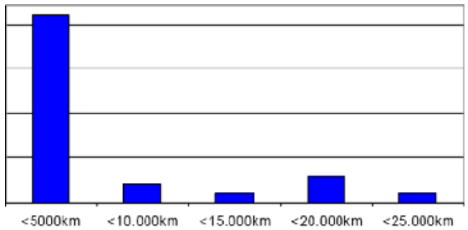
WLBI Motivation

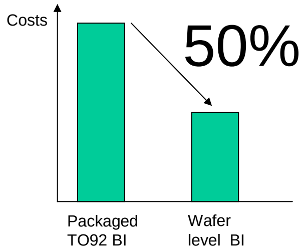
Eliminate early failures …

to improve initial quality …

by burn in on wafer level

75% of failures occur before 5000km





Minimize burn in costs…

to achieve industry best cost level…

by burn in on wafer level

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WLBI

- Burn-In to reduce infant mortality
- WLBI versus packaged part burn-in
  - Wafer versus packaged part handling
  - Burn-in before packaging
  - Shortened BI time by higher temperature
  - Failure traceability to wafer and die
  - Known Good Die applications
    - Smaller combined package size
    - Stacked, unserviceable packages

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Known Good Die Process

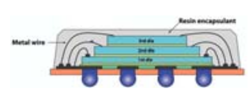
Wafers In

WaferPak Loader

WaferPaks

WLBI System

KGD Wafers Out



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Automotive Conclusions

- Hall-Effect Sensors are critical to the reliability of modern automobiles
- Burn-in is critical to improve the reliability of Hall-Effect Sensors
- WLBI is the most cost-effective burn-in methodology for Hall-Effect Sensors

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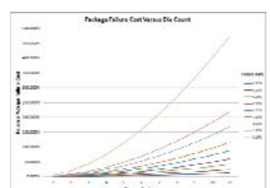
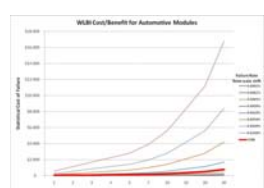
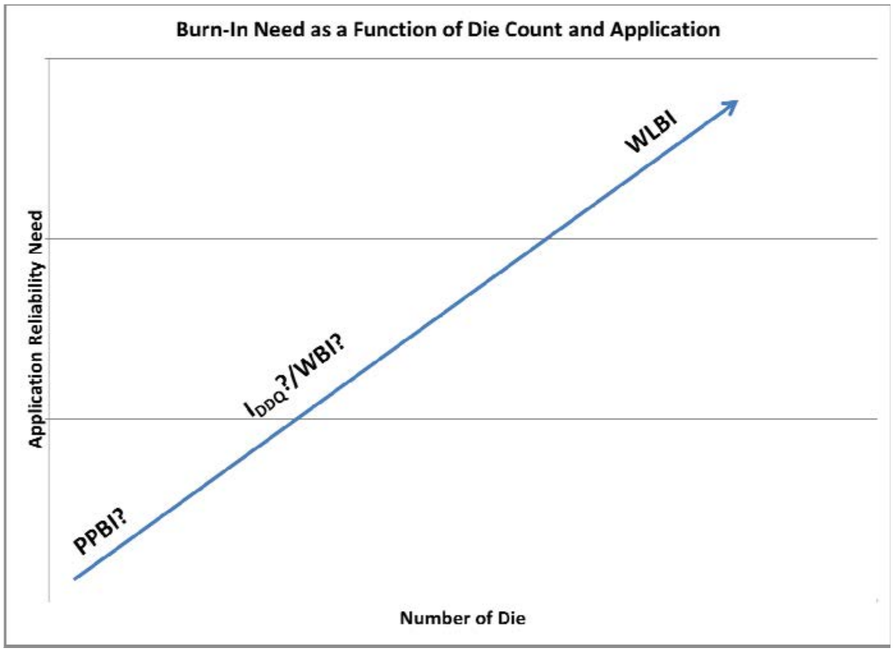
Conclusions





- Reliability Implications of Stacked Die
  - Need Known Good Die (KGD)
- Application study
  - Application determines reliability requirements
  - Critical applications require HIGHLY reliable die
- Automotive case study
  - WLBI cost effective for 0 ppm

Cost Versus Reliability Tradeoffs for Stacked Die 32



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Acknowledgements

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