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Design, Diagnosis, and Digitization for Efficient System Test and Analytics to Accelerate Time to Quality across the End to End Value Chain

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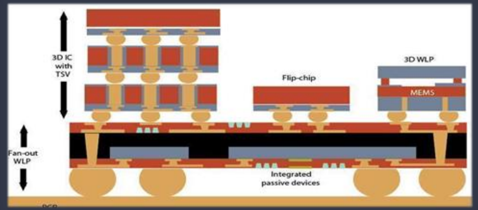
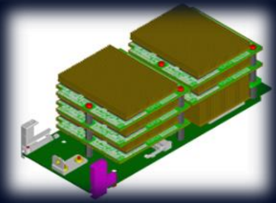
Areas of Discussion

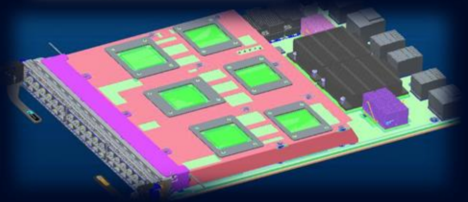
- KGD life over End-To End (ETE) Value Chain
- Where can KGD become Known Bad Die (KBD)
- Why KGD become KBD
- How to alleviate the problem
  - Orchestrating across multiple domains
  - Facilitating co-optimization with other components
  - Extending characterization
  - Expected results
  - ETE Analytics

Known Good becomes Known Bad



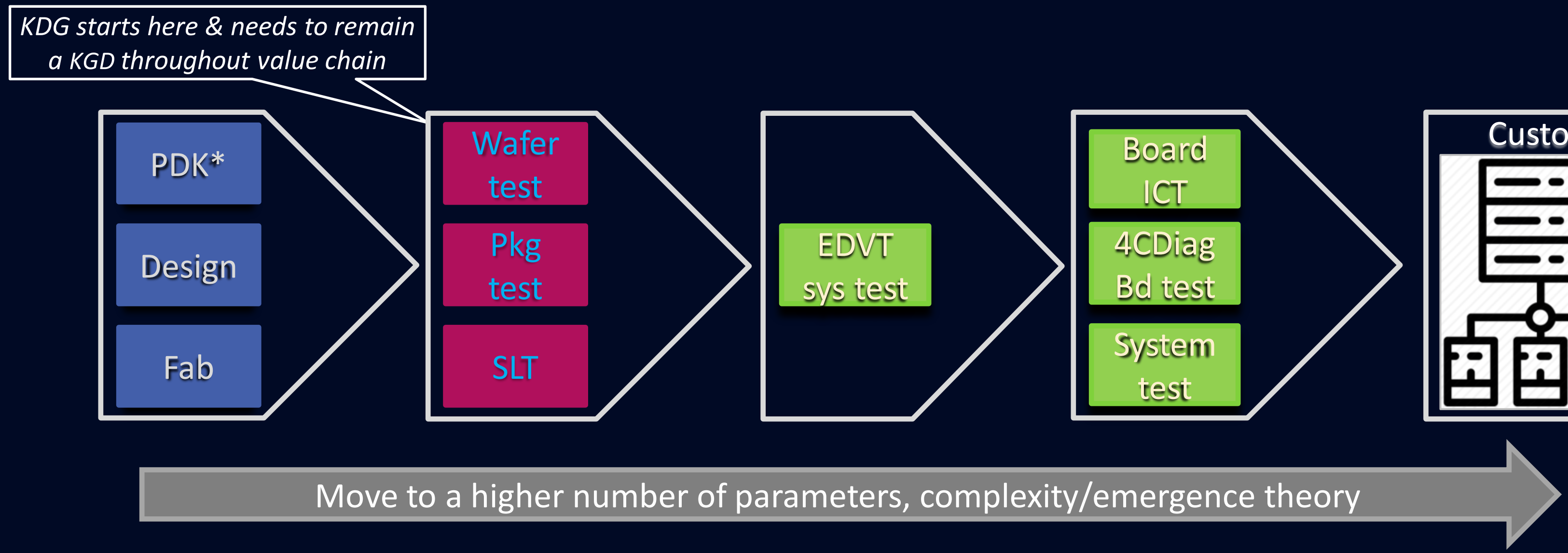
- You test for a KG ‘something’ at any point in the ETE test flow.
  - You start with KGD, KGStack,
  - KGD in package/module,
  - KG part on board, KG part in system,
  - KG at customer in the ETE value chain.
- What is KG at one point, may not be good at the next step:
  - Can you detect it isn’t?
  - If you can detect it, can you diagnose it?
  - Why does this happen?
  - From the diagnosis are you able to drive detection earlier to previous step or steps?
  - How can you avoid this in future?





ETE Value Chain Mapping - Technically

- We are operating in the multidimensional Value Chain.
- It is not just about our small space and what we do.
- Influence is from design to end product at customer
- It is about execution up and down the ETE value chain.



‘Complex’ system transpires where KGD behavior outcomes are affected by multiple dependencies. Emergence is coalescence of data into something meaningful.

*PDK – physical design kit, ICT – in-circuit test, EDVT – engineering design validation test, 4C diag bd test – diagnostic board test

Examples of What can go Wrong

Fab process	• Design vs wafer process interaction
WaferTest	• Design vs package process interaction • No coverage of package, chip to chip interfaces, different thermal/voltage map
Package/ Heterogeneous/ Stack Test	• Test + temperature/power/voltage map does not fully represent system • Limited functional coverage, PS/cooling ATE/system mismatch
SLT	• Margin assessment possible, lacks full system interoperability. • Supplier bases development on limited set of specs from foundry that may not fully extend to manufacturing flow and environment in customer application + degradation requirements
System Testing	• Functional test - first observation of interactions spawn more fails. • Degradation effects observable

Each step widens interaction of die in environment, new parameters/settings can affect die performance.
Complexity Theory/Emergence: properties/behaviors emerge only when parts interact in a wider whole.

ETE Value Chain Mapping - Relationally

Moving to a higher number of technical parameters is one dimension

Another dimension complementing technical is relational

- Goal clarity: Plan upfront with ETE in mind.
  - Plan across domains. Build a common language. Be credible, sell proposal that is a win-win.
- Building a Guiding Coalition.
  - Build relationships for active Collaboration across all product functions (IP, design, test, yield, product dev, Q&R) to co optimize for performance, TTM, cost.
- Orchestrate Cross-Functionally and Outside-In.
  - Define Shared metrics with the end product in mind.
  - Enable data flow from the product (test, field) to supply chain to co-optimize process control and future design
- Embrace New Technologies. Test and Learn.
  - The greatest value in end-to-end supply chain projects are fueled by decision support technologies, cognitive learning and visualization analytics.
  - These are the infrastructures needed to sense, adapt and respond. They drive agility

Diagnosis Through Parameters & Data

- Parameters - if not ‘spot-on’ or ‘addressed ’ effect yield, quality, and performance:
  - Power / Power Integrity, thermal map
  - On die voltage map, noise margin, voltage bin
  - Signal Integrity (die/package), resistance, timing (margin)
- This drives the need for:
  - Fault isolation to sub-die
  - Margin matching across test steps and chip to chip, board to board
  - Thermal/noise measurements at all test steps
  - Reliability compliance
  - WS data* as feedback to foundry for improved process target and yield
  - Data to create best matching (voltage bin, power, etc) with other dies
  - Voltage/Noise marginality to comply with system PS requirements
  - Thermal map/resistance data to identify compliance with thermal map of other dies and system thermal solution

*ATPG, Functional, On die sensor

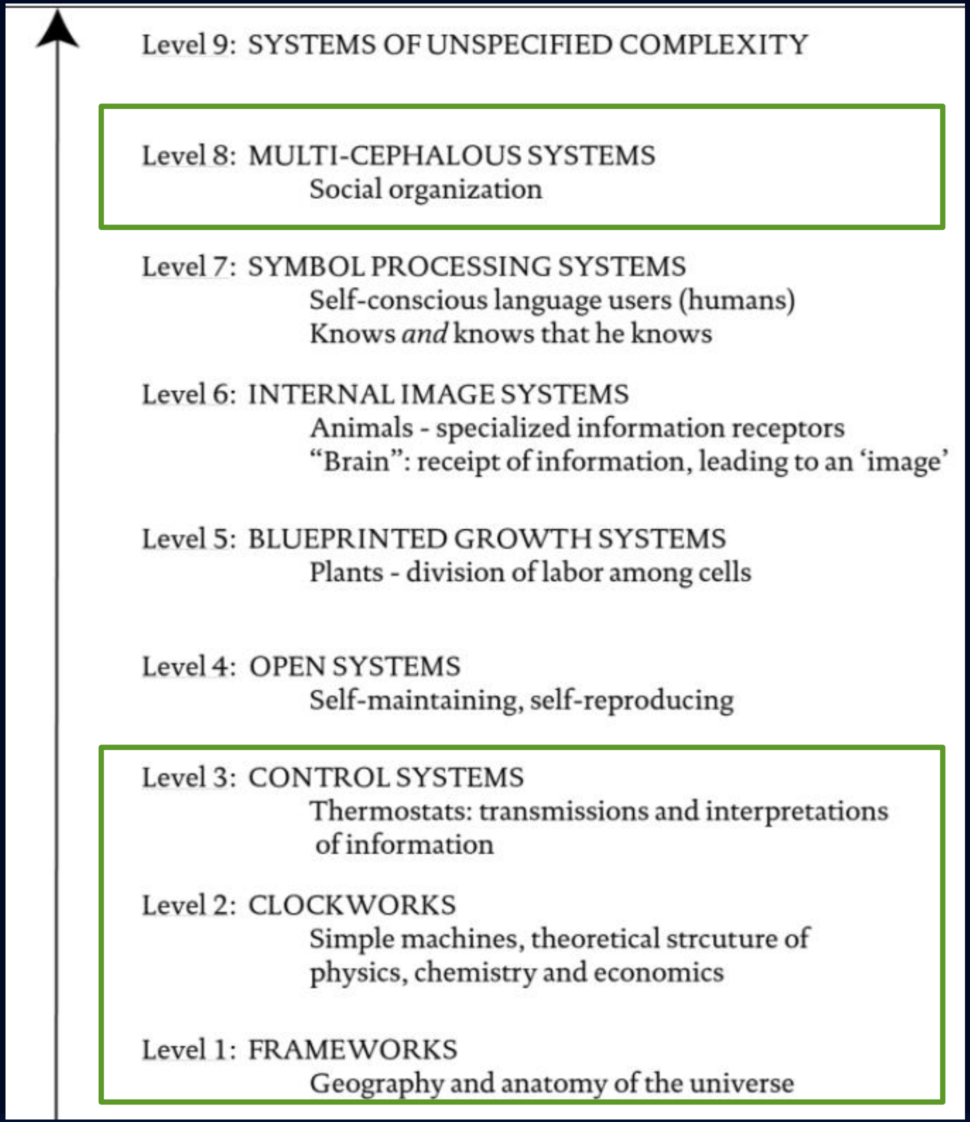
PPVCT power perf volume cost time

Complex Systems and Emergence

- *Complex Systems are systems in which large collections of components interact in nonlinear ways.*
- *Nonlinear interactions cause the whole to be “more than the sum of its parts”*
- *New system properties may result in Emergence*
  - – forward motion emerges when a bicycle and its rider interoperate, but neither part can produce the behavior on their own.
  - – ant colonies, cells, brains, immune systems, social groups, or economic markets exhibit emergent property: self-organization.

Cat vs Washing Machine*

- Simple: You push a button, say, a light switch, and get an exact response, with no possible ambiguity in the consequences
- But with complex systems, interdependencies are severe.
- Is “component” complicated or complex?
- “System with components” is one step further from a “washing machine” to a “cat”



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*Nassim Taleb, “Antifragile”

Note on Formal Modeling and Simulation

- Because a complex system is usually composed of many components and their interactions, it can be represented by a network in which nodes represent the components and links represent their interactions.
- Complex networks can largely simplify real systems and preserve the essential information of the interaction structure that leads to emergent complex phenomena.

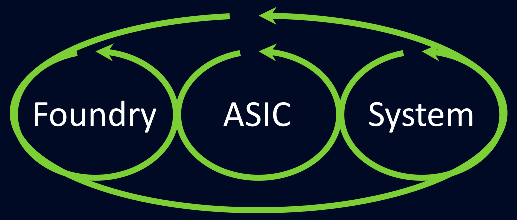
Revealing Interactions Across Domain Boundaries

- Improve coverage and real time Fault Isolation (FI)
  - FI at MBIST, Scan, Functional test
  - Test insertions (e.g SLT) for earlier problem detection
- Map circuit performance to environment
  - Monitor environment (e.g. V/T/noise sensors)
  - Monitor process parameters: PMRO, in situ delay,
  - System cooling characterization (Simulations ,HS, TIM2,)
  - System Power Supply characterization
- Map circuit performance over time
  - In situ degradation: stressing PMRO/delay agents along with functional performance in HTOL and ORT
  - Validate degradation model→ “just enough margin”

Design and Characterization to Discover Interactions

- Top down (system→ design→ foundry):
  - Map system and SLT results down to circuit margins and process performance.
    - Example: map transistor performance at WC customer system setup to WAT and design corner simulations
- Bottom up (circuit → to system):
  - Quantify high risk issues detected in component characterization into SLT/system.
    - Example: Quantify circuit parametric sensitivity (e.g. Vmin) to V/T in customer system setup.

Expected Results



- More realistic modeling
  - S2S: certain IR-drop and thermal gradient has non zero probability to cause memory failure undetectable by BIST.
  - Yield model: will include system level yield loss dependencies
  - Q&R risk model: will add degrade of transistor across Lifetime to assess failure rate in the field
- Application for ETE:
  - S2S mechanism & FI model to be shared with foundry,
  - Cooling design (thermal gradient), system PS design (V noise),
  - SW- Functional test (extend similar tests),
- Recap:
  - Propagate margin from customer environment back inn the form of specs: System -> Component -> Foundry -> Suppliers
- Resource Allocation Philosophy:
  - use model above to identify pareto, allocate resources towards bottle necks and major system constraints provides the best ROI

Extend Current Analytics to Cover for ETE and “across domain concept”

- Goal:
  - Capture all data in DB to create effective communication, provide data interface for every supplier to cover their design space
- Data Features:
  - Cloud hosting across all test insertions + supplier data + subset sharing with supplier
- Enrich data by stage:
  - Characterization/NPI, Pilot/HVM, Field

Mapping Back to “Extended KGD Philosophy”:

- Addressing Complexity: Mapping from customer application to ‘known good’
  - System/Module+Package/Die/Process/Incoming materials
- ETE based approach:
  - Extend design space (co-design/co-optimization) to stake holders/supply chain partners to preserve autonomy, maximize collaboration, align roadmap
- Make the data tell the story:
  - Improves collaboration across industry domains (e.g. materials, equipment, component, PCB, cooling, system, software)

Current Gaps and Solutions that may help

- ETE supply chain- enhance component/system design model abstraction to enable direct inputs from and co optimization with suppliers
- Map circuit performance to circuit environment – more advanced in die/in system sensing IP and data processing methodology
- Circuit performance over time- accumulate across industry degradation data for more relevant degradation model

References and Acknowledgement

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