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Fraunhofer Institute for Reliability and Microintegration IZM

Electronic Packaging Days 2025

Karl-Friedrich Becker

Packaging Technology in the Digital Realm:
Digital Twins & AI-related Tools

Flashback to the 1980s

When chip foundries and microelectronics packaging became mainstream, digitalization was in its early days.

Today we are using a variety of digital tools to control production/logistics, to monitor process quality, to coordinate testing and to personalize products.

Actually …

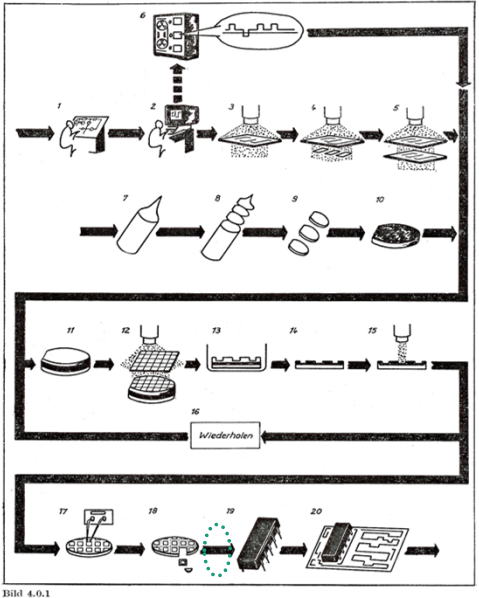

Bild 4.0.1

Aus: H. Völz, Elektronik für Naturwissenschaftler, Akademie-Verlag Berlin, 4. Auflage, 1986

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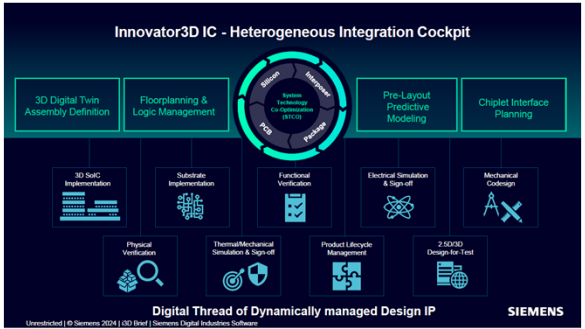
Today’s capabilities – Frontend vs. Backend

… frontend processes are almost completely digitized.

Design tools as Cadence, Keysight, Siemens EDA, Synopsis, Zuken, … are used to design ICs as well as systems and integrate PDK/DRC infrastructure and component simulation.

Packaging is mapped to such tools by using Assembly Design Kits [ADK], data based technology description today seen as a result of System Technology Co-Optimization [STCO].



Siemens EDA Concept for System Design / 3D Integration

Research Landscape in 3D Heterointegration

Different Background between OSAT´s and IDM´s, Foundries to build 3D Modules

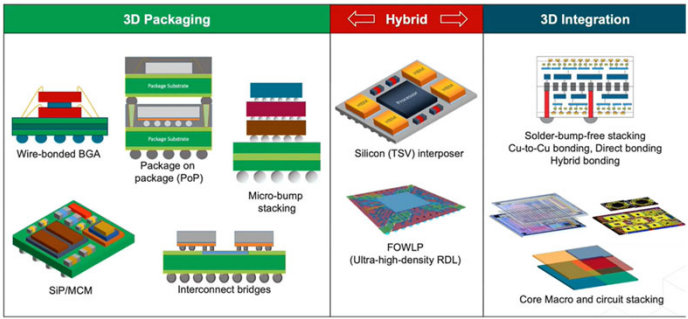
Heterogeneous Toolbox

- **Interconnect:** Wire bond, Flip Chip, TxV, Solder Balls, Hybrid Bond, …..
- **Encapsulation:** Mold, Underfill, Paste, Glob Top, ALD,….
- **Substrates:** Organic, Glass, Silicon, Ceramic, Leadframe,….
- **Packaging Concepts:** 2,5D, 3D, Fan Out, Embedding, PoP, CSP, ….

Huge variety of materials

OSAT´s

3D Packaging (Back-End 3D) vs. 3D Integration (Front-End 3D)



Source: Cadence

Semiconductor Toolbox

- **Deposition:** Thin films of conducting, isolating or semiconducting materials.
- **Photoresist coating:** resist: positive and negative.
- **Lithography:** exposed to DUV or EUV light.
- **Etch:** remove the degraded resist.
- **Ion implantation:** tune the electrical conducting properties

Typical frontend materials

IDM, Foundry

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Digital Twins covering all phases of Product Lifetime

Wikipedia definition:
A digital twin is a digital model of an intended or actual real-world physical product, system, or process (a physical twin) that serves as the effectively indistinguishable digital counterpart of it for practical purposes, such as simulation, integration, testing, monitoring, and maintenance

Our working definition:
A digital twin is a digital representation
of a material, component or process
that you can ask questions (and you get answers!)
the more sophisticated the digital twin, the more complex the questions may be.

… Digital Twins for packaging can become quite complex!

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Reference Projects – Chiplet-Related Projects

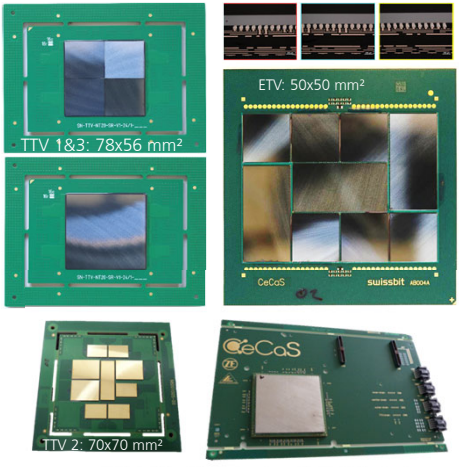
Process Development and Data Acquisition

Small-Volume Manufacturing of Engineering Samples for an Industrial Partners – yielding valuable information on process quality and stability depending on varying boundary conditions: Die Size & Configuration, PCB Stackup, Materials

-> **Data collection towards a process model / Digital Twin**

Inside CeCaS a Lab-to-Industry Scenario was deployed -
In cooperation between Conti (System Owner), Swissbit (Manufacturing Source) and Fraunhofer IZM (RTD); assembly feasibility was proven at IZM – data transfer to Swissbit allowed fast manufacturing setup -
Chiplet assy on Carrier Board at Conti based on IZM/Swissbit data

-> **Data Transfer from Lab2Industry**



Chiplet Test Vehicles from CeCaS Project

Reference Projects – Chiplet-Related Projects

Data Depolyment towards a Reliability Digital Twin

Material Data For Chiplet Assembly:

PCB / Underfill / Solder / Silicon / Structural Adhesive

Process Description:

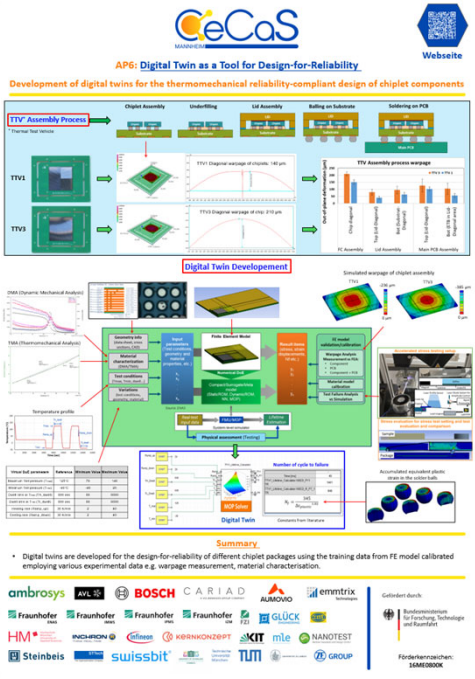
Process Steps / Equipment & Handling / Temperatures

Device Analysis:

Structural Integrity / Geometry / Warpage as f(t/T) / Functionality

… is used to build a Digital Twin for reliability

-> a versatile tool to calculate product remaining lifetime depending on load cycles



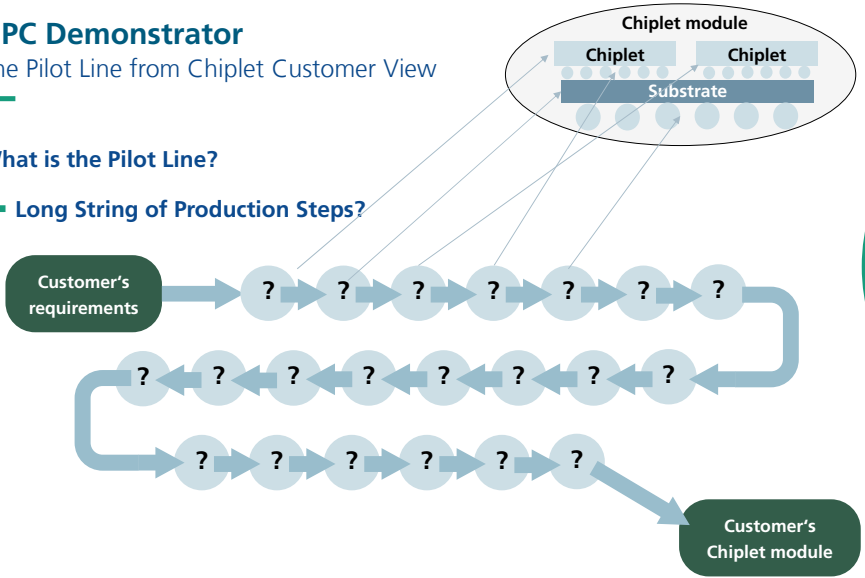
Ghanshyam Ghadya, Sven Rzepka, FhG ENAS & Volker Bader, Karl-F. Becker, FhG IZM

HPC Demonstrator

The Pilot Line from Chiplet Customer View

What is the Pilot Line?

- **Long String of Production Steps?**

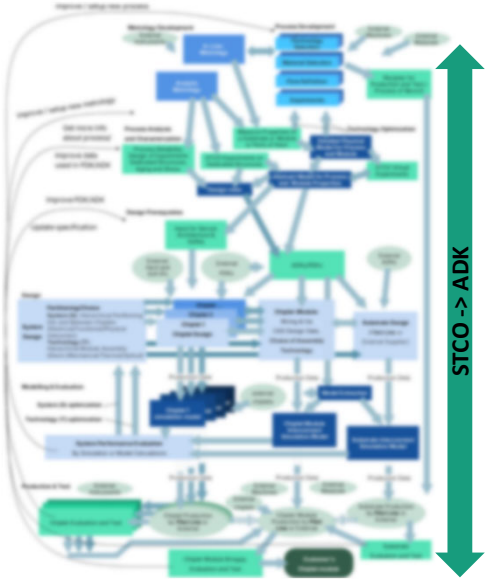


HPC Demonstrator

The Pilot Line from Chiplet Customer View

What is the Pilot Line?

- **Based on customer requirements,**
  specific Chiplets are designed & manufactured,
  general IP block Chiplets and passives are sourced,
  a system is designed based on advanced packaging technology selection,
  interposer/substrate are procured,
  the system is assembled and tested …
- **Sounds straight forward, but …**
- **… it's rather a complicated mesh!**



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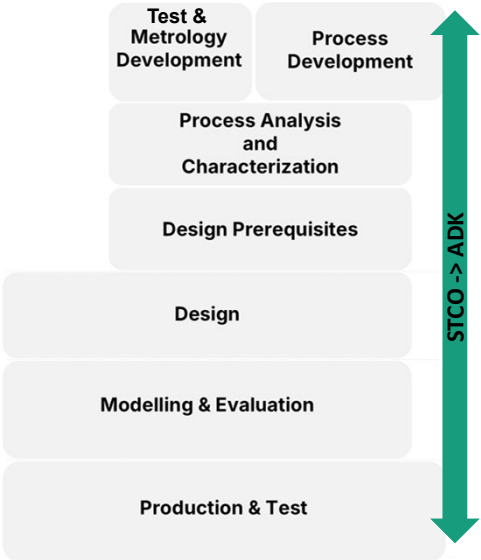
HPC Demonstrator

The Pilot Line from Chiplet Customer View

Research Areas within APECS are

- **Process Development & Metrology Development**
  (incl. Test Methodology & Strategy Development)
- **Process Analysis & Characterization**
  (STCO towards process modeling and ADK)
- **Design Prerequisites**
  (IPs, KnowHow, PDK/ADK)
- **Design (-> System Design)**
- **Modelling & Evaluation**
  (of the designed system -> Digital Twin)
- **Production & Test**
  (aligned with customer needs/data model)



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Industrie 4.0

Digitalization at IZM – in a research environment

At Fraunhofer IZM, we are working on digitalization ...

... through digitalised production planning using a wide variety of tools **-> MES/PMS**

... through the development of data sets and material laws for evaluating property changes, e.g. due to thermal ageing (Mature with IFAM) or moisture storage, e.g. to optimise service life predictions **-> Digital twin of materials in the area of design/reliability**

... through the abstract description of processes (flow chart, Ishikawa diagram) and the recording of a wide variety of production data and the normalised summarisation of the data in order to optimise knowledge-based/AI-supported processes. **-> Digital twin of production processes**

... by analysing process flows and variants to evaluate manufacturing costs and ecological implications **-> Digital twin for cost/eco-balancing**

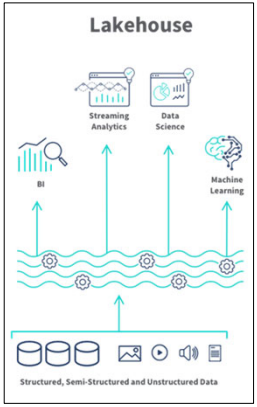
... AI-supported by correlating product quality and ZV analyses **-> Digital twin for product reliability**

... by deriving design parameters through technology analysis using statistical methods **-> ADK/PDK**

➢ **Digitalization and AI are an integral part of our research work!**

Packaging Technology in the Digital Realm

Digital Twins & AI-related Tools



- **Automated data acquisition and processing is the foundation of all data-based technology optimization - ADAPT**
- **Ontologies are a key enabler for system technology co optimization [STCO] in holistic data landscapes**
- **Increasing performance needs and cost reduction requirements call for data-based process optimization in the design phase of a product**
- **Advanced data analysis needs AI related tools to manage data of and optimize complex process chains**
- **As the essence of digitization, Assembly Design Kits (ADKs) make technology available to system designers**

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Thank you:
Ole Hölck, Steve Voges, Marcus Voitel, Tanja Braun - SIIT-AET
Dennis Choy - R3S; Johannes Jaeschke - ERE