Modeling and Simulation for Design support of 3D-Systems

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Outline

– **Introduction**

– Methodology for multi-level and multi-physics analysis of interconnect structures

– Thermal analysis and electro-thermal simulation

– Modeling of electrical behavior at low and high frequencies

– Design flow integration and system level simulation

– Conclusions
Key elements of SiP / 3D integration technology

- system partitioning/modularization
- chip-package co-design (on chip, off chip)
- integration of different functions in one package
- application of “add-on” technologies
- high-density component integration
- short time to market cycles

Source: SINTEF Source: ITRS-Roadmap 2005
### Basic approaches for 3D integration

<table>
<thead>
<tr>
<th>Structure</th>
<th>Possible physical effects</th>
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</thead>
<tbody>
<tr>
<td><strong>face to face</strong></td>
<td>- Cross talk between metal layers</td>
</tr>
<tr>
<td></td>
<td>- Thermal coupling between active areas</td>
</tr>
<tr>
<td><strong>back to face</strong></td>
<td>- Electrical influence of trough vias</td>
</tr>
<tr>
<td></td>
<td>- Heating in stack structure</td>
</tr>
<tr>
<td>Back to face with thinned die</td>
<td>- Heating in stack structure</td>
</tr>
<tr>
<td></td>
<td>- Substrate coupling between layers</td>
</tr>
<tr>
<td>Back to face with MEMS die</td>
<td>- Heating in stack structure</td>
</tr>
<tr>
<td></td>
<td>- Electrical influence of trough vias</td>
</tr>
<tr>
<td></td>
<td>- Mechanical stress due to different thermal expansion</td>
</tr>
</tbody>
</table>
3D Integration – Impact on System Behavior

Very high density of inter-chip wiring and functional blocks leads to some physical effects with influence on device functions and system behavior:

– signal integrity
– cross talk
– interconnect delays
– power and thermal behavior
– thermo-mechanical issues

Design of 3D systems is a multi-criteria optimization problem !!!
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Methodology for multi-level and multi-physics analysis of interconnect structures

Goal
Derive information from integration technology and provide it for system design

Basic elements
1. Modular multi-level modeling approach
2. Simulation on component level, e.g. using FEM
3. Methods for computer-aided model generation for system level (e.g. reduced order modeling)
4. Model validation
5. Integration of equivalent circuit or behavioral models into the design flow
6. Derivation of design guidelines for interconnect structures
Representation of structures
Tool independent descriptions of basic structures

XML Description

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  ...
</Project>

FEM models for ICV-SLID with different geometry

Geometry
Material
„Physics“
Mesh quality

Model generation
Representation of structures
Modular FEM modeling

basic structure
type 1

exchange of
partial models

basic structure
type 2

model 1 of the stack (FEM)

model 2 of the stack (FEM)
Representation of structures
Modular system level modeling – equivalent circuit and/or behavioral model

Structure 1

Structure 2

system level model structure 1

system level model of the stack

system level model structure 2
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Thermal simulation
Thermal characterization of different interconnect technologies

Au stud bumps

m-flip-chip

Thermal resistance

Thermal capacity
Thermal simulation
Thermal analysis of entire stack structure

Stack structure with vias for heat spreading

Stack layers with heat source (red square) and sensitive devices at P1, P2 and P3
Thermal simulation
Modular modeling of stack structure

ICV SLID

Stack cross section

ICV SLID array

Stack model

3µm Metalisation (30%)
20µm Silicon
1µm Backside POX
5µm Cu
3µm Sn
Thermal simulation
Results of FEM and system level simulation

FEM simulation with ANSYS

System simulation with reduced order model

System level model for thermal system:
- 40 system variables
- derived from FEM description with 95,000 system variables by model order reduction
- Simulation carried out with SABER
Electro-thermal simulation

FEM model

Thermal network

Electrical circuit

Reduced order behavioral model

Electro-thermal device models

Electro-thermal simulation

electric network  thermal multipole
power dissipation  temperatures

circuit simulator
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System level modeling

Direct estimation of model parameters

ICV structure → FEM results → FEM model (equations) → Optimization → Order reduction → Behavioral model

VHDL-AMS, Verilog-AMS, SystemC-AMS, ...

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Calculation of circuit parameters

Field calculation
network model

Table models or analytical approximation

Fraunhofer IIS
Institut Integrierte Schaltungen
Electromagnetic analysis
3D simulation

Simulation with CST Microwave Studio - Current density in via structures
Electromagnetic analysis
S Parameter for varying via distance

Tungsten via structure

$S_{11}$ $S_{21}$
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System level modeling – crosstalk simulation

4 coupled ICVs

models of transmission lines

models of ICVs with coupling.
System level modeling – crosstalk simulation

Crosstalk 2->1

Increasing distance of vias

Input signal

Output signal

Via1

Crosstalk 2->3<-4

Increasing distance of vias

Input signal

Output signal

Via2

Via3

Via4
Design Flow Integration
Standard Parasitics Exchange Format – Layout structure and SPEF file

*SPEF "IEEE 1481-1999"
*DESIGN "o2"
*DATE "Mon Aug 20 12:23:31 2007"
*VENDOR "Synopsys"
*PROGRAM "Star-RCXT"
*VERSION "2006.06"
*DESIGN_FLOW "PIN_CAP NONE" "NAME_SCOPE LOCAL"
*DIVIDER /
*DELIMITER :
*BUS_DELIMITER []
*T_UNIT 1.00000 NS
*C_UNIT 1.00000 FF
*R_UNIT 1.00000 OHM
*L_UNIT 1.00000 HENRY

... CAP
1 *1:5 0.155816
2 *1:7 0.0210339

*RES
1 *5:A *1:10 6.17814
2 *6:A *1:5 1.85000
3 *1:5 *1:10 8.3476189
4 *1:10 *1:7 0.0691947
5 *7:Z *1:7 7.25068
*END
Conclusions and outlook

Main challenges for design automation
– Multi-technology / multi-functional / multi-disciplinary / multi-physics
– handling of complexity by hierarchical modeling methodology

Knowledge about interconnect implementation
– is mandatory for robust design of actual system concepts
– enables the development of new system concepts and architectures

Development of manufacturing and design technology has to go hand in hand

Improvements in both technologies will be driven by applications
Acknowledgement

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