Electro-Thermal Analysis of 3D Power Delivery Networks

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ABSTRACT

Reliable design of power delivery networks for three-dimensional integrated circuits face several challenges due to electro-thermal coupling, TSV substrate coupling, long parasitic current paths, frequent and large current demands. Since these challenges are triggered by excessive voltage droop and high temperatures, the need for dedicated methods to model electrical and thermal behavior of 3D systems in an accurate and physically correct way has become inevitable. In this paper, we present PDNETA, an electro-thermal simulation environment based on electrical and thermal macro-models. To emulate a 3D system's thermal properties equivalent RC-models are developed based on the electrical-thermal duality principle. To verify the accuracy, PDNETA is compared to SPICE, exhibiting up to 96% accuracy and increase in simulation performance of up to 90% for analyzing a three-tier PDN.

Categories and Subject Descriptors

B.7.2 [**Integrated Circuits**]: circuit simulation, design aids

General Terms

Design

Keywords

Power delivery networks, electrical–thermal analysis.

1. INTRODUCTION

Three-dimensional (3D) integrated circuits present novel design techniques and heterogeneous implementation while enhancing performance, functionality and circuit density. The benefits of moving toward 3D integration are also the very own reliability challenges for resilient 3D ICs. The increase in current demand, power density, fast switching frequencies, and sensitivity to non-uniform temperatures introduce critical power/thermal integrity and reliability challenges on 3D power delivery networks (PDNs) compared to conventional 2D PDNs. As a result 3D PDNs together with parasitics of TSV array and package bumps require a comprehensive electrical and thermal analysis.

Previous works [1-3] have addressed power integrity analysis and analytical models have been established. In [4], a static electrical-thermal co-analysis was proposed. In contrast to the existing works, we provide a comprehensive dynamic electro-thermal analysis while considering: (i) substrate coupling between TSVs, (ii) electro-thermal coupling effects, and (iii) various switching frequencies. The developed simulation environment is called power delivery network electro-thermal analysis (PDNETA) and supports simultaneous analysis of electrical and thermal behavior.

2. PROPOSED ELECTRO-THERMAL ANALYSIS FLOW

PDNETA simulation environment is built based on the following three steps: (1) parasitic extractions for TSVs, package bumps, and PDNs, (2) development of dynamic electrical and thermal macro-models, and (3) simultaneous electro-thermal analysis using macro-models by applying model reduction techniques for managing the complexity and large size of the circuit. PDNETA flow is an iterative process due to interdependency between power and thermal dissipation. Fig. 1 shows PDNETA simulation flow.

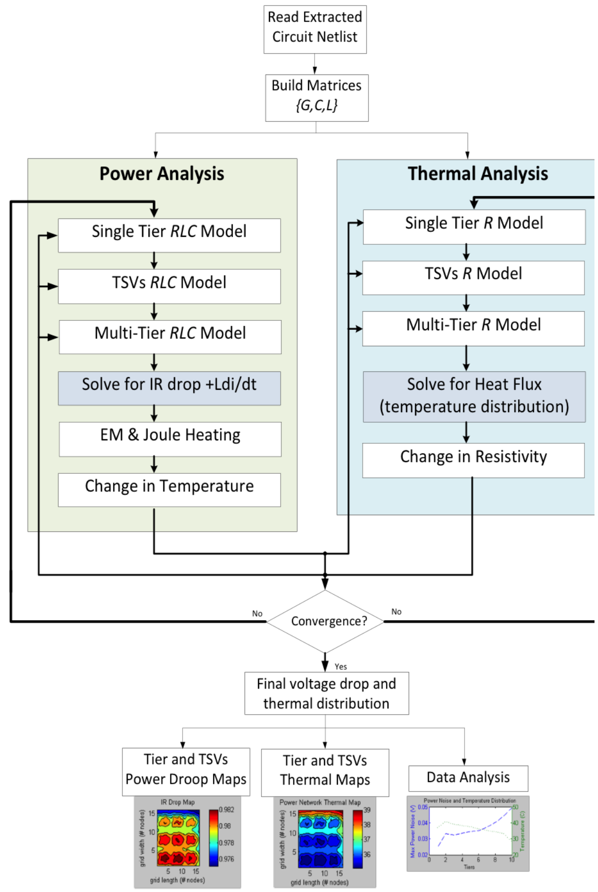

Fig. 1. Proposed electro-thermal simulation environment.

Model order reduction models and advanced numerical analysis methods are employed for performing fast and accurate electro-thermal analysis. Preliminary experiments are performed on a three-tier system where PDNs of each tier differ in granularity and power density. Voltage droop and temperature distribution maps for each tier and TSVs are obtained. Furthermore, trade-off analysis plots can be obtained for exploring distribution of TSVs and PDN metal track widths. Early results of show up to 96% accuracy compared to SPICE and increase in simulation performance up to 90%.

3. REFERENCES

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4. Additional Figures

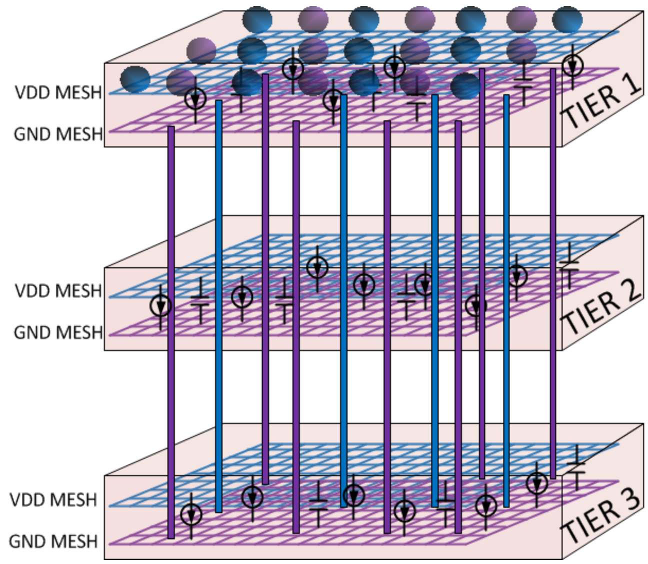

Fig. 2. 3D PDN electrical model.

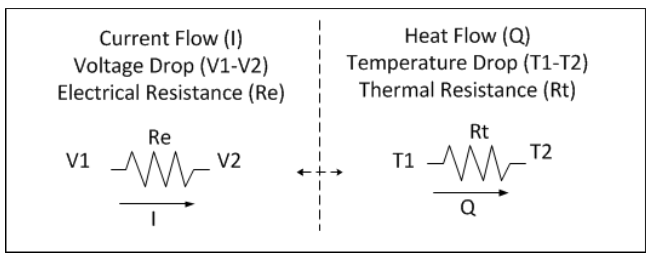

Fig. 3. Electrical-thermal duality principle utilized for thermal modeling.

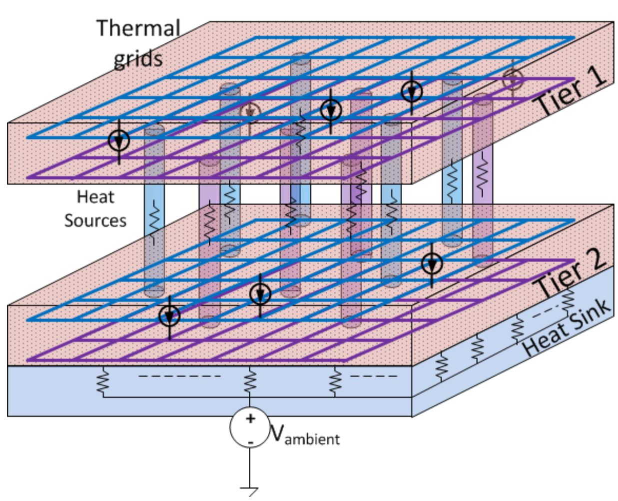

Fig. 4. Illustration of thermal modeling.