Thermal Sensor Distribution Method for 3D Integrated Circuits Using Efficient Thermal Map Modeling

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Introduction

- In a three-dimensional integrated circuit (3DIC) two or more layers of active components are integrated vertically into a single chip.
- Stacking active layers of silicon increases power density which results in higher junction temperatures.
- Thermal sensors are crucial for run-time thermal management of 3DICs.
- A thermal sensor distribution method customized for 3DICs is proposed in this work.
- Any thermal sensor distribution algorithm should consider possible thermal maps of the 3DIC to find an optimum number of sensors and their proper locations.
- A fast 3D thermal map modeling is proposed to be used in thermal sensor distribution algorithm.

Motivation

- Previous 3DIC thermal modeling approaches are detailed and very time-consuming.

The Finite Element Analysis (FEA)

Compact modeling

Effect of distance from heatsink on each layer's thermal map

A Layer’s Thermal Effects on Other Layers

Scaling Matrices

Experimental Results and Conclusion

- Thermal Sensor Distribution for 3DICs

  - The optimum thermal sensor positions using a 3D k-means clustering algorithm for sensor allocation are shown in the
figure.
  - We can see that with a minimum number of sensors, for 100% coverage of the critical area and an acceptable reading error of less than 5%, thermal sensors are only located in middle layers and they also monitor their adjacent layers' temperatures.

- Figure shows the efficiency of using the k-means clustering algorithm in the 3D space instead of solving the problem for each individual layer.
- With the same number of sensors and error tolerance, using 3D k-means clustering covers a much higher percentage of the thermal macro cells than 2D k-means clustering.
- Using 3D k-means clustering, we avoid assigning an excessive number of unnecessary sensors to the same spatial hotspots.

- Employing our fast 3D thermal map modeling
- Employs k-means clustering problem solved in 3D space

Given an integer $k$ and a set of $n$ data points in an $m$-dimensional space, determine $k$ centers such that the mean square distance from each data point to its nearest center is minimized.

$k$: number of sensors
$n$: number of hotspots

<table>
<thead>
<tr>
<th>Applications</th>
<th>Benchmark runtime on core 1 through core 8</th>
<th>Max. Modeling Error (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>128x128 grid cells</td>
<td>2.22</td>
</tr>
<tr>
<td>2</td>
<td>256x256 grid cells</td>
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<tr>
<td>3</td>
<td>512x512 grid cells</td>
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<tr>
<td>4</td>
<td>equate all cores</td>
<td>2.98</td>
</tr>
<tr>
<td>5</td>
<td>go on all core</td>
<td>2.98</td>
</tr>
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</table>

- Employing proposed 3D thermal map modeling in the thermal sensor allocation algorithm results in a 53x speedup compared to HotSpot 5.0 thermal modeling.

- Previous 3DIC thermal modeling approaches are detailed and very time-consuming.

- Our 3DIC thermal model is:
  - Fast
  - Developed with conventional 2D CAD tools
  - Developed in three steps:
    1. Capturing effect of distance from heatsink on each layer’s thermal map
    2. Finding each layer’s thermal effects on others
    3. Each layer’s final thermal map: superposition of its own scaled thermal map and other layers’ effects

- The proposed modeling yields maximum error of less than 5.5%, which is quite acceptable for the purpose of a sensor distribution algorithm.
- With the proposed method less than 4.4% error in maximum sensor reading of the temperature is accomplished.
- The algorithm uses the proposed 3D thermal map modeling, which improves evaluation time by 53x compared with using of HotSpot 5.0 embodied in the algorithm.
- Thermal sensor distribution for 3DICs must be solved as a 3D problem, which results in 44% fewer sensors.