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AI-Assistant Thermal Hotspot Prediction and Chip Placement Optimization for Semiconductor Packages

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Abstract: *Semiconductor packages are becoming more complex due to the increasing integration of multiple chips and chiplets within a single package. This can lead to higher heat generation and uneven temperature distribution, resulting in the formation of thermal hotspots. Excessive temperature can affect the performance and reliability of semiconductor devices. Conventional thermal analysis methods generally require repeated simulations to evaluate different chip placement arrangements, which can increase the time and computational effort. This project proposes an AI-based thermal hotspot prediction and chip placement optimization system for semiconductor packages. The proposed approach uses HotSpot thermal simulation to generate temperature data for different chip placement configurations. The generated dataset is processed using Python or MATLAB and used to train a Machine Learning model. The trained model predicts the maximum temperature and identifies possible thermal hotspot regions for different placement arrangements. Based on the predicted temperature, suitable chip placement configurations are selected and validated using HotSpot simulation. The proposed system aims to reduce the effort required for evaluating multiple placement configurations and support improved thermal-aware chip placement*

Keywords: Artificial Intelligence, Machine Learning, Semiconductor Packaging, Thermal Hotspot, Chip Placement, HotSpot Simulator, Thermal Management, Optimization

I. INTRODUCTION

Semiconductors are used in a variety of electronic devices. Semiconductor technology has advanced to produce very high performance and compact systems. This can be done using advanced packaging technologies such as 2.5D and 3D integrated circuits. Multiple chips or chiplets can be integrated into one single package. However, thermal dissipation will increase as more chips are included within a system. If the thermal dissipation isn't even within the system then thermal hotspots will occur. Thermal hotspots can affect the performance of the device, require a greater cooling system and reduce the reliability of the semiconductor package.

The positioning of the chips can be very important in reducing thermal hotspots. High power chips can be positioned in specific spots with spacing between them. If chips aren't positioned well then thermal hotspots can occur. It's important to find good positions for the chips.

Traditionally thermal distribution in a package would be determined using simulation tools. However, finding the best possible chip layout can take a long amount of time and computation. Using Machine Learning techniques can help to predict thermal values using previous simulation data. HotSpot thermal simulations have been used along with Machine Learning techniques to find thermal hotspots. A dataset was developed using results from the thermal simulations. This dataset was used to train the ML model. The ML model was able to predict thermal temperatures of different chip layouts. The chip layout with the lowest max temperature was selected and confirmed using thermal simulations.

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II. RELATED WORK

Many researchers have looked into thermal management of advanced semiconductor packages. Chiplet packaging has widely been researched in terms of thermal modelling. This is to provide insight into the temperature distribution in 2.5D packages with through silicon via interposers. This demonstrates that important factors such as package structure, material and thermal properties will have an impact on the thermal performance of the integrated chips. Furthermore, the layout of the chips and materials used will influence the heat distribution. Machine Learning has also been researched to analyse the thermal properties of integrated circuits. Supervised learning methods have been used to find optimal layout designs for active hotspots in 3D integrated circuits. This is done by using past data to understand the relationship between the locations of the chips and the temperatures. Graph Convolutional Networks have also been studied to allow quick analysis of thermal properties of chiplet designs. This shows how Machine Learning can be used to predict the thermal properties from the package design.

Other researchers have focused on temperature aware floor planning in 3D integrated circuits. Floor planning helps to find the locations of the different functional blocks on the chip. A temperature aware floor plan takes into account the constraints of the chip and the thermal properties. It is clear that how the chips are laid out will have an impact on the temperatures. Using optimal placement methods can help reduce the build up of heat.

Recently, Artificial Neural Networks, Bayesian Optimisation and Reinforcement Learning have been studied for thermal aware placement and optimising the layout of heat sources. Artificial Neural Networks can be used to predict temperatures from past data. Bayesian Optimisation and Reinforcement Learning have been studied to find optimal placement layouts. This shows how useful it can be to combine thermal modelling with intelligent optimisation. However, the performance of the Machine Learning models will depend on the quality and amount of training data.

From this research, this project will create an AI based approach to predict thermal hotspots and optimise chip placement. A HotSpot thermal simulation is used to create a dataset of different chip placements. This dataset is then analysed using Python/MATLAB. This dataset is then used to train a Machine Learning model. The model is then able to predict the highest temperature of different potential placements. An optimal layout can then be chosen based on the predicted temperature. The layout is then validated using HotSpot. This will help reduce the amount of work needed to analyse many different chip placements and will help improve thermal aware design of semiconductor packages.

III. SYSTEM ARCHITECTURE

3.1 Overview of the Proposed System

The proposed system will utilise Hotspot thermal simulation and Machine Learning to predict thermal hotspots and optimise chip arrangements in semiconductors. The aim is to find an optimal chip arrangement which will reduce maximum temperatures. The input includes parameters such as chip size, power consumption, package details, material properties and initial chip arrangement. These parameters are input into Hotspot to produce the temperature distribution. The results are recorded to build a dataset with varying chip arrangements and temperature values. The recorded dataset is then cleaned using either Python/Matlab. This is used to train a Machine Learning algorithm. The algorithm can be used to predict temperatures of different candidate chip arrangements. The optimal arrangement can be chosen and then verified using Hotspot.

3.2 Major Components of the System

• Input Parameters: These include the chip size, power consumption, package details, material properties and initial arrangement of the chip.

• Hotspot Simulation: This finds the thermal behaviour of the semiconductor package.

• Dataset Creation: Results from the varying simulation parameters are recorded. This dataset contains chip arrangements, power values and thermal results.

• Data Cleaning: Python/Matlab is used to organise and clean the data. This will include checking for any missing data and defining the input parameters.

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• Machine Learning Algorithm: The Machine Learning algorithm will be trained on the data from the simulations. A regression model can be used to learn how the chip arrangement parameters affect the maximum temperature.
• Chip Arrangement Optimisation: The different candidate chip arrangements can be analysed using the trained Machine Learning algorithm. The optimal arrangement is chosen based on the lowest predicted maximum temperature.
• Thermal Verification: The chosen arrangement can be simulated once more using Hotspot. This will show how accurate the model was by comparing the predicted temperature to the simulated temperature.

3.3 Software Architecture

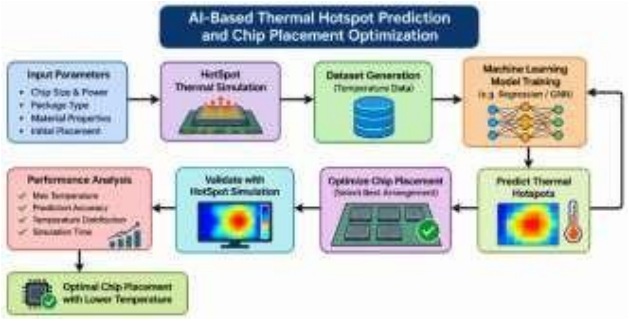
Most of the project will involve using software to perform the thermal simulation and Machine Learning. Using a computer system the Hotspot simulation can be performed and the prediction model can be created. The semiconductor package can be represented using the chip size, power, materials and arrangement.
In the initial stages of this project there will not be a physical semiconductor package needed. The computer will process the input parameters, run the thermal simulations and store the resulting data from the simulations. This means different chip arrangements can be analysed without having to create a physical prototype.

3.4 Software

The software includes the thermal simulation, data cleansing, Machine Learning and chip optimisation. Hotspot is used to find the temperature distribution. Python/Matlab is used to clean the data.
The Machine Learning algorithm will be trained on the data generated from the simulations. This will then be used to predict the temperatures of different candidate chip arrangements. The optimal arrangement can be found using the optimisation routine. The arrangement can then be verified using Hotspot.

3.5 Block Diagram

This block diagram shows how the information flows throughout the different parts of the system. The input parameters are passed to the Hotspot simulation. Results are gathered and used to create the dataset. The dataset is cleaned and passed to the Machine Learning algorithm.
The trained model can be used to predict thermal hotspots within different candidate chip arrangements. The chip optimisation routine can be used to find the optimal chip arrangement based on the predicted maximum temperature. This can then be verified using Hotspot simulation. The performance analysis can be used to analyse the maximum temperature, accuracy and temperature distribution.



3.6 Data

The data is an important aspect of the project. The temperature values can be found from the thermal simulation. These values can be recorded and stored with the input parameters.
The data can be organised using Python/Matlab. This will include input parameters such as the position of the chip, chip size, power consumption, and package parameters. The output can include the maximum temperature from the thermal simulations. Additional information can be added regarding the temperature distribution.

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The data can then be split into training and test sets. The training set can be used to train the Machine Learning model. The test set can be used to analyse how accurately the model can predict. Using appropriate techniques to clean the data and split the data can increase the accuracy of the evaluation.

3.7 Design Considerations

There are many things to consider when designing this system. Accurate thermal simulation is important as the data generated will be used to train the Machine Learning model. The input parameters should accurately represent the package.

There should be enough varied simulations performed to give a good representation of different chip arrangements and power values. The Machine Learning algorithm should be chosen based on the data available and what needs to be predicted. Constraints should be considered when optimising the chip arrangement such as the package limits, overlapping chips and available space.

The chosen chip arrangement should always be checked using thermal simulation. Comparing the predicted temperature and simulated temperature will show how accurate the model is. This will increase the reliability of the system.

3.8 Benefits of Proposed Architecture

The proposed architecture will provide a structured way to predict thermal hotspots and optimise chip arrangements. Using the data from the simulations a Machine Learning model can be trained. This can be used to estimate temperatures for different candidate chip arrangements without having to run a full thermal simulation.

The system can help to identify chip arrangements that have a low predicted maximum temperature. This can save time when evaluating many chip arrangements. The system can also be used to create packages that are aware of thermal issues. As the system is structured different Machine Learning algorithms can be tried in the future.

IV. CORE CONCEPT

The main concept behind this project is to simulate thermal and apply Artificial Intelligence to predict thermal hotspots and optimise chip layout within semiconductor packages. Within advanced semiconductor packaging, chips (or chiplets) are arranged very closely together to increase integration. However, each chip will produce heat when operating.

If the chips are not laid out correctly then there will be an uneven flow of heat and thermal hotspots. Choosing a suitable chip lay out will help improve the thermal performance. The proposed system will use Hotspot thermal simulation. Various input data including chip dimensions, power consumption, layout coordinates and package properties can be inserted into the simulator. This data will be used by Hotspot to calculate the temperatures. These results are recorded to create a dataset.

This dataset can be processed using python or MATLAB. The data will be prepared ready to train the model, separating the correct inputs and their temperature. A Regression Machine Learning model can be trained to determine the relationship between the chip layout, power consumption and thermal performance. Once the model has been trained the maximum temperature can be predicted for various candidate layouts.

The predicted temperatures can be used to determine which layout should be chosen. A suitable layout will be picked based on the lowest predicted maximum temperature and meeting any constraints. This reduces the number of accurate thermal simulations needed for initial layout. The chosen chip layout will be sent to the Hotspot simulator. The temperature produced by the simulation will be compared to the predicted temperature to show how well the model has performed. Overall the process provides an AI assisted method of determining suitable chip layouts.

Overall the idea behind this project is to produce accurate data using thermal simulation and use Machine Learning to quickly predict the temperature. By predicting the temperature, optimising the layout and validating the results using thermal simulation the system will provide an improved way of analysing the thermal performance.

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V. OPERATIONAL WORKFLOW

The operation of the AI Based Thermal Hotspot Prediction and Chip Placement Optimization System can be separated into the following steps.

5.1 Input Parameters

The required inputs for the semiconductor package such as chip size, power consumption, type of package, material and initial chip placement are obtained.

5.2 Temperature Evaluation

These parameters are inputted into the thermal simulator (Hotspot). This allows for the calculation of the temperature distribution based on the chip layout and power consumption. Identifying areas of high temperature.

5.3 Dataset Creation

Various placements of chips are considered and the temperatures obtained are recorded. This creates a dataset of the input parameters and the temperatures.

5.4 Data Preparation

The dataset is prepared using either Python or MATLAB. The input parameters are converted into relevant features and the temperature values are prepared as outputs. The dataset is checked and split into training and testing data.

5.5 Training of Machine Learning Model

The preprocessed training data is inputted into an appropriate Machine Learning algorithm. A regression model could be used to find the correlation between the chip placement parameters and the maximum temperature. This is trained using the data available.

5.6 Temperature Hotspot Prediction

Once trained, the Machine Learning model takes in the proposed placements of chips as inputs and predicts the expected maximum temperature. This will identify potential hotspots and good placements.

5.7 Chip Placement Optimization

The proposed placements are assessed based on their maximum temperature predictions. The optimization module will select a good placement that has a lower predicted temperature but meets the set constraints of the package.

5.8 Temperature Evaluation

The chosen chip placement is inputted into the thermal simulator (Hotspot) to calculate its temperature distribution. This can then be compared to the predicted temperature.

5.9 Evaluation

The performance of the proposed system is evaluated based on the maximum temperature, temperature distribution, accuracy, error and simulation time. The original and optimized placements are compared.

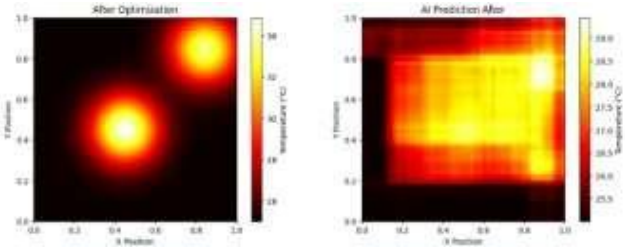
5.10 Final Output

The final output will be the chosen chip placements with a lower maximum temperature than the original. If it has been validated using the thermal simulation. The system will provide the predicted temperature and validated temperature.

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VI. IMPLEMENTATION AND RESULTS

The proposed system is implemented using HotSpot and Machine Learning techniques. The implementation consists of defining package parameters, thermal analysis, dataset creation, pre-processing, model training, chip placement optimisation and thermal analysis.



A. Thermal Analysis

The chip parameters (chip dimensions, power consumption, material properties and chip placement) of the semiconductor package are defined and fed into HotSpot. A variety of chip placements are simulated. The temperature results are then obtained. This will give an indication of the highest temperature and overall distribution of heat. It can then be used for further processing.

B. Dataset Creation

The results are organised into a dataset. Within the dataset each row shows the chip placements and the associated temperature results. The dataset will consist of inputs (chip placements, chip dimensions and power values) and outputs (maximum temperature). This can be done in Python or MATLAB. The data will be checked for consistency and converted into the correct format. The dataset will then be split into training and testing data.

C. Machine Learning

An appropriate regression based model will be trained on the simulation data. Once trained the model can be tested using the test data. The predicted temperatures can be compared to the HotSpot result. Metrics can be used to show how accurate the prediction was (Mean Absolute Error and Root Mean Square Error).

D. Chip Placement Optimisation

The model can be used to predict the maximum temperature of various possible chip placements. The model will be given each possible chip placements. The predictions can then be compared to find the most suitable chip placements. The chip placements must take into account the package dimensions, chip dimensions and ensure there is no overlap. The aim is to find a chip placement that has a lower predicted maximum temperature.

E. Thermal Analysis

The chosen chip placements can be simulated in HotSpot. This will show if there is an actual decrease in maximum temperature. The temperature distribution can be compared to the original package. The predicted temperature can be compared to the simulated temperature. This will give an indication of how accurate the ML model was. If there is a large discrepancy between the predicted and simulated temperatures then the dataset and/or model could be further improved.

F. Evaluation

The proposed system can be evaluated using the following:

• Maximum Temperature – Compares the highest temperature of the original and optimised chip placements.

• Accuracy – Shows how accurately the ML model can predict the simulation results.

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• Mean Absolute Error – Shows the average absolute error between the predicted and simulated temperatures.
• Root Mean Square Error – Shows how large the error is in the predictions.
• Temperature Distribution – Can see where the hotspots are and how they are distributed.
• Simulation Time – Compares the time taken for the simulation.
• Chip Placement Optimisation – Shows if there is an improvement in the thermal performance of the chosen chip placements.
• Actual temperature values, accuracy, error values and simulation times must be included once the implementation has been completed. In this report there will be no improvements in numbers.A. Prototype Development

VIII. CONCLUSION

The proposed project illustrates an AI based solution for predicting thermal hotspots and optimizing the chip placement in semiconductor packages using HotSpot thermal simulation tool and Machine Learning. The thermal simulation data is used to produce a dataset containing various parameters of semiconductor packages and their corresponding temperature values. This dataset is then processed to form a Machine Learning model. This model is then used to predict the maximum temperature value for various chip placements. Based on this prediction an optimum chip placement is chosen which is validated using the HotSpot simulation.

This system can be used to reduce the time and effort required when validating different placements during the initial design phase. It can also aid in finding optimum chip placements for thermal reasons. However, the success of the system depends upon the quality of data produced by the simulation, correct choice of Machine Learning model and accurate thermal validation.

The system can be improved by implementing some advanced Machine Learning and Deep Learning algorithms to increase the accuracy of the temperature predictions. A large dataset can be created containing different types of chips with varying sizes, power values and package structure/material.

Advanced optimization techniques can be explored such as Genetic Algorithms, Bayesian Optimization and Reinforcement Learning to find optimum chip placements. This can also be expanded to more complex 2.5D/3D packages.

Other enhancements that could be looked into are different cooling conditions, package materials and heat dissipation methods. Real time temperature monitoring and integration with advanced electronic design tools could also be considered. These enhancements could lead to the development of more efficient thermal management systems for advanced semiconductor packages.

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