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研究論文題目
Characterization of thermal parameters of electronic assemblies by means of in situ measurements

研究論文概要

Industry advancements prompt more efficient methods for the design of cooling solutions to be applied during the development phase of modern electronics. The development process of the cooling solution for electronic assemblies can be loosely separated in two stages. Prior to prototyping of a particular assembly, and after it. The main objective before building the prototype is to run accurate thermal analyses, such that no rework regarding the thermal solution for the assembly is required. In order to achieve this, methodologies such as analytical modeling, lumped approximation with thermal networks, or computer aided engineering tools which use finite discretization can be used. In the second stage, the temperature limits for the prototype are verified, and if passable, the development continues. Here, passing implies that the thermal simulations and overall analyses so far have been successful in representing the heat transfer characteristics of the prototype.

On the other hand, there are cases where the temperature distribution of the prototype does not agree with stipulated limits. In such situations, this indicates that thermal models used for the pre-design of the cooling solution do not agree with the actual prototype. Thus, verification of the model needs to be carried, which is where the focus of this dissertation lies. The main objective of this work is to introduce verification methodologies for the thermal parameters of the heat problem, such that thermal engineers are able to systematically identify where the problem with the thermal model for a particular prototype is. The parameters in question are the thermal properties, boundary conditions or source term. The verification methods introduced in this text vary according to the temporal regime that their respective analyses require (i.e., steady or transient), and the model used to represent the thermal response of the electronic system. Generally, the steps of each method require the acquisition of experimental data, usually in the form of surface temperature, such that it can be compared against theoretical models. The structure of this dissertation is as follows:

- **Chapter 1: Introduction.** This chapter firstly introduces the target of this dissertation, which is to introduce experimental and numerical methodologies for in situ verification of the thermal parameters of electronic assemblies. Then, the overall trends of power electronics and thermal constraints are presented associated with market competitiveness. This section serves to highlight the importance of efficient thermal management procedures for electronic assemblies. Further, common modeling approaches are introduced, followed by the difficulties associated with thermal analyses of electronics. Aside from thermal modeling, challenges related to the model verification of prototypes are discussed. This is where the focus of this dissertation lies, i.e., the proposal of methods to aid in the systematic verification of the thermal parameters of electronic assemblies, such that the faults with existing thermal models may be properly identified.
- **Chapter 2: Bessel function based source term estimation.** In this chapter, given the challenges related to power loss verification, a novel method which uses the surface temperature of the PCB of electronic assemblies to measure the power loss of semiconductor devices is presented. The heat diffusion in the substrate (i.e., PCB) is solved in cylindrical coordinates, which prompts the application of Bessel functions. The internal heat generation of the device is assumed to be exchanged with the environment through two main paths. The PCB and the mold of the device. Thus, the total power loss is measured by verifying the heat transfer through the PCB with Bessel functions, and a heat flux sensor to detect the heat flow through the mold. By adjusting the heat

transfer coefficient of the PCB based on the global thermal conductance of the prototype, the maximum relative error was observed to decrease to 3%.

- **Chapter 3: Inverse heat transfer problem for parameter characterization**. This chapter introduces the application of the inverse heat transfer problem for the in situ verification of the thermal parameters of electronic assemblies. Firstly, the forward heat transfer problem is presented as a basis for the theory, from which the inverse problem is characterized. The objective of this chapter is to propose a method which yields the thermal conductivity of the mold and internal layers inside semiconductor packages. In addition, the boundary condition in the form of a bulk heat transfer coefficient, and the source term are also targets. The method is based on measuring the temperature on the mold of the target device and using it as input for the inverse problem. The novelty introduced in this chapter is the application of the Levenberg-Marquardt regularization scheme with FEM simulations to solve the multiscale problem. Another unique feature introduced herein is the employment of a dummy heater. The heater is used in the early stages of the analysis to act as a known heat source, such that the thermal properties and boundary condition of the thermal problem can be obtained with good convergence through the inverse analysis procedure. The thermal properties, heat transfer coefficient and source term are successfully obtained, with a maximum relative error of 10% for the power loss of one of the semiconductor devices verified.
- **Chapter 4: Thermal verification of assembled systems via TSP based probing.** This chapter proposes a verification method of property distributions of electronic assemblies by means of the structure function. To achieve this, a probe based on an N-channel metal oxide field effect transistor is used for its temperature sensitive parameter (i.e., TSP). By using the TSP, a procedure based on JEDEC standards and network identification by deconvolution is employed to determine the structure function of the probe. Then, the probe is placed on the target electronic assembly in different locations, such that the thermal properties of the system can be verified. By combining the structure function analysis with FEM based simulations and the inverse problem, it is possible to identify which regions of the system are not being accurately represented in the thermal model.
- **Chapter 5: Characterization of thermal properties in nanometer scale structures.** To investigate in situ device level characteristics, such as the junction region in the die, an approach which uses the nanosecond order transient thermal impedance curve is presented. By obtaining the thermal response of thin-layers via pump-probe thermoreflectance measurements, it is demonstrated that the NID method is capable of identifying property distributions in nanometer scale structures.
- **Chapter 6: Conclusion.** Prompted by a need for more efficient thermal design procedures, this dissertation focuses on the issues resulting from thermal models which sometimes fail to represent real electronic assemblies in a satisfactory manner. By combining the novel methods presented in each chapter, systematic procedures can be defined to improve the efficiency of model verification. This work is concluded with some discussions about the combined methods and recommended future directions for the overall procedure of thermal model verification.