（様式乙 4）

SUMMARY OF Ph.D. DISSERTATION

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Title
Thermal Design of Power Semiconductor Modules for Mobile Communication Systems

(Development of Thermophysical Property Measurement Technique and Package Design with Low Thermal Resistance)

Abstract

A radio frequency communication (RF) circuit is an electrical component for mobile communication systems. A power amplifier amplifies the transmission signal from a transmitter in an RF circuit, and the heat dissipated from the power amplifier has generally accounted for about the half of the electrical power consumption of the cell phone. In the thermal design of power amplifiers, the objective is to develop a package structure where the temperature does not exceed the allowable limit. Since the downsizing of power amplifiers has advanced significantly, their thermal design has been a key factor in developing cell phone handsets.

The thermophysical properties of materials used in cell phones are fundamental data for the phones' thermal design. The properties used in the chassis, electrical equipment, printed circuit boards, and semiconductor devices installed on the board are difficult to obtain from the database provided by material suppliers, since some properties depend on their fabrication processes, or are withheld to protect trade secrets. Thus, it is very important to develop a reliable property measurement technique and to have a comprehensive property database that can be used as a resource in the thermal design of power semiconductor devices for cell phones.

Other relevant issues are to decrease the turn around time for product development and to find a numerical method to optimize the thermal structure of products, which will be of significant use in the thermal design. Modeling know-how is also important in the thermal design since automated modeling is difficult to apply to semiconductor devices. This paper describes the importance of the thermal design of power modules as well as thermophysical property measurement technique we developed. The objective of this thesis is to recommend a comprehensive study on the thermal design of devices and modules used in mobile communication systems.

The first chapter explains the importance of thermal design of cell phones handsets and the reason why their thermal design requires the thermophysical property measurement. Since the trend to downsize power amplifiers is continuing, the heat dissipation density has increased to 100 W/cm^2. Also, there is an allowable limit of heat discharged from the handsets to the environment. This is why their thermal design is important.

The second chapter describes the technique to improve the thermal contact conductance between metal materials in cell phones, since its improvement is an important issue for their thermal design.

The third chapter describes the thermophysical property measurement technique and its challenges. In this technique, the thermal diffusivity of thin solid samples and the thermal contact conductance between the samples is measured using an optical method. The effect of spot size and misalignment of the two lasers is studied, and conditions for making robust measurements are suggested. As a benchmark of this technique, the thermal diffusivity of a single-crystal silicon sample was measured to within two percent of reported values. Also, it was found that the deformation of test materials should be considered before measurement to improve the measurement accuracy of the thermal contact conductance.

The fourth chapter explains the thermal design technique of power amplifier modules in cell phones using a finite element method (FEM). Unlike the case such as an automobile, automatic modeling is not easily applied to the numerical modeling of semiconductor modules since their design data – such as mask layout data – are two-dimensional. Also, the modeling has to treat a huge dynamic range, from 10 nm of thin film thickness to 10 cm of characteristic length of the printed board. By applying FEM, thermal design, which involves optimizing the packaging structure, predicting the device temperature, and reducing the device temperature so that it does not exceed the allowable limit, is feasible. The results of the simulations showed that the periodic heating mode of cell phones should be considered to reduce the risk of overspecifying thermal design specifications. The results also showed that it was possible to reduce the temperature difference inside of the module to optimize the position of the heat dissipating area in the device.

Fifth chapter summarize the property measurement technique and numerical method described in the third and the fourth chapter, and studies the issues to improve the thermal design of power modules in cell phones.

In the sixth chapter, the results of our research are summarized, and a recommendation on the thermal design of power semiconductor modules for mobile communication systems is given.