主　論　文　の　要　約

論文題目　STUDY ON THERMOPHYSICAL AND THERMOELECTRICAL PROPERTY MEASUREMENT METHODS FOR ADVANCED MATERIALS USING LOCK-IN THERMOGRAPHY
(ロックインサーモグラフィによる先端材料の熱物性および熱電物性計測法に関する研究)

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論　文　内　容　の　要　約

Advanced materials have opened new frontiers in many engineering aspects due to their superior properties. Specifically, they provide a wide range of thermophysical properties values in different shapes and sizes. Utilizing such materials expanded the possibility to enhance and revolutionize a wide variety of engineering and industrial applications. Practical examples of their impact can be seen in the recent development in thermal energy generation and control systems in power plants, solar collector systems, microelectronics, spacecraft, satellites, robotics, automotive, medical devices, and so many more. In this context, the accurate knowledge of the thermophysical properties of advanced materials, especially the thermal conductivity, thermal diffusivity, and heat capacity, is essential for the efforts to optimize the structure and the thermal performance of any designed application. Nevertheless, measuring and determining the properties of a wide variety of advanced materials is still a great challenge. This is due to the limited versatility and capability of the available measurement and characterization techniques. In this work, we propose different approaches for measuring the thermophysical properties of advanced materials by developing and demonstrating four novel measurement techniques based on lock-in thermography.

In Chapter 2, two measurement techniques were developed for measuring the thermometric figure of merit with the associated thermoelectric and thermophysical properties based on the lock-in thermography techniques. The methods provide non-contact, systematic, high-throughput, and versatile measurements of the thermal diffusivity, thermal conductivity, Seebeck (Peltier) coefficient, and consequently thermometric figure of merit of multiple thermoelectric materials simultaneously with a single apparatus without the need of an external heater and without the disturbance of parasitic heat loss effect. Therefore, the methods can be utilized to ease and accelerate the development of highly efficient thermoelectric materials through understanding the intercorrelated thermal and electrical transport mechanism, as we observe with the Bismuth-Antimony thermoelectric material. In addition to that, the versatility of the lock-in thermography-based techniques gives the capability to perform highly sensitive measurements under magnetic fields at different intensity directions. This opens the way for elucidating the physics and behaviors of the magneto-thermal resistance and magneto-thermoelectric effects. On the other hand, the second measurement technique extends the measurements to multi-harmonics thermal response signals detection. This can be beneficial for further facilitating the investigation of thermoelectric materials and open the possibility of exploring high-order thermoelectric and spin-caloritronic effects.

In Chapter 3, another lock-in thermography-based measurement technique is developed for measuring the in-plane thermophysical properties of thin films. The method is based on extracting the in-plane thermal conductivity, thermal diffusivity, and heat capacity from the thermal analyses of the transient temperature distribution induced by Joule heating from a deposited metallic line heater with a single apparatus. This enables noncontact visualizing measurement with high sensitivity of the in-plane thermophysical properties at different nano-scale thicknesses. It also reduces the complexity of performing systematic investigations, as demonstrated with Ni thin films. Furthermore, the versatility of the lock-in thermography method facilitates performing versatile measurements in different magnetic field directions enabling the study of the anisotropic thermal magneto resistance and giant magnetoresistance, and thermal rectification effects. Therefore, the proposed approach can be useful for the investigation and understanding of heat conduction and magneto-thermal transport/resistance properties of thin films at the nanoscale.

In Chapter 4, we focus on solving the problem of determining and mapping the thermophysical properties of composites. The developed lock-in thermography-based measurement technique provided the feature of mapping the effective out-plane thermal conductivity, thermal diffusivity, and heat capacity through the thermal analysis of the frequency dependence and power dependence of the out-plane heat waves diffusion in the material, which is induced by a laser surface heating. This enables noncontact determining and mapping of a wide area of materials without the need for special or destructive sampling. The method also gives the chance to visualize the effect of the arrangement of the component in a composite on the effective thermophysical properties, which are usually difficult to be observed by conventional methods. The resolution of the presented system is micrometer level. However, it can be easily increased with a high magnification lens, such as the one used in thin film measurement, which will open the possibility to characterize micro/nano composites. Moreover, since the measurement can provide visualized thermophysical properties data, this can be utilized with an image recognition algorithm to understand the structure of the materials, optimize the composite design, enhance the fabrication methods, or detect early failure through notable local decay in the thermophysical properties. Accordingly, we anticipate that the lock-in thermography-based mapping measurement method will participate in advancing thermal science research for composites. Chapter 5 concludes this paper and presents future issues and prospects.