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Book review

Liquid Cooling of Electronic Devices by Single-Phase Convection; Frank P. Incropera

Electronic components and systems manufacturers are one of the most pro-active engineering communities in committing resources to insure unrestricted growth in the functionality and pervasiveness of their products, along the path charted by the celebrated Moores' Law. Projections of trends by the Semiconductor Industries Association in the USA show significant thermal management challenges to be addressed during the next decade for the sustained growth of the currently burgeoning mobile electronic product markets. Even for high performance computers and servers that have received the bulk of the attention of the thermal community so far, emerging hardware trends such as higher clock rates, increasing integration, and development of single-chip processors with reduced heat generation area due to on-chip integration of cache memory are requiring a new look at aggressive cooling options, discarded in the past in favor of simpler and lower cost air cooling.

Incropera's timely book introduces the reader to a set of high performance thermal management options based on single phase liquid cooling. The book is largely a compilation of research activities in this area during the decade spanning mid 1980s to mid 1990s and focuses heavily on the efforts at Purdue University. The highly readable presentation style follows that of the popular earlier books by the author on heat transfer. Numerous example problems with detailed solutions followed by liberal illustrative comments and end of chapter summaries are included to help the reader follow the material easily. The ample illustrations are of high quality and help in easy understanding of the text. A comprehensive and up-to-date bibliography is included.

Following an introduction to the direct and indirect liquid cooling options and a discussion of coolants in Chapter 1, the basics of heat transfer and fluid flow within the context of electronics thermal management are presented in Chapter 2. Included are the highly useful concepts of thermal resistance, overall surface efficiency of extended surfaces, and convection and pressure drop correlations for internal flows and jet impingement. Subsequent Chapters (3–5) deal with three single-phase liquid cooling schemes that offer considerable promise. Direct immersion natural convection, addressed in Chapter 3 can provide an order of magnitude improvement in thermal performance compared to air cooling, with no external pumping power requirement. The discrete nature of heating, flush versus protruding heaters, the important role of substrate conduction in dielectric liquids, and orientation effects are discussed in detail for selected configurations. For laminar flows, several computational and experimental studies have been carried out within the past decade. The author focuses largely on the Purdue research to illustrate the key aspects of the physics of transport and provides several heat transfer correlations.

The discussion on channel flows (Chapter 4) focuses on the, by now, familiar themes of discrete flush and protruding heaters, conjugate effects and downstream variations in transport. Results for mixed convection showing enhancement compared to pure forced convection due to thermal instabilities are presented. Such enhancement is found to depend on several factors, requiring customization of configuration and operating conditions for specific applications. The discussion on microchannels provides a comprehensive treatment of this currently extremely important and rapidly growing research and application topic. Transport in free surface and submerged jets, under un-confined and semi-confined conditions is discussed in Chapter 5. It is unclear whether these schemes can be implemented widely in the near future, considering that other high performance alternatives, e.g. with phase change may offer significantly better performance with similar packaging complexity. A number of very useful thermal enhancement techniques are discussed in Chapter 6. These include the use of extended surfaces (e.g. for natural convection and forced channel flows) and surface roughness effects (e.g. "millistuds" and radial grooves for jet impingement).

One minor criticism of the book is its exclusive focus on thermal management at the chip/chip carrier level. Electronic systems are hierarchical in physical architecture, with length scales of typical interest to thermal packaging engineers ranging from 10^{-4} to 1 m. Any new thermal management solutions have to include a systems approach for implementation, with additional considerations that span material compatibility, electrical, mechanical, reliability, manufacturability and economic issues. Indeed, these are complex, product specific and necessarily a function of the packaging technology.

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This book is a must for any researcher involved in electronics cooling. For packaging engineers, the techniques described will be most useful to those entrusted with the task of reducing the overall thermal resistance external to the package. Often the packaging engineer charged with the development of the next generation system hardware has only a minimal background in heat transfer. The present book offers an authoritative and comprehensive treatment of a number of candidate high performance cooling options to enable applications beyond the capabilities of the today's ubiquitous heat sink and fan assembly.

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