Thermal Management Heat Dissipation In Electrical Enclosures

The Eurotherm Committee has chosen Thermal Management of Electronic Systems as the subject of its 29th Seminar, at Delft University of Technology, the Netherlands, 14-16 June 1993. This volume constitutes the proceedings of the Seminar. Thermal Management is but one of the several critical topics in the design of electronic systems. However, as a result of the combined effects of increasing heat fluxes, miniaturisation and the striving for zero defects, preferably in less time and at a lower cost than before, thermal management has become an increasingly tough challenge. Therefore, it is being increasingly recognised that cooling requirements could eventually hamper the technical progress in miniaturisation. It might be argued that we are on the verge of a revolution in thermal management techniques. Previously, a packaging engineer had no way of predicting the tempera tures of critical electronic parts with the required accuracy. He or she· had to rely on full-scale experiments, doubtful design rules, or worst-case estimates. This situation is going to be changed in the foreseeable future. User-friendly software tools, the acquisition and integrity of input and output data, the badly needed training mea sures, the introduction into a concurrent engineering environment: all these items will exert a heavy toll on the flexibility of the electronics industries. Fortunately, this situation is being realised at the appropriate management levels, and the interest in this seminar and the pre-conference tutorials testifies to this assertion.

The complete editorial contents of Qpedia Thermal eMagazine, Volume 3, Issues 1 - 12 features in-depth, technical articles covering the most critical areas of electronics cooling.

There is great interest in improving the thermal management of laser diodes intended for use as pumps in inertial confinement fusion systems. Laser diode power is currently constrained by heat dissipation in the diodes. Diodes typically dissipate a quantity of heat that is comparable to their optical power output. This heating of the diode junction causes a thermal rollover that prevents the output power from scaling linearly with current drive, and also results in reliability limits due to catastrophic failure at diode mirror facets. For the pulsed, quasi-continuous wave (QCW) operating mode employed for LIFE and certain DOD applications, ?5 kW/cm2 of heat must be removed on timescales of ?100[mu]s, which is determined by thermal paths located within ?200 [mu]m of the laser junction. For these reasons, QCW thermal management is extremely challenging. Reducing the diode junction temperature enables more efficient operation, reduced thermal chirp, and operation at higher output power without compromised reliability - which improves the diode costs as measured in $/W. We have proposed the use of latent heat reservoirs to improve thermal management of diodes used in pulsed, quasi-continuous wave (QCW) operation. Our basic concept involves placement of a reservoir of low-melting-point metal within a few hundred microns of the laser junction, as in Fig. 1-1. This metal's latent heat of fusion maintains a nearly constant temperature (like a cold plate) in the very near vicinity of the diode junction. This cold reservoir creates large thermal gradients, which in turn are anticipated to drive a large heat flow from the diode. In contrast, conventional QCW devices rely on thermal diffusion into a large solid mass which cannot be held at a fixed temperature, which significantly limits the thermal extraction. Our operational concept involves phase changes within the reservoir during every QCW pulse. During the early portion of the pulse, heating of the diode and its surrounding material initiates melting within the latent heat reservoir. This phase change results in a near-constant reservoir temperature that facilitates heat transfer. During the long (?100 ms) time between QCW pulses, the reservoir metal resolidifies. A simple back-of-the-envelope calculation based on Gallium metal shows that a 50 [mu]m thick Gallium reservoir is sufficient to absorb all heat generated by a 350 [mu]s pulse at 5 kW/cm2. While this calculation shows that a latent heat reservoir can provide sufficient capacity to handle the magnitude of heat generated, it does not address the transient change in the diode junction temperature, which depends on details the heat flow into and through the reservoir. For this reason, we undertook a set of numerical experiments to quantitatively assess the impact of latent heat reservoirs on junction temperature. This report documents the results of these simulations.

Thermal Management for LED Applications provides state-of-the-art information on recent developments in thermal management as it relates to LEDs and LED-based systems and their applications. Coverage begins with an overview of the basics of thermal management including thermal design for LEDs, thermal characterization and testing of LEDs, and issues related to failure mechanisms and reliability and performance in harsh environments. Advances and recent developments in thermal management round out the book with discussions on advances in TIMs (thermal interface materials) for LED applications, advances in forced convection cooling of LEDs, and advances in heat sinks for LED assemblies.

In Thermal and Power Management of Integrated Circuits, power and thermal management issues in integrated circuits during normal operating conditions and stress operating conditions are addressed. Thermal management in VLSI circuits is becoming an integral part of the design, test, and manufacturing. Proper thermal management is the key to achieve high performance, quality and reliability. Performance and reliability of integrated circuits are strong functions of the junction temperature. A small increase in junction temperature may result in significant reduction in the device lifetime. This book reviews the significance of the junction temperature as a reliability measure under nominal and burn-in conditions. The latest research in the area of electro-thermal modeling of integrated circuits will also be presented. Recent models and associated CAD tools are covered and various techniques at the circuit and system levels are reviewed. Subsequently, the authors provide an insight into the concept of thermal runaway and how it may best be avoided. A section on low temperature operation of integrated circuits concludes the book.

The continuing trend toward miniaturization and high power density electronics results in a growing interdependency between different fields of engineering. In particular, thermal management has become essential to the design and manufacturing of most electronic systems. Heat Transfer: Thermal Management of Electronics details how engineers can use intelligent thermal design to prevent heat-related failures, increase the life expectancy of the system, and reduce emitted noise, energy consumption, cost, and time to market. Appropriate thermal management can also create a significant market differentiation, compared to similar systems. Since there are more design flexibilities in the earlier stages of product design, it would be productive to keep the thermal design in mind as early as the concept and feasibility phase. The author first provides the basic knowledge necessary to understand and solve simple electronic cooling problems. He then delves into more detail about heat transfer fundamentals to give the reader a deeper understanding of the physics of heat transfer. Next, he describes experimental and numerical techniques and tools that are used in a typical thermal design process. The book concludes with a chapter on some advanced cooling methods. With its comprehensive coverage of thermal design, this book can help all engineers to develop the necessary expertise in thermal management of electronics and move a step closer to being a multidisciplinary engineer.

With this systematic examination of the factors that govern the thermal performance of electronics, the authors solve design problems encountered in developing and analyzing very-high-performance and high-heat-dissipation devices, as well as intermediate and lower-power devices. They explore a wide range of heat transfer technologies and consider their options when employing several different heat transfer modes simultaneously in a system. This important reference provides: Data and correlation's for the analysis and design of electronic equipment; Latest updates on thermal control technology; Review of the fundamentals of heat transfer; Approaches to solving real-world problems of vast complexity. While emphasizing the physics of each subject, the book keeps high-level mathematics to a minimum. Two chapters on conduction and extended surfaces deal with the fundamentals of various heat transfer modes; the other fifteen chapters focus on specific subjects of practical importance to the design of electronic systems. The nine appendices provide useful material, such as property tables for solids and sixteen types of fluids, as well as a comprehensive catalog of topics in connective heat transfer that includes heat transfer correlation's for various physical configurations and thermal boundary conditions. Contents: Introduction; Conduction; Convection; Radiation; Pool Boiling; Flow Boiling; Condensation; Extended Surfaces; Thermal Interface Resistance; Components and Printed Circuit Boards; Direct Air Cooling and Fans; Natural and Mixed Convection; Heat Exchangers and Cold Plates; Advanced Cooling Technologies; Heat Pipes; Thermoelectric Coolers. Appendices: Material Thermal Properties; Thermal Conductivity of Silicon and Gallium Arsenide; Properties of Air, Water, and Dielectric Fluids; Typical Emissivities of Common Surfaces; Properties of Phase-Change Materials; Friction Factor Correlation's; Heat Transfer Correlation's; Units Conversion Table.

Thermal comfort is significant for the human body. The human body is a very delicate system that has a narrow temperature operation range (normal temperature range at rest: 36 °C to 38 °C). Both high temperature and low temperature are usually harmful and even life-threatening. Nevertheless, to maintain thermal comfort, we still tend to rely on the ambient environment temperature control for thermal comfort until now, such as utilizing the heating, ventilation, and air conditioning (HVAC) system. Insufficient attention has been paid to the textiles we wear every day which are the interface of energy exchange between the ambient and the human body. In my Ph.D. study, I focused on the human body itself and its local environment, explored novel materials and tailored thermal regulation properties for textiles, to realize improved personal thermal management. In Chapter 1, I will introduce the background of human body thermal comfort, basic heat dissipation routes including radiation, conduction, convection and evaporation, and the personal thermal management strategy. This thermal regulation strategy is effective for providing enhanced thermal comfort and decreases dependency on the environment for the human body. Besides, considering the huge thermal mass of the entire environment as compared to the individuals, personal thermal management may help save considerable energy for building heating and cooling. The state-of-the-art textiles for thermal comfort will be generally introduced in this chapter as well. Aiming at controlling human body thermal radiation mainly in the mid-infrared (mid-IR) wavelength range, I will demonstrate the radiative cooling textiles based on polyethylene (PE) in Chapter 2. Nanoporous polyethylene (NanoPE) fibers with cotton-like softness that is mid-IR transparent and visibly opaque were explored with large-scale continuous production technology. Utilizing industrial knitting/weaving techniques, NanoPE fabrics were realized by massively produced NanoPE fibers, showing a 2.3 °C cooling effect corresponding to over 20 % of indoor cooling energy saving, compared to commercial cotton fabric of the similar thickness. Besides superior cooling effect, the nanoPE fabric also displays impressive wearability and durability. Furthermore, through identifying and utilizing unique inorganic pigment nanoparticles that have negligible absorption in the mid-IR region and compounding them into polyethylene matrix, colored radiative cooling textiles based on polyethylene were achieved. In Chapter 3, I will show the work of developing advanced textile for personal perspiration management. Integrating the water transportation channels and heat transport matrix together, the integrated cooling (i-Cool) textile not only shows the capability of liquid water wicking, but also exhibits superior evaporation rate than traditional textiles. Furthermore, compared with cotton, about 2.8 °C cooling effect causing less than one-third amount of dehydration has also been demonstrated on the artificial sweating skin platform with feedback control loop simulating human body perspiration situation. Moreover, the practical application feasibility of the i-Cool textile design principles has been validated as well. Owing to its exceptional personal perspiration management performance in liquid water wicking, fast evaporation, efficient cooling effect and reduced human body dehydration/electrolyte loss, the i-Cool textile can utilize sweat much more efficiently, which is significant for expanding human body activity and adaption limit. Next in Chapter 4, I will introduce a bifunctional asymmetric textile with tailored heat conduction and radiation regulation for personal cooling and warming. A facile surface modification approach applied on an asymmetric textile was demonstrated to realize the bifunctional textile with both cooling and warming modes. The engineered heat conduction and radiation properties in either mode resulted in improved cooling/warming effect. Plus, the expanded difference of heat conduction and radiation in cooling and warming modes also enlarged the thermal comfort zone for the human body with one piece of textile. Finally, in chapter 5, I will summarize my Ph.D. work and prospect the future work that can be explored in the near future.

The complete editorial contents of Qpedia Thermal eMagazine, Volume 2, Issues 1 - 12 features in-depth, technical articles on the most critical topics in the thermal management of electronics.

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A powerful methodology for producing superior thermal performanceat low cost with minimum added mass . . . Here is the only available comprehensive treatment of the designand analysis of heat sinks. It provides all the theoretical andpractical information necessary to successfully design and/orselect cost-effective heat sinks for electronic equipment. Thepresentation includes detailed explanations of the governing heattransfer phenomena, complete coverage of thermal modeling tools forgeometrically complex fin structures, and extensive discussion onrecognizing thermal optimization opportunities. Other topics covered include: * Fundamentals of heat transfer * Thermal modeling of electronic packages * Mathematical tools for heat-sink analysis and design * Prevailing thermal transport processes * Models for a variety of fin geometries * Simple "transfer function" relations for single fin, cascadedfin, and fin array heat sinks * Thermal characterization and optimization of plate-fin heatsinks Completely self-contained and filled with valuable information notavailable from any other single source, Design and Analysis of HeatSinks is both a superior reference for accomplished thermalspecialists and an excellent textbook for graduate courses inadvanced thermal applications for mechanical engineering students.This book can also serve as a text in thermal science for studentsof electrical engineering.

Channeling or controlling the heat generated by electronics products is a vital concern of product developers: fail to confront this issue and the chances of product failure escalate. This third book in the series explores yet another method of heat management-the use of liquids to absorb and remove heat away from vital parts of the electronic systems.

The ever increasing requirements for heat dissipation in various thermal management applications such as computer chip cooling and high power electronics have necessitated the need for novel thermal management techniques. Thermal management using heat sinks with microscale features is amongst the prominent techniques developed over the past two decades. In this dissertation, single and phase change heat transfer and pressure drop through one such heat sink, namely microscale pin fin heat sinks ([mu]PFHS), is examined experimentally. In particular, effects of pitch-to-diameter and aspect ratio variations are studied on the thermofluidic performance of studied [mu]PFHSs. Single phase heat transfer and pressure drop of two distinct fluids, liquid nitrogen and Performance Fluid (PF5060) are characterized experimentally through the [mu]PFHSs with staggered diamond shape pin fins. The LN2 and PF5060 experiments' Reynolds number (Re_Dh, based on pin fin hydraulic diameter) is in range of 108-570 and 8-462, respectively. Results are presented in a non-dimensional form in terms of the friction factor (f), Nusselt (Nu), and Reynolds numbers and are compared with the predictions of existing correlations in the literature for micro pin fin heat sinks. Heat sinks with the higher pitch ratio (coarser array) not only show lower pressure drops at a fixed Re_Dh, but also enhance significantly heat transfer rate when compared against the heat sink of the same pin fin size but denser arrangement. Flow visualization experiments using an infrared camera on PF5060 single phase tests are performed to understand the counter-intuitive trends seen in the global results. Flow through heat sinks with the same aspect ratio but larger pitch ratio exhibit unsteady vortex shedding in the wake region of pin fins, which markedly enhances convective heat transfer rate. Existing correlations developed for [mu]PFHSs (such as that by Prasher et al. [1] and Ko?ar and Peles [2]) are capable of predicting the f and Nu data with good agreement only in the absence of vortex shedding, while the unsteady flow past the transition Re_Dh results in poor comparison of correlations with experimental data. A comparison of the experimental Nu data of PF5060 (Pr[approx. equal to]12.2) with the data of LN2 (Pr[approx. equal to]1.9) shows significant change between the slopes of the curves of two fluids only in the heat sinks without vortex shedding. In the heat sinks with unsteady vortex shedding, the Nu_Dh curves show significantly decreased dependency on Pr number. Consequently, separate correlations are developed for predicting Nu in the case with and without unsteady vortex shedding using data from two distinct fluids and four PFHS geometries over a range of Re_Dh from 8 to 643. Given the clear heat transfer enhancement that occurs for certain pitch ratio designs of PFHSs in single phase flows, flow boiling experiments with PF5060 are performed to clarify whether additional changes to the pressure drop and two-phase heat transfer coefficient occur upon the introduction of the unsteady vortex shedding. Subcooled ([delta]T_sub=12.5°C) and saturated flow boiling of PF5060 through the micro pin fins are investigated. The heat sinks are tested at three constant mass fluxes of 30, 60, and 100 kg/m2.s with heat fluxes ranging from 1.1 to 17.8 W/(cm2) based on the planform area of the heat sinks. Flow regimes are studied with high speed imaging. Nucleate boiling heat transfer is the dominant mechanism for exit vapor qualities less than 0.5; at higher qualities annular film evaporation becomes dominant. The salient effect of unsteady vortex shedding is in elimination of wall temperature overshoot. In nucleate boiling regime, the heat sinks with unsteady flow flapping show higher two-phase heat transfer coefficients. The predictions of existing correlations for h_tp in literature are not in good agreement with the experimental data (MAE>30%) and show a systematic deviation depending on the [mu]PFHSs dimensions.

For the second time, the Eurotherm Committee has chosen Thermal Managment of Electronic Systems as the subject for its 45th Seminar, held at IMEC in Leuven, Belgium, from 20 to 22 September 1995. After the successfui first edition of this seminar in Delft, June 14-16, 1993, it was decided to repeat this event on a two year basis. This volume constitutes the edited proceedings of the Seminar. Thermal management of electronic systems is gaining importance. Whereas a few years ago papers on this subject where mainly devoted to applications in high end markets, such as mainframes and telecommunication switching equipment, we see a growing importance in the "lower" end applications. This may be understood from the growing impact of electronics on every day life, from car electronics, GSM phones, personal computers to electronic games. These applications add new requirements to the thermal design. The thermal problem and the applicable cooling strategies are quite different from those in high end products. In this seminar the latest developments in many of the different aspects of the thermal design of electronic systems were discussed. Particular attention was given to thermal modelling, experimental characterisation and the impact of thermal design on the reliability of electronic systems.

Improved thermal management is needed to increase the power density of electronic and more effectively cool electronic enclosures that are envisioned in future aircraft, spacecraft and surface ships. Typically, heat exchanger cores must increase in size to more effectively dissipate increased heat loads, this would be impossible in many cases, thus improved heat exchanger cores will be required. In this Phase I investigation, MRi aimed to demonstrate improved thermal management using graphite foam (Gr-foam) core heat exchangers. The proposed design was to combine Gr-foams from POCO with MRi's innovative low temperature, active metal joining process (S-Bond{trademark}) to bond Gr-foam to aluminum, copper and aluminum/SiC composite faceplates. The results were very favorable, so a Phase II SBIR with the MDA was initiated. This had primarily 5 tasks: (1) bonding, (2) thermal modeling, (3) cooling chip scale packages, (4) evaporative cooling techniques and (5) IGBT cold plate development. The bonding tests showed that the ''reflow'' technique with S-Bond{reg_sign}-220 resulted in the best and most consistent bond. Then, thermal modeling was used to design different chip scale packages and IGBT cold plates. These designs were used to fabricate many finned graphite foam heat sinks specifically for two standard type IC packages, the 423 and 478 pin chips. These results demonstrated several advantages with the foam. First, the heat sinks with the foam were lighter than the copper/aluminum sinks used as standards. The sinks for the 423 design made from foam were not as good as the standard sinks. However, the sinks made from foam for the 478 pin chips were better than the standard heat sinks used today. However, this improvement was marginal (in the 10-20% better regime). However, another important note was that the epoxy bonding technique resulted in heat sinks with similar results as that with the S-bond{reg_sign}, slightly worse than the S-bond{reg_sign}, but still better than the standard heat sinks. Next, work with evaporative cooling techniques, such as heat pipes, demonstrated some unique behavior with the foam that is not seen with standard wick materials. This was that as the thickness of the foam increased, the performance got better, where with standard wick materials, as the thickness increases, the performance decreases. This is yet to be completely explained. Last, the designs from the thermal model were used to fabricate a series of cold plates with the graphite foam and compare them to similar designs using high performance folded fin aluminum sinks (considered standard in the industry). It was shown that by corrugating the foam parallel to fluid flow, the pressure drop can be reduced significantly while maintaining the same heat transfer as that in the folded fin heat sink. In fact, the results show that the graphite foam heat sink can utilized 5% the pumping power as that required with the folded fin aluminum heat sink, yet remove the same amount of heat.

The disproportionate use of fossil fuels has turned into a serious environmental issue. Thus, we are encountering one of the biggest challenges of the twenty-first century, satisfying the energy demand with respect to the environment. Thermoelectricity is an emerging technology, which contributes to reducing the impact of the use of traditional technologies, harvesting the waste heat, and eliminating the use of refrigerants. The book Bringing Thermoelectricity into Reality covers the current thermoelectric investigations: the study of novel thermoelectric materials, the development of computational models, the design of proper assemblies, and the optimization of thermal designs, as well as novel thermoelectric generators, coolers, and heating applications. This book looks for the definitive thermoelectric applications applied to everyday life.

Over the past few decades there has been a prolific increase in research and development in area of heat transfer, heat exchangers and their associated technologies. This book is a collection of current research in the above mentioned areas and describes modelling, numerical methods, simulation and information technology with modern ideas and methods to analyse and enhance heat transfer for single and multiphase systems. The topics considered include various basic concepts of heat transfer, the fundamental modes of heat transfer (namely conduction, convection and radiation), thermophysical properties, computational methodologies, control, stabilization and optimization problems, condensation, boiling and freezing, with many real-world problems and important modern applications. The book is divided in four sections : "Inverse, Stabilization and Optimization Problems", "Numerical Methods and Calculations", "Heat Transfer in Mini/Micro Systems", "Energy Transfer and Solid Materials", and each section discusses various issues, methods and applications in accordance with the subjects. The combination of fundamental approach with many important practical applications of current interest will make this book of interest to researchers, scientists, engineers and graduate students in many disciplines, who make use of mathematical modelling, inverse problems, implementation of recently developed numerical methods in this multidisciplinary field as well as to experimental and theoretical researchers in the field of heat and mass transfer.

The need for advanced thermal management materials in electronic packaging has been widely recognized as thermal challenges become barriers to the electronic industry’s ability to provide continued improvements in device and system performance. With increased performance requirements for smaller, more capable, and more efficient electronic power devices, systems ranging from active electronically scanned radar arrays to web servers all require components that can dissipate heat efficiently. This requires that the materials have high capability of dissipating heat and maintaining compatibility with the die and electronic packaging. In response to critical needs, there have been revolutionary advances in thermal management materials and technologies for active and passive cooling that promise integrable and cost-effective thermal management solutions. This book meets the need for a comprehensive approach to advanced thermal management in electronic packaging, with coverage of the fundamentals of heat transfer, component design guidelines, materials selection and assessment, air, liquid, and thermoelectric cooling, characterization techniques and methodology, processing and manufacturing technology, balance between cost and performance, and application niches. The final chapter presents a roadmap and future perspective on developments in advanced thermal management materials for electronic packaging.

Thermal energy storage using phase change materials (PCMs) is a research topic that has attracted much attention in recent decades. This is mainly due to the potential use of PCMs as latent storage media in a large variety of applications. Although many kinds of PCMs are already commercial products, advanced materials with improved properties and new latent storage concepts are required to better meet the specific requirements of different applications. Moreover, the development of common validation procedures for PCMs is an important issue that should be addressed in order to achieve commercial deployment and implementation of these kinds of materials in latent storage systems. The key subjects addressed on the five papers included in this Special Issue are related to methodologies for material selection, PCM validation and assessment procedures, innovative approaches of PCM applications together with simulation and testing of latent storage prototypes.

A suppressor is disclosed for use with a weapon having a barrel through which a bullet is fired. The suppressor has an inner portion having a bore extending coaxially therethrough. The inner portion is adapted to be secured to a distal end of the barrel. A plurality of axial flow segments project radially from the inner portion and form axial flow paths through which expanding propellant gasses discharged from the barrel flow through. The axial flow segments have radially extending wall portions that define sections which may be filled with thermally conductive material, which in one example is a thermally conductive foam. The conductive foam helps to dissipate heat deposited within the suppressor during firing of the weapon.

Publisher's Note: Products purchased from Third Party sellers are not guaranteed by the publisher for quality, authenticity, or access to any online entitlements included with the product. The "hands-on" guide to thermal management! In recent years, heat-sensitive electronic systems have been miniaturized far more than their heat-producing power supplies, leading to major design and reliability challenges — and making thermal management a critical design factor. This timely handbook covers all the practical issues that any packaging engineer must consider with regard to the thermal management of printed circuit boards, hybrid circuits, and multichip modules. Readers will also benefit from the extensive data on material properties and circuit functions, thus enabling more intelligent decisions at the design stage — and preventing thermal-related problems from occurring in the first place.

Heat dissipation is a critical limitation in a range of electronic devices including microprocessors, solar cells, laser diodes and power amplifiers. The most demanding devices require dissipation of heat fluxes in excess of 1 kW/cm2 with heat transfer coefficients more than 30 W/cm 2K. Advanced thermal management solutions using phase change heat transfer are the most promising approach to address these challenges, yet current solutions are limited due to the combination of heat flux, thermal resistance, size and flow stability. This thesis reports the design, fabrication and experimental characterization for an evaporation device with a nanoporous membrane for high heat flux dissipation. Evaporation in the thin film regime is achieved using nanopores with reduced liquid film thicknesses while liquid pumping is enhanced using the capillary pressure of the 120 nm pores. The membrane is mechanically supported by ridges that form liquid supply channels and also serve as a heat conduction path to the evaporating meniscus at the surface of the membrane. The combination of high capillarity pores with high permeability channels facilitates theoretical critical heat fluxes over 2 kW/cm2 and heat transfer coefficients over 100 W/cm2K. Proof-of-concept devices were fabricated using a two-wafer stack consisting of a bonded silicon-on-insulator (SOI) wafer to a silicon wafer. Pores with diameters 110 - 130 nm were defined with interference lithography and etched in the SOI. Liquid supply microchannels were etched on a silicon wafer and the two wafers were fusion bonded together to form a monolithic evaporator. Once bonded, the membrane was released by etching through the backside of the SOI. Finally, platinum heaters and Resistive Temperature Detectors (RTDs) were deposited by e-beam evaporation and liftoff to heat the sample and measure the device temperature during experiments, respectively. Samples were experimentally characterized in a custom environmental chamber for comparison to the model using R245fa, methanol, pentane, water and isopropyl alcohol as working fluids. A comparison of the results with different working fluids demonstrates that transport at the liquid-vapor interface is the dominant thermal resistance in the system, suggesting a figure of merit: ... The highest heat flux recorded was with pentane at ... and the highest heat transfer coefficient recorded was with ... not including the substrate resistance. However, the samples were observed to clog with soluble, nonvolatile contaminants which limited operation to several minutes. The clogging behavior was captured in a mass diffusion model and a new configuration was suggested which is resistant to clogging. Evaporation from nanopores represents a new paradigm in phase change cooling with a figure of merit that favors high volatility, low surface tension fluids rather than water. The models and experimental results validate the functionality and understanding of the proposed approach and provide recommendations for enhancements in performance and understanding as well as strategies for resistance to clogging. This work demonstrates that nanoporous membranes have the potential for ultra-high heat flux dissipation to address next generation thermal management needs.

Energy Efficient Thermal Management of Data Centers examines energy flow in today's data centers. Particular focus is given to the state-of-the-art thermal management and thermal design approaches now being implemented across the multiple length scales involved. The impact of future trends in information technology hardware, and emerging software paradigms such as cloud computing and virtualization, on thermal management are also addressed. The book explores computational and experimental characterization approaches for determining temperature and air flow patterns within data centers. Thermodynamic analyses using the second law to improve energy efficiency are introduced and used in proposing improvements in cooling methodologies. Reduced-order modeling and robust multi-objective design of next generation data centers are discussed.

Advanced Thermal Management Materials provides a comprehensive and hands-on treatise on the importance of thermal packaging in high performance systems. These systems, ranging from active electronically-scanned radar arrays to web servers, require components that can dissipate heat efficiently. This requires materials capable of dissipating heat and maintaining compatibility with the packaging and dye. Coverage includes all aspects of thermal management materials, both traditional and non-traditional,with an emphasis on metal based materials. An in-depth discussion of properties and manufacturing processes, and current applications are provided. Also presented are a discussion of the importance of cost, performance and reliability issues when making implementation decisions, product life cycle developments, lessons learned and future directions.

The field of power electronics devices has seen two significant trends in recent years: rapid miniaturization of devices and the replacement of silicon-based devices with wide bandgap semiconductor materials-based devices (Silicon Carbide (SiC), Gallium Nitride (GaN)). The end result of these advancements are devices that need advanced cooling technologies to dissipate ultrahigh high and concentrated heat loads. Multiple advanced thermal management solutions such as liquid cooling, jet, and spray impingement have been proposed as potential solutions. The present dissertation quantifies the benefits of key advanced cooling techniques for thermal management of power electronics packages. An analytical modeling framework based on a thermal resistance circuit has been utilized to estimate the maximum heat flux that can be dissipated from a power electronics package, and the junction temperatures at varying levels of power dissipation. Analysis was conducted for heat sinks made of copper (k=400 W/mK) and a polymer (k=20 W/mK). The developed modeling framework takes into account heat spreading in both lateral directions while capturing the influence of material properties on the spreading angle. The model can, therefore, be considered to capture 3D effects as well. Additionally, 3D Finite Element Analysis (FEA) simulations have been carried out to compare with the findings of the analytical model. This dissertation also studies the influence of polymeric encapsulants of varying thermal conductivities on the resulting temperature distributions in the package via steady 2D coupled electro-thermal simulations. Overall, the methodology and results presented in this dissertation provide insights for selecting optimal combinations of thermal management technologies and advanced polymeric materials, based on the heat dissipation requirements of power electronics packages

Thermal and mechanical packaging — the enabling technologies for the physical implementation of electronic systems — are responsible for much of the progress in miniaturization, reliability, and functional density achieved by electronic, microelectronic, and nanoelectronic products during the past 50 years. The inherent inefficiency of electronic devices and their sensitivity to heat have placed thermal packaging on the critical path of nearly every product development effort in traditional, as well as emerging, electronic product categories.Successful thermal packaging is the key differentiator in electronic products, as diverse as supercomputers and cell phones, and continues to be of pivotal importance in the refinement of traditional products and in the development of products for new applications. The Encyclopedia of Thermal Packaging, compiled in four multi-volume sets (Set 1: Thermal Packaging Techniques, Set 2: Thermal Packaging Tools, Set 3: Thermal Packaging Applications, and Set 4: Thermal Packaging Configurations) provides a comprehensive, one-stop treatment of the techniques, tools, applications, and configurations of electronic thermal packaging. Each of the author-written volumes presents the accumulated wisdom and shared perspectives of a few luminaries in the thermal management of electronics.The four sets in the Encyclopedia of Thermal Packaging will provide the novice and student with a complete reference for a quick ascent on the thermal packaging 'learning curve,' the practitioner with a validated set of techniques and tools to face every challenge, and researchers with a clear definition of the state-of-the-art and emerging needs to guide their future efforts. This encyclopedia will, thus, be of great interest to packaging engineers, electronic product development engineers, and product managers, as well as to researchers in thermal management of electronic and photonic components and systems, and most beneficial to undergraduate and graduate students studying mechanical, electrical, and electronic engineering.Set 3: Thermal Packaging ApplicationsThe third set in the Encyclopedia includes two volumes in the planned focus on Thermal Packaging Applications and a single volume on the use of Phase Change Materials (PCM), a most important Thermal Management Technique, not previously addressed in the Encyclopedia. Set 3 opens with Heat Transfer in Avionic Equipment, authored by Dr Boris Abramzon, offering a comprehensive, in-depth treatment of compact heat exchangers and cold plates for avionics cooling, as well as discussion on recent developments in these heat transfer units that are widely used in the thermal control of military and civilian airborne electronics. Along with a detailed presentation of the relevant thermofluid physics and governing equations, and the supporting mathematical design and optimization techniques, the book offers a practical guide for thermal engineers designing avionics cooling equipment, based on the author's 20+ years of experience as a thermal analyst and a practical design engineer for Avionics and related systems.The Set continues with Thermal Management of RF Systems, which addresses sequentially the history, present practice, and future thermal management strategies for electronically-steered RF systems, in the context of the RF operational requirements, as well as device-, module-, and system-level electronic, thermal, and mechanical considerations. This unique text was written by 3 authors, Dr John D Albrecht, Mr David H Altman, Dr Joseph J Maurer, with extensive US Department of Defense and aerospace industry experience in the design, development, and fielding of RF systems. Their combined efforts have resulted in a text, which is well-grounded in the relevant past, present, and future RF systems and technologies. Thus, this volume will provide the designers of advanced radars and other electronic RF systems with the tools and the knowledge to address the thermal management challenges of today's technologies, as well as of advanced technologies, such as wide bandgap semiconductors, heterogeneously integrated devices, and 3D chipsets and stacks.The third volume in Set 3, Phase Change Materials for Thermal Management of Electronic Components, co-authored by Prof Gennady Ziskind and Dr Yoram Kozak, provides a detailed description of the numerical methods used in PCM analysis and a detailed explanation of the processes that accompany and characterize solid-liquid phase-change in popular basic and advanced geometries. These provide a foundation for an in-depth exploration of specific electronics thermal management applications of Phase Change Materials. This volume is anchored in the unique PCM knowledge and experience of the senior author and placed in the context of the extensive solid-liquid phase-change literature in such diverse fields as material science, mathematical modeling, experimental and numerical methods, and thermofluid science and engineering.

Packaging, the physical design and implementation of electronic systems is responsible for much of the progress in miniaturization, reliability and functional density achieved by the full range of electronic, microelectronic and nanoelectronic products during the past several decades. The inherent inefficiency of electronic devices and their sensitivity to heat have placed thermal management on the critical path of nearly every organization dealing with traditional electronic product development, as well as emerging, product categories. Successful thermal packaging is the key differentiator in electronic products, as diverse as supercomputers and cell phones, and continues to be of critical importance in the refinement of traditional products and in the development of products for new applications.The Encyclopedia of Thermal Packaging, compiled into four 5-volume sets (Thermal Packaging Techniques, Thermal Packaging Configurations, Thermal Packaging Tools and Thermal Packaging Applications), will provide comprehensive, one-stop treatment of the techniques, configurations, tools and applications of electronic thermal packaging. Each volume in a set comprises 250–350 pages and is written by world experts in thermal management of electronics.

These days, the cooling of new generation electronic servers is a challenge due to the immense heat generated by them. In order to avoid overheating caused by the important rise in temperature appropriate cooling procedures must be used in order to meet the thermal requirement. The current study aims at addressing the issue of overheating in this field, and focuses on the thermal management of electronic devices modelled as a discrete heat sources (mounted in a rectangular cavity) with uniform heat flux applied from the bottom. A review of the literature published regarding the convective heat transfer from heated sources as well as a thorough background on the theory of the cooling of discrete sources by forced convection in rectangular channel is provided in this study. It was showed that the heat transfer performance in channel is strongly influenced by the geometric configurations of heat sources. Therefore, the arrangement and geometric optimisation are the main considerations in the evaluation of thermal performance. Unlike experimental methods that were carried out widely in the past, which provided less cost-effective and more time-consuming means of achieving the same objective, in this study we first explore the possibilities and the advantages of using the CD-adapco's CFD package Star-CCM+ to launch a three dimensional investigation of forced convection heat transfer performance in a channel mounted with equidistant heatgenerating blocks. Numerical results were validated with available experimental data, and showed that the thermal performance of the heat transfer increases with the strength of the flow. The second objective was to maximise the heat transfer density rate to the cooling fluid and to minimise both the average and the maximum temperature in the channel by using the numerical optimisation tool HEEDS/Optimate+. The optimal results showed that better thermal performance was not obtained when the heated sources followed the traditional equidistance arrangement, but was achieved with a specific optimal arrangement under the total length constraint for the first case. Subsequently, for the second case study, on the volume constraints of heat sources, the results proved that optimal configurations that maximise the heat transfer density rate were obtained with a maximum of either the height-to-length ratio or the height-to-width ratio. It was concluded that the heat transfer rate to the cooling fluid increases significantly with the Reynolds number and the optimal results obtained numerically are found to be fairly reliable.

Water and Thermal Management of Proton Exchange Membrane Fuel Cells introduces the main research methods and latest advances in the water and thermal management of PEMFCs. The book introduces the transport mechanism of each component, including modeling methods at different scales, along with practical exercises. Topics include PEMFC fundamentals, working principles and transport mechanisms, characterization tests and diagnostic analysis, the simulation of multiphase transport and electrode kinetics, cell-scale modeling, stack-scale modeling, and system-scale modeling. This volume offers a practical handbook for researchers, students and engineers in the fields of proton exchange membrane fuel cells. Proton exchange membrane fuel cells (PEMFCs) are high-efficiency and low-emission electrochemical energy conversion devices. Inside the PEMFC complex, physical and chemical processes take place, such as electrochemical reaction, multiphase flow and heat transfer. This book explores these topics, and more. Introduces the transport mechanism for each component of PEMFCs Presents modeling methods at different scales, including component, cell, stack and system scales Provides exercises in PEMFC modeling, along with examples of necessary codes Covers the latest advances in PEMFCs in a convenient and structured manner Offers a solution to researchers, students and engineers working on proton exchange membrane fuel cells

To celebrate Professor Avi Bar-Cohen's 65th birthday, this unique volume is a collection of recent advances and emerging research from various luminaries and experts in the field. Cutting-edge technologies and research related to thermal management and thermal packaging of micro- and nanoelectronics are covered, including enhanced heat transfer, heat sinks, liquid cooling, phase change materials, synthetic jets, computational heat transfer, electronics reliability, 3D packaging, thermoelectrics, data centers, and solid state lighting. This book can be used by researchers and practitioners of thermal engineering to gain insight into next generation thermal packaging solutions. It is an excellent reference text for graduate-level courses in heat transfer and electronics packaging. Contents:A Review of Cooling Road Maps for 3D Chip Packages (Dereje Agonafer)Thermal Performance Mapping of Direct Liquid Cooled 3D Chip Stacks (Karl J L Geisler and Avram Bar-Cohen)Dynamic Thermal Management Considering Accurate Temperature-Leakage Interdependency (Bing Shi and Ankur Srivastava)Energy Reduction and Performance Maximization Through Improved Cooling (David Copeland)Optimal Choice of Heat Sinks from an Industrial Point of View (Clemens J M Lasance)Synthetic Jets for Heat Transfer Augmentation in Microelectronics Systems (Mehmet Arik and Enes Tamdogan)Recent Advance in Thermoelectric Devices for Electronics Cooling (Peng Wang)Energy Efficient Solid-State Cooling for Hot Spot Removal (Kazuaki Yazawa, Andrei Fedorov, Yogendra Joshi and Ali Shakouri)An Overview of the Use of Phase Change Materials for the Thermal Management of Transient Portable Electronics: Benefits and Challenges (Amy S Fleischer)Estimation of Cooling Performance of Phase Change Material (PCM) Module (Masaru Ishizuka and Tomoyuki Hatakeyama)Optimization Under Uncertainty for Electronics Cooling Design (Karthik K Bodla, Jayathi Y Murthy and Suresh V Garimella)Hydrophilic CNT-Sintered Copper Composite Wick for Enhanced Cooling (Glen A Powell, Anuradha Bulusu, Justin A Weibel, Sungwon S Kim, Suresh V Garimella and Timothy S Fisher)A Cabinet Level Thermal Test Vehicle to Evaluate Hybrid Double-Sided Cooling Schemes (Qihong Nie and Yogendra Joshi)Energy Efficiency and Reliability Risk Mitigation of Data Centers Through Prognostics and Health Management (Jun Dai, Michael Ohadi and Michael Pecht)Damage Pre-Cursors Based Assessment of Accrued Thermomechanical Damage and Remaining Useful Life in Field Deployed Electronics (Pradeep Lall, Mahendra Harsha, Kai Goebel and Jim Jones)Towards Embedded Cooling — Gen 3 Thermal Packaging Technology (Avram Bar-Cohen) Readership: Researchers, practitioners, and postgraduates in mechanical engineering, nanoelectronics, computer engineering, and electrical & electronic engineering. Keywords:Electronics Cooling;Electronics Packaging;Thermal Management;Thermal Sciences;Electronics Reliability;Thermoelectrics;Computational Heat Transfer;Liquid Cooling

Thermal design in electronics cooling is to achieve effective heat removal to increase reliability and life of the components and systems. This book focuses on cooling of a Flip Chip (FC) package without the use of phase change materials(PCM). A numerical thermal model was developed and validated. CFD Simulation is performed for PCM and non-PCM based material studies. Relevant thermal performance data were obtained to show the effects of thermal interface material, lid, heat sink and process variables. Excellent agreement found between the numerical and the measured data. A novel PCM-based passive thermal control of electronic devices was investigated experimentally. A tall enclosure with uniform/discrete heat sources applied on sides for PCM melting and another with a PCM-filled heat sink setup developed and tested. PCM-based cooling technique is attractive thermal concept for transient applications. Effects of various parameters on melting/freezing times were studied. Flow visualization experiments were also made to determine the PCM melting rates. Finally, a 2D numerical study was conducted to compare simulation results with experimental data.