iNEMI
International Electronics Manufacturing Initiative

Advancing manufacturing technology

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Roadmap Overview

The 2019 Roadmap will include seven Product Emulator Group (PEG) chapters that anticipate the product needs of the future. The PEGs define the technology needs of key market segments by focusing on the market demands and functionality requirements of seven industry segments: aerospace & defense, automotive, consumer & office systems, high-end systems, industrial Internet of things (IIoT) & wearables, medical, and portable & wireless.

In addition to the product segments, there are 21 Technology Working Group (TWG) chapters that identify key technology developments anticipated and required within the electronics manufacturing supply chain to meet product needs between now and 2029.

Product Emulator Group (PEG) Chapters

Aerospace & Defense

Several primary considerations continue to distinguish the products covered by the Aerospace & Defense PEG from other product sectors included in the roadmap. These features include the extreme environments in which these products operate, need for security, desire for reworkability, long duration storage requirements and the functional lifetime over which the products are expected to perform and be supported. This chapter discussed several evolving product requirements, manufacturing infrastructure issues, technological needs and gaps.

Automotive

The main factor that differentiates the Automotive product sector emulator from the other product emulators is the operating environment. These products must perform reliably in automobiles as well as in light-duty, medium-duty and heavy-duty trucks. Many of the attributes, such as cost, density and components, overlap with the other emulators. Increasing density is important for these applications because of cost, size and weight reductions.

The assembly and manufacturing/test equipment requirements are also critical due to the reliability demands. Automotive applications are extremely cost sensitive and, therefore, require cost targets similar to those of consumer products. The challenge for the Automotive product sector emulator is to adapt other emulators' technologies to meet the high temperature, environmental and reliability requirements cost effectively.

This chapter identifies four key paradigm shifts that will impact product development in the Automotive sector: (1) vehicle electrification, (2) connected vehicles, (3) enhancement of safety systems and (4) autonomous driving vehicles. One of the most important research areas identified is related to the electrification of the vehicle. For example, battery cost must be significantly lowered (targeting $200 / KWh). There are also immediate needs to reduce the size, mass and cost of the electronics used on HEVs, PHEVs and EVs.

Consumer & Office Systems

This sector, driven by business and consumer spending, has grown only marginally in recent years given the continuing price erosion across all markets and a mixed outlook for unit growth within each of the sub-segments. However, there are segments within this sector — workstations, entry-level servers, 4KTV — expected to maintain growth.

The main technology driver for the consumer & office products sector is still cost top to bottom. This focus on cost will be challenged by the emerging focus on the mobile user experience. With the wide acceptance of tablet computers by businesses and consumers, the traditional office systems will focus on reinventing the notebook category, creating hybrid (tablet/notebook combo) system designs that seek to duplicate both the tablet user experience and the notebook user experience in one device. These designs will drive thin, low-power, form factors with high-resolution touch screens and multiple integrated sensors. The technologies to enable these hybrid systems include HDI PCBs, thin metal enclosures or structurally equivalent plastics, ultra-thin package substrates, die thinning technology, 3D packaging with die stacking and TSVs, more efficient batteries, low-cost touch panels, and lower profile/thinner disk drives, connectors, ICs, fans/heatsinks and keyboards.

High-End Systems

The High-End Systems product emulator spans a portfolio of technologies that cover high-performance computing, data centers and communication systems. Included in these broad categories are enterprise networking and storage systems.

The proliferation of interconnected devices and the resulting amount of data that needs to be communicated, analyzed and stored drives the growth of all sectors discussed in this chapter. These forces are transforming the high-end system structures to a higher level of integration of computing, storage and networking components. The data bandwidth demand is resulting in systems with ever faster interconnect speeds, even as processor speed is staying constant. The size of the data centers creates a challenge for power demand creating an increasing focus on power efficiency of the systems.

The assembly and packaging technology to support the four categories of systems continues to advance. Some of the packaging technology is introduced in the higher premium HPC and mainframe systems and trickles down to consumer products, while others are introduced in the mobile space where high-bandwidth and high-density interconnect are essential. The chapter discusses through-silicon vias (TSV) for stacked chips and silicon interposers, system-in-package (SiP) and package-on-package (PoP) advanced packaging, optics including silicon photonics, lower loss interconnect such as low-loss laminates in printed circuit boards and packages, and techniques for more efficient power conversion.

The High-End Systems chapter includes the product emulator spreadsheet enumerating the trending key attribute “needs” over the next decade including PCB costs, power, pin densities and assembly technologies.

Industrial Internet of Things (IIoT)

In utmost synthesis, IoT can be considered a family of technologies whose goal is to enable anything that can be connected to the Internet – even things that do not have any electronic purpose – to be monitored and controlled from afar and thus to provide a service to its users. In the industrial sector, the IoT is linked to the concept of Industry 4.0, foreseeing the application of IoT in an intelligent machine context: systems and people connected to each other. An evolution in which factories continue to be more intelligent, and with their assembly line components more closely interconnected, will create the possibility to make decisions based on a wide range of highly sophisticated, extensive databases, opening the way for new types of business. This chapter will also address wearable technologies.

Medical

The Medical product sector continues to be a growth area. Worldwide demographics and lifestyle changes are increasing the demand for medical technologies that will be accelerated by improved diagnostic methods for a variety of diseases such as cancer. On the technology front, introduction of stretchable electronics substrates is a paradigm shift in the business. This will become the third major substrate technology for medical over the course of the next several years (rigid and flex being the other two).

The focus of healthcare will continue to shift from treatment to prevention. Technology advancements have enabled wearables that provide access to real-time data, and sensors allow any individual to become a more hands-on patient. Employers, insurers and even governments will likely fund preventive care and healthy living to reduce costs. This trend presents a tremendous opportunity for medical electronics manufacturers.

Security concerns are front and center, making it imperative that systems and software be more robust. Security needs go beyond patient records to include devices that transmit information wirelessly along with devices that deliver therapy or a pharmaceutical dosage. The growth of handheld devices and apps that monitor, track and store personal health information increase the risk that private data can end up in the wrong hands.

Portable & Wireless

The Portable & Wireless chapter covers high-volume consumer products for which cost is the primary driver including handheld battery powered products driven by size and weight reduction. It contains electronics devices such as computers, tablets, mobile phones and smartphones, and portable gaming devices. Form factors for these devices will continue to scale down into smaller, thinner and increasingly wearable and flexible devices, enabled by advances in flexible displays.

A significant portion of this sector continues to be dedicated to the relatively mature, but still evolving and growing smartphone/phablet/tablet and 2-in-1 computer space. This chapter addresses the continuation of the integration strategy of mobile internet, QHD (Quad High Density) displays, flexible/curved displays, cameras (both for video as well as perceptual sensors), music players and connectivity via Wi-Fi and Bluetooth.

Several other factors will affect this sector. Cost, power, bandwidth, and form factor of these devices continue to be driving factors for acceleration of integration of silicon and system capabilities into single package or single die. Software-enabled services are expected to expand as growth opportunities for the consumer segment. The transition to perceptual computing will require evolution of advanced sensors and enhanced user interface experiences. In addition, the use of motion-gesture sensors in various portable and wireless devices will expand the MEMS gyroscope landscape.

Technology Working Group (TWG) Chapters

Board Assembly

SMTA and its members assist in development of this chapter. Board assembly is a critical part of the overall electronic products supply chain. It accounts for most of the direct material cost, and is closely associated with component packaging, interconnection, inspection, thermal management, final assembly and environmental compliance. This chapter identifies four main common drivers for development in board assembly processes:

- Conversion cost reduction
- Reduction in new product introduction (NPI) time
- Increased component I/O density
- Transition to environmental and regulatory requirements

In this chapter, discussion of board assembly process includes leaded component insertion (for wave soldering) and/or solder paste application for (SMT) on the bare PCB and ends at printed circuit board assembly (PCBA) test. It also includes special processes such as underfill application, odd form component placement, etc. Although test and inspection actions occur throughout the board assembly process, they are not addressed in this chapter.

Sections within the Board Assembly chapter focus on several sub-areas within the assembly process. These are: new product introduction, assembly materials, surface mount technology (SMT), placement, dispense technology, wave and selective soldering, press fit, rework, and direct chip attach (DCA).

Ceramic Substrates & Photovoltaic Technology

This chapter is provided by iMAPS. As the electronics industry continues its dramatic changes, not only with mobile device applications, but also focusing on 5G/IoT devices and applications. Innovative ceramic interconnection substrate technology is a key enabling technology for 5G devices, offering a toolset that will enable adopters to realize a competitive advantage through increased functionality, 3D integration and portability demanded by the 5G electronic systems packaging requirements.

This chapter looks at the several ceramic substrate technologies, including: thick-film, high and low temperature co-fired, thin film, pure copper metallization on ceramic, and lead-free thick film. It discusses the status of technologies and identifies trends, future directions, paradigm shifts and key infrastructure issues.

Additionally, the materials, processes and the supply chain that are well developed for ceramic interconnect continue to be applied to enable dynamic growth in the photovoltaic industry. The chapter also includes a section that summarizes crystalline silicon solar cell design, fabrication and testing.

Connectors

Electronic connectors are small precision-engineered de-mateable electrical contacts and housings designed to provide secure mechanical and electrical connections between printed circuits, cables and packages, and in or between electrical/electronic systems. Connector technologies support a huge variety of standard and custom designs, specifications and physical / ergonomic requirements. These technologies have few technical barriers because of the huge variety of materials and component parts; however, achieving minimum size is one. Fiber optic connectors are used where speed and bandwidth requirements transcend Cu circuitry's limits. Where integrated circuit feature sizes are required, connections such as wire bonds or ball grid arrays are used.

This chapter provides a wealth of information about electronic connectors with both an excellent overview of the current situation as well as projected technology enhancements and challenges over the 10-year roadmap horizon.

The chapter also looks at photonic connectors. Silicon photonics (SiPh) technology is defined as photonic (lightwave) circuitry that employs (hopefully) low-cost Si as a device and circuit platform, and employs heterogeneous micro-packaging of various photonic chips and devices including GaAs, InP, and preferably Si micro-laser technology to drive low-cost/high-volume computer/datacom/networking/ video streaming applications. The compelling requirement for these technologies is increasing circuit speed and bandwidth. Terabit speed will be necessary by the 2020s, and can be accomplished via massively parallel systems, or with wave division multiplexed optical fibers.

Energy Storage

Consumer electronics, electric transportation and the smart grid all require a reliable and efficient energy storage technology; however, the details vary drastically. Batteries for consumer electronics, while still imperfect, are widely deployed, and have become household staples. In contrast, energy storage for the electrical grid remains in its early stages of development and implementation, building and evaluating small-scale pilot projects. Government and regulatory bodies continue to work new legislation and implement new standards for the future. While it is fair to say that batteries for consumer electronics are maturing as an industry, and energy storage for the grid is in its infancy, the status of batteries for electrical transportation is somewhere in between.

This roadmap chapter deals with a number of energy storage markets, including consumer electronics, electric/hybrid vehicles, and electric grid storage. In addition to quantifying technical and business attributes over the 10-year roadmap horizon, the chapter addresses related topics such as EV charging infrastructure, government incentives, regulatory regimes, power conversion cost reduction and efficiency improvement, plus reuse, recycle and disposal of battery systems.

Final Assembly

Final assembly is an important part of electronic systems manufacturing. As defined in the iNEMI Roadmap, it encompasses operations that integrate or assemble electronic subassemblies with other electronic, mechanical/fluidic and optical content. As the last step in the manufacturing process, final assembly often involves product configuration; test, inspection and measurement (TIM); cleaning and sanitization/sterilization; along with country-specific packaging and labeling.

This chapter addresses strategic and implementation challenges such as the lack of common industry strategies and solutions for final assembly, advancements in human-centered automation, increasing product traceability requirements, quality improvement through test and performance metrics, and more. It also looks at the technology needs and gaps related to a lack of adequate assembly process control, monitoring, and verification; and a lack of adequate and economical assembly solutions.

Flexible Hybrid Electronics

This chapter was developed with support from NextFlex. Previously called the Large Area, Flexible Electronics TWG, this chapter's name has been changed to reflect the market's adoption of the term "flexible hybrid electronics" (FHE).

The FHE market has been strengthened by the integration of evolutionary technologies (e.g., thin and ultra-thin die) with revolutionary technologies (e.g., additive solution processes). This integration has resulted in an increase of new applications opportunities. The chapter provides an overview of the most critical technology platforms required for commercial launch and market diffusion. The value of this roadmap is its attempt to provide scientists and engineers with a deep appreciation for the state of the art of the field and to highlight key areas that require additional efforts to be undertaken (e.g., strategic new development projects) to accelerate the growth and establishment of the FHE components, modules and systems enabled market.

In the 2017 Roadmap, the FHE chapter introduced the use of Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) methods for assessing technology and manufacturing maturity levels. The use of TRL and MRL will provide guidance to engineers and designers as they develop strategies and long-term plans for advanced technology introduction for launch of new products.

Interconnect PCB-Organic

This chapter is developed in conjunction with IPC, EIP and TPCA. The interconnecting substrate can, and generally does, provide many functional attributes in addition to the basic electrical circuit. Organic printed boards account for more than 90% of the present types of interconnecting structures. The characteristics and capabilities of the global infrastructure have been able to meet the demand for circuit precision. However, achieving cost expectations while simultaneously satisfying design intents and time-to-market expectations for high-volume production continues to be a major challenge. Additionally, the need to manage the competing, and sometimes contradictory, legal demands posed by various worldwide governments, means an additional set of requirements for organic materials.

This chapter looks at rigid, flexible and optoelectronic substrates, along with manufacturing equipment and processes, materials, waveguide technology and more. It discusses some of the most critical issues with regards to such things as embedded components, computer buses, package conductor routing, and liquid coolants and heat sink requirements. It also identifies technology, research and development needs.

Mass Data Storage

Mass data storage technology for digital electronic systems is evolving and expanding in importance and impact. From its origins primarily in high-end computing and business systems in the 1940s and 50s, it has broadened to encompass a wide range of technologies and applications. Current technologies include solid state non-volatile flash memory based on NAND semiconductor cells, ferroelectric, magneto-resistive random access memory, magnetic recording on rigid disks and tape, and a number of different optical storage technologies. The list of potential emerging additional mass data storage technologies which have already entered, or may enter, the mainstream continues to increase, including solid state phase change ('Ovonic') memory, hybrid flash/disk drives, memristor storage, spin-torque MRAM, or other magnetic spin base memories and optical holographic based storage.

This chapter covers a wide variety of storage technologies, including both well-established and emerging technologies. It covers technologies in the areas of solid state, magnetic storage and optical data storage. It is an excellent tutorial on mass data storage, and it points out the trends and developments that are required to meet the mushrooming growth in data storage capacity.

MEMS & Sensors

The MEMS & Sensors Industry Group (MSIG) has been working with iNEMI on the MEMS chapter since 2011. Earlier editions of the roadmap were near term, within a 5-year timeframe. The 2017 edition extended the horizon to 15 years and beyond.

Recently, MSIG has teamed with the TSensors Initiative, creating a forum for discussion about the future needs for MEMS and sensors for the Internet of Things. The vast number of sensors envisioned by the TSensors initiative give rise to two important issues that must be solved: (1) the sheer numbers of sensors that are required to meet the TSensors vision indicate that lower-cost MEMS and sensor manufacturing technologies must be developed, and (2) there is a potential lack of wireless bandwidth available to accommodate the information that will be generated by this vast network of sensors.

This chapter discusses these issues along with the role of MEMS and sensors in the automotive as well as the consumer and portable sectors. It also looks at standards, testing and packaging needs.

Modeling, Simulation & Design Tools

A key shift is the rise of smart, connected devices riding on the backbone of the cloud infrastructure and driven by the availability of “big data.” Although the key elements of the MS&DT chapter remain constant, this revolutionary shift in the computing paradigm needs to be considered and integrated and is a key focus for this chapter. Fundamentally, this shifts the focus of MS&DT elements from component-level analysis to a more holistic and system-level approach that must also consider more nuanced types of analysis at a local level.

The focus areas for this chapter are:

- System & component thermo-mechanical reliability
- Thermal and thermo-fluid simulations
- Electrical modeling, simulation and design tools
- Materials characterization and correlation
- Micro-electrical mechanical systems (mems) related
- Design tools
- High-temperature electronics

Optoelectronics

This chapter includes support from OIDA and the Integrated Photonic Systems Roadmap (IPSR). It chapter covers data transmission utilizing optical technology over telecommunication distances of thousands of kilometers down to on-chip distances of a few millimeters. The 2017 chapter also included and began to address free space optical communication used within a room and between spacecraft over interplanetary distances.

As data rates rise in all of these applications, optical technology continues to displace copper for data transmission over shorter distances. The higher the data rate required, the shorter the distance over which optical methods become superior.

A key driver of the demand for data transmission capacity is the Internet, where traffic is growing 28-42% per year, and this increasing demand is fueled primarily by significant growth in video traffic.

This chapter divides optical data transmission into 11 applications:

- Telecommunications
- FTTX (including CATV)
- Local area networks
- Data cetners
- Plastic optical fiber (POF) (automotive)
- Active optical cables
- Backplanes
- On-card
- In-to and out-of package
- On-chip
- Free space

Packaging & Component Substrates

This chapter is a collaborative effort between iNEMI and IEEE's IRDS (International Roadmap for Devices & Systems) and Heterogeneous Integration Roadmap (HIR), and the final ITRS2.0.

This chapter provides focus and direction to industry, academia and government on critical technology trends and motivations for research needed to meet next-generation semiconductor packaging requirements. Emerging packaging trends like wafer-level packaging, 2.5D and 3D integration, system in package (SiP) and heterogeneous integration are projected to be major enablers in maintaining the pace of Moore's Law scaling. This roadmap attempts to highlight the main challenges for each of the new packaging trends, including such topics as wafer/device stacking challenges, packaging of electronic/photonic systems, and the need for coherent chip-package-system co-design, modeling and simulation. It also proposes starting point solutions to extoll the reader into developing more comprehensive and new insights towards advancing these trends or create new ones in the process of aiding packaging innovation.

Passive Components

iNEMI collaborates with ECIA on this chapter. Passive components (resistors, capacitors, inductors, and circuit protection) are the highest volume components in electronic devices. They support power management, signal conditioning, and protection of active devices. The 2017 Roadmap showed the downsizing trend in passive components continuing, and component manufacturers have responded by developing ever-smaller 0201 and now 01005 components. The new trend that has emerged is the drive toward thinner (lower height) components. One millimeter or sub-millimeter requirements are now common.

Handling of these components continues to be a challenge. An additional challenge is fitting the functionality into the smaller, thin form factors as packaging efficiency significantly decreases with size. Even though discrete passive devices are expected to be replaced by embedded versions, especially on the main boards of systems, the evidence of such changeover is not apparent for various reasons including cost, the challenges of technical implementation, and unrealistic market opportunities. It appears, however, that many of them will move to the system-in-packages (SIPs) or modules, as more functions become "commoditized" into functional blocks.

Ceramic-based technologies continue to find increasing use in the smaller form factor components. The trend towards ceramic capacitors replacing tantalum capacitors that began after the year 2000 continues. In addition, environmental stress, reliability, and failure mode remain active areas of development.

Power Conversion Electronics

This chapter is developed by PSMA. In previous roadmaps, the power conversion markets were described as technology responsive, rather than technology driven. This statement largely remains true for traditional applications; however, many emerging applications have power technologies as their core, including solar inverters, variable frequency drives, electric vehicles, and LED lighting systems.

This chapter highlights dramatic changes happening in the power semiconductor space that will benefit the power conversion technologies in coming years. These changes are led by the advances in the wide bandgap (WBG) semiconductors such as GaN and SiC devices. Some applications and sub-segments are better positioned to take advantage of these changes, including the HEV/EV market.

The chapter also presents a combined qualitative and quantitative picture of key technologies and trends in the four representative power converter technologies (AC-DC frontend power supplies, AC-DC external power supplies, isolated dc-dc power supplies and non-isolated DC-DC power supplies).

Key component areas (magnetics, capacitors, semiconductors, packaging) are addressed from the perspective of how they impact the growth of the power conversion technologies. The association or relationship between the component technologies and the power conversion technologies is not always harmonious. Sometimes, the component technologies are racing ahead without the ability of the end systems to keep pace and other times, it is quite the opposite.

RF Components & Subsystems

This chapter describes the current and future technology trends in RF components and subsystems used in handsets to provide connectivity through cellular networks, wireless local and personal area networks, location services, and video and audio broadcast reception. By definition, this area includes portable electronic devices (computers, tablets, mobile handsets, smartphones and portable gaming devices). However, in practice, this area includes much more than that. In today's marketplace there are a vast number of electronic devices that include RF components. The number of such devices is expected to continue significant growth (both in volume and type).

The extremely high volumes, densities and time-to-market pressures drive dynamic RF technology developments and deployments. This area has seen significant changes in technology over the past few years, and will continue to see strong technical and revenue growth due to the transition from 3G/4G to the 5G era and the emergence of the Internet of Things (IoT) as the primary market drivers. It is predicted that there will be 50B IoT devices connected to the network with access to the cloud by the year 2020. The IoT revolution will bring about a global transformation (Industry 4.0) using technologies such as machine learning/vision, autonomy, and next-generation communication 5G access to provide a $6T economic impact.

Semiconductor Technology

This chapter looks at the main trends in the semiconductor industry over the next 10 years. Minimal power consumption of transistor operation has become the main requirement for the semiconductor industry. On the other hand, the requirement for a continuously increasing number of transistors according to Moore's Law continues unabated. To satisfy the demand for higher transistor counts the semiconductor industry is approaching a new era of scaling. As features approach the 10nm range and below it becomes clear that the semiconductor industry is running out of horizontal space. Multiple companies have announced that future products will fully utilize the vertical dimension. This new scaling method is called "3D power scaling." This chapter discusses multiple new and exciting devices that, after 10 years of research, are demonstrating the possibility of becoming key players in the next decade.

Finally, high-volume manufacturing (HVM) factories are required to realize these new technologies. Controlling nanometer features across 300mm wafers remains an amazing challenge that the industry is managing across the globe, but will this be possible on 450mm wafers? Real time data collection, analysis and consequent disposition of wafers via a fully automated material handling system will remain the goals of the HVM factory in the next decade until "full lights out" operation is reached.

Smart Manufacturing

Smart Manufacturing will be pervasive as part of the next industrial revolution, and many topics that iNEMI addresses through its roadmaps will be impacted by it or will enable its success. iNEMI is developing a new Smart Manufacturing TWG for the 2019 Roadmap cycle. Focus and parameters are currently being defined.

Solid State Illumination

The Solid State Illumination chapter addresses technologies specific to inorganic light emitting diodes (simply LED) and organic-LED (OLED) fabrication (i.e., materials, assembly, packaging, manufacturing), test and measurement, devices and circuits, reliability and standards. Although the focus of this roadmap is on lighting, it does not exclude technologies and materials that may start out for applications other than general illumination (like display backlights, automotive lighting etc.), but eventually may get adopted for a lighting segment. Examples of such trends include adoption of OLED for automobile tail lights and use of mid-power LEDs from backlight applications for general lighting — without binning.

Sustainable Electronics

Environmental sustainability is a primary focus of this chapter, but there are also references made to governance, social responsibility and economic factors, and their respective interrelationships.

The 2017 Sustainable Electronics chapter incorporated five dedicated sections and was structured to reflect the flow of a product's lifecycle. The first section on Sustainability provided a holistic overview and set the scene for the subsequent sections on: Eco-Design, Materials, Energy and End-of-Life.

Test, Inspection & Measurement

Test, inspection, and measurement (TIM) technologies are important parts of electronics manufacturing. As defined in this roadmap chapter, TIM encompasses technologies that allow for the identification of product defects and the characterization / improvement of the product and associated manufacturing process. Challenges for both the users and providers of TIM technologies include: higher product complexity and reduced test access, energy and environmental concerns, the globalization of manufacturing and the diffusion of test development and support throughout the supply chain.

The chapter reviews electrical test, boundary scan and electrical test pad access. It also discusses such issues as test economics; test coverage, defect detection and prevention; and the impact of switching to environmentally friendly materials on TIM.

Thermal Management

Demand for more effective and cost-efficient means of removing heat from electronic systems continues to grow across all segments of the industry from compact, portable electronics to large, high-end systems, as well as power electronics associated with transportation and the electrical grid. In the absence of major new breakthroughs in thermal management technology this demand is being met by broader, more aggressive use of existing techniques and increased emphasis on reducing the generation of heat through improved product design.

The weakest link in thermal management is the thermal interface material [TIM], and a significant portion of the chapter is devoted to a discussion of this issue. For any thermal management technique to be effective, the heat must be moved from the source to an area where it is dissipated to the ambient.

This chapter addresses the need to develop improved cooling technology in terms of heat transfer processes, materials and innovative designs. If successfully implemented, enhanced thermal management will contribute to continued performance improvement trends and increased competitiveness of packaged electronic products.