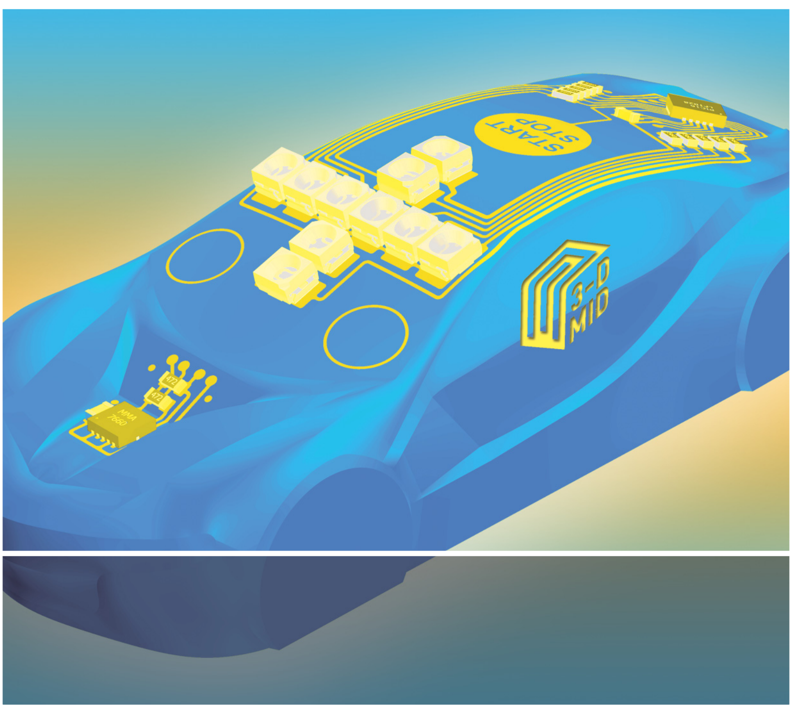
Jörg Franke

Three-Dimensional Molded Interconnect Devices (3D-MID)

Materials, Manufacturing, Assembly, and Applications for Injection Molded Circuit Carriers



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Preface

A molded interconnect device (MID) is an injection-molded thermoplastic part with structured circuit traces. This definition still applies, although the term 3D-MID has also become common. An extension of the meaning to mechatronic integrated device, moreover, allows for the fact that thermoplastics are not the only materials used, and MID are not necessarily produced by injection molding.

There have recently been major advances in MID development, particularly with regard to substrate materials, the methods of producing the interconnect devices with structuring and metallization, and the various connection technologies. Potential areas of application have therefore expanded and impressive advances have been made in viable optical, fluidic, mechanical, electrical, and thermal functionalities and in amalgamating MID with other technologies. The multiplicity of fascinating applications outlined in the MID Survey 2011 illustrated many of these new fields. As in 2003 and 2006, the 2011 survey was commissioned by Germany's Forschungsvereinigung 3-D MID e.V. With its membership now numbering almost 100, the Research Association Molded Interconnect Devices (3-D MID) is an active network bringing together manufacturers, suppliers, users, and research institutes in Germany and elsewhere. The close link between the industrial and scientific communities and intensive cooperation in innumerable projects afforded an excellent basis for the development of this reference volume for MID technology.

This book is not a revision of the manual originally entitled "3D-MID-Technologie: Räumliche Elektronische Baugruppen; Herstellungsverfahren, Gebrauchsanforderungen, Materialkennwerte" (3D-MID Technology: Molded Interconnect Devices, Manufacturing Processes, Requirements for Use, Material Characteristics), published in 2004. The main fields have changed so much since then and so many new areas of interest have arisen as to render a revision of that kind unnecessary. This book aims at presenting the state of the art in 3D-MID technology along the entire process chain. The individual chapters deal with MID-specific terms of reference, merely touching on the topic of guidelines and standards for conventional technologies.

This book, therefore, addresses experts and newcomers to the field of MID, by providing a comprehensive overview of the very latest developments in research activities. For developers and innovation managers it will be an introduction to the subject matter and a source of inspiration.

In-depth knowledge and determined utilization of the integration potential afforded by MID are crucial when it comes to implementing existing ideas in successful MID projects. Consequently, readers will find inspiration in a comprehensive overview of the strengths of MID technology and numerous case studies. Despite many exciting series-production applications, hurdles remain in the form of the as yet unadapted development and the prototyping of 3D-MID. Implementation as a follow-on from production-oriented and function-optimized conceptualization calls for know-how and experience along the entire process chain. The major methods, software tools, substrate materials, and processes for the manufacture of interconnect devices and application of the conductor traces are described in detail in the individual chapters, which also include discussions of the available systems.

Despite the dynamic of recent years, by no means can technological development be considered to have reached its conclusion. Ongoing research is pushing further miniaturization and expansion across the areas of application, for example by reduction in structure size, enhanced qualification of thermoset materials for the LDS process, and productive print technologies for additive conductor metallization, or the manufacture of thermally conductive materials for LED applications.

I would like to take this opportunity to extend my sincere thanks to my assistants Dr.-Ing. Christian Goth and Dipl.-Wirtsch.-Ing. (FH) Thomas Kuhn, who displayed tremendous commitment and strict management in their organization of the book. My thanks also go to all those who submitted contributions, and to the consulting experts who gave the text its final polish. The tremendous support that was forthcoming from industry, particularly from the members of the Research Association, affords this volume the practical relevance it requires. The English-language version of this book is intended as a vehicle to help promote MID technology in the international community. My thanks to Dr. Ingo Kriebitzsch, BMW AG, for organizing the translation.

It is my hope that everyone who reads this book will extract from it new incentives and new ideas for the future development of mechatronic modules in MID technology.

Erlangen, April 2013

Jörg Franke

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1 MID Technology and Mechatronic Integration Potential

C. Goth, T. Kuhn

In line with the variety of applications, the requirements that apply to the functionality, integration density, reliability, and costs of electronic modules have increased enormously, and this in turn has driven the demand for mechatronic solutions. On account of the high degree of design freedom they allow, molded interconnect devices (MID) permit highly integrated systems and, consequently, open up a huge potential for rationalization with regard to the production process. This chapter outlines the technological basics, possible areas of application, and the latest technological developments.

1.1 Technological Basics

1.1.1 Definition and Root Principle

MID is the abbreviation for *molded interconnect device*. On account of the versatility of the injection molding process and with structured metallization, mechanical and electrical functions can be integrated directly into MID parts, as can optical, fluidic, or thermal functions, among others. Widely differing processes can be employed for manufacturing the basic body and for applying or building the conductive structures. The root principle is illustrated in Fig. 1.1.

Extending the significance of the term MID to include *mechatronic integrated devices* takes account of the fact that the three-dimensional carriers do not necessarily have to be injection-molded or indeed made of plastic; other materials such as ceramics can also be used [50]. These mechatronic integrated devices are becoming increasingly important, because as new substrate materials become available they permit the use of new structuring processes, which in turn opens the way to other or further-reaching functionalities and areas of application.

As far as an understanding of MID technology is concerned, however, it is essential to appreciate that besides three-dimensional integration, the material bond between

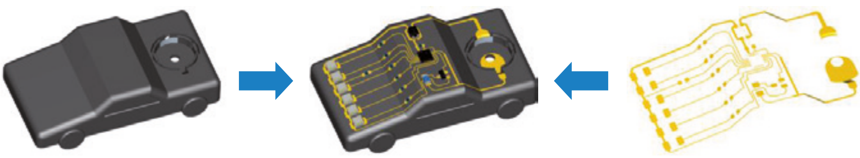


FIGURE 1.1 Underlying principle of MID technology

the component parts is crucial in terms of functional diversity. Mechatronic systems, by contrast, are frequently made by putting together individual components manufactured using conventional build techniques. Function-integrated devices of this nature are constructs made up of modular individual components. The term "three-dimensional circuit board," although commonly used, fails to convey the strengths of MID technology, deriving as they do from the interplay of diverse functions from different disciplines rather than the isolated extension of one particular field. The borders between MID and related areas of technology are drawn in Section 1.1.6. [59, 113, 129]

1.1.2 Geometric Classification

Unequivocal definition of the various dimensional configurations is practical for arriving at the precise geometric classification of molded interconnect devices. One system of geometric classification of the possible modules that is still in use today was introduced in [51]. Figure 1.2 illustrates this system of classification with current examples from the MID world. This system of classification takes into account the layout and the form of the structured process surfaces complete with their complements of electronic components. This is a starting point for deriving the requirements applicable to the production process. The interconnect devices have to be classified as a function of the process step in question. In terms of their placement, it is the distribution of the electronic components on the process surfaces that is crucial, whereas application of the circuit trace is the key factor in terms of functionalization with conductive structures. Modules are classified as belonging to 2½D, n × 2D, and 3D categories.

Conventional circuit boards, for which standard placement machines are used, are flat modules in 2D (class 0) with planar process surfaces. 2½D, on the other hand, has flat or plane-parallel process surfaces plus geometric elements in the *z* direction. Further distinctions can be drawn to yield subdivisions within this class. Class 1A is characterized by flat process surfaces, with 3D elements (e.g., cooling

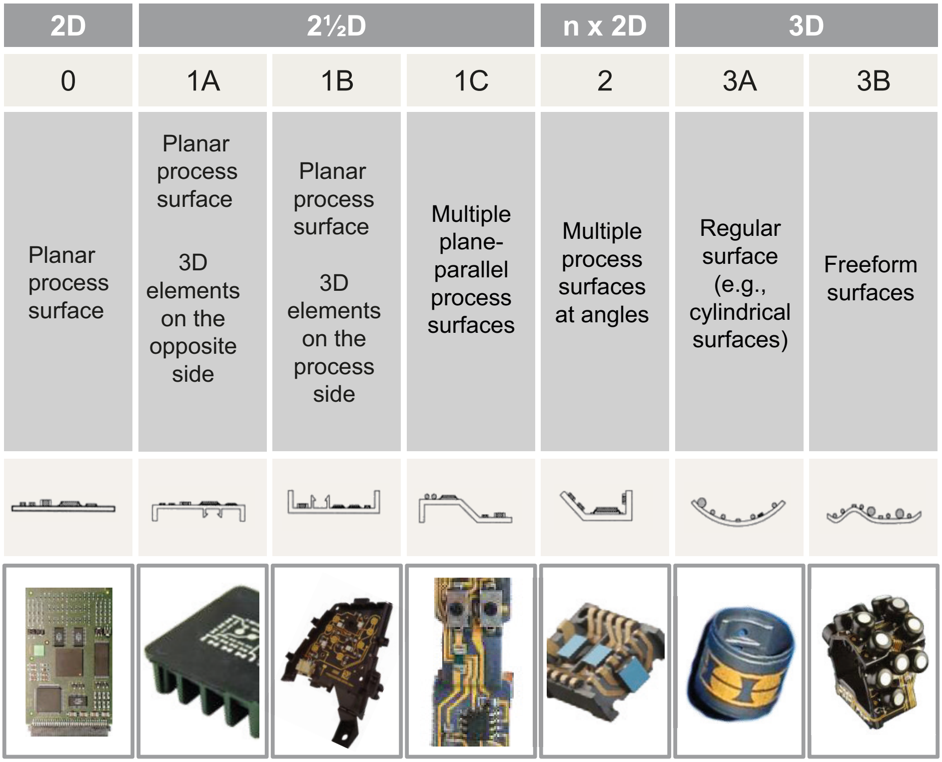


FIGURE 1.2 Geometric classification of 3D-MID [51] (Graphics courtesy of FAPS, TRW Automotive Safety Systems, HARTING Mitronics, Kromberg & Schubert)

fins) on the reverse side. Class 1B has 3D elements (e.g., interconnects) on the process surface; class 1C has two or more plane-parallel process surfaces. Class 2 n × 2D interconnect devices consist of multiple process surfaces intersecting at angles. Applications in 3D are distinguished as having regular surfaces (class 3A) or freeform surfaces (class 3B). [51]

1.1.3 Potential of 3D-MID Technology

The potential of MID technology derives from geometric design freedom in combination with selective structuring and metallization. The 3D layout permits defined angles between components, stacking and precision placement of chips, and the forming of cavities. The versatility of the MID layout therefore enables the integration of contact surfaces for switches or sensors and passive electrical functions (including capacitances, inductances, or resistances) and antennas for transmission or reception of electromagnetic waves. Partial full-coverage metallization of surfaces

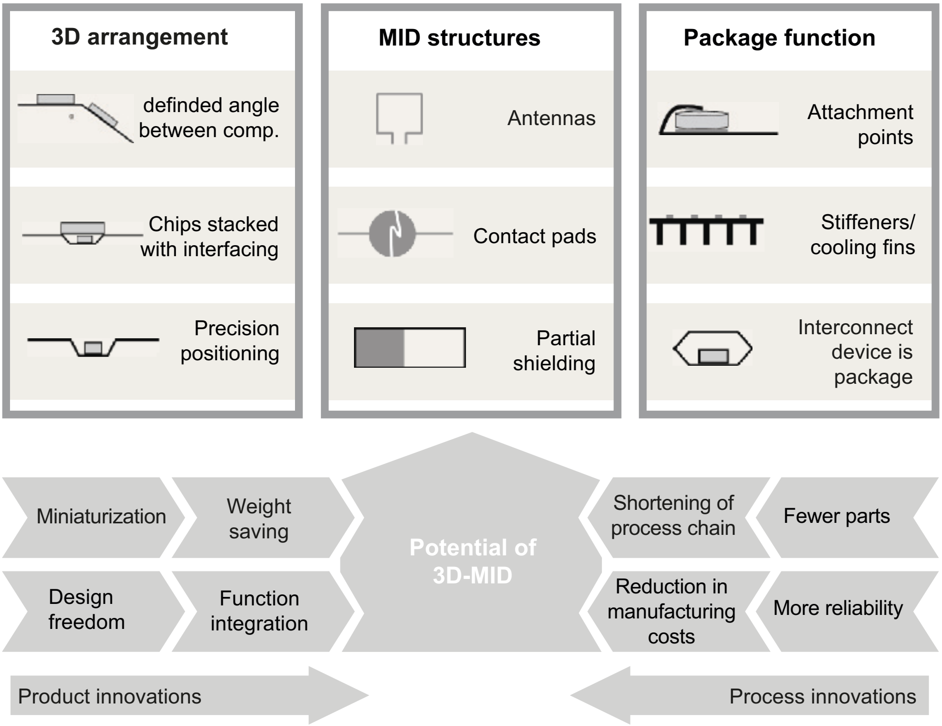


FIGURE 1.3 Potential of 3D-MID

produces shielding to protect against electromagnetic irradiation and emission and heat sinks for dissipating waste heat. Design geometry can be adapted to incorporate attachment points, stiffeners, and cooling fins, for example, directly into the package (Fig. 1.3).

MID technology, in association with production-perfect and function-oriented product development, can thus be utilized to tap into tremendous potential for rationalization and to optimize both product structuring and the production process. In this context product innovations follow on primarily from miniaturization and weight savings and from the function integration mentioned above. This, in turn, is keyed by the virtually unlimited freedom of design in 3D.

Shortening the process chain, reducing the number of parts, cutting production costs, and boosting yield all contribute to optimization of the production process. The reduction of the number of interfaces by system integration is a prime advantage in this respect, streamlining production while at the same time boosting reliability. Yield can be increased by integrating poka-yoke constraints, particularly where the MID interfaces with its periphery, although much the same effect is achieved when the number of parts is reduced.

The environmental compatibility aspect is another advantage. MID are generally made of recyclable thermoplastics and pose no difficulties in terms of EOL disposal. Materials consumption and materials diversity, moreover, are reduced. [51]

On the one hand, these advantages help boost the competitiveness of companies manufacturing electronic or mechatronic systems. On the other hand, they also contribute to increasing customer benefit and maximizing the options open to users and system manufacturers for optimizing the overall system.

1.1.4 MID Reference Process

MID manufacturing processes are many and varied. In any given case the most appropriate has to be chosen on the basis of the stated criteria. The most important processes include two-shot molding, laser structuring (additive and subtractive), hot embossing, and film insert molding. At this time, too, printing technologies and plasma structuring are of growing significance. Other technologies such as masking and primer technology, by contrast, are of minor significance in the MID environment, as are the physical processes of metallization.

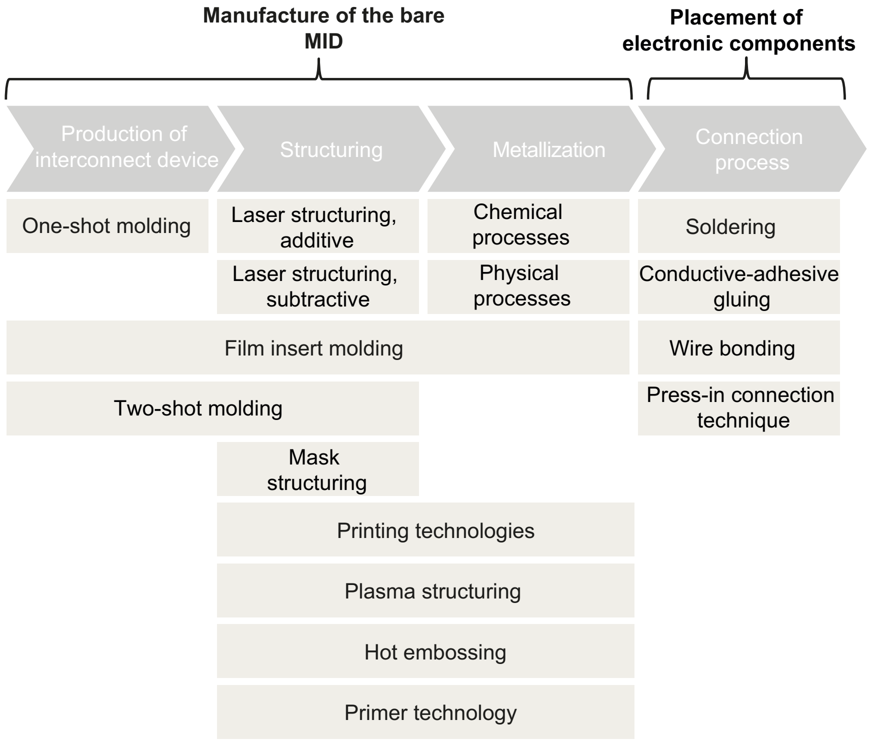


FIGURE 1.4 Reference process, MID [51, 58, 63]

All these processes are oriented toward the higher-order MID reference process (Fig. 1.4). A three-step process for production of the MID blank, it has a follow-up step in which any of the various connection techniques for completing the MID are applied [58]. The primary connection techniques for MID are soldering, conductive-adhesive gluing, wire bonding, and press fitting. The various manufacturing processes for MID parts are described in Chapter 3; Chapter 5 focuses on interconnection technologies. References 51, 58, and 63 are among the studies that set out other, similar reference processes for MID technology. As a standard reference volume for MID technology, this book pursues the aim of comprehensively covering all possible process chains, with the production processes of relevance for MID technology being examined in greater detail.

1.1.5 Factors Influencing Choice of Technology

The decision in favor of a particular technology or material invariably reflects the trade-off between the dictates of the market and the capabilities of any given option. The difficulty at the crux of optimum utilization of the technological, economic, and ecological potential of MID technology resides in an integrated product and design approach, which is also invariably a conceptual approach. Frequently more complex than those associated with conventional technologies, the decision-making processes this entails pose relatively high requirements for individuals and for corporate structures alike. Arriving at the ideal design for an MID necessitates taking a multiplicity of influencing factors duly into account. [135]

The challenges for the production of optimum MID assemblies are the constraints of the technical requirements (current-carrying capability, chemical and thermal resistance) that apply to the product, balanced against the opportunities afforded by the MID production processes and the materials used (Fig. 1.5). There is a library of design guidelines and data sheets for MID materials, some of which are developments specific to this purpose. Economic perspectives also factor into design considerations, because in many instances costs and, in turn, price are crucial in terms of the success of a given innovation.

The choice of materials and a structuring process that fits the applicable requirements are crucial for the implementation of any MID-based electronic component. Invariably, the substrate material must be suitable for the conditions of use and for the connection technology of choice. An important factor in this respect is the adhesive strength of the metallization, because this will undoubtedly have a major effect on long-term reliability.

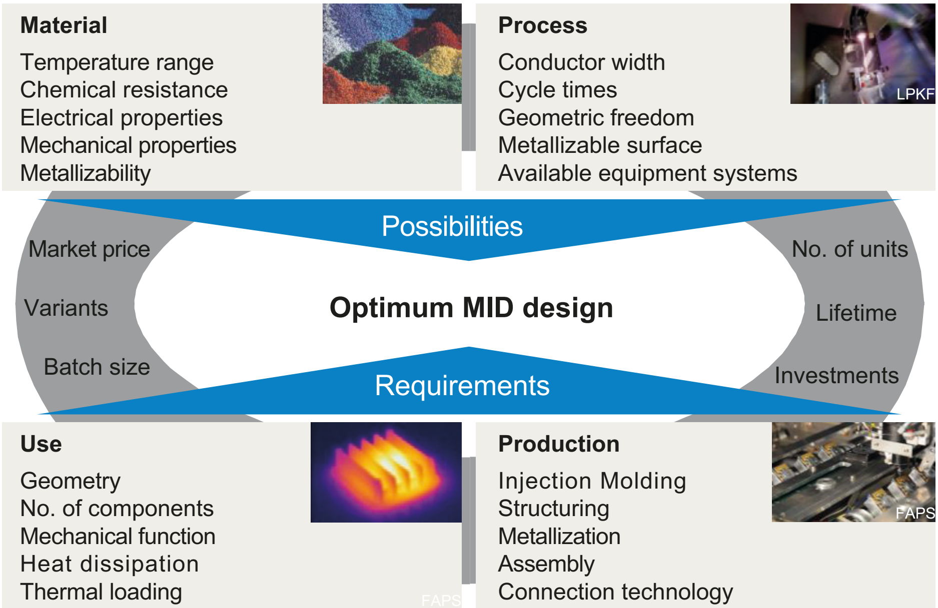


FIGURE 1.5 Decision-taking for MID in the context of possibilities and requirements [129]

1.1.6 Differentiation from Related Technology Fields

MID technology stands clearly apart from leadframe, printed-circuit board, and film technologies on account of the specific potential discussed in Section 1.1.3. None of the other candidates can fully replicate this potential (Fig. 1.6).

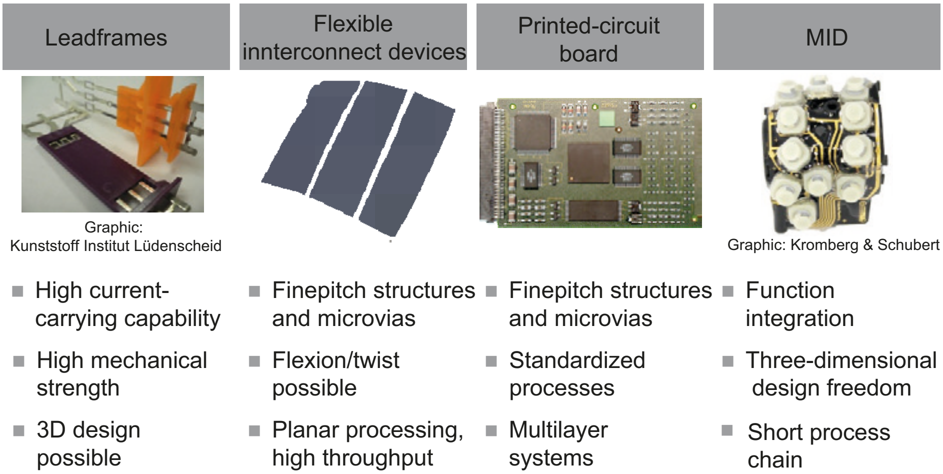


FIGURE 1.6 MID vis-à-vis conventional technologies

These conventional build technologies, moreover, are subject to technical constraints that MID can circumvent, for example with regard to miniaturization. The case studies in Chapter 9 depict current applications demonstrating overall-system miniaturization through 3D layouting. Difficulties in handling limp components and the restrictions on reducing the number of interfaces, which is a potential weak point for reliability, are further constraints to which the established technologies are prone. Conversely, MID technology is only conditionally suitable for areas of application in which these technologies are very much at home. Choosing the most suitable technology is always a matter of weighing up requirements, the intended area of use, and the complexity of the application.

In leadframe production, a die and punch set is used to emboss an electrically conductive structure from flat, strip-feed sheet material. The leadframe itself is then jacketed in plastic. The finished components are combination wiring carrier and package. In some instances they are also the interconnect device with galvanic finishing of the surface (e.g., tinning). Leadframes are used primarily in situations requiring high current-carrying capability and mechanical strength. Their potential for miniaturization is limited, even though individual lands can be very narrow (100 µm) [59, 129]. Flexible and rigid printed-circuit boards are suitable for mounting highly integrated components with minute connection structures and high packing density and for stacking into multilayer systems. Detailed standards and test criteria have been formulated. Substrate materials, connection mediums, and components are intensively qualified and closely matched to each other. Highly efficient systems engineering for high throughput rates in planar production is available. Film technology is often the first choice whenever the finished interconnect devices are likely to be subjected to bending or twisting action or shock and vibration loading [63, 153].

1.2 Relevant Industries and Areas of Application

An outline of published MID applications reveals a high level of diversification in terms of products available, the industry sectors serviced, and the areas of application (Fig. 1.7). Successful MID applications have been realized in all markets for conventional electronic modules. Chapter 9 presents in-depth case studies illustrative of many different projects. Current issues and developments in the MID-relevant industries and areas of application are discussed in more detail below. A great deal of this information was sourced from [50], with the addition of the latest findings from publications and press releases and the expert knowledge base.

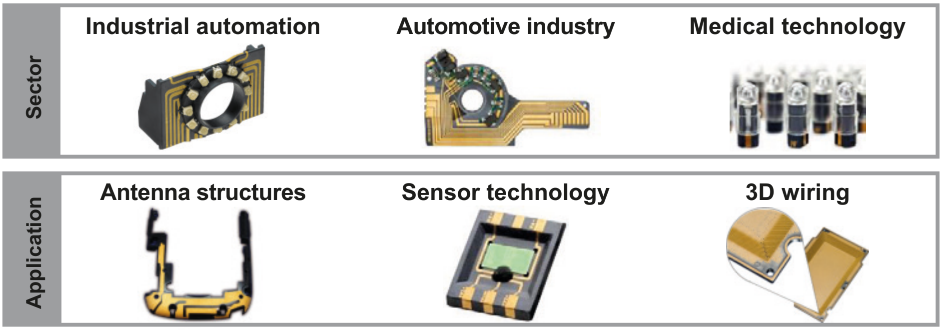


FIGURE 1.7 Typical MID applications from various industries and different applications (graphics courtesy of HARTING Mitronics, LPKF, 2E mechatronic)

Two industries in particular show considerable potential for high-end MID applications and can be graded as technology drivers. On account of the large number of high-profile projects in Europe in particular, these two sectors are the automotive industry and medical technology. The IT and telecommunications market is characterized by the mass production of MID antennas in Asia. Industrial automation and aerospace technology are other interesting sectors.

Among the multiplicity of potential applications, sensor technology and antenna technology are of particularly high significance at this time. In the future there is a strong possibility of optical functions leading to many new applications, for example in combination with LED technology.

1.2.1 MID-Relevant Industries

The following is an overview of developments and current trends in the relevant industries.

Automotive

In automotive engineering, the number of electronic systems is increasing constantly on account of the demand for enhanced road safety, access to the latest trends in communications and IT, and environmental compatibility. Miniaturization is essential and functional diversity continues to expand, and both these factors have a positive effect on demand for MID integration. At the same time the high pressure of costs in the car-making industry dictates that over and above technical advantages, MID parts have to be an economically viable alternative to conventional technologies. The solutions as implemented generally afford the makers an edge on costs, but one that does not emerge until the complete system is taken into account instead of the MID on its own. Reliability is crucial in the automotive industry, and many experts are of the opinion that this requirement can be satisfied. MID materials (substrates, connection mediums) have been developed for applications extending to elevated-temperature environments, such as the conditions inside an engine compartment. Further development in the field of fully automated production will be necessary for other high-volume MID applications in the automotive industry.

Medical Technology

On account of demographic development and the booming interest in healthy lifestyles, medical technology is experiencing a rising demand for miniaturized, low-cost, high-efficiency medical devices. Important MID applications in this sector include, for example, systems for audiology (e.g., hearing aids). Microphone directional precision within a tiny package is essential in this application, to enable the user to pinpoint audio sources. Single-use, disposable products are another possible application. Sterile sample carriers have to be used for bioanalysis. Two-shot molding is an ideal process for implementing the functions of a sample carrier, because the method enables a microfluidic channel to be integrated into the carrier body along with analysis electronics.

IT and Telecommunications

Tremendous use has been made of MID technology in recent years for antennas, for example in smartphones. Production volume of MID antennas to date extends to millions of units. The benefits lie in the combination of 3D design freedom with electromagnetic transceiver properties for different wireless standards, including for example WLAN, Bluetooth, UMTS, and LTE. Antennas up to 300 mm in length are being used increasingly in mobile computers, and relocating the antenna modules directly into the casing makes the overall package both slimmer and lighter [107].

Industrial Automation

High flexibility, availability, and cost efficiency are the crunch factors for success in automation technology. Smart sensor concepts and lighting modules based on 3D arrays of LEDs or sensor chips are major possibilities for MID. MID can also be used for long-range RFID antennas, because three-dimensional antenna structures enable noncontacting signal transmission. This in turn opens the way for optimized logistics control and process monitoring.

Others

The aerospace industry and the military sector are other important fields for MID. These applications focus on the three-dimensional arrangement of sensors, but to date very little information has been put into the public domain. The household-goods sector is of no more than secondary importance at this time, but this is not to say that potential for MID applications might not unfold in future, for example within the major-appliances part of the domestic-equipment market.

1.2.2 Areas of Application

The areas of application of relevance for MID are outlined below.

Sensor Technology

Current sensors, light sensors, pressure sensors—these are only some of the many established sensor applications that demonstrate the strengths of MID technology. Sensor build and positioning lay the groundwork for development of function integration and miniaturization in these applications. In many metrological processes, the optimum arrangement or precision alignment of the mechanical and electrical components is crucial, and this is one important consideration. Another is that the measurement process should be sited as close as possible to the medium. These spatial dependencies are at the crux of precision in measurement. MID can be made much smaller than conventional sensors.

Antennas

MID antennas have become mainstream in recent years, and nowhere more so than in the mobile-communications sector. Units of this kind are manufactured in very high numbers in Asia. Molex announced the production of its twenty millionth LPKF-LDS® antenna [76] back in 2009, and a large proportion of MID antennas are two-shot moldings. The sector is further expanding to include tablet PCs, with demand leaning more toward larger antenna structures. RFID antennas for very widely varying applications constitute yet another sector.

3D Wiring

The design freedom afforded by MID technology removes the planar constraints of a conventional circuit board, so conductors can be tracked virtually anywhere in the available 3D space. The three-dimensionalism attained in this way gives us highly integrated, multifunctional constructs. In complicated layouts with many electronic components, conventional techniques with planar placement can be combined with the 3D conductor tracking singular to MID technology.

Interconnect Device/Package

It is not possible to define clear borders around the application potential of MID as interconnect devices in or as packages for electronic modules. This is because, seen purely as interconnect devices, MID parts can compete with conventional printed-circuit boards only subject to certain constraints. Certainly, both individual electronic components and multifunctional chips can be surface-mounted and wired, but in general the functions involved are of the signal-processing or data-processing kind. The voltage supply is limited on account of the current-carrying capability of MID parts. Consequently, the greatest potential is in using MID parts as packages with directly integrated conductor tracks. The simplest example is the MID protective cap: an MID package with meandering conductor structures used as an electronic surveillance device to detect attempted burglary. Component integration can also be interesting for certain applications (e.g., seat-positioning switches).

Plug Connectors

The use of MID parts as plug connectors is set to become much more important in future. Every MID application has to be connected to its periphery, so a connector has to be integrated into the MID component. The pins for this purpose can be either metal or metallized plastic. This use of MID as plug connectors will necessitate standardization and the production of a code of practice for the design of an MID plug connector.

Optical Function

Optical functions can lead to new applications in various sectors. For example, MID technology can be used in lighting, a field where development is now keenly led by advances in LED engineering. The requirements for the positioning and alignment of LEDs are similar to those for sensors. Using MID as reflectors with optical coatings is another possible avenue, although surface roughness and heat dissipation both look challenging in this respect. Yet another interesting aspect is the integration of fiber-optic waveguides into MID.

1.3 The MID Market, a Global Comparison

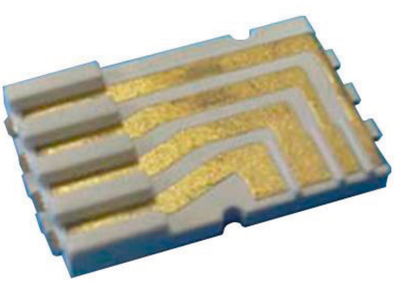
Pioneering work on MID technology was undertaken by companies in the 1970s, mostly in the United States but also increasingly in Europe. In this early phase attention was focused primarily on developing substrate materials and the various metallization processes. By the 1990s companies and research institutes were combining their development capacities and forming interdisciplinary project teams. The section below describes the development of the technology and points out the current main areas of attention and the preferred processes in the individual regions of the world.[1]

[1] This information was collected jointly with Dr. Wolfgang John.

1.3.1 Historical Development

A patent filed by E. W. Lehtonen back in 1969 mentioned the possibility of manufacturing electrical interconnects by molding thermoplastic materials [51]. Further thoughts about integrating electronic and mechanical functions in a molded part date back to patents from the late 1970s and early 1980s. It was during these years that the first design and feasibility studies were undertaken as joint projects by AT&T Bell Labs, Union Carbide, and General Electric Plastics in the United States. US company Circuit-Wise linked up with Leicester Circuits in England to examine the possibilities of producing conventional printed-circuit boards as injection-molded parts. As long ago as 1984 an early German MID pioneer, Volker Zippmann, was nurturing his company Buss-Werkstofftechnik's first steps toward the new technology with the new material PEI (Ultem), a development of General Electric Plastics. In the years that followed, large international players took up the challenge of developing high-specification plastics and the accompanying specific metallization processes. Companies from many different walks came up with tentative solutions for implementing mechatronic product concepts and, in turn, provided input for evolution of the technology and its emerging processes (Fig. 1.8). But when Eastman Kodak and Mitsui Petrochemical & Pathtek developed new two-shot molding techniques, from about 1986 onward the fledgling technology got the push it needed with the hugely increased freedom of the third dimension. As it turned out, primarily on account of economic aspects, the dominant notion of the day—that molded interconnect devices would eventually supersede conventional printed-circuit boards—proved impractical.

The leading processes of those early days derived from the printed-circuit board industry and included a modified form of masking, laser etching, two-shot molding, and hot embossing. A raft of evolutions and modifications of these established processes emerged during this time. For example, two-shot molding was streamlined by using core-catalyzed plastics for the plateable component, so it was no longer necessary to eject the first shot from the mold and seed it before laying on the second shot.



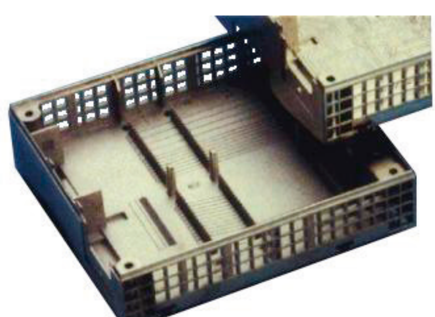


FIGURE 1.8 Early MID applications: Solder base for an airbag system, Buss-Werkstofftechnik GmbH (left); SPS AG 95 control unit for PLC, Siemens AG (right)

By the early 1990s the term Molded Interconnect Device (MID) had displaced the various other nomenclatures used until then (e.g., molded printing wiring board, molded electronic assembly). The term and the abbreviation were ratified by MIDIA (Molded Interconnect Devices International Association) at its inaugural meeting in March 1993. The notion of forming this association was first mooted in the fall of 1992 at a meeting of the two largest MID manufacturers Mitsui-Pathtek and Circuit-Wise in the United States, and the declared aim was to unite the national and international activities of the big MID players. In the United States these were the three companies: Mitsui-Pathtek, Circuit-Wise, and ufe. Their ranks were later joined by other companies, including Fuba Hans Kolbe, Siemens, and Buss-Werkstofftechnik from Germany and a handful of Japanese specialists such as Sankyo Kasei.

In Germany too, interdisciplinary workgroups had been brought into being in the early 1990s to tackle cross-industry problems. In 1992 these developments culminated in the founding of the Forschungsvereinigung Räumliche Elektronische Baugruppen 3-D MID e. V. (Research Association Molded Interconnect Devices), and today this body's activities are still coordinated by the Institute for Factory Automation and Production Systems (FAPS) of the Friedrich Alexander University Erlangen-Nuremberg. The stakeholding companies saw in this form of joint research with a close university tie-in the ideal platform for the launch and evolution of MID technology in Germany. The approach is unique in international terms, and it has brought the technology the high level of importance it enjoys in the country today (see Section 1.6 for more information). By 1995 a national association for the development of MID technology had been formed in Japan. The member companies of this association also became affiliated members of MIDIA in the United States.

1.3.2 MID Focuses by Region

Until 1996, the US market was very transparent. It bore the stamp of the three big players Circuit-Wise, Mitsui-Pathtek, and ufe, companies that had brought out a raft of products, including many for the US automotive industry. From the European or German perspective, it looked at times as though projects of this nature were being pursued with a great deal more vigor in the United States. In 1996, however, Circuit-Wise took over Mitsui-Pathtek's MID business and moved energetically toward concentration in the sector. Market response to the move was reticent and skeptical, and income dropped off sharply. Recovery did not follow until increasing acceptance for the MID business of Circuit-Wise emerged across the industry. Circuit-Wise founded a spin-off company that it called MID LLC to handle MID-related business.

In 2000, Rochester-based MID LLC was acquired by Tyco Electronics. The new owner continued MID operations in the town of Rochester until 2008, concentrating heavily

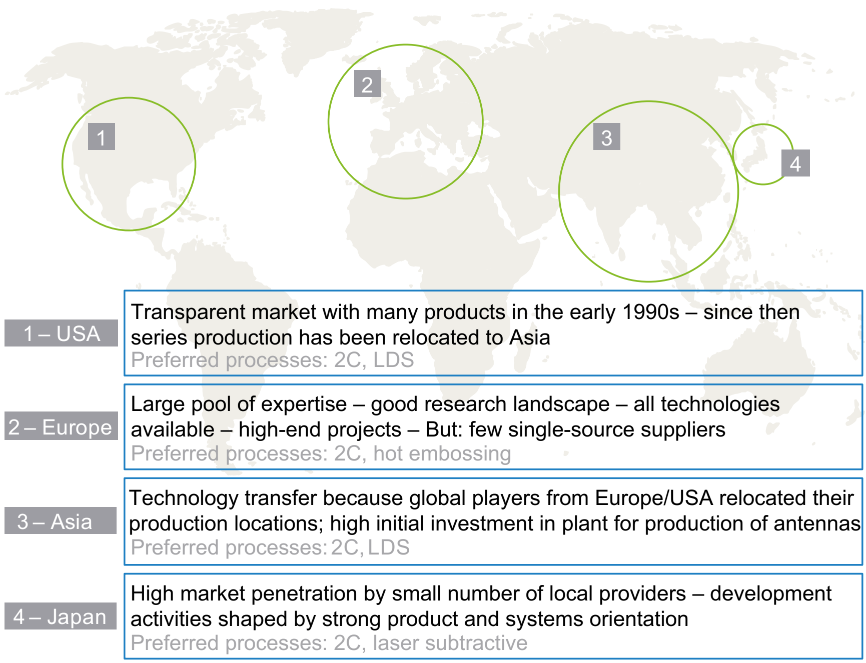


FIGURE 1.9 Preferred processes and focuses per region [50]

on mobile-communications antennas on a two-shot molding basis and adding laser direct structuring (LDS) as a second process in 2006, before relocating production to China. The biggest EMS service providers, especially for the mobile communications market, have all relocated production to Asia. The preferred processes are two-shot molding and, increasingly, LDS (Fig. 1.9).

Virtually the entire set of production processes is available in Europe. With a very well established and broad-based scientific background, the LDS process has greatly enlivened the European MID market in recent years. The number of high-end component-set MID projects that reached series-production status, including many for the automotive sector, is proof of the high level of MID development in Europe. It also demonstrates the leading position in the international rankings for the production of mechatronic components, with a raft of product-matched MID technologies. There is a downside to the further propagation of the technology in that, until now, only a few single-source providers have emerged to handle the entire process chain, and this applies to two-shot molding and also to LDS, including the buildup and connection technologies.

Regarding process development in particular, Japan's MID history is characterized by a very strong focus on the product-oriented use of the technology by a very small number of MID manufacturers. Sankyo Kasei and Matsushita are the two lead players. Japan looks primarily to function integration and the miniaturization of products developed by the country's own industry. Preferred production processes are two-shot molding and laser subtractive structuring. Japan's official association of MID stakeholders dissolved itself at the end of the 1990s and was refounded in 2002 with the declared aim of encouraging joint activities.

Following the expansion in globalization since the late 1990s and the pressure of costs confronting major companies in industries such as mobile communications, the big suppliers of cellphone antennas have put all of their production facilities in Asia. This in turn has meant high-volume production of antennas in Asia from early on. Two-shot molding was the process of choice at the beginning, but LDS has also become increasingly common on account of its flexibility for accommodating design changes. Cellphone antennas can scarcely be compared to complex, highly integrated MID modules such as those developed and used for automotive applications, for example. In Asia, nonetheless, high-volume production has engendered a huge process knowledge base that can be put to good use in the development of higher-specification products.

1.4 Main Fields of MID Research

Broadly speaking, the main fields of MID research can be broken down into five principal sectors (Fig. 1.10):

1. substrate materials
2. interconnect-device manufacture
3. 3D placement and interconnection technology
4. quality and reliability
5. planning and development

Other activities focus on end-to-end optimization of the process chain (e.g., reel-to-reel production, variable-output production solutions with modular plant configurations) and MID as part of the overall system (e.g., integration by standardized interfaces). Chapters 2 through 7 discuss the state of the art in these areas.

Substrate Materials

Thermally conductive plastics will significantly expand the potential use of MID. High-current applications call for new materials to deal with heat generation. Characterization of the key between metallization and plastic substrate is another important factor. Pigmentizing MID plastics to produce colors other than gray or black makes MID a much more attractive solution for packages. Biocompatible materials can extend the range of possible applications in the medical-technology sector.

Substrate materials	Thermally conductive plastics
	High-temperature thermoplastics
	Bio-compatible, transparent or colorized materials
	Thermosets as substrate material
Interconnect-device manufacture	Printing technologies/plasma structuring
	Multilayer constructs
	Increased current-carrying capability
	Rapid prototyping
3D assembly and interconnection technology	Multiple workpiece carriers for standard SMT process chains
	Chip-on-MID placement technologies
	Embedded components
	MID housing
Quality and reliability	Test and inspection criteria for MID
	Standardization and specification
	Forecasts on long-term reliability
	Simulation models
Planning and development	Design tools
	Development methodologies
	Heat-removal concepts
	Recycling

FIGURE 1.10 Main areas of research in MID technology [50]

Interconnect-Device Manufacture

Printing technologies (Aerosol-Jet®, inkjet) and plasma structuring (Flamecon®, plasmadust®) have major potential for future use in series production. Sustaining long-term stable functional reliability for MID under extreme operating conditions necessitates protecting the electronic components against medium exposure and high thermal and mechanical loads. One avenue currently being explored in this respect is that of enclosing MID modules by assembly injection molding. Another point of importance in the manufacture of interconnect devices is increasing current-carrying capability. Limited by chemical metallization in the case of some technologies, this necessitates practical extension by galvanic processes.