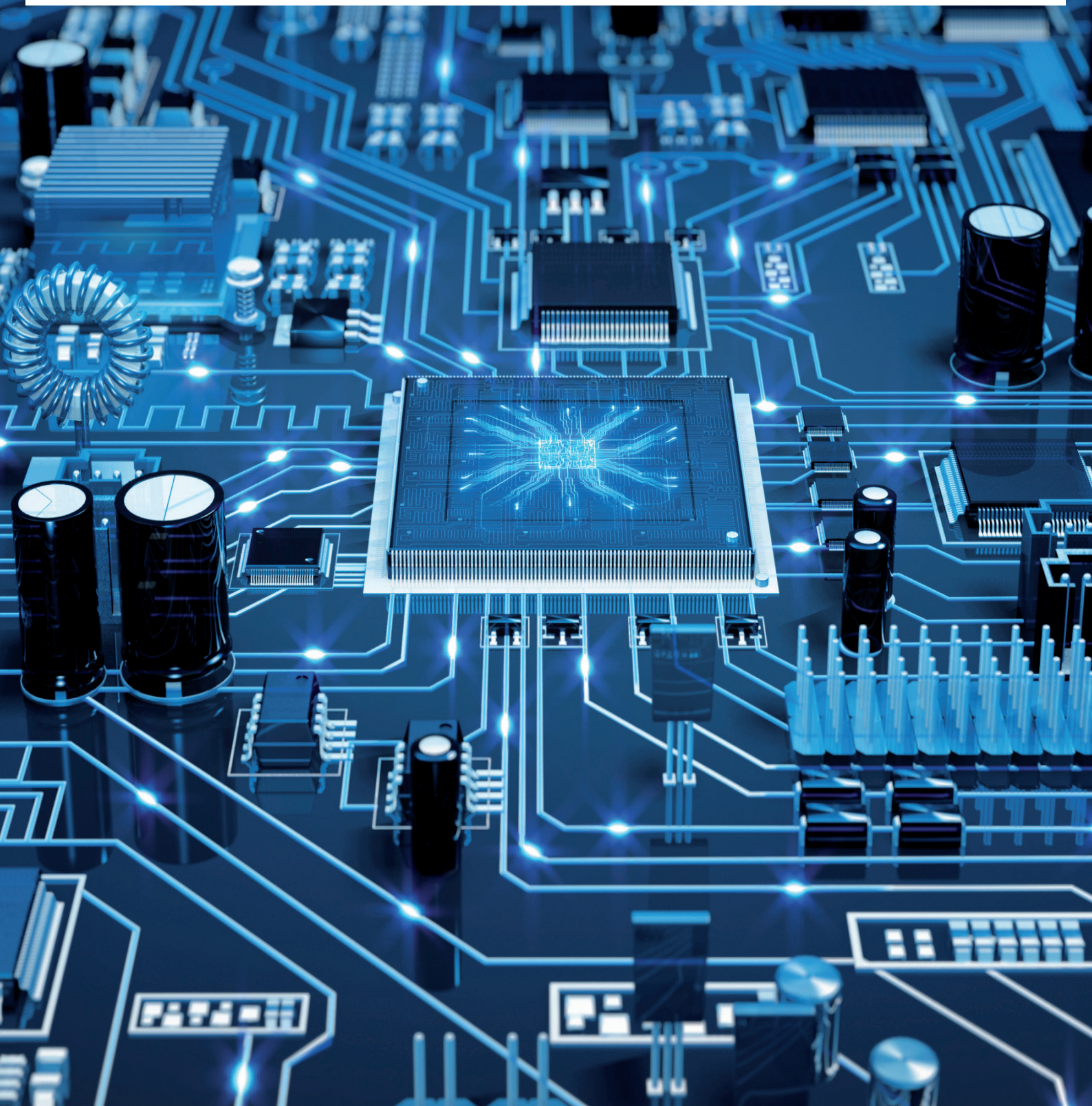
Federal Ministry
of Education
and Research

THE NEW
HIGH-TECH
STRATEGY
Innovations for Germany

Microelectronics from Germany – Driver of innovation for the digital economy

The German Federal Government's Framework Programme for Research and Innovation 2016-2020



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Foreword

Microelectronics is making a decisive contribution to the advancement of Germany's innovative potential. As a leading industrial nation, we will continue to require comprehensive electronics expertise in research and industry in the future.

With its new Framework Programme for Research and Innovation, the German Federal Government is strengthening and bundling its measures to expand the microelectronics sector in Germany. The Framework Programme fosters the potential of microelectronics to bolster the innovative dynamics of industry in Germany and contributes to the implementation of the new High-Tech Strategy and the Federal Government's Digital Agenda.

With the Framework Programme, the Federal Government is also supporting the European Commission's Strategy for Micro- and Nanoelectronic Components and Systems of May 2013. This strategy aims to significantly increase value creation in the European electronics sector by 2025. One of the targets is to transform new research findings into innovations that can then be rapidly applied in microelectronics sectors in Europe. Research is thus focusing on value-added chains ranging from microelectronics through to the strong user sectors in Germany and Europe.

The Framework Programme is targeted at small, medium and large companies in microelectronics and related application industries as well as at universities and non-university research institutes. It also addresses companies and investors who wish to establish production in Germany as one of the leading locations for innovations worldwide.

An agenda process was initiated to formulate the Framework Programme, the strategic cornerstones of which were identified by the Federal Government in a position paper in June 2014. The dialogue with representatives of relevant research institutions, companies and industry associations was a central component of this process and will be continued over the duration of the Programme until 2020. This will help to systematically identify relevant focal areas for research and continually improve the framework conditions for innovations in microelectronics in Germany.

Johanna Wanka

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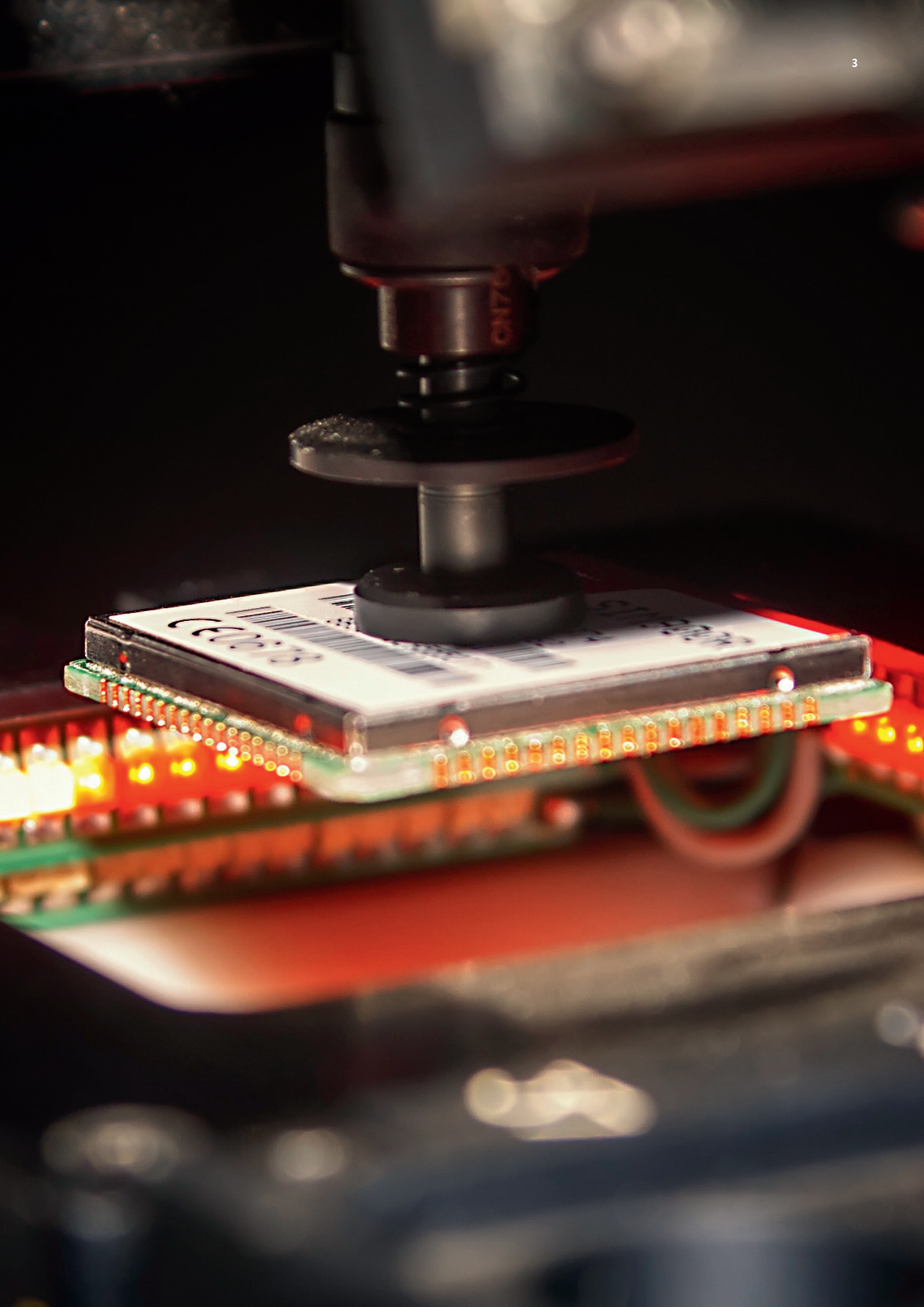
Federal Minister of Education and Research



1. Microelectronics as a driver of innovation for industry and society

Without microelectronics there would be no computers, no cars, no industrial production and no identity cards as we know them today. Microelectronics is one of the most important key technologies for innovations. Either integrated into new products or serving as the technological basis for services, microelectronics offers solutions to important societal and economic challenges. Regardless of whether the application in question involves drives and sensor systems for sustainable and intelligent mobility, diagnosis systems for a healthy life, communications building blocks for the digital revolution in society or industry, or grid control systems for a sustainable energy supply: microelectronic systems are a fundamental prerequisite for competitiveness and prosperity in Germany.

In their everyday lives, most people regularly use products whose manufacture and operation significantly depend on microelectronics. However, microelectronics is rarely visible on the outside. As a result, only specialists are generally aware of the enormous amount of effort that goes into this innovative technology. The importance of microelectronics for the digitalisation of many areas of life and for value creation and the competitiveness of Germany is of concern to all of us, however.

More functionalities in a smaller volume

For a long time, the driving force for research and innovation was the miniaturisation of integrated circuits consisting of transistors, diodes and storage capacitors that facilitate quicker data-processing and decreasing energy consumption. Modern smartphones not only have more computing power, but also offer significantly more functionalities than a PC did a decade earlier. The unparalleled success of information and communication technologies only became possible thanks to microelectronics as a driver of innovation and the foundation provided by semiconductor technology.

Today, the application areas for microelectronics are much broader: cars, houses, factories and even entire cities are increasingly “intelligently networked”. Innovations with regard to functionalities, safety, reliability and energy efficiency depend on electronic systems in important user industries such as vehicle construction, manufacturing, medical technology and the energy sector. Future applications such as networked production in industry 4.0, the Internet of Things, electromobility and driverless vehicles can only be realised with microelectronics and microsystems. At the same time, secure chips and hardware will play a key role in the protection of our IT infrastructure and our data.

Not just integrated circuits, but other components such as sensors too are increasingly being created directly on chips with the aim of combining as many functionalities as possible. The integration of various semiconductor chips in a single housing has also been receiving increasing attention in recent years. Often only these types of complex microelectronic systems are able to offer the functions that are needed to tackle the requirements of the future. For this reason, it will also be necessary to develop specific expertise in the future too to ensure that Germany’s innovative advantage can be maintained.

Germany’s competitive position

Germany is in an excellent starting position: the microelectronics industry and its user sectors are currently benefitting from the close innovation partnerships, symbiotic value- added chains and a productive research landscape in Germany and Europe. In addition, microelectronics in Germany is primarily organised in terms of strong regional clusters that create important networks within the value-added chain of suppliers and purchasers. The federal state of Saxony has a prominent role in semiconductor production: a large proportion of the chips manufactured in Europe now originate from the region around Dresden.

In order to play a significant part in structuring the international market, Germany must continue to develop its expertise in microelectronics in a targeted manner.

Existing strengths have to be enhanced in a long-term approach: these exist in the areas of complex high-

quality, high-performance electronics that are used in the manufacturing of vehicles, machinery and plant equipment and in the implementation of energy and climate goals. In addition, new potentials must be harnessed – such as energy-efficient, reliable electronics and security chips. This requires joint efforts together with industry and research where the German Federal Government coordinates its activities with those of the federal states and the European Union (EU).

The networking of the technological capabilities of the microelectronics industry with the system expertise of German user sectors is unique in Europe; this cooperation along value-added chains will continue to be supported. The productive research landscape will also continue to be strengthened from basic research right through to application-oriented research, as this research community is a driver of innovation and an important partner for industry.

An additional factor in the success of microelectronics is the presence of internationally competitive economic framework conditions. In Europe, the electronics industry is responsible for over 200,000 jobs directly, and over one million jobs in the entire industrial value-added chain are also dependent on this sector. Because of their great importance for the services sector, microelectronics innovations and knowledge account indirectly for at least 10 percent of Europe's gross domestic product. Microelectronics is a key technology and an important "raw material" for Industry 4.0 and for the implementation of the Digital Agenda. Progress in these areas is being driven by government and industry working in close partnership.

Microelectronics is a basis for value creation

2. Guidelines and aims for microelectronics in Germany

Microelectronics is a basis for value creation

One in every three chips manufactured in Europe is from Germany. German companies are particularly strong in sensor systems, energy-saving electronics and chip-based security. The support provided to microelectronics – with a focus on user sectors such as automobile construction, machine-building and medical technology, in particular – is facilitating a high level of value creation with knowledge-intensive products from Germany.

Microelectronics is research-intensive

Physics and chemistry are continually opening up new potential and driving rapid progress in microelectronics. In the future, too, we will strengthen a research landscape in Germany that covers all areas – from basic research through to application-oriented research.

Microelectronics fosters innovation

Forward-looking projects such as Industry 4.0, the Internet of Things, driverless vehicles and the energy revolution are increasingly becoming reality. We are supporting the development of innovative new types of chips that can quickly be used in applications in these areas.

Microelectronics is systematically relevant

We are strengthening microelectronics in research and industry so that established and new sectors will be able to meet future digitalisation challenges and, as a result, preserve Germany's competitiveness.

Microelectronics offers security

As a result of its many years of experience and its comprehensive expertise, the German microelectronics industry can guarantee safe and secure applications with its products – for example, in energy technology or the automobile industry. Safety and security are thus an important aspect of support for microelectronics.

Microelectronics supports climate protection

Innovations in power electronics increase the energy efficiency of the generation and transmission of electricity and of industrial plants. They also help to achieve greater ranges for electric cars. In short, microelectronics can help us to achieve environmental and climate-protection goals.

Microelectronics offers solutions for societal challenges

The process of digitalisation of economic activity and society has already begun: more and more products and services are becoming "smart" and "intelligent". Only with our own expertise in microelectronics will we be able to help to structure the process of digitalisation – i.e. preserve our digital sovereignty.

Microelectronics offers opportunities to investors

With its strong user sectors and excellent research landscape, Germany offers favourable conditions for investors. We are ensuring that the framework conditions for investments in new products and manufacturing capacities – including the availability of specialist personnel – will remain competitive from a global perspective.

Microelectronics requires action at a European level

In the context of worldwide competition, it is necessary to act together with our partners in the European Union. Transnational projects and a common European strategy for investments will strengthen Germany's position here.

3. Research and innovation

3.1 Expanding technology expertise

The strengths of the microelectronics industry in Germany include intelligent and safe electronic and microsystems, energy-efficient and compact power electronics, and chip and system design for complex systems. German companies and research institutions are also successful in production technologies and plant engineering for semiconductor manufacturing.

One goal of this Framework Programme is to expand these strengths and develop new capabilities. This is to be accomplished as part of five strategic research focuses in the area of technologies that are described here in Section 3.1. In order to harness the opportunities offered by progress in the natural sciences, research will also be carried out on the foundations of future technologies – as will be described in Section 3.2. At the same time, it is particularly important to foster existing technologies in areas where they directly strengthen the innovative potential of user sectors in Germany – this will be dealt with in Section 3.3.

Electronics systems with a diverse range of functions

The electronic systems of the future will be characterised by a strong degree of miniaturisation and, at the same time, will have to fulfil demanding requirements as regards functionality, autonomy, network capability, reliability, safety and energy efficiency. These multifunctional systems combine many component parts – for example: components for data processing and communication, and sensors and building blocks for energy generation or energy management. This combining of digital, analogue and microelectromechanical components – all on one chip, in certain cases – is referred to as the "More than Moore" trend by those in the field – as distinct from increasing miniaturisation of chip structures ("More Moore").

The research topics here include:

- Innovative system-integration technologies at the wafer and substrate levels and a combination of these for highly integrated, energy-optimised, high-quality electronics systems

Microelectronics is research-intensive

- Hetero-integration technologies and component concepts for multifunctional electronics systems that are suitable for the integration of various functions and chip technologies and for the integration of heterogeneous systems on and in sheets, for example
- Innovative sensor concepts and their implementation on a semiconductor basis
- Embedding technologies and micro-nano contacting technologies
- Strategies for the optimisation and improvement of housing technologies and materials for electronic circuits and modules
- Innovative test procedures and simulation models for system behaviour
- Models for understanding and predicting the technological and functional reliability and long-term stability of highly integrated electronics systems
- Production-oriented measurement and test procedures for highly integrated electronics systems
- Modularisation and standardisation of highly integrated electronics systems for a broad range of applications

Power electronics for efficient energy utilisation

Power electronics is an important interdisciplinary technology. In all cases where electrical energy is used, it has to be distributed, transformed or controlled. This task is carried out by power electronics. Important applications include power supply in industrial processes, drive technology, information and communication technologies, and lighting equipment. Power electronics includes broad areas of value creation: starting off with complex basic materials, first of all components, then assemblies and finally entire systems are built using suitable assembly and connection technology. Energy efficiency is always the high-level goal here.

Power electronics systems based on silicon semiconductors represent the state-of-the-art technology today. On the one hand, the integration density of these systems will continue to increase; on the other hand, research has developed many very promising precursor

materials that can be used to achieve a great increase in the efficiency of the conversion of electrical energy and of miniaturisation.

The research topics here include:

- Innovative circuit-technology solutions for efficient overall systems on the basis of power semiconductor materials
- New approaches in assembly and connection technology and thermomanagement with the aim of harnessing the potential of new materials – for example, for higher switching frequencies and different operating temperatures
- Modelling for error mechanisms and optimisation of the reliability at assembly and system levels
- Stronger networking and system intelligence for highly integrated solutions on the basis of all material classes

Innovative tools for chip and system design

Today's processors and integrated circuits consist of up to several billion transistors in a very confined space, with some individual structures that are just 14 nanometres wide in certain cases – for the sake of comparison, this is less than one thousandth of the diameter of a hair! In order to plan and design complex chips or electronic systems, highly developed computer algorithms and sophisticated simulations are necessary – regardless of whether this is for "More Moore" or "More than Moore". These tools for design automation and validation are the basis for the functionality of chips and systems; they take into account physical interactions and the framework conditions that result from manufacturing processes, for example. It is only possible to master the increasing complexity of innovative (micro-)electronics systems thanks to the refinement and creative use of these tools and a comprehensive understanding of technology. The effectiveness, degree of automation and the quality of the design determine the development cycles of industry and thus also the increasingly important time factor for market entry.

The research topics here include:

- Complex design rules for increasingly smaller structural widths where physical effects which did not have an impact for larger structural widths play an increasingly important role
- Consideration of non-functional aspects such as power consumption, robustness and ageing effects
- Highly automated design of "mixed signal circuits" where analogue components (e.g. in wireless communications interfaces) and digital circuits are integrated into a single system
- Use of assembly and connection technology for 3D-integrated, highly compact systems
- Test and verification methods for mixed analogue-digital systems and 3D-integrated systems
- Expansion of the computer-aided design environment over the entire value-added chain to safeguard the entire system at an early stage before the start of production

Secure chips for a digital society

Chip-based security technologies and functions are the key to secure digitalisation at the hardware level. Chip cards that are resistant to counterfeiting and manipulation are already being used for secure identification on official documents such as identity cards and passports. The demand for secure chips will continue to grow due to the strong networking dynamics in applications such as Industry 4.0, energy supply, mobility and payment systems and also due to the increasing numbers of mobile end devices.

This development is being accompanied by increasing volumes of real-time data that is provided by intelligent sensor systems that are fitted on increasing numbers of devices. The secure and efficient use of this "Internet of Things" and of the services that are based on this are only possible if the high degree of development expertise in Germany in chip-based security technologies continues to be expanded and if these technologies can be manufactured in a competitive manner. Security chips

are a particular strength of the microelectronics industry in Germany and Europe. However, new attack methods are always being developed in this area that can circumvent existing protective mechanisms. For this reason, it is necessary to continuously improve chip-based security technologies and to implement new types of methods in chip manufacturing.

The research topics here include:

- Methods for the unique identifiability of chips – for example, by implementing physical fingerprints using so-called "physical unclonable functions (PUFs)" – and for the verification and validation of specified security levels
- Circuit-technology measures to protect chips against external attacks
- The implementation of authenticity protection by manufacturers – for example, to prevent manipulation during production by a contract manufacturer (foundry)

Existing capabilities in chip-based security technology must be strengthened and expanded in order to successfully meet current and future challenges. Germany's leading position as a supplier of microelectronics can be consolidated and expanded in the long term by the manufacturing of cost-effective and secure chips. Chip-based security technologies are being supported primarily on the basis of the German Federal Government's framework programme for research "Self-determined and secure in the digital world 2015-2020".

Electronics production technologies and electronics production for the future

In order to join up the value-added chain from semiconductors through to end products, it is necessary to continue to strengthen capabilities in electronics production technology. The development of new production technologies demands a holistic consideration of processes, materials and systems/equipment. This applies not just for standard components, but also all the more for multifunctional components. German suppliers in the areas of materials and equipment are involved in development here to a significant extent – in the area of lithography, for example, with extreme ultraviolet radiation (EUV lithography) for the manufacturing of particularly small chip structures. Many processes for the manufacturing of microelectromechanical systems (MEMS) have also been developed in Germany. Independence with regard to electronics innovation capability and, in particular, the security of supply for users at competitive conditions represent further important reasons for the ongoing development of advanced manufacturing technologies.

The research topics here include:

- Further automation of manufacturing
- Systems and processes for high-precision, reliable and cost-effective processing of the smallest, most diverse components to create complex, multifunctional electronic components and systems
- Measurement and testing technology to support fast innovation cycles and high quality requirements

European value-added chains are particularly important for electronics production technologies, which is the reason why support will be preferentially implemented in the form of joint European projects. Research on the sustainability and resource efficiency of production processes and on challenges in disposal and raw material recovery is being supported by the German Federal Government in the BMBF's programmes "Research for Sustainable Development – FONA³" and "From Materials to Innovation *(Vom Material zur Innovation)*" (calls: "Materials for a Resource-Efficient Industry and Society" or "Safe Use of Synthetic Nanomaterials") and in the departmental research carried out by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. The strategic framework for this is provided by the Federal Government's "German Resource Efficiency Programme (ProgRess)".

3.2 Identifying the foundations of future electronics

A comprehensive mastery and the general availability of current technologies are of fundamental strategic importance as regards the innovation capacity of business sectors that use microelectronics. In addition,

access to future technological developments must also be ensured. The aim here is to acquire knowledge regarding the next generations of technology and, in this way, to put in place the prerequisites for innovative and also for radically new solutions and applications. This represents an important contribution to digital sovereignty and is therefore being supported accordingly – also in consultation and cooperation with the German Research Foundation. The European Framework Programme "Horizon 2020" also offers relevant funding opportunities here – for example, in the "Future and Emerging Technologies" area, where the German Federal Government is participating accordingly in setting the research agenda.

Progress on the basis of alternative physical effects, new materials and innovative components and system concepts is expected from the radical development of new approaches, i.e. the so-called "Beyond CMOS" principle. The following research and development topics are among those that can currently be identified for these alternative technologies:

- One-dimensional electronics (nanowire, carbon nanotubes [CNTs] etc.)
- Organic and printed electronics
- Graphene-based electronics
- New assembly and connection technologies (e.g. self-assembly, etc.)

One important trend in the development of electronics up to now ("More Moore") was characterised by increasing miniaturisation and a resulting increase in integration density on the basis of the CMOS technology (complementary metal-oxide-semiconductor).

Every step in this ongoing development process was associated with higher performances and also with rapidly falling chip prices, with the result that only a few very large semiconductor companies – mostly outside of Europe – are now able to produce these highly integrated standard processors and storage

Microelectronics is systematically relevant

components in an economically viable manner. In the area of "More Moore", the ongoing development of design capabilities (Section 3.1) is of primary importance for Germany in order to be able to use the corresponding components for innovative electronics systems. The components themselves and access to the relevant manufacturing facilities outside of Europe are generally available on the world market and these are used accordingly by German companies. Research and development in this area is not a focus of the programme funding.

3.3 Tackling future tasks using microelectronics

The digital economy, a sustainable and reliable energy supply, intelligent mobility and the preservation of health will require further progress in electronics and sensor systems. For this reason, system expertise and innovation partnerships between the microelectronics sector and its clients in Germany and Europe will be harnessed and further expanded. Accordingly, funding for research and development will be targeted at these strategic application focal points. This will happen in a complementary manner to the strategic research focuses in the area of technologies (Section 3.1) and in identifying of the foundations of future electronics (Section 3.2).

Microelectronics offers security

Towards Industry 4.0

Industry 4.0 refers to the coming together of production and information technologies. It offers the opportunity to bring the flexibility and the energy and resource efficiency of production processes to the next level using intelligent control and networking. Electronics and sensor systems play a key role here: they turn production equipment and products into cyber-physical systems (CPS) that communicate with one another, optimise production and interact with humans in a safe and reliable manner. The required hardware is based on complex microelectronics systems for the recording, processing and exchanging of data and for controlling equipment. These "More than Moore" systems combine sensor and actuator components, high-frequency and communication components, power supplies, power electronics, microelectromechanical systems (MEMS), and components from the area of optoelectronics, for example.

The data to be recorded is becoming increasingly diverse. Important applications include the tracking of manufactured goods, preventive maintenance of production facilities and relevant infrastructures by continuous monitoring, and the statistical evaluation of process data. All of this gives rise to considerable impetus for innovations for the services sector; other areas such as agriculture will also benefit. Various sensors and measurement procedures need to be used and combined for these applications. As a result, the complexity of microelectronics systems is increasing; at the same time, these systems also have to fulfil demanding requirements as regards performance, reliability, robustness and energy efficiency.

Alongside expertise in system integration, the portfolio of basic technologies is also being further expanded in order to meet these challenges. There is a need for research into the design of complex electronics systems and into three-dimensional and heterogeneous system integration in a housing ("system-in-package", SiP) as an interdisciplinary technology, for example. Recommendations on research needs, norms and standards, the security of networked systems, the legal framework and the requirements for work and training will be developed within the framework of the Industry 4.0 platform. According to a recent survey of trends among ICT companies, the importance of the topic of Industry 4.0 has increased significantly, particularly for small and medium-sized enterprises in Germany. Thirty-nine percent of small and medium-sized enterprises (SMEs) reported that Industry 4.0 was a very important issue, which places them just behind the large companies, which had a corresponding value of 50 percent.

Electronics systems for electromobility

The range of the vehicles available on the market must continue to increase if electromobility is to become a success story and is to make an important contribution to climate protection. At the same time, however, costs must be reduced. Innovations in microelectronics are making a significant contribution here. Work is required in areas such as: new electronic battery management systems that feed more energy into battery cells and can extract more from them, energy-efficient, intelligent on-board power supplies and control devices, and highly integrated, energy-saving electrical drives. Both space and costs can be saved by integrating control and power electronics into engines. The prerequisites for higher efficiencies at a system level and for more compact assembly forms include new technologies on the component and circuit levels – such as elements made of the semiconductor materials gallium nitride and silicon carbide – and innovative engine control.

Also important for the success of electromobility is the availability of easy-to-use charging systems – with charging capacities that are as high as possible, where needed. These also benefit from small, light, efficient and cost-effective power electronics systems. Non-contact charging by means of induction also requires light, highly efficient coil systems for energy transmission.

Progress in electronics and sensor systems is not only of benefit to electromobility, but also offer innovation potential for vehicles with other drives that increasingly make use of electrical functions. Around 80 percent of the most important innovations in automobile construction today are already being driven by microelectronics and software.

Driverless vehicles of the future

Electronics and sensor systems in driver-assistance systems are already reducing the risk of accidents and protecting lives today. However, the highly or fully automated vehicles of the future will not just further improve road safety, but will change our mobility in a fundamental manner: they will improve traffic flows on motorways and similar road types and in cities too, and will deliver greater energy efficiency on the vehicle and traffic-system levels. Noise and air pollution will also be reduced. In addition, driverless vehicles will make mobility more accessible and allow older people, in particular, to make use of road transport. In this way, new services in personalised mobility will be opened up. Electronics also unlocks the engineering synergy potential of electrical and driverless road transport.

Microelectronics supplies the technological prerequisites here. Detection of the surroundings that works in a reliable manner under difficult surrounding conditions and in complex traffic situations will require further research. The focus here is on recognition of the surroundings using compact sensors and sensor data fusion/interpretation in real time by powerful control units. Automatic functions in vehicles also require a high degree of reliability as well as security against unauthorised access. Chip-based security technologies are a prerequisite for providing this security.

In addition, autonomous electric vehicles can be integrated into intelligent grids for decentralised energy supply or embedded into future urban infrastructures that will offer solutions to the challenges of demographic change and urbanisation. Complex sensor, electronics and communication systems are also necessary for this purpose. The market potential is considerable: the worldwide demand for semiconductors for automobile electronics had already increased to almost 35 billion dollars by 2014, and annual growth of around 4.5 percent is expected in the next five years.

A sustainable and efficient energy supply

Germany is one of the pioneering countries worldwide in electronics for renewable energies. The feeding-in of renewable energy sources presents new challenges to the electricity grid and the controlling of the electricity system. The task of intelligent electricity grids (or "smart grids") is the integration of alternative energies into distribution grids, in particular. For this purpose, the status of the grid needs to be detected and controlled to an increasing degree.

In particular, power electronics is a key technology for the successful connection of regenerative energy sources and storage systems to the public grid. This task requires electronics systems for voltage conversion and feeding-in of energy from photovoltaics and wind power, for the integration of energy storage systems, and for ensuring grid stability. "Virtual power plants" and intelligently networked generation and loads also require increasingly intelligent electronic systems. The efficient functioning of the grid needs to be ensured here at all times; new technologies for increasing security and reliability and redundancy concepts for the highest levels of availability need to be developed here. These topics of sustainable and efficient energy supply have already been tackled in the German Federal Government's "Research for an environmentally sound, reliable and affordable energy supply" energy research programme. Microelectronics can make significant contributions here, as a small increase in efficiency in an individual device can multiply to become a large saving in the overall system: for example, the modern power electronics in current converters could reduce energy consumption in the EU by around 16 terawatt hours (TWh) per annum, thus saving about 3.7 million tonnes of CO^2 emissions each year – which corresponds to approximately half of the annual electricity consumption of Denmark. In this way, the promotion of microelectronics supports German industry in the area of climate-friendly technologies, and thus also contributes to climate protection.

Electronics systems for a healthy life

Germany is currently the third largest producer of medical technology worldwide and is also a leading supplier of electronic system solutions for health care.

The turnover of German companies in this area has been continually growing at two to three times the rate of gross domestic product since 1995; it is now significantly over 20 billion euros per annum. This sector is mainly characterised by medium-sized companies.

Against the background of aging societies worldwide, the increasing individualisation of medical care, and – in particular – as a result of new technical potential (e.g. increasing miniaturisation, autonomy and communication for electronic components), this is a market where long-term growth can be predicted. At the same time, competitive pressures are also growing. Germany is able to respond to this with a very active, well-networked and industry-oriented research landscape. After all, the innovative capacity of German companies is based on the fact that the national research, industrial and supply landscapes cover the entire value-added chain – from basic research right through to marketing as medical products and the use of these products in human health care.

Electronics is entering into more and more areas of health care. As a key technology, it is promoting the development of improved – i.e. more intelligent or better networked – medical products ("smart health"). These range from electronics-based diagnosis and treatment systems for in-patient use in hospitals through to wearable energy-efficient electronics and sensor systems for mobile diagnosis and therapy on and in the human body. Medical applications present special requirements with regard to biocompatibility, energy consumption, reliability and integration capability, for example.

3.4 Strengthening Germany as a place to do business

In recent years, the German microelectronics industry has concentrated on its technological strengths – partly as a result of international competition.

Instead of manufacturing standardised mass products, companies in Germany have specialised in complex, multifunctional microelectronics and sensor systems for areas of application such as automobile technology,

Microelectronics supports climate protection

secure identification and transactions, energy generation and distribution, and industrial automation. In addition to actual manufacturers of semiconductors, nowadays there are also successful companies without their own production capacities that use contract manufacturers. There are also important contract manufacturers in Germany, so-called foundries that produce the latest semiconductor components in a flexible, individual manner in accordance with customer-specific requirements.

Also of particular importance for Germany as a location for innovation is the wide range of application-oriented research, including the transfer of research results into applications. The institutes of the Fraunhofer-Gesellschaft are at the forefront of these efforts. The Fraunhofer Group for Microelectronics combines the expertise of eleven institutes with a total of around 3,000 employees, together with five guest institutes from other Fraunhofer Groups in related subject areas. This group is an important advantage for Germany as a location, particularly for small and medium-sized enterprises that are driving progress with innovations based on microelectronics (Section 4.3).

In this way, leading industrial sectors and companies with R&D expertise have emerged in Germany that have been able to achieve significant market successes with highly innovative products and services that are based on electronics systems. This includes both the supplier sector (materials, components and plant equipment) and user sectors in Germany. Germany has a very good competitive position on a global basis with regard to the range of coverage and the quality of all these innovation factors.

The German Federal Government will expand the exchange process with companies, advocacy groups and research institutions in the area of microelectronics. An important element here is dialogue with representatives of various sectors, both in the context of the expert discussions of the Federal Ministry of Education and Research (BMBF) on technological developments

Microelectronics offers solutions for societal challenges

and future requirements as part of the Microelectronics agenda process and also within the framework of dialogue between the Federal Ministry for Economic Affairs and Energy (BMWi) and industry.

Microelectronics makes the digitalisation of industry and commerce possible in the first place. However, technological expertise is not the only requirement: framework conditions, standards and regulations also play a decisive role in the success of German industry in the global competitive environment. These are to be discussed and advanced within the framework of the new Industry 4.0 platform. The BMWi, BMBF and leading representatives from industry, industrial associations, trade unions and the research community are represented here.

3.5 Ensuring the availability of skilled labour and young professionals

The availability of highly qualified employees is a decisive factor in the success of Germany as a location for industry. As a high-tech sector, microelectronics can only be successful in the international competitive arena if it can find and keep specialist staff. At the moment, there is no general lack of specialist personnel, but there are already significant bottlenecks in technical professions. This applies not just to academic qualifications, but also increasingly to those with vocational qualifications. In the coming years, this situation will become significantly more acute.

The BMBF is fostering support for the next generation of academic personnel. As part of funded joint projects, students and doctoral candidates are working closely with industrial partners and, in this way, are acquiring specialist knowledge and interdisciplinary skills. This will help to smooth their transition into working life, and can also make it easier for them to enter the microelectronics industry. The BMBF is active in trying to encourage interest in microelectronics among young scientists at an early stage – for example, with the "INVENT a CHIP" competition, where pupils in schools have been encouraged to submit their own ideas for microchips since 2002.

The Federal Government has set up the "Alliance for Initial and Further Training 2015-2018" together with the Federal Employment Agency, industry, trade unions and the federal states. The common goal of all partners here is to strength dual vocational training and to promote the equal importance of vocational training and academic education. The Alliance partners have agreed on important measures that will enable and encourage more young people to take up vocational training.

The profiles of various professions will also be examined on a continuous basis in the context of digitalisation, and training regulations will be updated with relevant content on electronics, for example. One current example of this is the inclusion of various aspects of power electronics in professions relating to vehicles as part of the process of developing skills in electromobility.

Cross-sector challenges such as ensuring the availability of specialist personnel and requirements relating to training are to be addressed by "The Future of Industry" alliance, which is currently in its initial stages. The BMWi founded this platform in 2015 with 13 additional partners from industry with the aim of preserving and strengthening the industrial core of German industry and commerce. Microelectronics will also benefit from the results of these efforts.

The Federal Government's concept for specialist personnel also provides for enticing additional specialists to come to Germany from other countries. For example, the "Make it in Germany" welcoming portal provides information about living and working in Germany and offers tips to employers. The Federal Government is also supporting immigrants and other interested persons with its "Working and Living in Germany" telephone hotline.

The foundation for better integrating people with foreign professional qualifications into the employment market was put in place by the Federal Government with its initiative for a Federal Recognition Act for foreign qualifications, which came into force on 1 April 2012 and has proven itself as an instrument for attracting specialists. This Act gives specialists from abroad the right to have their professional qualification examined as regards its equality of status with a comparable German profession.

Tailored information and advice are significant factors that contribute to successful recognition in such cases. The "Recognition in Germany" Internet portal (www.anerkennung-in-deutschland.de), which is operated on behalf of the BMBF, helps people to quickly find the relevant responsible body. In addition, the BMWi supports the "BQ portal – The information portal for foreign professional qualifications": this online knowledge and working platform (www.bq-portal.de) provides comprehensive information on foreign qualifications and professional training systems for the relevant responsible bodies. The BQ portal also helps companies to evaluate and assess foreign professional qualifications.

Small and medium-sized enterprises are particularly affected by bottlenecks with specialist personnel. The BMWi's "Centre of Excellence on securing skilled labour" provides help with finding and keeping specialist staff. The BMWi's "*Passgenaue Besetzung* (Well-matched recruitment)" programme aims to help SMEs to fill vocational training positions and to create a welcoming environment for foreign trainees and specialists.

With these activities, the Federal Government is helping the microelectronics sector in particular, which is attracting both companies and specialists/scientists from all over the world to Germany.

3.6 Supporting networks and clusters

Nowadays, innovations in microelectronics are almost always the result of cooperation between partners from various disciplines and sectors. Networks and clusters offer a suitable framework in this regard: as a result of their network activities and lobbying for common interests, they provide their members with an opportunity to exchange information on their experience and help them to achieve advances with innovations more quickly and to become more successful on the marketplace. This potential is to continue to be harnessed at both state and federal level.

The approximately 100 clusters that have been accepted into the BMWi's "go-cluster" programme are pioneers in innovation and reflect the high level of expertise present in Germany in many sectors and areas of technology.

In addition, the BMWi is actively supporting research cooperation within industry and also between industry and the research community with its Central Innovation Programme for SMEs (ZIM), which is open to all technologies and sectors. As part of a ZIM cooperation network, companies – together with participating research institutions – are developing a technological roadmap that the stakeholders will use to achieve their joint goals. Research and development projects are being initiated by this network. Since the start of the ZIM in July 2008, over 300 networks have been supported. Almost 4,000 companies and just under 500 research institutions have participated in this activity. Microelectronics as a subject area is playing a major role here: up to now, around 6 percent of the networks can be assigned to the technology areas of "Electronics, measurement technology, sensor systems" and "Microsystem technology".

Strong regions

Germany has strong regions in the area of microelectronics that have a high profile in the European and global arenas. Under the banner of "*Deutschlands Spitzencluster – Mehr Innovation. Mehr Wachstum. Mehr Beschäftigung*. (Germany's excellence clusters – More innovation. More growth. More employment.)", the BMBF is supporting the transformation of regional innovation potentials into permanent value creation by means of its excellence cluster competition. The BMBF is promoting international cooperation within these clusters with top specialists worldwide within the framework of "*Internationalisierung von Spitzenclustern, Zukunftsprojekten und vergleichbaren Netzwerken* (Internationalisation of excellence clusters, future projects and comparable networks)". This is increasing the innovation potential of the research community. At the same time, these measures are also strengthening the competitiveness of companies and helping to advance solutions to global challenges.

For example, the federal state of Saxony – which is now the most significant location for microelectronics and nanoelectronics in Europe – is benefitting here. The

microelectronics sector in the region between Dresden, Freiberg and Chemnitz currently generates a turnover of around 6 billion euros per annum with its approximately 25,000 employees. With eleven Fraunhofer Institutes, five Leibniz Institutes and three Max Planck Institutes, this region is also one of the most important research locations in eastern Germany.

The "Silicon Saxony" cluster has also contributed to the success of microelectronics in Saxony: it was founded in the year 2000 and now includes over 300 manufacturers, suppliers, service providers, universities, research institutes and public-sector bodies in the microelectronics and nanoelectronics sector in Saxony. Up to now, the BMBF has funded two subject-oriented excellence clusters in Saxony: the "Cool Silicon e. V." cluster on energy-saving microelectronics and the "Organic Electronics Saxony" cluster. The BMBF will be promoting the internationalisation of "Organic Electronics Saxony" – alongside "*Cluster Leistungselektronik im ECPE e. V.*" and other clusters – from 2016 onwards.

Strong networks in the area of electronics have also been established in other regions: the cross-sector *"microTEC Südwest"* cluster, which includes over 350 companies and research institutions in the state of Baden-Württemberg, deals with microsystem technology for production, mobility, health and energy. The BMBF has supported *"microTEC Südwest"* as part of the excellence cluster competition. The BMBF is fostering research and development in automation technology and mechatronics within the "it's OWL" excellence cluster, which brings together partners from mechanical engineering and the electrical, electronics and automobile supplier industries in Ostwestfalen-Lippe. The focal point of the "Forum Organic Electronics" excellence cluster in the Rhine-Neckar region is the development of printed electronics as a future technology.

Some clusters are also benefitting from funding from federal states that are running their own support programmes. The Bavarian cluster initiative "*Cluster-Offensive Bayern"* is supporting the "*Cluster Leistungselektronik* (Power electronics cluster)", for example, which covers the entire innovation and value-added chain in the area of power electronics.

Networking of expertise

With its "Twenty20 – Partnership for Innovation" funding programme, the BMBF is supporting transregional and multidisciplinary research cooperations. With this framework, the "fast – fast actuators sensors & transceivers" consortium – which networks 50 partners from nine federal states in Germany in research projects – was established in 2014 in order to improve the real-time performance of sensors and actuators for applications such as improved driver-assistance systems.

In 2001, the "edacentrum" was founded in Hanover, which bundles the research and development resources of more than ten university institutes on the subject of EDA (electronic design automation) in Germany and supports these resources in cooperation with industry. Progress in the automated design of electronic circuits is being achieved as part of joint research projects.

European cooperation between high-tech locations is also being strengthened by industry-driven European initiatives such as "Silicon Europe", which networks the "Silicon Saxony" cluster with other regional clusters in microelectronics and nanoelectronics in Belgium, France, the Netherlands and Austria.

In the area of power electronics, the "ECPE European Center for Power Electronics e. V.", an industry-led European research network, brings together around 70 companies and 70 university and research institutes from all over Europe. The ECPE is supporting the pre-competitive joint research within the "ECPE Joint Research Programme" and also serves as a platform for participation in public research projects at national and international level, as a centre of expertise, and as an advocacy group.

The expertise of German trade associations is also being harnessed with the aim of strategic further development of microelectronics: the associations involved include ZVEI – the German Electrical and Electronic Manufacturers' Association, the GMM VDE/VDI Society of Microelectronics, Micro and Precision Engineering, the IVAM Microtechnology Network, the AMA Association for Sensors and Measurement and the German mst-Netzwerk Rhein-Main e.V.

4. Measures and instruments

4.1 Targeting of research funding

Research funding is an important element in the expansion of existing expertise and the harnessing of new technologies and applications in microelectronics. It accelerates innovation processes along the entire value-added chain and aims to achieve sustainable value creation in Germany and Europe. Its effectiveness can be further improved by the coordination of research funding with European programmes and by international cooperations.

Expansion of national funding

With its new High-Tech Strategy, the German Federal Government has set itself the goal of harnessing and strengthening the potential offered by microelectronics in cooperation with industry and the research community. Focal areas for the targets of the associated research funding include societal needs and technological goals in Germany and Europe, and also global developments in microelectronics and its applications. Working on the basis of the Federal Government's position paper on microelectronics of June 2014, thematic focuses for funding were developed as part of an agenda process – in close cooperation with the relevant research institutions, companies and industrial associations.

The measures here range from workshop discussions that take a broad approach – for example, for future manufacturing technologies for microelectronics – through to discussions on individual topics with specialists. In particular, research needs with regard to electronics and sensor systems for use in Industry 4.0 were discussed with the participation of stakeholders from the areas of mechanical and plant engineering. The continuous analysis of ongoing research projects – in power electronics, for example – is an additional element in the BMBF's strategy development. The BMBF has discussed future prospects and research projects in one-dimensional electronics – which offers potential for innovative electronic and sensor systems – within

Microelectronics offers opportunities to investors

the context of expert discussions with the participation of the German Research Foundation, for example.

Focal areas for research funding that are to be further developed, prioritised and taken into account in discussions over the duration of the programme up to 2020 have already been specified in Section 3. This funding will primarily be granted to joint and individual projects. As part of selection decisions regarding individual funding measures, the opportunities for applications and the multiplier effect for Germany as a location will be taken into account alongside the quality of the research approach. The BMBF is planning to make up to 400 million euros available for the Framework Programme for Research and Innovation in Microelectronics over the duration of 2016 to 2020.

Coordination with European measures

Between 2014 and 2020, the European "Horizon 2020" Framework Programme for Research and Innovation will support the positioning of European economies by strengthening key technologies, for example. In addition, the European Commission published "A European Strategy for Micro- and Nanoelectronic Components and Systems" in 2013. The core aims of this document are a significant increase in Europe's world market share in semiconductors, focussing on European strengths and leading expertise clusters, and support for the growth of small and medium-sized enterprises.

With this Framework Programme, the Federal Government is supporting the European Commission's strategy for micro- and nanoelectronic components and systems. The European programmes and strategies form a framework that is built upon by the measures implemented by individual member states. The German Federal Government's aim is to strengthen the national microelectronics sector as a part of the European innovation system in order to access new markets with innovative and sustainable products and to significantly increase value creation in microelectronics in Germany and Europe by 2020.

Of particular importance for the area of microelectronics is the "Electronic Components and Systems for European Leadership" (ECSEL) research initiative, which is co-financed on a European basis and for which the EU has earmarked around 1.4 billion euros between 2014 and 2020 from "Horizon 2020" funds. As part of ECSEL, application-oriented and technology-oriented projects along the entire value-added chain are being funded with partners from at least three countries. In particular, ECSEL offers an opportunity to support research-driven pilot lines that prepare the way for the manufacturing of new products at the interface between research and value creation in Europe. The European Union and the participating member states are financially participating in ECSEL in equal parts. In its research funding, the BMBF will contribute to ECSEL with the focal points presented in this programme and will thus significantly increase the funding for German stakeholders from ECSEL.

France, the Netherlands, Belgium and Germany – with the support of Spain, Hungary and Turkey – have initiated the "Pan-European partnership in micro- and nanoelectronic technologies and applications" (PENTA) EUREKA cluster, which will run for the duration of 2016 to 2020, with the aim of further strengthening European research cooperation in selected areas beyond the scope of ECSEL. Within PENTA, there is the additional opportunity to advance strategically focussed research topics that could not be covered to a sufficient extent in ECSEL due to the large number of participating funding agencies. In addition, the PENTA cluster is focussing its attention increasingly on applications in automobile electronics, medical technology and Industry 4.0 and is facilitating projects with two or more partners from two EUREKA countries.

The participation of German companies and research institutions in PENTA is being supported on the basis of this programme. To ensure that better chances of participation are created for SMEs both in ECSEL and in PENTA, targeted information measures have been established within the BMBF's funding advice services (Section 4.2).

Cross-national cooperation is important in order to consolidate expertise – for example, with France with regard to application-specific CMOS technologies and with the Netherlands on lithography and production technologies. In this regard, the initiative of the Fraunhofer-Gesellschaft on the intensification of cooperation with European research institutions such as CEA-Leti in France, IMEC in Belgium and TNO in the Netherlands is to be welcomed.

4.2 Strengthening innovative small and medium-sized enterprises

Small and medium-sized enterprises are drivers of innovation and an important interface for the transfer of scientific findings and research results into industry. Many of these companies are already market leaders today in specialised areas in sensor systems, actuators, assembly and connection technology or system integration, and they also work successfully in innovation partnerships with large companies and research institutions. With their expertise, they have played a crucial role in the development of Germany to become a leading technology location for industrial automation, medical technology and other applications of microelectronics.

The BMBF and BMWi will continue to strengthen innovative small and medium-sized enterprises. With its "Central Innovation Programme for SMEs" (ZIM), the BMWi has been funding research and development in all areas of technology – including microsystem, electrical, measurement and sensor technology – since 2008. In addition to its thematic funding programmes, the BMBF has been offering quick and easy access to support for SMEs with its *"KMU-innovativ"* funding initiative (Funding for Innovative SMEs) since 2007. Open selection of subject areas and comprehensive advice are intended to make this measure even more attractive for companies.

Another goal of the BMBF is more intensive participation of SMEs in German and European support programmes that focus on electronics systems. The particular strengths of SMEs are to be taken into account when national funding measures are being initiated. In ECSEL and other European programmes, it is intended that advice services will ensure that SMEs will be able to deal with the complex framework conditions for European funding. The "PENTA" EUREKA cluster will support SMEs with networking events and advice services, and will also offer a simpler application procedure. As SMEs often do not have their own semiconductor production facilities, the BMBF also supports research in technology platforms. These supply established manufacturing processes and subcomponents that companies can use and combine in new ways based on a modular principle. In addition, participation in ECSEL projects in particular opens up new opportunities: for example, SMEs that do not have their own semiconductor production can use a broad spectrum of technologies for the development of electronics and microsystems that would not otherwise be available to them.

4.3 Harnessing the potential of research institutions

One particular strength of the research landscape in Germany is its comprehensive spectrum of capabilities and infrastructures that are targeted at both basic and application-oriented research. Microelectronics and nanoelectronics are firmly established at the major research institutions such as the Fraunhofer-Gesellschaft, Max Planck Society, Helmholtz Association and Leibniz Association. For example, the Research Centre Jülich is carrying out research on topics such as future electronics materials and assembly elements within the Helmholtz Association's "Future Information Technology (FIT)" programme. The Fraunhofer-Gesellschaft has established performance centres such as the centres for functional integration in nanosystems and microsystems in Dresden and for electronics systems in Erlangen. The Fraunhofer Group for Microelectronics was founded back in 1996. With its eleven institutes, this group is an important partner for industry in the implementation of the strategy for the strengthening of microelectronics expertise in Germany. In addition, the group has research infrastructure such as clean rooms, which are an important location factor for SMEs in particular. With the aim of ensuring that the Fraunhofer Group for Microelectronics remains an excellent partner for industry even in the case of increasingly complex research tasks and customer requirements, closer cooperation – for example, in the form of a distributed "research foundry" – is being targeted so as to strengthen the group and thus also Germany as a location.

There is a diverse range of activities in basic and applied research at universities and other third-level institutions. The BMBF is supporting applied research directly in the form of joint projects with commercial industry, while basic research at universities is funded by the BMBF through the German Research Foundation. The excel-

lence initiative of the Federal Government and the federal states is also strengthening top-class research in microelectronics. One example here is the "Center for Advancing Electronics Dresden" (cfAED), a centre of excellence that was set up at the Technische Universität Dresden (TUD) in 2012.

Research carried out in joint projects between industry and research institutions is the core of the BMBF's support of microelectronics. Other opportunities for transfer exist in non-subject-specific programmes by the BMWi and BMBF – e.g. within ZIM or the VIP+ measure, which helps researchers to identify the innovation potential of their basic research and to transfer it to possible applications in transfer projects. As part of the EXIST programme, the BMWi is also providing support for entrepreneurs and for spin-off companies at universities and non-university institutions.

4.4 Creating a foundation for innovation and investment

The microelectronics industry, which has over 50 years of successful history, is still growing globally today at a rate of around 6 percent per annum (cf. "*Mikroelektronik – Trendanalyse bis 2019* (Microelectronics – Analysis of trends up to 2019)", ZVEI) and will continue to gain in importance as a result of advancements in digitalisation. Technological expertise and sovereignty in microelectronics are essential for the implementation of Industry 4.0, the Internet of Things and driverless vehicles.

Complex electronics systems are among the strengths of the German microelectronics industry, which serves growth markets both in Europe and worldwide.

Microelectronics requires action at a European level

Microelectronics companies and their customers are benefitting from the close innovation partnerships, symbiotic value-added chains and a productive local research landscape.

Microelectronics is a very research- and investment-intensive field. In recent years, companies based in Germany have successfully expanded their core competences. Good support must be provided for this growth and for the harnessing of quickly growing application areas. Germany can only remain an attractive location for innovation and investment in microelectronics in the international competitive environment if appropriate measures are coordinated with one another.

An important element on a national level is cooperation with federal states where successful companies and clusters are based. For example, the BMBF is cooperating with the federal state of Saxony in the ECSEL electronics initiative: Saxony is contributing to funding for projects by Saxony-based participants in ECSEL up to 2024 with total additional funds of up to 200 million euros, and has already supported a number of strategic pilot-line projects. The prerequisites for the participation of other federal states in ECSEL are already in place.

Within the framework of its rules for the funding of "Important Projects of Common European Interest" (IPCEI), the European Commission has been facilitating support since 2014 for transnational projects that aim to increase economic growth, employment and the competitiveness of Europe. The Federal Government supports this new measure as an important strategic instrument for the promotion of innovation and investment. The Federal Government regards IPCEI as an opportunity to respond to distortive practices by other regions of the world in this technological area. A number of companies in the microelectronics sector in Europe are involved in dialogue with the European Commission and national governments with the aim of preparing a concrete suggestion for an IPCEI for microelectronics.

Standards and platforms are an important additional element in securing the innovative advantage of the German microelectronics industry. For this reason, the Federal Government is supporting initiatives such as the Industry 4.0 platform and standardisation measures by the German Institute for Standardization (DIN). The BMWi previously initiated funding programmes such as "Innovation with Norms and Standards" (INS) and "Transfer of Research and Development (R&D) Results through Standardization" (TNS) with the targeted aim of promoting innovation by means of norms and standards; these two programmes will be replaced by the "WIPANO – Knowledge and Technology Transfer via Patents and Standards" funding programme from 2016 onwards.

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