W. Menz, J. Mohr, O. Paul

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Microsystem Technology

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Prof. Dr. Wolfgang Menz
IMTEK (Institut für
Mikrosystemtechnik)
Albert-Ludwigs-Universität
Georges-Köhler-Allee 103
D-79110 Freiburg

Dr. Jürgen Mohr
Institut für Mikrostrukturtechnik
Forschungszentrum Karlsruhe
Postfach 3640
D-76201 Karlsruhe

Prof. Dr. Oliver Paul
IMTEK (Institut für
Mikrosystemtechnik)
Albert-Ludwigs-Universität
Georges-Köhler-Allee 103
D-79110 Freiburg

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Illustration on front page: Array of CMOS-compatible silicon bulk micromachined thermoelectric infrared detector pixels (courtesy of the Physical Electronics Laboratory, ETH Zurich)

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To Margrit, Sonja and Corinne

Preface

Writing a book about microsystem technology is no simple task, since technology evolves at such high speed and new variants are reported all the time. If as an author one had to keep one's manuscript up-to-date, one would have to continuously rewrite it, making a publication impossible. There is a further reason hindering the publication of such a book: the rapid expansion of microsystem technology into new fields of application. Not so long ago, applications in metrology, e. g., in domotics or in the automobile sector, dominated. Today, solutions in minimally invasive surgery, health care, or biochemistry are claiming a rapidly growing share of the market.

When we set out to write this book it was not our intention to report the most recent research and development results. This should remain the privilege of the proceedings of relevant technical meetings. However we do believe that the microsystems engineer currently benefits from a large body of experience that has accumulated since the pioneering days of microsystem technology. With this book, we therefore wish to provide the student and the interested engineer with a source of information describing the necessary fundamentals and the basic techniques of the field. In particular is was our wish to show how many of its techniques have evolved out of microelectronics by transcending the limits of electronics, and how they have conquered new areas in physics, chemistry, and biology. On this basis, systems with mechanical, optical, fluidic, chemical and biochemical content can be built. Some day these will perhaps parallel the economic success of microelectronics.

The material in this book has been taught and optimized in several courses at the University of Karlsruhe, at the Swiss Federal Institute of Technology ETH Zurich, and finally at the new Faculty for Applied Sciences of the University of Freiburg. The German predecessor of the book, i. e., „Mikrosystemtechnik für Ingenieure" of VCH-Weinheim, in its second edition, was elaborated on the basis of these course notes. In view of the fact that microsystem technology is undissociable from the idea of international exchange and communication, we now present

an English edition. The material contained in the German edition was thoroughly revised and Chapter 6 on silicon-based microsystems was considerably expanded. With these improvements, we hope that the book will add another bright piece to the colorful mosaic of the international endeavor in our fascinating field.

Finally it is our pleasure to thank the numerous colleagues and collaborators who have contributed to this project with their contributions, proposals, and constructive criticism. An eminent role was played by Dr. Eric Kay, Mendocino CA, who reworked the manuscript with respect to language and technical content, so that hopefully the book can successfully compete on the market of technical literature in English.

Freiburg, July 2000

Wolfgang Menz
Jürgen Mohr
Oliver Paul

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1 General Introduction to Microstructure Technology

1.1 What is Microstructure Technology?

Microsystems technology leads the engineer away from a comprehensible seize regime to an area which is beyond the natural realms of perception. He must learn to work with these new opportunities as well as use his own experience, but not arbitrarily impose it onto the new technology. This mental transformation already started with microelectronics, the problem though was not as much apparent, since the electrical engineer is used to deal with "abstract" matter such as electricity. The real conflict with personal experience began initially with the merging of microelectronics with mechanical structures.

Nowadays microsystems technology is mentioned everywhere. Unfortunately this does not contribute to clarity, but on the contrary the concepts seem frequently unclear and misunderstandings remain. First, however, the basic difference between microstructure technology and microsystems technology has to be clarified, although the choice of words should make it quite unequivocal.

Microstructure technology is the tool, with which a particular geometrical structure of a body can be produced, whose dimensions lie in the micrometer region. In some cases however, only one of the body's dimensions lies in the micrometer range, whilst the other two dimensions remain in the millimeter range. In other cases they are already in the sub-micrometer region. However, the actual dimensions are less important than the technology, which derives from microelectronics, and its potential to enter the micrometer region. Nanotechnology is even more difficult to define than microtechnology. Of course, it would be wrong to talk of nanotechnology if a structure is described, whose dimensions are only a fraction of a micrometer. Here too one must refer to the technology which enables the production and measurement of nanostructures. Both technologies have very different origins, therefore it would be very wrong to presume that one technology continually evolves into the other.

On many occasions the terms microstructure technology and microsystems technology are mixed up or at least not well defined. By means of microstructure technology, it is possible to manufacture microbodies or microcomponents,

whereas microsystems technology integrates these microcomponents to arrays, adds signal processing and controlling, and provides interfaces to the outside macroscopic world. An example from microelectronics should clarify this point: The smart connection of a hundred or thousand "dumb" transistors leads to an "intelligent" microsystem, the microprocessor, which constitutes the initial efficient capability of microelectronics.

This book deals firstly with the basics of microstructure technology, followed by a discussion of microsystems and the technological requirements which lead to them.

A basic question about the microsystem will be put to the reader first:

What is the motivation to pursue microstructure technology?

To answer this question it is necessary to understand the development of microelectronics over the last 40 years. What has happened during this time? Before microelectronics, there existed conventional electronics and electronic components like resistors, capacitors and electron tubes. These components were assembled to form an electronic circuit, tested and adjusted by trimming the parameters of the components, until the circuit met the required specifications. Therefore each circuit was in its own way unique. The packing density and likewise the function density of an electronic circuit was limited by the size of the individual elements.

By introducing microelectronics a dramatic change took place in electronics. Components were no longer produced and assembled mechanically but were optically transferred and multiplied using photolithography onto the workpiece *i. e.* the silicon wafer. It is noteworthy, that by optical imaging only two-dimensional structures could be transferred. At first this appeared to be a considerable disadvantage for the technology as a common concept was to design and manufacture in three dimensions. This disadvantage of optical imaging is, however, outweighed by its technological advantages because (*i*) it is possible to transfer structures whose dimensions are only limited by the wavelength of light, (*ii*) the imaging of the patterns is free of deterioration and thus highly reproducible and (*iii*) the optical transmission is parallel enabling an extremely high data flow (in state-of-the-art-lithography $4 \cdot 10^8$ pixels are transferred with one exposure).

Over the course of the last decades the development of microelectronics led to dimensions of the components being reduced by many orders of magnitude. These days critical dimensions far into the sub-micrometer region (0.3 µm) can be achieved. As the manufacturing process occurs "batchwise" *i. e.* with a group of wafers onto each of which millions of transistors are placed, many integrated circuits can be manufactured in parallel. It is also possible to reduce the cost of production by many orders of magnitude because of the increase in packing density. An important sign of quality of a circuit, which is necessary for a computer, is the switching speed. This can be greatly decreased by shortening the length of internal conductance paths and thereby improving the overall quality of an integrated circuit.

Microelectronics rules our everyday lives. Microelectronics has infiltrated into all technical areas and has set the criteria for the development of the information

age. These influences are difficult to quantify, but taking the improvement of quality over a timespan of three decades, multiplied by the decrease in fabrication costs one receives a value of 10 000 000. For comparison, take any other technology like manufacture of steel or construction of vehicles, and the huge differences against such developments become obvious.

With microelectronics being successful to such a degree, the question arose whether similar technological advancements in other non-electronic areas are possible. Can these development concepts, processes, and materials not be transferred to mechanical, optical, fluidic or chemical and biological areas?
The answer to this question finally lead to microsystems technology. It can be stated:

Microsystems technology is the inevitable, logical development of microelectronics into non-electronic areas.

Therefore microsystems technology profits from the enormous technological and theoretical base of knowledge of microelectronics, which has been developed over several decades. Many technologies that we take for granted today, were developed from the economically booming microelectronics industry involving high financial and personal expenditure. So for example, photolithography remains an essential ingredient. This notion will be emphasized throughout this book. Thin film technology, surface analysis and simulation are also areas, which have gained critical momentum from microelectronics.

In order to be able to build on these experiences of a new technology it is first necessary to explore the underlying "philosophy" of microelectronics. In other words to define the recipe of success of microelectronics in order to be able to modify it so that its significance to other technologies can be ascertained.

From numerous procedures and thought processes three topics can be highlighted, which will now be dealt with in turn.

The design of an integrated circuit is done almost exclusively on the computer. The design of a circuit in the traditional trial and error approach, to find an optimum solution, is not feasible in microelectronics for economical reasons. The development steps must already be performed on the computer using expensive design- and simulation-methods. For an established process, a circuit (at least a digital circuit) already fills the requirements at the first production run. Only in a few cases a second production run is required to optimize the product. The simulation programs have been developed at great expense using many thousands of man years. It is both noteworthy and new, that knowledge of theoretical physics such as quantum mechanics, leads directly into the product configuration. Nowhere else does scientific basic research and product configuration come into such close contact as within microelectronics. A concept which illustrates this state is the phrase "band gap engineering" in which the knowledge of theoretical solid state physics and production know-how overlap with each other.

The design, simulation and optimization of the product by means of the computer can be considered as objective one.

The second objective is the transfer of the computer generated structure onto the work piece. The transference of geometrical data is done by optical means. The advantage of this method of transference is that it is free of "wear and tear" and therefore there is no attrition. On imaging, the structure can be reduced to such an extent which is limited only by the wavelength of the light used and by the inaccuracies of the optical system.

Optical transference or "photolithography" has the largest technological influence on microelectronics, aside from the production of the basic material, the silicon single crystal. The word "photolithography" is taken from an old printing technology where a flat ground stone (λιθοσ = stone, γραφειν = to write) is appropriately etched, so that is takes on printing ink only at particular parts but prevents it from sticking to others.

By reducing the structures to the sub-micrometer region, the packing density per square unit of the components brought onto the work piece is higher by many orders of magnitude than conventional technologies of transmission would allow. Therefore, despite increasing processing costs, the costs for the single element can be greatly reduced. By reducing the linear dimensions by a factor of two it is possible to produce four times as many structures on the substrate using a parallel process. Even if the expense for photolithography increases by a factor of three, one has still achieved an overall profit for the production. Besides the cost advantage, miniaturization brings with it a considerable quality advantage. Integrated circuits are generally measured by their function density and their speed of switching. By miniaturization, the electrical connections within the circuit are correspondingly shortened, which has a direct effect on the speed of signal processing. A simple calculation already shows that the vacuum speed of light amounts to 0,3 mm per picosecond. The pathways per picosecond of a signal on a circuit, which is affected by capacitances and inductances, are accordingly smaller and fall within the geometrical dimensions of the circuit.

Optical imaging means a parallel transference of information. With a high quality objective, as is used in lithography, structures with minimum dimensions of 0.5 μm can be transferred onto a panel of 1 cm^2. A parallel flow of $4 \cdot 10^8$ pixels is thus achieved. At the same time the process of transference is independent of the pattern transferred. A complex structure requires no higher expenditure than a simple one, as long as the minimum dimensions are not surpassed. If by skilful design, structures are interlaced, it is possible to achieve high packing densities without the need for additional technological advances.

At the moment one restriction is the two dimensionality resulting from optical transmission. As the image shows a limited focal depth, all transferred patterns are two dimensional. A microelectronic circuit tends to expand laterally by a few millimeters or even centimeters *i. e.* in the x- and y- direction. In the z-direction *i. e.* the depth, it rarely stretches to above 10 μm. Therefore it is claimed that the whole of microelectronics is quasi two dimensional. Of course it is possible with other processes to produce a circuit which is made up of more than one level stacked on top of each other. This does not affect the fact that the structures are transferred two dimensionally. It is actually surprising that one neglects one third of the possibilities of geometrical design, in comparison to conventional

electronics. However the optical transmission of the structure holds many more advantages, which greatly outweigh the disadvantages. The importance of microelectronics is proof enough. The second objective of microelectronics is, without a doubt, the application of photolithography.

Due to the higher packing density of the building elements on the wafer, millions of structure elements experience exactly the same process on subsequent processing. In turn the process scattering is very small. Processes which, in the course of development, became more expensive, are compensated for by the minimum costs of producing thousands or millions of building elements on one single wafer. Due to lower process scattering and higher yield the processes in turn can be described more precisely and simulated. Therefore the assertions, which can be made with the software-tools to design the circuit, are more accurate and more realistic which results in a positive feedback in the design routine *i. e.* a closed loop. Batch fabrication, is considered to be the third objective in microelectronics.

What has now changed in the development philosophy of electronics parallel to the manufacturing process towards microelectronics? Multiple individual building elements have been replaced by few, standardized sets of components within close tolerances. However by focusing the research and development onto the comparably less standard types, the performance could be increased by a large order of magnitude in contrast to conventional basic circuits.

The basic building blocks, taken from libraries, can be combined and connected to optimal complex circuits using appropriate computer aided design tools. By improving the design-tools, just as by the constant improvement of quality of the building elements, nowadays functions can be obtained, which were technically not feasible a few years ago. An example would be the development of the personal computer, which has already surpassed the performance of the mainframe computers of the 80's. Therefore, the use of standard components and the application of strictly standardized manufacturing processes are the fourth objective.

The same basic concepts of microelectronics also apply to microstructure technology. For the latter, it is of great advantage to take advantage of the enormous technological know-how made available by microelectronics. Even if some of the processes have to be newly developed, essentially it is possible to build on the theoretical and technological basics, which have evolved with microelectronics.

In conclusion, microstructure technology demands that:

Microstructure technology must follow in general the path of microelectronics in order to be as successful.

Within microstructure technology the development philosophy must include:

- Enabling the supply of sufficiently powerful and efficient software development tools for microcomponents; development, simulation and optimization of structures on the computer, the avoidance of unnecessary process runs.

- Transference of the structure, designed on the computer, onto the substrate by means of photolithography, using the advantages of a higher packing density and a decrease in the size of the structure.
- Batch manufacturing with narrow manufacturing tolerances by precise control and monitoring of the process.
- Development of only a few, but carefully designed basic structures which, by having a higher packing density and miniaturization, can be cost effectively multiplied onto the same substrate and can be integrated by a suitable connection technology to an "intelligent" system. This therefore leads (just as it did in electronics) to a complete change of ideas in the sensor and actuator technology and in precision engineering and finally mechanical engineering.

Although the processes of microstructure technology were closely related to those of microelectronics, the means to develop a microstructure into the third dimension had to be developed, since it is not supplied by microelectronics. Over the course of years this has lead to many variants, and each would fill a whole chapter of a book. Two of the most important are briefly described here and will be discussed in more detail in Chapter 6 and 7 in this book.

Silicon micromechanics rely heavily in every aspect on microelectronics. Not only has it taken over a similar manufacturing process, but also the silicon single crystal is again the basic material for the microstructure. At the beginning of the 80's and as the leading authority of this process K. E. Petersen, at that time a co-worker of IBM, had already written a fundamental publication [Pete82]. The third dimension was developed from an anisotropic etching process, with which the single crystal can be subtractively levelled to a desired shape. Special etching solutions strip the material anisotropically from a single crystal, corresponding to the crystal morphology.

Using silicon oxide or silicon nitride masks, parts of the silicon surface are exposed to the etching solution, which etches different crystal planes at different rates. Artificial layers can be build into the crystal, which serve as additional etch stop layers. Using suitable etching masks, etch stop layers and the application of isotropic and anisotropic etching solutions, three dimensional structures can be produced from silicon wafers, which in turn form the basic elements for sensors or any other components (Fig. 1.1-1). The specific advantage of silicon micromechanics lies in the ability to install on the same substrate both the microstructure body (*e. g.* sensor element) as well as the suitable electronic evaluation circuits.

A second important process is the so-called **LIGA technology** which was developed at the beginning of the 80's at the Nuclear Research Center, Karlsruhe (today Research Center, Karlsruhe) under the guidance of Erwin Becker, then head of the Institute for Nuclear Process Technology (today the Institute for Microstructure Technology), and Wolfgang Ehrfeld, as leading scientist. With this technology it was possible to manufacture components for isotope separation of uranium-hexafluoride, UF_6 [Beck86].

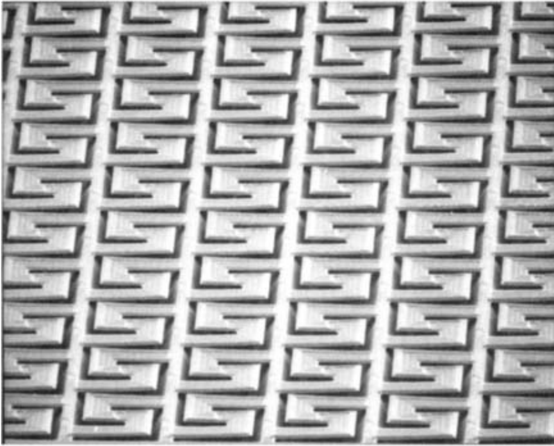

Fig. 1.1-1 Array of front micromachined infrared detector pixels fabricated using commercial CMOS technology followed by compatible anisotropic silicon etching [Schn98] (Courtesy of the Physical Electronics Laboratory, ETH Zurich).

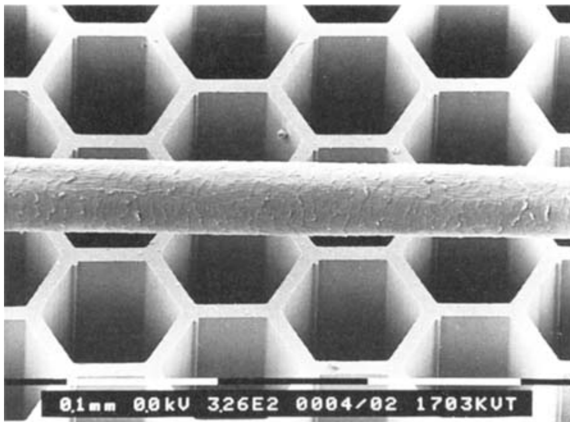

Fig. 1.1-2 Typical microstructure fabricated in LIGA technology. For comparison a human hair is put across the structure. The inner width amounts to 80 μm, and the wall thickness is 8 μm.

Figure 1.1-2 shows an array of identical geometric shapes, which are used as mechanical filter. This microstructure was produced using the LIGA process, a structure building process which employs X-ray lithography, electroplating and molding. This process is described in Chapter 7. A structure design which is generated on the computer is transferred by means of an electron beam writer onto a mask. The structure of this mask is imaged onto the workpiece using par-

allel X-ray light (synchrotron radiation) as a shadow projection onto a radiation sensitive polymer layer. Because of the low absorption of the X-ray radiation in this polymer layer, the radiation penetrates without noticeable scattering deep into the layer. A layer thickness of more than one hundred micrometers can be irradiated without distortion of the structure. In microelectronics, light in the visible or near ultra violet region can be used to irradiate the photosensitive layer, since these so-called photoresists are only one micrometer or less thick. The parallel beam of the X-ray light and the extreme layer thickness permits the manufacture of structures with an aspect ratio (*i. e.* the ratio of structure height to the smallest possible lateral structure) of over 100. In microelectronics aspect ratios of only about 1 are normal.

In this first step of the LIGA process a structured microbody is obtained with the lateral structure of the mask and a structure height, which is determined by the layer thickness of the resist. In further processing steps the irradiated and later removed polymer is replaced by electroplated metal. After the non-irradiated polymer is subsequently also removed, the negative form of the structure now remains as metal. This metal structure serves as a mold for further copying of the microstructure using processes such as injection molding or hot embossing. Although the manufacture of the original structure is relatively cost intensive, the process can be used for mass production of a variety of materials and therefore microstructure bodies can be manufactured highly economically.

In addition to these two fundamental processes there are numerous variants which use some processes of the above described production technologies and which, for special applications, have their particular advantages. These alternative processes are fully described in a special chapter. At this point an example of **mechanical microproduction** (Fig. 1.1-3) should be mentioned [Bier88]. A microprofile is milled in a flat metal surface with an appropriately formed diamond. By

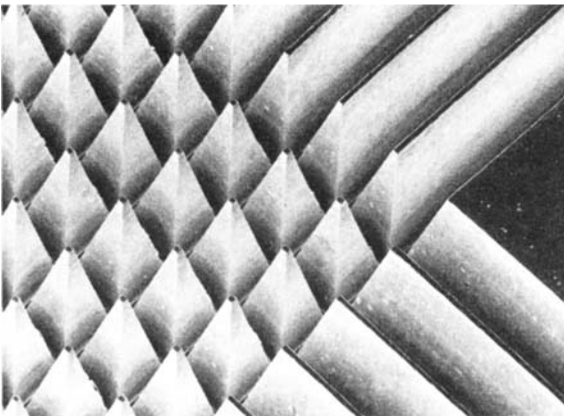

Fig. 1.1-3 Typical microstructure manufactured in mechanical microproduction. The structure is fabricated by milling a brass substrate with a diamond tool. The pitch size is about 100 μm (courtesy of Research Center Karlsruhe).

manufacturing regular structures and by suitable stacking of microformed foils on top of each other, relative inexpensive three-dimensional microstructure bodies can be produced [Bier90]. The production method is different compared with both previously mentioned processes. However, partial steps from the other processes can be used such as, for example, the electroplating of the structure to produce a molding tool for the mass production of microbodies by injection molding or hot embossing.

1.2 From Microstructure Technology to Microsystems Technology

The examples of microstructure technology given above would only be of moderate technological importance would it not have the potential to integrate components to a microsystem. Only then can microsystems technology develop to its full potential. This is again exemplified by microelectronics with the development of transistors which filled the basic requirements for economic success and which acted as a trigger on the development of microprocessors. Also within microsystems technology, the production of microcomponents is the basis, from which system technology derives. If however, technology were to idle at this stage, then the microsystems technology would be reduced to only replacing conventional components with microcomponents. If this were the case a technological revolution would not be under discussion. Only the integration of many sensors to an array, the connection with actuators and the control of all components by efficient signal processing on site makes an "intelligent" system out of "dumb" components.

Microbodies which are manufactured using microstructure technology must be connected to each other on a common substrate. At first only the pure mechanical mounting of a structure onto a suitable support should be considered. This is not trivial if one thinks about the optical communication technology. At the moment a suitable method, which is stable over a long period and is inexpensive, is still being sought to precisely orientate a mono-mode glass fibre to an optoelectronics component within a fraction of a micrometer. Another problem illustrates the connection of several components with different thermal expansion coefficients.

A particular problem exists in sensor technology, where on the one hand the delicate microstructure must be protected from damage and corrosion and on the other hand, be exposed as widely as possible to the environment to obtain a true and undistorted value of the physical and chemical properties of the environment. The connection and packaging technology plays a key role, which can be seen later in many examples of the microsystems technology.

A microsystem consists not only of a purely mechanical construction but also of a large amount of interfaces between the single components as well as between the macroscopic external environment and the microsystem and *vice versa*. These in-

terfaces are of different types. The electrical interface, which predominates in microelectronics, is only one of many. For these interfacial processes microelectronics offers only techniques such as soldering, wire-bonding, the TAB (Tape Automated Bonding) technology or the flip chip process. Because the microsystem includes more than electronics, such interfaces as optical, mechanical, fluidic or acoustic interfaces must also be considered. The technologies for these are for a large part not yet developed. They differ greatly from electrical interfaces, so that it is necessary to find a new name which replaces the concept "interface" from microelectronics with its electrical joining processes. A suggestion would be to introduce the concept "coupling site".

An important method to protect sensitive microstructures mechanically is covering them with a glass plate. A suitable process for this is anodic bonding. The surfaces of an assembly (preferably silicon and glass) are brought into contact with one another. By heating to about 400 °C and with the aid of an electrical field, ions in the dielectric are irreversibly displaced. The resulting electrostatic energy is large enough to bind both surfaces continually together leading finally to the formation of a chemical bond.

Using the described processes, the technological requirements are met to integrate micromechanics, microoptics, microfluidics *etc.*, and microelectronics within monolithic or hybrid solutions to complex systems. This would open a channel for new fundamental concepts of sensor technology, measuring and control technology, communication technology, environment and medical technology and other applications, which perhaps have not yet been thought of.

The previous discussion dealt with the technological requirements which must be fulfilled for the production of microsystems. The following sections will discuss the role which information and software development plays in microsystems technology.

The most important property of a microsystem is the possibility of having a whole array of sensors with high packaging density at low manufacturing cost, rather than one individual sensor. During a conventional construction, the analogue value of the one sensor is amplified and "delivered" at the output of the amplifier for further treatment. On the other hand, the intelligent system has the ability to pick up the signal using many sensors in parallel and process it on site. Every sensor displays cross sensitivity also for parameters, which are not supposed to be measured. A pressure sensor generally has a temperature dependence and is in addition dependent on the medium to be measured. If we consider a sensor array, then the true value without distortion by other parameters can be calculated, if the parameter function of each individual sensor element is known. The problem is then described as finding the solution of a system of n equations with m unknowns, with n as the number of independent sensor elements and m the number of parameters to be measured. In other words, for every measurement with a sensor array, several parameters can be calculated in parallel. This can be a demanding task for an on-board microprocessor with mostly very limited capability. In many cases however, the quality of a measurement already increases significantly, if calculation of one or two of the most influential parameters is achieved.

With the same technique it is possible to improve the selectivity of a sensor system. If for example a gas sensor had the task of detecting a complex gaseous composition in low concentrations, a single sensor *e. g.* CHEMFET (chemical field effect transistor) could not achieve this task. A whole array of CHEMFET's each with a different parameter function, could solve such a task by using suitable algorithms for sample recognition. The special feature of this sensor system would be that with unchanged hardware configuration many different gas compositions could reliably be detected with a high degree of selectivity.

The combination of sensor elements with analogue-digital converters, a microprocessor and an interface to the exterior are demanding requirements for a microsystem. Other components like multiplexers, ROM and RAM, complement the systems capabilities (Fig. 1.2-1).

By storing a parameter mapping for a sensor array, the cost intensive laser trimming could be eliminated in the first operation and on replacement of a sensor array. Ageing processes could be identified by the recorded thermal history of sensors and can be compensated for. By averaging of several sensors the quality of measurement could be improved. Sensors with different ranges of sensibility could be connected and thus the working range of the sensor system could be increased considerably. Using microactuators, which again effect the sensor, feedback and motion compensated physical measurement systems can be released.

Even though the list of possibilities is endless we should limit ourselves in this introduction. However at this point the ability to adapt such an intelligent system

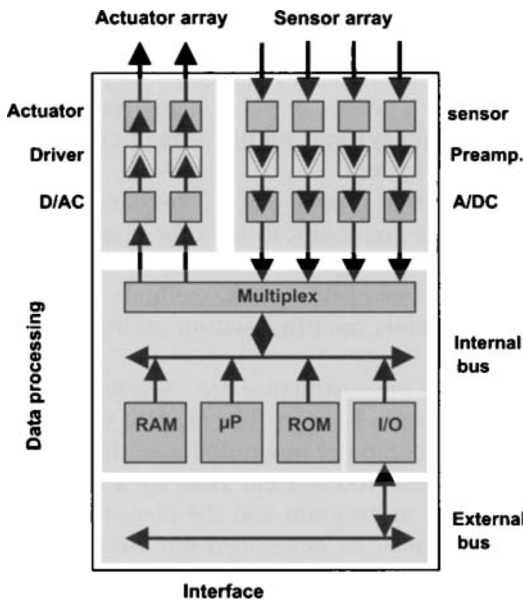

Fig. 1.2-1 Scheme of a complete microsystem. The device consists of arrays of sensors and actuators, as well as on-board signal processing and interfaces to the outside (macroscopic) world.

to a certain task will be highlighted once more. Microsystems could be used to explore unknown, dangerous, or usually inaccessible areas. These properties would be of an enormous advantage for applications such as environmental monitoring, exploration tasks, space missions and medical implants.

In many cases a microsystem must be able to communicate with other systems. The microsystem must be able to transmit and receive data. These data must be transferred free of errors in sometimes highly disturbed surroundings. The compatibility with other systems or a central computer, with which the system communicates, is also of importance. Using simulation methods the system's performance is to be checked whether it runs in a controlled mode or changes into a chaotic state.

What are the tasks in microsystems technology for information technology? An important requirement for the concept of a microsystem is the system specification and the simulation of its properties on the computer. From this, one begins to establish the system specification and as a consequence describes the components and in particular, the desired properties of the sensor. If these properties are not realizable the system concepts must be varied until the optimum one has been discovered.

As well as the system specification, the appropriate signal processing algorithms are of great importance. Here concepts must be developed in order to be able to solve complex tasks of measurement and control with the greatest computing efficiency for microprocessors in real time.

Another field is the enabling of test routines for the self-test of microsystems. In some applications the requirements in reliability are crucial to such a degree, that the system must be tested at regular intervals or even continually. In case of malfunction the system will self correct or switch itself off in a defined way. In this way the bus system connecting a set of other systems or subsystems remains in operation and in emergencies other participating systems on this same bus system could take over the tasks of the switched off system.

It has already been mentioned that an important property of microsystems must be the ability to communicate. However, these communications take place partly in a highly disturbed surrounding *e. g.* on a welding robot or next to the spark plugs in an automobile. Therefore for transfer free of distortion, methods of channel coding must be developed or present methods modified within microsystems technology.

Production processes and performance of a microstructure are closely related. Here too the close parallels to microelectronics can be seen. The modern semiconductor plant of the late 90's operates on strict computer integrated manufacturing, in which the production line is kept in the ideal 100%-yield state by a constant input-output comparison between the simulation program and the measured production parameters. For this, expert systems must be developed not only for the product development but also for the process control. The microsystems technology must go in the direction of these expensive methods, if it is to fulfill the technological demands.

The opportunities of microsystems technology are so diverse, that only a small segment at this point can be mentioned. In which direction microsystems techno-

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