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Microsystems - from Technologies to Products

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ABSTRACT

In this paper, we outline the process leading from technologies to successful products in the MEMS (Microelectromechanical Systems) and MST (Microsystems Technology) field. The development of new products involves a lot of factors, such as mature technologies, interdisciplinary team, identifying the right business potential and long term oriented investors. The paper summarizes a survey of different technologies and point out that packaging, test and calibration are still major shortcomings for the concerned industries.

Keywords: Product development, Microsystems, Micro technology, Economics, Interdisciplinary team, Packaging, LTCC

1. INTRODUCTION

Micro-technology and Microsystems have played an important role in the development of a large number of products as well as in the basic technology necessary for their manufacturing. Typically, one new technique will require the integration of a number of distinct disciplines, such as physics, chemistry, engineering, and materials science. The requirement for better performing electronic devices is the driving force for innovation, generated largely by the telecommunications and computing industries; and these markets are expected to increase faster in the coming years than the average economies. For clients, this market demand has resulted in improved new standards for quality / price ratio and is providing an idea of what they might expect from microsystems technology based developments in the near future.

2. A SURVEY OF A NUMBER OF RELATED TECHNOLOGIES:

The success of a company working in the micro-technology area depends on a large number of factors. To ensure durable prosperity, it is necessary to possess a certain know-how, limited to the company, combined with a well-adapted manufacturing technology. In this context, it is convenient to divide the discussion into the three stages of technology:

- basic technology
- key technology
- advanced technology

The enterprise must have a clear idea of the technologies at its disposition, and in particular of those that will be employed to guarantee its success.

It must be able to maintain a visionary spirit with the goal of preparing a technological platform that will be adequate for its commercial objectives. The establishment of such a platform is a continuous and long-term process, distinct from product development, subject to time-to-market constraints.

The **basic technologies** are well-established and broadly applicable. Their use does not provide any particular competitive edge.

Key technologies refer to those techniques that are not yet highly distributed. The specific competencies of a company should include certain key technologies that offer a competitive advantage, either in terms of cost or processing.

Advanced technologies are those that allow the company to plan the development of new products that exist at present only in an embryonic form. The use of advanced technology offers the possibility of significant advantages, but at the same time, it often requires that the company increase its budget for training and therefore, the risk for failure is significant.

Below we give a brief overview of some of the important areas of research and technology that falls into the general category of MST and MEMS.

2.1. Micro-mechanics

The elements of mechanical construction, when it takes place on the micron scale, represent the fundamental building blocks for the conception of micro-technological products. Starting with basic micro-components, it is possible to create complex microsystems.

With regard to these elements of construction, the frontier of classical mechanics is now described by using a space scale of about 10 microns.

Mechanical integration has made enormous progress over the past years; as a consequence, the number of elements involved in the construction has been drastically reduced. There are a growing number of new processes that are finding their place alongside the classical techniques. Lithography, which has been used for many years with success in the area of micro-electronics, can be applied to the manufacture of micro-structures. It is possible to obtain three-dimensional components by applying an anisotropic attack of silicon, by laser treatment, or by processes such as LIGA (lithography, galvanic shaping, and milling.) The micro-forming can be applied to materials other than silicon; for example, it works with metals, with ceramics, and with synthetic materials. Finally, great progress has been made these past few years with injection technology of plastic materials, with which specialists now are able to make increasingly small structures at the micrometer scale.

2.2. Micro-electronics

The market for semiconductors, which had a value of about 100 billion US$ yearly already in 1994, has been steadily growing over the past few years at 14% per year, and there is no real sign of slowing down. During the past decade, memory circuits has grown from 29% to 36% of the total market; over the same period, the share of microprocessors has grown from 15 % to 25%.

Gordon Moore, the co-founder of INTEL, predicted in 1965 that the power of microprocessors would double every 18 months for the foreseeable future. The facts have proven him right.

As there is no known limit with respect to the current technology, to the current production methods, or to the economics of the micro-technology involved, this development is likely to continue without stop for several years. At INTEL, it is anticipated that this relationship will remain valid for at least another 10 years. The semiconductor components will continue to work for the community active in microsystems in the future, not only as basic components for micro-technological products, but also as an essential and growing part of the know-how as it is applied to systems and applications.

2.3. Telematics

Professional life without the computer is unthinkable today. Mainly, the multimedia technology and mobile communications are two of the “mega-trends” at present and are expected to remain so for several more years.

This situation has stimulated the development of new basic elements in micro-technology, such as batteries, low-power displays integrated circuits, and novel software tools for embedded applications. It is thus clear that the handling of video and audio information is one of the prime motivations and stimulus for the micro-electronic industry. The process of real-time compression and decompression of data, need for its transmission over networks using a limited bandwidth, will require a greatly increased calculation power, and thus, more powerful microprocessors. Many telecommunications applications will migrate to a wireless, mobile technology. Finally, a growing attention will be paid to the consumption of electrical power. Micro-technological products will greatly benefit from these developments.

2.4. Materials Science

Micro-technology benefits from innovation in materials science. In the future, special materials, designed for specific fabrication processes, will play a decisive role. Materials such as ceramics, composites, or special types of polymers will play an ever increasing role. The demand on materials is becoming even more complex because their properties must satisfy requirements on every level. This means that technical, functional, ecological, and economic consideration must be taken into account for the entire life cycle of the products. This analysis must include a consideration of the overall energetic balance, from the beginning of the material fabrication, to the disposal of the component, and including the actual manufacturing of the product and its useful lifetime. The acquisition of knowledge concerning less-polluting materials and products and the mastering of the processes that might lead to an efficient use of energy are identified as key know-how for any company that plans an activity in the area of microsystems.

2.5.Sensors and Actuators

In almost every micro-technological product, there are sensors that transform data from the real world into electrical signals. These sensors can be classified according to the quantity that they detect (thermal, optical, mechanical, magnetic, electrical, chemical, biological, etc.) or they may be classified according to some other technological aspect, such as sensitivity, precision, range of measure, resolution, selectivity, cost, size, composition, or use of specific “transduction” phenomena. New functional materials, such as conducting synthetic materials or ceramics, play an important role in the development of sensors. There is a similar situation with respect to processing of signals where it is possible to compensate for the shortcomings of currently available sensors with the application of digital computing. In other words, new sensing elements can be developed based on transformation phenomena (which would not be usable without digital compensation or linearization). One important trend in sensing technology is miniaturization and batch production. Technical knowledge concerning the treatment of silicon and the application of functional layers of novel materials will provide the basis for the development of new products. Good examples of these include acceleration sensors for the automotive industries like airbag inhibitors, pressure sensors for various application fields, specific gas sensors for safety and security, as well as surface-sensitive sensors for the determination of position, speed and magnetic fields.

2.6. Biotechnology

Alongside micro-electronics and telematics, biotechnology is widely considered as one of the key technological hopes of the 21st century. The combination of cells and proteins with microsystems opens an enormous potential for the development of new products.

Biosensors allow the extremely sensitive detection of certain chemicals in various environments. The union of biotechnology with the techniques of microsystems illustrates the way in which the natural sciences and engineering sciences can be brought together to develop new techniques involving organisms, cells, cell fragments and related molecules. It follows that biotechnology will be involved in the introduction of biological processes into the micro-technological framework of industrial production. In the future, micro-technology will continue to benefit from the advances in this area of research and will, in addition, make its own established tools available to the advantage of scientists and engineers working in the area of biotechnology.

3. WHAT ARE THE CHALLENGES IN SUCCESSFUL PRODUCT DEVELOPMENT?

Most of these technologies demand a lot of basic science effort, long term investments and an expensive infrastructure for research and development as well as manufacturing. Even after 15 years of huge investment made by the academic community, there are not yet many successful products on the market. The most successful application one will find is in the automotive industry and for the computer peripheral industry like pointing devices and hard disk drive components [1].

MEMS will play an increasingly important role in various technologies. A convenient model of MEMS is that of a control system (figure 1) Micro sensors detect changes in the parameters to be controlled; electronic control logic then operates micro actuators, based on information from the sensors, to bring the parameters to be controlled within the desired limits. Future MEMS will integrate with electronic, optical and fluidic components onto a variety of substrates to create powerful Microsystems.

An example of such a system would be to refresh the medium in a small cell culture dish. Sensors could detect changes in pH, pO_2, or pCO_2, and a micro pump could deliver new culture medium from a reservoir as required. Another example would be the control of glucose concentration in the blood or the amount of air in a gas burner, based on the composition of the natural gas. In the simplest case, MEMS are sensors with some sort of self-control.

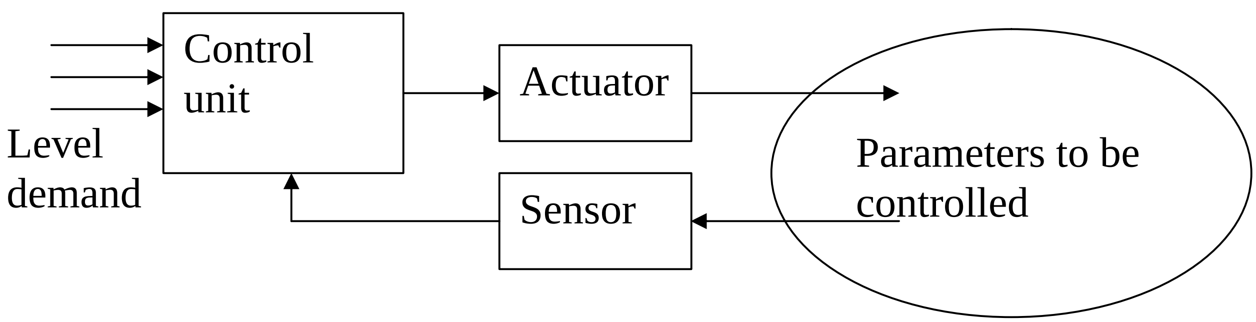

Figure 1 shows a convenient model of MEMS as that of a control system

Production of Microsystems becomes mainly a packaging problem [2,3]. Assembling complex devices from many components can add tens to hundreds times the cost of the actual active parts of the device. If the packaging and assembly constrains are not considered correctly in the conception phase, it gets even worse and there will be no economical break-through. To integrate most of the components into silicon devices has turned out to be only partially successful. Assembling Microsystems with new tools (e.g. self-organization driven by surface forces, capillary forces of external fields, etc.) will be an important and challenging aspect.

3.1. The situation in Switzerland

Having the right technology at the right time is becoming an important part of the success of modern economies. In mechanics (e.g. watches, automotive components, medical implants, scales etc.) and chemistry including pharmacy, Switzerland has succeeded in being in a top position (Novartis, Roche). Opportunities that we missed are in the fields of informatics (even though major computer languages here developed in Switzerland 40 years ago), the semiconductor technology (even though Swiss Federal Institute of Technology in Zurich was excellent in semiconductor science 50 years ago), and the display industry (Switzerland started the technology 30 years ago). Switzerland is partly successful in the field of sensors, e.g., mouse and other pointing devices (Logitech), pressure sensors (Keller, Kistler, Huba), optical instruments (Leica), hearing aids (Phonak) etc.

5. SOLUTIONS TO THE PACKAGING PROBLEM

Research and Development in MST and MEMS is much affected by the packaging problem; where it is not only the cost aspect that dominates, but the functionality, that can make the crucial difference. In applied scientific research it can be the integration of a catalytic reaction into a micro reactor, the integrated heat, temperature, viscosity, pressure or flow measurement, etc. It can be the control of flow with micro pumps and micro valves. Engineers have to attack the microsystem packaging challenge head on by integrating functional elements into the packaging. In the ideal case, the intelligent packaging performs all the functions.

LTCC (**l**ow **t**emperature **c**o-fired **c**eramics) and other ceramic materials like Alumina are excellent candidates for packaging support [4]. LTCC can be defined as a multilayer circuit fabricated by laminating single green sheets (term for unfired ceramic tapes) with printed conductor lines, etc,. on the surface on top of each other and firing them all together in one step. It is also possible to integrate passive elements like resistors, capacitors and inductors into the substrate. Capacitors and inductors are built only with the help of special forms of the conductor lines (plates or spoils). There are and there will be many more materials like ferrite pastes and piezoelectric pastes, which offer a great range of possibilities to be applied by screen printing. In addition, one can integrate active elements on the surface of the multilayer structure. It is obvious that standard silicon chips as well as micromachined chips can be attached to this ceramic packaging and wire bonded for electrical connections.

LTCC is well suited for the harsh environment that automotive applications present, and therefore, will become a leading choice. The LTCC technology is also an excellent choice for microwave applications, e.g., Bluetooth RF transceiver can be built with reduced size, overall system cost and total parts count. Lower weight and smaller size requirements are necessitating increased density in electronics packaging. The primary advantage of LTCC technology is its capability to reduce weight, size and cost, while improving reliability. Integrating resistors and capacitors into the LTCC substrate eliminates many solder joints and wire bonds. Because of the excellent insulation provided by the thin layers of ceramic material, circuits can be alternately stacked, allowing digital, analogue and microwave assemblies to be embedded in the same LTCC structure. This eliminates the need for separate housings and provides significant space and weight reduction. An example is shown in figure 2.

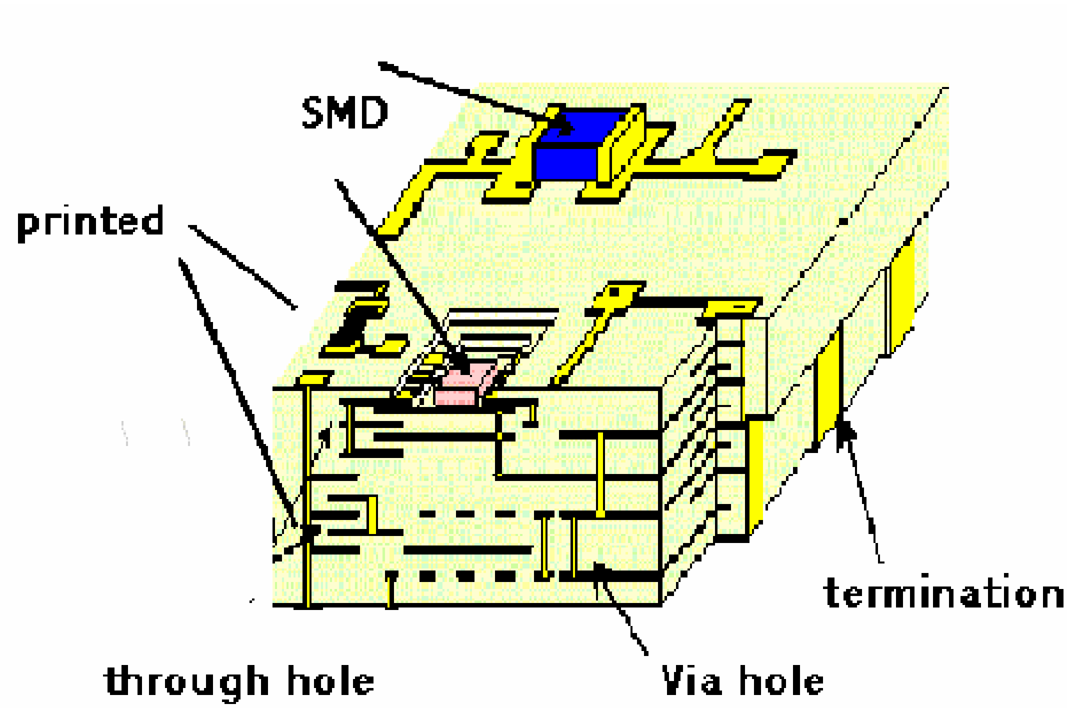

Figure 2, Example of LC filter LTCC structure with high level of integration (source Siemens)

6. THE ADDED VALUE CHAIN

Basic technology development for Microsystems is not directly moneyed; product, solution and services for the end user are the cash generators. An end user of a car or a computer does not care about technology. That is why engineers active in the field of MEMS and MST product development need not only skills in science and technology but also a good knowledge of economics.

The realization of microsystem products needs enormous financial resources. Companies that have this potential, use well established mature technologies for solving a specific problem. This path allows better success of their R&D investments.

The concept of value chain can be illustrated by the following schematic illustration.

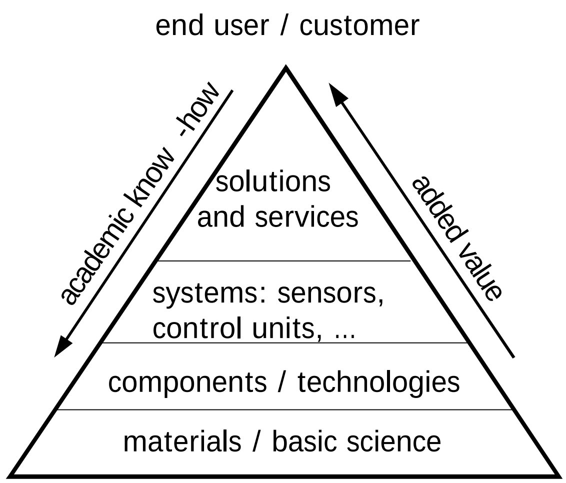

Figure 3 shows the added value pyramid. The end users like to deal with solutions and services, that are built on systems, sensors, control units. For successful system development one needs technologies. Component and technology development can only be done thanks to a deep understanding of basic and material science.

It is the task of academia to bring the MEMS/MST technologies to a well mastered state. The technology transfer to industries is even then very difficult. The applications are seldom understood by PhD students or even engineers working in research institutes. One often does not take into account the elementary return of investment calculations. For successful realizations, companies always need to follow a checklist with the following items:

- Market Analysis
- Market specifications
- Planed volume per year
- Lifetime of the product
- Transfer price / manufacturing costs
- Market introduction costs
- R&D costs
- Investments in production technologies.

One can easily understand that a lot of this basic homework is often not well done and the MEMS/MST development ends in a disaster.

A clever engineer knows this economic base and he is able to create added value for his employer. The training at academia has to also highlight market mechanisms that allow breakthroughs. One has to massively invest in applications where the market is big and existing technologies do not allow reasonable solutions. With this focus in mind, academia and industries together will be able to bring this fascinating discipline to the right path.

CONCLUSION

It seems that the investment climate for MST/MEMS activities has not changed much during the last 3 years. There are many opportunities that can be addressed for BioMEMS, optical MEMS and RF MEMS. The last one is for sure an excellent candidate for new start-up companies. These applications have potential opportunities for niche solution in the magatrend markets like wireless terminals. Bio- and optical MEMS, do not compete against well established technologies. Nevertheless, the situation must be carefully analyzed and the players have to respect the rules of the "old" economy.

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