MICROSYSTEMS AT AUSTRIA MIKRO SYSTEME

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Abstract: Based on the Microsystem development activities of Austria Mikro Systeme Int., the typical problems of Microsystem development and the most important solutions are presented for a microelectronic compatible manufacturing environment. With it, the paper describes CMOS-compatible products like magnetosensor ICs based on Hall elements, mechanical systems like acceleration sensors and specific pre and post processing process extensions with service possibilities for external organizations, which enable them to develop monolithically integrated Microsystems within a microelectronic manufacturing environment.

Mikrosistemi v podjetju AMS

Ključne besede: mikroelektronika, polprevodniki, MST tehnologije mikrosistemske, problemi razvoja, rešitve problemov, CMOS polprevodniki kovinskooksidni komplementarni, senzorji magnetni, IC vezja integrirana, HALL elementi, sistemi mehanski, senzorji pospeška, integracija monolitna, CMOS kompatibilno predprocesiranje, CMOS kompatibilno poprocesiranje, obdelava globinska, MM obdelava najfinejša

Izvleček: Na osnovi dosedanjih aktivnosti pri razvoju mikrosistemov v podjetju AMS, predstavljam tipične probleme in rešitve, ki smo jih uporabili pri vpeljavi tehnologije mikrosistemov v mikroelektroniki kompatibilno proizvodno okolje. V prispevku so predstavljeni izdelki kompatibilni s CMOS tehnologijo, kot so magnetosenzorsko integrirano vezje na osnovi Hallovih elementov ter nekateri mehanski mikrosistemi, kot je senzor pospeška. Opisani so tudi pred in po-procesni dodatki osnovni CMOS tehnologiji, vključno z nekaterimi zunanjimi uslugami, ki omogočajo izvedbo monolitnih integriranih mikrosistemov znotraj mikroelektroniki kompatibilnega proizvodnega okolja.

Introduction

Computers and communication technique created an information processing environment penetrating, more and more, all spheres of human activities. The performance of modern computers has grown over the last three decades with a speed unprecedented in the history of technique. Communication networks have extended not only the information transfer between individuals but have also created computer networks and clusters leading to an information processing power comparable with the performance of high developed living organisms. Assuming the same performance growth as in the past, the local processing power of parallel computers will reach the performance of the human brain within the next 10 years.The basis for this development is undoubtedly the microelectronics with its unbelievable capability to double the complexity of integrated circuits every 18 months. The DRAM-memory of the year 2010 is expected to have a capacity of 64 Gbit, which is nearly the amount necessary to store the information of the human genome.

Contrary to this, the complexity of technical sensing and actuating remains far behind the technical information processing capabilities. The human eye has more than 120 Mio rods and 7 Mio cones with up to 160 thousand receptors per mm^2. The human skin has 20 thousand tactile sensors per cm^2 plus nearly 1600 temperature, pressure and pain sensors on the same area - altogether nearly one billion sensors, all of them with complex transducing and signal processing capabilities. Even for technical vision, which represents the area of sensors with the highest technical integration level, the nature will remain an unreachable model for a long time yet. However, to our present understanding, an adequate and comparable integration level of sensors and actuators on the one side, and information processing on the other, is necessary for the development and implementation of really intelligent systems. Intelligence is not an information processing issue but the result of an evolution of systems, which are able to sense, to act and to process the information perceived from its environment and from the interaction with it. The first technological revolution has opened the way towards very large scale on-chip integrated information processing systems. The second Silicon revolution brings additional non-electrical functions like mechanical structures and multifunctional materials onto the same chip. Pressure and acceleration sensors, micropumps and valves, optical and RF blocks, chemical and thermal sensors, non-electrical interface elements and micro-actuators are monolithically integrated together with transistors and other electrical devices creating a new generation of integrated Microsystems. Chips emerge which are able to sense, to think, to act and to communicate. The first modest steps on the way towards really intelligent systems have been made.

However, presently the market success of Microsystems depends on the price/performance ratio of the new systems. Low production costs and mature manufacturing technologies are necessary preconditions for the commercial success. Therefore, going back to the well proven and cost efficient microelectronic technologies and production plants was one of the most important ways towards the broad market penetration of Microsystems. For the Microsystem technologies, microelectronics offers a unique basic material – the Si -, a variety of additional materials, powerful technologies for the construction of planar structures, mature test environments as well as a lot of packaging and assembly technologies.

Some of the microsystems like temperature sensors or special magnetosensors can be created by using these microelectronic technologies without significant extensions. Most of the microsystems however, require additional possibilities to build three-dimensional structures and often need new materials. An extension of the microelectronic technologies is inevitable.

2. Microsystem technologies

2.1. Principles of Microsystems

There are a lot of physical effects which can be used for the transformation of mechanical, magnetic, thermal, chemical, optical and electromagnetic impacts in electrical signals and vice versa. For instance, mechanical deformations can be transferred in capacitance or resistance changes or can be measured by using the piezoelectric or piezoresistive effects.

Magnetic fields can be measured using the Hall effect, the Gauss-effect, magnetoresistive changes, and the Wiegand-effect or inductance changes. Thermal values are captured by using the thermodependence of resistors, the thermoelectric (Seebeck) effect, polarization changes in crystals (pyroelectric effect), and temperature effects in semiconductors etc.Optical and infrared radiation can be transformed into electrical signals using internal and external photoeffects in semiconductors, changes of the photoresistance, or the photovoltaic effect. For chemical and biological values, a broad spectrum of mass or conductivity changes, as well as the gas-sensitive field effect, or the Volta effect can be used.

Part of these effects is reversible and suited for the generation of actions (forces, fields, deformations, motions and radiation).

However, all the well known manifestations in the macroworld and properties of these effects can not simply be transferred into the world of Microsystems. Microsystems are not only small macrosystems but are often dominated by effects negligible in a macrosystem environment. New and unknown phenomena appear which have to be understood.

In the world of Microsystems, the relation between gravitational and inertial forces on the one side, and adhesive and frictional forces on the other, changes dramatically. Volume and mass of moving microparts shrink with the third power of the dimension, while the surface-proportional friction and stiction decreases with the second power only. Surface effects increasingly exceed inertial effects. The missing inertia of flywheels for example makes it difficult to get a smooth rotation of micromotors and requires multiple stimulation of the rotating part within one turn.

Very often already for parts as small as tens of micrometers , forces caused by adhesion, capillary tension and friction begin to dominate and dictate the construction of the microsystem. A well known and feared effect in micromechanical systems is the Stiction –Effect, a combination of adhesive and frictional forces, which lead to an undesired sticking of moving parts at surfaces of the Microsystems. Due to the complicated dependency of the adhesive forces on the surface state and the remaining liquids, this effect is difficult to cope with. Parts may become useless within the manufacturing process especially during the removal of etchants, surface tension of which lets stick two parts. More dramatically, Microsystems like airbag sensors may become defect during exploitation losing their function after the functional part sticks to surfaces in its vicinity. Low-tension surface layers are able to reduce the adhesive forces by some orders of magnitude and can reduce the risk of failures after shock-like mechanical loads.

However, the high adhesive forces may have a positive impact, too. They can be used for handling fluids in new microvalves and pumps. Electrostatic forces also offer new possibilities.

Generally, a better understanding of surface energies, stiction, friction and lubricant free wear in microdimensions is necessary.

Surface interactions are often the key for chemical microsensors. Usually, chemical sensors are based on electrochemical, optoelectrical or surface acoustical transducer effects. The transfer response of such systems is changed by the corresponding chemical components. For the detection of individual components, a selective embedding of the corresponding molecules into the basic structure is required - a process mainly based on surface sensitive interactions.Other separation techniques are based on the different transit times for different chemical components passing microchannels. These differences are caused by the different surface chemical bindings.

Completely new structures are needed for microoptical systems. Traditional approaches for manufacturing of laser diodes, photorecievers, optical switches, filters, modulators, mirrors, diffractive gratings etc. are based on the usage of the corresponding best suited materials like compound III/V semiconductors or special crystals. However, due to technological reasons, the monolithic integration limits the spectrum of usable materials and methods of structurisation already. Consequently, new developments are orientated towards monolithic integrated lenses, diffractive gratings and other optical elements that are based on digital structures in the sub-wavelength area. Photonic lattices (periodic structures of posts or beams in the sub-wavelength area with directional or wavelength selectivity allowing the construction of filters, mirrors, resonators or prisms) or monolithic integrated lasers like VCELs (Vertical-cavity surface-emitting lasers) as well as other elements allow the on-chip integration of complete systems for optical communication and analysis and follow the same trend.

3.2. Monolithic Integration of Microsystems

The overwhelming part of Microsystems developments in the last 20 years have followed the classical approach of developing discrete sensor and actuator components and integrating them together with signal and information processing ICs on the package level in the final system.The on-chip monolithic integration of Microsystems is mainly cost driven. Monolithic integration leads to less packaging and interface costs. Additionally, volume, weight and power consumption can be reduced. The reliability increases mainly due to the reduction of the number of bond wires and mechanical connectors. On-chip integration of sensors and signal conditioning is often crucial for robustness against electromagnetic disturbances and for high sensitivity/low noise applications.

On the other hand, for small volumes of monolithic integrated Microsystems, the unit costs are often higher than for hybrid, package level integrated systems because the cost potential of the microelectronics usually only becomes effective for relatively high volumes. Computer aided Microsystems design and reuse of cells and macros will close this gap in the future.

The elements described in 3.1 and the effects on the monolithic integration of Microsystems require well defined, customized geometric structures, which usually cannot be directly realized by standard microelectronic technologies. For instance, a simple, one sided clamped beam with additional mass on the other side for acceleration measurement cannot be manufactured using the well established microelectronic technology flow of repeated cycles for planar layer deposition, photolithography exposition and material removal. Consequently, technology extensions of the basic microelectronic technologies are needed to fabricate monolithic integrated Microsystems.

The most important requirement for developing technologies for monolithic integration is the closeness to the well established microelectronic manufacturing technologies because any deviation from proven manufacturing steps and established materials may jeopardize the whole production or will require a great effort to verify a riskless compatibility with the basic technology.

3.3. CMOS Pre- and Postprocessing

The compatibility requirement with respect to Microsystems-specific process and material extensions of basic microelectronic processes represents the fundamental challenge for the monolithic integration of Microsystems. It includes the request for separate handling of special process steps, which can be realized most easily as Pre- or Postprocessing. These process steps should not in any way destroy, or even only degrade the devices built up within the basic process. This means, for instance, that only temperature treatments within the allowed temperature budget of the basic process are possible.

For instance, one of the most frequently used materials for mechanical structures is polysilicon. To eliminate the stress within thin polysilicon beams, membranes or fingers, a high-temperature annealing process around 1000 °C is necessary; otherwise, the structures will bend, curl and show mechanical properties which are difficult to predict. However, temperatures of 1000°C exceed the melting point of the aluminum connections and destroy the chip. Additionally, junctions will be driven deeper into Silicon and diffusion profiles will change. Consequently, it was necessary to develop low temperature annealing processes or to use metallic materials like tungsten with higher melting points.

Over the last few years, PolySiGe became more and more favorable because it can be manufactured nearly stress free at temperatures below 650°C. Additionally, the thermal conductivity is lower then with polysilicon and allows the creation of thermally isolated elements like Infrared sensors.At Austria Mikro Systeme Int. we solved the problem of polysilicon stress of beams and membranes by using a separate body of bulk Si carrying the polysilicon structures. This sensor die is than connected to the IC by a special soldering procedure. The high temperature annealing process allows to tune precisely the remaining stress and to set a well defined, reproducible bending of a beam.

A second problem is the material incompatibility: Foreign materials which are used as structural components of the Microsystems or as technological tools like etchants, gases etc. have to belong to the class of CMOS-compatible materials, otherwise, their integration has to be realized in strict separation from the basic CMOS process.

Considering these basic limitations, it was necessary to extend the traditional microelectronic technologies with respect to the creation of different transducer and actuator components on-chip.

The first high volume manufacturing technology for Microsystems was the wet chemical anisotropic etching of monocristallyne Silicon – the so-called Bulk Micromachining. It is based on the differences of the etch rates of alkaline etchants like KOH along the different crystal planes. Anisotropic active etch solutions have a two order of magnitude higher etch rate in the <110> and <100> direction than in the <111> direction. In (100) and (110) Silicon, they can create structures lateral borders of which consist of {111}planes. These planes establish a well-defined angle with the crystal surface: for (100) Si – 54,7°.

Photolithographically structured etch stop layers can be used to form cantilever beams, membranes or other fine structures.

This Bulk Micromachining process can also be used as a process subsequent to the CMOS-fabrication (CMOS compatibility). Front and backside etching is possible.

KOH slightly attacks Sioxid, is CMOS incompatible and therefore can only be used for backside etching, whereas the toxic EDP (Ethilendiamin based) which slightly attacks the Alu-metallisation as well as the TMAH (Tetramethylammonium) can also be used for front side etching.

CMP Grenoble (Circuits Multi Projects) and Austria Mikro Systeme Int. offer an integrated Microsystems process with Front Side Bulk Micromachining. This process is based on the 0,8 μm CMOS and BiCMOS processes of AMSInt and on a corresponding postprocess of CMP. It is also part of the EUROPRACTICE Service.

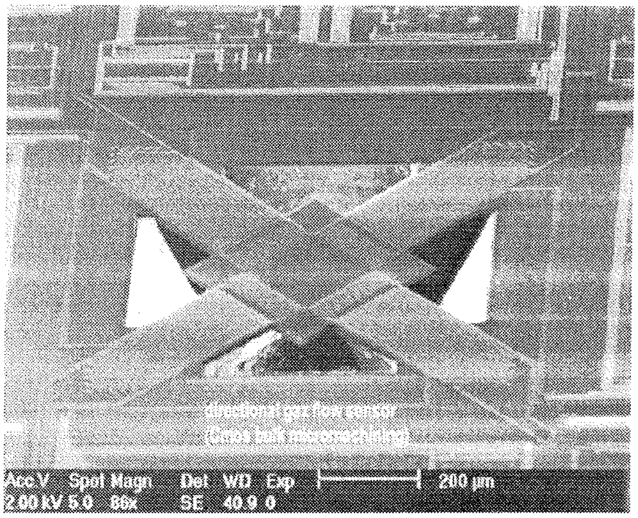

Fig. 1: Gas Flow Sensor (by courtesy of CMP)

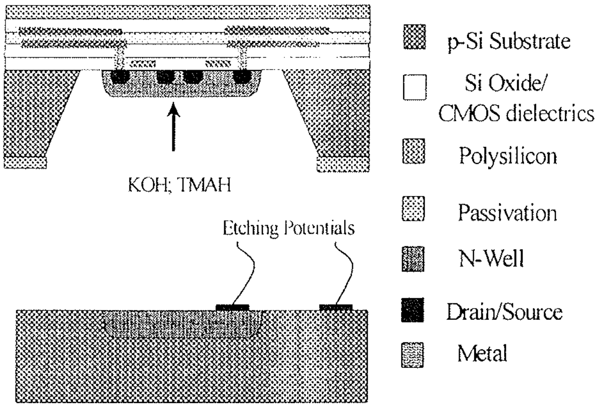

Fig. 2: Bulk Micromachining with elektrochemical etch stop

In the last few years, a great number of microsystem prototypes and small volume products were developed using this process.A typical example is the Gas Flow Sensor shown in Fig.1. The working principle is based on the measurement of the temperature differences of a locally heated gas flow. For reasons of thermal isolation, the whole system is placed on a membrane.

Very precise etch stops can be realized at reverse biased pn-junctions. Austria MikroSysteme Int. and the ETH Zurich developed a corresponding Back-Side Bulk Micromachining process which is used for different sensor developments.

In Fig. 2 the principle of the electrochemical etch stop is presented: the p-substrate and the n-doped well, which normally represents the active area for the implementation of the p-channel transistors, are supplied by appropriate potentials. These potentials guarantee a precise etch stop during the KOH etch process. They are initially applied to all dies using a wafer level connecting network (see Fig. 3). Within the dies, the potentials are applied to the stop-wells and to the substrate by metal connections corresponding to the chip level design rules. This process is available for all CMOS and BiCMOS processes of Austria Mikro Systeme Int. between 2 μm and 0.8 μm.

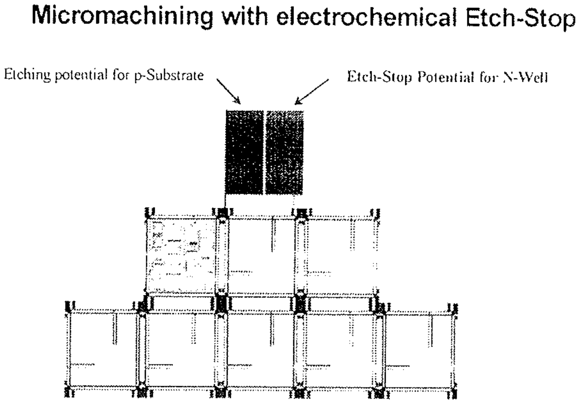

Fig. 3: Connecting network

Besides Bulk Micromachining, the structuring of surface layers – the so-called Surface Micromachining – has become a widely used technology. One of the first monolithically integrated Microsystems in volume production was the capacitive accelerometer of Analog Devices manufactured with surface micromachining technologies.

The basic idea of surface micromachining is the usage of sacrificial layers to form freestanding structures like beams. For instance, sacrificial layers can be the dielectric layers of the basic CMOS process (SiO_2) or the first metal layer (Alu). Buffered with ammonium fluoride, flour acid is well suited for the release of polysilicon structures by etching away the surrounding dielectric layers. In case of metallic sacrificial layers, all metal contacts on the surface have to be carefully protected by photoresist, leaving only the access openings to the sacrificial layer unprotected.

Usually both techniques can be combined and are performed as postprocessing steps with the fully processed CMOS wafer.

However, to make high temperature annealing possible, the surface micromachining should be integrated into the CMOS process before deposition of the metal layers. Care has to be taken in this integration to control the additional diffusion during the high temperature steps, which may enlarge the source- drain areas up to transistor shorts. Special deposition steps for low stress polysilicon deposition lower the requirements for high temperature treatment and ease this integration.

The preprocessing of micromechanical structures may cause considerable difficulties for the subsequent processing of active devices and connections. Destroyed planarity is one of the reasons. Sacrificial fillings of the prefabricated cavities are complicated and expensive. Such processes are used only in singular cases.

Micromachining technologies based on Reactive Dry Etching (RIE-Reactive Ion Etching) or deep RIE have reached a broad acceptance in the last years. A decisive factor for high aspect ratios and etch deepness in Si is the formation of the passivation layer on the etched walls to avoid further lateral etching.

In the case of anisotropic etching of dielectric layers, the top metal layer can be used as etch mask.This means that no additional mask is required. By combining the deep RIE through all dielectric layers of the CMOS wafer with a subsequent Si underetch process, one can release complete sandwich structures as shown in Fig.4. These sandwiches may contain metal or/and polysilion structures and offer wide possibilities for the creation of complex micro-structures.

With the cooperation of partners Austria Mikro Systeme Int. is considering the preparation of a corresponding process service.

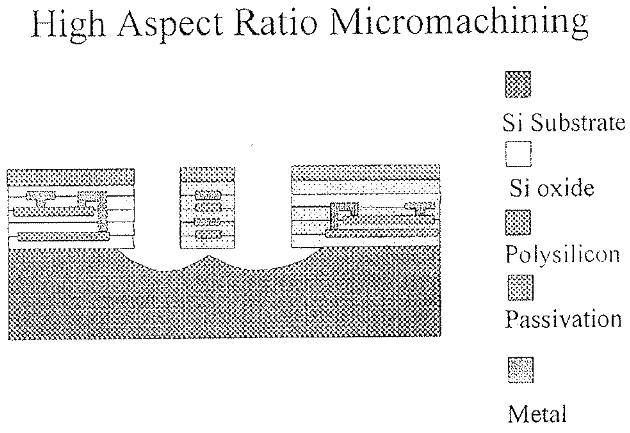

Fig. 4: Deep RIE based Surface micromachining

The spectrum of wafer level Microsystems technologies is much broader than the described methods.

For instance, the well-known LIGA process allows the realization of extremely large aspect ratios. However, many of these technologies are very special and only seldom suited for a cost efficient production. Additionally, often they do not allow the integration of signal and information processing blocks on the same chip.

This lack of monolithic integrability is also especially true for many of the joining technologies like Silicon Fusion Bonding or Field Assisted Bonding where sensor chips or Si wafers are connected with glass or Si. Planar surfaces in close mechanical contact are needed for this kind of joining technologies. Therefore, a hermetical connection of an IC surface with a corresponding Si or glass top part is difficult due to the insufficient planarity of the IC surface. Generally, the major problem of Microsystems development is packaging, including first level packaging.

ICs only need electrical and thermal contact to the environment. To a great extent, they can be protected from other environmental impacts. In contrast, Microsystems like pressure sensors, flow sensors, optical components etc. often need a direct contact to the environment. The packages have not only to protect the system, but also to guarantee a well-defined access to the outer world.

But even if no additional contact is necessary, the fragile microstructures are difficult to protect during wafer sawing and packaging. Consequently, dicing becomes more complicated and the clean room requirements for Microsystems assembly are usually stricter than for ICs.

However, the main problem is the cost. For microelectronic devices, plastic packages often represent the most cost efficient solution. Special assembly technologies, leadframes, mold materials, coating and soldering techniques allow the realization of dedicated plastic packages for different space and topology requirements, pin counts, thermal resistances, temperature ranges, humidity protection etc. The relative insensitivity of digital ICs to the internal package stress and –more important- to stress changes, is one of the preconditions for such solutions. In contrary, some analog devices like bandgap references and, to a much larger extent, many Microsystems are extremely sensitive to stress. This stress sensitivity makes the plastic packaging of many Microsystems like stress sensitive mechanical or magnetic structures, a very challenging task. Many promising Microsystems projects failed due to problems with finding cost efficient package solutions. This is true not only for monolithic integrated systems but also for discrete and hybrid approaches. When commencing with the development of Microsystems, it is necessary to include the development of the package concept and its verification from the very beginning of the project.

4. A new accelerometer

Analog Devices developed the first monolithic integrated, commercially available accelerometer sensor for airbag release. It is based on the measurement of the capacitance changes which are caused by the in-chip plane movement of a finger-like structure relative to the opposite fingerlike electrodes. The whole structure with the fixed parts, as well as the movable part suspended by springs is manufactured by a special surface micromachining process embedded in a CMOS process, with a total of 23 masks. The process is complicated, as the structure is yield critical and endangered by the sticing effect. Other manufacturers like Sensonor, Temic or Bosch also offer hybrid or integrated solutions.

Austria Mikro Systeme Int. has developed a prototype of high performance low cost accelerometer sensors. The goal was to develop a customizable sensor module and a corresponding control and signal conditioning module which could be adapted to the different requirements, such as different measurement ranges (from Low G sensor for 2-3 g until High G sensors for up to 200 g) and different accuracies.

The principle of the system is shown in Fig. 5. The sensor module consists of an elastic polysilicon beam over a cavity and represents the top die of the two component system. A two-mask Front Bulk Micromachining process releases the beam. The bottom die consists of the ASIC part including sensing, actuating and reference electrodes as well as all control and signal processing electronics. The signal interface between both of the components is the capacitance between the polysilicon beam and the sensing electrode of the ASIC part.

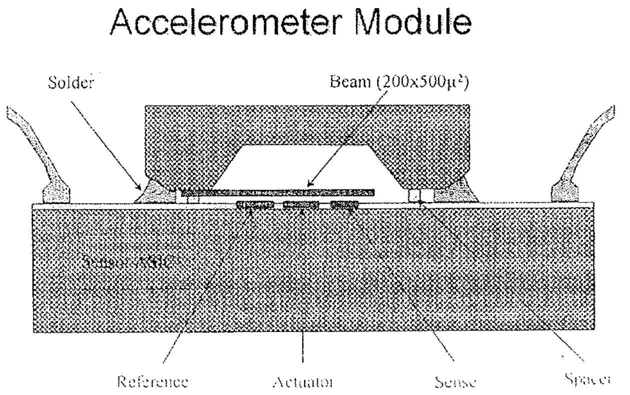

Fig. 5: Principle of Austria Mikro Systeme´s accelerometer sensor module

The capacitance measurement allows the exact determination of the distance between the beam and ASIC and in particular, the distance changes caused by accelerations perpendicular to the chip plane. The measurement is realized with accuracies in the area of some ato-Farad (10^{-18} Farad) and includes the elimination of the parasitic, signal dependant capacitances. The high precision measurement method was developed in cooperation with the Laboratory of Electronics of ULM.

The acceleration measurement is performed in closed loop operation, where the beam is fixed with high accuracy in a predefined bended position by the electrostatic force of the actuator. The control signal within the loop is linearly proportional to the acceleration of the beam.

The prebending of the beam guarantees a sufficient return force to eliminate instabilities caused by large excitations in the direction of the sensing electrode. For an acceleration range between + 50 g and -50 g, the beam has a thickness of 1 μm and a size of 500 x 200 μm^2 (see Fig. 6). The noise of the system is better than 0,1 g (peak to peak) for 200 Hz bandwidth.

Selftest of the system is realized using the actuator electrode.

The stress of the polysilicon beam is exactly controlled by a high temperature annealing process. Together with an exact distance control of the two dies, this allows an accurate positioning of the tip of the beam with respect to the surface of the chip. The sensor IC is manufactured in standard CMOS process with Solder Bump Post-processing extension. This manufacturing concept is insensitive against process variations. Customer specific information processing can be easily realized. The enormous shock resistance and robustness against electromagnetic disturbances are additional advantages of the concept. Stiction effects are completely excluded.

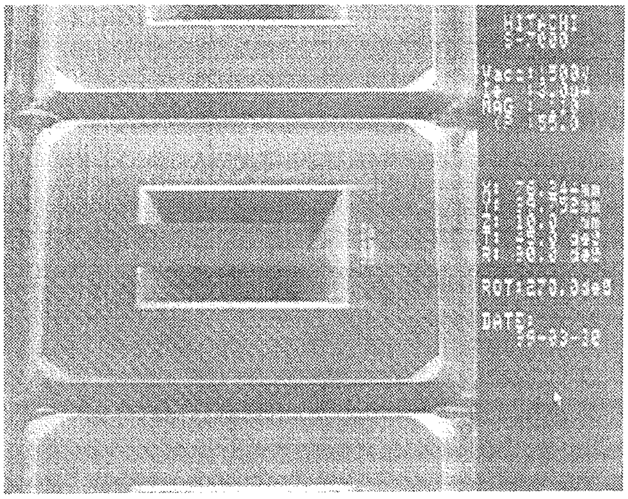

Fig. 6: Etched polysilicon beam

The system can be assembled in standard plastic packages or in special SIP packages, which are mounted perpendicularly to the PCB-surface.

5. Magnetosensors

Magnetosensors are a good example for the monolithic integration of Microsystems formerly realized mainly by discrete components like Hall or magnetoresistive sensors. Especially in case of Hall sensors, the monolithic integration can be realized using standard CMOS processes. On-chip magnetoresistive sensors or Flux Gate Magnetometers require additional deposition of permalloy or other magnetic materials, which can be performed on top of the dielectric layers or the planarized and finalized chip surface.

Austria Mikro Systeme has concentrated its efforts on the development of integrated Hall sensor systems. Hall Sensor ICs are used for angular, position, current and field measurements or as magnetic switches in machinery, automotive environment, white and consumer goods etc.

In comparison with discrete Hall elements monolithic integrated Hall sensor ICs are better suited for many applications, because build in offset compensation, calibration and application specific trimming as well as array topology adaptation to the external field can be realized more easily.

In Fig. 7 the principle of the Hall element is presented. The magnetic induction B via Lorentz forces affects the current I through the plate, generating the Hall voltage V_H which is perpendicular to the orientation of the magnetic field and the current. This voltage is inversely proportional to the carrier concentration n. Therefore, for the practical exploitation of the Hall effect semiconductors are the best-suited materials (R_H-Hall factor, G-Formfaktor, τ - average time of free carriers between two collisions which depends on their energy). For instance, doped Silicon like a n-well in p-Si forms an appropriate Hall plate, which only yet has to be contacted. This horizontal Hall element is sensitive against magnetic fields perpendicular to the surface of the integrated circuit.

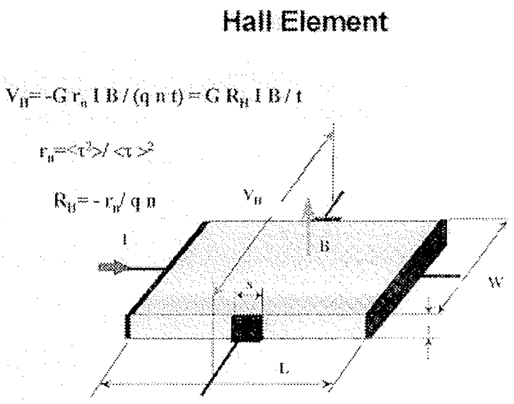

Fig. 7: Principle of the Hall element

The basic problem of all semiconductor Hall elements is the large, temperature dependent offset signal at zero induction. It is mainly caused by piezo effects within the crystal and by anisotropic geometric mismatches and doping gradients. It is stress dependent. The offset compensation is based mainly on the so called spinning current principle, which can be much more easily implemented on-chip than with discrete Hall elements. The idea behind this is the switching of the current direction through the Hall plate using different configurations of the plate with 2, 4, 6 etc. contact pairs and averaging of the Hall voltages over one turn. Sometimes Hall plates with different orientations arranged closely to each other are used synchronously assuming a nearly homogenous stress field over short distances. A solution patented by ETH Zurich solution is based on a continuous rotation of the vector of the current density by applying periodical supply currents to both of the contact pairs and measuring the Hall voltages between the same contacts. Generally, depending on the crystal orientation, suppression rates in the range of three to five orders of magnitude can be reached.

Another problem is the stability of the intrinsic sensitivity of the Hall elements. First of all, the sensitivity depends on temperature changes of the Hall coefficient itself, on the impact of the stress or stress changes on the Hall effect (the Piezo- Hall effect) and on the piezoresistive (stress-dependent) changes of the Hall element (strain gauge effect). Especially during packaging the stress conditions may change considerably changing the overall temperature behaviour of sensitivity.

If the measurement can be interrupted by calibration intervals, sensitivity changes can be measured and corrected using calibration coils around the Hall elements. A very precise voltage or current reference as well as relatively high calibration currents are requested.

In many cases for technical and cost reasons, the stress dependence has to be eliminated by appropriate packaging.

Austria Mikro Systeme Int. has specially developed very thin packages for Magnetosensor ICs. Here, the single in line arrangement of the pins allows using these packages for small magnetic gaps or mechanical slots. Temperature and reliability ranges typical for automotive applications are covered.

A great advantage of integrated Magnetosensors is the possibility to design array topologies, which are well adaped to the structure of the magnetic field to be measured on chip.

An example is shown in Fig. 8. Here, the angular measurement is based on the evaluation of the magnetic field in all four quadrants. The vertical components of the magnetic field under the magnet change periodically with the rotation angle. The point by point measurement of the field is substituted by a multiple measurement with higher accuracy and robustness against eccentricities. Of course, the measurement in any of the quadrants may again be a distributed measurement by sensors arranged along segments and followed by a weighted or unweighted summing of the component signals.

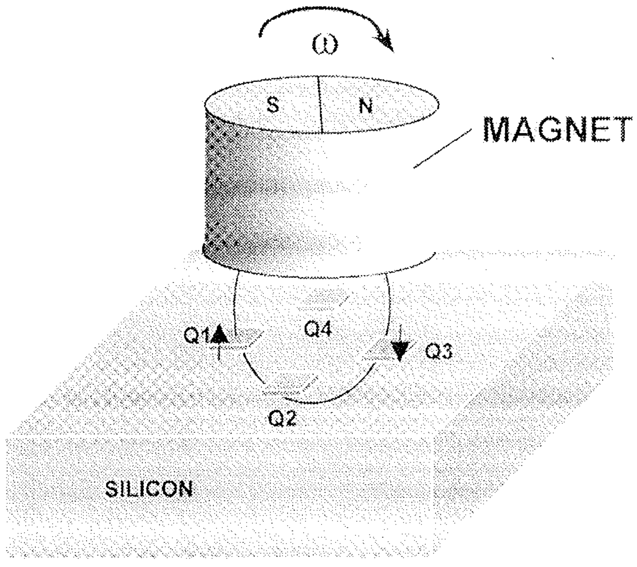

Fig. 8: Measurement of absolute angle using lateral Hall elements

AMSInt has also successfully used the principle of array measurement for the determination of the relative angular position where a multi-periodic field is generated by pole pairs arranged along a full circle. In the case of current measurement, this principle is extremely useful: using a corresponding sensor arrangement for the differential measurement of the field on both sides of the current conductor can eliminate external-disturbing fields.

Application specific sensor arrays on-chip, high performance compensation circuitry for the elimination of offset and temperature dependencies of sensitivity, programmability of dynamic range, of bandwidth and temperature behaviour, on-chip generation of magnetic fields for test and in field calibration, special packages, 3 D magnetic measurement capabilities for system design support - these are the techniques used respectively developed at Austria Mikro Systeme for the creation of customer specific solutions. Some of the methods are the result of the EU funded ESPRIT project MagIC and of the close cooperation with research institutes like ETH Zürich and University of Ljubljana.

As mentioned, the used lateral Hall elements are sensitive against the magnetic field component that is perpendicular to the chip surface. In some cases the parallel measurement of both in plane field components would be beneficial. For instance, the both components of a homogeneous field parallel to the chip surface could be measured allowing deriving the angular position of the chip relative to the field orientation. The implementation of the corresponding vertical Hall elements requires special technology steps. Austria Mikro Systeme Int. and ETH Zürich developed prototypes of vertical Hall elements which were realized by preprocessing steps consisting of the etching of two parallel, deep trenches, subsequent n- diffusion via the walls and isolation of the created perpendicular plate by oxidation. The trenches are filled with polysilicon.

Today, integrated Magnetosensors are mainly based on Hall elements and magnetoresistors.

Roughly one third of the worldwide market are magnetoresistive systems. Emerging products are based on integrated Flux-Gate magnetometers /4/, NMR systems / 5 / and magneto-mechanical resonators, which are opening the way to considerably higher sensitivities.

Austria Mikro Systeme offers not only its system and implementation competence to its customers but permanently completes its technological base in the magnetosensor area by acquiring and developing newest sensor principles and devices.

6. Conclusion

The monolithic integration of sensors, actuators and information processing on-chip is one of the main trends in the Microsystems area. The base is formed by the well-established microelectronic technologies that are properly extended for the integration of mechanical, optical, chemical and other functional elements. To use the cost advantages of the established microelectronic manufacturing equipment and infrastructure, the additional Microsystems-specific technology steps must be at least CMOS compatible.

Based on its high flexibility and the availability of all technological steps from design over mask production, chip manufacturing, test and assembly under one roof Austria Mikro Systeme Int. follows the sketched approach of CMOS compatible pre and post processing. In the first step, fully CMOS based sensors like horizontal Hall Plates and photodiodes were used to create a design and application environment for monolithically integrated Magneto and Opto Sensor Systems for absolute and relative angular measurement, position measurement, field measurement and magnetic data transmission. Especially for Magneto Sensor Systems well characterized sensor models, and a special library including different Hall structures, spinning current offset compensation blocks, on-chip field generators, different arrays for angular and field measurement, temperature compensation systems, field programming blocks etc, were developed. Special packages, test and evaluation techniques support the system design and application.

In a second step - which was practically done in parallel - Austria Mikro Systeme Int. introduced the surface and Bulk Micromachining technologies, most of them in cooperation with partners like CMP and ETH Zürich. The in house technologies were used for the development of mechanical sensors like a new accelerometer module. A special electrostatic etch stop technique was developed for backside bulk micro machining, which allows the manufacturing of very precise Si-membranes or beams.

The strong emphasis of monolithic integration and a high degree of CMOS compatibility for well selected Micro system products and market segments within the focus areas of the company are the guidelines for the present and future development of Microsystems at Austria Mikro Systeme.

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