MICRO ELECTRO-MECHANICAL SYSTEMS – MEMS

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Contents

Summary

MEMS have characteristic dimensions in the micrometer range. The integration of nano-scale effects and materials is ante portas. MEMS technologies have become a mature industrial platform with a steadily growing number of killer applications in the automotive, consumer, industrial and medical fields. MEMS is not a homogeneous industrial branch but rather an approach to create microscale devices for all possible applications using microfabrication technologies including non-standard packaging and test methods, and exploiting an ever growing repertoire of MEMS-building blocks. Beside fabrication technologies, transducers which convert signals from one physical domain to another are key tools for creating links between the outer world and the information processing systems as well as between the different physical, chemical or biological effects that are combined in a given MEMS. A broad spectrum of transducers like piezoresistive, piezoelectric and capacitive stress/deflection-to-voltage converters, thermal sensors and actuators, magnetic transducers, optical sensors and actuators, flow sensors and fluidic actuators have been created by the MEMS community using new materials and technologies. It is continuously expanding and more and more also includes nano-technologies.

Many operating principles for creating ready-for-application micro-sensors and actuators have been newly developed or adapted to the MEMS environment. Pressure sensors, accelerometers, gyroscopes, fluidic MEMS and BioMEMS, opto-electromechanical systems for light projectors and optical communication as well as RF-MEMS exploit a great variety of different functional principles and, hence, system solutions. The tight interdependence of a given application target and the corresponding MEMS technologies requires a strong interaction of application experts and MEMS specialists, which in the end is the basis for a successful MEMS product.

1. Introduction

The chapter gives an overview on the nature of MEMS, their main application areas, on the most important transducers and MEMS technologies as well as on some operating principles used to design various MEMS.

The term ‘Microelectromechanical systems’ has been created in 1987 during some subsequent workshops on microdynamics in order to differentiate from electronic integrated circuits (IC) the myriad of new product ideas and prototypes emerging within the microelectronics environment. The new MEMS-products have characteristic dimensions between sub-micrometers and hundreds of micrometers and typical sizes between parts of mm^2 and hundreds of mm^2. They are fabricated by microelectronic technologies and their extensions – often summarized under the concept of ‘micromachining’, a term which came up in 1982. In contrast to microelectronic devices, MEMS integrate non-electronic effects based on movable parts, mechanical

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resonators, tunneling tips, electrolytic and other fluids, active chemical and biological reactions, optical beam forming and redirection and others. Accordingly, the repertoire of basic MEMS-elements includes proof masses, springs, diaphragms, capacitances with movable electrodes, beams, mechanical RF-resonators and filters, piezoresistive and piezoelectric transducers, mechanical switches, gears, nozzles, valves, pumps, mirrors, micro lenses, beam splitters, hotplates, thermal actuators, Hall elements – to name just a few. Today there is a tendency to sub-summarize all microsystems with multi-domain or non-electronic functionality under the MEMS umbrella. A common feature is that the multi-domain character of MEMS implies signal transformations between domains. Therefore, micro-transducers play a fundamental role in designing MEMS.

In general, MEMS elements are not simply scaled-down macroscopic devices ([23]). The micro-world is dominated by completely different relationships between the various physical effects. The basic reason is that a geometric down-scaling of the characteristic dimensions changes the ratio between volume and surface. The volume reduces faster than the surface leading to an increased weight of surface effects like adhesion, stiction, mechanical noise, structural and surface-caused damping, surface-state-dominated instabilities etc. For instance, inertial forces that are proportional to the volume become comparable to damping forces which are determined predominantly by the interaction of the surface with a gaseous environment. The characteristic mass movements in MEMS cover a huge velocity range from sub-micrometer per second up to many meters per second. Therefore, the impact of viscous forces, friction and fatigue may be dictated by completely different mechanisms. Many of such micro-scale effects are very complex and are subject to intense research trying to understand the performance limits of different MEMS elements.

MEMS technologies are basically based on batch fabrication. As in the case of microelectronics, the wafer remains the basic carrier of the MEMS component dies. Thousands of dies can be fabricated in parallel, making this approach attractive also for small MEMS companies. Silicon substrates appear as basic material. However, glass, quartz, SiC, GaAs, Ge and other materials are also used. Further, a broad spectrum of new materials including ceramics and polymers has been adapted for forming MEMS elements. Moreover, the fabrication sequence of MEMS often consists of additional processes such as the so called Zero-level-packaging (see Section 4.1). Most of the active MEMS elements are electrically excited or sensed. The corresponding electronic signal-conditioning and possible trim and test support may be performed on-chip or off-chip. In the first case one speaks of monolithic integration, which puts additional challenges on technology integration and is technically and economically not always favorable.

The overwhelming majority of MEMS products are sensors and actuators. They provide control systems with 'eyes, ears and noses' to acquire information on the status of the object to be controlled. They can directly perform some specific actions like fluid transport in microsystems (e.g. droplet generation in ink-jet cartridges) or initiate actions in the macro world. However, many new functions emerge. Among them are micro-energy sources such as micro fuel cells, energy harvesting based on the transformation of kinetic energy (e.g. vibrations) and of solar and thermal energy into charge, and remote energy supply. They open the way to building supply-independent sensor networks which are especially needed for environmental monitoring and protection. A prerequisite is often the integration of wireless communication, as it is state-of-the art, for instance, in tire pressure monitoring sensors. The broad range of functional principles, governing micro-scale effects and technologies makes the MEMS area a multidisciplinary field where engineering disciplines and basic research are tightly interwoven. Since the MEMS product is usually only a component within a complex application that requires an often not less complicated research and/or design work, the link between MEMS and its applications must be covered by a broad penetration of MEMS knowledge into the different application areas. The integration of MEMS courses into the basic engineering education is one way to support the propagation of the MEMS paradigm into the development of new products and systems in nearly all areas of human endeavor.

2. MEMS Applications and Market

A commercial MEMS-device is a packaged, calibrated, and tested product, which has to satisfy very different application conditions with respect to temperature range, shock robustness, life-time, reliability etc. Orders of magnitude may separate the complexity and the price of MEMS for different applications even if the underlying principles are identical. The extreme diverseness of application requirements entails very fragmented markets which have predominantly low volume and only few large to truly high volume applications.

The early stage of MEMS is characterized by broad research, technology development and creation of MEMS prototypes in order to find out their cost and performance limits. High-volume production and mass applications have been the exception. Among them are the well known first diaphragm-based, piezoresistive MEMS pressure sensor successfully marketed around 1974 by National Semiconductor and the MEMS-based bubble jet print-head developed around 1979 by Canon and commercialized by Hewlett-Packard in 1984 (see [40]). Within the last decade the MEMS market is transforming more and more into a high volume market with steadily expanding size, and, crucially, with growing number of different application classes. MEMS have become an established industry with impressive growth and an increasing number of well defined applications ([33]) which feature typical Compound Annual Growth Rates (CAGR) between 5% and 20%.

In the 1990s three to five years were needed to develop new MEMS designs and five to eight years were required from prototypes to volume production. Texas Instruments started the research for the Digital Light Processing (DLP) and digital micro-mirror device (DMD) in 1976 and only about 20 years later commercialized it. It is now the heart of beamers and microdisplays. Now – within the established MEMS environment – the typical overall time from design start to volume production has decreased by a factor of two to three and is shrinking further. According [13] 150 companies manufactured in 2009 about 98 % of the commercial MEMS devices – altogether around $ 6 Bill. A doubling is expected until 2015. More than 90 R & D industrial facilities, which are able to develop prototypes and to perform small volume production, and a countless number of university laboratories, round off the picture of today's MEMS community.

The largest MEMS producer in 2009 was Hewlett Packard with its ink-jet print heads; the second place was occupied by Texas instruments with its DMD. The largest MEMS-sensor producer – the company Bosch – followed on third place.

Most likely, in the next years accelerometers will occupy the first place and displace the long-time leading ink-jets. For the next years the expected CAGR for the whole MEMS market is around 10 - 12 % – about 25 % higher than the corresponding value for the semiconductor market ([25]), which in 2009 has been approximately 50 times larger than the MEMS market. However, the importance of MEMS is primarily not determined by their market share, but by the new applications which become possible in combination with other macro- and micro-technologies.

It should be noted that the MEMS market sometimes is understood as the market of MEMS systems and not of MEMS devices. Here a MEMS system represents the complete module ready for inserting into the next higher-level system. Correspondingly the price difference between both may be one to two orders of magnitude.

2.1. Mechanical MEMS

Pressure sensors belong to the oldest MEMS and are used under harsh conditions in cars, for instance, controlling the air-fuel ratio for the engine and the hydrocarbon emission, or monitoring the tire pressure. They are used in medicine for invasive and non-invasive blood pressure measurement, for the control of infusion pumps, micro-pumps, etc. They can be integrated in sports watches, but also in cell-phone to support level-detection in the upcoming in door navigation systems. Their market share in 2010 was about 15 % of the overall MEMS device market.

MEMS microphones for portable electronics and especially for cell-phones quickly gained market shares. Due to their solderability they offer substantial cost advantages against the excellent electret microphones.

Autofocus and zoom actuators for digital cameras are another high volume application of mechanical MEMS. For instance, capacitive comb actuators are used to move lenses within the photo objective. MEMS with movable nanometer-sharp tips are used for material surface investigation down to the atomic scale as, e.g., in the atomic force microscopes (AFM).

The Millipede from IBM Research, Zurich ([19]), is another example of prototyping possible fundamental new applications – here for ultradense information storage in the range of Terabit/inch^2 on very thin polymer films by using an array of thermomechanical scanning probes. Mechanical MEMS actuators for driving cutting tools in microsurgical applications have become indispensable tools in medicine, especially for neurosurgeons. Microengines with small gears at rotational speeds greater than some 100,000 rpm have been prototyped. Possible applications include driving the wheels of microcombination locks or pop-up micro-mirrors.

2.2. Inertial Sensors

Basically, inertial sensors belong to the mechanical sensors. They include accelerometers for cars, for instance, for airbag release, for tilt measurement and antiskid systems. Accelerometers are integrated in laptops in order to detect a possible free-fall and to bring the disc-head into a save position before crash. In smartphones and iPad displays they perform portrait-landscape detection depending on the vertical or horizontal position of the display.

In the medical area activity control of, e.g., patients with pacemakers or of sportsman are well-known applications. Gyroscopes are the second type of inertial sensors and used, for instance, in cars for electronic stabilization systems (ESP), for roll-over detection and antiskid systems. In digital cameras they support image stabilization. The combination of accelerometers and gyroscopes allows to aid navigation not only in cars (dead reckoning) but also within buildings (in door navigation), where GPS-navigation suffers from bad reception.

Three axes (3D) accelerometers and 3D gyroscopes are combined with 3D magnetometers in order to have an external, stable reference angle given by the local magnetic field. Adding a pressure sensor level detection in buildings becomes possible. Such systems which consist of a set of MEMS chips are presently in wide introduction in smartphones and aid the orientation within fair halls and other building complexes. Sensor fusion for such complex applications is a challenge and normally performed by programmable sensor fusion IC’s.

Game controllers or, more generally, human-computer interfaces are another booming application of inertial sensors. The motion of the platform is analyzed and initiates different on-line commands. Beside motion pods for medical applications such systems also find growing acceptance in fitness and sport. Overall, the inertial sensor market in 2010 was the largest segment with a share of about 30 %.

2.3. Microfluidics

In 2010 microfluidic devices have had a share of about 28 %, of which 25 % stem from the ink-jet device mentioned above. Microfluidic devices transport and store fluids. The quantities are in the order of nanoliter or less. They inject, separate, and merge continuous liquids or droplets and are especially promising for drug dispensing and the miniaturization of medical, biotechnological and chemical analysis (Lab-on-a chip, DNA-chips). Fuel cells for electric energy generation are under development. The applications of microfluidic devices are countless, however, apart from the ink-jet, they are mainly in the early stage of broad industrialization.

2.4. Micro-Opto-Electromechanical Systems (MOEMS)

The DMD chip from Texas Instruments for displays based on digital light processing is the most popular and high volume representative of MOEMS. An alternative that is gaining market share is the interferometric modulator display (IMOD) from Qualcomm based on interferometric color selection.

Optical laser scanners based on oscillating micro-mirrors are used, for instance, for fast bar code reading or for obstacle detection. They represent the class of MEMS-based imaging systems with active illumination. Micro-mirror-based optical switches for routing optical signals between fibers in cross connects represent key elements for improved performance of optical networks. Attenuators, tunable optical filters, beam splitters, analogue and digital light modulators, microlenses etc. are other basic devices, used in a great variety of applications. The optical switch segment was over-hyped before the crash of some network companies in 2001-2002 by unrealistic expectations, however since then has taken a solid development.

2.5. RF MEMS

RF MEMS are mechanical resonators, switches, varactors, tunable mechanical filters etc. aimed at operating in wireless communication systems in the upper MHz and GHz-range. The development is driven by the high-performance requirements of test equipment, radar and multi-band cell-phones. Mechanical resonators have begun to substitute expensive and bulky quartz clocks – a multi billion market. Their advantage is lower power consumption and the possibility to be cointegrated with IC's. The performance of high-temperature compensated quartz resonators is achievable.

2.6. Magnetic MEMS

Hall sensors are fabricated for long using standard microelectronic technologies. Magnetic sensors based on the Anisotropic Magnetoresistive (AMR) or the Giant MagnetoResistive effect (GMR) have been developed also independently on MEMS efforts. They are used mainly for angular and position measurement within industry, for current sensing and for the measurement of external magnetic fields. MEMS technologies have extended the possibilities of magnetic microsystems especially with respect to performance improvement. In the last years magnetic sensors have found applications in cell phones where they function like a compass detecting the orientation of the Earth's magnetic field (30 to 60 μ Tesla).

The drawback of many magnetic MEMS is the need of an external magnet which occupies size and weight. Hard-magnetic materials deposited on-chip are used to produce internal magnetic fields which are necessary, for instance, for magnetic write-read heads of magnetic discs.

2.7. Other MEMS

There exist many MEMS which do not fit unambiguously into the above classes. For instance, non-fluidic bio and chemical MEMS based on thermomechanical, weight-changing absorption or chemical reactions are using thermo-chemical-mechanical effects. Thermal sensors and actuators like heat pumps exploit a combination of various thermoelectrical and thermomechanical effects. Often the corresponding devices act as transducers of higher-level MEMS devices. BioMEMS cover a broad spectrum of domain specific MEMS and their combinations for diagnosis, drug delivery, neural prosthetics, tissue engineering and minimal invasive surgery ([16]). They integrate, for instance, on-chip opto-electrical or acoustic-electrical transducers with connections to neurons, like in the case of artificial retinas or hearing aids.

3. Transducers

This section gives a short introduction to the main transducer principles used in MEMS. MEMS transducers form the links between signals of different energy domains. Most MEMS consist of several transducers. For instance, an acceleration sensor includes a mechanical transducer which transforms the inertial force (mechanical energy) via moving masses and suspensions into displacements or stress and strain in the elastic members (elastic energy). The subsequent electrical transducer converts the latter into electrical output signals.

Silicon (Si) with its outstanding mechanical properties (see, e.g., [21],[23] and [46]) plays a key role for building transducers. It is as strong as steel. It is ideally elastic, not exhibiting plastic deformations up to the yield point, unlike metals. The E-modulus may be as large as 190 GPa depending on crystal orientation, and the yield strength is about 7 GPa. With corresponding doping concentration (boron, phosphorus) the resistivity can be changed by eight orders of magnitude between 10^{-4} and 10^{4} ohm cm. This allows structures such as conductive plates or comb fingers to be manufactured ([34]). Silicon has a diamond structure based on a cubic crystal lattice and exhibits pronounced orientation dependent properties like piezoelasticity, piezoresistivity and piezo-Hall effects ([51]).

Silicon monocrystals are grown as cylinders. The wafers for Complementary Metal Oxide Semiconductor (CMOS - the basic technology for manufacturing integrated circuits) and bulk micromachined devices are usually cut out of the cylinder along one of the six planes of the crystal lattice as shown in Figure 1. To identify the lattice orientation a so called wafer flat is introduced serving as reference orientation. The flat lies in the diagonal plane of the cubic lattice as shown in Figure 1, left (The numbers in the Figure are the so called Miller indices which are used to describe the orientation of crystal axes and planes.). A device on the wafer that is oriented perpendicularly to the flat has an angle of 45° with one of the cubic lattice planes. Stress dependent material parameter matrices are related to a stress impact oriented perpendicular to the cube planes. For orientations which differ from this basic configuration the corresponding parameters must be calculated by rotating the material matrix.

Polycrystalline silicon or ‘polysilicon′ for short, which is made up of small single-crystal domains of silicon (grains), has similar properties and is the most popular building material for Surface Micromachined devices (see section 4.4).

Mechanical and electrical properties of polysilicon are slightly inferior compared to monocrystalline silicon but are very close to an isotropic; thus, the material is much easier to handle than monocrystalline silicon.

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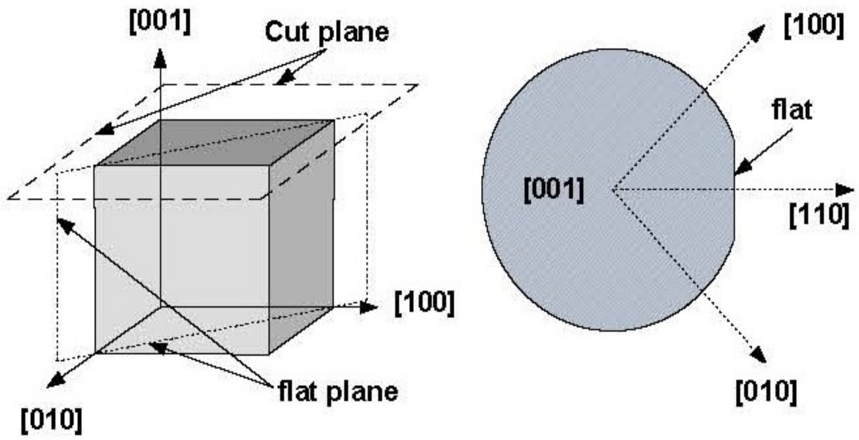


Figure 1. Silicon orientation on wafer

3.1. Mechanical Transducers

Mechanical transducers convert mechanical forces such as pressure or inertial forces into deflections and/or the corresponding stress and strain. They belong to the standard repertoire of MEMS transducers and can be implemented in nearly all technologies.

The most frequently used mechanical transducers are cantilever beams, linear and torsional springs, elastic bridges, composed suspensions and diaphragms which are now sketched one by one.

A cantilever beam may serve as an example for a simple force-to-deflection or force-to-stress transducer. The notations for a bend beam are given in Figure 2. The beam is fixed at the origin of the coordinate system.

Cantilever beams in MEMS are usually long and wide, but not high. Such beams are mainly compliant (elastic) in the z-direction. If B and H are comparable then the bar becomes sensitive to rotation for moments about the longitudinal axis and may act as a torsional spring.

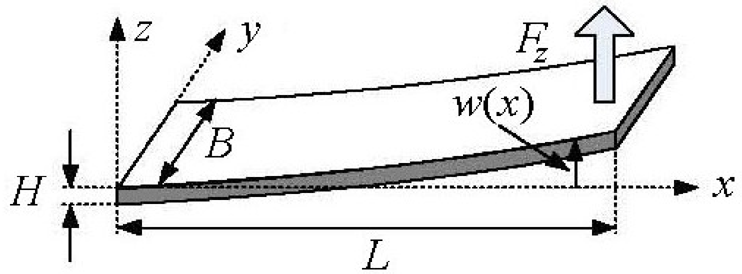


Figure 2. Bend beam and corresponding coordinate system

The spring rate k_z of suspensions is used for the calculation of the force-to-deflection relation. For the cantilever beam it can be derived as (see, e.g., [8])

$$k_z = F_z / w(L) = 3EI_y / L^3 = \frac{1}{4} EB\left(\frac{H}{L}\right)^3 . \quad (1)$$

E is the Young's modulus, which for polysilicon (and silicon) is about 166 GPa; $I_y = \int_S z^2 dS$ is the geometric moment of inertia which in the case of a rectangular beam equals to $I_y = BH^3/12$.

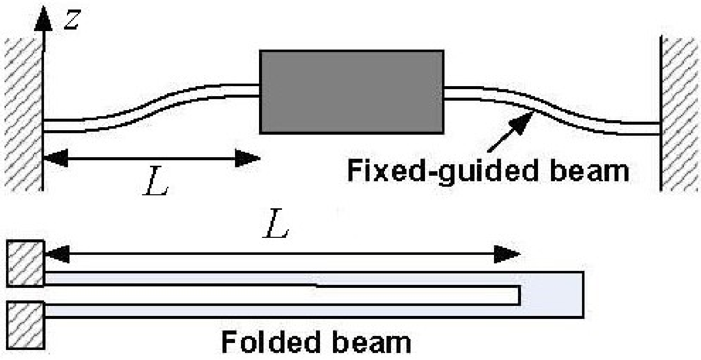


Figure 3. Fixed-guided (top) and folded (bottom) beams

If the force is captured by a corresponding stress measurement, the stress must be known. Stress is the force per area related, in general, to the planes of infinitesimal small cubes. Normal stresses act orthogonal to a cube's plane, sheer stresses act in plane and cause a deformation of an initially quadratic face, i.e. shear strains (see, e.g., [53], [54]).

For the cantilever considered here the longitudinal stress at location x is $\sigma(z-H/2) = -(L-x)(z-H/2)F_z I_y$ (H - thickness of the beam). It is positive on the lower surface ($z=0$), which corresponds to tension, and negative on the top surface (compression). The maximum stress is located at the anchor point $x=0$. Therefore, stress-sensitive piezoresistors should be positioned nearby.

If the cross section of the beam is not ideally rectangular, but with inclined sidewalls, the cross-coupling spring rate $k_{yz} = F_z/v$ which characterizes the parasitic deflection v in the y-direction, is proportional to the sidewall angle.

Mainly due to large temperature gradients during production and to the non-identical temperature coefficients of the different layers polysilicon films often feature non-negligible 'frozen' or residual stress σ_0. Special annealing is used to reduce such stress. The residual stress changes the force balance in beams. This leads to changes in the spring rates. Bulk silicon is basically free from residual stress and therefore often better suited for high-performance applications.

Elastic suspensions in MEMS are usually composed of elastic bars. For instance, a proof mass may be elastically suspended on a rigid frame as illustrated in Figure 3 above. Two fixed-guided beams carry the proof mass on one of their ends and are fixed to an outside frame.

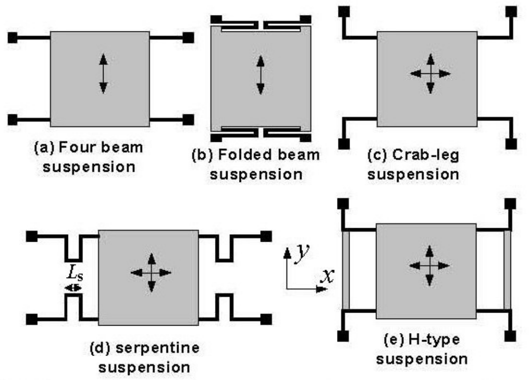
Fixed-guided beams are exposed not only to transversal but also to longitudinal stress that change with temperature and are subject to asymmetries.

Folded beams as in Figure 3 bottom avoid such problems and are usually preferred.

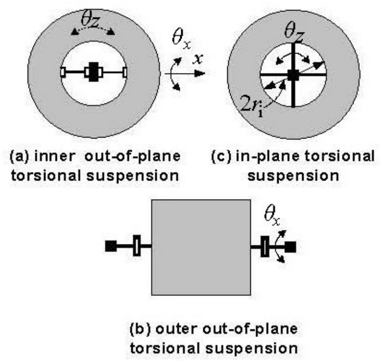
A bridge is basically a double clamped beam where the ends at $x = 0$ and at $x = L$ are fixed. The load is applied between the ends. The double clamped beam – if excited by a force in *z*-direction – is a beautiful resonator like a violin string. Similarly to a cantilever beam with residual stress the properties of the double clamped beam depend on additional longitudinal stress that may be caused by axial forces. If, for instance, both supports are pressed towards each other, compressive stress develops inside the beam, and tensile stress – for pulling apart both supports. The action of axial loads can be treated as a change of the spring rates for the z-deflections. Consequently, the resonance frequencies of the beam change. This effect is used for designing resonance accelerometers and pressure sensors.

Most suspensions in MEMS are composed out of parallel and serial spring connections of beam-like springs. For parallel connections of two springs the total deflections are equal and the spring rates add up. In contrast, for serial connections the forces on the springs are equal, but the displacements add, so that the inverse spring rates sum up.

If a rectangular plate that should deflect in one of the in-plane axis, say the y-axis, is suspended by four identical springs on the surrounding frame as illustrated by Figure 4, parts (a) to (d), the resulting spring rate of the suspension is four times the spring rate of a singular spring. Accelerometers which are sensitive in the y-direction are usually equipped by such proof-mass suspensions which restrict the deflections in the x and z-directions but favor y-deflections. Part (e) of Figure 4(a) shows a suspension that can support x- and y-deflections to an equal extend.



(a) Standard Suspension for supporting orthogonal linear motions



(b) Typical Suspensions for rotating plates or discs

Figure 4. Some typical linear and torsional suspensions (after [32])

In Figure 4(b) some torsional suspensions are presented. As shown, stress-compensating loops are often built into the springs in order to prevent additional longitudinal stress.

Thin diaphragms are the basic elements of MEMS pressure sensors. The displacement of the diaphragm or the stress developed at certain locations are used as indicators for the acting pressure P or, more precisely, for the actual pressure difference (net pressure ΔP).

Most of the diaphragms in MEMS are circular, quadratic or rectangular. If a circular diaphragm with constant thickness H_{D} and radius R_{D} is positioned in the *x*-*y*-plane, the displacement in z -direction, $w(r)$, at the distance r from the center of the diaphragm satisfies the relation (e.g. [62])

$$w(r)=\frac{PR_{\mathrm{D}}^{4}}{64D}\left(1-\frac{r^{2}}{R_{\mathrm{D}}^{2}}\right). \tag{2}$$

where D is the so called flexural rigidity of the diaphragm: $D=EH_{\mathrm{D}}^{3}\big/12\left(1-\nu^{2}\right)$; ν – the Poisson ratio and ρ – the density. $w(0)=PR_{\mathrm{D}}^{4}\big/64D$ is the maximal deflection in the center of the diaphragm.

Pressure sensing can be performed by capacitive measurement of the (averaged) deflection; for instance, in the middle of the diaphragm or over the full area, or by piezoresistive measurement of the produced stress.

There are two components of the stress: in radial direction, σ_{r}, and in tangential direction (in-plane of the diaphragm but orthogonal to the radius), σ_{t}. Due to symmetry the shear component σ_{rt} is always zero.

It can be shown (e.g. [8]) that the absolute values of the stresses are maximal at the edges $\sigma_{\mathrm{r}}\left(R_{\mathrm{D}}\right)=\sigma_{\mathrm{t}}\left(R_{\mathrm{D}}\right)=\pm\frac{3R_{\mathrm{D}}^{2}}{4H_{\mathrm{D}}^{2}}P$ and reduce to $\sigma_{\mathrm{r}}\left(0\right)=\sigma_{\mathrm{t}}\left(0\right)=\mp \quad +\nu)$ in the middle. An optimal pressure measurement should use both stresses, σ_{r} and σ_{t}, at the diaphragm boundaries.

Similar considerations can be made for rectangular or quadratic diaphragms. For a quadratic diaphragm with side length $2L_{\mathrm{D}}$ the maximum stresses arises at the middle of the edges. Consequently, the middle points of the diaphragm edges are predestined for the positioning of the piezoresistors.

As for double clamped beams the resonance frequency of a diaphragm depends on the pressure load. This dependency is used for the design of resonance pressure sensors.

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Biographical Sketch

Volker Kempe has a unique double background in both fundamental science (physics) and engineering (communication technology). From 1957 – 1963 he studied Physics and Communication Science at the Moscow Energetic Institute, received his PhD degree (Dr.-Ing.) in 1968 with Summa Cum Laude and in 1976 his PhD degree (Dr.sc.nat.) for his work on the theory of stochastic systems (on which he wrote two books). In 1978 he was appointed Professor of Information and Control Theory by the Academy of Sciences in Berlin, and became a full Member in 1986; and in 1988 was elected full Member of the International Academy of Astronautics. His research interests include Stochastic Systems, Conditional Markov Processes, Optimal Estimation Theory and MEMS. He led the development of Infrared Fourier Interferometers for remote sensing of the earth's atmosphere by satellites used later, among other things, for the exploration of the atmosphere of the planet Venus. Accompanying a lifelong investment into research are 40 years of experience in the management of research and development, both in academia and industry. From 1977 to 1990 Volker Kempe headed the Institute of Cybernetics and Information Processes of the Academy of Sciences in Berlin and set up an internationally strong research institute in informatics, artificial intelligence and automation, with a leading role in selected areas such as image processing, and expanded the institute from less than 200 to over 600 employees. He worked on topics including powerful image processing systems and established and organized broad research activities in special directions of control and automation, in robotics, and in foundations of microelectronic design.In 1990 he moved to the microelectronic industry and led the Engineering Department of Austria Mikro Systems and later its Strategic Product Development. In 2003 he co-founded SensorDynamics AG, a fast-growing semi-fabless semiconductor company that focuses on innovative sensor solutions, of which he has been the VP of R&D. He has authored over 100 papers and more than 20 patents, four books and five scientific anthologies, and edited four journals and book series. He has been in the program committee of several major international conferences, including ESSCIRC and DTIP.