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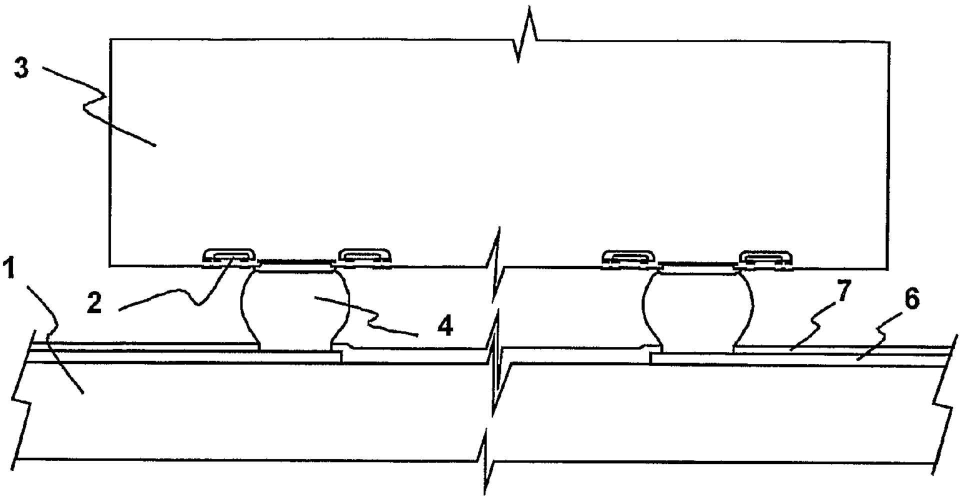
(54) **Title:** ACCELEROMETER SYSTEM



(57) **Abstract:** Disclosed is an accelerometer using integrated sensors (2) which measure the forces acting on each interconnection joint (4) between a semiconductor chip (3) and a base (1), whereby the entire chip (3) serves as proof mass. The chip (3) may be flipchip bonded to the base (1). The sensors (2) are preferably integrated on the chip (3), surrounding/underlying each interconnection joint and provide sensor signals proportional to the forces acting on the interconnection joints (4). Acceleration forces in all three dimensions can be separated. The interconnection joints (4) serve also as electrical connection for the readout of the sensor signals. The elimination of any bulk etching processes to form the proof mass results in an accelerometer highly suitable for compact low-cost applications.

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Accelerometer System

DESCRIPTION

Technical Field

The present invention relates to a semiconductor accelerometer, i.e. an acceleration detecting device using semiconductor technology, particularly suitable for low-cost applications and/or applications requiring compactness of such a device.

Background and Prior Art

Common acceleration devices use displacement of a proof mass, also named sensing, inertial, or seismic mass, in a cavity relative to a support for determining the acceleration. The displacement can then be measured or sensed by e.g. capacitive sensors or by the force acting on any support elements of the proof mass. Some acceleration sensors use integrated piezoresistive sensor elements or capacitive reading of displacements are commonly used.

Various approaches exist to structure a proof mass in a cavity. Often the sensor signals are amplified in the same package. To reduce the cost of an acceleration measuring system, electrical circuitry may be integrated on the same silicon die, as decribed by J. Bausells et al. in “Mechanical Sensors Integrated in a Commercial CMOS Technology”, Sensors and Actuators, A 62, pp. 698 - 704, 1997.

To increase the ratio between fixed and movable chip section, the circuitry might be directly integrated on the proof mass, as shown by Yamamoto et al. in US patent 5 460 044, dated 24 Oct. 1995.

The separation of the proof mass from the rest of the sensor unit is usually done by etching. If this etching process is not compatible with the etching process used for circuitry production, circuitry and proof mass have to be produced on separate components and assembled during packaging, as shown by Dunn et al. in US patent 5 164 328, dated 17 Nov. 1992.

If the proof mass structure is integrated on the same chip as the electrical circuitry, it has to be protected from environment. The forming of protecting caps results in additional production steps and thus increases the cost of the accelerometer device.

For the electrical connection of the proof mass and/or the electrical circuitry, wire bonding or flip-chip methods are used as disclosed by J. A. Plaza et al. in “Piezoresistive Accelerometers for MCM Package,” Journal of Miroelectromechanical Systems, vol. 11, 6, pp. 794 - 801, 2002 and by Honda et al. in US patent 5 659 196, dated 19 Aug.1997.

Flip-chip bonding might also be used for connecting the different parts of the cavity and/ or proof mass. This approach is shown by Zimmermann in DE patent 196 36 543, dated 13 March 1997.

Solder balls of flip-chip processes or plated metal structures on top of a semiconductor die are also used as proof mass, as disclosed by Kim in US patent 5 905 044, dated 18 May 1999. As such a metal mass is limited in size, cavities under the ball pad are used to increase the sensitivity. This has also to be done with additional etching processes. The acceleration forces are measured near the pad with piezoresistive sensor structures. A plurality of sensors can be used to also determine the acceleration direction, as shown by Miyazaki in US patent 5 723 792, dated 7 Sep. 1995.

It is thus apparent that a variety of acceleration measurement devices and structures are known, serving different needs and providing advantages depending on their particular environment. However, practically all of them are using one or more discrete sensing or proof masses which are mostly separate from the other components and usually require a number of process steps to be made. Also, these mostly additional, discrete mass structures increase both volume and weight of the acceleration measurement device and thus make it relatively bulky and expensive. When using a small existing component, as in the case of the solder balls as disclosed by Kim in US patent 5 905 044, supra, additional measures must be taken to compensate for their small size and therefor limited signal strength.

In a paper "Eight-beam piezoresistive accelerator fabricated by using a selective porous silicon etching method" by J.H. Sim et al., published in Transducers '97, 1997 Intl. Conference on Solid-State Sensors and Actuators, Chicago 1997, the authors disclose a flip-chip fabrication method for an accelerometer. However, here also is a separate proof or seismic mass provided which must be fabricated, and which increases total weight and size of the accelerometer.

Shinogi et al. US patent 6 158 283 discloses an acceleration sensor in form of a cantilever whose free end reacts on acceleration/deceleration forces and whose evaluation circuits are partly located on or in the cantilever. A seismic mass or "dead weight" is attached to the free end of the cantilever. Here again, a separate proof mass is provided which increases total weight and size of the accelerometer.In a very different field of technology, local stress fields around mechanical contacts are being investigated and sensor structures developed for measuring forces occurring in wire bond applications. Here, ultrasound stresses and bond forces during the bonding process are being measured, as described by Mayer et al. in EP 1 204 143, dated 26 Oct. 2001, and EP 2 002 445, dated 1 Feb 2002. This technology is also described by Bolliger et al. in EP 953 398 of 6 Feb. 1998 and by J. Schwizer, H. Baltes et al. in "Analysis of

Ultrasonic Wire Bonding by in Situ Piezoresistive Microsensors," Proc. Transducers '01 / Eurosensors XV, 2001. None of these disclosures however address, or hint towards, any other application of the described stress measuring arrangements, and none mentions any possibility of using the integrated circuit whose contacts are being investigated.

Brief Summary of the Invention

The present invention now creates a novel approach for establishing the necessary proof mass in an accelerometer. There are two elements in this invention: First, instead of using a discrete mass, be it a separate component or part of an existing component of an accelerometer, as proof mass, the entire semiconductor chip carrying the accelerometer's electronic circuits is the proof mass. Second, to accomodate this solution, the acceleration forces are measured at the mechanical and/or electrical connection(s) between the "proof mass chip" and its base or substrate, i.e. the structure the chip is attached to. In other words, any movement of the proof mass chip results in a force at the mechanical and/or electrical contacts, these forces are measured by sensor elements and evaluated by circuitry on the proof mass chip.

The solution according to the invention provides for a number of advantages:

- No "dead" weight is added to the accelerometer device.
- The size of the accelerometer device can be kept to am minimum.
- No additional etching steps are needed to form the proof mass.
- All that results in lower production cost of the accelerometer device.

The support of the proof mass chip results from the packaging process. This is preferably a flip-chip packaging process which is highly suitable for mass production. The elimination of the etching steps commonly needed for proof mass formation further lowers production cost.

Forces between chip and substrate resulting from temperature changes are crossed out by symmetry. This may be done by weighted summation of the forces that act on the individual contacts as explained below.

Brief Description of the Drawings

The present invention and its advantages will be better understood when the written description provided herein is taken in conjunction with the drawings wherein:

Fig. 1	is a cross section of an acceleration sensor chip, i.e. a "proof mass chip" mounted on a substrate by flip-chip bonding;
Fig. 2	is a perspective view of a partial proof mass chip showing a solder ball and integrated stress sensor elements on the chip;
Fig. 3	shows a top view of a proof mass chip with sensor structures;
Fig. 4	shows a close-up cross-section of a proof mass chip with a solder ball and associated sensor elements in detail;
Fig. 5	is a top view of piezoresistive sensor elements surrounding a solder ball; these sensor elements may form a Wheatstone bridge;
Fig. 6	is a top view of an alternative arrangement of sensor elements;
Fig. 7	shows an example for a possible measuring principle;
Fig. 8	is a schematic showing a possible layout of a circuitry for evaluating the signals of an array of sensor elements;

Fig. 9	is a cross section of an exemplary embodiment;
Fig. 10	shows another force sensor structure;
Fig. 11	is an alternative embodiment using a ball bump as mechanical/electrical contact to the substrate; and
Fig. 12	is an acceleration device with inceased sensitivity due to an additional mass bonded on the device.

For the sake of clarity, the figures do not necessarily show the correct dimensions, nor are the relations between the dimensions always in a true scale.

Description of Preferred Embodiments

The fabrication of an accelerometer system according to the invention can be seen as a two step process.

In a first step, desired electrical circuitry and sensor structures are formed on a silicon substrate or wafer. The result is a chip or die comprising both sensor elements for the electrical and mechanical bonds of the chip and circuitry, connected to said sensors, for evaluating the signals derived from them.

In a second step, the chip is packaged, using an essentially established packaging technology, whereby the chip is arranged such that forces are exerted on desired ones of the mechanical or eletrical connections or bonds when said package is accelerated, i.e. the result of the packaging step is the completed accelerometer.

Fig. 1 shows a cross section of an accelerometer according to the invention. The "proof mass chip" 3, which comprises both the sensors 2 and the here not shown evaluation circuitry, is mounted on a substrate 1. The substrate type is irrelevant; it may be a part of a housing, a laminated plastic structure, ceramic substrates, epoxy laminates, polyimide laminates, a silicon die, etc. Generally, the better the matching of the temperature coefficients of expansion between the substrate 1 and the chip 3, the lower the supplementary force of temperature expansion and the lesser the need for compensation of temperature effects. To electrically connect the chip 3 to the substrate 1, which in this embodiment occurs by solder balls 4, at least one metal layer 5 on top of the substrate 1 is provided. This metal layer 5 can be covered with a solder mask 6 to improve the definition of the contact area to the solder.

In this embodiment, the sensors 2 are integrated on the chip 3 close to the solder balls 4. The production of the sensors 2 is fully compatible with complementary metal-oxide semiconductor processes (CMOS), i.e. no additional or different production steps are needed to form the sensors. A two-metal/one-polysilicon layer CMOS process with a gate length of 0.8 µm, which is a commercial available process offered by numerous companies, may be used. Thus, since the production of the electronic circuitry is a rather standard procedure, only the structure of the sensors 2 will be discussed here in detail.

As shown in Fig. 2, each sensor structure consists of a plurality of sensors each of which provides a sensor signal proportional to the force exerted by the solder ball 24 in a selected direction. An x-force sensor 25 produces a signal corresponding to forces occurring in x-direction. An y-force sensor 26 and a z-force sensor 27 produce signals corresponding to the respective forces. All sensor structures 25, 26, and 27 are integrated on the silicon chip 21, surrounding the solder ball 24 which here serves as both electrical and mechanical contact to the substrate (not shown in Fig. 2).

Fig. 3 shows an example of four sensors 31 integrated on a chip 32, but any other arrangement and number of sensors may be used. Each sensor is placed around a solder ball 33 that here also serves as electrical and mechanical connection. The rest 34 of the chip area is occupied by electrical circuitry used for processing the sensor signals. This may include one or more amplification stages, multiplexing circuitry, analog-to-digital conversion circuitry, etc. Even a microprocessor and a memory may be integrated on such a chip. The derived signals, being indicative of the measured acceleration, are routed to the external via the solder balls 33 either as analog signals or digitized and thereafter transmitted with an appropriate serial or parallel interface.

Fig. 4 shows a close-up of a cross section of such a sensor and its solder ball 44. One or more p^+-doped drain-/source implantations or diffusions 41 are used as stress sensing elements. Each diffusion 41 is electrically isolated from the chip's substrate 42 by an n-doped well 43. The sensor elements are covered with a passivation layer 45. The electrical connections 46 on the chip are done with metal layers of the CMOS process. The passivation layer 45 is opened over the pad metallization 47 which serves as base for the underbump metallization 48 and solder ball 44.

Other sensor elements may be based on a n^+-doped or n-well implantations integrated in the slightly p-doped substrate. Even other CMOS / BiCMOS / SOI-CMOS processes may offer additional possibilities to integrate stress sensing elements. This includes, for example, stress sensitive transistors and/or piezoelectric or piezoresistive structures.

Fig. 5 shows a first example of a geometry or layout for the elements of a sensor. Each of the uniaxial force sensor elements consists of four piezoresistive serpentine-shaped resistors, arranged in a rectangle. For an x-force sensitive sensor structure, the piezoresistors 52, 53, 54, and 55 are connected in such a way that only forces in x-direction are sensed, provided the (mechanical) contact is at least approximately circular. The piezoresistors 56, 57, 58, and 59 of the y-force sensor are identical to the y-force sensor except that they are rotated 90 degrees. The piezoresistors 50, 51, 50a, and 51a, forming the z-force sensor, are placed on the diagonal axes.

The piezoresistive sensor elements of Fig. 5 are connected in a full Wheatstone bridge configuration as shown in Fig. 8. This arrangement of the sensor elements minimizes temperature sensitivity and geometric offset of the sensors.

Other geometric arrangements of the sensor elements are also possible. Fig. 6 gives an example of a sensor based on slanting n^+-doped structures. The piezoresistors 60, 61, 62, and 63 measure the x-force. The piezoresistors 64, 65, 66, and 67 measure the y-force. The z-force piezoresistors 68, 69, 68a, and 69a are used for the z-force measurement. Z-force piezoresistors under the contact zone will increase the sensitivity. However, placement sensitivity and temperature sensitivity will also increase and the arrangement shown may restrict the pad design.

Accelerometers active in only two axes or just one axis can be designed without any major change in the general layout by omitting the piezoresistors for the unused axes.

As mentioned above, the packaging of the chip is based on commercially available processes. Packaging is the subsequent step and consists in brief of the following.

Coming back to Fig. 4, an under-bump metallization 48 separates the pad metallization layer 47 and the solder ball 44. Here, a nickel layer of 5µm and a 50nm gold layer are stacked. Solder paste is then placed on this under-bump metallization with a screen printing process. A subsequent heat treatment forms solder balls 44 on the pad.

Other contact forming processes are also applicable as the sensor usually does not restrict the pad design. The sensitivity of the sensors is defined by the solder ball footprint. It is therefore important to control the solder ball footprint with a well defined under-bump metallization size and form in order to get equal sensitivities for all sensors. The sensitivity and dynamic range of the accelerometer system can be controlled by varying the amount and the size of the interconnection joints.

Thus each individual chip houses the electrical circuitry, the sensors with their elements, and the electrical contacts. And each individual chip is, when attached to a base, so-to-speak a self-contained, acceleration-sensing proof mass.

Fig. 7 explains how the acceleration signals are extracted from the signals of the individual sensors at the solder balls and how they are balanced. In the case of four solder balls, as also shown in Fig. 3, acceleration forces and forces that result from other effects can be separated. To correct temperature-induced forces, i.e. forces due to temperature expansion coefficient mismatches between base and chip, the forces acting on the different solder balls 75 are summed. Temperature-induced, i.e. thermally caused, forces will be point symmetrical as indicated at 77 in a kind of force diagram and therefore crossed out. Homogeneous bending of the chip 74 or the substrate (not displayed in this figure) results also in a force distribution on the solder balls that can be crossed out. The acceleration in x-direction is given by the sum

$$a_x = \frac{\gamma_x}{u_{\text{bridge}} m_{\text{die}}} \sum_{i=1}^{4} s_x^i \qquad (1)$$

of the sensor force signals s_x^i in x-direction as shown in 76, another force diagram. The signal has to be normalized by the applied voltage u_{bridge} of the

Wheatstone bridge. The calibration factor γ_x is the sensitivity of the sensor. To get the acceleration, the mass of the chip m_{die} must be known. The accelerations in y-direction

$$a_y = \frac{\gamma_y}{u_{bridge} m_{die}} \sum_{i=1}^{4} s_y^i \tag{2}$$

and in z-direction

$$a_z = \frac{\gamma_z}{u_{bridge} m_{die}} \sum_{i=1}^{4} s_z^i \tag{3}$$

are calculated correspondingly. The calibration values γ_x and γ_y are equal because both the x-force sensor and the y-force sensor are identical in the present embodiment. In addition, the acceleration torque of the z-axis, as indicated in force diagram 78

$$\dot{\omega}_z = \frac{1}{u_{bridge} I_{die}} \sum_{i=1}^{4} \gamma_y r_x^i s_y^i - \gamma_x r_y^i s_x^i \tag{4}$$

is a function of the x- and y-force sensor signals and the position of the sensors. The sensor position (r_x, r_y) is given relative to the center of the chip and the mass is replaced by the moment of inertia I_{die} of the chip.

Fig. 8 shows the analog circuitry that is used for switching and amplifying the sensor signals. The sensors 80, 81, 82, and 83 of a sensor structure are connected in a full Wheatstone bridge configuration. Table 1 below assigns the sensors of Figs. 5 and 6 to the wiring scheme in Fig. 8. Due to the particular arrangement of the sensors, as shown in the figures and explained above, forces along the different axes or directions can be separated.

Table 1: Electrical connection table of the sensors to form a uniaxial force sensor

	Piezoresistor number of Wheatstone bridge (refer to Fig. 8)			
	80	81	82	83
x-force sensor (refer to Fig. 5)	52	54	53	55
y-force sensor (refer to Fig. 5)	56	58	57	59
z-force sensor (refer to Fig. 5)	50	51	51a	50a
x-force sensor (refer to Fig. 6)	65	67	66	64
y-force sensor (refer to Fig. 6)	63	60	61	62
z-force sensor (refer to Fig. 6)	69	68	69a	68a

To reduce power consumption and space used for the electrical circuitry, each on-chip integrated sensor structure is connected to a bus system 85 with analog switches 84 and 84a. The sensors are powered by a constant voltage source 86. Sensor signals on the bus system 85 are amplified by a differential amplifier 87. High frequency noise can be removed by a low-pass filter 87a. An offset correction circuitry 88 is used for offset reduction. The resulting sensor signal 89 is converted from analog to digital, preferably on-chip.

The control and signal lines of the electrical circuitry are connected with the same solder balls as the ones used for the measurement. In other words, there is no additional wiring necessary that could mechanically distort the measurement.

Further, an on-chip integrated temperature sensor can be used for correction of the temperature coefficient of the sensors or any other component on the chip. The person skilled in the art would know how to implement such a temperature compensation.

Fig. 9 is a cross section of another exemplary embodiment. Though it looks somewhat similar to Fig. 7, it implements a different measuring approach. This approach shall be explained in the following. Whereas the measurement principle shown and explained with regard to Fig. 7 uses the acceleration and deceleration forces occurring parallel to the movement of the proof mass chip, the principle of the Fig. 9 embodiment essentially exploits the "tilting forces" occurring because the chip's center of gravity usually has a certain orthogonal distance from the measurement plane.

The sensor chip 93 is connected by four solder balls, of which only two, 92 and 92a, are visible, to a substrate or base 99.

As the center of gravity 91 of the sensor chip 93 is above the chip surface with the solder balls 92 and 92a, an acceleration or deceleration in x-direction, indicated by arrow 90, will not only generate forces 95 in that direction, but also generate forces 96 and 97 perpendicular to the chip surface. These forces are detected with piezoresistive sensors 98 and 98a and can, for four solder balls (of which only two are visible in Fig. 9), be calculated according equation

$$F_z = \pm \frac{1}{4} \frac{w_{die}^2 h_{die}^2 \rho}{p_{pad}} a . \qquad (5)$$

The acceleration a is the acceleration at the center of gravity 91. The "pad pitch" p_{pad} is the distance between the solder balls 92 and 92a in the x-direction. The chip has the dimensions width w_{die} and height h_{die} which can thus be selected to tailor the sensitivity of the accelerometer system to the application needs. Obviously, the same applies to the forces in y-direction.

A n^+-force sensor element 98 and 98a integrated under each of the solder balls 92 and 92a (and also under the not shown other two solder balls) produces a resistance change when normal forces 96 and 97 are applied, see equation (5) above.

An appropriate design of a force sensor structure for the embodiment of Fig. 9 is shown in Fig. 10. A serpentine-shaped piezoresistor 36 is integrated under the pad 38 for the solder ball. Other sensor shapes may also be adaptable. The production of the sensor structure is the same as described for the previous embodiment. To make the sensor sensitive to acceleration forces directed in a selected direction, four of such sensors structures under different solder pads are connected in a full Wheatstone bridge configuration as also described above. For a dual axis acceleration device, the four pads are preferably placed in a square matrix as shown in Fig. 3. A force acting in x- or y-direction will increase the resistance of two of the sensor structures, whereas it will decrease the resistance for the other two sensor structures. These resistor changes are converted by a Wheatstone bridge into a sensor voltage that is proportional to the acceleration.

The normal force, i.e. the force perpendicular to the x- and y-directions, causes a stress field σ_{zz} in the silicon. This stress field is localized under the pad 38 in Fig. 10. Therefore, sensor structures placed beneath the contact pad 38 can be used to compensate sensor drifts in first order. Sensor elements 35 and 37 are joined and form one resistor of a second Wheatstone bridge which is used as reference for compensating offset drifts.

The signal conditioning is comparable to the embodiment shown in Fig. 7, except that less sensors are needed which in turn results in a simpler circuitry.

In the prior embodiment elucidations, solder balls are used as mechanical and electrical contact between the acceleration-sensing proof mass chip and the substrate or base. This however is not the only embodiment possible. Any other suitable contacts can be used which allow local electrical and/or mechanical contact between substrate and chip.

Fig. 11 shows such an alternative contact embodiment. The sensor structure with the electrical connection 100, passivation layer 101, n-doped well 102, and drain/source implantation/diffusion 103 is equivalent to the embodiment shown in Fig. 4. To form the contact however, a gold ball 104 is bonded on the aluminum pad 105. This gold ball 104 is the first bond of a wire bond interconnection. This kind of mechanical/electrical connection is widely used for interconnecting a semiconductor chip with a substrate. Wire bonder suppliers offer this special mode which only bonds the first connection and then tears the wire off. The remaining gold ball 104 can be used as flip-chip interconnection bond. To improve the reliability under harsh environmental conditions, additional diffusion barrier layers may be added between the aluminum pad 105 and the gold ball 104. After bonding all gold balls, the chip is flipped and bonded on the substrate. This can be done with ultrasound vibration and/or heat and/or by applying sufficient pressure.

Fig. 12 exhibits an exemplary possibility to further increase the sensitivity of a acceleration system according to the invention. Here an additional mass 108 is glued or otherwise affixed on top of the chip 106 which is bonded to the substrate 107 as described above. The additional mass 108 is bonded on top of the chip 106. The bond 109 between the two bodies can be established by anodic bonding, e.g. prior to ball placement and flip-chip bonding, or by using epoxy adhesives.

While the present invention has been described by way of a few examples, these shall not limit the scope of protection since it is obvious to someone skilled in the art that the invention can be easily adapted to match many requirements in the field of accelerometer systems, including their design and/or manufacturing and integration.

CLAIMS

1. An accelerometer system with a base (1), an integrated circuit chip (3), an acceleration force sensor (2), and electrical and/or mechanical connecting means (4, 9) between said base (1) and said chip (3), *wherein*
   - said chip (3) is the proof mass of said system and includes at least part of the evaluation circuitry of said system,
   - said sensor (2) is located adjacent said connecting means (4, 9) and activated by mechanical forces exerted by said connecting means.

2. The accelerometer system according to claim 1, *wherein* the sensor (2) comprises a plurality of sensor elements (5, 6, 7) surrounding and/or underlying, preferably in a symmetric arrangement, the connecting means (4, 9).

3. The accelerometer system according to claim 1, *wherein* a plurality of sensors (2) is provided and at least one of them is located on the chip (3) and electrically connected to the evaluation circuitry (Fig. 8) on said chip.

4. The accelerometer system according to claim 1, *wherein* a plurality of sensors (2) is provided and at least one of them is located on the base (1) and electrically connected to evaluation circuitry (Fig. 8) on the chip (3), providing acceleration force signals to the evaluation circuitry.

5. The accelerometer system according to claim 1, *wherein* the connecting means (4) is one or more solder balls and the chip (3) is attached to the base (1) by flip-chip technology.

6. The accelerometer system according to claim 1, *wherein* the connecting means (4) is one or more wires serving as mechanical and electrical connection between the chip (3) and the base (1) in so-called wire-bonding technology.

7. The accelerometer system according to any preceding claim, *wherein* the acceleration force sensor (2) is an integrated stress-sensitive sensor, preferably a piezoresistive sensor, and/or is connected in a Wheatstone bridge configuration.

8. The accelerometer system according to any preceding claim, *wherein* a plurality of connecting means (4) with associated sensors (2) is provided in a symmetrical arrangement.

9. The accelerometer system according to any preceding claim, *wherein* the integrated circuitry on the chip (3) comprises integrated switching means for routing sensor signals through the connecting means (4).

10. The accelerometer system according to claim 9, *wherein* the integrated circuitry on the chip (3) further comprises integrated amplification (60) and/or analog-to-digital conversion means, preferably arranged around a bus structure.

11. The accelerometer system according to claim 9, *wherein* the integrated circuitry on the chip (3) further comprises an integrated temperature sensor.

12. The accelerometer system according to any preceding claim, *wherein* the chip (3) includes an additional proof mass attached to it.

AMENDED CLAIMS

[received by the International Bureau on 02 April 2004 (02.04.04);
original claims 1-12 replaced by new claims 1-14 (2 pages)]

1. An accelerometer system with a base (1), an integrated circuit chip (3), an acceleration force sensor (2), and electrical and mechanical connecting means (4, 9) between said base (1) and said chip (3), *wherein*
   - said chip (3) is the proof mass of said system and includes most or all of the evaluation circuitry of said system,
   - said connecting means (4, 9) is fabricated with a standard semiconductor packaging process, and
   - said sensor (2) is located adjacent said connecting means (4, 9) on said chip (3) and activated by mechanical forces exerted by said connecting means.

2. The accelerometer system according to claim 1, *wherein* the sensor (2) comprises a plurality of sensor elements (5, 6, 7) surrounding and/or underlying, preferably in a symmetric arrangement, the connecting means (4, 9).

3. The accelerometer system according to claim 1, *wherein* a plurality of sensors (2) is provided and at least one of them is located on the chip (3) and electrically connected to the evaluation circuitry (Fig. 8) on said chip.

4. The accelerometer system according to claim 1, *wherein* a plurality of sensors (2) is provided and at least one of them is located on the base (1) and electrically connected to evaluation circuitry (Fig. 8) on the chip (3), providing acceleration force signals to the evaluation circuitry.

5. The accelerometer system according to claim 1, *wherein* the connecting means (4) comprises one or more solder balls and the chip (3) is attached to the base (1) by means of said solder balls in flip-chip technology.

6. The accelerometer system according to claim 1, *wherein* the connecting means (4) is one or more wires serving as mechanical and electrical connection between the chip (3) and the base (1) in so-called wire-bonding technology.

7. The accelerometer system according to any preceding claim, *wherein* the acceleration force sensor (2) is an integrated stress-sensitive sensor, preferably a piezoresistive sensor, and/or is connected in a Wheatstone bridge configuration.

8. The accelerometer system according to any preceding claim, *wherein* a plurality of connecting means (4) with associated sensors (2) is provided in a symmetrical arrangement.

9. The accelerometer system according to any preceding claim, *wherein* the integrated circuitry on the chip (3) comprises integrated switching means for routing sensor signals through the connecting means (4).

10. The accelerometer system according to claim 9, *wherein* the integrated circuitry on the chip (3) further comprises integrated amplification (60) and/or analog-to-digital conversion means, preferably arranged around a bus structure.

11. The accelerometer system according to claim 9, *wherein* the integrated circuitry on the chip (3) further comprises an integrated temperature sensor.

12. The accelerometer system according to any preceding claim, *wherein* the chip (3) includes an additional proof mass attached to it.

13. The accelerometer system according to any preceding claim, *wherein* the chip (3) consists of semiconductor material and the base (1) consists of a non-semiconductor material.

14. The accelerometer system according to any preceding claim, *wherein* a plurality of sensors (2) is provided, located exclusively on the chip (3) and electrically connected to the evaluation circuitry (Fig. 8) on said chip.

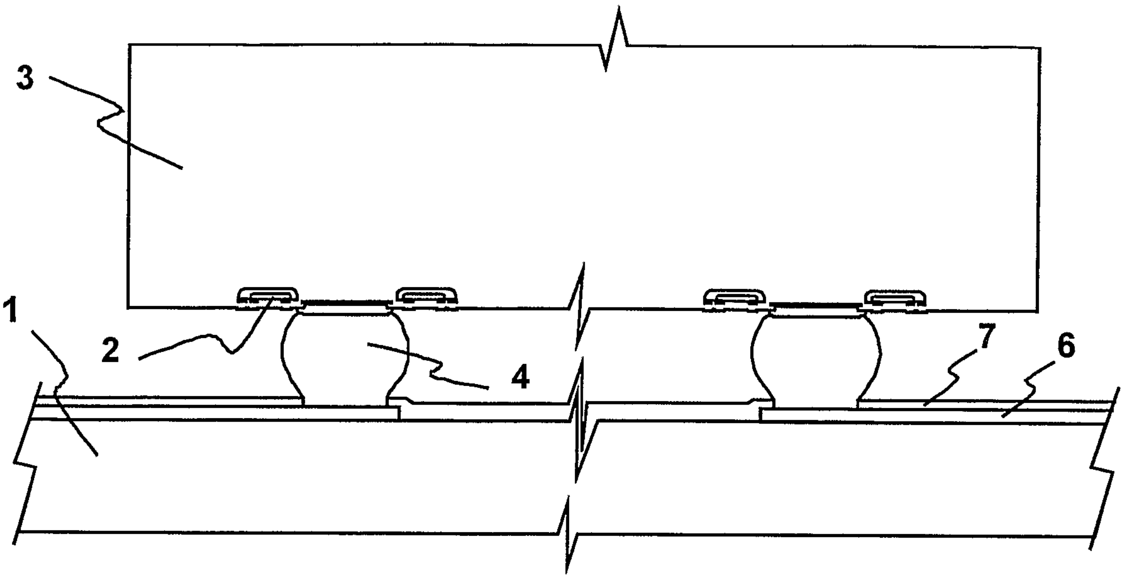

Fig. 1

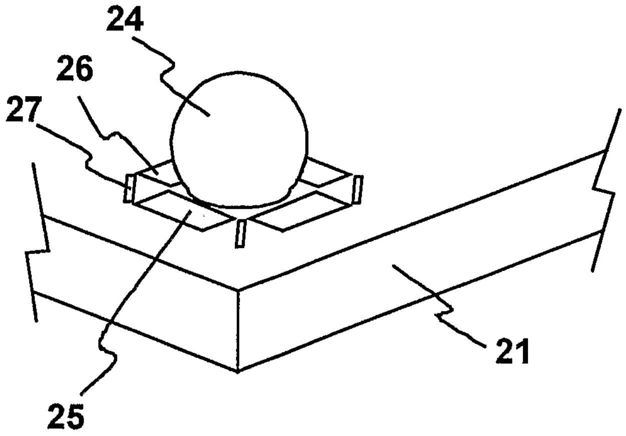

Fig. 2

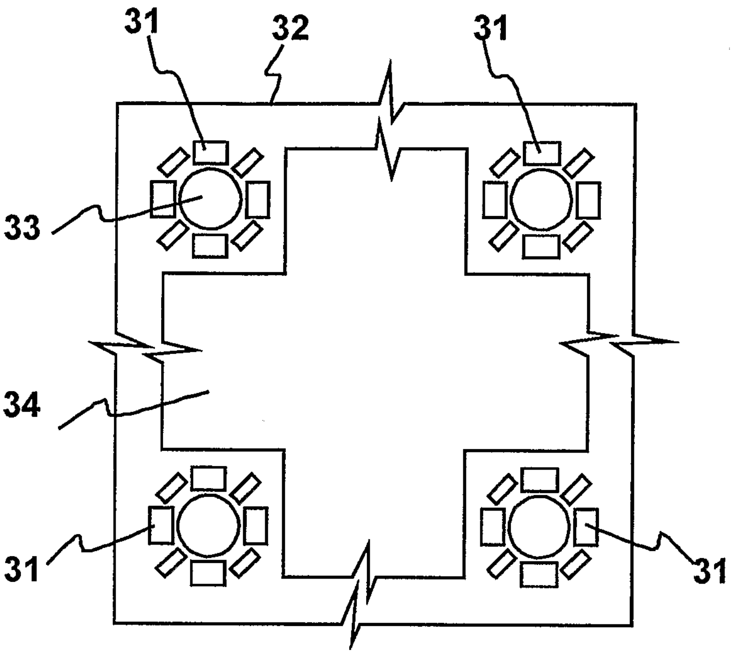

Fig. 3

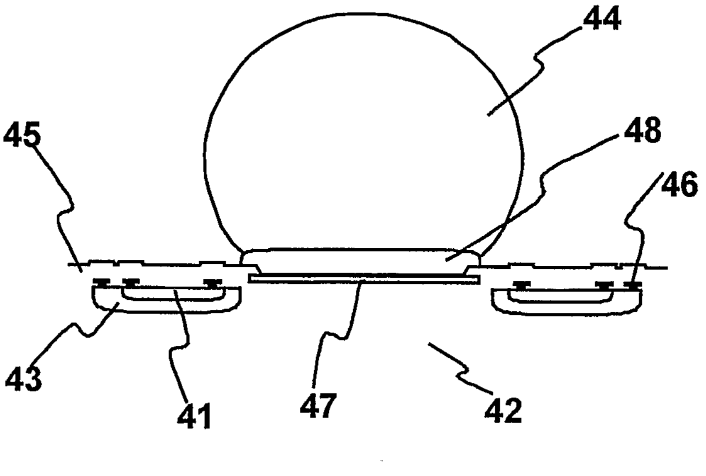

Fig. 4

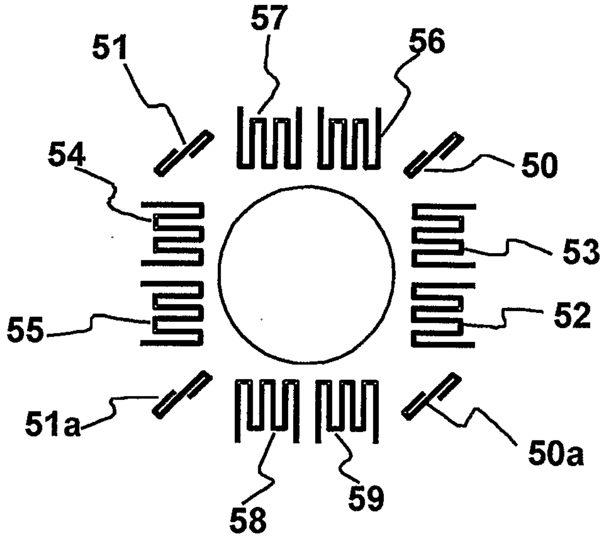
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Fig. 5

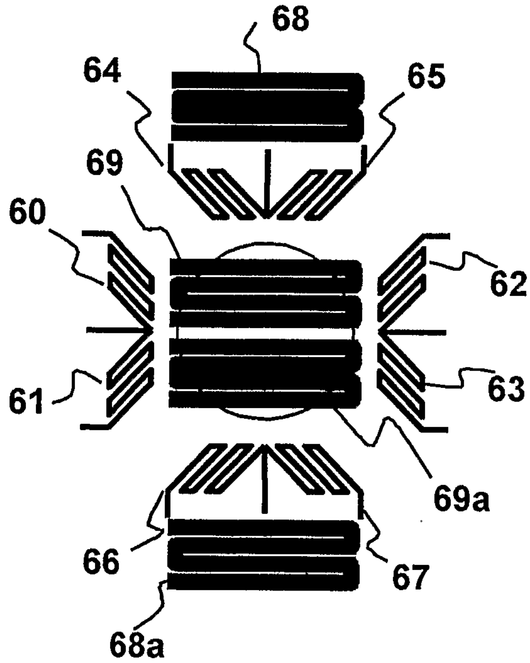
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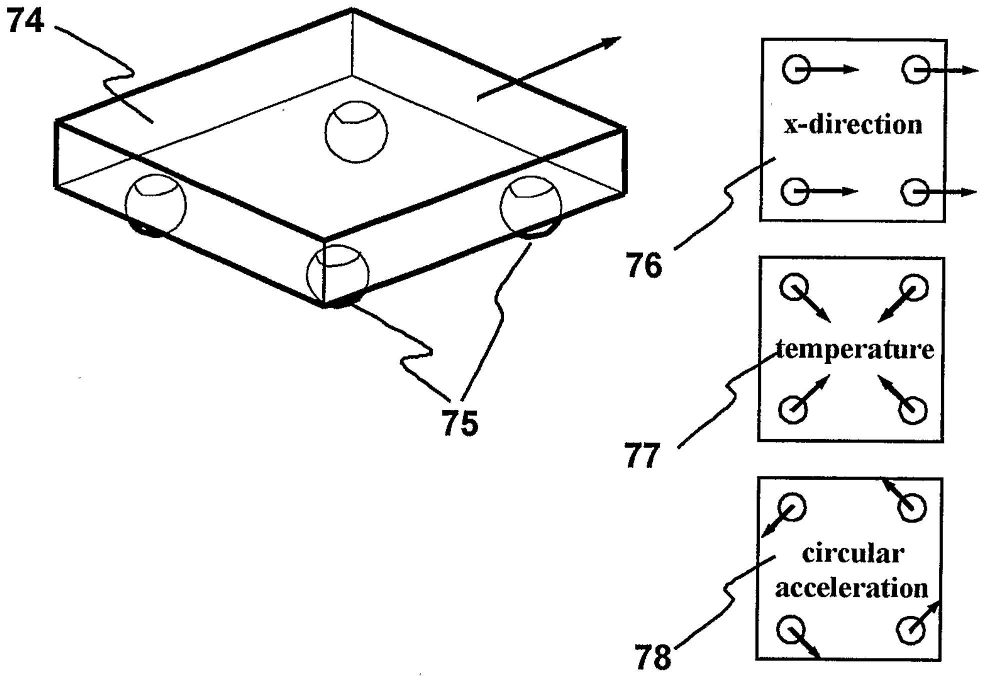
Fig. 6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x-direction
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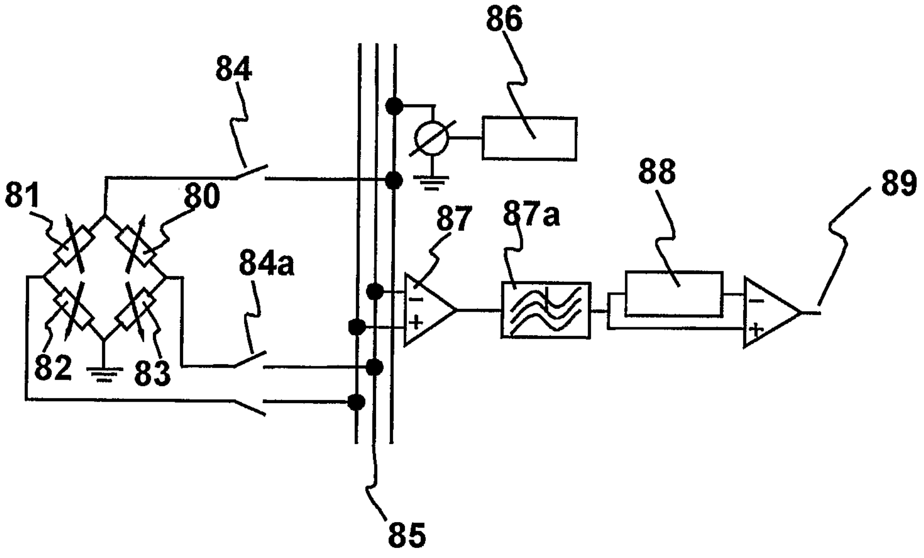
temperature
78
circular
acceleration

Fig. 7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83
85

Fig. 8

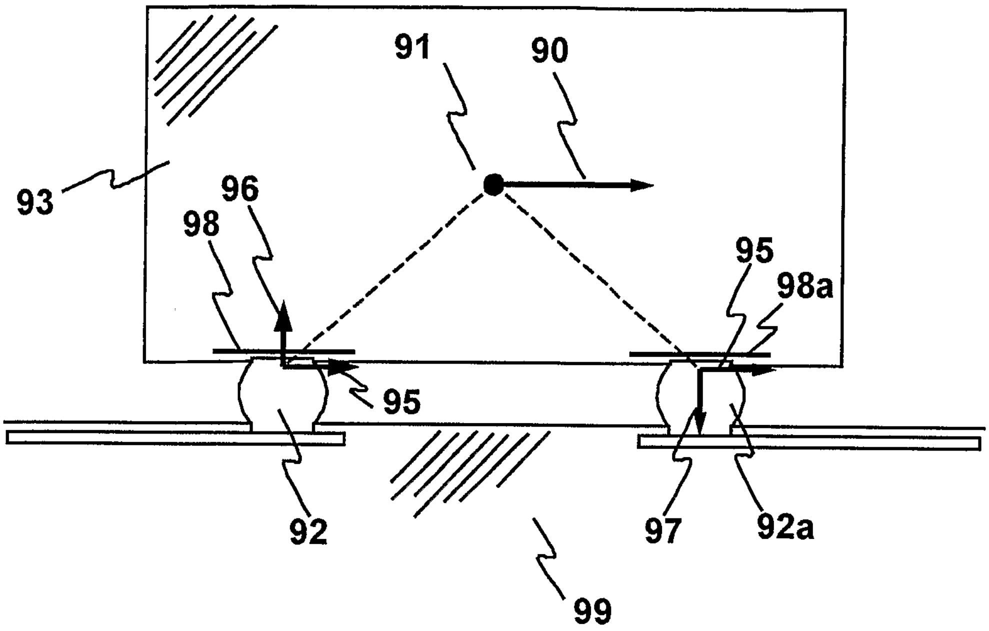

Fig. 9

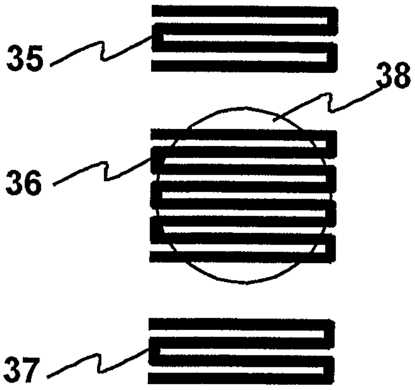

Fig. 10

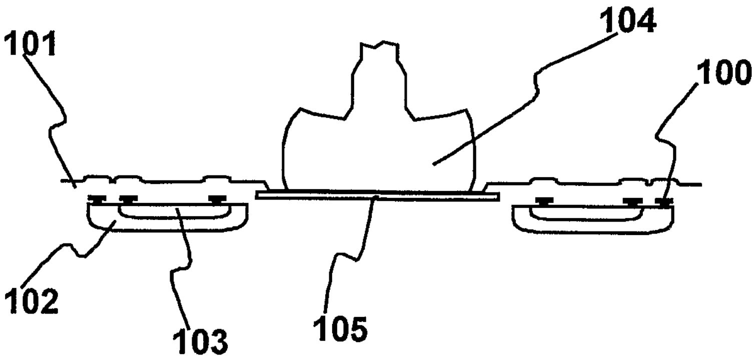

Fig. 11

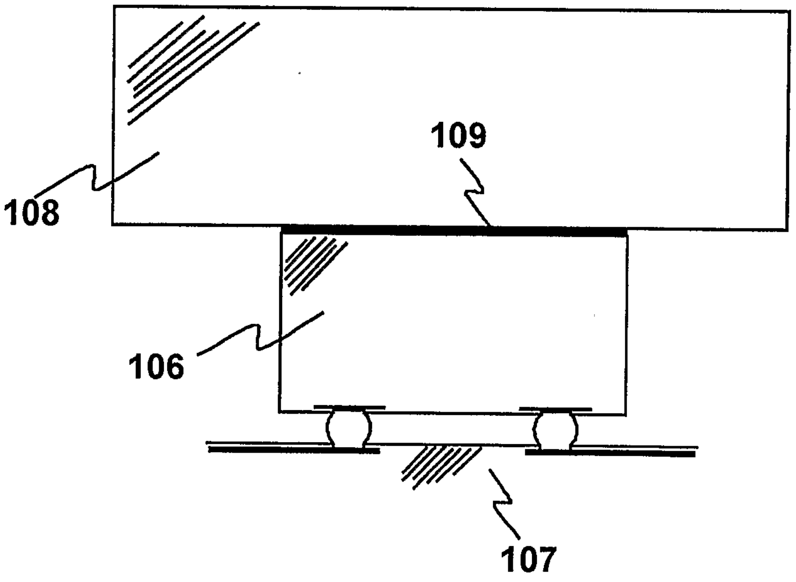

Fig. 12

INTERNATIONAL SEARCH REPORT

Internation ication No
PCT/IB 03/02040

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01P15/12 G01P15/08 G01P15/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y		2,4-6,8, 11
	column 3, line 25 -column 4, line 11 column 5, line 16 - line 17 figures 1,2 ---	
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search 15 January 2004	Date of mailing of the international search report 30/01/2004
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Trique, M

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PCT/IB 03/02040

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 5 279 162 A (TAKEBE KATSUHIKO ET AL) 18 January 1994 (1994-01-18) abstract column 6, line 29 - line 46; figure 1A ---	1
A	SCHWIZER J ET AL: "ANALYSIS OF ULTRASONIC WIRE BONDING BY IN-SITU PIEZORESISTIVE MICROSENSORS" , TRANSDUCERS '01 EUROSENSORS XV. 11TH INTERNATIONAL CONFERENCE ON SOLID-STATE SENSORS AND ACTUATORS. DIGEST OF TECHNICAL PAPERS. MUNICH, JUNE 10 - 14, 2001, INTERNATIONAL CONFERENCE ON SOLID-STATE SENSORS AND ACTUATORS. DIGEST OF TECHNICAL PAPERS, BER XP008002207 ISBN: 3-540-42150-5 cited in the application page 1426 -page 1427; figures 1,2 -----	1

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Information on patent family members

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