METHOD OF MANUFACTURE OF CONVECTIVE ACCELEROMETERS

FIELD OF THE INVENTION

The present invention relates to an improved method of making convector accelerometers and tilt sensors using complementary metal-oxide semiconductor (CMOS) technology.

BACKGROUND OF THE INVENTION

Miniaturization and integration of accelerometers in standard integrated circuit (IC) processes has been the topic of extensive research (see J. Bausells, J. Carrabina, A. Merlos, S. Bota, and J. Samitier, Mechanical sensors integrated in a commercial CMOS technology, Physical Proceedings of the 1996 EUROSENSORS Conference, Part 3 (of 3) Sep. 8–11 1996, Vol. 62, no. 1–3, pt. 3, 1997; G. A. MacDonald, Review of low cost accelerometers for vehicle dynamics, Sensors and Actuators, A, vol. 21, no. 1–3, Pt 2, 1990; H. Seidel, U. Fritsch, R. Gottiner, J. Schalk, J. Walter, and K. Ambaum, Piezoresistive silicon accelerometer with monolithically integrated CMOS-circuitry, Proceedings of the 1995 Eurosensors Conference, Stockholm, Sweden, Part 1, 1995). In most cases, accelerometer structures involve a solid proof mass which is allowed to move under accelerating conditions. This approach has many disadvantages. One key disadvantage is the difficulty of processing of such components in IC technologies inherently unsuited for these components.

More recently, micromachining techniques have brought about many novel miniaturized accelerometer structures, although the fabrication process includes many masks and etching steps. One aspect of the invention concerns the integration of accelerometer devices in CMOS technology, where on-chip drive and sense circuitry is available, and overall costs are lower. Because of these advantages of CMOS technology, many other classes of sensors have been implemented in CMOS by simple post-processing micromachining (see N. H. Tea, V. Milanovi, C. A. Zincke, J. S. Suehle, M. Gaitan, M. E. Zaghloul, and J. Geist, Hybrid Post-processing Etching for CMOS-compatible MEMS, Journal of Microelectromechanical Systems, vol. 6, no. 4, pp. 363–372, Dec. 1997; C. Zincke, V. Milanovi, M. E. Zaghloul, Microelectromechanical Systems Integration in Standard CMOS, Proceed. of 8th International Conference on Microelectronics, ICM96, Cairo, Egypt, 1996; d. Moser, H. Baltes, High sensitivity CMOS gas flow sensor on a thin dielectric membrane, Sensors and Actuators, A: Physical Proceedings of EUROSENSORS VI, vol. 37–38, no. 2, pp 33–37; 1993).

Recently, a new concept and a class of devices for acceleration and tilt sensing were developed as disclosed in U.S. Pat. No. 5,581,034 to Dao et al. The devices require no solid proof mass, and instead the operation of the devices depends on the effect of acceleration on the natural heat convection from heated resistive wires in a gas surrounding the device. In such a device, the sensor is hermetically packaged to deny any influence of external airflow on the gas inside. An implementation of this device by custom fabrication on a silicon substrate is discussed in Leung et al (A. M. Leung, J. Jones, E. Czyzewska, J. Chen, and M. Pascal), Micromachined Accelerometer with no Proof Mass, Technical Digest of Int. Electron Device Meeting (IEDM97), pp. 899–902, Dec. 97. Although the implementation discussed in this reference is a step toward miniaturization and integration, the proposed devices require custom fabrication, and only sensitivity to tilting is discussed in the reference.

In addition to the Dao et al patent, the patented prior art includes the following U.S. Pat. Nos. 2,445,394; 2,554,512; 3,241,374; and 5,719,333. Briefly considering these patents, U.S. Pat. No. 2,445,394 to Webber discloses a convective accelerometer comprising a fluid filled envelope within which is mounted a resistance element with a high temperature coefficient of resistivity. The resistance element can be used to create the thermal convective stream or, alternatively, additional means can be employed for this purpose. U.S. Pat. No. 2,554,512 to Varian discloses an accelerometer based on the resistance of a filament of electrically conducting material. The filament has a high temperature coefficient of resistivity. An electric current passes through the filament, heating the surrounding gas, and creates a convection current. A change in acceleration will affect the rate of heat removal from the filament and proportionally change the filament resistivity. The accelerometer is primarily designed to measure angular acceleration and acceleration in the direction of gravity. U.S. Pat. No. 3,241,374 to Menkis discloses an accelerometer comprising a gas-filled enclosure also containing a heater and a pair of heat receivers. The heat receivers are positioned on opposite sides of the heater, along a line which acceleration of the enclosure may have a component. The heat receivers are electrically connected such that when at the same temperature they yield a composite output voltage of zero. U.S. Pat. No. 5,719,333 to Hosoi et al. discloses an accelerometer constructed by etching a semiconductor board using a photoengraving process. Two sensor cases are joined to form a cavity wherein a heater and a temperature-sensing resistor element are placed. Acceleration effects the temperature distribution within the closed space, changing the resistivity of the temperature-sensing resistor element.

Returning to the Dao et al. patent which was briefly discussed above, this patent discloses a convective accelerometer comprising, in one preferred embodiment, a sealed enclosure containing a heating element, two temperature sensing elements, and a gas sealed within the enclosure. The enclosure includes a header assembly with a plurality of posts extending therethrough. Two pairs of the posts serve as a mounting means for the two temperature sensing elements while a further pair of posts serves as a mounting means for the heating element. The temperature sensing elements comprise wires made of a metal, such as nickel, platinum or tungsten, having a relatively high temperature coefficient of resistivity and the heating element is formed as a wire of the same, or a similar, material. The heating and temperature sensing wires are each suspended at the ends thereof between respective pairs of posts.

SUMMARY OF THE INVENTION

In accordance with the invention a convective accelerometer and tilt sensor device is provided which is implemented in a commercial CMOS process to provide monolithic integration of drive, detection and output circuitry with the sensor on a single chip. The capability of fabricating the convective accelerometer device using CMOS technology affords a significant advantage with respect to cost as well as other advantages.

Considering these advantages in more detail, the convective accelerometer and tilt sensor device made by the method of the invention uses thermocouples as the temperature sensing elements. This approach provides significant benefits and, moreover, would be impractical to implement with the techniques such as those disclosed in the Dao et al patent. In this regard, as described above, making of the devices disclosed in the Dao et al patent involves suspending