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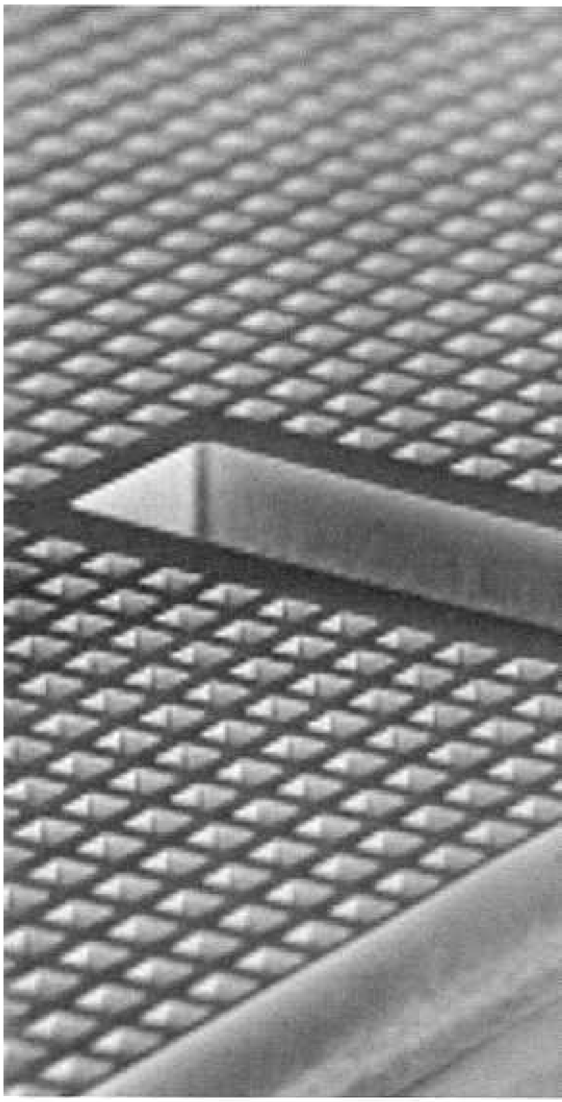


Microsensors take-off

MEMS ACCELEROMETERS ARE REPLACING ELECTROMECHANICAL DEVICES AND ARE BEING UTILIZED MORE AND MORE IN MILITARY AEROSPACE APPLICATIONS

"Stability performance relies on the quality of the raw material"

JEAN-MICHAEL STAUFFER

BY JEAN-MICHAEL STAUFFER

MEMS accelerometers are replacing established, expensive, and fragile high-end electromechanical devices in the military aerospace market. The driving forces for this revolution are the need for devices offering the same or even better performance at lower cost, lower power consumption, a smaller size, and greater strength.

The success of MEMS accelerometers started in the early 1990s with the airbag application in the automotive industry. Today, MEMS accelerometers and gyros are used successfully in numerous automotive and consumer applications. In the beginning, MEMS accelerometers replaced existing devices. They have now enabled previously impossible functionalities such as camera stabilization, human body control, cell phones, and toys. The key factors in the success of these applications were: extremely low cost, reliability, and a low power consumption for moderate performance (4- to 12-bit resolution). The market for automotive and consumer motion sensors is expanding rapidly, with estimated growth of 22.9% in 2010. It is expected to surpass today's most popular MEMS applications (inkjet printing and projectors) by 2014.

A similar process has begun for high-end MEMS accelerometers. High-performance products already on the market are becoming popular in various military aerospace applications, such as testing, instrumentation, and the energy markets. The first barrier to entering these fields is technical, with the issues of stability (1-100ppm of the full scale) and resolution (16-24bits) needing to be addressed. Factors such as cost and performance are now considered more important than robustness, power, and size.

To address these requirements, some people try upgrading versions of automotive sensors but they have relatively little success. It turns out that the basic technologies developed for automotive and consumer applications, which are driven by cost, can not reach the required performance. This limitation is exposed by a different business model. The volumes and qualifications for long-term commitments are radically different for automotive/consumer and high-end markets. In the world of motion sensors, Colibrys has a unique position in the market. It focuses on the high-end markets with an appropriate business model and with technologies specifically designed for performance.

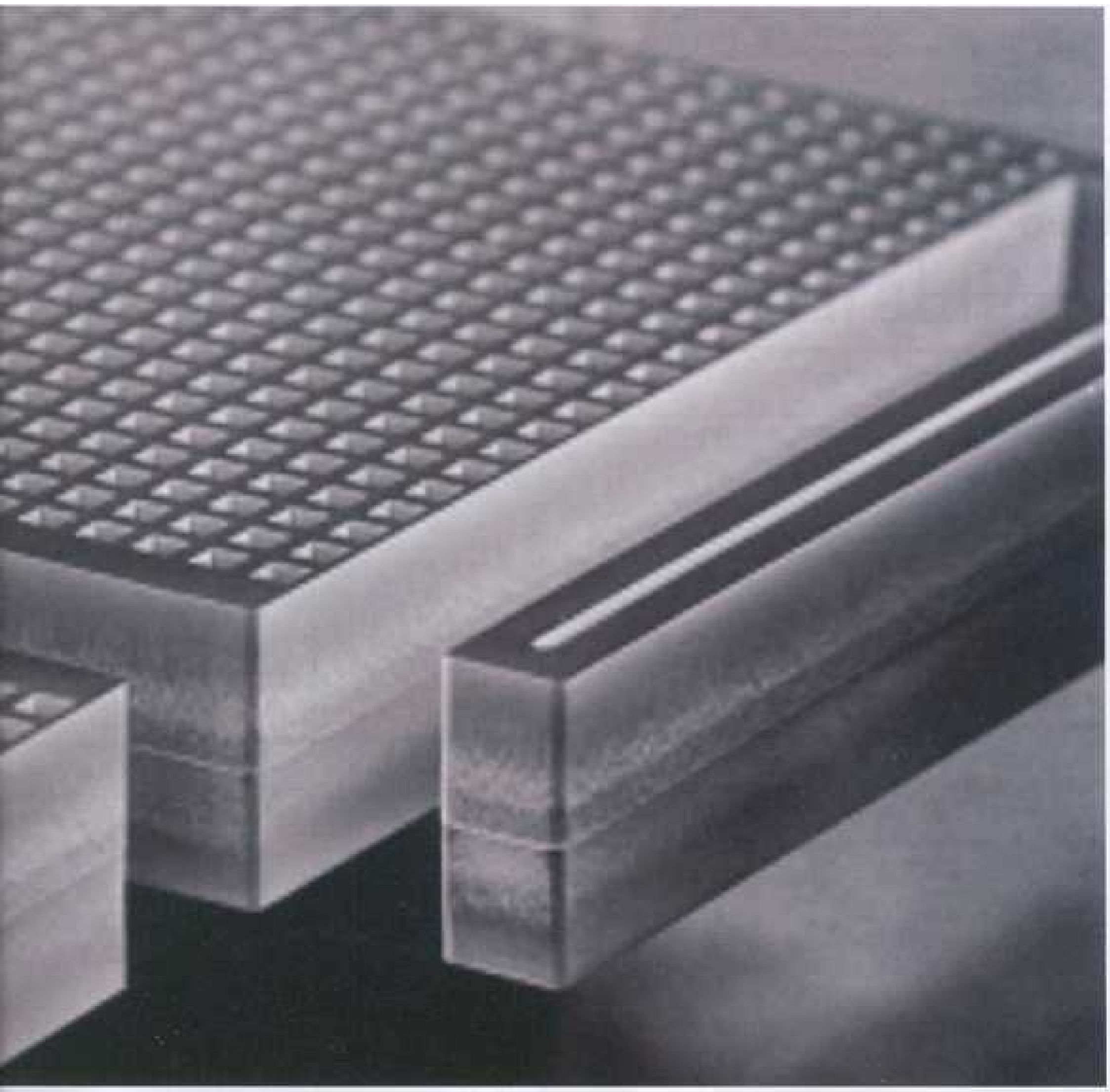
The three key ingredients needed to make a high-performance accelerometer are a stable MEMS sensor, state-of-the-art assembly and packaging technology, and high-quality electronics. The advantage of this technology over traditional electromechanical solutions comes from the lower manufacturing cost of MEMS devices.

Stability performance relies on the quality of the raw material (silicon wafers) and capability of the design in meeting performance with manageable manufacturing tolerances and manufacturing processes, thereby avoiding lengthy and expensive burn-in and selection procedures. High-end MEMS accelerometers need a few hours at most for testing whereas electromechanical devices can sit on test benches for days.

Colibrys has developed innovative proprietary solutions for the three key constituents of MEMS accelerometers over the years.

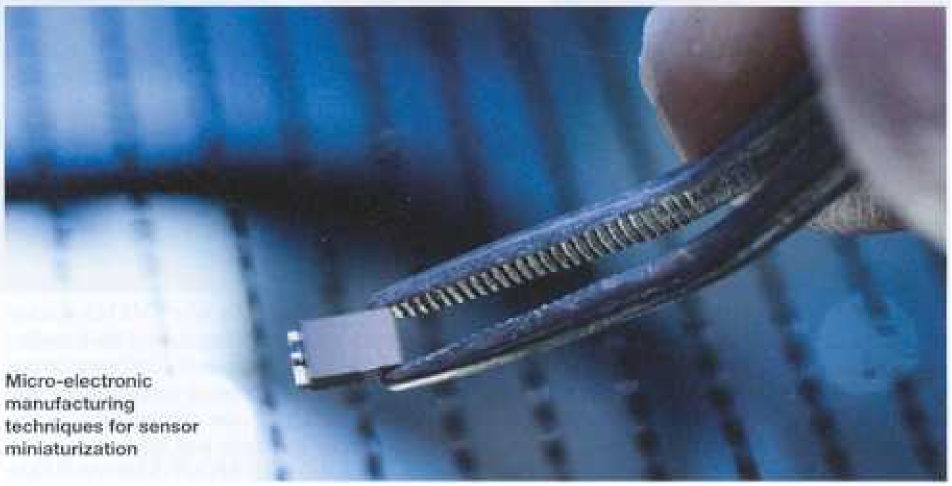
MEMS Sensor

The basic structure of the MEMS sensor is shown in the figure next page. A proof mass with a surface of a few square millimeters and a thickness of



Left: Scanning electronic microscope (SEM) picture of a Silicon MEMS structure realized by deep reaction etching (DRIE)

Below: Custom electronic designed for advanced applications under harsh environments



Micro-electronic manufacturing techniques for sensor miniaturization

several hundred microns is attached by a silicon spring to a frame, which constitutes the basic acceleration detector. Acceleration is electrically determined by the movement of the proof mass and the corresponding variation of the capacitance formed by the proof mass and detection plates separated by a narrow gap (typically 2μm). This structure is realized by the so-called bulk micromachining MEMS process. The three wafers are manufactured independently and are then hermetically bonded in a vacuum at high temperatures to form a wafer stack of hundreds of accelerometers. Compared with automotive/consumer technologies that operate with the thin proof mass moving in the plane, this technology is somewhat more expensive (thicker plates and larger surfaces) but it boasts considerably better performance.

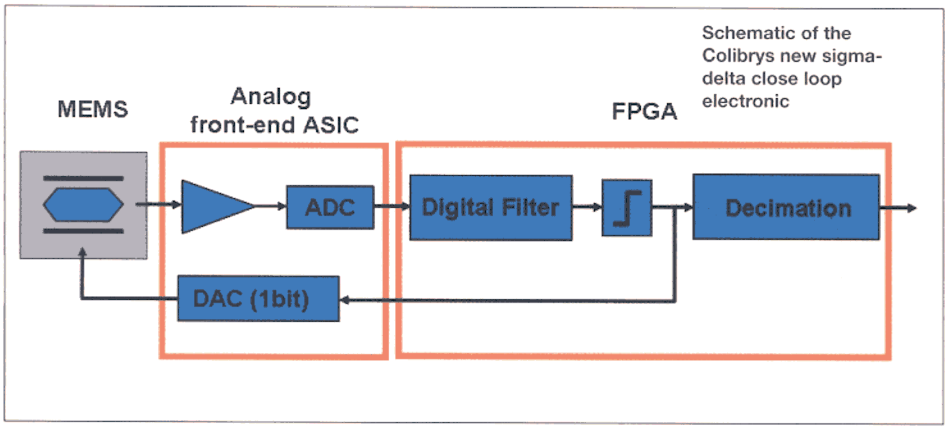
Recently, the design and technology for high-end accelerometers have been refined, increasing the performance of Colibrys accelerometers. The basic stability of the sensor is representative of the repeatability of the proof mass position at zero g. For a fully assembled sensor, the proof mass returns to an initial position within 0.03Nm or 1/30 of the radius of a silicon atom even after extensive temperature and environmental testing. With regard to resolution, extremely low mechanical noise is vital for devices designed for seismic applications. A noise floor of 20ng/√Hz and lower, which is 5,000 times quieter than the noise of quality automotive-grade devices, is maintained during production. This enables the machine to detect the seismic waves from earthquakes tens of thousands of kilometers away. Finally, the gas damping used to induce squeezed film effects leads to non-linear behavior generating vibration rectification errors (or bias shift induced by vibrations). The latest designs have virtually eliminated these effects.

In spite of their fine performance parameters, these devices are extremely robust. Inertial grade accelerometers, for example, can be used in smart munitions where data needs to be collected immediately after the device has been shot from a six-inch cannon with initial accelerations of more than 20,000g. At the same time, high-sensitivity devices need to remain intact and continue functioning after being dropped thousands of times from various heights. This is a major improvement over traditional electromechanical devices that have shock limits of 1,000g.

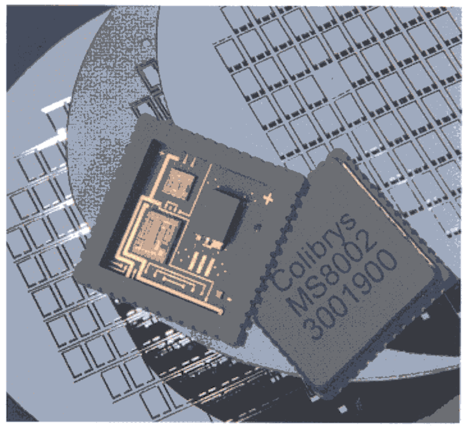
Assembly and packaging

The sensor assembly is critical for precision in harsh environments. Colibrys has chosen a multichip module (MCM) approach that combines the MEMS device and its electronics in a hermetically sealed ceramic package. The MEMS die is attached during a low-stress process to prevent the performance of the MEMS from degrading during assembly.

The package has to protect the sensor and related electronics from external perturbations such as humidity. The MCM modules are qualified against MIL standards, insuring long-term stability and reliability. With a plastic packaging approach that by definition is non-hermetic, and which is commonly used in automotive/consumer devices, performance and long-term stability will suffer.



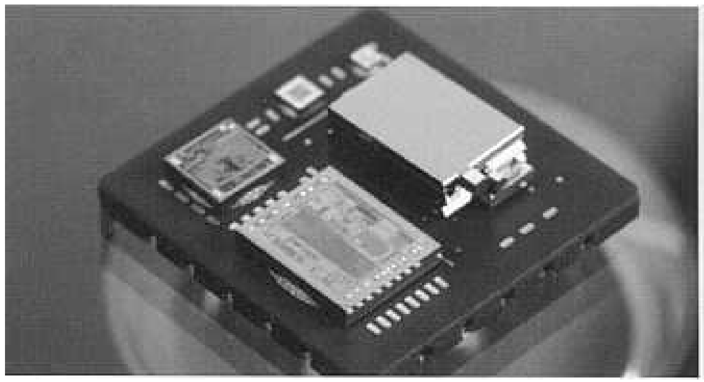
Schematic of the Colibrys new sigma-delta close loop electronic



Above right: Combination of three different structured silicon wafers to produce capacitive MEMS accelerometers

Right: Close view of a Colibrys hybrid MEMS accelerometer assembly (MS9000)

left: Advanced manufacturing clean room for MEMS accelerometer production



Electronics with MEMS Sensors

The electronics associated with the MEMS Sensor are crucial for performance. There are two ways to operate a capacitive MEMS Sensor. For the open-loop approach, mechanical plate deflection is measured via a change in associated capacitance.

This concept provides excellent results for its size and power. However, the system has limitations in terms of noise and linearity. Typically, open-loop sensors work at their best when 16- to 20-bit resolution is required. For closed-loop (or servo) accelerometers, the proof mass is held in a fixed position and the inertia is compensated for by electrostatic forces. With this concept, the limits of MEMS Sensors can be further explored in terms of stability, noise, and linearity. In the future, closed-loop sensors will work in the 20- to 24-bit resolution range and beyond. For these open-loop sensors, a patented, self-balancing bridge concept was implemented in an ASIC. This allows for stable, low noise, and highly linear analog output with low power consumption (~1mW).

With traditional closed-loop accelerometers, Colibrys uses a servo concept based on analog voltage force feedback. This concept is used for the SiFlex family of seismic sensors.

The best performance can be achieved by placing the MEMS Sensor in a Sigma Delta servo loop and applying electrostatic force pulses to rebalance the position of the proof mass. This concept was initially developed for sensors used in seismic imaging but Colibrys is adapting this concept into its navigation-grade accelerometers.

The Sigma Delta servo loop gives exceptional performance in terms of bias stability, noise (20- to 24-bit resolution), and linearity, and it also provides a direct digital output signal. This concept is implemented in a small front-end ASIC and combined with digital signal processing in a FPGA.

This concept uses somewhat more power than the open-loop sensors but it's still only a quarter of comparable traditional electromechanical devices.

Products and applications

For several years Colibrys inertial and vibration open-loop product families – MS8000, MS9000, and VS9000 – have been gaining worldwide acceptance. Colibrys is about to launch its new RS9000 series, which boasts better performance in terms of bias stability, linearity, and vibration rectification.

These inertial products are used in a broad range of applications. Accelerometers are fitted to Inertial Measurement Units (IMU) such as aircraft, UAVs, short-range missiles, and guided munitions. Guided munitions applications usually require the products to be hardened (HS8000) so they can survive the acceleration when fired from a six-inch gun (20,000*g*) and still send a precise and reliable signal.

Inertial sensors are also used for attitude, heading, and reference systems (AHRS) in aircraft, as well as for land navigation. Accelerometers can also be used to measure vibrations and monitor the structural health of airplanes, helicopters, and trains, reducing maintenance downtime. Finally, accelerometers can be used as tilt sensors to aid platform stabilization for cameras, antennas, turrets, and weapons stations. Measuring tilt angles when drilling boreholes in temperatures of over 150°C is also vital. Experimentation with higher temperatures is ongoing.

The SF2006 and SF1600 Colibrys seismic sensors are used as part of the earthquake monitoring network to assess the structural stability of dams, bridges, and nuclear plants. Due to their extremely high resolution, they can also be used for seismic imaging (this is a customer-specific product) or perimeter security.

New products based on closed-loop technology will address demanding inertial applications such as precision navigation and north-finding systems. Their smaller size, lower cost, and higher strength are expected to lead to new applications. It is being investigated, for example, whether accelerometers can be used to assess aircraft wing dynamics and control systems.

For several decades, electromechanical accelerometers such as the Q-flex family from Honeywell and its counterparts from other suppliers were the undisputed leaders when it came to high-end accelerometers.

Since the early 1980s when MEMS accelerometers were being developed, they have revolutionized the automotive and consumer sensor markets, replacing existing technologies and enabling a wealth of new applications. In the high-end sector evolution was slower.

Vibrating beam MEMS accelerometers have proven to be a solution for some specific applications but they did not meet expectation in terms of cost and performance. Recent incarnations of capacitive open- and closed-loop sensors will gradually replace established electromechanical accelerometers as this new technology enters the mainstream. ∎

CONTACT
Jean-Michael Stauffer is VP marketing & sales, Colibrys SA based in Switzerland
Tel: +41 32 720 58 11