Mems Pressure Sensor in Automotive Industry

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Abstract: ***Micro-electromechanical systems (MEMS) are free scale's enabling technology for acceleration and pressure sensors. MEMS based sensor products provide an interface that can sense, process and/or control the surrounding environment. Free scale's MEMS-based sensors are a class of devices that builds very small electrical and mechanical components on a single chip. MEMS-based sensors are a crucial component in automotive electronics, medical equipment, hard disk drives, computer peripherals, wireless devices and smart portable electronics such as cell phones and PDAs. For automotive safety, acceleration sensors provide crash detection for efficient deployment of forward and side airbags as well as other automotive safety devices. Accelerometers are also used in electronic stability control (ESC) to measure the lateral acceleration of the vehicle to help drivers maintain control of their vehicles during potentially unstable driving conditions. Acceleration sensors are also part of free scale's tire pressure monitoring system (TPMS) to detect whether the car is moving to save power, wheel speed and/or direction of rotation.***

Keywords: MEMS, Pressure Sensors, Automotive Application

1. Introduction

MEMS: MEMS is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. The **M**icro **E**lectro **M**echanical **S**ystems technology (**MEMS**) allows to integrate on the same silicon substrate both electronic circuits and optical mechanical devices, adopting semiconductor fabrication technologies similar to those used to make integrated circuits. A MEMS device can be thought of a "brain" (an integrated IC) and a set of "arms" and "eyes" through which it monitors and controls the environment. Micro sensors (the "eyes") gather information from the environment measuring position, movement, temperature, pressure, magnetic field, optical and chemical phenomena, that information can then be processed by the "brain" which acts on the environment by means of the "arms", that are basically micro actuators.

Transducer: A transducer is a device that transforms one form of signal or energy into another form. The term transducer can therefore be used to include both sensors and actuators and is the most generic and widely used term in MEMS.

Sensor: A sensor is a device that measures information from a surrounding environment and provides an electrical output signal in response to the parameter it measured. Over the years, this information (or phenomenon) has been categorized in terms of the type of energy domains but MEMS devices generally overlap several domains or do not even belong in any one category. These energy domains include:

- Mechanical - Force, Pressure, Velocity, Acceleration, Position
- Thermal - Temperature, Entropy, Heat, Heat flow
- Chemical - Concentration, Composition, Reaction rate
- Radiant - Electromagnetic wave intensity, Phase, Wavelength, Polarization, Reflectance, Refractive index, Transmittance
- Magnetic - field intensity, flux density, magnetic moment, permeability
- Electrical - voltage, current, charge, resistance, capacitance, polarization

Actuator: An actuator is a device that converts an electrical signal into an action. It can create a force to manipulate itself, other mechanical devices, or the surrounding environment to perform some useful function.

1.1 Materials for MEMS

There are many materials that used in MEMS manufacturing,
Silicon-Compatible Material, such as: Silicon, Silicon Oxide and Nitride, Thin Metal Films, Polymers
Other Materials and Substrates: Glass and Fused Quartz Substrates, Silicon Carbide and Diamond Gallium Arsenide and other Group III-V Compound. Semiconductors, Polymers, Shape-Memory Alloys. But the most common material used in MEMS is **Silicon** since it has the following features:

(a) It's the second most abundant element in the Earth's crust coming after oxygen, making up 25.7% of it by weight. In its crystalline form, it has a dark gray color and a metallic luster.
(b) Silicon possesses excellent materials properties, which make it an attractive choice for many high-performance mechanical applications.

1.2 MEMS Fabrication

Most of the MEMS fabrication methods are adopted from standard IC technology. The most common techniques are: bulk micromachining and surface micromachining.

1) Bulk Micromachining
In bulk micromachining, a 3D micro-mechanical structure is built directly on the silicon wafer by selectively removing portions of the substrate. The exposed area on the substrate is subjected to further chemical etching.

2) Anisotropic etching
Utilize the crystallographic structure of the silicon lattice.

3) Isotropic etching
In this the silicon substrate is attack in all directions with equal rate.

4) Surface Micromachining

Surface micromachining is based on the deposition of layers on the substrate, and on the subsequent definition of the micro-mechanical structure by means of photolithographic techniques. Surface micromachining builds structures on the surface of the silicon by depositing thin films of ‘sacrificial layers’ and ‘structural layers’ and by removing eventually the sacrificial layers to release the mechanical structures.

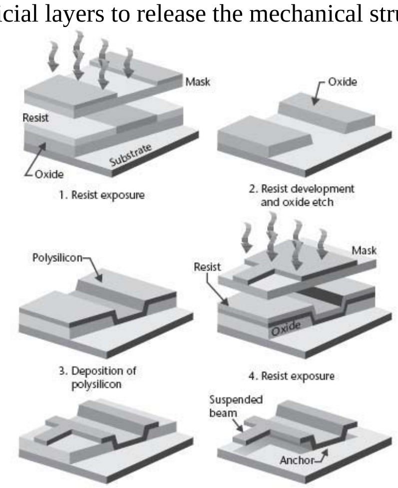


Figure 1: MEMS Fabrication

2. Automotive: The First High Volume Application

Early airbags required the installation of several bulky accelerometers made of discrete components mounted in the front of the car, with separate electronics near the airbag (at a cost of over $50). Today, because of MEMS, the accelerometer and electronics are integrated on a single chip at a cost of under $10. The small size (about the dimensions of a sugar cube) provides a quicker response to rapid deceleration. And because of the very low cost, size (about the dimensions of a sugar cube) provides a quicker response to rapid deceleration. And because of the very low cost, manufacturers are adding side impact airbags as well. The sensitivity of MEMS devices is also leading to improvements where size and weight of passengers will be calculated so the airbag response will be appropriate for each passenger. Figure shows examples of some MEMS devices in the car.

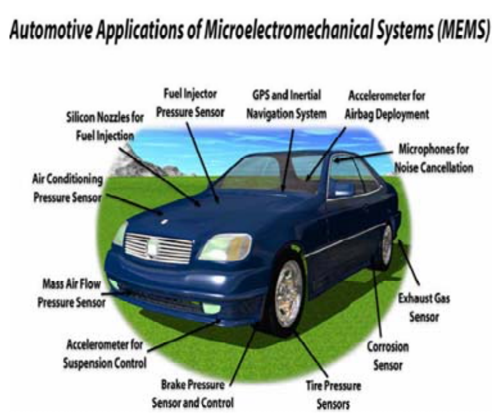


Figure 2: MEMS in Automotive Applications

2.1 Fuel Injector Pressure Sensor

The MPFI (multi point fuel injection) system is used, assuring proper air fuel ratio to the engine by electrically injecting fuel in accordance with various driving conditions. MPFI system injects fuel into individual cylinders, based on commands from the ‘on board engine management system computer’ – popularly known as the Engine Control Unit/ECU. These techniques result not only in better ‘power balance’ amongst the cylinders but also in higher output from each one of them, along with faster throttle response. The electronic fuel injection system supplies the combustion chambers with air/fuel mixture of optimized ratio under widely varying driving conditions.

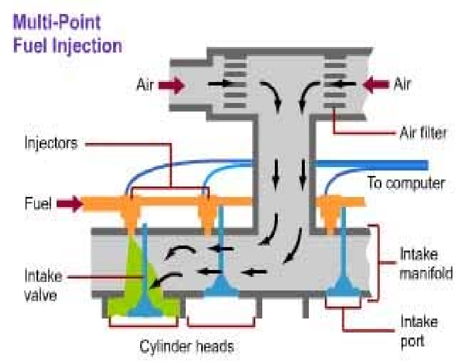


Figure 3: Fuel Injector Pressure Sensor

Sensors used are:

- Manifold absolute pressure (MAP) sensor, Throttle position sensor, Intake air temperature sensor
- Engine coolant temperature sensor, Oxygen sensor, Vehicle speed sensor, Camshaft position sensor
- Crank shaft position sensor.

Advantages:

1. More uniform A/F mixture will be supplied to each cylinder; hence the difference in power developed in each cylinder is minimum. Vibration from the engine equipped with this system is less; due to this the life of engine components is improved.
2. No need to crank the engine twice or thrice in case of cold starting as happens in the carburetor system. Immediate response, in case of sudden acceleration/deceleration.
3. Since the engine is controlled by ECM*(Engine Control Module), more accurate amount of A/F mixture will be supplied and as a result complete combustion will take place. This leads (Engine Control Module), more accurate amount of A/F mixture will be supplied and as a result complete combustion will take place. This leads to effective utilization of fuel supplied and hence low emission level.
4. The mileage of the vehicle will be improved.

Some engine tuners will tell you that if your car has a duty cycle of 80%, you have a possible gain of 20%. However, the injector is an electronic solenoid and cannot be held open for too long or it will overheat and fail. Shorter duty cycle does not allow for the proper atomization of the fuel, and proper atomization is important for the proper burning of the air/fuel mixture. Increasing the injector nozzle size will result in increased fuel delivery all the time. As "Langer" mentioned in engine basics, a rich fuel mixture results in power loss. Therefore, increasing the nozzle size could have a negative effect on performance and economy. The oxygen Sensor (O2S) will correct the fuel mixture for an injector that is about 20% larger than stock. However, on a pre-1996 EFI system, the ECU will ignore the O2S sensor under full throttle conditions.

2.2 Tier Pressure Sensor

The direct tire-pressure monitoring method places a sensor module at each wheel. The sensors measure the pressure in each tire and transmit the data wirelessly to a central receiver in the vehicle, which analyzes the information and displays it to the driver. The information varies from simple warning lights when pressure gets too low to readouts of pressure measurements. Some systems may also include pressure information about the spare tire. The main advantage of the inferred method is that it is relatively inexpensive, since it requires no extra hardware. It has no battery life concerns or remote sensors that can be damaged by tire mounting or road hazards. On the other hand, it won't detect significant under inflation when all four tires are equally soft or when two tires on the same side of the vehicle are under inflated, according to a NHTSA test report. Typically, a tire-pressure sensing module is located inside the rim of the wheel. The MEMS package must stand up to vibration, heat, and corrosive fluids. Tire-pressure sensor contains several components. A MEMS pressure sensor is the key element, but the package may also include a temperature sensor, voltage sensor, accelerometer, microcontroller, radiofrequency circuit, antenna, and battery.

A typical tire-pressure monitoring system integrates many functions. Sensors in each wheel measure temperature and pressure at regular intervals. That information is sent by radio-frequency signal to an electronic control unit inside the vehicle. The unit analyzes the data it receives. Initiators interrogate sensors as needed to rapidly confirm possible warnings and to ensure that accurate information is sent to the driver. A display warns the driver in real time of any critical deviations from normal conditions.

Figure 4: Tier Pressure Sensor

2.3 Airbag system

In this application, an accelerometer continuously measures the acceleration of the car. When this parameter goes beyond a predetermined threshold, a microcontroller computes the integral of the acceleration (i.e., the area under the curve) to determine if a large net change in velocity has occurred. If it has, the air bag is fired. The decision to fire front air bags has to be made in dozens of milliseconds; the decision to fire side air bags must be made even more quickly because the car door is closer to the occupant than the steering wheel or dashboard.

2.4 Rollover detection system

Few vehicles have rollover detection systems, but automakers are rapidly adopting this feature. This is particularly true for vans, pickup trucks, and sport utility vehicles, which are more likely to roll over because of their higher center of gravity. These systems read the roll angle and roll rate of the vehicle to determine if it is tipping over. If it is, the system fires the side curtain air bags to protect the occupants. Rollover detection systems use a gyroscope to read the roll rate. The roll rate is integrated to determine the roll angle of the vehicle, but roll rate data alone are not enough to predict if a vehicle is (or will be) rolling over. An accelerometer reading vertical acceleration (Z axis) is also required because large roll angles can be encountered in banked curves with no possibility of rollover.

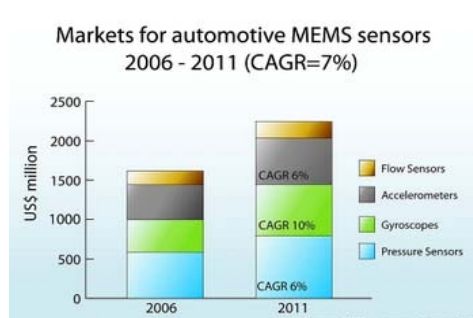
2.5 Vehicle dynamic control system

Vehicle dynamic control (VDC) systems help the driver regain control of the automobile when it starts to skid. If the VDC works properly, the driver may not even be aware that the system intervened. A VDC system consists of a gyroscope, a low-g accelerometer, and wheel-speed sensors at each wheel (the wheel-speed sensors may also be used by the ABS). Wheel speed is measured, and the predicted yaw (or turn) rate of the car is compared with that measured by the gyroscope. A low-g accelerometer is also used to determine if the car is sliding laterally. If the measured yaw rate differs from the computed yaw rate, or if lateral sliding is detected, single-wheel braking or torque reduction can be used to make the car get back in line.

2.6 Throttle Position Sensor

The TPS is a potentiometer attached to the throttle shaft. A voltage signal is supplied to the sensor, and a variable voltage is returned. The voltage increases as the throttle is opened. This signal and the MAP output determines how much air goes into the engine) so the computer can respond quickly to changes, increasing or decreasing the fuel rate as necessary.

3. Markets for Automotive MEMS Sensors



Today's high-end vehicles feature up to 100 different sensors. About 30 these are now MEMS. The market is made up of accelerometers, gyroscopes and inclinometers as well as pressure and flow sensors. Emerging applications include IR sensors for air quality, micro scanners for displays and, further out, MEMS oscillators and energy scavengers for TPMS. We estimate this will equate to insertion from 200 million accelerometers today to 350 million in 5 years, with as many as 8 accelerometers per electronic control unit (ECU).

4. Conclusion

The potential exists for MEMS to establish a second technological revolution of miniaturization that may create an industry that exceeds the IC industry in both size and impact on society. Micromachining and MEMS technologies are powerful tools for enabling the miniaturization of sensors, actuators and systems. In particular, batch fabrication techniques promise to reduce the cost of MEMS, particularly those produced in high volumes. Reductions in cost and increases in performance of micro sensors, micro actuators and micro systems will enable an unprecedented level of quantification and control of our physical world. Although the development of commercially successful micro sensors is generally far ahead of the development of micro actuators and micro systems, there is an increasing demand for sophisticated and robust micro actuators and micro systems. The miniaturization of a complete micro system represents one of the greatest challenges to the field of MEMS. Reducing the cost and size of high-performance sensors and actuators can improve the cost performance of macroscopic systems, but the miniaturization of entire high-performance systems can result in radically new possibilities and benefits to society. The problem of controlling stable and unstable time delayed processes has been tackled by proposing a new parallel cascade control structure. NEMS stands for Nano-Electro-Mechanical-Systems is the technology that is similar to MEMS, however it involves fabrication on the nanometer scale rather than the micrometer scale.

5. Future Work

The market for MEMS devices is still being developed and comparison will always be made between the two, but this is not realistic as there is no ‘dominant technology’ in MEMS analogous to metal oxide semiconductor circuitry, which accelerated the exponential growth of the digital electronics industry. Although some surface micro machined devices are being produced in volume, it will take a few more years for this approach to make a large impact; devices using both surface and bulk continue to be marketed. Despite MEMS being an enabling technology for the development and production of many new industrial and consumer products, MEMS is also a disruptive technology in that it differs significantly from existing technology, requiring a completely different set of capabilities and competencies to implement it. For the true commercialization of MEMS, foundries must overcome the critical technological bottlenecks, the economic feasibility of integrating MEMS-based components, as well as the market uncertainty for such devices and applications. Cost reduction is critical and will ultimately result from better availability of infrastructure, more reliable manufacturing processes and technical information as well as new standards on interfacing.

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