The New Generation of MEMS-Based Combustible Gas Sensors

Advancements in Low-Power Catalytic Detection

watchgas detection

What is MEMS Technology?

MEMS (Micro Electro Mechanical Systems) is a technology that combines miniaturised mechanical and electrical components into a single silicon-based chip. MEMS devices are manufactured using semiconductor fabrication techniques (such as photolithography, etching, and deposition), enabling high precision, small size, and low power consumption.

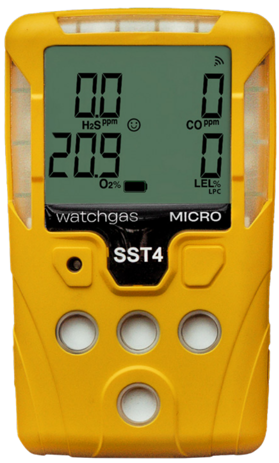
Key components of a MEMS device

A MEMS sensor typically consists of:

1. **Micromechanical Structures**
   Tiny movable parts that respond to external stimuli (e.g., gas, temperature, pressure).
2. **Microelectronics (ASIC - Application Specific Integrated Circuit)**
   Processes the sensor's electrical signals.
3. **Thin Film Layers**
   Enhances mechanical and chemical properties.
4. **Packaging and Encapsulation**
   Protects the MEMS structure from the environment.

The LPC (Low Power Catalytic) LEL sensor incorporates these MEMS principles into Catalytic bead sensing technology.

MEMS implementation in the LPC LEL Sensor



The Watchgas SST4 Micro and SST4 Pump sensor uses MEMS fabrication to construct a miniature catalytic bead sensor with an integrated microheater, catalytic coating, and sensing element. Gas molecules oxidize on the catalyst, generating heat, and increasing the bead's resistance, which is measured to detect gas concentration.

This MEMS implementation brings **key benefits** such as:

- **Miniaturization**
  The sensor is significantly smaller than traditional catalytic bead sensors.
- **Low Power Consumption**
  MEMS heaters consume far less power than conventional wire-wound heaters.
- **Fast Response Time**
  The reduced thermal mass of the MEMS heater allows it to heat up and cool down quickly.

MEMS Catalytic Bead Sensor Structure

The sensor consists of a pair of miniature MEMS pellistors (beads), placed in a Wheatstone bridge circuit:

1. **Sensing Bead (Active Pellistor)** contains a catalytic coating that enables the oxidation of combustible gases.
2. **Reference Bead (Passive Pellistor)** lacks catalytic coating and serves as a baseline for signal comparison.

MEMS Micro-Heater

A platinum micro-heater is integrated into the MEMS chip to maintain the sensor's operating temperature (~500-550°C). The heater is fabricated using thin-film deposition, making it more efficient than traditional wire-wound heaters. Due to its small thermal mass, it requires less than 40mA of current, making the sensor ideal for battery-powered applications in portable gas detectors.

MEMS-Based Catalyst Layer

A thin layer of precious metal catalyst (such as platinum or palladium) is deposited onto the active pellistor. This catalyst promotes the oxidation of combustible gases at lower temperatures compared to conventional catalytic sensors.

Advantages of MEMS-Based Catalytic Sensors

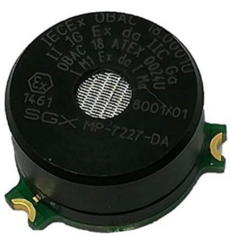
Compared to Traditional Catalytic Bead Sensors

Low-power MEMS-based catalytic sensors and traditional catalytic bead sensors both operate on the principle of catalytic combustion for detecting combustible gases (e.g., methane, propane, hydrogen).
However, they differ significantly regarding power consumption, size, and response time.
Below is a detailed breakdown of their advantages and disadvantages.

Traditional Catalytic Bead	Feature	MEMS-Based LPC LEL
Larger, bulky	**Size**	Miniaturized, compact
Higher (~100-200mA)	**Power Consumption**	Lower (~40mA)
Slower (15-30 sec)	**Response Time (T90)**	Faster (<12 sec)
Fragile, wire-wound heaters Prone to damage (wire-wound structure)	**Durability**	Robust, thin-film MEMS heaters Highly shock-resistant (MEMS fabrication)
Prone to gradual drift	**Temperature Stability**	More stable
High, can detect complex hydrocarbons	**Gas Sensitivity**	High, basic hydrocarbons (C1-C5)
Moderate	**Mechanical Shock Resistance**	High
Poor	**Suitability for Battery Operation**	Excellent

Unique MEMS Advantages

- **Low Power Operation:** Extended running time on SST4 Range of gas detectors;
- **Faster Heating & Cooling:** Reduces power-on time and response delay;
- **Poison Resistance:** Stable against silicone, lead, and sulfur poisoning;
- **Increased durability:** Minimal mechanical degradation across its usage period;
- **Compact Design:** MEMS allows miniaturization of catalytic sensors without sacrificing performance;
- **Energy Efficiency:** Power-efficient micro-heater improves battery life and performance;
- **High Accuracy:** Thin-film platinum sensor ensures high accuracy and reliability;
- **Stable Signal Output:** Wheatstone bridge configuration provides a stable and precise signal output.



LPC LEL-based Catalytic Sensor Advantages

Lower Power Consumption
LPC sensors used in the SST4 Micro and SST4 Pump significantly extend the battery runtime of the detectors. The SST4 Micro lasts up to 48 hours on a single charge, while the SST4 Pump can last 50 hours.

Faster Response Time
The sensor has a T90 response time of <12 sec, whereas traditional catalytic bead sensors take 15-30 sec.
The reduced thermal mass of MEMS heaters allows faster warm-up time to cycle power in the sensor.

Higher Shock and Vibration Resistance
Traditional catalytic bead sensors have a fragile wire-wound structure, which makes them prone to mechanical damage. LPC sensors, on the other hand, are fabricated using semiconductor techniques, making them more robust against vibrations, drops, and shocks.

Exhibits steadiness
Sensor maintains stability over the life cycle and reduces thermal stress on the bead.
Increased resilience to sensor poisoning with a silicone filter applied to the catalyst.

Operating Principle

Miniature LPC LEL Catalytic Combustible Bead Gas Sensors

The silicon pellistor structure consists of a pair of accurately micro-machined diaphragms with two embedded planar heater meanders coated with a layer incorporating a noble metal catalyst for the detector device and with an inert layer for the compensator device. The meander acts both as an electrical heater and as a resistance thermometer.

The device is mounted on a PCB with wire bonding and is surrounded by a plastic can with the end open to the atmosphere. If a flammable gas is present when the device is heated to about 400 – 500 °C, the gas will oxidise, and the resultant release of energy will heat the device still further. This increase in temperature is detected as an increase in resistance of the meander.

The temperature of the meander is also affected by ambient temperature and by variations in the thermal conductivity of the air caused by the possible presence of inert gases such as carbon dioxide. To compensate for temperature changes not caused by the oxidation of the flammable gas a second, inert device is used.

The compensator is made in the same way as a detector device except that instead of incorporating a catalyst in the coating layer, the device is treated so that oxidation cannot take place. The two devices are then used in a circuit that detects the difference in their resistances.

Since the two devices are generally a different colour, they have different emissivity and hence different slope resistances. Therefore, to obtain the best temperature performance, it is necessary on occasion to connect a fixed resistor in parallel with the compensator to correct for its higher slope resistance.

Step-by-Step Working Mechanism

Power Application to Micro-Heater:
A small voltage (typically 2.9V–3.1V) is applied to the MEMS micro-heater.
The heater warms the catalytic bead to its operational temperature (~500-550°C).

Gas Exposure and Oxidation Reaction:
When combustible gas (e.g., methane, propane, hydrogen) enters the sensor chamber, it comes into contact with the catalytic bead.

The gas undergoes a controlled oxidation reaction:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + Heat$$

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This reaction releases heat, increasing the temperature of the active bead.

Resistance Change in Platinum Heater:
The rise in temperature causes a change in the resistance of the platinum wire embedded in the bead. This resistance change is proportional to the gas concentration.

Wheatstone Bridge Signal Output:
The sensor elements are configured in a Wheatstone bridge circuit, which detects the resistance difference between the active and reference pellistors. The bridge produces a small voltage signal (mV level), which corresponds to the gas concentration.

Signal Processing and Output:
The signal is amplified and conditioned by the internal electronics. The output is then fed into a microcontroller or analog-to-digital converter (ADC) for further processing.

Best Detected Gases (Optimal Performance)

The sensor is best optimised for hydrocarbon and hydrogen-based gases, which readily undergo catalytic combustion. Flammable gases detected include the following:

Common Hydrocarbon Gases (Excellent Sensitivity)

- Methane (CH_4) – Found in natural gas, biogas, and landfill gas. Most common gas on earth.
- Propane (C_3H_8) – Used in LPG, industrial applications, and heating systems.
- Butane (C_4H_{10}) – Found in LPG, cigarette lighters, and aerosol propellants.
- Pentane (C_5H_{12}) – Used in industrial solvents and fuels.
- Hydrogen (H_2) – Used in fuel cells, welding, and chemical plants.

Limited or Less Effective Gases
While the sensor can detect certain gases, however, its sensitivity may be lower, or it may require higher concentrations for reliable detection. It features a built in silicone filter designed to protect the beads from poisons and by removing most silicone vapor before it reaches the sensor. While this filter helps, it can also slow or reduce the response to heavier hydrocarbons. Over time, it may become saturated, necessitating sensor replacement.

Heavier Hydrocarbons (Reduced Sensitivity)

- Kerosene, Diesel Vapors, Petrol, Aviation Grade Fuel – High molecular weight fuels have low vapor pressure, are less volatile and have more complex hydrocarbon chains reducing their catalytic oxidation rate.
- Toluene, Styrene, Ethyl Acetate, Methyl Ethyl Ketone, Ethanol, Methanol, Heptane, Nonane - generally are not detectable / reduced with a silicone filter installed on the LEL sensor.

Halogenated & Sulphur-Containing Compounds (Inhibitors)

- Chlorinated Hydrocarbons (E.g., Freons, Trichloroethylene) – These compounds do not readily oxidise and may poison the catalyst.
- Sulfur-Containing Gases (H_2S, SO_2, Mercaptans) – These can deactivate the catalyst over time, leading to sensor drift, sensitivity loss or failure.