A Dive into the Latest MEMS Pressure Sensors for Wearable and IoT Applications

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Agenda

- MEMS Technology and Products
- Pressure Sensor Technology
  - Process
  - Principle of Design
  - Packaging
- Pressure Sensor Applications
MEMS Technology and Products

MEMS Technology

Sensors
- Inertial
  - Accelerometers
  - Gyroscopes
  - IMUs
  - Inclinometers
  - Vibrometers
- Audio
  - Microphones
- Magnetic
  - Magnetometer
  - Compass Modules
- Pressure/Humidity
  - Pressure Sensors
  - Humidity Sensors
  - Humidity / Temp modules
- Chemical
  - VOCs
  - CO2
  - CO

Actuators
- Micro-actuators
  - Camera AutoFocus
  - MEMS Speaker
  - PMUT
  - Smart dosing
  - Smart Printing
  - MEMS valves
  - MEMS pumps
  - NDT
  - Flow meter
  - Level metering
- Micro-mirrors
  - Mirrors and Drivers
  - VR/AR
  - HUD
  - Structured Light
MEMS Processes and Products

Next Generation ThELMA*
- Higher accuracy
- Ultra-low power
- Embedded Machine Learning Core

Next Generation BASTILLE*
- Higher accuracy
- Size reduction
- Waterproofing

Thin Film Piezoelectric PeTRA*
- Innovative piezoelectric materials
- Higher efficiency
- Lower cost

Motion sensors for Personal Electronics, Automotive & Industrial

Environmental sensors for Personal Electronics & Industrial

Microactuators for Ink Jet printing, Speakers & Infrared Scanners

*ST proprietary MEMS technologies
Pressure Sensor Technology

Typical Conventional technology

Monolithic Silicon → Back Die Etching → Glass bonding → Piezoresistive Resistor diffusion

Full Silicon Pressure Sensor technology

Monolithic Silicon → Cavity creation → Cavity completed → Piezoresistive Resistor diffusion

Full Silicon Technology Advantages

• Monolithic sensor: no need for wafer to wafer bonding to create the cavity
• High burst pressure - Intrinsic mechanical stopper
• High shock survivability
• Good temperature behavior – one temperature coefficient (only silicon)
• More robust and thinner sensor
Piezo-resistive Technology

Principle of Design

• Piezoresistivity: a change in the electrical resistivity of a metal or semiconductor due to an applied stress (force, pressure, flow, acceleration)

• All the materials show a piezoresistivity effect but semiconductors possess stronger piezoresistivity property: Si is the best one (Smith, 1953).

• Four resistors are connected in a Wheatstone bridge configuration.

• Pressure variations change the bridge balance.

\[ \alpha_1 = (\pi_1 + \nu \pi_2) \sigma_1 = (67.7 \times 10^{-11}) \sigma_1 \]

\[ \alpha_2 = (\pi_1 + \nu \pi_2) \sigma_1 = (61.7 \times 10^{-11}) \sigma_1 \]
Pressure Sensor with Sensing Element & ASIC

Ultra high-performance pressure sensor in small fully molded PKG for vertical position (i.e indoor navigation / E911 application / dusty environment)

New Sensor
- Better Pressure accuracy & faster response
- Better mechanical robustness

New ASIC
- Better Pressure accuracy, Less RMS noise
- RF immunity

ST Unique package advantage
- Improved shock and vibration suppression
- Improved reliability and moisture resistance
- Ultra-thin package
Water-Resistant Package
Tests and Sealing

- Over pressure test
  - Test condition: 1.5 / 3 / 5 / 10 bar over pressure for 10sec & 60sec
  - No impact in accuracy nor other performance

- Hot Chlorine, Bromine and Salt water test
  - Potting GEL not affected to cause any accuracy error

- Detergent water (commercial shampoo, hand soap and water mixed in)

- Aging & corrosion test in n-Pentane liquid for 72hr
  - No physical damage by n-Pentane after 72hr with performance in SPEC

Sealing is guaranteed by rubber o-ring and housing design
Water Resistant Pressure Sensor for Harsh Environment

**Features**

- 260 to 1260 mbar absolute pressure (18-3PSI)
- RMS noise 0.007 hPa with embedded filter
- Absolute accuracy ±1 hPa @ 0 ~ 65°C
- Relative Pressure accuracy ± 0.1hPa
- ODR from 1 Hz to 200 Hz
- Low power consumption: 4 μA
- Embedded FIFO (128 slots/40 bits)
  - Pressure and Temperature data
- Water resistant up to 10Bar
- Cylindrical Water proof package 3.3x3.3x2.9mm
- Potting GEL protects electrical components.
- 24 bit pressure resolution (0.0002 hPa/bit), 16 bit temperature
- SPI, I2C, I3C interface (I2C/I3C can be disabled)

**PKG Structure**

- Metal Lid
- MEMS
- ASIC
- Substrate
- Ceramic

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**For Swim user case in swimming pool & Sea**

**Compatible with human body**

**Corrosion Test for industrial**
Internal Block Diagram of a Pressure Sensor

- The sensor is calibrated at 3 temperatures and 2 pressures for better accuracy
  - Trimming parameters are loaded at each start-up.
  - No need for re-calibration in application.
Embedded Linear Compensation

- Latest pressure sensors are factory calibrated
- Compensation uses the embedded temperature sensor
- Result is a good linear accuracy which is specified in the datasheet
- SW compensation can be used for even better temperature and noise accuracy
How to Interface with the Device

• **Power supply**
  - Separated Vdd and Vdd_IO lines (ultra low drop, low noise LDO)
  - Supply voltage range: 1.71 to 3.6V for both, VDD_IO <= VDD

• **The device is capable of communicating over 2 digital serial interfaces**
  - SPI 3-wire (CS, SPC, SDI/O) or 4-wire (CS, SPC, SDI, SDO)
  - I2C (SCL, SDA) with slave address selectable by SA0 pin
  - CS pin is used to select between SPI and I2C
  - I2C interface can be disabled using I2C_EN bit of CTRL_REG2 (21h)

• Device setup and data acquisition is done by accessing registers of the sensor

• INT_DRDY interrupt push-pull pin has programmable functionality (pressure high, pressure low, data ready, FIFO interrupts)
Pressure Sensor Applications in Wearables and IoT devices
Pressure Sensor Applications

- Altimeter and Barometer
- Asset tracking: Takeoff/landing pressure
- Gas meter: Leakage detection
- E-cigarette: Detect inhalation
- Indoor & outdoor Navigation: Floor level detection
- Smart Glasses
- Smart Watch
- Drone: Pressure measurement
- Weather station / Air quality monitoring
- Vacuum cleaner: Floor type, dust bag content level
- Smart AC
- Man Down Detection
- Performance Measurement: Measure pressure variation
- Water L. management
- Blood pressure sensors
- Balloons

And many others….
Pressure Sensor as an Altimeter

Pressure range from 260 to 1260 mbar

RMS Noise Level 7µbar

Maximum altitude range 11800 m

Minimum altitude difference ~6 cm

1800m → 815mbar

-10m ↔ +1mbar

1000m → 899mbar

~6 cm
Pressure Sensor in Drone Application

- The barometric pressure sensor is needed in drone application in order to give an accurate position of the UAV height (Altitude Hold).

LPS22HH

5cm * With sampling rate of 100Hz, ascent/descent @10ms*5m/s=5cm

Sampling rate up to 200Hz
Waterproof PS in a Wash Machine
Water/Laundry Detergent Level/Temp Control

Pressure Sensor in Washing Machines

In the stream water level and temperature control
- Remove pressure hose
- Precise water level detection
- Sensing/control water temperature for different type of clothing
- Any liquid

[Graph and diagram showing pressure level output and temperature output]
Water Level Monitoring / Alarm with Pressure Sensor

Pressure Sensors in Water Level Monitoring / Alarms

- Pressure sensor used to measure Water Level in SMART Water Level monitoring / Alarm
- Usage of two pressure sensors one on the top of the tank (LPS22HB) measuring the ambient temperature and one on the waterproof device (LPS33HW) as a probe within the water.

LPS22HB Pressure Sensor

- P1 : Ambient Pressure

LPS33HW Water Proof Pressure Sensor

- P2 : Pressure in Water & Need Water Proof

- P2-P1: Calculate to Water Depth in below.
  ✓ P2 – P1 : 100hPa (0.1Bar) = 1 meter (3.3feet)
  ✓ P2 – P1 : 1000hPa (1Bar) = 10 meter (33 feet)

Media’s specific gravity/Density

Hydrostatic Pressure
Fall Detection

• SW Algorithm can detect fall of users
  • Uses Accelerometer and Pressure sensor combination to minimize false alarm.
  • Uses change in acceleration + change in height from pressure sensor to detect fall.
  • Combining sensors allows fast detection and better rejection of false positives.
  • 36/36 falls classified correctly (forward, backward, left, right) with no false positive (sit down, lie down, stairs down, elevator).
  • Tested for belt position

Water Resistant Pressure Sensor enables the monitor used in bath/shower
Take off & Landing Detection

Pressure Sensors use case

**Nano digital absolute pressure sensor**
- Embedded temperature compensation
- Pressure range 260 to 1260 hpa
- Over pressure capability: 20xFs
- Embedded FIFO
- HLGA 10L 2.0 x 2.0 x 0.73mm

**Water resistant absolute pressure sensor**
- Absolute pressure range 260 to 1260 hpa
- Embedded temperature compensation
- Water resistant package
- Embedded FIFO
- CCLGA 10L 3.3 x 3.3 x 2.9mm
Pressure Sensor for Flow Metering in Industrial Market

Flow sensors used for flow metering in **Industrial market**

Flow meters are based on different 3 kinds of **Orifice**, **Venturi** and **Ultrasonic** methodology

<table>
<thead>
<tr>
<th>How it works</th>
<th>Orifice / Venturi Metering</th>
<th>Ultrasonic Metering</th>
</tr>
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<tbody>
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<td>Flow monitoring</td>
<td>Q = K\sqrt{\Delta P}</td>
<td>One pressure sensor needed for compensation of flow meter.</td>
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<td>Pressure / Velocity</td>
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**LPS33HW**

- Robustness to harsh environment (chemical compounds)
- Accuracy for precise measurement

**How it works**

- **Orifice / Venturi Metering**
  - **Flow monitoring** with differential or two pressure sensors.
  - Q = Flow Rate
  - K = A constant determined by orifice size type of liquid
  - P = Differential Pressure

- **Ultrasonic Metering**
  - One pressure sensor needed for compensation of flow meter.
• Dedicated MEMS Process for Pressure sensors.

• New advances in MEMS technology and ASIC has lead to higher accuracy, better resolution, lower current consumption, and smaller size.

• These improvement have enabled a wider range of applications in addition to conventional altimeter application.

• Advancements in packaging for high volume manufacturing.

• Full-scale range and packaging technology are the primary determining factors for pressure sensor applications.
Thank You!

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