

# How the sensors work

## Introduction

There are six different sensor types integrated into SensorStick. Some are shown in Fig. 1.

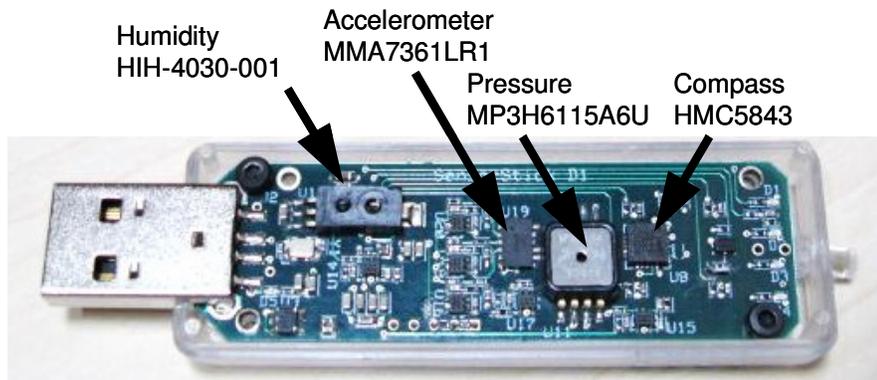


Figure 1: Photograph showing some of the sensors integrated into SensorStick.

## Temperature

Temperature can be measured using a “Negative Thermal Coefficient” (NTC) device, a “Positive Thermal Coefficient” (PTC) device, or a “Resistance Temperature Detector” (RTD).

A typical NTC or PTC device is made from special material that behaves as a thermistor (from the word thermal and resistor). They are made from ceramic materials (a mix of different metal oxides) whose electrical conduction depends sensitively on temperature. The resistance of a NTC decreases with increasing temperature and the resistance of a PTC increases with increasing temperature. Some thermistors are made of semiconductor materials such as silicon and germanium. The resistance of thermistors is very sensitive and can vary exponentially with temperature. For this reason, for a constant current applied across the device, special circuitry is used to linearize the voltage output with respect to temperature. In the device used by SensorStick this is all done in a single chip. The manufacturer part number for the temperature sensor used in SensorStick is MCP9701AT-E/LT.

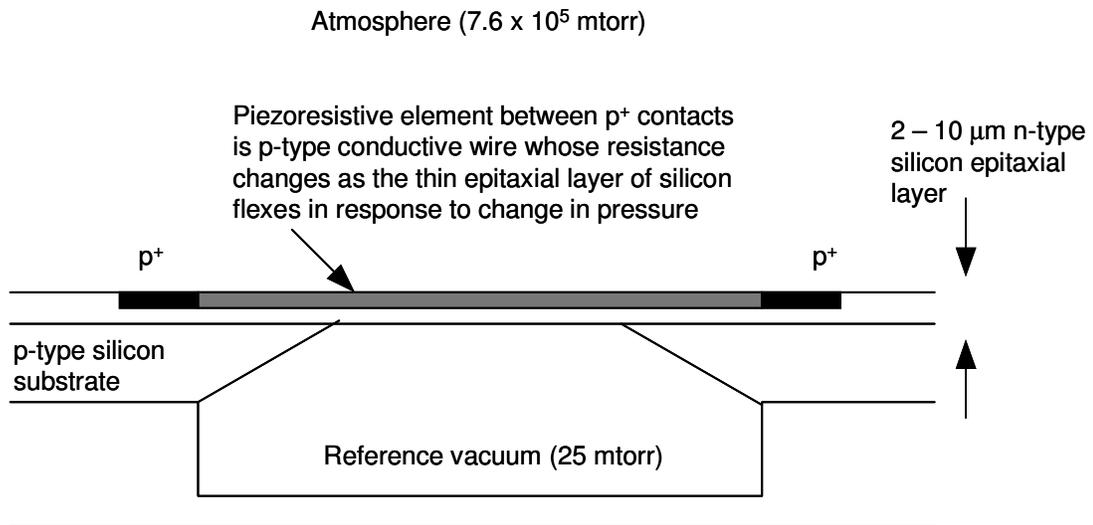
Another type of temperature sensor is the RTD that typically consists of a length of fine pure metal wire wrapped around a ceramic or glass core or a thin metal film deposited on an

electrically insulating substrate. The RTD element is made from material such as platinum, nickel, or copper. The known change in resistance as the temperature is used to accurately determine temperature.

The NTC, PTC, and RTD temperature sensors require accurate measurement of resistance. Driving a current through the temperature sensitive material and measuring the voltage developed across the device can achieve this.

### Pressure

Absolute pressure is measured using a Micro-Electro-Mechanical System (MEMS) device incorporating a piezoresistive sensor. The device is machined, using chemical etching, out of a single-crystal silicon wafer. A cavity etched into the silicon wafer is sealed using a thin, flexible, single-crystal membrane that is less than 1/10-th the thickness of a human hair. A cross-section of the device is illustrated in Fig. 2. The pressure difference between atmosphere and a reference vacuum causes a thin silicon membrane to bend, like a drum skin, with change in pressure relative to the reference vacuum. An integrated piezoresistive wire embedded in the membrane changes its resistance as the membrane bends. The change in resistance is proportional to absolute pressure and measured using a sensitive bridge circuit.



**Figure 2: Illustration of cross-section of absolute pressure sensor. A thin silicon membrane bends with change in pressure relative to the reference vacuum. An integrated piezoresistive wire changes its resistance as the membrane bends. The change in resistance is measured using a sensitive bridge circuit.**

The manufacturer part number for the pressure sensor used in SensorStick is MP3H6115A6U.

## Humidity

Relative humidity is measured using a capacitor whose dielectric permittivity changes with the presence of water vapor. A typical dielectric used in the parallel plate capacitor is polyamide. The polymer structure allows water vapor to easily diffuse into the material, increasing its permittivity. Because parallel plate capacitance,  $C$ , is proportional to area,  $A$ , permittivity of free space,  $\epsilon_0 = 8.854 \times 10^{-12} \text{ F m}^{-1}$ , relative permittivity,  $\epsilon_r$ , of the dielectric and inversely proportional to dielectric thickness,  $d$ , separating the metal plates, we can write

$$C = \frac{A\epsilon_0\epsilon_r}{d}$$

Large area  $A$  increases device sensitivity. Reducing the value of  $d$  decreases the response time of the device because it takes less time for water vapor to diffuse into the polymer and reach equilibrium. The metal electrodes of the parallel plate capacitor consist of a multi-finger structure that allows water vapor to pass through metal gaps into the polymer.

To get an idea of the capacitance of a 6 mm diameter device with 1  $\mu\text{m}$  thick dielectric of relative permittivity  $\epsilon_r = 2$  one can estimate

$$C = \frac{\pi \times (3 \times 10^{-3})^2 \times 8.854 \times 10^{-12} \times 2}{1 \times 10^{-6}} = 5 \times 10^{-10} \text{ F} = 500 \text{ pF}$$

Capacitance can be measured using a bridge similar to that shown in Fig. 3.

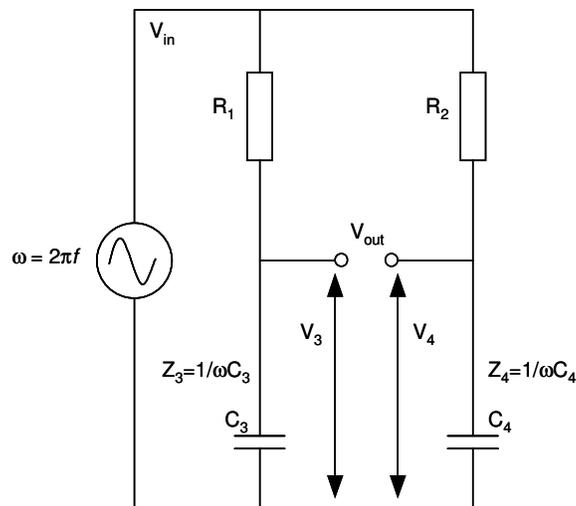


Figure 3: Illustration of a capacitance bridge used to measure small changes in capacitance of humidity sensor  $C_4$ .

The value of  $C_3$  is chosen to be close to that of the humidity sensor  $C_4$ . The balance condition for the bridge circuit operating with an input voltage frequency  $\omega = 2\pi f$  is

$$\frac{R_1}{R_2} = \frac{Z_3}{Z_4}$$

where impedance  $Z_3 = \frac{1}{\omega C_3}$  and  $Z_4 = \frac{1}{\omega C_4}$ . If a frequency of 10 kHz is used to measure a capacitor of nominal value 500 pF, the impedance is

$$Z = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 10^4 \times 500 \times 10^{-12}} = 31.8 \text{ k}\Omega$$

and this would be a good choice for the values of the resistors used in the bridge circuit. Voltage division across each arm of the bridge gives the relations

$$V_4 = \frac{V_{in} Z_4}{R_2 + Z_4} = \frac{V_{in}}{1 + \frac{R_2}{Z_4}} \text{ and } V_3 = \frac{V_{in} Z_3}{R_1 + Z_3} = \frac{V_{in}}{1 + \frac{R_1}{Z_3}}. \text{ The measured output voltage is}$$

$$V_{out} = V_3 - V_4$$

The manufacturers part number for the humidity sensor used in SensorStick is HIH-4030-001.

### Light

Light consists of fundamental particles called photons. Each particle of light carries a small amount of energy proportional to its frequency of oscillation. In SensorStick light is measured using a photodiode made of silicon. Photons with enough energy to be absorbed by silicon do so by converting to another fundamental particle, the electron. Current generated by the creation of electrons from photons is amplified and converted to a voltage using a transistor circuit in the light sensor chip used in SensorStick. The voltage output is proportional to the light intensity.

The manufacturers part number for the light sensor used in SensorStick is TPS852.

### Acceleration

Components of acceleration in three orthogonal Cartesian coordinates, x, y, z, is measured using a single chip Micro-Electro-Mechanical System (MEMS) device. Relative mechanical motion of a micro-machined silicon element of mass m attached via a spring to a silicon substrate is measured using capacitive sensing. In SensorStick the displacement of the mass m

is accurately measured using a capacitance bridge operating at 11 kHz. Any force due to acceleration moves the mass element closer or further away from the substrate. Because force is proportional to mass times acceleration,  $F = ma$ , and because the displacement of a known mass attached to a spring is proportional to the force, if one can measure the displacement then one can know the force and hence the acceleration. There are two selectable sensitivity settings  $\pm 1.5g$  and  $\pm 6g$  where  $g = 9.81 \text{ m}^{-1} \text{ s}^{-2}$  is acceleration due to gravity.

Under normal operation a component of acceleration due to gravity is present and detected by the sensor. However, if the sensor is in free-fall then the sensor will detect zero gravity. This special condition can be detected by the sensor chip or using SensorStick software.

The manufacturer's part number for the accelerometer used in SensorStick is MMA7361LR1.

### **Magnetic compass**

There are different ways to measure magnetic field. SensorStick uses magneto-resistive sensor chip. Components of magnetic field in three orthogonal Cartesian coordinates,  $x$ ,  $y$ ,  $z$ , is determined by accurately measuring resistance of a material that depends on magnetic flux.

The sensor can detect magnetic fields as small as a few tens of micro-gauss to 6 gauss. The magnetic field of the Earth is about 0.5 gauss.

The manufacturer's part number for the magnetic compass sensor used in SensorStick is HMC5843.