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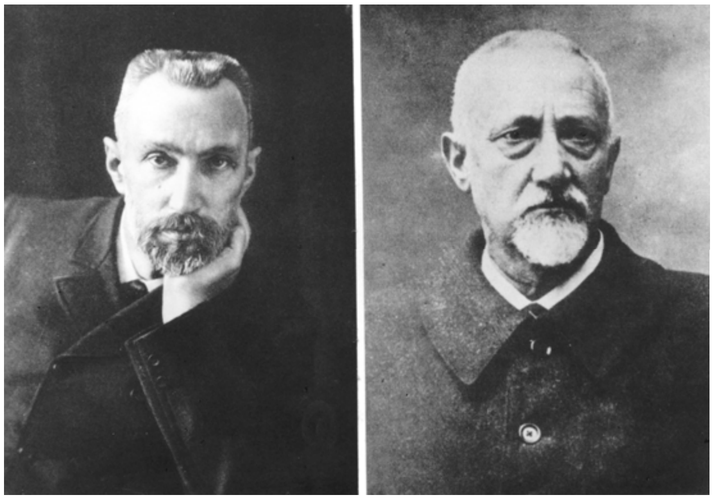
New Piezoelectric Materials Improve Sensor Performance

Introduction

- Wide range of piezoelectric materials are used in sensors
- The selection of the PE material depends on the applications
- Sensor companies may develop and produce their own materials
  - Ferroelectric Ceramics
  - Crystals
- New piezoelectric crystal, PiezoStar®, improves the sensor operational characteristics and provides enhanced performance:
  - Dynamic and low frequency (quasi-static)
  - Increased stability and temperature range
  - Higher sensitivity
  - Useable for low and high impedance sensors

Piezoelectric History



- The piezoelectric effect was discovered by Pierre and Jacques Curie in 1880
  - First experimental proof of mechanical load vs. produced electrical charge
  - Found effect in tourmaline, quartz and Rochelle salt (NaK tartrate, phonograph pickup)
  - Technology remained a mere curiosity until the 1940s (sonar)
- The invention of the charge amplifier in 1950 by W.P. Kistler was a major breakthrough
- The introduction of solid state circuitry and the development of highly insulating materials such as PTFE (Teflon, 250°C) and Kapton (400°C) improved the performance of piezoelectric measurement systems.

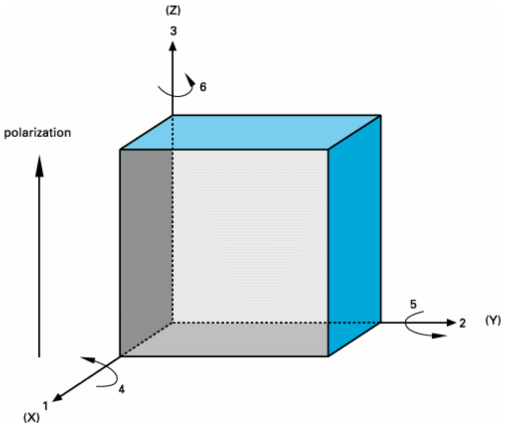
Piezoelectric Materials

- Piezoelectric single crystals (natural & manufactured)
    - Quartz (SiO_2)
    - Tourmaline
    - Gallium Orthophosphate ($GaPO_4$)
    - PiezoStar® (CGG group: calcium – gallium - germanate)

- Piezoceramics (ex. lead zirconate titanate; PZT)
    - Ferroelectric material that is processed to become piezoelectric
    - Widely used for accelerometers

Piezoelectric crystals and ceramics create a electric charge directly proportional to the amount of force applied.

Materials for Sensing Elements: Piezo-Ceramics



Ferroelectric Ceramics

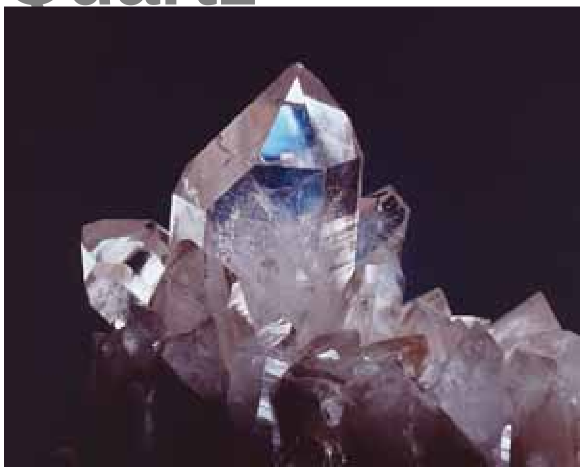
- Lead Zirconate Titanate (PZT)
  - Heat raw materials, shape, sinter (1250°...1350°C), cut/grind/polish, apply electrodes, poling - expose to high electrical field (several kV/mm)- direction of polarity
- Wide variety of shapes possible
- Significant higher sensitivity and capacitance compared to quartz, PiezoStar or tourmaline
- Piezoelectric properties may change over time.
- Pyroelectric and high temp. coefficient
- Relatively low insulation resistance – limits low frequency response

Materials for Sensing Elements: Tourmaline

Tourmaline

- Can not be manufactured synthetically
- Selecting raw crystals including finishing is difficult and expensive
- Z-cut most suitable for sensors
- High pyroelectric effect limits applications
- Applicable up to 600°C (1112 °F)

Materials for Sensing Elements: Quartz



- Natural quartz crystals
  - Crystals were used for a number of years
  - Natural quartz contains too many imperfections resulting in high scrap rate

- Artificially grown quartz crystals
  - Quartz crystals are grown in autoclaves at a pressure of 1 to 2 kbar (14 to 29 kpsi) and at temperatures between 350 and 400 °C
  - Large quartz crystal (2 lbs) may take several weeks to grow
  - Quartz bars are cut to various sizes using ultrasonic techniques and diamond tools

Materials for Sensing Elements: Quartz

- The quartz crystal acts as a very stiff, ideal spring
- Very high rigidity (6…350 lbf/µin), high linearity and negligible hysteresis
- High mechanical stiffness ⇒ high natural frequency ⇒ wide frequency range
- Wide frequency range – quasi-static to greater than 1MHz
- Ultra high insulation resistance (>10^{14} Ohms) = low freq. measurements (<1 Hz)
- Very wide dynamic range – typically 1,000,000 : 1 (in charge mode)
- Temperature resistance up to 400°C (752°F)
- Although the charge sensitivity of quartz is relatively low compared with other materials, quartz has the highest measuring range, highest frequency response, the longest life with virtually no sensitivity shift over it's lifetime.

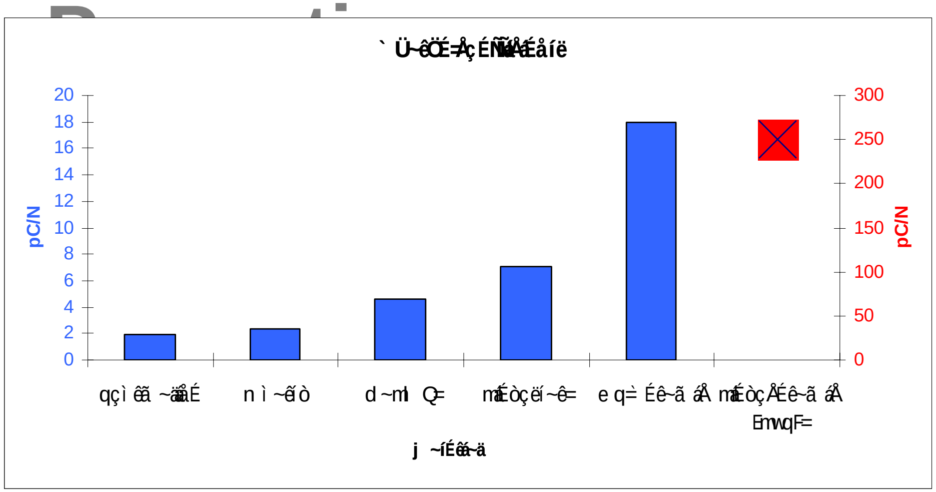
Materials for Sensing Elements: Piezostar

PiezoStar® Crystals

- High piezoelectric sensitivity (up to 5x higher than quartz)
- Low temperature coefficient of sensitivity, not pyroelectric (low temp. transient response)
- High stability of properties, even at high temp.
- Applicable up to > 600 °C (1112 °F)
- No phase transition up to the melting point (1300C)
- Reproducible growing process and industrial scaling
- Tested and successfully used on instrumentation grade PE and IEPE sensors

Sensors with PiezoStar Crystals

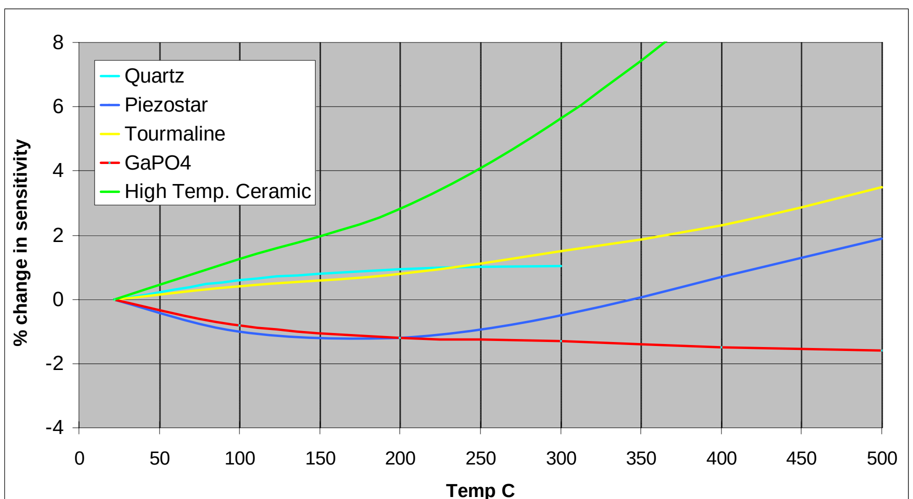
Piezoelectric Material



Charge coefficient for compression orientation

Material	PE Constant (pC/N)	Curie Point (ºC)
Tourmaline	1.8	≥ 900
Quartz	2.3	560
$GaPO_4$	4.5	≤ 700
PiezoStar	**9.1**	**> 1300**
HT Ceramics	20	680
PZT	250	200

Curie Point:
- loss of piezoelectric properties



Variation of Charge Sensitivity with Temperature

The output of a high impedance sensor is expressed in a unit of charge, Q, of pico-Coulombs (pC):

Q (pC) = C (pF) * V(Volts)

Sensitivity Temperature Coefficient

- In dynamic temperature environments, temperature variations contribute to measurement errors.
- Sensitivity Temperature Coefficient varies depending on PE material
    - Piezo-Ceramic
    - Quartz
    - PiezoStar®
- Post processing
    - Thermal compensation can be performed by characterizing the accelerometer
    - Time consuming
    - Post processing only useful for thermal sensitivity coefficient, not transient temperature effects

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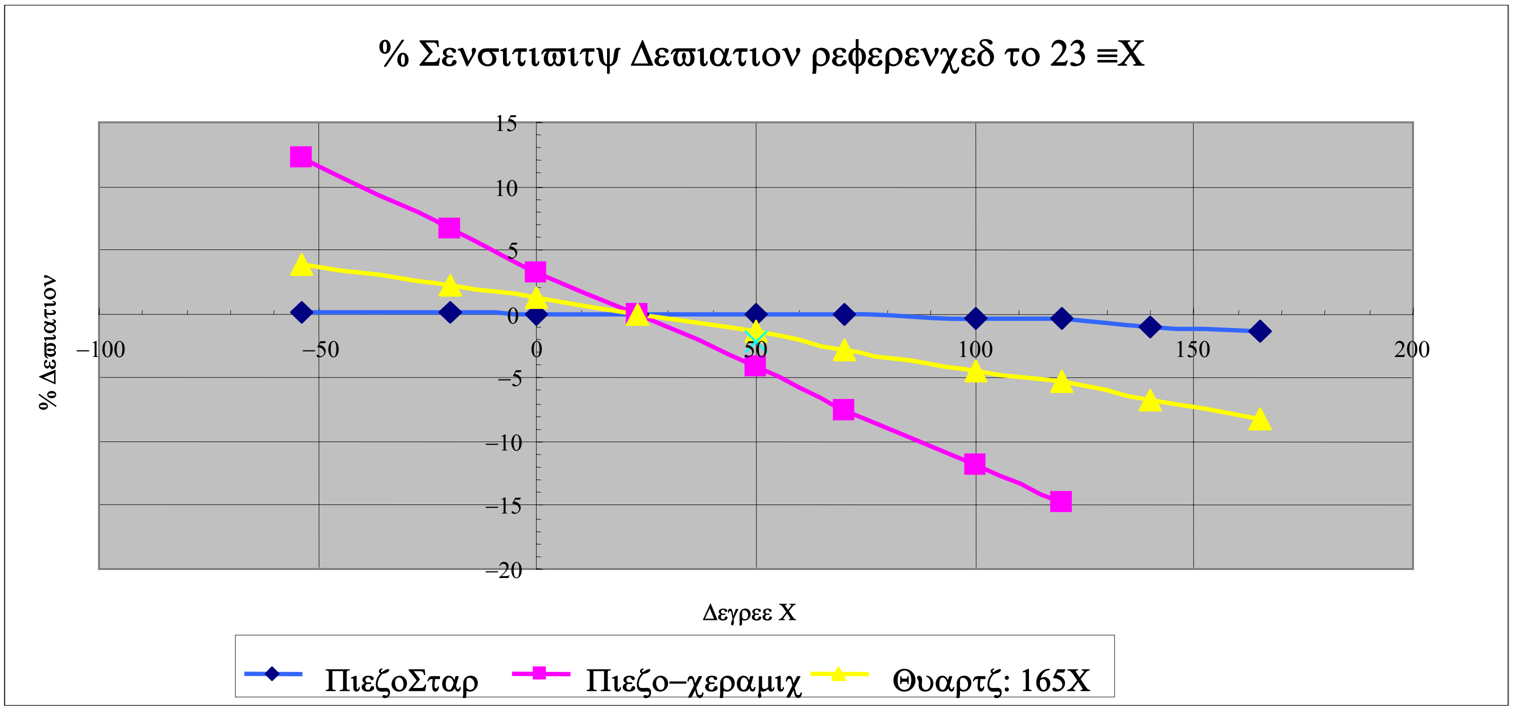
Typical Sensor Temperature Deviation Comparison of Voltage Mode…IEPE Sensors



Comparison Ceramic – Quartz - PiezoStar

Accelerometer Type			
Sensing Element	Ceramic	Quartz	PiezoStar
Temp. Coefficient of Sensitivity	0.08 %/ºF	0.02 %/ºF	0.002 %/ºF
Temperature Range	-65 …250ºF	-320 … 250ºF	-320 … 330ºF
Sensitivity	50 mV/g	50 mV/g	50 mV/g
Frequency Response (+5 %)	10,000 Hz	10,000 Hz	10,000 Hz

Summary

Piezoelectric materials directly affect the performance and size of the sensors

PE sensors using quartz and PiezoStar provide both quasi-static (very low frequency) and dynamic measurement capabilities

PiezoStar operating temperature range: -320 ºF to +1100 ºF

PiezoStar has low temperature coefficient of sensitivity, low thermal transient sensitivity, high sensitivity, wide temperature operating range

PiezoStar high impedance systems (using charge amplifiers) provide flexible systems specifications and higher temperature capability

PiezoStar IEPE accelerometers have negligible sensitivity errors over a wide temperature range

Ideal for applications with highly dynamic temperatures such as:

Flight - Road – and Product Testing