SENSOR TECHNOLOGY LTD

# The Future of Ceramics Performance is Textured Ceramics

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President & CEO

# What we will be discussing Today

- Who is Sensor Technology Ltd.
- Current Status and Performance of PZT Ceramics
- Summary of Single Crystals Performance
- What are Textured Ceramics?
- Benefits/Challenges of Textured Ceramics
- What's Next

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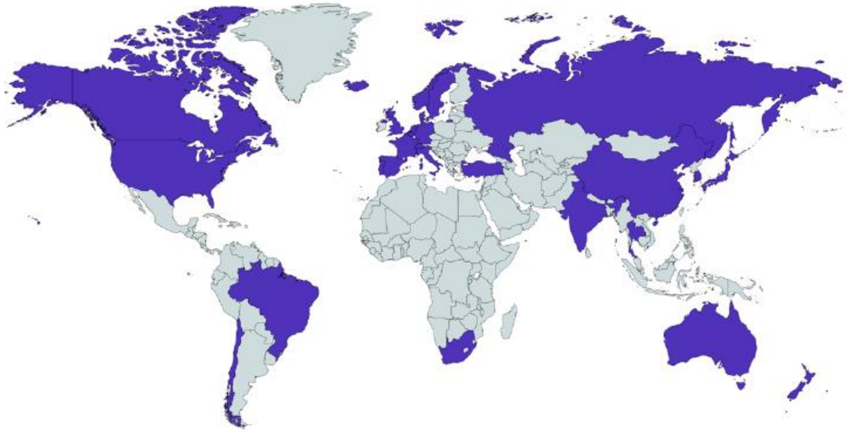
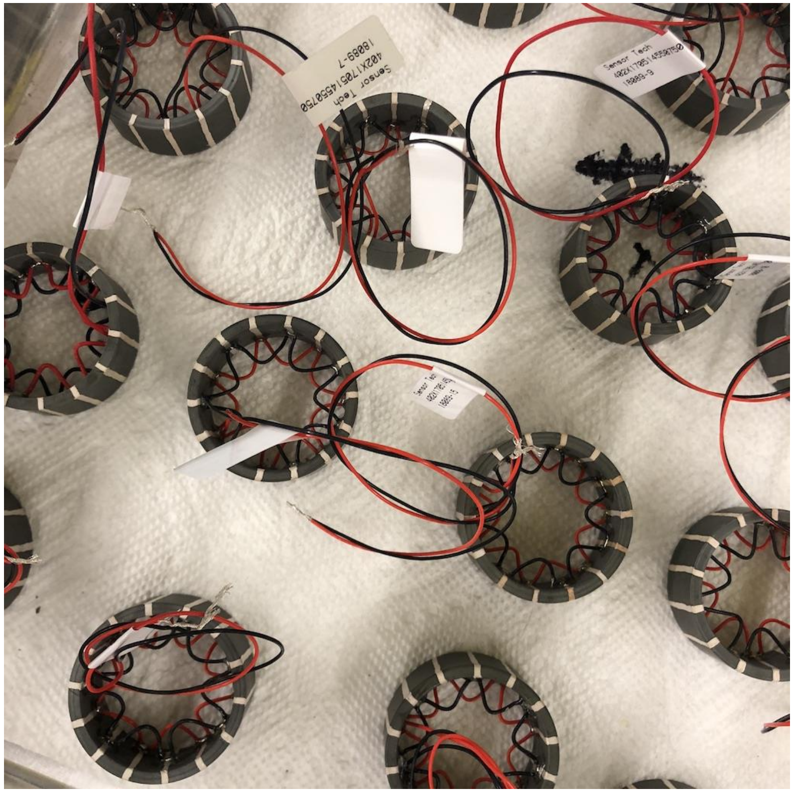
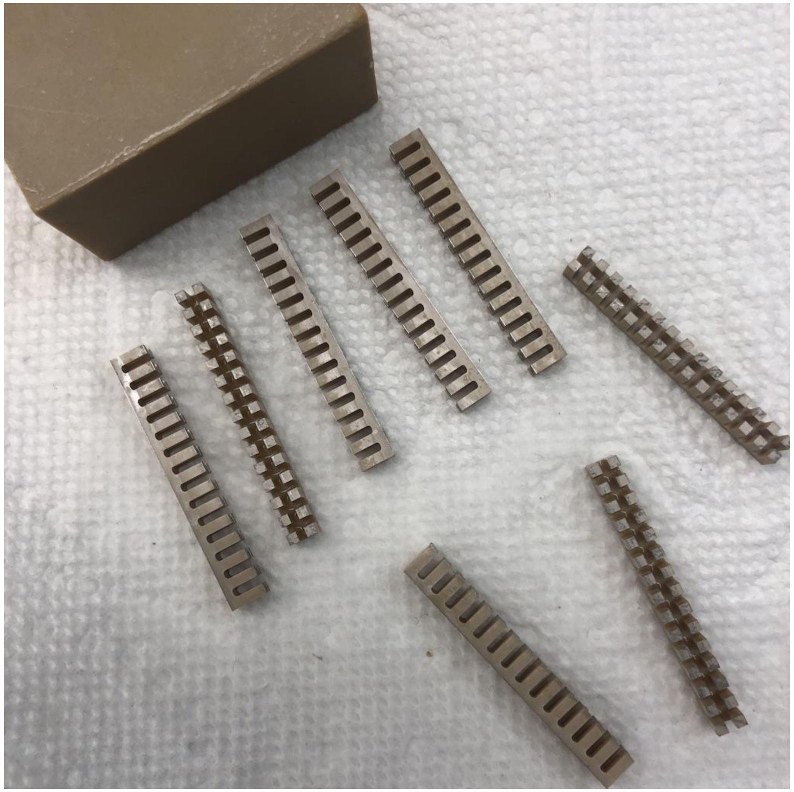
# Who is Sensor Technology



## We build high quality, reliable, customized piezo-based products to support acoustic systems globally

# Our Work in Piezo’s





# Current PZT Uses

"Soft" PZT for sensing applications: Navy Type II, V and VI. Example: hydrophones

"Hard" PZT for sound projection applications: Navy type I and III. Example: free flooded rings, tonpilz transducers

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# General PZT Performance Definition

General piezoelectric performance given by coupling factor *k,* on a scale of 0 to 1

$$k^2 = g \cdot d \cdot E_y$$

Measure of the ratio of the stored electrical energy to the input mechanical energy

Maximum coupling coefficient for PZT ceramics is approximately 0.73-0.75

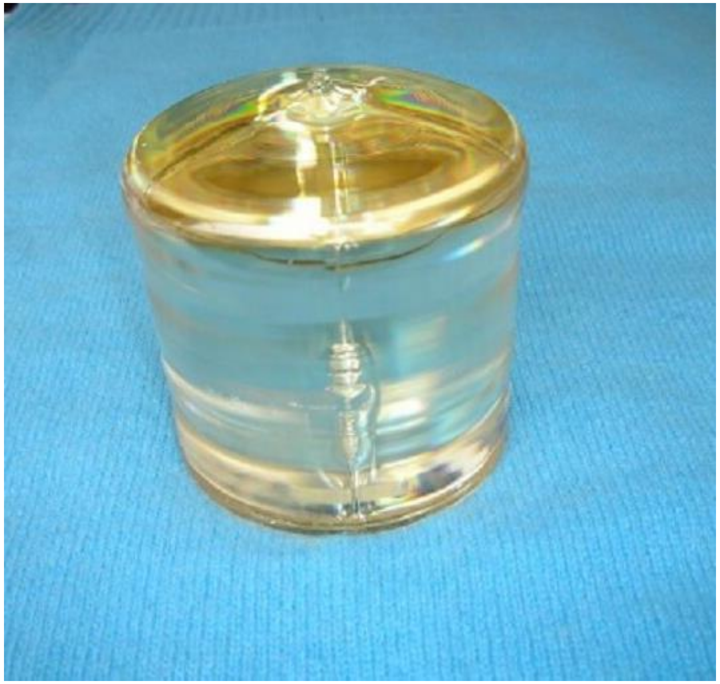
*d•g* product determines the coupling coefficient

Also found in the hydrophone figure of merit

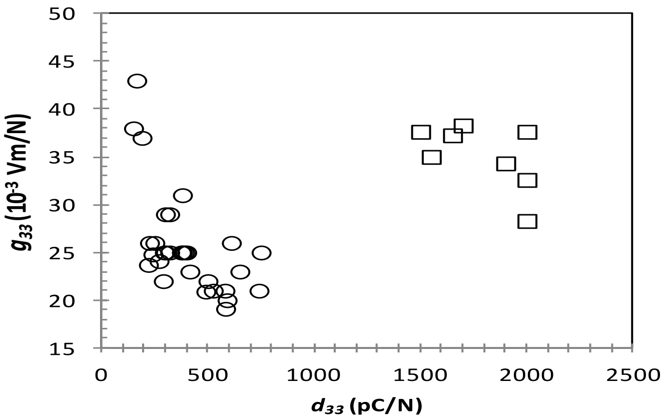
$$FOM_h = g \cdot d \cdot V_o$$

# What are Single Crystals?

- A three dimensional repetition of an atomic lattice structure
- The pattern repeats and extends throughout the material in a regular and periodic manner over long distances
- A diamond is an example of crystalized carbon; quartz is an example of a silicon-oxygen crystal



# Why has widespread adoption of single crystal been limited?




Piezoelectric constants $g_{33}$ and $d_{33}$ for commercially available PZT ceramics (circles) and single crystals (squares).

**PIEZOELECTRIC MATERIAL SPECIFICATIONS**[4]

| | Symbols | Units | Hard PZT | | | Soft PZT | | |
|---|---|---|---|---|---|---|---|---|
| | | | BM400 | BM800 | BM200 | BM500 | BM527 | BM532 |
| **Electrical**[1] | | | Navy Type I | Navy Type III | | Navy Type II | Navy Type V | Navy Type VI |
| Relative Dielectric Constant | $K_{33}^{T}$ | — | 1350 | 1000 | 1080 | 1750 | 2750 | 3250 |
| Dissipation Factor | $Tan\delta$ | % | 0.4 | 0.3 | 0.3 | 1.6 | 2.0 | 2.0 |
| **Piezoelectric** | | | | | | | | |
| Coupling Factor | $k_p$ | — | 0.60 | 0.50 | 0.60 | 0.62 | 0.62 | 0.65 |
| | $k_{31}$ | — | 0.35 | 0.30 | 0.31 | 0.37 | 0.37 | 0.39 |
| | $k_{33}$ | — | 0.70 | 0.64 | 0.64 | 0.72 | 0.72 | 0.75 |
| Charge Constant | $d_{31}$ | $10^{-12}$ C/N | -125 | -85 | -100 | -175 | -215 | -270 |
| | $d_{33}$ | $10^{-12}$ C/N | 300 | 225 | 250 | 365 | 500 | 590 |
| Voltage Constant | $g_{31}$ | $10^{-3}$ V·m/N | -10.5 | -10.5 | -10.0 | -11.5 | -9.5 | -9.0 |
| | $g_{33}$ | $10^{-3}$ V·m/N | 25 | 26 | 26 | 25 | 22 | 20 |
| Mechanical Quality Factor | $Q_M$ | — | 500 | 1000 | 1000 | 80 | 70 | 70 |
| Frequency Constants[2] | $N_p$ | Hz·m | 2150 | 2350 | 2350 | 2050 | 2050 | 2000 |
| | $N_1$ | Hz·m | 1650 | 1700 | 1770 | 1400 | 1400 | 1425 |
| | $N_4$ | Hz·m | 1900 | 2000 | 1900 | 1800 | 1850 | 1850 |
| **Mechanical** | | | | | | | | |
| Compliance | $S_{11}^{E}$ | $10^{-12}$ m²/N | 12.5 | 11.0 | 10.8 | 15.5 | 14.5 | 14.0 |
| | $S_{33}^{E}$ | $10^{-12}$ m²/N | 15.0 | 13.5 | 15.4 | 19.0 | 19.5 | 20.0 |
| Density | $\rho$ | g/cm³ | 7.6 | 7.6 | 7.6 | 7.65 | 7.6 | 7.65 |
| Curie Temperature | $T_c$ | ℃ | 350 | 325 | 330 | 360 | 225 | 210 |
| **Ageing Characteristics**[3] (% change/time decade) | | | | | | | | |
| Coupling Factor | $k_p$ | — | -2.5 | -2.5 | -2.5 | -0.5 | -1.0 | -1.0 |
| Relative Dielectric Constant | $K_{33}^{T}$ | — | -6.0 | -6.0 | -6.0 | -1.0 | -1.0 | -1.0 |
| Frequency Constant | $N_4$ | Hz·m | 1.5 | 1.5 | 1.5 | 0.5 | 1.0 | 1.0 |

This table provides a quick comparison of the electrical and physical properties of Sensor Technology's piezoelectric materials.

Simultaneously high *d* and *g* values are not available in the PZT ceramic system; performance is capped.

Single crystals do provide simultaneously high *g* and *d* values. Coupling coefficients >90% possible.

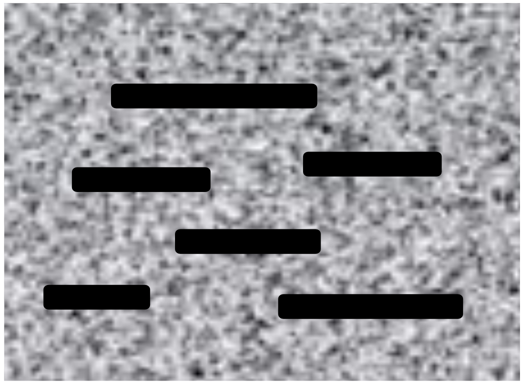
# Drawbacks of Single Crystals

Along with PZT, there are challenges to widespread adoption of Single crystals within certain industries:

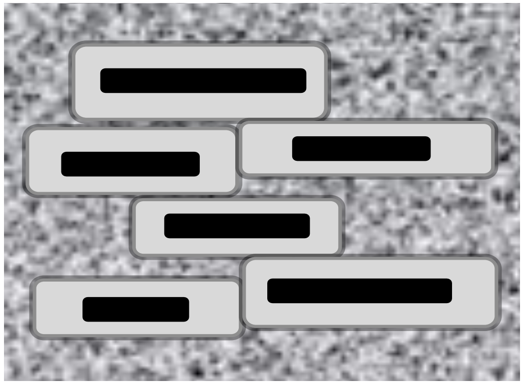
- Highly variable properties from part to part
  - And also within the part itself due to compositional inhomogeneity occurring during crystal growth process
- Relatively low Curie temperature
  - large dielectric property variance with temperature
  - partial depoling at relatively low temperatures (70 C to 90 C), more recent single crystal compositions have improved upon this.
- Low material toughness, poor chip resistance, easy crack propagation
- Crystal sizes relevant to underwater acoustics are difficult to produce and are very costly

# What are Textured Ceramics?

All ceramics are composed of small crystallites (or grains).
In textured ceramics, these crystallites are oriented (or aligned) in the same direction. (Conventional ceramics have randomly oriented grains; single crystals can be thought of as one large grain)



oriented crystal templates (black) embedeed in a powder matrix

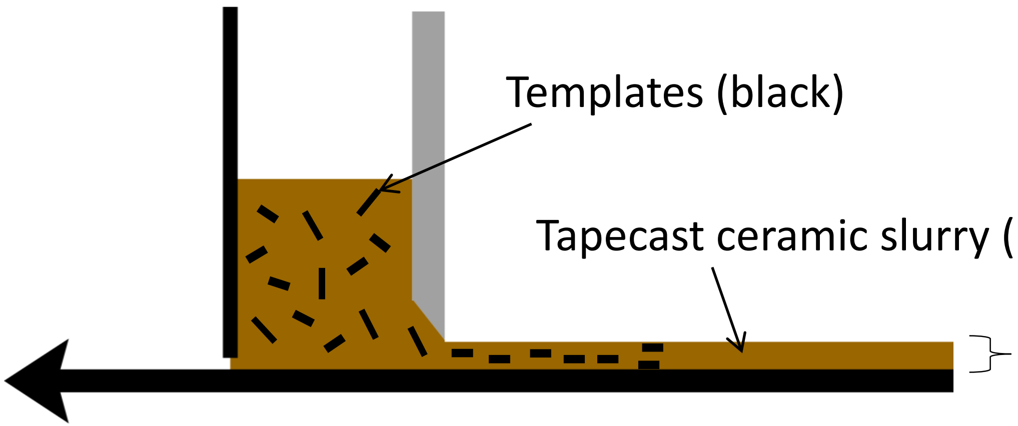


crystal growth (gray) around the oriented templates (black)

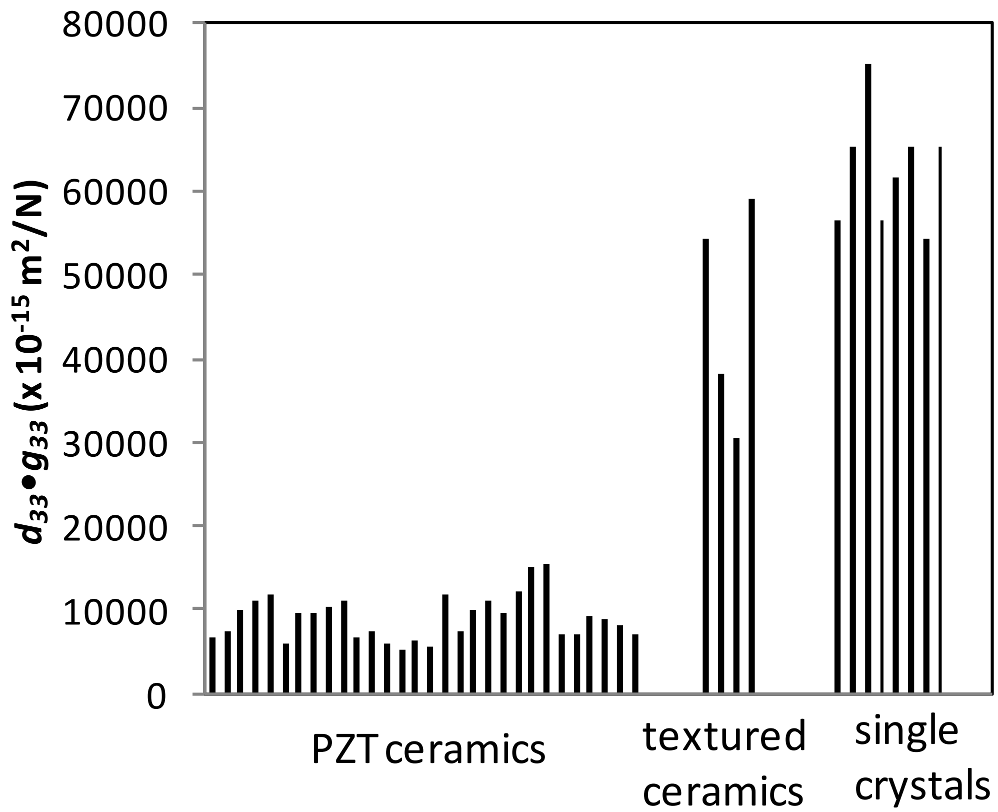
# How are Textured Ceramics Made?

Seed crystal template alignment is critical.

- Templates alignment yields crystallographic direction during crystal nucleation and growth
  - Shear flow of the slurry forces alignment of templates
  - Tape is approximately 300 micron thick
- Usable part thickness is built up by laminating many layers of tape prior to sintering



# What can be expected for the performance of textured ceramics?



# Benefits of Textured Ceramics

There are many benefits/advantages to the adoption of Textured Ceramics

- Textured ceramics mimic the properties of single crystals but are manufactured using low-cost ceramic processes
  - Properties have been reported to be consistent from part to part and within a part
  - High manufacturing yields

- Crystal growth occurs within the ceramic powder approximating single crystal behaviour

# Research and Development Efforts

- Formulations identified
  - Targeting higher Curie temperature formulations

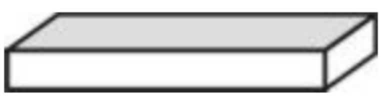
- Crystal nucleation and growth conditions have been determined
  - Crystals have been grown from the powder matrix, 0.1mm in size approximately
  - Sintering shrinkage and machining behavior appear comparable to PZT

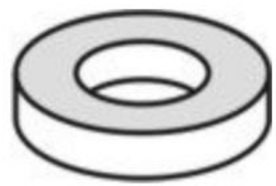
- Iterative texturing and performance testing is underway.

# Current Challenges faced by Textured Ceramics

While there is much supportive data for Textured Ceramics adoption, there are still challenges to be overcome:

- Part size and geometry is currently limited
- Performance has not be standardized





# THANK YOU!

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