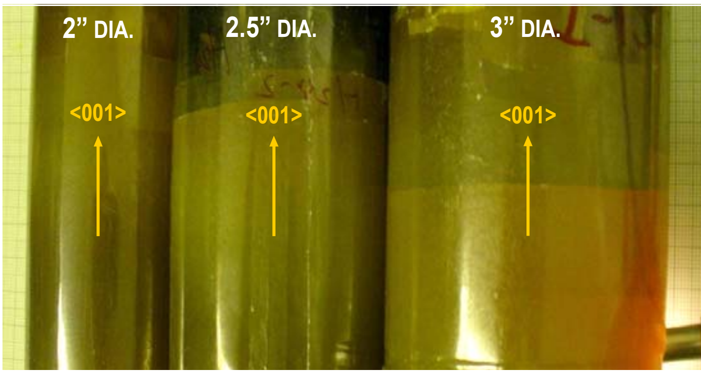
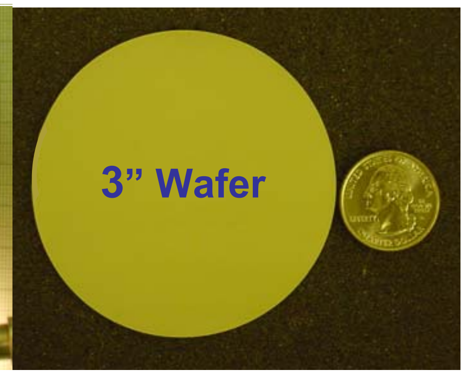
Giant-piezo crystals

ISO-9001-2000 Company





Giant-piezoelectric crystals leading to the next generation of acoustic transduction devices

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COMPANY

HCMC is ISO 9001:2000 company, a leader in the development and manufacture of high-performance piezoelectric single crystals, specializing in lead magnesium niobate - lead titanate (PMN-PT) based piezocrystals.

Founded in 1995, HCMC is a rapidly expanding R&D and manufacturing company, that has fulfilled customer's expectations, performance requirements, delivery, value, quality and service by implementing superior technologies, responsive engineering, and efficient production methods, for the defense and ultrasonic industries.

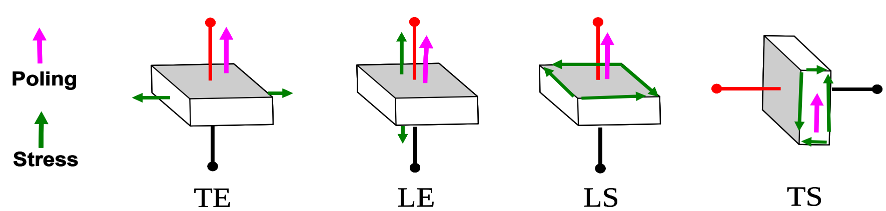
HCMC has supplied over fifty thousand high-quality piezoelectric crystal elements for acoustic transduction devices such as actuators, sensors, ultrasound imaging, active vibration control, and bulk acoustic wave devices for telecommunications.

HCMC has a dedicated team of scientists and engineers to assist in all your needs. The staff has experience in crystal growth, characterization, and applications for over 30 years.

BREAKTHROUGH IN PIEZOELECTRICITY

PMN-PT based crystals exhibit giant-piezoelectric characteristics compared with conventional ceramics such as polycrystalline lead zirconate titanate (PZT). In the history of piezoelectricity, it is the first time that a commercialized piezocrystal can give the super high piezoelectric characteristics: electromechanical coupling over 0.9, field-induced *useable* strain up to 0.3% (i.e., d_{33} = 2500 pC/N, E = 12 kV/cm), piezoelectric charge coefficients d_{33} over 2500 pC/N, d_{31} better than -1600 pC/N and d_{15} greater than 6000 pC/N. PMN-PT crystals also offer dissipation factors significantly lower than PZT ceramics that are important for sensor and large-signal operation. Newly we developed PIN-PMN-PT (with / without dopant) piezoelectric crystals give higher depoling temperature over 137 C and larger coercive electrical field up to 6 kV/cm, that meet the requirement of high drive acoustic actuator.

Superiority of PMN-PT crystals over PZT-5H ceramics



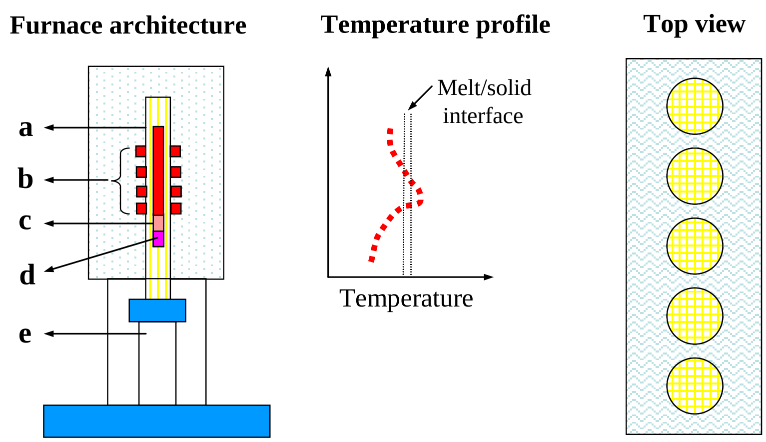
PMN-PT CRYSTALS	d_{31} -1200~ -1800 pC/N k_{31} = 0.84~0.90 *zxt*-0° cut <011> poling	d_{33} 2000~3000 pC/N k_{33} > 0.90 *zxt*-0° cut <001> poling	d_{36} 2000~2500 pC/N k_{36} > 0.90 *zxt*-45° cut <011> poling	d_{15} 4000~7000 pC/N k_{15} > 0.95 *xzt*-22.5° cut <111> poling
PZT-5H CERAMICS	d_{31} -270 pC/N k_{31} ≈ 0.39	d_{33} 590 pC/N k_{33} ≈ 0.75	d_{36} n/a n/a	d_{15} 740 pC/N k_{15} ≈ 0.68

TE: Transverse Extension, LE: Longitudinal Extension, LS: Longitudinal Shear, TS: Transverse Shear

PATENTED TECHNOLOGY

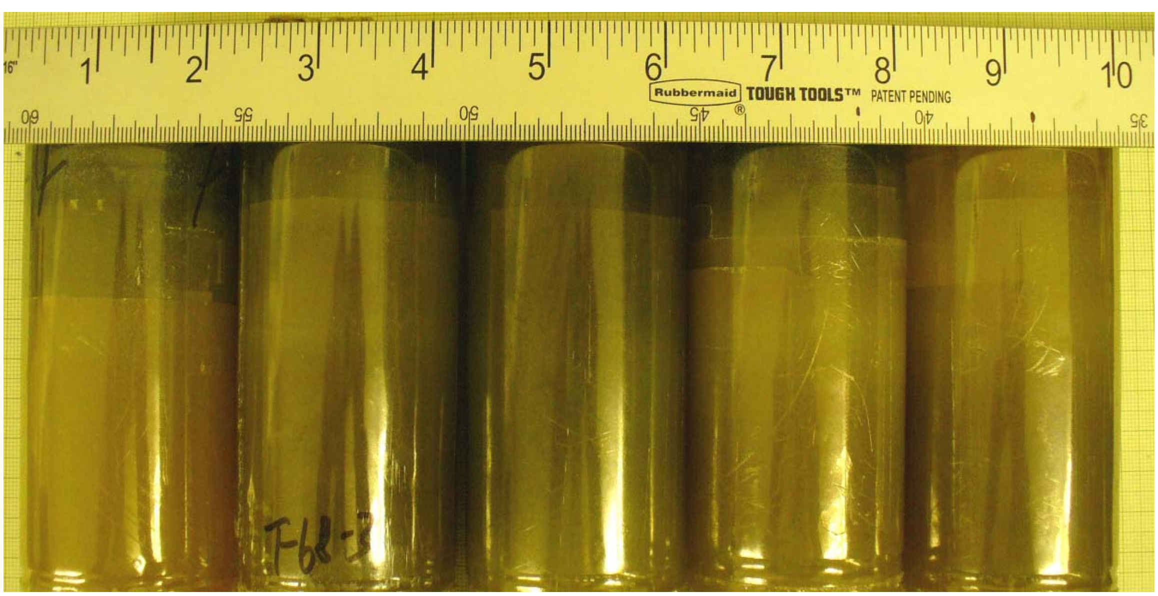
HCMC has a ***proprietary*** crystal growth method (US Patent 6,972,730 B2) based on a multi-crucible Bridgman growth approach with zone-leveling modifications. The technique enables the growth of large 3”-diameter PMN-PT single crystals by <001> seeding, which gives high yield in a cost-effective manner ready for commercialization.

The unique <001>-seeding developed at HCMC is technically challenging but practically essential for improvements in piezoelectric properties suitable for new and advanced applications. HCMC is able to grow PMN-PT crystals by <001> seeding in a reproducible and productive manner.



a. Tube liner; **b**. Heater; **c**. Crucible. **d**. Seed; **e**. Levitation mechanism.

Crystal-growth system (US Patent 6,972,730 B2)

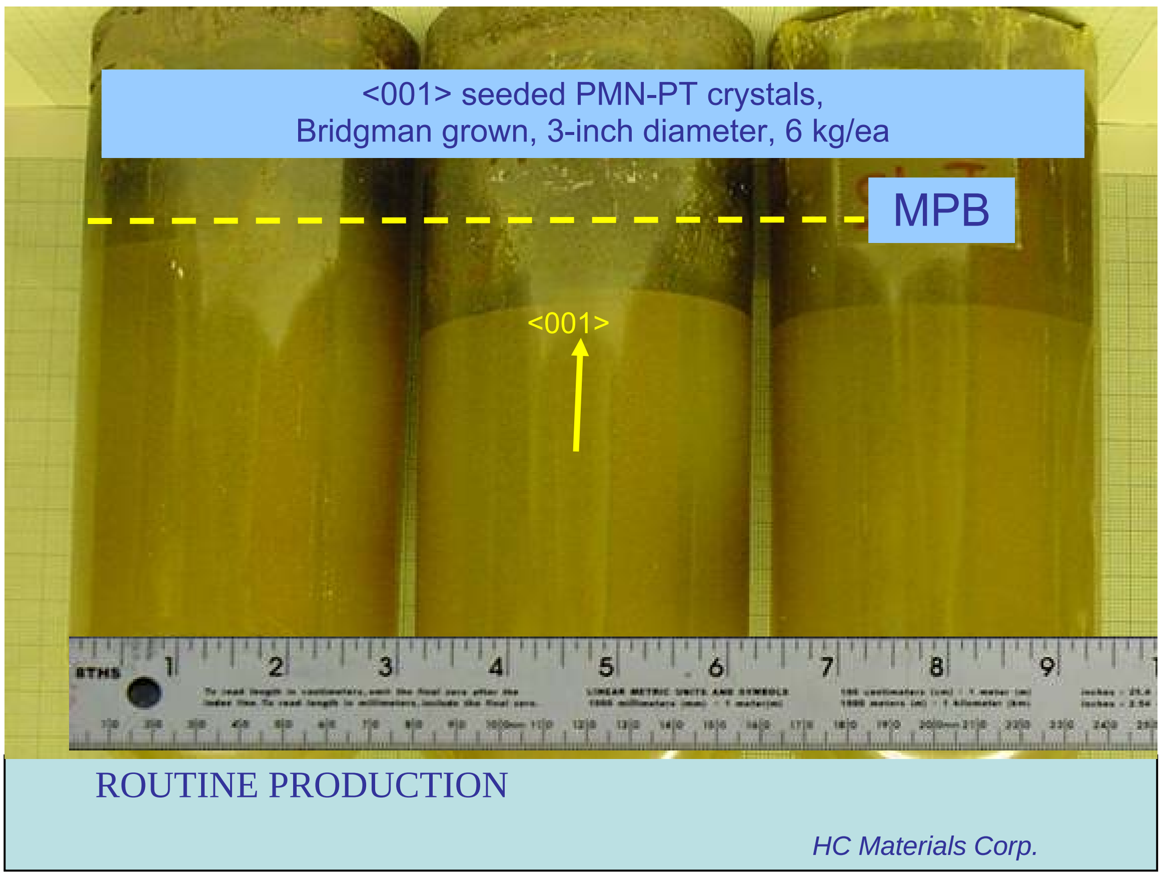


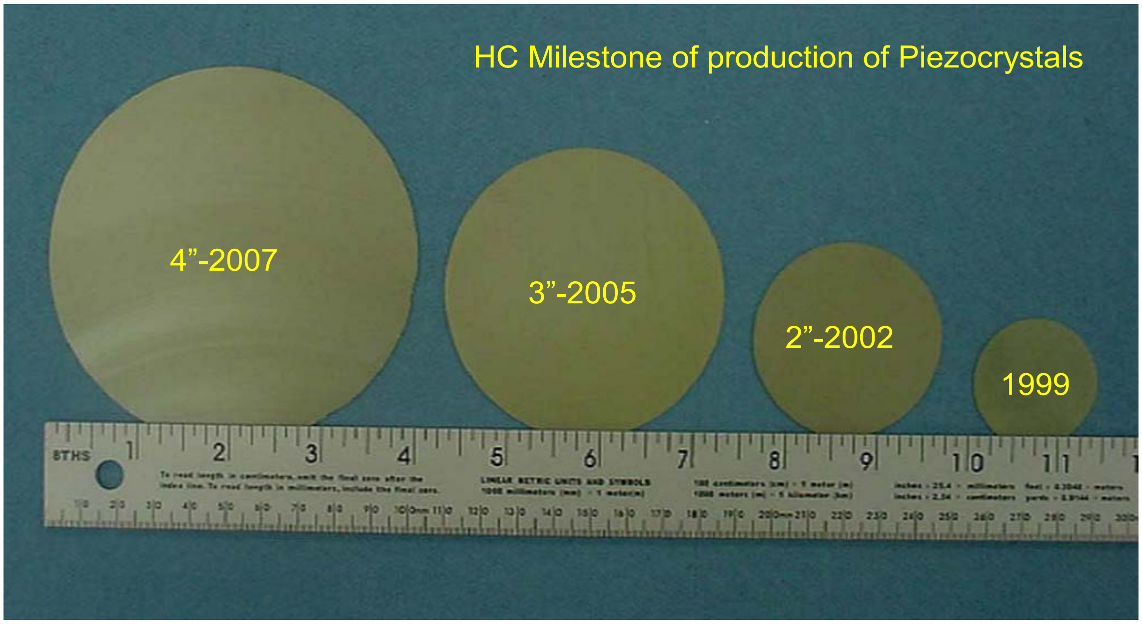
PRODUCTS

HCMC supplies a variety of PMN-PT crystal products. Customer's specifications are welcome. Crystal elements supplied to customer specifications, include, cut direction, vibration mode, piezoelectric properties and dimensions. Crystal elements are usually electroded and poled, with data sheets.

Examples are given below:

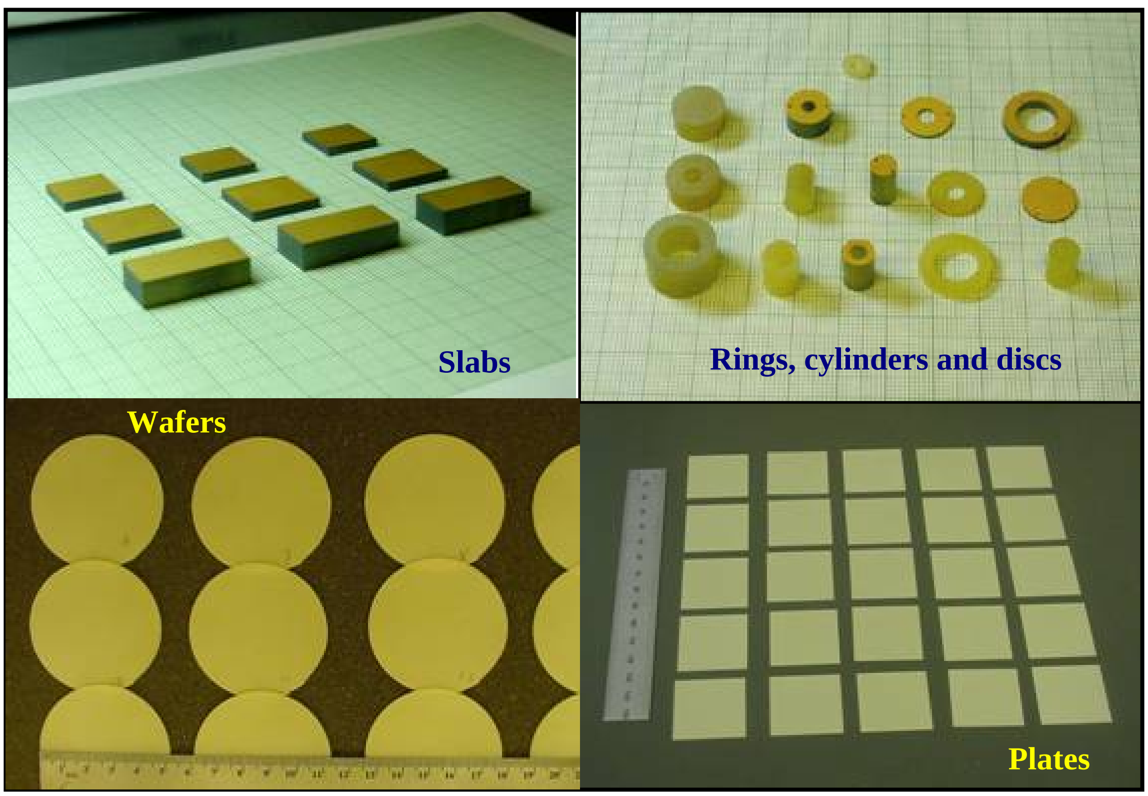
Size: 3" diameter crystal boule grown by <001> seeding.





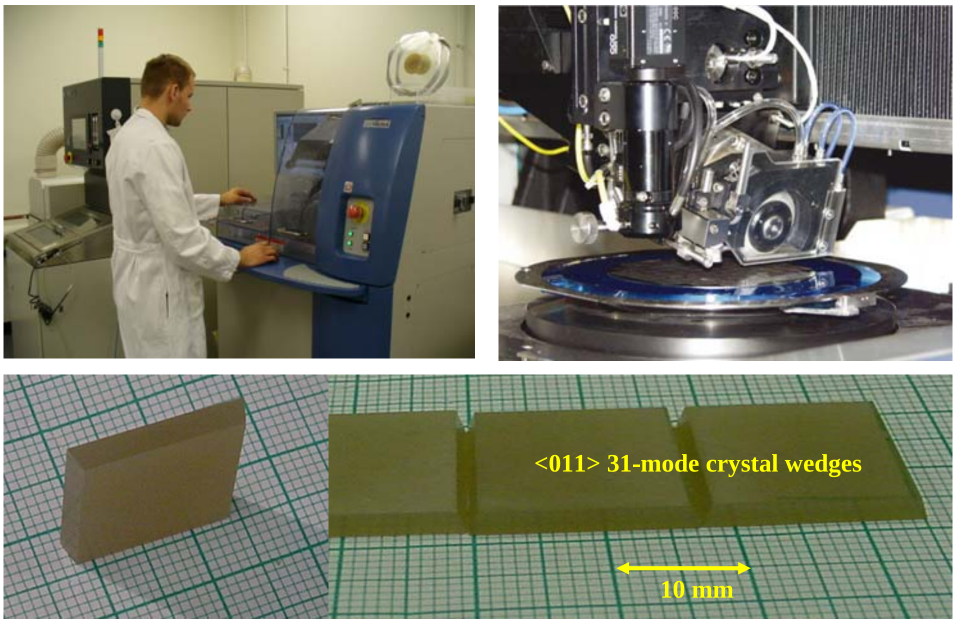
Shapes:

Plates, bars, slabs, wedges, discs, cylinders, tubes and rings.



CAPACITY OF PRODUCTION

HCMC has supplied over 40,000 PMN-PT crystal elements to clients for defense and commercial applications over the past few years. With the recent expansion of production facilities in the Chicago area, we are capable of producing PMN-PT crystal products at a rate of thousands of crystal elements per month. Production planning, scheduling, inventory control, quality assurance, and accounting methods are established and certified.



Wedge Fabrication Auto-Dicing with tiled spindle

Crystal growth facilities

R & D

Our R&D team, with over 30 years of experience in crystal growth and characterization, has developed a series of crystal-growth methods, including top-seeded solution growth, multi-crucible Bridgman, and internal resistance heating melt growth.

New crystal-growth techniques are under refinement for improved compositional homogeneity and increased crystal yield.

Investigations are underway on new compositions for piezocrystals with improved thermal stability and larger coercive field strength.

Post finishing of crystal elements is implemented to enhance mechanical strength and device performance characteristics.

Recently, we discovered new cut directions for PMN-PT piezocrystals through theoretical calculation and experimental verification. These discoveries provide customers with new opportunities for the development of the next generation of acoustic transduction devices for defense and commercial applications.

New facilities have installed to develop composite crystal products.

Oxford PlasmaLab 100 RIE unit

Hitachi-3400 SEM with EDS

APPLICATIONS

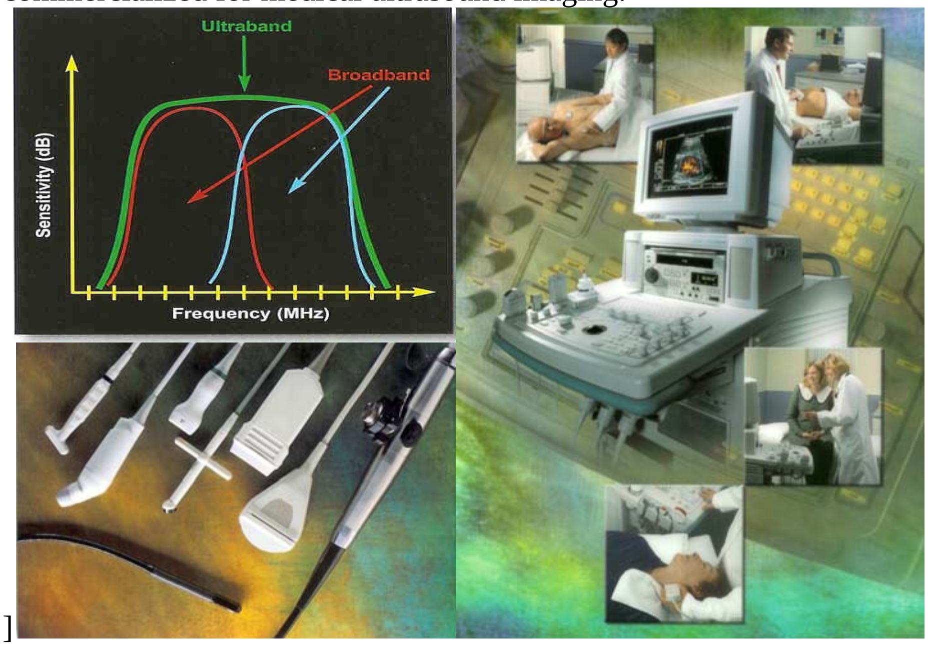
The superior properties of PMN-PT crystals lead to the following benefits for piezoelectric applications.

- Broad bandwidth
- High source level
- High signal : noise ratio
- Size reduction

Examples of successful applications for PMN-PT crystals:

1. **Medical ultrasound imaging**

<001> - poled large single-crystal wafers have been successfully commercialized for medical ultrasound imaging.



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2. **Sonar**

<001> and <011>-poled PMN-PT crystal elements have been successfully demonstrated for torpedo guidance and torpedo countermeasure transducers.

3. **Accelerometer**

   Super-high shear mode (36-mode and 15-mode) PMN-PT crystal elements with the highest shear charge coefficients (e.g. d_{15}>7000 pC/N) in the history of piezoelectric materials. Prototype devices exhibit excellent performance characteristics.

4. **Acoustic vector sensors**

   <011>-poled PMN-PT crystal elements with low noise and high sensitivity have been used for 3D vector sensor array, with significantly enhanced sensitivity and reduced size

5. **Non-destructive detection**

6. **Hydrophones (Ocean mining-oil & gas)**

7. **Adaptive optics (deformation mirror)**

8. **Non-linear optics (tunable harmonic generation)**

FACILITY

HCMC has state-of-the-art crystal growth and processing facilities located in a modern industrial building. Equipments include crystal growth systems, crucible fabrication, chemical processing, crystal orientation and finishing (e.g., slicing, dicing, and lapping), plasma magnetron sputtering for electrode deposition, and IEEE standard electrical property testing for quality assurance and control.

QUALITY CONTROL

HCMC , an ISO-9001-2000 company, has established a formal Quality Assurance Program that addresses various quality standards for compliance with Navy and other customer's requirements.

ENVIRONMENT CONTROL

The established facilities meet regulations for Federal, State and Local Governments, and environmental laws for airborne emissions, waterborne effluents, radiation levels, noise, solid and bulk waste disposal, and handling and storage of toxic and hazardous materials.

CONTACT INFORMATION

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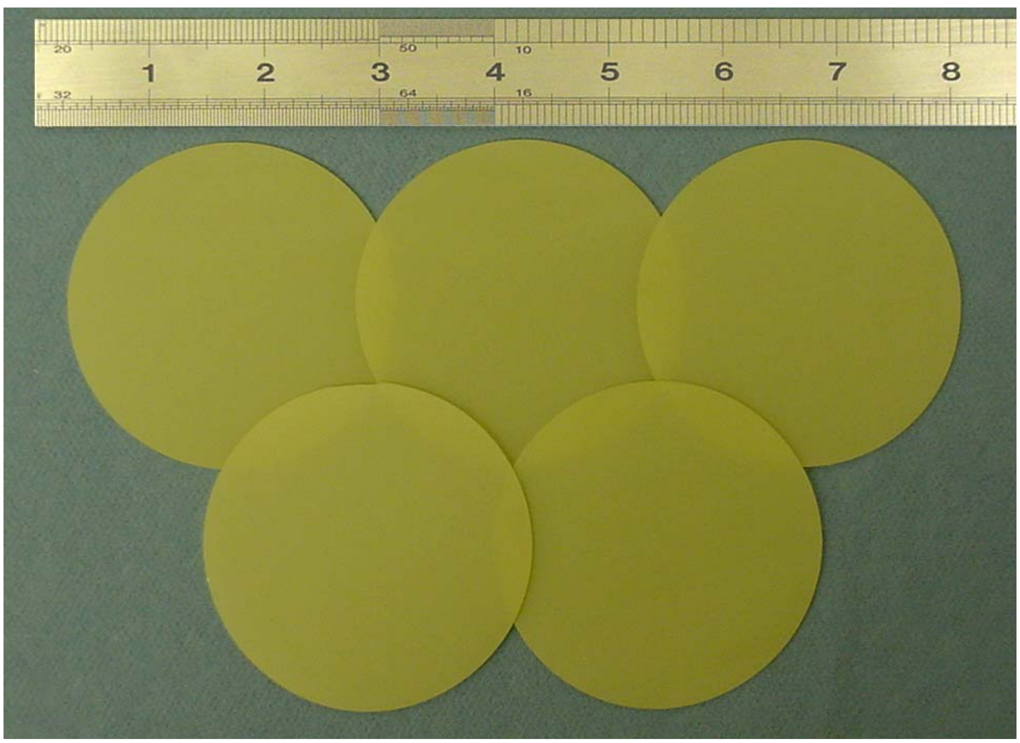
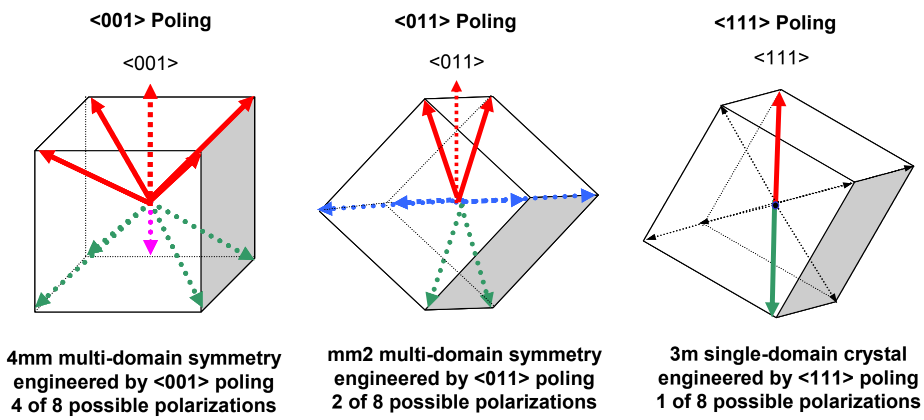


Appendix

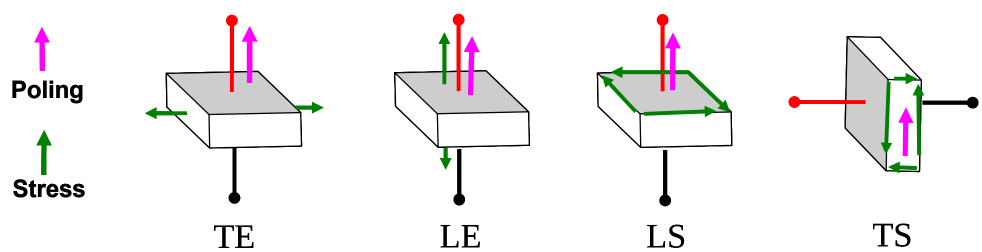
HOW PIEZOCRYSTALS WORK

Piezocrystals can be domain-engineered into three symmetric states that are *impossible* for PZT ceramics. For PMN-PT single crystals, polarization directions can be aligned optimally in the following three domain states: <001>-poled, <011>-poled and <111>-poled. By comparison, PZT ceramics have only one domain state regardless of the poling directions because of the random grain orientations. PMN-PT crystals with different domain states have different piezoelectric properties for the same composition.



Engineered domain states for PMN-PT piezocrystals

Choice of vibration mode with poling direction



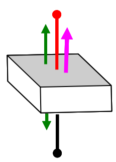
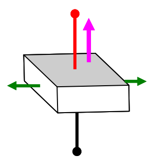
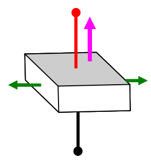
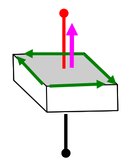
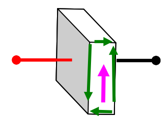
<001> poling	d_{31}, d_{32} -800 ~ -1000 pC/N k_{31} > 0.80	d_{33} 2000 ~ 3000 pC/N k_{33} > 0.90	d_{36} n/a	d_{15}, d_{24} <100 pC/N
<011> poling	d_{31} -1200 ~ -1800 pC/N k_{31} ~ 0.84 -0.90	d_{33} <500 pC/N	d_{36} 2500 pC/N k_{36} > 0.90	d_{15}, d_{24} 2000~3500 pC/N k_{15} > 0.90
<111> poling	d_{31}, d_{32} <150 pC/N	d_{33} <200 pC/N	d_{36} n/a	d_{15}, d_{24} 4000~7000 pC/N k_{15} > 0.95

TE: Transverse Extension, LE: Longitudinal Extension, LS: Longitudinal Shear, TS: Transverse Shear

HOW TO SELECT PIEZOCRYSTALS

To facilitate the selection of piezocrystals, we have systematically surveyed the maximum piezoelectric coefficients in terms of vibration modes and cut directions through tensor calculation and experimental verification for each domain state. The results are listed in Table 1.

Table 1. Summary of optimized cut directions for different vibration modes.[1]

Vibration Mode	Longitudinal Extension 33-mode(001)	Transverse Extension 31-mode(001)	Transverse Extension 31-mode(011)	Longitudinal Shear 36-mode(011)	Transverse Shear 15-mode(111)
	 LE	 TE	 TE	 LS	 TS
Poling direction	<001>	<001>	<011>	<011>	<111>
Domain Symmetry	4mm	4mm	mm2	mm2	3m
Cut direction	***zxt*** 0°	***zxt*** 0°	***zxt*** 0°	***zxt*** ±45°	***xzt*** -22.5°
Calculated value (31% PT)	d_{33} 2000 pC/N	d_{31} -900 pC/N	d_{31} -1750 pC/N	d_{36} 2600 pC/N	d_{15}, d_{16} 5190, 0 pC/N
Measured value (31% PT)	d_{33} 2000 pC/N	d_{31} -900 pC/N	d_{31} -1750 pC/N	d_{36} 2520 pC/N	d_{15}, d_{16} 5300, 60 pC/N

[1] P. Han, W. Yan, J. Tian, X. Huang, and H. Pan. "Cut directions for the optimization of piezoelectric coefficients of lead magnesium niobate - lead titanate ferroelectric crystals". Appl. Phys, Lett. **86**, No.1, 2466, (2005)

There are five choices of cut directions for PMN-PT piezocrystal elements (Table-1). We supply all of the vibration modes for customer specifications.

1) Longitudinal Extension Mode (33 Mode; <001> poled)

<001>-poled PMN-PT crystals give maximum d_{33} and k_{33}. The detailed parameters are listed in the Appendix. For large-signal operation, the crystals can work safely under 15kV/cm with pre-pressure to achieve stains up to 0.3%. For small-signal operation (i.e., sensors), we can supply PMN-PT crystals with d_{33} of 3000-3500 pC/N and k_{33} > 0.92.

2) Transverse Extension Mode (31 Mode; <001> poled)

<001>-poled PMN-PT crystals give d_{31} values 3-5x greater than PZT ceramics. The detailed parameters are listed in the Appendix. *Note: The piezoelectric response in the plane ⊥ axis-3 is isotropic, i.e.,* $d_{31} = d_{32}$.

3) Transverse Extension Mode (31 Mode; <011> poled)

<011>-poled PMN-PT crystals give the greater d_{31} values (up to -1700 pC/N). *Note: This mode is highly anisotropic. The maximum d_{31} value occurs in the <100> direction. The maximum d_{32} value occurs in the* <0$\bar{1}$1> *direction. d_{31} is negative and d_{32} is positive, i.e., d_{31} = -2d_{32}. This anisotropy is particularly useful for vector sensors. Details are in the figure below.*

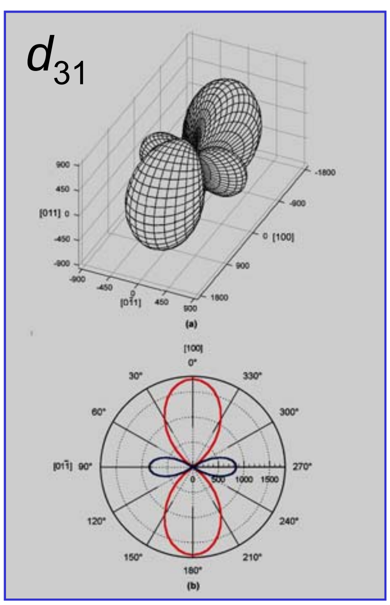
4) Longitudinal Shear Mode (36 Mode; <011> poled)

We have discovered a unique 36 mode that only exists in <011>-poled PMN-PT crystals (***zxt*** ±45° cut). Such a vibration mode is *impossible* in PZT ceramics. The piezoelectric response is 4x greater than d_{15} for PZT-5H. *Note: This is the only shear mode that is re-polable in all of the existing piezoelectric materials.*

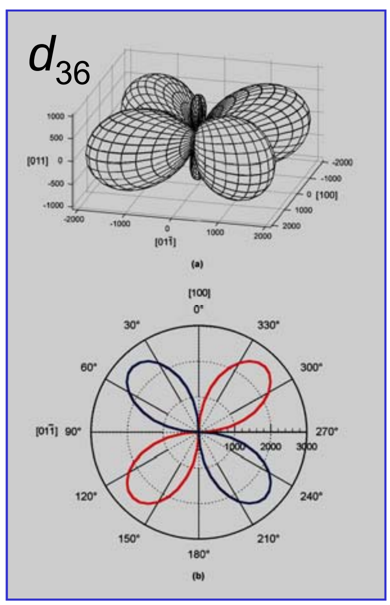
5) Transverse Shear Mode (15 Mode; <111> poled)

We discovered a super-high shear coefficient d_{15} (up to 7000 pC/N) for <111>-poled PMN-PT piezocrystals with ***xzt*** -22.5° cut. *Note: This mode has minimum cross-talk from d_{11} and d_{16} to d_{15}.*

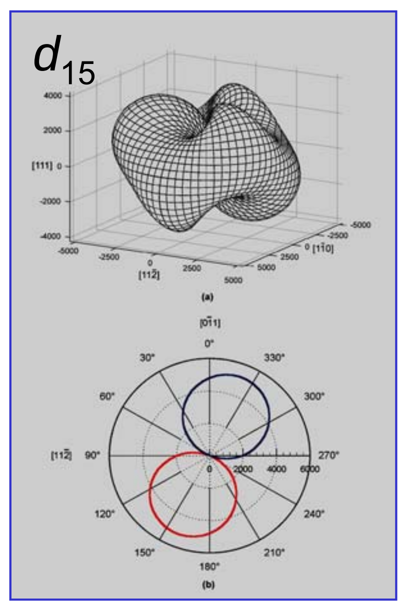
Piezoelectric representation surfaces for d_{31}, d_{36} and d_{15}



(a) d_{31}, mm2 multi-domain symmetry
(b) Cross section in (011) plane



(a) d_{36}, mm2 multi-domain symmetry
(b) Cross section in (011) plane



(a) d_{15}, 3m single-domain crystal
(b) Cross section in(1$\bar{1}$0) plane

Piezoelectric properties for <001>-poled and <011>-poled PMN-PT crystals.

<001> -poled 33-mode				<011> - poled 31-mode			
Property	**Unit**	**Type A**	**Type B**	**Property**	**Unit**	**Type A**	**Type B**
K_{33}^T		5000	6500	K_{33}^T		3200	4600
tan δ		0.0040	0.0060	*tan* δ		0.0035	0.0024
d_{33}	pC/N	1400	2500	d_{31}	pC/N	-1100	-1750
d_{31}	pC/N	-580	-900	d_{32}	pC/N	301	564
k_{33}		0.88	0.92	k_{31}		0.69	0.90
s_{33}^E	10^{-12} m^2/N	38	60	s_{11}^E	10^{-12} m^2/N	53	84
s_{33}^D	10^{-12} m^2/N	9.8	12	s_{11}^D	10^{-12} m^2/N	26	30
g_{33}	10^{-3}Vm/N	32	37	g_{31}	10^{-3}Vm/N	-34	-38
E_c **Coercive**	kV/cm	2.5	2.3	***E*** **c Coercive**	kV/cm	4.5	4.0
De-poling	˚C	93	85	**De-poling**	˚C	95	85
Acoustic imp. <001>	mrayl	28	27	**Acoustic imp. <001>**	mrayl	32	30

Property comparison between PMN-PT and PIN-PMN-PT crystals, <001>-poling

Property	**Unit**	**PMN-PT**	**PIN-PMN-PT**
K_{33}^T		4500~7000	3500~6000
tan δ		0.0040	0.0050
d_{33}	pC/N	1400~2500	1200~2000
d_{31}	pC/N	-580~-900	-500~ -900
k_{33}		0.88 ~ 0.92	0.86-0.92
s_{33}^E	10^{-12} m^2/N	42	47
s_{33}^D	10^{-12} m^2/N	11	12
g_{33}	10^{-3}Vm/N	34	39
E_c **Coercive**	kV/cm	2.4	5~6
De-poling	˚C	85~93	100~135