Material Properties

We recognize the need to perform FEA and modeling to predict and design a piezoelectric transducer. This article provides resources on our material properties.

In this Article

Piezoelectric Materials

A full comparison of the material properties we have is available on the main site (https://piezo-systems.myshopify.com/pages/piezo-material). The table comparing PZT-5A to PZT-5J and PZT-5H is included below. Here is a brief summary:

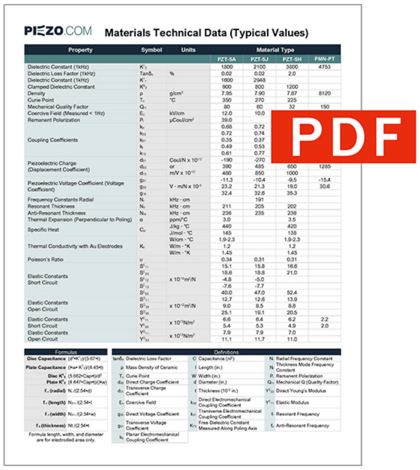
- **PZT-5A** - is best for applications that have extreme temperatures and/or a widely varying temperature but the performance is desired to remain constant.
- **PZT-5H** - has the best piezoelectric material properties but is influenced by temperature change and has a slightly reduced temperature range.
- **PZT-5J** - a compromise between 5H and 5A
- **PMN-PT Single Crystal Piezo** - It is inherently different that piezoceramic both in application and in handling, and therefore should not be thought of as a 'drop in' replacement of piezoceramic

parts, but rather as 'ground up' design option for applications requiring higher energy density than possible with piezoceramics.

PIEZO.COM'S Designation	**Symbol**	**Units**	**PSI-5A4E**	**PSI-5J1E**	**PSI-5H4E**	**Single Crystal Piezo**
PIEZOELECTRIC						
Industry Designations			Navy type II; Industry Type 5A	Navy type V; Industry Type 5J	Navy type VI; Industry Type 5H	PMN-PT
Material Number			3195HD	3222HD	3203HD	
Composition			Lead Zirconate Titanate (PZT)	Lead Zirconate Titanate (PZT)	Lead Zirconate Titanate (PZT)	
Relative Dielectric Constant (@ 1 KHz)	K^T_3		1800	2100	3800	4753
Piezoelectric "d" coefficients relate the Strain Produced / Electric Field Applied or the Short Circuit Charge Density Produced / Stress Applied						
	d_{33}	meter/Volt or Coulomb/Newton	390×10^{-12}	500×10^{-12}	650×10^{-12}	1285^{-12}pC/N
	d_{31}	meter/Volt or Coulomb/Newton	-190×10^{-12}	-210×10^{-12}	-320×10^{-12}	-646^{-12}pC/N
Piezoelectric "g" coefficients relate the Open Circuit Electric Field Produced / Stress Applied or the Strain Produced / Charge Density Applied						

PIEZO.COM'S Designation	Symbol	Units	PSI-5A4E	PSI-5J1E	PSI-5H4E	Single Crystal Piezo
	g_{33}	Volt-meter/Newton or meter ^{2}/Coulomb	24.0×10^{-3}	23.0×10^{-3}	19.0×10^{-3}	30.55 $^{-3}$Vm/N
	g_{31}	Volt-meter/Newton or meter ^{2}/Coulomb	-11.6×10^{-3}	-10.4×10^{-3}	-9.5×10^{-3}	-15.36 $^{-3}$Vm/N
Coupling Coefficient	k_{33}		0.72	0.74	0.75	0.89
	k_{31}		0.35	0.37	0.44	0.46
Polarizing Field	Ep	Volt/meter	$> 2 \times 10^6$	$> 1.7 \times 10^6$	$> 1.5 \times 10^6$	
Initial Depolarizing Field	Ec	Volt/meter	$\sim 5 \times 10^5$	$\sim 4 \times 10^5$	$\sim 3 \times 10^5$	
Coercive Field	Ec	Volt/meter	$\sim 1.2 \times 10^6$	$\sim 1.0 \times 10^6$	$\sim 8 \times 10^5$	4.5-6 kV/cm
MECHANICAL						
Density	δ	Kg/meter ^{3}	7800	7800	7800	8.12 g/cc
Mechanical Q			80	60	32	~150
Elastic (Young's) Modulus	Y^E_3	Newton/meter ^{2}	5.2×10^{10}	5.1×10^{10}	5.0×10^{10}	2.04 ^{10}N/m^2

(https://info.piezo.com/hubfs/Data-Sheets/piezo-material-properties-data-sheet-20201112.pdf)


PIEZO.COM Materials Technical Data (Typical Values)

Property	Symbol	Units	PZT-5A	PZT-5J	PZT-5H	PMN-PT
Dielectric Constant (1kHz)	K^T_3		1800	2100	3800	4753
Dielectric Loss Factor (1kHz)	$Tan\delta_e$	%	0.02	0.02	2.0	
Dielectric Constant (1kHz)	K^T_1		1600	2948		
Clamped Dielectric Constant	K^S_3		900	800	1200	
Density	ρ	g/cm³	7.95	7.90	7.87	8120
Curie Point	T_c	°C	350	270	225	
Mechanical Quality Factor	Q_m		80	60	32	150
Coercive Field (Measured < 1Hz)	E_c	kV/cm	12.0	10.0	[illegible]	[illegible]
Remanent Polarization	P_r	μCoul/cm²	39.0		[illegible]	[illegible]
Coupling Coefficients	k_p		0.68	0.72	[illegible]	[illegible]
	k_{33}		0.72	0.74	[illegible]	[illegible]
	k_{31}		0.35	0.37	[illegible]	[illegible]
	k_t		0.49	0.53	[illegible]	[illegible]
	k_{15}		0.61	0.77	[illegible]	[illegible]
Piezoelectric Charge (Displacement Coefficient)	d_{31}	Coul/N x 10^{-12}	-190	-270	[illegible]	[illegible]
	d_{33}	or	390	485	650	1285
	d_{15}	m/V x 10^{-12}	460	850	1000	
Piezoelectric Voltage Coefficient (Voltage Coefficient)	g_{31}		-11.3	-10.4	-9.5	-15.4
	g_{33}	V · m/N x 10^{-3}	23.2	21.3	19.0	30.6
	g_{15}		32.4	32.6	35.3	
Frequency Constants Radial	N_r	kHz · cm		191		
Resonant Thickness	N_t	kHz · cm	211	205	202	
Anti-Resonant Thickness	N_a	kHz · cm	236	235	236	
Thermal Expansion (Perpendicular to Poling)	α	ppm/°C	3.0		3.5	
Specific Heat	C_p	J/kg · °C	440		420	
		J/mol · °C	145		138	
Thermal Conductivity with Au Electrodes	K_t	W/cm · °C	1.9-2.3		1.9-2.3	
		W/m · °K	1.2		1.2	
		W/m · °K	1.45		1.45	
Poisson's Ratio	υ		0.34	0.31	0.31	
Elastic Constants Short Circuit	S^E_{11}	x 10^{-12}m²/N	15.1	15.8	16.6	
	S^E_{33}		18.6	18.8	21.0	
	S^E_{12}		-4.8	-5.0		
	S^E_{13}		-7.6	-7.7		
	S^E_{55}		40.0	47.0	52.4	
Elastic Constants Open Circuit	S^D_{11}	x 10^{-12}m²/N	12.7	12.6	13.9	
	S^D_{33}		9.0	8.5	8.8	
	S^D_{55}		25.1	19.1	20.5	
Elastic Constants Short Circuit	Y^E_{11}	x 10^{10}N/m²	6.6	6.4	6.2	2.2
	Y^E_{33}		5.4	5.3	4.9	2.0
Elastic Constants Open Circuit	Y^D_{11}	x 10^{10}N/m²	7.9	7.9	7.0	
	Y^D_{33}		11.1	11.7	11.0	

Formulas	
Disc Capacitance	$(d^2 \cdot K^T_3)/(5.67 \cdot t)$
Plate Capacitance	$(l \cdot w \cdot K^T_3)/(4.45 \cdot t)$
Disc K^T_3	$(5.662 \cdot Cap \cdot t)/d^2$
Plate K^T_3	$(4.447 \cdot Cap \cdot t)/(l \cdot w)$
f_r (radial)	$N_r/(2.54 \cdot d)$
f_r (length)	$N_{31}/(2.54 \cdot l)$
f_r (width)	$N_{31}/(2.54 \cdot w)$
f_t (thickness)	$N_t/(2.54 \cdot t)$

Formula length, width, and diameter are for electroded area only.

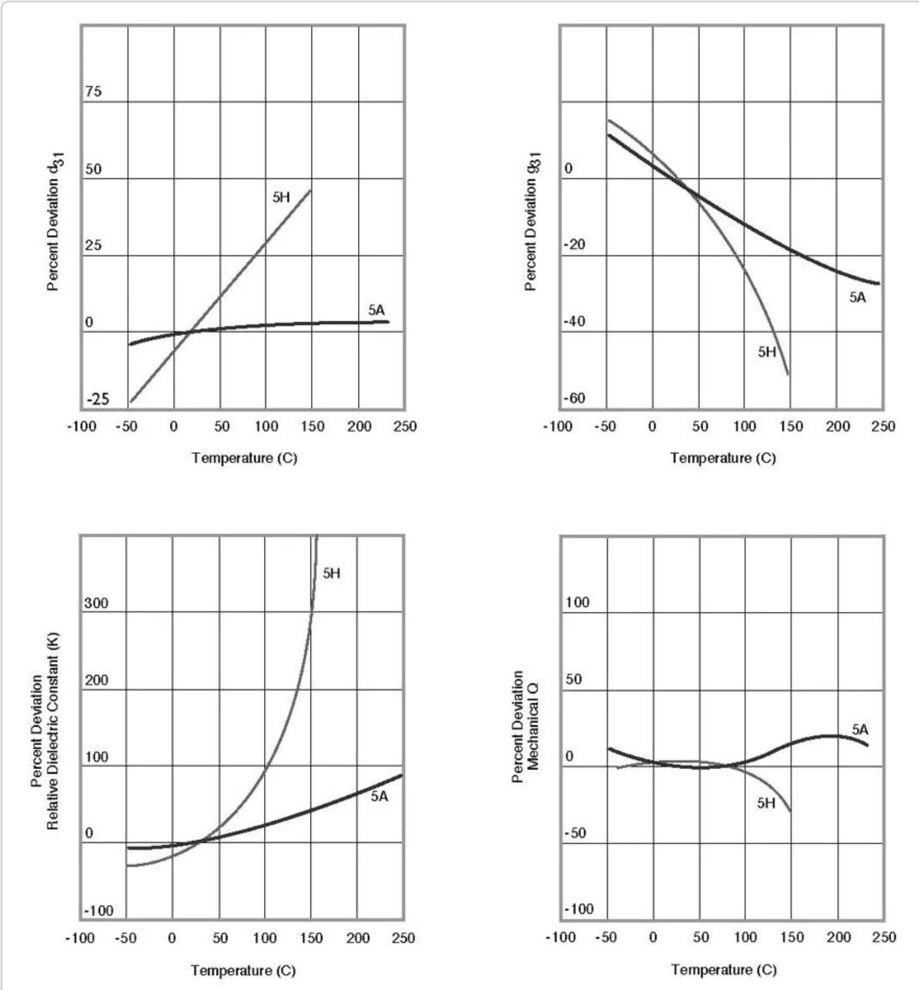
Definitions					
$tan\delta_e$	Dielectric Loss Factor	C	Capacitance (nF)	N_r	Radial Frequency Constant
ρ	Mass Density of Ceramic	l	Length (in.)	N_t	Thickness Mode Frequency Constant
T_c	Curie Point	W	Width (in.)	P_r	Remanent Polarization
d_{33}	Direct Charge Coefficient	d	Diameter (in.)	Q_m	Mechanical Q (Quality Factor)
d_{31}	Transverse Charge Coefficient	t	Thickness (10^{-3} in.)	Y^E_{33}	Direct Young's Modulus
E_c	Coercive Field	k_{33}	Direct Electromechanical Coupling Coefficient	Y^E_{11}	Elastic Modulus
g_{33}	Direct Voltage Coefficient	k_{31}	Transverse Electromechanical Coupling Coefficient	f_r	Resonant Frequency
g_{31}	Transverse Voltage Coefficient	K_{T3}	Free Dielectric Constant Measured Along Poling Axis	f_a	Anti-Resonant Frequency
k_p	Planar Electromechanical Coupling Coefficient				

Piezo Material Properties

Some additional material properties can be gleaned from the Piezo Material Properties Datasheet (PDF) (https://info.piezo.com/hubfs/Data-Sheets/piezo-material-properties-data-sheet-20201112.pdf).

Thermal Dependency of Material Properties

The material properties can change due to temperature. PZT 5J is not pictured but it is a hybrid between PZT-5A and PZT-5H.



MSDS: PZT-5A & PZT-5H

The material safety datasheet (MSDS) of our piezoelectric materials is included here:

MSDS PDF (https://info.piezo.com/hubfs/Data-Sheets/msdspsi5a4e.pdf). A breakdown of the lead content and other materials is included below.

Hazardous Component	CAS#	%	OSHA PEL (mg/m^3)	ACGIH/TLV (mg/m^3)
Lead Oxide	1317-36-8	60-72	0.05	0.05
Zirconium Oxide	1314-23-4	5-25	5.0	5.0
Titanium Oxide	13463-67-7	5-15	15.0 (Total Dust)	10.0
Lanthanum Oxide	1312-81-8	0-4	5.0 (Respirable Dust) 15.0 (Total Dust)	10.0
Niobium Oxide	1313-96-8	0-20	None	None
Nickel Oxide	1313-99-1	0-7	1	1.5

PZT materials, although they contain lead, are ROHS exempt under Article 58(2). (https://s3.amazonaws.com/helpscout.net/docs/assets/5a60b15b0428635d7f439dde/attachments/5bec8e162c7d3a31944dfc7f/235_exemption-argument-for-the-industrial-use-of-Piezo-ceramics.pdf)

Here is the MSDS of the solder (https://s3.amazonaws.com/helpscout.net/docs/assets/5a60b15b0428635d7f439dde/attachments/5c813fba04286350d088c1e6/MSDS---AIM-SN100C-Solder.pdf) and the solder flux (https://s3.amazonaws.com/helpscout.net/docs/assets/5a60b15b0428635d7f439dde/attachments/5c813fd02c7d3a0cb9325bdf/67DSA-16-part.pdf) we use and recommend in our kit (https://piezo.com/collections/piezo-prototyping-kits/products/solder-flux-kit).

Packaging Materials

There are thin layers of epoxy between each material; but for modeling purposes this layer can be ignored (<0.02 mm thick). The operating temperature range for sealed products is -40 to 120 C due to the epoxy used. Higher temperature, up to 150 C, is available with alternative epoxy.

Properties	Units	FR4	Copper	Polyimide	304 Steel	Polysulfone	Polyester	Brass
Young's Modulus	GPa	26	110	4.1	193	5.72	3.65	100

Properties	Units	FR4	Copper	Polyimide	304 Steel	Polysulfone	Polyester	Brass
Poisson's ratio		0.17	0.34	0.34	0.29	0.4	0.48	0.32
Density	g/cc	1.9	8.93	1.81	8.00	1.37	1.38	8.30
Ultimate Tensile Strength	MPa	368	210	231	505	81	177	800
Tensile Yield Strength	MPa	340	33.3	90	215	87.9	92.8	500
Thermal Expansion Coefficient	µm/m-C	15	16.4	34.3	17.3	31	17	22.0
Thermal Conductivity	W/m-K	0.4	398	0.26	16.2	0.26	0.15	200
Specific Heat	J/g-C	0.6	0.39	1.09	0.5	910	1.17	0.38
Maximum Operating Temperature	C	130	1083	275	1400	160	220	750

Chip Specs and Surface Blemishes

It is Piezo.com's policy to only send out fully functioning, inspected products. Please be aware that occasionally there may be minor blemishes on the electrodes and/or chips on the edge of the ceramic wafer. Nickel electrodes are very soft, and movement between plates during shipping/handling can cause darker blemishes on the electrodes. **These blemishes will not affect form, fit or function of the parts**.

Our chip limit specification is chips less than 5 mils in from edge and less than 30 mils long are acceptable. If you are concerned about a physical blemish or chip please feel free to reach out to us, however know that in the majority of cases it will not affect the performance of the piezo product.

Last updated on November 16, 2020

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Materials Technical Data (Typical Values)

Property	Symbol	Units	Material Type: PZT-5A	PZT-5J	PZT-5H	PMN-PT
Dielectric Constant (1kHz)	K^T_3		1800	2100	3800	4753
Dielectric Loss Factor (1kHz)	$Tan\delta_e$	%	0.02	0.02	2.0	
Dielectric Constant (1kHz)	K^T_1		1600	2948		
Clamped Dielectric Constant	K^S_3		900	800	1200	
Density	ρ	g/cm^3	7.95	7.90	7.87	8120
Curie Point	T_c	°C	350	270	225	
Mechanical Quality Factor	Q_m		80	60	32	150
Coercive Field (Measured < 1Hz)	E_c	kV/cm	12.0	10.0	8.0	5.3
Remanent Polarization	P_r	$\mu Coul/cm^2$	39.0		39.0	
Coupling Coefficients	k_p		0.68	0.72	0.75	
	k_{33}		0.72	0.74	0.75	0.89
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Frequency Constants Radial	N_r	kHz · cm		191		
Resonant Thickness	N_{tr}	kHz · cm	211	205	202	
Anti-Resonant Thickness	N_{ta}	kHz · cm	236	235	236	
Thermal Expansion (Perpendicular to Poling)	α	ppm/°C	3.0		3.5	
Specific Heat	C_p	J/kg · °C	440		420	
		J/mol · °C	145		138	
Thermal Conductivity with Au Electrodes	K_d	W/cm · °C	1.9-2.3		1.9-2.3	
		W/m · °K	1.2		1.2	
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f_r (length)	$N_{31r}/(2.54 \cdot l$
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f_t (thickness)	$Nt/(2.54 \cdot t$

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k_p	Planar Electromechanical Coupling Coefficient				