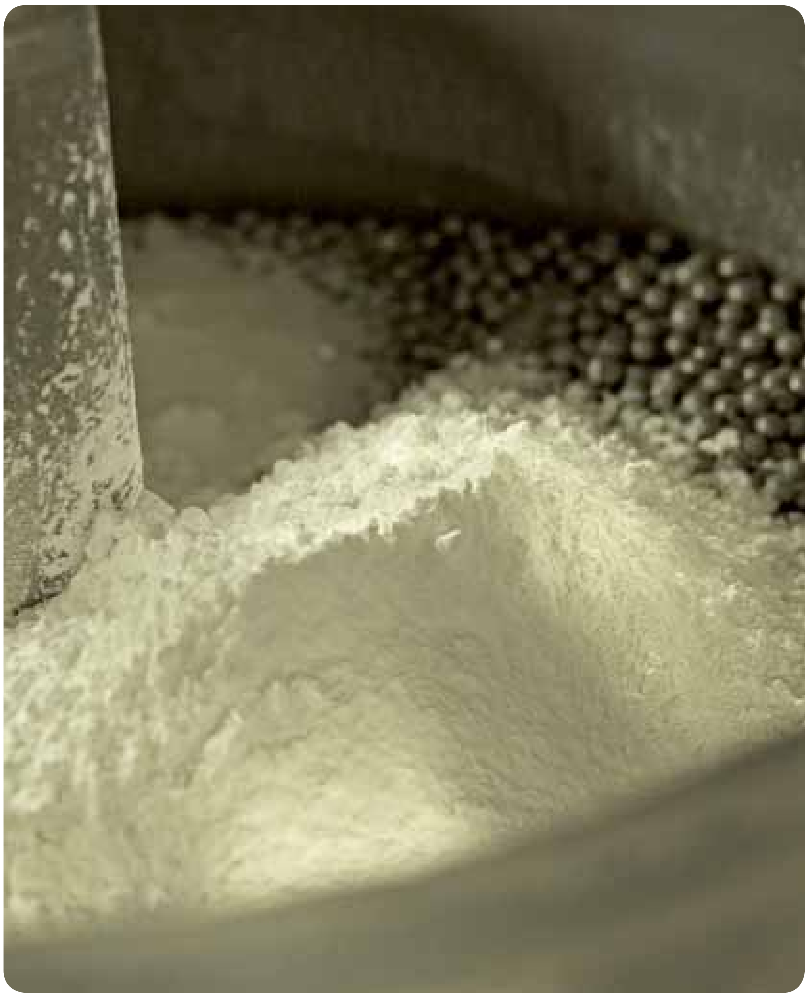
PIEZO CERAMICS

Noliac Group develops and manufactures piezoelectric ceramics based on modified lead zirconate titanate (PZT) of high quality and tailored for custom specifications.

Piezoelectric components may be used as e.g.:

- Actuators
- Sensors
- Generators
- Transducers



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Piezo ceramics specifications

Properties	Symbol & unit	NCE40	NCE41	NCE46*	NCE51	NCE53	NCE55	NCE56	NCE57*	NCE59*	NCE80
DIELECTRIC PROPERTIES (tolerances +/- 10%)											
Relative Dielectric Constant	$\frac{\varepsilon^T_{33}}{\varepsilon_0}$	1250	1350	1300	1850	1600	5000	2900	1800	2900	1050
Dielectric Loss Factor	$tg\delta$ [10^{-4}]	25	40	30	190	130	220	140	170	190	20
Dielectric Loss Factor at 400V/mm	$tg\delta$ [10^{-4}]	140	200								100
ELECTROMECHANICAL PROPERTIES (tolerances +/- 5%)											
Coupling Factors**	k_p	0.58	0.57	0.57	0.65	0.56	0.62	0.64	0.59	0.64	0.55
	k_{31}	0.34	0.33	0.33	0.37	0.32	0.39	0.37	0.33	0.37	0.30
	k_{33}	0.70	0.68	0.68	0.72	0.65	0.72	0.74	0.70	0.75	0.68
	k_t	0.50	0.50	0.47	0.51	0.47	0.50	0.50	0.47	0.52	0.48
Piezoelectric Charge Constants	$-d_{31}$ [10^{-12} C/N]	140	130	130	195	150	260	250	170	240	100
	d_{33} [10^{-12} C/N]	320	310	290	460	360	670	580	425	575	240
Piezoelectric Voltage Constants	$-g_{31}$[10^{-3} Vm/N]	11	11	11	13	9	9	9	11	10	11
	g_{33} [10^{-3} Vm/N]	27	25	28	27	23	19	20	27	23	27
Frequency Constants	N^E_p [m/s]	2160	2280	2230	1940	2180	1970	2000	2010	1970	2270
	N^D_t [m/s]	1980	2000	2040	2010	2040	1990	2030	1950	1960	2050
	N^E_1 [m/s]	1470	1600	1500	1400			1530	1400	1410	1610
	N^D_3 [m/s]	1340	1500	1800	1390			1400	1500	1500	1500
PHYSICAL PROPERTIES (tolerances +/- 5%)											
Mechanical Quality Factor	Q_m	700	1400	>1000	80	80	70	80	80	90	1000
Density	ρ [10^3 kg/m^3]	7.75	7.90	7.70	7.80	7.60	8.00	7.65	7.70	7.45	7.80
Elastic Compliances	s^E_{11} [10^{-12} m^2/N]	13	13	13	16	16	17	18	17	17	11
	s^E_{33} [10^{-12} m^2/N]	17	16	20	19	18	21	20	23	23	14
Curie Temperature	T_c [°C]	325	290	330	340	340	170	250	350	235	305

*) For multilayer components only.

**) Measured in accordance with standard EN 50324.

The values listed above are for reference purposes only and cannot be applied unconditionally to other shapes and dimensions. Values vary depending on the components' actual shape, surface finish, shaping process and post-processing.

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Piezo ceramics characteristics

Piezoelectric ceramics have the property of developing an electric charge when mechanical stress is exerted on them.

In these materials, an applied electric field produces a proportional strain. The electrical response to mechanical stimulation is called the direct piezoelectric effect, and the mechanical response to electrical stimulation is called the converse piezoelectric effect.

Piezoelectric ceramics are usually divided into two groups. The antonyms “hard” and “soft” doped piezoelectric ceramics refer to the ferroelectric properties, i.e. the mobility of the dipoles or domains and hence also to the polarization/depolarization behaviour.

Hard doped piezoceramic materials
Hard doped PZT materials can be exposed to high electrical and mechanical stresses. The stability of their properties makes them ideal for high-power applications.

Piezoceramic materials NCE41 and NCE40 are low loss materials for high power applications. The low dielectric and mechanical losses (tan(δ), Qm) combined with high piezoelectric charge constant (d_{33}) make them suitable for high-performance ultrasonic applications.

Furthermore NCE41 and NCE40 can be exposed to high repetitive quasi-static and dynamic loads for ignition applications. NCE41 and NCE40 differ from each other in permittivity and mechanical quality factor values. This variability enables to fulfil all specific requirements.

Piezoceramic material NCE80 is intended for power transducers with highest electric drive. Its low dielectric and mechanical losses at extremely high electric drive and high coupling factors make it suitable for high-power applications.

Soft doped piezoceramic materials
Soft doped piezoelectric ceramics are distinguished by a comparatively high domain mobility and thus “ferroelectrically soft” behaviour, i.e. relatively easy polarization.

These materials are characterized by high relative permittivity, large electromechanical coupling factors, large piezoelectric constants and low mechanical quality factors. They are particularly suitable for sensing applications, receivers, actuators and low power transducers.

Piezoceramic materials NCE51 and NCE57 are standard soft materials, particularly suitable for actuators and low power non-resonant applications in which high coupling factor and /or high charge sensitivity are requested.

Piezoceramic material NCE53 has slightly lower electro-mechanical coupling factor, but has the advantage of higher temperature stability, and it is suitable especially for shear mode vibration sensors.

Piezoceramic materials NCE55 and NCE56 are very high sensitivity materials featuring extremely high permittivity, large coupling factor and piezoelectric constant. They have a relatively low Curie temperature. These materials are suitable for a wide range of high sensitivity applications with limited temperature range of operation.

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Navy types - equivalences										
	Hard materials				Soft materials					
Material	NCE40	NCE41	NCE46	NCE80	NCE51	NCE53	NCE55	NCE56	NCE57	NCE59
Navy Type	I	I	I	III	II	II	VI	V	II	V
European standard EN 50324-1	100	100	100	100	200	200	600	600	200	600

Technical piezo ceramics description

Piezoelectricity is the property of nearly all materials that have a non-centrosymmetric crystal structure.

Some naturally occurring crystalline materials that possess these properties are quartz and tourmaline. Some artificially produced piezoelectric crystals are Rochelle salt, ammonium dihydrogen phosphate and lithium sulphate. Another class of materials possessing these properties is polarized piezoelectric ceramic. In contrast to the naturally occurring piezoelectric crystals, piezoelectric ceramics have a polycrystalline structure.

The most commonly produced piezoelectric ceramics are lead zirconate titanate (PZT), barium titanate and lead titanate. Ceramic materials have several advantages over single crystals, especially the ease of fabrication into a variety of shapes and sizes. In contrast, single crystals must be cut along certain crystallographic directions, limiting the possible geometric shapes.

PZT (and many other piezoelectric materials) have crystal structures belonging to the perovskite family with the general formula $AB0_3$. In the following figure the ideal, cubic perovskite structure (centrosymmetric) and tetragonal (ferroelectric) structure are shown.

A piezoelectric ceramic material consists of small grains (crystallites), each containing domains in which the polar direction of the unit cells are aligned. Before poling, these grains and domains are randomly oriented; hence the net polarization of the material is zero, i.e. the ceramic does not exhibit piezoelectric properties. The application of a sufficiently high DC field (called poling process) will orient the domains in the field direction and lead to a remanent polarization of the material.

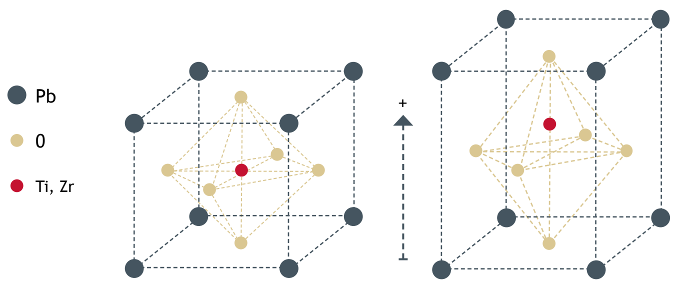

Fig.1 The Perovskite crystal structure.

The perovskite structure is very tolerant to element substitution (doping) by formation of solid solutions. The possibilities of doping in these materials lead to an unlimited number of possible perovskite-type oxides. Even small amounts of a dopant may cause huge changes in the properties of a material.

The coupling of electrical and mechanical energy makes piezoelectric materials useful in a wide range of applications.

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Constitutive equations
The piezoelectric effect depends on directions. The reference axis, called axis 3, is taken parallel to the direction of poling. Axes 1 and 2 are defined arbitrarily in order to form a direct coordinate system with axis 3. 4, 5 and 6 represent shear movements around axes 1, 2 and 3 respectively.

Piezoelectric coefficients
Based on this coordinate system, the piezoelectric effect can be described in a simplified way by matrix coefficients. The coefficients "d" (piezoelectric change constant 3×6 matrix) and "s^E" (elastic compliance 6×6 matrix) are commonly used.

Basic piezoelectric equations
These coefficients are used to relate the strain "S" (6-components tensor) to the stress "T" (6-components tensor) and electrical field "E" (3-components vector).

$$S = s^E.T + d.E$$

In this equation, the "s^E.T" term describes the mechanical compliance of the component, similarly to any mechanical component. The "d.E" term describes the piezoelectric effect, i.e. strain generated by electrical field.

The above equations are useful for designing a piezoelectric application. However, it must be kept in mind that they represent an approximation.

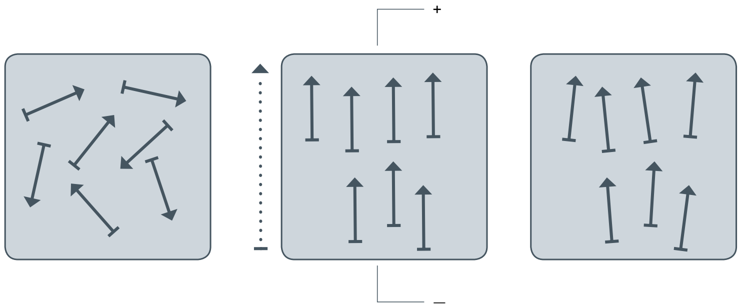

Fig.2 Electric dipoles in piezoelectric materials before, during and after poling.

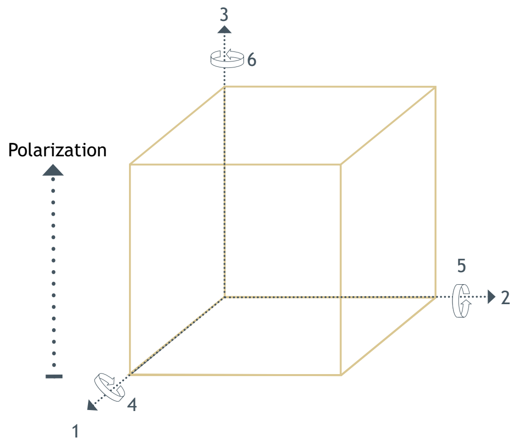

Fig.3 Designation of axes in piezoelectric materials.

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Definition of piezoelectric properties

Properties	Symbol / Definition	Dimension
ELECTRICAL PROPERTIES		
Relative Dielectric Constant (at 1V/1kHz)	$K^T = \frac{\varepsilon^T}{\varepsilon_0}$ *with* ε^T=*permittivity (F/m)* ε_0=*permittivity of free space (8.854 × 10^{-12} F/m)*	1
	K_3^T All stresses on material are constant or no external forces Electrodes are perpendicular to 3 axis	
Dielectric Loss Factor	$\tan(\delta) = \frac{\textit{Effective series resistance}}{\textit{Effective series reactance}}$	
ELECTROMECHANICAL PROPERTIES		
Electromechanical Coupling Factors	$k = \sqrt{\frac{\textit{Mechanical energy stored}}{\textit{Electrical energy applied}}} = \sqrt{\frac{\textit{Electrical energy stored}}{\textit{Mechanical energy applied}}}$	
	k_{31} Applied stress, or the piezoelectrically induced strain, is in 1 direction Electrodes are perpendicular to 3 axis	1
	k_{33} Applied stress, or piezoelectrically induced strain, is in 3 direction Electrodes are perpendicular to 3 axis	1
Piezoelectric Charge Constants	$d = \frac{\textit{Strain developed}}{\textit{Applied field}} = \frac{\textit{Charge density}}{\textit{Applied stress}}$	
	d_{31} Applied stress, or the piezoelectrically induced strain, is in 1 direction Electrodes are perpendicular to 3 axis	C/N
	d_{33} Applied stress, or piezoelectrically induced strain, is in 3 direction Electrodes are perpendicular to 3 axis	C/N
Piezoelectric Voltage Constants	$g = \frac{\textit{Strain developed}}{\textit{Applied charge density}} = \frac{\textit{Field developed}}{\textit{Applied mechanical stress}}$	
	g_{31} Applied stress, or the piezoelectrically induced strain, is in 1 direction Electrodes are perpendicular to 3 axis	Vm/N
	g_{33} Applied stress, or piezoelectrically induced strain, is in 3 direction Electrodes are perpendicular to 3 axis	Vm/N

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Properties	Symbol / Definition	Dimension
Frequency Constants	*$N = F.X$* *With F = resonance frequency (Hz)* *X = dimension governing the resonance (m)*	m/s
	N^E_p Planar mode, disc Measured with closed circuit	m/s
	N^E_l Transverse mode, thin bar Measured with closed circuit	m/s
	N^D_3 Longitudinal mode, cylindar Measured with closed circuit	m/s
Elastic Compliances	$S = \frac{1}{Y} = \frac{Strain}{Stress}$ *with Y = Young modulus*	
	s_{11}^E Compliance is measured with closed circuit Stress or strain is in 1 direction Strain or stress is in 1 direction	10^{-12} m^2/N
	s_{33}^E Compliance is measured with closed circuit Strain or stress is in 3 direction Stress or strain is in 3 direction	10^{-12} m^2/N
Curie Temperature	T_C	°C