PI CERAMIC

Lead-Free Piezoceramic Materials

Lead-Free Piezoceramic Development at PI Ceramic

Potassium Sodium Niobate (KNN) & Bismuth Sodium Titanate (BNT)

Lead zirconate titanate (PZT) is the gold standard for performance and reliability in most piezoelectric applications since its invention more than 70 years ago. However, since the early 2000s the European Commission encourages the industry in Europe to look for alternative material systems via the Restriction of Hazardous Substances Directive (RoHS). The aim is to reduce environmental pollution from lead in electronic waste.

One way to get closer to this goal is to develop and use lead-free piezoelectric materials. PI Ceramic has been working on this theme for a long time and is working on alternatives to lead-containing materials. During the development the material systems bismuth sodium titanate (BNT) and potassium sodium niobate (KNN) have proven to be the most promising candidates for industrial use. Ongoing work with regards to different customer applications has resulted in various variants of these material systems with different levels of technological maturity. Our many years of experience enable us to meet most of our customers' requirements in terms of geometries.

Especially in resonant applications, lead-free piezoceramics can be an alternative to lead-containing materials. First positive development results can be demonstrated for ultrasonic nebulizers and power ultrasonic transducers as well as sensors. It is particularly worthwhile testing the performance of lead-free alternatives when designing new or redesigning existing devices.

 |

Lead-Free Piezoceramic Development at PI Ceramic

Sample Applications

	Application	PIC700	PIC701	PIC753	PIC758
Medical Technology	Nebulizers			xx	
	Sonication & Lysis				xx
	Mixing & Dispersion				xx
	Therapeutic & Surgical Ultrasound				x
	Air Bubble Detection	xx	x		
	Flow Metering	xx	x		
Industrial Applications	Material Processing				x
	Flow Metering	xx	x		
	Hydro Acoustics			x	x
	Level Sensors			x	
	Ultrasonic Cleaning				x
	Non-Destructive Testing	x	x		
	Ultrasonic Sensors			x	
	Ultrasonic Motors				x

Potassium Sodium Niobate (KNN)

Performance

KNN components can be easily soldered and glued and exhibit superior planar and transversal piezoceramic properties compared to BNT components. As a result, they can serve as an alternative to PZT components in the following applications:

- air ultrasonic sensors
- power ultrasonic transducers
- nebulizer units
- ultrasonic motors

For the production of lead-free piezoelectric components, PI Ceramic uses raw materials with a better environmental footprint than PZT.

Material datasheet: Ceramic Material Data

				PIC753[1]	PIC758[2]
Physical & dielectric properties	Density	ρ	g/cm³	4.8	4.8
	Curie temperature	T_c/T_d	°C	300	290
	Coercive field strength	E_c	kV/mm	1.1	1.2
	Relative permittivity ∥ polarization	$\varepsilon_{33}^T/\varepsilon_0$		1341	850
	Relative permittivity ⊥ to polarization	$\varepsilon_{11}^T/\varepsilon_0$		1222	950
	Dielectric loss factor	tan δ	10^{-3}	13	20
Electro-mechanical Properties	Coupling factor	k_p		0.53	0.43
		k_t		0.45	0.42
		k_{31}		0.3	0.27
		k_{33}		0.59	0.57
		k_{15}		0.58	0.55
	Piezoelectric charge coefficient	d_{31}	10^{-12} C/N	-118	-75
		d_{33}	10^{-12} C/N	241	170
		d_{15}	10^{-12} C/N	316	287
	Piezoelectric voltage coefficient	g_{31}	10^{-3} Vm/N	-9.9	-9.9
		g_{33}	10^{-3} Vm/N	20.0	22.5
Acousto-mechanical properties	Frequency coefficient (fs)	N_p	Hz·m	2869	
		N_1	Hz·m	2065	2296
		N_3*	Hz·m	2445	2582
		N_t*	Hz·m	2739	2803
		N_5*	Hz·m	1555	1315
	Elastic complience coefficient	S_{11}^E	10^{-12} m²/N	12.2	9.8
		S_{33}^E	10^{-12} m²/N	13.6	11.6
	Elastic stiffness coefficient	C_{33}^D	10^{10} N/m²	17.2	17.8
	Mechanical quality factor	Q_m		200	585

Modified materials on request. The materials are not yet approved for full scale production. The reliability of lead-free materials must be re-evaluated in each application case.

[1] Preliminary data, subject to change
[2] Material under development

The following values apply approximately for lead-free materials from PI Ceramic:

Specific heat capacity:
WK KNN = approx. 420 J kg^{-1} K^{-1}

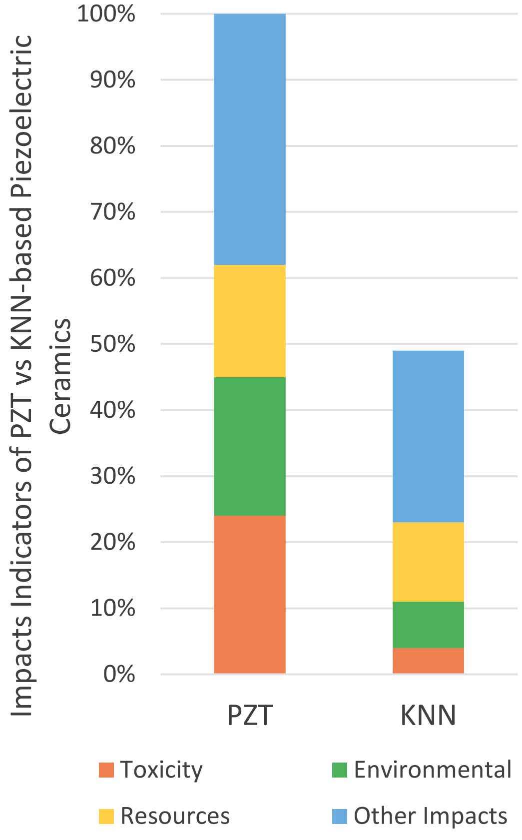
Specific thermal conductivity:
WL KNN = approx. 2.5 W m^{-1} K^{-1}

The data is determined using test pieces with the geometric dimensions laid down in EN 50324-2 standard and are typical values. All data provided is determined 24 h to 48 h after the time of polarization at an ambient temperature of 23 ± 2 °C. A complete coefficient matrix of the individual materials is available on request. If you have any questions about the interpretation of the material characteristics, please contact PI Ceramic.

Sustainability of Potassium Sodium Niobate (KNN)

Better than PZT when Choosing the Right Raw Materials

The ecological footprint of KNN has been subject of various discussions in research as well as in companies within in recent years. Initial results have shown an even worser footprint than PZT due to the poor valuation of the raw material niobium oxide when chemically prepared.[1,2] Later studies dealt with the different fabrication methods of niobium oxide. Mining fabrication has been shown to improve the global warming factor as well as human carcinogenic toxicity a lot.[3] Thus, the overall environmental impact of KNN materials is less than half of PZT.[4] This factor could be further improved by advanced fabrication technologies, which are under investigation.



Total impact indicators of PZT and KNN-based piezoceramics.[4]

[1] Ibn-Mohammed. T.; Koh, S.C.L.; Reaney, I.M.; Sinclair, D.C.; Mustapha, K.B.; Acquaye, A.; Wang, D. 2017: *Are lead-free piezoelectrics more environmentally friendly?* MRS Communication 7: 1-7.
[2] Ibn-Mohammed. T.; Reaney. I.M.; Koh. S.C.L.; Acquaye. A.; Sinclair. D.C.; Randall. C.A.; Abubakar. F.H.; Smith. L.; Schileo. G.; Ozawa-Meida. L. 2018: *Life cycle assessment and environmental profile evaluation of lead-free piezoelectrics in comparison with lead zirconate titanate.* Journal of the European Ceramic Society 38(15): 4922-4938.
[3] Da Silva Lima. L.; Alvarenga. R.A.F.; de Souza Amaral. T.; de Tarso Gonçalves Nolli. P.; Dewulf. J. 2022: *Life cycle assessment of ferroniobium and niobium oxides: Quantifying the reduction of environmental impacts as a result of production process improvements.* Journal of Cleaner Production 348(18): 131327.
[4] Wu, Y.; Soon, P-S.; Lu, J-T.; Zhou, J.; Liu, Y-X.; Guo, Z.; Wang, K.; Gong, W. 2024: *Life cycle assessment of lead-free potassium sodium niobate versus lead zirconate titanate: Energy and environmental impacts.* EcoMat 6(5): 12450.

Bismuth Sodium Titanate (BNT)

Performance

BNT materials are particularly well suited for thickness-mode applications and perform reliably in applications such as air bubble detection and flow sensor technology.

However, they are not suitable for applications that require planar vibration.

The PI Ceramic BNT materials feature a high depolarization temperature. As a result, unlike many other materials on the market, they can be processed by low-melting solders or with thermosetting adhesives.

Material datasheet: Ceramic Material Data

				PIC700	PIC701
Physical & dielectric properties	Density	ρ	g/cm³	5.7	5.7
	Depolarization temperature	T_c/T_d	°C	190	230
	Coercive field strength	E_c	kV/mm	2.8	3.9
	Relative permittivity ∥ polarization	$\varepsilon_{33}^T/\varepsilon_0$		750	542
	Relative permittivity ⊥ to polarization	$\varepsilon_{11}^T/\varepsilon_0$		800	629
	Dielectric loss factor	tan δ	10^{-3}	30	30
Electro-mechanical Properties	Coupling factor	k_p		0.13	0.14
		k_t		0.45	0.39
		k_{31}		0.08	0.09
		k_{33}		0.41	0.37
		k_{15}		0.31	0.32
	Piezoelectric charge coefficient	d_{31}	10^{-12} C/N	-20	-17
		d_{33}	10^{-12} C/N	120	71
		d_{15}	10^{-12} C/N	120	108
	Piezoelectric voltage coefficient	g_{31}	10^{-3} Vm/N	-3.3	-3.5
		g_{33}	10^{-3} Vm/N	15	15
Acousto-mechanical properties	Frequency coefficient (fs)	N_p	Hz·m	3000	3071
		N_1	Hz·m	2270	2302
		N_3*	Hz·m	2240	2403
		N_t*	Hz·m	2340	2503
		N_5*	Hz·m	1470	1535
	Elastic complience coefficient	S_{11}^E	10^{-12} m²/N	8.5	8.3
		S_{33}^E	10^{-12} m²/N	9.1	7.6
	Elastic stiffness coefficient	C_{33}^D	10^{10} N/m²	15.2	13.5
	Mechanical quality factor	Q_m		100	100

Modified materials on request. The reliability of lead-free materials must be re-evaluated in each application case.

Preliminary data, subject to change

The following values apply approximately for lead-free materials from PI Ceramic:

Specific heat capacity:
WK BNT = 101 J kg^{-1} K^{-1}

Specific thermal conductivity:
WL BNT = 1.4 W m^{-1} K^{-1}

The data is determined using test pieces with the geometric dimensions laid down in EN 50324-2 standard and are typical values. All data provided is determined 24 h to 48 h after the time of polarization at an ambient temperature of 23 ± 2 °C. A complete coefficient matrix of the individual materials is available on request. If you have any questions about the interpretation of the material characteristics, please contact PI Ceramic.

Physik Instrumente

PI Ceramic GmbH
Lindenstraße
07589 Lederhose
Germany

Phone +49 36604 882-0
E-Mail info@piceramic.de

Please visit us at: www.piceramic.com