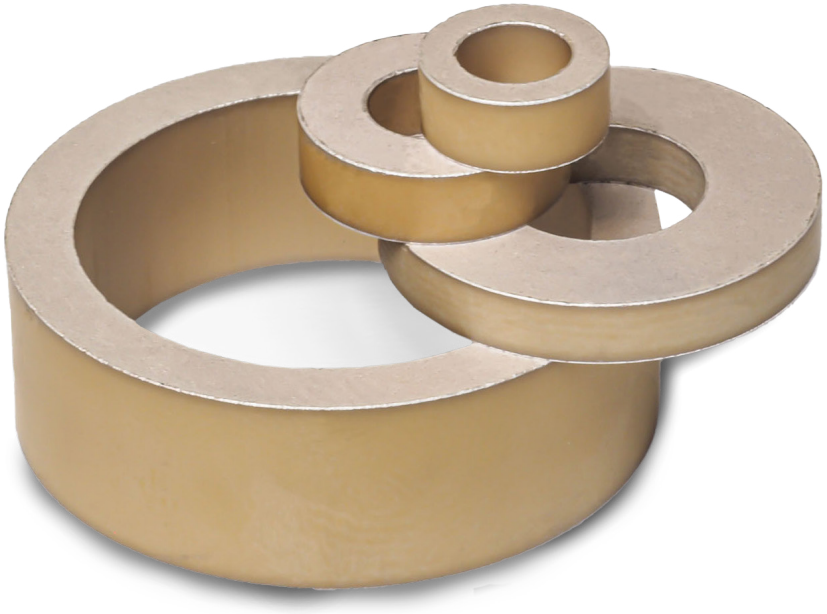
CTS® Your Partner in Smart Solutions®

Piezoelectric Components and Devices



Product Catalogue

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CTS Corporation

At CTS Corporation, we develop and manufacture state-of-the-art piezoelectric products, providing you with custom-made components that meet your exact geometrical, dimensional and performance specifications. Our product portfolio encompasses both bulk and multilayer piezoceramics, single crystals as well as a number of novel and innovative material solutions. Our production capabilities in these areas are nearly unmatched, and our components are continuously achieving an industry-low batch-to-batch variation.

A Product for Every Purpose

Our piezoelectric products are widely used across major industries including med-tech, aerospace/defense and the industrial sector. Components from CTS enable complex and high-performance applications such as diagnostic and therapeutic medical equipment, underwater acoustics, flow/vibration measurement and non-destructive testing. For any and every sensing, actuating and transducing purpose, we can provide you with a fitting solution. In addition to manufacturing your components, our piezoelectric expertise allows us to offer various value-add services such as composite manufacture, wire soldering as well as transducer sub-assembly and testing to further optimize your product for its intended use.

Advancing Next-Gen Tech

In addition to our commercial activities, we have built strong and lasting relations with academic insitutions worldwide, collaborating with leading universities in Europe and North America. Working closely together with scientists, scholars and private developers alike, we stay at the forefront of the development, spurring research into the next generation of piezoelectric solutions and helping entrepreneurs and start-ups turn their innovative product ideas into reality.

Pursuing Perfection

In accordance with our company values and long-standing business tradition, we at CTS Corporation remain committed to guiding our customers through the development phase in order to find the optimal balance between specifications, tolerances and pricing.

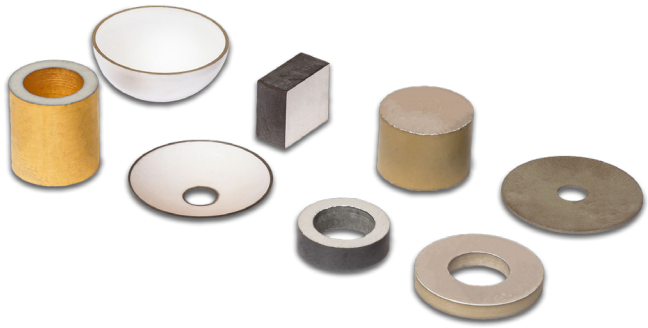
Contact us and let us together find the piezoelectric solution that is just right for you.

Ultrasound scanning and imaging enabled by a piezoelectric transducer

Bulk Piezoceramic Components

Our polycrystalline piezoceramic components find use in many high-demanding industrial and medical applications and are vital to the functionality of ultrasound transducers, vibration sensors and sonar devices – just to name a few. Several large industries are contingent on the capabilities and performance of piezoceramic components, and ours are among the most durable and reliable products on the market, continuously achieving the highest possible electromechanical performance and reproducibility while displaying some of the lowest aging rates in the industry.

The majority of our components can and will be manufactured according to your exact dimensional and performance requirements. They come in every standard geometry such as discs, plates, rings, tubes, hemispheres and focusing bowls and in all industrial grade material types. We can also provide you with customized electrode designs in various materials.

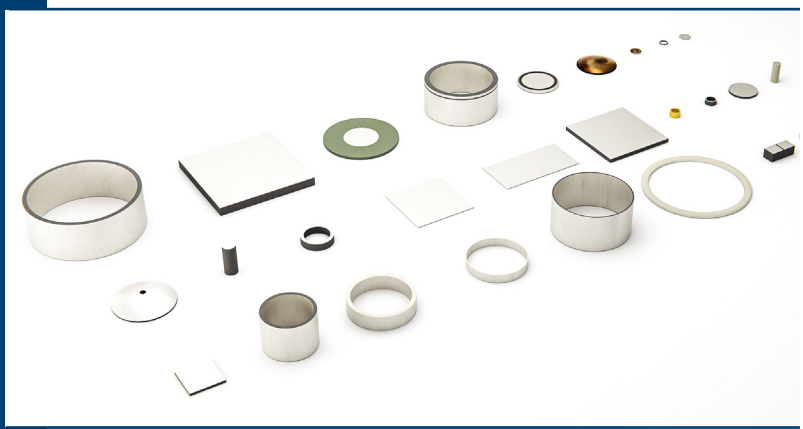


Selection of piezoceramic component geometries

Over the years, we have fine-tuned our ceramic formulations to the point where we can now offer a range of piezoceramic materials, optimized for specific end user applications such as HIFU, imaging and high temperature. We also offer a lead-free program where NBT and KNN components are available for testing so you can get a head start on integrating them in your applications, preparing you for a lead-free transition.

> "From our six piezo facilities across the globe, we produce over 100 million components annually, supplying industries around the world with high-end piezo products."
>
> Charles Mangeot
> Piezo Line Product Manager

Advanced Piezoceramic Components



High-Intensity Focused Ultrasound (HIFU)

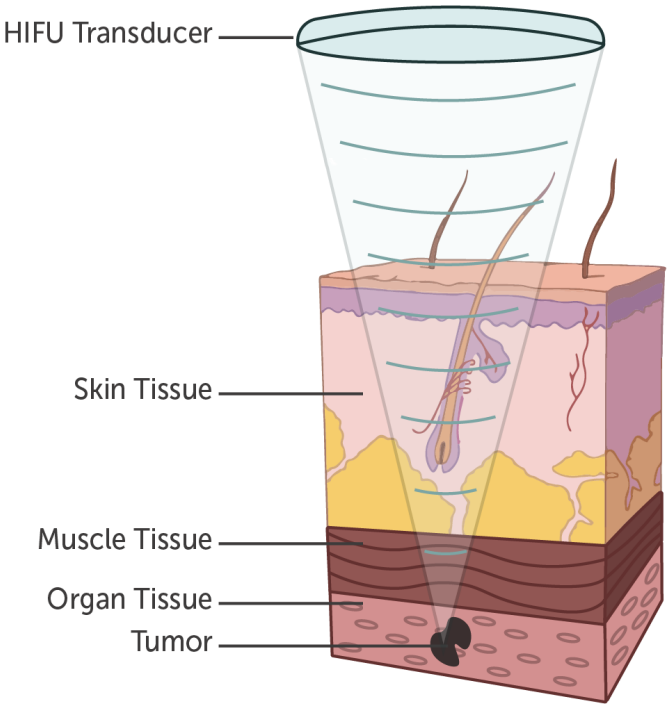
In recent years, the use of ultrasonic devices powered by piezoceramic components has expanded from diagnostic medical applications to encompass therapeutic applications as well.

HIFU offers non-invasive tissue treatment with minimal adverse effects by targeting areas with pinpoint precision. The technology utilizes a piezoceramic lens or an array to focus ultrasonic energy on a specific target. The beams will penetrate the body tissue without harming it, only reaching full intensity at the point of convergence.

HIFU radiation is a common way of breaking up kidney stones, but it is also being used to ablate early stage cancer tumors and to perform non-invasive brain stimulation to treat for instance essential tremors.

HIFU has also found use in aesthetics and cosmetic treatments as an alternative to surgical procedures since ultrasonic wave stimulation can result in a tighter skin with fewer wrinkles.

We have developed a range of materials specifically intended for HIFU use. See the materials section for our dedicated HIFU solutions.

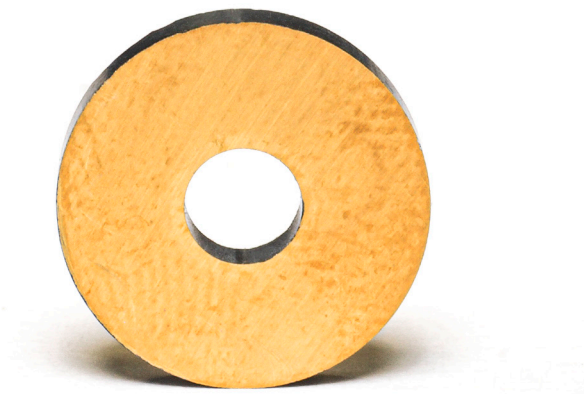


HIFU transducer ablating tumor

HIFU
High-Intensity
Focused Ultrasound

Single Crystals

CTS is the world's largest, fully integrated developer and manufacturer of piezoelectric single crystals, specializing in lead magnesium niobate-lead titanate (PMN-PT) materials.



Ring component in single crystal material

While not offering the same flexibility in terms of shaping, piezoelectric single crystals nevertheless hold distinct advantages over their polycrystalline, ceramic counterparts.

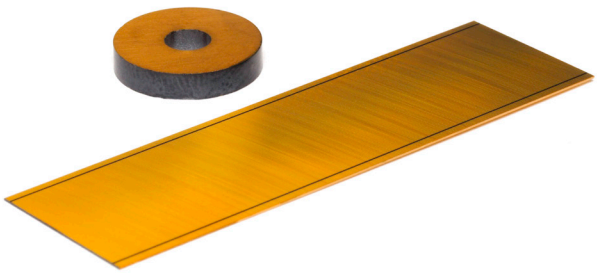
Most notably, single crystals can reach levels of sensitivity otherwise unachievable by standard PZT materials, displaying significantly higher coupling factors and approximately 70 % higher piezoelectric charge coefficients. These features make our PMN-PT crystals ideal for transducer applications, particularly medical imaging where they offer notably increased bandwidth.

The superior energy conversion of single crystals also allows for more compact designs with fewer and smaller components, opening the door for an overall lower power consumption. These features are beneficial to hand-held devices such as portable ultrasound scanners, but also to underwater applications e.g. Underwater Autonomous Vehicles, where our PIN-PMN-PT formulation is recommended due to its wider temperature range.

> "Our single crystal materials offer greater resolution and penetration depth for medical imaging with notable application in cardiac and abdominal ultrasound procedures."

Jian Tian
Director of Single Crystal Technology

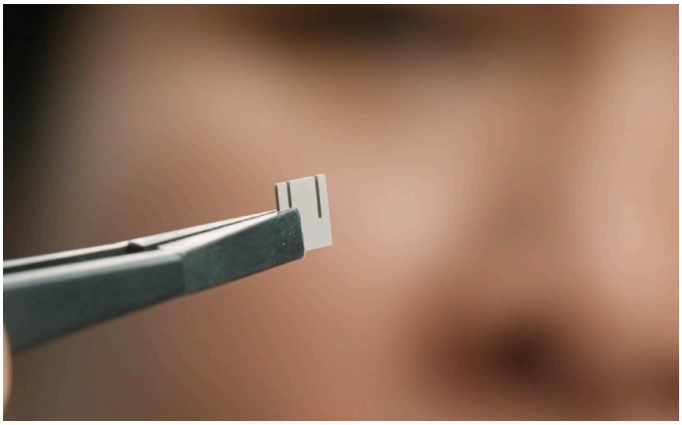
PMN-PT and PIN-PMN-PT Single Crystals



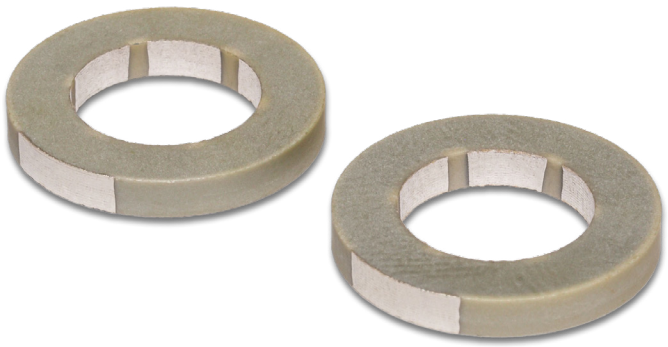
Multilayer / Tape Casting

Through our advanced tape casting method, we can produce complex and sophisticated multilayer structures, otherwise unachievable by standard bulk manufacturing processes.

Our multilayer components are comprised of extremely thin piezoceramic layers, deposited upon each other with alternating positive and negative electrodes in between. All positive electrodes are connected by an external electrode on one side of the component while all negative electrodes are connected on the other side. This design enables the multilayer component to run in actuating applications at a much lower driving voltage than standard piezoceramic components.



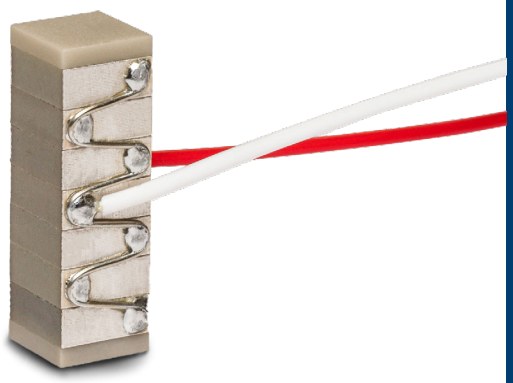
Piezoceramic bimorph – Ideal for miniaturized actuators and sensors



Multilayer ring actuators

Additionally, higher electrical fields can be applied across the material since the electrodes are embedded in the ceramic material, resulting in higher strain levels. This also has the added benefit of providing better environmental protection for the active material. Also, the multilayer approach enables designs with multiple functions such as integration of several actuators within a single component or the combination of both actuator and sensor.

Our multilayer products excel in applications that require the smallest possible component size such as miniaturized actuators and sensors. They have seen much use in micropositioning, laser tuning and semiconductor applications in addition to medical equipment - particularly pacemaker units.



Tape-Casted Multilayer Structures

InSensor™ Thick Film

Piezoelectric thick film is the ideal material choice for miniaturized sensors and transducers. Our dedicated InSensor™ team specializes in the production of advanced PZT thick film which can be deposited onto various commonly used substrates in the electronics industry. These include alumina, silicon (often used in MEMS-applications) and porous ceramic materials.

Transducer employing thick film applied on cylinder of porous ceramic

The deposition of our InSensor™ thick film onto flat surfaces can be performed by means of standard screen printing. For more complex surface structures, we have developed a unique printing method comparable to pad printing - a procedure that is traditionally used for printing graphics on round objects such as golf balls.

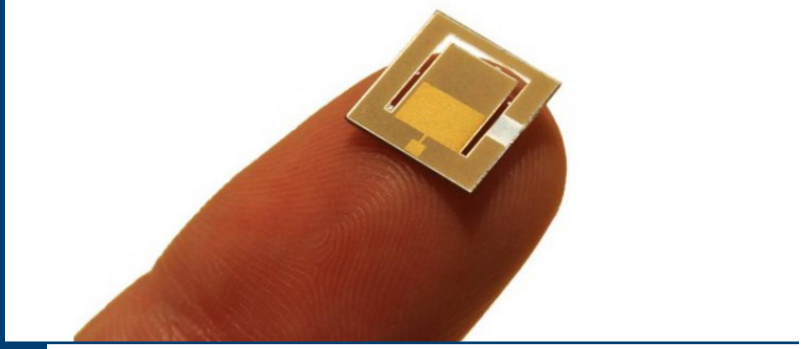
By applying this method, we can deposit active thick film layers onto curved and uneven substrate surfaces with a radius of curvature down to 10 mm - greatly expanding the application range of our PZT thick film.

As we are continueously increasing our expertise in this field, our thick film deposition capabilities will eventually come to encompass additional industry substrates. If you have a specific substrate in mind, our InSensor™ team will be happy to assist you in the development and production of new devices for your application. Please contact us with details on your specific challenge, and we will do our best to accomodate your needs.

Currently, our InSensor™ thick film has found use in the following applications:

- Transducers in the 10-60 MHz range
- Phased and annular arrays
- MEMS accelerometers
- Energy harvesting

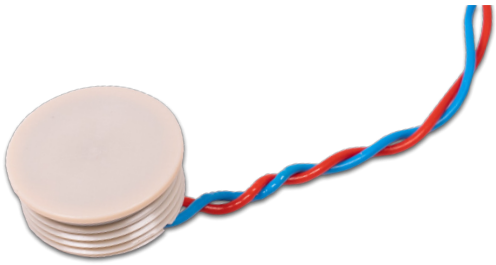
InSensor™
Thick Film



Piezoelectric Transducers

High-performance piezoelectric transducers from CTS enable numerous advanced technologies across the medical, aerospace/defence and industrial sectors such as diagnostic and therapeutic ultrasound equipment, sonar devices, flow meters and vibration sensors. We offer both build-to-print and custom-designed solutions.

Working closely together with you, the customer, we determine the optimal choice of design and material for the application. Once a reference design has been chosen, we will conduct feasibility studies and simulations, subsequently producing a prototype batch for further testing. Based on prototype performance, the transducer design can be further optimized to meet the specification requirements before entering production.



Piezoelectric transducer used in ultrasonic flow meters

We have experience with all transducer types:

- Immersion transducers for flow meters and hydrophones.
- Contact transducers used in non-destructive inspection and testing.
- Sensors for vibration and strain monitoring.
- Power transducers for ultrasonic applications.
- Aerial transducers for gas flow and distance measurement.

> "From defense sonar to vibration-assisted surgery, our transducers are used far and wide, enabling and sustaining critical applications where failure is not an option."
>
> Vytautas Bakanauskas
> Transducer Engineering Manager

Piezoelectric Transducers

PiezoPaint™

Our novel PiezoPaint™ technology has been developed with flexible substrate compatibility in mind. We can apply PiezoPaint™ to a variety of textiles and other flexible materials such as plastic and paper and print it onto large or curved surfaces using common commercial techniques, including screen-, pad- and stencil printing.

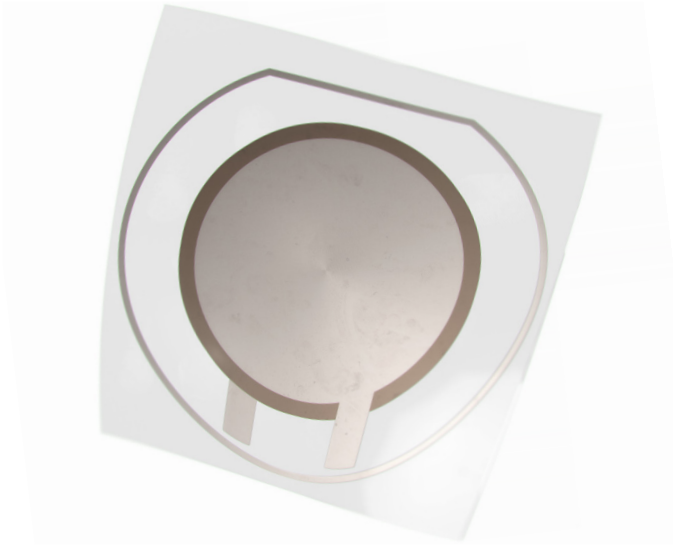
PiezoPaint™ excels as a cost-effective, highly sensitive and broadly applicable alternative to PVDF materials in textile and other soft substrate utilizations. It has a processing temperature of less than 100°C and also possesses an extremely low acoustic impedance, making it a good choice for applications where acoustic matching to tissue is critical.

Thanks to its compatibility with flexible materials and the ease and cost-effectiveness with which it can be manufactured, PiezoPaint™ opens up a vast realm of possibilities for wearables and smart textile applications.

Based on this technology, we have developed a number of innovative prototypes, including piezoelectric buzzers and motion sensors, that can be incorporated into garments and various textiles. PiezoPaint™ also enables emerging medical applications for instance smart bandages, capable of administering medicine and stimulating recovery.

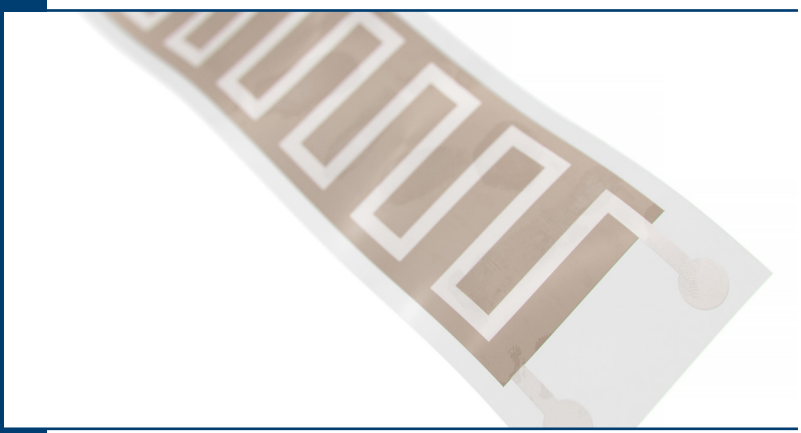
To explore the vast potential of PiezoPaint™, we encourage collaboration with possible end-users and will happily supply you with sample patches or initiate a project to apply PiezoPaint™ on your particular substrate.

Contact: dk.innovation@ctscorp.com



Electrode on PiezoPaint™ patch

PiezoPaint™



Material Data

Applications and Properties

Material Applications - Recommended Materials for Your Application

Each application is different. To achieve optimal performance, a technology must be paired with a material that meets the demands of its intended use. The table below shows which of our material types that are suited for specific applications. If in doubt, do not hesitate to contact us.

Material category	Soft			Very soft			Single Crystal	
Materials	**Pz27, 3195STD, 3195HD, NCE51**	**Pz29,3222HD, NCE56**	**Pz62* (Lead-Free)**	**Pz21, 3203STD, 3221HD, 3203HD, 3241HD**	**Pz94**	**Pz59, NCE55, 3257HD**	**PMN-PT**	**PIN-PMN-PT**
Underwater and Defense								
Transmitters (High Power)								x
Receivers, Hydrophones	x	x	x	x			x	x
Generator (Fuze)	x	x						
Medical								
Therapeutic (HIFU/HITU, Surgery, Dental)								
Diagnostic (Imaging, IVUS)	x	x	x	x	x	x	x	x
Combined, Doppler	x	x	x	x				x
Implantable Devices (Hearing Aids, Pacemakers, Valves etc.)	x	x					x	
Industrial								
Non-Destructive Testing	x	x	x	x	x			
Transducers (Flow, Level)	x	x	x					
Sensors (Shock, Acceleration)	x		x					
Acoustic Emission	x	x		x				
Actuators (Positioning, Valves, Inkjet)	x	x						
High Power Ultrasound (Cleaning, Cutting, Welding)								

***Material in advanced development stage.**

Material Applications - Recommended Materials for Your Application

Material category	Hard				HIFU		Low Acoustic Impedance	
Materials	**Pz24**	**Pz89, K1000, NCE81. K1100**	**Pz26, K1300, NCE40, NCE41, K1450**	**Pz12*, Pz12X* (Lead-Free)**	**Pz34**	**Pz52, Pz54**	**Pz36**	**Pz37, Pz39**
Underwater and Defense								
Transmitters (High Power)	x	x	x	x	x	x	x	
Receivers, Hydrophones								x
Generator (Fuze)			x					
Medical								
Therapeutic (HIFU/HITU, Surgery, Dental)	x	x	x	x	x	x	x	
Diagnostic (Imaging, IVUS)								
Combined, Doppler								
Implantable Devices (Hearing Aids, Pacemakers, Valves etc.)								
Industrial								
Non-Destructive Testing					x		x	x
Transducers (Flow, Level)								x
Sensors (Shock, Acceleration)								
Acoustic Emission								
Actuators (Positioning, Valves, Inkjet)			x					
High Power Ultrasound (Cleaning, Cutting, Welding)	x	x	x	x	x	x		

***Material in advanced development stage.**

Material Properties

Property	Symbol	Units	Hard Materials									
			Pz24	K1000	NCE81	K1100	Pz89	NCE40	K1300	PZ26	NCE41	K1450
Relative Free Dielectric Constant (1kHz)	K_{33}^{σ}	-	420	1000	1030	1100	1180	1250	1300	1300	1350	1450
Dielectric Dissipation Factor (1kHz)	tanδ	-	0.003	<0.004	0.0017	<0.004	0.003	0.0025	<0.005	0.003	0.004	<0.012
Curie Temperature	T_C >	°C	330	325	300	325	320	318	325	330	318	320
Density	ρ	g/cm³	7.7	7.55	7.75	7.55	7.65	7.7	7.55	7.7	7.93	7.55
Mechanical Quality Factor	Q_m	-	>1000	1000	1300	550	>1000	700	550	>1000	1400	350
Coupling Coefficients	k_p	-	0.50	0.56	0.56	0.57	0.53	0.58	0.58	0.56	0.57	0.57
	k_t	-	0.50	0.52	0.47	0.52	0.47	0.48	0.51	0.47	0.5	
	k_{31}	-	0.29	0.33	0.31	0.33	0.32	0.35	0.32	0.33	0.33	0.32
	k_{33}	-	0.57	0.64	0.69	0.66	0.65	0.68	0.7	0.68	0.68	
Piezoelectric Charge Coefficients (Displacement Coefficients)	d_{31}	pC/N	-55	-110	-98	-120	-108	-133	-125	-130	-130	-130
	d_{33}		160	230	255	250	280	304	300	300	310	350
	d_{15}		150				280		500	330		
Piezoelectric Voltage Coefficients	g_{31}	V·m/N x 10^{-3}	-16	-14	-10.8	-12.3	-11	-12	-10.9	-11	-10.9	-10.1
	g_{33}		54	26	28	25.7	23	27.5	26.1	28	25.9	30.4
Frequency Constants	N_p	Hz·m	2400	2270	2300	2180	2350	2170	2200	2230	2280	2080
	N_t		2100	2067	2130	2024	2150	2070	2100	2040	2000	
	N_{31}		1670	1630		1620	1750		1570	1500		
	N_{33}		1600	1550		1520	2060		1500	1800		

Data represent typical material values. Actual production values may vary +/- 10% for dielectric properties and +/- 5% for electromechanical and physical properties.

Material Properties

Property	Symbol	Units	HIFU			High Temperature		Low Acoustic Impedance		
			Pz34	Pz52	Pz54	Pz46	Pz48	Pz36	Pz37	Pz39
Relative Free Dielectric Constant (1kHz)	K_{33}^{σ}	-	220	1900	2800	115	126	850	1200	1750
Dielectric Dissipation Factor (1kHz)	tanδ	-	0.014	0.003	0.003	0.004	0.003	0.003	0.017	0.019
Curie Temperature	T_C >	°C	400	235	220	650	815	330	350	220
Density	ρ	g/cm^3	7.65	7.35	7.8	6.4	6.8	6.3	6.4	6.4
Mechanical Quality Factor	Q_m	-	>1000	550	1500	>600	>1000	500	50	70
Coupling Coefficients	k_p	-	0.07	0.6	0.56	0.03	0.07	0.37	0.38	0.28
	k_t	-	0.42	0.53	0.48	0.2	0.2	0.51	0.52	0.53
	k_{31}	-	0.05	0.35	0.35	0.02			0.15	
	k_{33}	-	0.4	0.7	0.7	0.09			0.6	
Piezoelectric Charge Coefficients (Displacement Coefficients)	d_{31}	pC/N	-5	-170	-200	-2				
	d_{33}		50	440	460	20	19	260	380	230
	d_{15}		40			16				
Piezoelectric Voltage Coefficients	g_{31}	V·m/N x 10^{-3}	-3			-2				
	g_{33}		25	25	20	17		40	40	28
Frequency Constants	N_p	Hz·m	2770	2090	2120	2470	2850		1800	1920
	N_t		2170	1960	1980	1950	2250	1530	1450	1550
	N_{31}		2050			1900				
	N_{33}									

Data represent typical material values. Actual production values may vary +/- 10% for dielectric properties and +/- 5% for electromechanical and physical properties.

Material Properties

Property	Symbol	Units	Soft Materials									
			Pz23	Pz27	3195STD	3195HD	NCE51	3222HD	Pz29	NCE56	3203STD	3221HD
Relative Free Dielectric Constant (1kHz)	K_{33}^{σ}	-	1500	1800	1800	1900	1900	2650	2820	2900	3250	3450
Dielectric Dissipation Factor (1kHz)	tanδ	-	0.015	0.017	<0.02	<0.02	0.015	<0.02	0.019	0.014	<0.02	<0.02
Curie Temperature	T_C >	°C	350	350	350	350	360	270	235	242	225	242
Density	ρ	g/cm^3	7.7	7.7	7.7	7.95	7.85	7.9	7.45	7.65	7.7	7.87
Mechanical Quality Factor	Q_m	-	100	80	80	80	80	80	90	75	50	50
Coupling Coefficients	k_p	-	0.51	0.59	0.63	0.68	0.65	0.72	0.62	0.64	0.69	0.74
	k_t	-	0.43	0.47	0.49	0.49	0.5	0.53	0.51	0.5	0.56	0.54
	k_{31}	-	0.29	0.33	0.35	0.4	0.39	0.45	0.37	0.38	0.41	0.46
	k_{33}	-	0.65	0.7	0.7	0.72	0.74	0.74	0.75	0.74	0.7	0.78
Piezoelectric Charge Coefficients (Displacement Coefficients)	d_{31}	pC/N	-130	-170	-175	-190	-208	-270	-240	-250	-270	-300
	d_{33}		330	440	350	390	443	485	575	580	530	600
	d_{15}		420	500	360	460		850	700		790	1000
Piezoelectric Voltage Coefficients	g_{31}	V·m/N x 10^{-3}	-10	-11	-11	-11.3	-12.4	-11.5	-10	-9.7	-9.4	-9.8
	g_{33}		25	27	24.2	23.2	26.3	21.3	23	22.6	18.4	19.7
Frequency Constants	N_p	Hz·m	2160	2010	2020		1925	1910	1990	1950	1920	1830
	N_t		2030	1980	2025	2110	2000	2050	1960	2020	1870	2020
	N_{31}		1480	1400	1420	1440		1420	1410		1400	
	N_{33}		1600	1500					1500			

Data represent typical material values. Actual production values may vary +/- 10% for dielectric properties and +/- 5% for electromechanical and physical properties.

Material Properties

Property	Symbol	Units	Very Soft Materials							Lead-Free		
			Pz21	3203HD	3241HD	Pz94	NCE55	Pz59	3257HD	Pz12*	Pz12X*	Pz62*
Relative Free Dielectric Constant (1kHz)	K_{33}^{σ}	-	3650	3800	4100	4300	5000	5100	5700	700	800	1140
Dielectric Dissipation Factor (1kHz)	tanδ	-	0.018	<0.02	<0.02	0.025	0.022	0.018	<0.03	0.027	0.032	0.02
Curie Temperature	T_C >	°C	220	225	223	185	160	150	155			333
Density	ρ	g/cm³	7.8	7.87	7.88	7.9	7.92	7.9	8.22	5.7	5.8	4.4
Mechanical Quality Factor	Q_m	-	65	50	50	60	70	40	75	170	200	200
Coupling Coefficients	k_p	-	0.58	0.75		0.59	0.65	0.55	0.7	0.17	0.32	0.4
	k_t	-	0.47	0.55	0.55	0.46	0.5	0.46	0.5	0.41	0.46	0.49
	k_{31}	-	0.34	0.43	0.44	0.38	0.37		0.41			
	k_{33}	-	0.69	0.78	0.77	0.7	0.72		0.76			
Piezoelectric Charge Coefficients (Displacement Coefficients)	d_{31}	pC/N	-250	-320	-325	-305	-320		-360			
	d_{33}		580	650	640	670	694	645	730	110	150	270
	d_{15}		620	1000	880				850			
Piezoelectric Voltage Coefficients	g_{31}	V·m/N x 10^{-3}	-7	-9.5	-8.9	-7	-7.2		-7.1			
	g_{33}		18	19	17.6	15	15.7		14.5			
Frequency Constants	N_p	Hz·m	2030			1980	1970	1955	1940	2700	2630	2100
	N_t		1970	2000	2000	1970	1990	2050	2090	2400	2440	2280
	N_{31}		1375			1380			1430			
	N_{33}		1325			1830			1590			

Data represent typical material values. Actual production values may vary +/- 10% for dielectric properties and +/- 5% for electromechanical and physical properties.

***Material in advanced development stage, specifications are subject to change.**

Material Properties

Property	Symbol	Units	Single Crystal			
			PMN-28% PT Type A	PMN-32% PT Type B	PIN-24% PMN-PT	PIN-33% PMN-PT
Relative Free Dielectric Constants (1kHz)	K_{11}^{σ}	-	1600	1620	1728	1666
	K_{33}^{σ}		5500	7000	4753	4532
Phase Transition	Trt	°C	90-100	80-90	100-115	115-135
Coercive Field	*Ec*	kV/cm	2.5	2.5	4.5-6	5.5-7
Density	ρ	g/cm^3	8.1	8.1	8.122	8.141
Coupling Coefficients	k_{15}	-	0.28	0.39	0.26	0.31
	k_t	-	0.6	0.62	0,5	0.54
	k_{31}	-	0.43	0.44	0.46	0.47
	k_{33}	-	0.9	0.93	0,89	0.89
Piezoelectric Charge Coefficients (Displacement Coefficients)	d_{31}	pC/N	-568	-760	-646	-651
	d_{33}		1190	1620	1285	1338
	d_{15}		135	192	122	147
Compliance Coefficients	s^E_{11}	m^2/N x 10^{-12}	45.86	58.85	45.76	47.18
	s^E_{12}		-28.11	-36.58	-19.60	-17.75
	s^E_{13}		-15.43	-20.80	-23.16	-26.39
	s^E_{33}		36.15	49.18	49.04	56.15
	s^E_{44}		15.53	16.53	14.33	15.50
	s^E_{66}		16.64	18.15	16.10	18.38

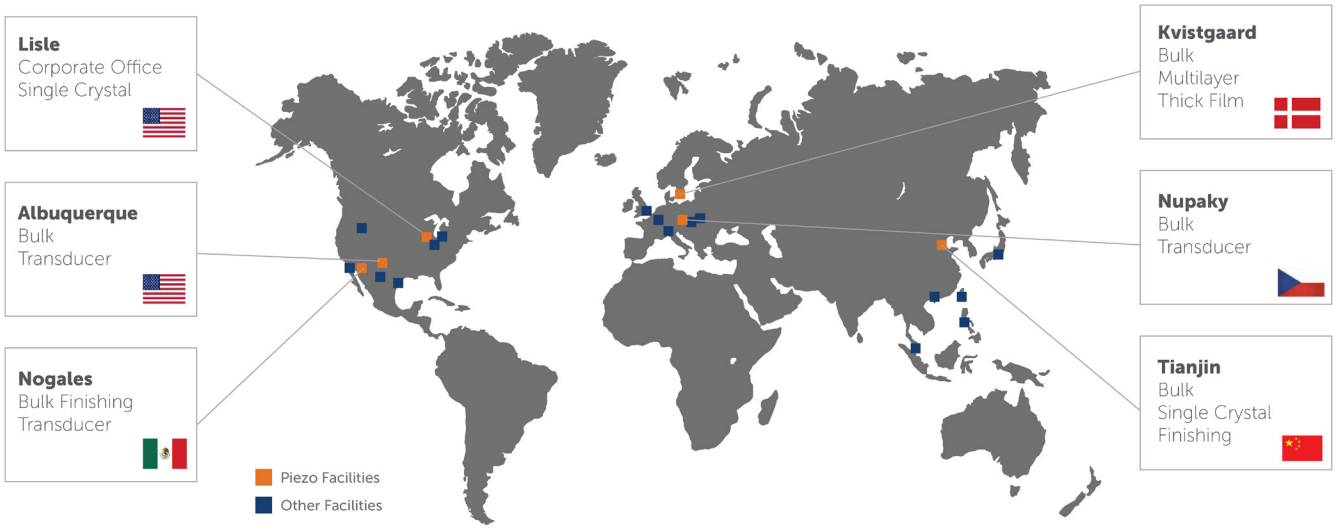
Data represent typical material values. Actual production values may vary +/- 10% for dielectric properties and +/- 5% for electromechanical and physical properties.

Notes

CTS Corporation

Headquartered in the USA, CTS Corporation (NYSE: CTS) is a leading designer and manufacturer of products that Sense, Connect, and Move. The company manufactures sensors, actuators, and electronic components in North America, Europe, and Asia, and provides engineered products to customers in the aerospace/defense, industrial, medical, and transportation markets.

Our Piezo Facilities around the World



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