Southern federal University
Institute of high technologies and piezotechnics
SCTB “Piezopribor”

PIEZOELECTRIC
MATERIALS AND ELEMENTS

Handbook

Russian Federation, Rostov-on-Don, Milchakova st., 10
☏ +7 (863) 222-34-01
piezo@sfedu.ru
https://ivtipt.ru

The history of the industry

Since the discovery of ferroelectricity, there are three stages in the development of research in this area. At the first stage, research was conducted on the physics of piezoelectric and ferroelectric effects. As a result, the main directions of using ferroelectrics were formulated. At the second stage, there was a rapid development of research, both new representatives of this class of materials, and opportunities for their industrial development. At the end of the second stage, the most effective piezomaterials were selected from the number of ferroelectric ceramics, each of which has advantages over the others in a specific application area. At the third stage, saturation occurred, that is, the effectiveness of the search for new piezoceramic compositions decreased, although several problems remained unresolved. At this stage, the further development of piezotechnics is associated with the use of new technologies, which allows not only to increase the efficiency of materials, but also to increase the reproducibility of properties in batches of products, the reliability of converters, etc.

In 2015, the Scientific constructional and technology bureau (SCTB) "Piezopribor" celebrated its 40th anniversary. Over the years, the organization has passed all stages of development of the piezoelectric instrument industry in the country. Today, we have a huge range of developed and introduced into production various types of high-quality, high-tech products, including those that have no analogues in Russia. Currently, SCTB "Piezopribor" has great opportunities in the field of creation, research and production of piezoceramic materials. A wide range of analytical, laboratory, and industrial equipment allows us to produce both standardized piezoceramics and materials with specified characteristics.

Employees of the Institute of high technologies and SCTB "Piezopribor" developed a line of piezoceramic materials with unique characteristics. The series was named PCP, which is a recursive acronym for the phrase "PCP: Ceramics of the Piezopribor".

General concepts of ferroelectric piezoceramics

Ferroelectricity is a physical phenomenon observed in polar dielectrics at certain temperature and pressure intervals. This phenomenon is characterized by reversibility (switching the vector of spontaneous polarization under the action of an external electric field, and in some cases-under the action of an external mechanical field.

A physical effect that links a mechanical action (mechanical stress or strain) and the electrical response of a dielectric crystal (electric field, electric displacement, or polarization) is called a piezoelectric effect, later called a direct piezoelectric effect. Later, the reverse piezoelectric effect was detected and investigated by experimental methods, accompanied by mechanical deformations (stresses) when an external electric field is applied to the sample

Ferroelectric-piezoceramic materials (FPC) are divided into soft and hard materials. The intermediate stage is occupied by medium-hard materials. Ferro-soft materials are characterized by relatively low EU coercive force, high values of dielectric permittivity, piezomodules, and Electromechanical coupling coefficients. In addition, ferro-soft materials are characterized by increased dielectric losses and reduced mechanical Q-factor. Ferro-hard materials are characterized by opposite combinations of properties in relation to ferro-soft compositions. As a rule, the Curie point of ferro-hard materials is > 300 °C as practice shows, hard materials are more difficult to polarize or depolarize. Ferro-hard materials are stable in relation to external influences, these secs do not exhibit significant piezoelectric deformations under the action of an external electric field.

The quality of piezoceramics is characterized by the following main parameters:

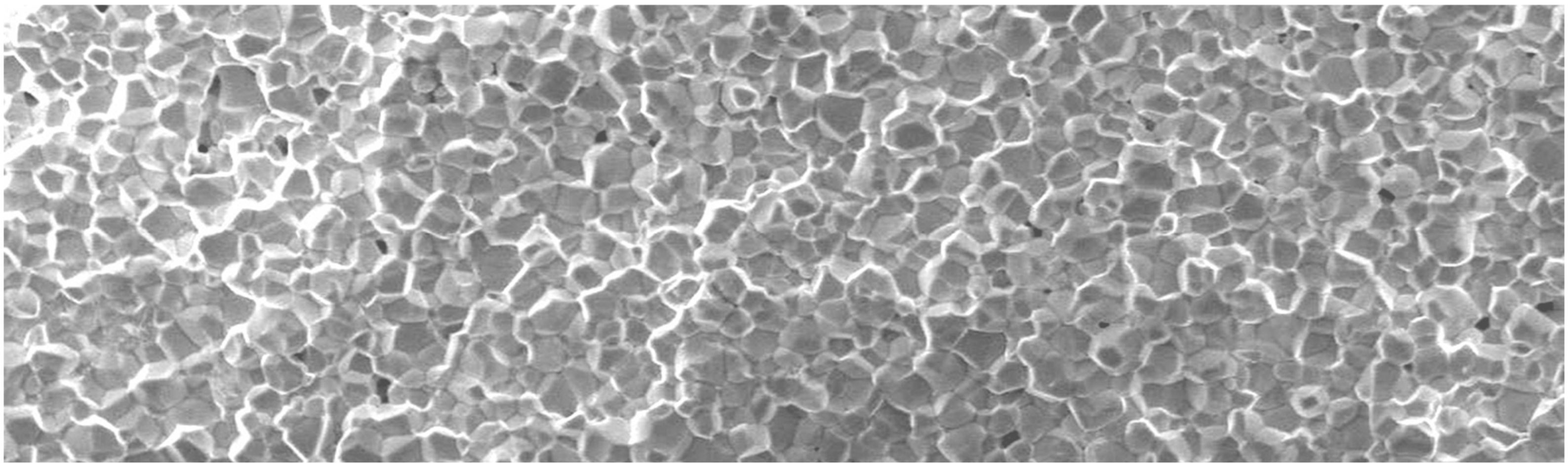
K^T_{33} ($\varepsilon^T_{33}/\varepsilon_0$) – **relative dielectric permittivity**;
tg δ– **tangent of the dielectric loss angle**;
T_c (T_k) – **Curie temperature (Curie point)**;
K_p K_{33} K_{31} K_{15} – **electromechanical constants**;
d_{33} $-d_{31}$ d_{15} – **piezoelectric constants**;
g_{33} g_{31} g_{15} – **electrical constants of voltage sensitivity**;
Y^E_{11} Y^E_{33} – **Young's modules**;
N_L N_T N_R – **frequency constants**;
S^E_{11} S^E_{33} – **elasticity constants**;
ρ – **density**;
Q_m – **mechanical Q-factor**.

Parameters of produced piezoceramic materials

Name of material	$\varepsilon_{33}^{T}/\varepsilon_0$	Tgδ no more	$К_p$, at least	Q_m	$\lvert d_{31} \rvert$, pC/N	d_{33}, pC/N	$T_к$, °C	$g_{33} \cdot 10^{-6}$ V·m/N
Soft piezoceramic materials								
ЦТС-19	1620-1980	0,010	0,50	50-120	150-200	310-460	290	169-206
ЦТС-21	429-600	0,018	0,27	100-200	30-60	75-120	400	155-177
ПКП-11	2700-3000	0,025	0,55	60-80	220-250	600-650	180	192-197
ПКП-11М	3500-3700	0,025	0,055	50-80	260-280	700-735	170	175-180
ЦТС-НВ-1	1840-2450	0,020	0,52	70-120	165-260	400-540	240	192-195
ПКП-12	3500-4500	0,030	0,55	60-100	270-330	700-800	180	157-177
Medium-hard piezoceramic materials								
ЦТБС-3	2300	0,012	0,45	350	135-200	360-400	180	139-154
Hard piezoceramic materials								
ПКП-31	900-1100	0,003	0,58	2000	130-180	200-220	325	177-197
ПКП-33	1100-1600	0,003	0,60	450-1000	130-200	300-420	280	232-241
ПКП-35	1150-1350	0,005	0,59	750-850	130-150	280-330	290	227-240
Non-Pb piezoceramic materials								
ТБ-1	1300-1900	0,020	0,20	100	45-70	100-150	110	68-70
ТБК-3	1000-1400	0,020	0,20	300	43-75	80-160	95	71-101
Materials with high voltage sensitivity								
ЦТС-36	650-800	0,020	0,58	60-80	90-150	290-380	350	395-420
ПКП-13	1100-1300	0,025	0,50	50-100	150-200	350-450	290	282-306
High-temperature and highly stable materials								
ТВ-3	120-160	0,02	-	-	-	14-18	650	-
НТВ-2	120-160	0,0065	-	-	-	24-28	660	-
ТНВ-2	130-170	0,008	-	-	-	12-14	950	-
ЦТС-83*	1600-1800	0,025	0,50	50-70	110-130	350-370	320	182-194
ЦТС-83Г*	1300±100	0,025	0,50	50-70	100-120	300-320	360	202-221
**** - operating temperature range - up to 300 °C***								

Composite piezoelectric materials

Name	$\varepsilon_{33}^{T}/\varepsilon_0$	Tgδ no more	g_v, mV*m/Pa	dv, fC/N	$T_к$ °C
Composite material with mixed connectivity type 3-0 and 3-3	200-1000	0,025	20-200	100-600	300
Composite material KMB-1	450-550	0,050	50-80	350-400	50

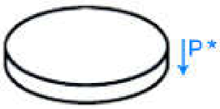
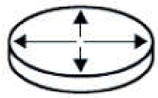
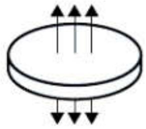
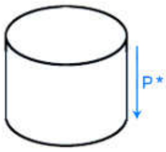
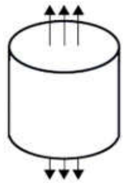
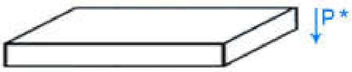
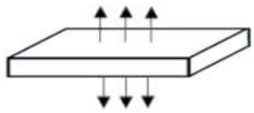
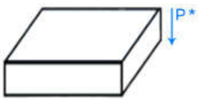
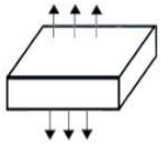
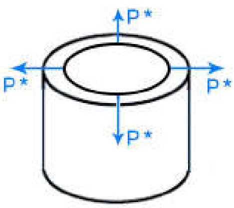
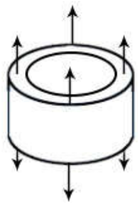
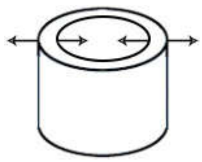
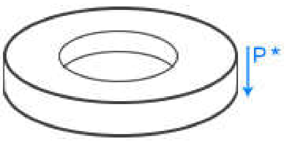
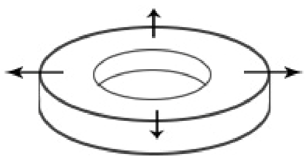


Classification of piezoelectric ceramic elements

Depending on the architecture and purpose of the designed devices, different types of piezoceramic elements are used. Vibrations directed in one direction or another are excited on elements of different geometric shapes. Table 3 shows the main types of elements used.

P* - direction of polarization.

The type of geometry and oscillation mode of the piezoceramic elements

The type of geometry	oscillation mode	Scheme
Disk 	radial	
	in thickness	
Cylinder 	Stretch-compression	
Plate 	Planar	
Prism 	Stretch-compression	
Ring 	Longitudinal	
	in thickness	
hoop 	in thickness	

Piezoceramic disk

From the Greek δίσκος (Paten) – a "round dish". A piezoelectric element that has the geometric shape of a circle of a certain height, provided that the height is much smaller than the diameter of the circle. When piezoceramic disks are polarized, radial and thickness vibrations can be excited in the element

Piezoceramic cylinder

Cylinder (Greek κύλινδρος) - a roller is a geometric body bounded by a cylindrical surface and two parallel planes that intersect it. The main difference between a cylinder and a disk is the ratio of diameter to height. In the case of a piezoceramic disk, the diameter may be less than or equal to the height.

Dimensions and allowance of elements made from piezoceramic materials in the SCTB "Piezopribor":

Type of element		dimension, mm	Allowance , mm
Disk	Diameter	2 ÷ 90	±0.1 ÷ ±0.3
	Height	0,15 ÷ 10	±0.05 ÷ ±0.1
cylinder	Diameter	2 ÷ 90	±0.1 ÷ ±0.3
	Height	1 ÷ 50	±0.05 ÷ ±0.1

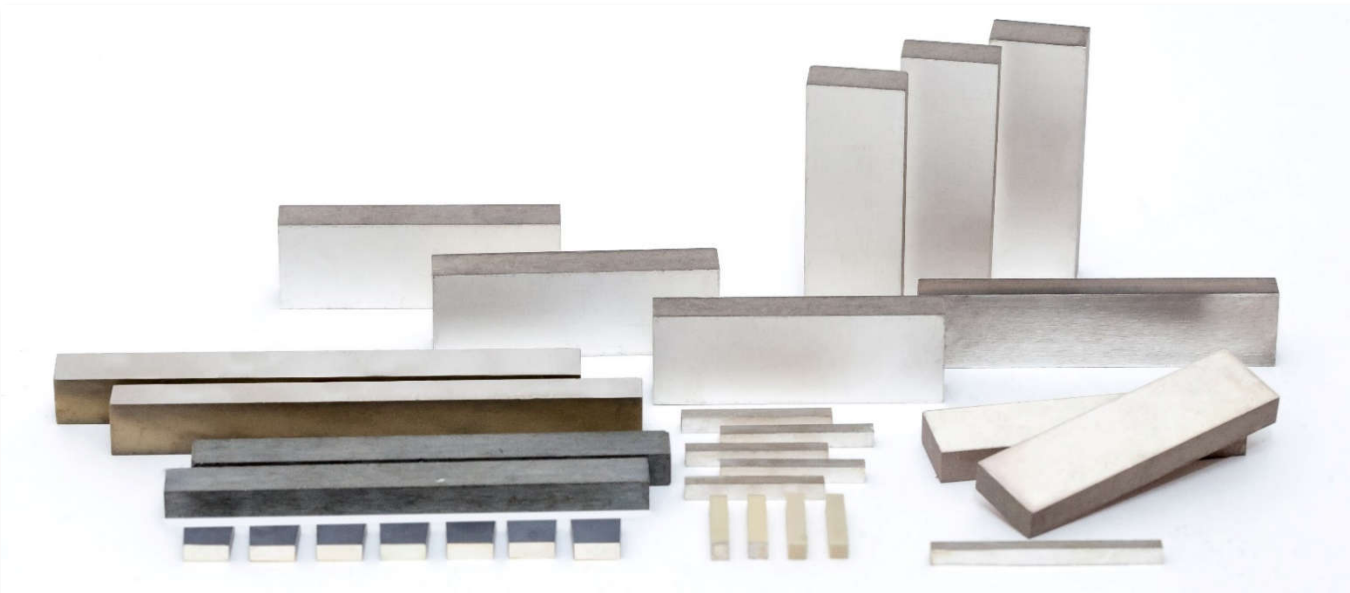
Upon agreement with the customer, additional slots, grooves, chamfers, and process holes can be made. Depending on the technical requirements, the thickness of the metal coating, its shape, area and composition are regulated.

The piezoceramic plate

A plate is a body bounded by two parallel planes, the distance between which, called the thickness of the plate h=const, is small compared to its other dimensions.

Piezoceramic prism

Prism (lat. prisma from Greek πρσσμα "something sawn off") is a polyhedron whose two faces are equal polygons that lie in parallel planes, and the other faces are parallelograms that share sides with these polygons.



<table>
<tr><th colspan="2">Type of element</th><th>dimension, mm</th><th>Allowance , mm</th></tr>
<tr><td rowspan="3">plate, prism</td><td>Length</td><td>2 ÷ 140</td><td rowspan="2">±0.1 ÷ ±0.15</td></tr>
<tr><td>Width</td><td>1 ÷ 50</td></tr>
<tr><td>The height (thickness)</td><td>0,15 ÷ 10</td><td>±0.05 ÷ ±0.1</td></tr>
</table>

In agreement with the customer, the prisms can be made with angles from 1º to 45º with a trapezoid section, a parallelogram. In addition, slits, grooves, chamfers, and process holes can be made. Depending on the technical requirements, the thickness of the metal coating, its shape, area and composition are regulated.

Piezoceramic ring

Ring (from old Russian. "Коло" - circle) – a round object with a hole inside. A piezoceramic ring is characterized by three variables- height h, inner diameter d, and outer diameter D. the aspect Ratio of a piezoceramic ring is expressed as follows:

(D - d) << h, Where D – outside diameter, d – inside diameter, h – height.

Piezoceramic hoop

A piezoceramic hoop differs from a piezoceramic ring in the following relation:

D >= h

Segment

A separate type of products manufactured by SCTB "Piezopribor" is a ring segment or a washer segment.

Type of element		dimension, mm	Allowance , mm
Ring, Hoop	Inside diameter d	2 ÷ 60	±0.1 ÷ ±0.15
	Outside diameter D	4 ÷ 90	
	Height h	0,25 ÷ 30	±0.05 ÷ ±0.1

In agreement with the customer, washers, rings and segments can be manufactured with various slots, grooves, chamfers, and process holes. Depending on the technical requirements, the thickness of the metal coating, its shape, area and composition are regulated.

Пьезоэлектрические композиты

Piezoelectric composites

One of the important electrophysical characteristics is the piezosensitivity (g_{33}), which is determined by the value:

$g_{33}=d_{33}/\varepsilon_{33}^{T}$, where

d_{33} - longitudinal piezomodule (piezoelectric constant),

ε_{33}^{T}-the absolute permittivity.

Therefore, to obtain materials based on PZT with increased piezosensitivity, it is necessary to look for ways to increase the piezomodule d_{33}, the ratio d_{33}/d_{31}, as well as to reduce the dielectric constant ε_{33}^{T}. To reduce ε_{33}^{T} in the PZT system, morphotropic region compositions enriched with lead zircon and representing the rhombohedral phase can be recommended. Another way to reduce ε_{33}^{T} can be implemented by creating composites.

Composite materials are heterogeneous systems that characterize the surface interaction of the phases that make up the system.

SCTB "Piezopribor" produces piezoceramic composites from various materials, depending on the customer's requirements. The most important direction is the production of composites of type 0-3, 3-3 and 1-3.

This handbook uses materials

A. E. Panich, V. Yu. Topolov, S. N. Svirskaya, A. Yu. Malykhin, A. V. Skrylev.

10 Milchakova st., Rostov-on-don, Russia, 344090

phone: + 7 (863)243-48-44

e-mail: piezo@sfedu.ru

https://ivtipt.ru