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CERAMIC MATERIALS IN RADIO ELECTRONICS

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ABSTRACT

The development of radio electronics, increasing reliability, reducing the dimensions and weight of devices is closely related to the development, study of properties and application of new materials. These include new ceramic and composite materials that can withstand high temperatures and successfully operate in aggressive environments. Ceramic materials are very diverse, each of them has its own unique chemical properties. They are very widely used in radio electronics and are promising for the development and improvement of designs of radio electronic devices. At present, industrial progress requires electronics to constantly increase the level of power, efficiency, reliability and durability. For modern devices, reliability under high currents and high temperatures is a key factor. The article analyzes the properties and advantages of various ceramic materials, their areas of application in radio electronics, and identifies promising areas of use.

KEYWORDS: *ceramic materials, radio electronics devices, materials and components of radio electronics*

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Introduction

Radio electronics development at the present stage, increasing reliability, reducing the dimensions and weight of devices are closely related to study of properties and application of new materials. These include new ceramic and composite materials that can withstand high temperatures and successfully operate in aggressive environments. They are promising for the development and improvement of radio electronic devices designs.

A fairly wide range of inorganic dielectric materials used in technology is represented by ceramic products. In the mid-1920s, the first capacitors using ceramics as a dielectric appeared in Germany. This happened due to a shortage of mica and experience in the production of porcelain - a special class of ceramics.

Paraelectric titanium dioxide (rutile) was used as the first ceramic dielectric. In 1926, these ceramic capacitors were produced in small quantities, and in the 1940s their number increased. In 1944, Soviet scientist B. M. Vul first synthesized a piezoceramic material, discovering the ferroelectric properties of barium titanate $BaTiO_3$.

Modern radio ceramics are characterized by: high heat resistance, non-hygroscopicity, good electrical insulation properties, mechanical strength, stability over time and resistance to external influences.

Ceramics: properties and advantages

Ceramics are materials obtained by sintering granular or powdered inorganic substances. They are multiphase structures containing crystalline, amorphous, and gas phases. The properties of ceramics depend on their chemical and phase composition, macro- and microstructure, and manufacturing technology.

Advantages of ceramics: high heat resistance, good and varied dielectric properties, and relatively high thermal conductivity.

In electronics, ceramics are used to manufacture insulating parts: support insulators, bases, housings for vacuum and semiconductor devices, housings, and substrates for microcircuits; capacitor ceramics are used in capacitors [1-3].

Ceramics are a multiphase system, the main phases of which are crystalline and glassy. The crystalline phase determines the electromechanical properties, and the glassy phase determines the manufacturing process of the parts.

In composition, all capacitor materials are mixtures of titanates, zirconates, and stannates of different metals. These compounds are classified as ferroelectrics by their electrical properties.

Ceramics are non-metallic polycrystalline materials (usually obtained by sintering powders), while sintering is only one of the methods (traditional) for obtaining ceramics; crystallization, impact pressing and other methods of obtaining it can be used:

– non-metallic ceramics are oxides, carbides, nitrides, etc.;

– polycrystalline ceramics are many micron-sized grains (otherwise – the field of nanomaterials);

– coarse ceramics (5-30% pores) – building materials, refractories;

– highly porous ceramics (~30% pores) – thermal insulation materials;

– fine ceramics (artistic – porcelain, earthenware) and functional (piezo-, ferro-, magnetic, thermoelectric, superconducting, insulating, optical, etc.).

Ceramics are not: pressed metal powders, glass and amorphous materials, aerogels, sitalls, glass wool, asbestos, single crystals, pressed granular plastics.

The properties of ceramics are determined by the physical properties of crystallites, the size and shape (anisotropy, etc.) of crystallites, the nature of the bond between crystallites, the presence of pores, liquid phases, etc.,

The manufacture of ceramic products is a very complex process, during which it is necessary to ensure a given chemical and mineralogical composition of ceramics, minimize the content of the gas phase and achieve the required accuracy of the dimensions of the products.

The production process begins with the preparation of a mass, the components of which are selected by composition, ground and mixed in ball mills to achieve homogeneity. From the resulting mass, blanks of products are made by one of the methods:

– pressing dry powder - when making small flat products;

– forming on a potter's machine or in plaster molds – for products of large sizes and a fairly complex shape;

– extrusion through a mouthpiece or drawing with subsequent mechanical processing – for elongated products (tubes, rods, frames, blocks, etc.);

– stamping – for mass-produced products of various configurations;

– casting of liquid mass into special molds – in the manufacture of large-sized products of complex configurations.

A mandatory operation of the technological process is the firing of blanks – the most important operation, since the firing time, temperature and composition of the environment (oxidizing, reducing) determine the final suitability of the product. Firing is carried out in tunnel kilns with a strictly specified temperature gradient and careful observance of the speed of movement. To improve the quality appearance, mechanical strength and electrical insulation properties of the product, they are sometimes glazed. To ensure the possibility of soldering, metallization of ceramics is carried out by burning in silver.

Ceramic dielectric materials are divided into passive and active. The most widely used passive ceramics are materials with a crystalline phase of the BaO Al_2O_3 SiO_2 system. These include radioporcelain, aluminoxide, ultraporcelain, corundum-mullite and Celsian ceramics [4]. Passive ceramics are divided into installation and capacitor ceramics according to their purpose and electrical properties.

Installation ceramics must have $\varepsilon < 10$, increased mechanical strength and good electrical insulation properties. It is used to manufacture support, feedthrough, suspension insulators, lamp panels, coil frames, and radio tube parts. Most types of installation ceramics are high-frequency dielectrics and have $\mathrm{tg}\ \delta \sim 2 * 10^{-3}$ at a frequency of 1 MHz.

Capacitor ceramics are used to manufacture high- and low-voltage capacitors and are divided into ceramics with increased (more than 12) and high (more than 900) dielectric constant ε.

Materials for high-frequency capacitors have moderate and increased permittivity $r = 14…250$, normalized value of temperature coefficient, which can be both positive and negative or close to zero, small $\mathrm{tg}\ \delta \sim 10^{-4}$ (tg of dielectric loss angle β), high electrical strength. Some types of ceramics belong to the class of active dielectrics, the properties of which depend on external influences and are used mainly as ferroelectrics and piezoelectrics.

Insulating products for radio-electronic systems (RES) are currently obtained from high-alumina ceramics (more than 94% alumina Al_2O_3). During firing of the workpiece, a modification of alumina is formed – Al_2O_3, called corundum.

There are two known brands of corundum ceramics: VK94-1 and Polikor. The first is the main material for housings of semiconductor devices and microcircuits. Polikor contains at least 99.7% – Al_2O_3 and can be obtained transparent, since it has virtually no pores, and the structure is fine-crystalline. These materials have a moderate permittivity $r = 9...10$, very small $\mathrm{tg}110^{-4}$, a fairly high thermal conductivity coefficient about 20...30 W/(m*K), a temperature coefficient of linear expansion $l = (4 ... 6)\ 10^{-6}\ K^{-1}$.

Ceramics on beryllium oxide BeO, called "brokerite", have a significantly higher thermal conductivity (~200 W/(m*K)) and good dielectric properties. It is used for substrates and housings of powerful microcircuits and semiconductor devices. A feature of brokerite is a low coefficient of linear expansion: $l = 1.410^{-6}\ K^{-1}$.

Even higher than that of brokerite, the thermal conductivity of diamond heat-conducting ceramics: = 500 W/(m*K), which is more than that of silver and copper. Such ceramics are made by sintering small crystals of synthetic diamonds. Despite the high cost, diamond ceramics are used in powerful semiconductor devices for special purposes.

Structural ceramic materials are divided into two groups: oxide ceramics (including silicates and glass ceramics) and oxygen-free (carbides, nitrides, borides). For a long time, materials scientists did not consider ceramics as a possible structural material. This was due to its main drawback – brittleness. But in other key performance parameters (heat resistance, hardness, corrosion resistance, density, availability and cheapness of raw materials) it significantly surpasses metals and alloys (Table 1).

Table 1

Ceramic materials types for electronics industry

Ceramic materials classification by purpose	**Ceramics properties**	**Ceramic material name**
Dielectrics		
Ceramics for installation products and small-capacity capacitors (high-frequency dielectrics)	Low permittivity ($\varepsilon < 10$); low dielectric losses (tgδ) at a frequency of 10^6 Hz; high values of: specific volume resistance, mechanical strength, breakdown voltage	Soapstone, ultraporcelain, corundum, celsian, corundummullite, forsterite, cordierite, bromellite ceramics
Capacitor ceramics		
For high-frequency circuit capacitors, including temperature-compensating and separating capacitors	High dielectric constant, negative temperature coefficient of permittivity (TKε)	Rutile ceramics (tikond T-80); perovskite ceramics – T-150 (based on $CaTiO_3$)
For high frequency thermally stable capacitors	Low value TK $\varepsilon \approx 0$	Titanium-zirconium ceramics (T-20, T-40); stannate ceramics C-15 (having a crystalline phase in the form of solid solutions of calcium stannate $CaSnO_3$, calcium titanate $CaTiO_3$ and calcium zirconate $CaZrO_3$); $CaTiO_3$ – $LaAlO_3$; TL-47*, TL-75*
For low frequency capacitors (linear)	Very high dielectric constant ($\varepsilon<300$)	SVT – strontium-bismuth titanate $SrTiO_3 \cdot Bi2O_3 \cdot 2NiO_2$
Porous ceramics (high temperature insulation)		
For electron tubes insulators	Low loss tangent value	Porous corundum and porous steatite ceramics
For bases of wire resistances (resistors)	High thermal resistance	Chamotte, alundum (sintered corundum), cordierite ceramics
For low frequency capacitors	Ultra-high dielectric constant (reaching several thousand)	SM-1, T-7500**, T-10000**, materials based on $BaTiO_3$
For piezoelectric elements	High piezoelectric modulus value	T-1700, zirconate – lead titanate $PbZrO_3$ – $PbTiO_3$
For nonlinear elements	Sharp dependence of permittivity on electric field strength	Variconds
Semiconductors *Semiconductor ceramics (high electronic conductivity)*		
For high power radio resistors, waveguide loads, high temperature heaters	Low dependence of resistance on temperature and voltage	Ceramics based on silicon carbide, as well as containing graphite (silite, kerax)
For nonlinear elements (varistors)	Sharp resistance versus voltage dependence	Ceramics based on silicon carbide (vilite, NPS based on ZnO with additives)
For thermal resistances (thermistors and posistors)	Sharp dependence of resistance on temperature	Ceramics based on copper and cobalt-manganese reverse spinels
Magnetic ceramics *(high magnetic permeability with high electrical resistance)*		
Magnetically soft	Low coercivity value	Nickel-zinc, manganese-zinc, magnesium and other ferrites
Magnetically hard	High coercivity value	Barium ferrites

* The number indicates the temperature coefficient of capacitance $\times 10^{-6}$;** The number usually indicates the value of permittivity; T – titanate.

Designations:

- TiO_2, ZrO_2 (YSZ, stabilization with yttrium or calcium oxides);
- Titanates, zirconates, niobates, tantallates Ba, Sr, Pb, K, Na, lead titanate-zirconate (PZT) – high density, required permittivity and loss tangent (piezoelectronics and radio engineering);
- ZrO_2 – ionic conductivity and oxygen sensors;
- Al_2O_3, MgO, SiO_2 – electrical insulation;
- Spinels, ferrites Ni, Co, Mn, Ca, Mg, Zn, Li – magnetic circuits, cores, memory devices;
- $MoSi_2$, resistance ~200 μOhm*cm, stability in an oxidizing atmosphere up to 1650 °C – electric heaters;
- perovskites (and intergrowth structures) $REEBa_2Cu_3O_7$;
- $Bi_2Sr_2CaCu_2O_8$ (2212, 2223) – current leads, limiters of maximum permissible current, superconducting tapes, solenoids, magnetic levitation;
- MgB_2 – electric heaters;
- Al_2O_3, SiO_2 – thermal insulation;
- SiC, Si_3N_4 – in the reaction chamber;
- SiC, Al_2O_3 – reaction limiters,
- Al_2O_3, BeO – reaction chamber windows;
- Al_2O_3, MgO, SiO_2 – electrical insulation;
- UO2, UC, UN, PuO_2 – nuclear fuel;
- SiC, Si_3N_4 – fuel element cladding;
- BeO, ZrO_2, Be_2C – neutron moderators and reflectors;
- B_4C, HfO_2, Sm_2O_3 – neutron shielding.

The increased susceptibility of ceramics to brittle fracture is associated with the extremely low mobility of defects, caused primarily by the specific (ionic-covalent) nature of the bond in ceramic structures. Therefore, the efforts of researchers are aimed primarily at eliminating such microscopic defects in ceramics that act as centers for crack initiation. One way to achieve this goal is to thoroughly clean and very finely grind the original powder and pack it tightly before sintering. The idea of using fine grinding of powders to intensify sintering was first put forward in Russia by Academician P.A. Rebinder back in the 1950s.

Hot pressing produces the most highly durable materials from silicon carbide, but products made from them are more expensive than those obtained by other methods, which is due to the impossibility of manufacturing parts of complex configurations without expensive mechanical processing with a diamond tool.

In the near future, fundamentally new ceramic materials are expected to be used [16]. An example is the superplastic ceramics obtained relatively recently in Japan based on the tetragonal modification of zirconium dioxide doped with 3 mol. % yttrium oxide.

Under specific conditions of raw material preparation and sintering, a polycrystalline material with a crystallite size of 0.3 μm is obtained, which is capable of deformation, stretching under external loads twice as much as the original length. It is characteristic that after such stretching, the ceramics have a strength exceeding the strength of silicon nitride, which is considered the most promising structural material.

Substrates based on beryllium oxide (BeO), although they have excellent heat-conducting properties and high electrical resistance, are expensive and very toxic. They are still indispensable in the manufacture of microwave transistors, since their losses at high frequencies are very low [12-14]. But here, too, in the production of devices based on SiC, a more promising solution is outlined. If the transistor or diode has a planar design, the thinnest AlN film grown on the back side of the SiC substrate provides reliable insulation due to its high breakdown voltage, practically not hindering heat dissipation. Operation of SiC semiconductor devices at temperatures above 200-250°C is impossible even on BeO substrates due to the significant difference in the coefficient of linear expansion.

Therefore, today the most popular product on the SiC device market is silicon carbide substrates. Their quality improves and their diameter increases every year. Now it is 100 mm.

Thus, new ceramic materials are promising for the manufacture of housings for electronic modules and substrates for printed circuit boards that experience high thermal and mechanical loads [6-10]. The development of these designs will help reduce both the dimensions and weight of products, and increase reliability and energy efficiency.

Examples of ceramic materials

The use of ceramics in technical applications is not only not decreasing, but also increasing, moving towards simplifying industrial processes with a simultaneous increase in manufacturability [11].

Examples of ceramic materials used in radio electronics:

Steatite ceramics. Talc serves as the basis for its production. Such ceramics are used to make mounting elements, terminals, stands, bobbins, switches, and axes for variable capacitors.

Forsterite ceramics. Magnesium orthosilicate serves as its basis. The material has low dielectric losses, good high-frequency characteristics, and high resistance even at high temperatures. Forsterite ceramics are used to make resistors, microcircuits, transistors, diodes, and terminals.

Alumina ceramics. It is produced by sintering alumina powder. The material has high mechanical strength (280-350 MPa for bending), hardness (9 on the Mohs scale), and abrasion resistance. Alumina ceramics are used to manufacture microcircuits, microcircuit housings, boards for film resistors and diodes, terminals that are resistant to high temperatures.

Aluminum nitride (AlN). The material is used in the manufacture of substrates for printed circuit boards, which experience high mechanical and thermal cyclic loads.

Beryllium oxide (BeO). It has better thermal conductivity than aluminum nitride and better electrical insulation than other ceramic materials for printed circuit board substrates.

Ceramic material is a multiphase system consisting of crystalline, amorphous (glassy) and gas phases. The main one is the crystalline phase, it determines high insulating and other indicators of the product. The glassy phase performs binding functions, provides mechanical strength. The gas phase is pores and microcracks that are formed during the firing process and reduce the mechanical and electrical properties of the material.

Steatite (enstatite) ceramics

Steatite is a ceramic based on natural magnesia (silicate) raw materials, mainly talc ($3MgO \cdot 4SiO_2 \cdot H_2O$), and clay components. Dense varieties of talc are called steatite. Steatite (clinoenstatite) ceramics are named after the main crystalline component of this type of ceramics – magnesium metasilicate $MgO \cdot SiO_2$ – clinoenstatite.

Magnesium metasilicate forms a number of polymorphic modifications. In addition, a widely occurring phase is known – enstatite (the rest are not found in nature, they exist only in artificial products). To date, there is no consensus in the scientific literature on the phase transformations of magnesium metasilicate.

Advantages of steatite ceramics:

- cheap material (the basis contains natural raw materials – finely crystalline talc);
- good dielectric properties and high mechanical strength at room and elevated temperatures and in a high-frequency field;
- low abrasiveness, which significantly simplifies the operating conditions of the mold and the process of semi-dry molding of products.

Disadvantages of steatite ceramics:

- narrow sintering range (10-30 °C), furnaces with silicon carbide heaters are used;
- aging (degradation of dielectric properties and mechanical strength over time).

Steatite has proven itself in countless areas of application, such as the housing of low-voltage fuses PPN, PN-2 or NH, as a base for halogen lamps, a carrier and holder of heating elements, a crown of gas burners, an insulator, a thermostat housing, etc. [15]. All types of steatite ceramics are characterized by low values of dielectric losses, high mechanical strength, twice as strong as electrical porcelain, and a high value of breakdown voltage. Due to these properties, steatite ceramics are widely used in electrical and radio engineering as high-voltage and high-frequency dielectrics.

Forsterite ceramics

Forsterite is an electronic material based on magnesium orthosilicate Mg_2SiO_4. The developers of this material in Russia are: G.I. Berdov, M.G. Korpachev, A.I. Korpacheva (Novosibirsk), P.G. Usov, V.I. Vereshchagin (Tomsk) et al. Manganese forsterite was developed in Japan. The mineral forsterite is found in nature.

Distinctive features of forsterite densely sintered ceramics:

- high values of electrophysical properties;
- increased coefficient of linear expansion compared to clinoenstatite ceramics.

Due to the high value of the coefficient of linear expansion, forsterite ceramics are used in vacuum tube technology as an insulator in contact with metals that have a corresponding coefficient of linear expansion. As a result of the absence of polymorphic transformations, forsterite ceramics are not subject to aging. Its main disadvantage is low heat resistance and high TCLE value. Due to this, the products are made in small sizes.

Advantages of forsterite ceramics:

- high mechanical strength;
- high dielectric properties up to 500 °C;
- the possibility of obtaining a vacuum-tight material;
- radiation-resistant material;
- the possibility of vacuum-tight connection with metallic titanium using active technology (without preliminary metallization);
- simple manufacturing technology using moderate firing temperatures (1350-1380 °C);
- a lower secondary electron emission coefficient than that of alumina ceramics, such as corundum.

Forsterite ceramics are used to manufacture bases of non-wire resistors and as an insulator in contact with metals. Recently, forsterite ceramics have been actively studied as a biocompatible and biodegradable ceramic for the production of bone prostheses. Due to the absence of polymorphic transformations, forsterite is a more promising material in this direction than steatite.

Cordierite ceramics

The $MgO-Al_2O_3-SiO_2$ system contains cordierite, a ternary crystalline compound with the formula $Mg_2Al_4Si_5O_{18}$, which occurs in nature. Cordierite ceramics are made from natural materials (talc, refractory clays) and artificial ones (alumina, electrofused corundum) [5].

A distinctive property of cordierite ceramics is a low thermal coefficient of linear expansion, due to which cordierite ceramics withstands sharp thermal shocks well, i.e. it is a very heat-resistant material. The high heat resistance of cordierite ceramics allows it to be used in high-voltage and low-voltage electrical engineering, in particular for the manufacture of arc-extinguishing chamber parts in high-voltage switches.

Cordierite ceramics are characterized by a low value of the dielectric loss tangent, equal to 10^{-2}, and a permittivity of 5 at a frequency of 1 MHz. High mechanical strength and chemical resistance allow cordierite to be used as a heat-stable carrier of oxidation-reduction catalysts for automobile exhaust control. Oxygen released from the cordierite surface in the form of anions or in molecular form may participate in catalytic reactions. Cordierite is used as a heat exchanger in gas turbines, as a refractory in industrial furnaces, and in the production of refractory metal coatings. Recently, cordierite has been actively used as a substrate material for integrated circuits and in multilayer low-temperature sintering ceramics (LTCC). Steatite and forsterite are usually white, cordierite can be yellowish due to iron impurities.

High Aluminum Ceramics

Depending on the $Al_2O_3-SiO_2$ ratio, the following types of high-alumina ceramics are distinguished:

- mullite-siliceous (pre-mullite composition) contains 45-70% Al_2O_3;
- mullite-corundum (for example, UF-46, UF-53, KM-1, M-4, etc.) contains 70-95% Al_2O_3; the phase composition of the ceramics is determined by the ratio of Al_2O_3 and SiO_2;
- corundum – 95-100% Al_2O_3.

The main component of high-alumina ceramics is aluminum oxide.

The physical and technical properties of high-alumina ceramics with mullite and mullite-corundum crystallization are influenced by the following factors:

- chemical composition, mainly the content of Al_2O_3;
- Al_2O_3/SiO_2 ratio and impurity content, as well as introduced additives;

– phase composition and ratio of the main crystalline phases – corundum and mullite, as well as the presence and composition of the glassy phase in the product;

– microstructure of the material - primarily the size and shape of grains, the nature of the distribution of the glassy phase and pores.

High-alumina and corundum ceramics are used as insulators for spark plugs of internal combustion engines, various parts of radio and electrical equipment, insulating ultra-porcelain UF-46 and UF-53.

Advantages of high-alumina ceramics:

– high dielectric properties at room temperature and at elevated temperatures (up to 300 °C);

– high chemical resistance;

– high mechanical strength;

– high heat resistance.

Disadvantages of high-alumina ceramics:

– use of relatively high firing temperatures (for corundum ceramics); narrow sintering range (for UF-46); high abrasiveness (for corundum ceramics).

Piezoceramics

Piezoceramics (ferroelectric ceramic) is an artificial material with piezoelectric and ferroelectric properties, having a polycrystalline structure. Piezoceramics do not belong to the classic types of ceramics, since they do not contain clay. Piezoceramic materials are synthesized from metal oxides. However, the use of a technique characteristic of ceramic technology - firing at a high temperature - justifies the classification of piezoceramics as a ceramic family. "Piezo" (from the Greek "piezo" – to press) indicates that this type of ceramics has a special property – the piezoelectric effect. Compared to single-crystal piezoelectrics, piezoceramics are characterized by their manufacturability, low cost and pronounced piezoelectric and dielectric properties. Piezoceramics can be used to manufacture products of any shape – plates, disks, cylinders, tubes, spheres, etc., which are extremely difficult or impossible to manufacture from single crystals. Piezoceramics are widely used to create acceleration and pressure sensors, shock wave piezoelectric transducers, powerful ultrasound and shock wave emitters, piezoelectric transformers, piezoelectric resonance filters, and delay lines. Piezoceramics are resistant to moisture, mechanical stress, and atmospheric influences.

In terms of physical properties, piezoceramics are polycrystalline ferroelectrics, which are chemical compounds or solid solutions (powders) of grains (crystallites). Crystallite sizes are usually from 2 to 100 μm. Each crystallite is a ferroelectric crystal. Piezoceramics have all the properties inherent in crystalline ferroelectrics. In terms of chemical composition, piezoceramics are complex oxides, usually including divalent lead or barium ions, as well as tetravalent titanium or zirconium ions. By changing the ratios of the starting materials and introducing various additives, piezoceramics compositions with certain electrophysical and piezoelectric characteristics are synthesized. Most piezoceramics compositions are based on chemical compounds with a perovskite-type crystal structure with the formula ABO3 (e.g. $BaTiO_3$, $PbTiO_3$, $LiNbO_3$) and various solid solutions based on them (e.g. $BaTiO_3$ – $CaTiO_3$; $BaTiO_3$ – $CaTiO_3$ – CoCO3; $NaNbO_3$ – $KNbO_3$ systems). Particularly widely used as piezoelectrics are compounds of the lead zirconate titanate system (PZT) $PbTiO_3$ – $PbZrO_3$ (“Piezoelectric ceramics” in the universal encyclopedia of Cyril and Methodius).

The basis of most modern piezoelectric ceramic materials is solid solutions of titanate – lead zirconate (PZT), modified with various components and additives. Piezoceramic materials are also produced based on barium titanate (TB), lead titanate (TS), lead metaniobate (MNS), bismuth titanate (TV), etc.

The first piezoelectric ceramic material was synthesized in 1944 by the Soviet scientist B. M. Vul, who discovered the ferroelectric properties of barium titanate $BaTiO_3$. Almost simultaneously, these properties of barium titanate were discovered by American and Japanese researchers.

In the initial state, the polarization of piezoelectric ceramic elements is zero, since each crystallite is divided into domains and has a random direction of the crystallographic axis. When an external electric field is applied that exceeds a certain value, called a coercive field, the polarization directions of the crystallites are aligned in the direction that is as close as possible to the direction of the polarizing field. Polarized piezoelectric ceramics have pronounced piezoelectric properties.

Depending on the piezoelectric properties, manufacturers divide it into ferroelectric-rigid and ferroelectric-soft. In domestic practice, there is an additional division – ceramics of medium ferroelectric rigidity. Highly stable, high-temperature, etc. materials are also distinguished.

The value of the piezoelectric modulus d33 reaches several hundred pC/N. Piezoceramics are characterized by high values of relative permittivity. The quality of piezoceramics is characterized by the following main parameters accepted abroad:

K^T_{33} (e^T_{33}/e_0) – relative permittivity;
tg d – dielectric loss tangent at 1 kHz in weak fields;
T_c (T_k) – Curie point temperature;
K_p K_{33} K_{31} K_{15} – electromechanical coupling coefficients;
d_{33} -d_{31} d_{15} – piezoelectric moduli;
g_{33} g_{31} g_{15} – electrical voltage coefficients;
Y^E_{11} Y^E_{33} – Young’s moduli;
N_L N_T N_R – frequency constants;
S^E_{11} S^E_{33} – elasticity parameter;
r – density;
Q_m – mechanical quality factor.

A composite may have a ceramic, metal or polymer matrix.

The continuous phase, which usually has a higher proportion in the volume of the composite material, is called the matrix. The second component is called a filler or reinforcing phase, the role of which is often to increase the mechanical properties of the matrix (Table 2).

The principle of chemical and physical compliance is the absence of degradation of the matrix properties due to contamination with foreign chemical elements or the formation of defects that worsen the functional properties (mutual chemical inertness, absence of phase transitions, compliance of thermal expansion coefficients, as well as: microparticles and globules in the matrix, layered composites, reinforcing threads, three-dimensional mesh, etc.).

Table 2

Matrix	Filler	Properties
Polymers	Fiberglass	High strength
Carbon	Carbon fiber	Low density, high thermal conductivity, fire resistance (~2000 °C)
Metal	Metal oxide	Dispersion hardening
Metal	Ceramics (cermets)	Heat resistance, hardness
Ceramics	Metal (ultracermets)	Increased strength, thermal conductivity
Al_2O_3	Cr, W-Cr	Gas turbines
TiC	Ni, Cr	Wear resistance
ThO_2	Mo	Emission cathodes
Ceramics	Ceramics	Pinning, refractories

Distinctive properties of composites:

1. Consist of two or more phases that differ in their chemical and mineral compositions; the phases are separated by a clearly defined boundary;
2. The materials acquire new properties that differ from the properties of their constituent components;
3. The materials are heterogeneous in the nano- and micrometer size range (up to 500 μm), but are fairly homogeneous in terms of macroscopic characteristics (density, hardness, color);
4. The composition, shape, and distribution of the material components are designed in advance;

5. The properties of the material are determined by each of its components.

The main stages of obtaining ceramic products:

- sorting and cleaning from impurities;
- grinding and mixing according to a given recipe with the addition of water;
- forming parts by pressing, stamping;
- drying and firing in kilns.

Advantages: high heat resistance and mechanical strength, high radiation resistance, resistance to aging, obtaining specified characteristics by changing the composition of the mass, non-hygroscopic and weather-resistant.

Disadvantages: impossibility of obtaining thin flexible products, difficulty of mechanical processing (products can only be ground), porosity.

According to their purpose, they are divided into three groups: insulator, capacitor and ferroelectric ceramics.

Porcelain is the oldest type of ceramics used as an insulating material. Porcelain is used at low frequencies, at low voltages as an insulating and structural material. The raw material is high-quality clay – kaolin (approximately 50%), quartz sand (approximately 25%) and feldspar (approximately 25%). Porcelain is used to make resistor and connector housings, lamp panels. At high voltages, porcelain is used to manufacture terminals of high-voltage equipment and insulators of overhead lines (Fig. 1).

Fig. 1. Insulating ceramics

Ceramic capacitor materials differ from ceramic insulator materials by a higher dielectric constant, which allows them to be used to manufacture ceramic capacitors of large capacity and relatively small dimensions. Ceramic capacitors are not hygroscopic and do not require protective housings and shells, which are necessary for paper and mica capacitors (Fig. 2).

Ceramic capacitors are manufactured using ceramic technology methods – casting in plaster or steel molds, and then fired in furnaces at a temperature of 1450-1700º.

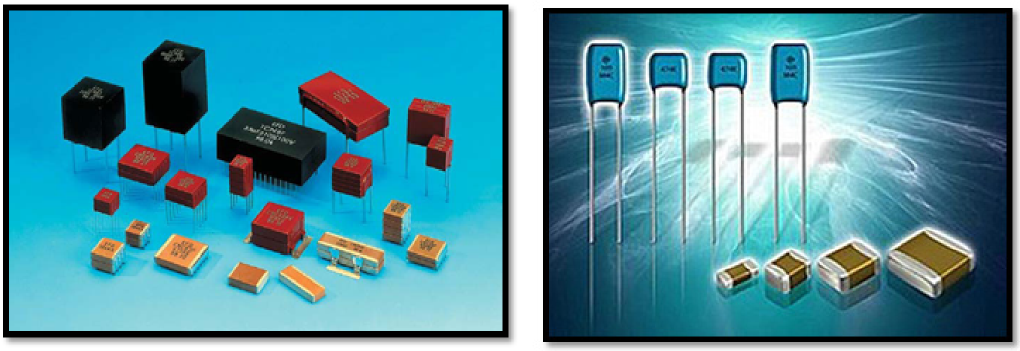

Fig. 2. Ferroelectric ceramics

Ferroelectric ceramic materials (ferroelectric ceramics) have abnormally high values of permittivity, which allows them to be used as temperature sensors when changing it by electrical methods. The high permittivity of ferroelectric dielectrics allows them to be used to manufacture miniature electric capacitors of large capacity. The permittivity of ferroelectric dielectrics increases significantly with the growth of the voltage applied to them, which is not observed in conventional dielectrics. This characteristic property is used in dielectric amplifiers. All ferroelectric dielectrics have characteristic properties only up to a certain temperature. When these temperatures are exceeded, they lose their properties and become conventional dielectrics.

Conclusion

The development of radio electronics at the present stage, increasing reliability, reducing the dimensions and weight of devices are closely related to the development, study of properties and application of new materials. These include new ceramic and composite materials that can withstand high temperatures and successfully operate in aggressive environments.

Ceramic materials are very diverse, each of them has its own unique chemical properties. They are very widely used in radio electronics and are promising for the development and improvement of designs of radio electronic devices.

Currently, industrial progress requires electronics to constantly increase the level of power, efficiency, reliability and durability. For modern devices, in particular powerful RF and microwave transmitters, power transistors, power converters, reliability under high currents and high temperatures is certainly a key factor.

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