

НЕОРГАНИЧЕСКАЯ ХИМИЯ

OXYFLUORIDE GLASSES AS A BASIS FOR OBTAINING MULTILAYER CO-FIRED GLASS-CERAMIC MATERIALS

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To expand the base of new technical glasses, glass-ceramics and composite materials based on them, it is always important to study new glass-forming systems which combine two important characteristics, such as relatively low fusibility and high dielectricity.

The purpose of this work is to study the glass formation and properties of the glasses in the systems $\text{MeB}_2\text{O}_4\text{-Al}_2\text{O}_3\text{-(SiO}_2\text{)-MeO / MeF}_2$ (Me – Mg, Ca, Sr, Ba), to identify the possibility of their use both as a glass-crystalline material and as a binder in compositions “Glass+ceramics” for obtaining low-temperature co-fired ceramic materials for electronics. The features of glass formation and the regularities of changes of the physicochemical properties of glasses and glass-ceramic materials have been studied. The materials are obtained by directional crystallization of glasses and glass-ceramics compositions synthesized by sintering a mixture of glass and crystal. General issues of the processes of wetting, adhesion and interaction of glass melts with crystalline fillers and their influence on the electrical and thermophysical parameters of co-fired composites have been considered. Based on the complex studies of the properties and structure of synthesized glass-crystalline materials, new compositions have been developed, combining high mechanical and dielectric characteristics, for low-temperature co-fired ceramics (Low Temperature Co-fired Ceramic, LTCC).

Figs. 3, table 1, references 24.

The development of complex high-frequency miniaturized circuits for electronics is related to the technology of obtaining substrates from low-temperature co-fired ceramics (Low Temperature Co-fired Ceramic, LTCC). Such small-scale integrated circuits combine many thin layers of ceramics and conductors, as a result of which the multilayer LTCC modules are usually used in the form of a three-dimensional circuit boards and composed of a dielectric compositions with a low dielectric permittivity (usually $\epsilon_r \approx 4$ -

9). In addition, it allows making flexible combinations of passive microwave components and makes it possible to design integer matrices, significantly reducing the size of the contours. Since LTCC boards can be sintered at low temperatures ($<950^{\circ}\text{C}$), power lines can be made of highly conductive metals such as silver or copper with low current loss and low electrical resistance at high frequencies [1-3].

There are two approaches for obtaining ceramic compositions which are sintered below 1000°C . The first approach is to obtain a glass-crystalline material (sitall), which supposes almost complete crystallization of the initial glass during sintering. The initial materials are glasses of practically stoichiometric composition, such as cordierite, spodumene, eucryptite, etc. [4, 5], which are condensed during firing and then crystallized. The glass-ceramic (sitallic) way assumes in some cases the complete crystallization of the pre-synthesized glass in the process of secondary heat treatment (sintering). The physical properties of the obtaining material are largely due to the degree of crystallinity, which can be increased by adding a small amount of the crystalline phase, acting as a crystallization center. The obtained glass-ceramic (sitall) materials are distinguished by minimal porosity, high mechanical and electro-physical characteristics, and low TCLE values. By using a catalyst, it is possible to change the crystallization kinetics, phase composition, and properties (relative dielectric permittivity ϵ_r , quality factor Q , TCLE and temperature coefficient of relative dielectric permittivity $\tau\epsilon$) of the synthesized material. In the second, the most common approach (glass + ceramics), the initial fired mixture consists of glass and crystalline material ($\alpha\text{-Al}_2\text{O}_3$, $3\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$, ZrSiO_4 , etc.) [6, 7]. Compaction of the “glass + ceramic” composition is described by three stages: the appearance of a liquid phase, partial dissolution of the filler in the liquid phase and the excretion of new phases, and solid-phase sintering. Depending on the type and amount of added glass, two sintering mechanisms are possible [8, 9]: reactive and non-reactive liquid-phase sintering. The compaction of the glass + ceramic composition can be classified as non-reactive, partially reactive and fully reactive, depending on the reactivity between glasses and ceramic.

The composition of glass has a great importance for sintering process, since the softening of the glass plays a major role in the mechanism of viscous flow and wetting of the developed surface of the crystalline particles of filler, ensuring the compaction of the composition. The glasses which are used for LTCC technology are mainly synthesized on the basis of oxide systems (borate, borosilicate, boroaluminosilicate, etc.), containing alkaline earth metal oxides, ZnO , PbO as modifiers and, in some cases, for adjusting properties and control glass crystallization process – Li_2O , La_2O_3 , TiO_2 , etc. [3].

The purpose of this study was to determine glass formation and study the properties of glasses in boroaluminosilicate systems $\text{MeB}_2\text{O}_4\text{-Al}_2\text{O}_3\text{-(SiO}_2\text{)-MeO / MeF}_2$ (Me- Mg, Ca, Sr, Ba), to identify the possibility of their use in the form of a glass-crystalline materials, and as a binder in compositions of “glass+ceramics” for obtaining low-temperature co-fired ceramic materials for electronics.

In this work some properties of glasses of fluorine containing aluminoborate systems are presented, as well as the comparison with the properties of known glasses which are used to obtain co-fired ceramics.

Experimental part

The synthesis of fluorine containing glasses was carried out in corundum and platinum crucibles at 150-250°C above the liquidus temperature with a duration of 40 *min.* (melt cooling rate $\sim 10 \text{ K s}^{-1}$). In order to reduce the volatility of boron and fluorine compounds, in the synthesis of glasses were used metaborates and Al_2O_3 , which in the glass-forming melt contributed to the formation of relatively stable aluminate and borate oxyfluoride complexes by reducing the loss of fluorine. Glass formation was determined by tempering 15-20 g of the melt on a metal plate. The measurement of the temperature coefficient of linear expansion (TCLE) of glasses and glass-crystalline materials was carried out on a DKV-4 quartz dilatometer at a heating rate of -5 K min^{-1} , $\Delta\alpha \pm 3 \cdot 10^{-7} \text{ K}^{-1}$. The viscosity of the glasses was determined in the range of $10^{12}\text{-}10^4 \text{ Pa}\cdot\text{s}$ by the method of indentation of a cylindrical indenter. The measurement accuracy was $\pm 0.061 \text{ g}\eta$. Specific volume resistance, dielectric losses and dielectric permittivity of glasses and sitalls were determined on an E6-13A teraohmmeter and an E7-20 universal meter by using silver electrodes at a frequency of $10^3\text{-}10^6 \text{ Hz}$. The measurement error was $\pm 0.11 \text{ g}\rho$. The contact angle of wetting was determined in an inert atmosphere using the resting drop method.

Results and discussion

Elements which oxides form glasses at melt cooling rates of $10\text{-}10^2 \text{ K s}^{-1}$ are characterized by average values of electronegativity and the nature of bonds in oxide glasses is mixed – covalent-ionic, and their structures represent a three-dimensional polymer framework. Consequently, oxide glasses in a softened or molten state are characterized by high values of viscosity, and the processes of spreading and wetting by the crystal melt proceed with more significant energy barriers than occurs in ionic or molecular liquids or melts. In oxide glasses, partial replacement of oxygen by fluorine, which is characterized by low polarizability, makes it possible to

synthesize glasses with a special course of changes in properties [10]. These are fusibility, low viscosity and activation energy of viscous flow, high chemical resistance to the action of fluorine-containing reagents, high values of electrical characteristics, and the possibility of synthesizing glass-crystalline materials with crystal sizes from 10 nm to 3-5 microns and from 30 to 85% or more degree of crystallinity.

Interest in the study of glass formation, three component glasses MeO-Al₂O₃-B₂O₃ (Me-Mg, Ca, Sr, Ba, Zn, Cd, Pb) and more complex systems containing oxides of these divalent metals is associated with their unique electro-physical characteristics and the possibility to obtain glass-crystalline materials with a wide range of properties.

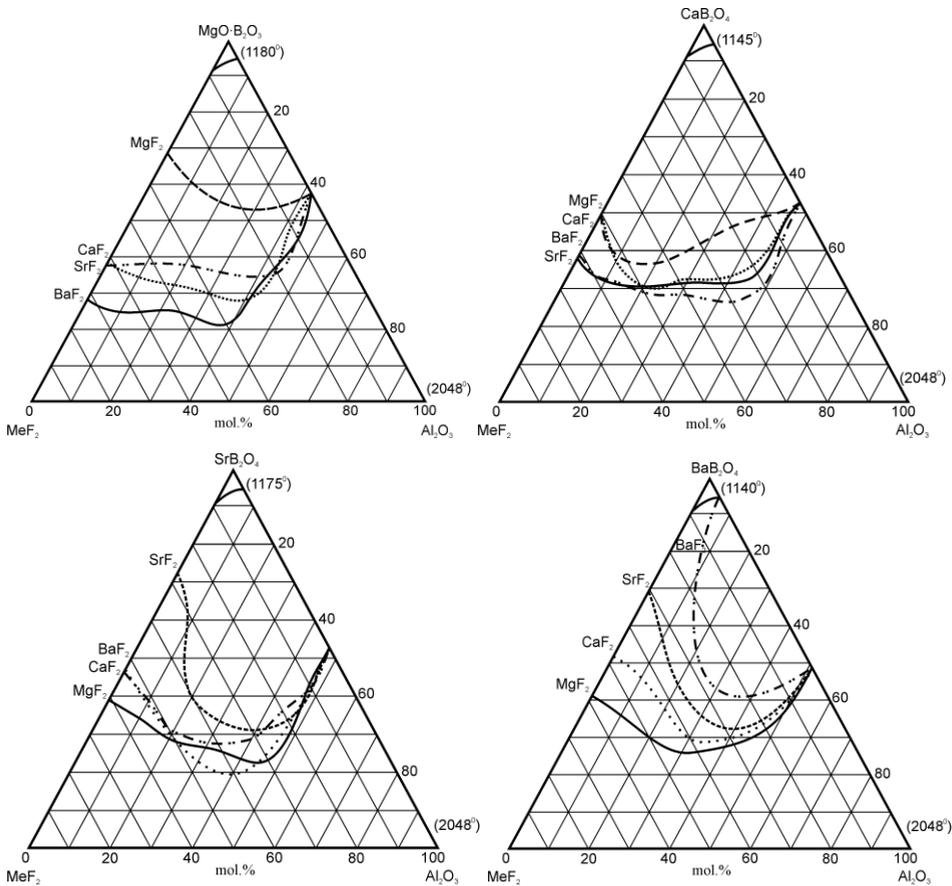


Fig. 1. Diagrams of glass formation of oxide and oxyfluoride systems. MeB₂O₄-Al₂O₃-MeO/MeF₂ (Me-Mg, Ca, Sr, Ba) [11-14].

Fig. 1 shows diagrams of glass formation of pseudo-ternary systems MeB₂O₄-Al₂O₃-MeO / MeF₂ (Me-Mg, Ca, Sr, Ba) and the compositions of the most studied glasses. Metaborate melts do not form glass upon air cooling in a platinum crucible, and upon sharp cooling (quenching in water) the content of the stellophase is from 5 to 15%. The formation of glasses is

also not observed when an oxide of the same metal is introduced into the initial metaborate. It can be seen from the diagrams that in fluorine-containing systems the areas of glass formation are much wider than the areas of glass formation for purely oxide systems. An increased glass-forming ability of melts is due to the simultaneous presence of oxide and fluoride structural groups of the same cations and the formation of terminal fluorine bonds, leading to increase the interionic distances. Depolymerization of the glass structure, accompanied by an increase of free volume, contributes to the optimal and energetically favorable distribution of the oxide and oxyfluoride groups of modifier cations [15].

The wetting of crystals, ceramics of metals and their alloys with molten or softened glass in the production of composite materials and coatings is of paramount importance for the technology of soldering dissimilar materials, regardless of whether it is an equilibrium or non-equilibrium process. The wetting precedes by dissolution and diffusion, and manifests itself in the form of droplets spreading over a solid. The driving force of spreading is determined in accordance with the ideas of Young [16], by the equation: $f = \sigma \cos\theta$, where θ is the contact angle. In real experimental conditions, the droplet sizes are taken to be deliberately small so that the effect of gravity on spreading to be insignificant in comparison with the surface stress. The driving force coincides in order with the surface tension of the melt. Depending on the chemical composition of the glass, the surface tension varies from 0.16 to 0.47 N/m (20-80 Pa) [17]. The normal component of the driving force of spreading σ is related to the viscosity and the velocity gradient by the equation [16] $\sigma = 3 \eta \frac{dv}{dx}$, where η is the dynamic viscosity, $\frac{dv}{dx}$ is the gradient of the flow velocity in the direction of the force action. Assuming that the normal component of the stress tensor does not depend on the distance, then after integration we obtain $-V = \sigma (x-x_0) / 3 \eta$, which is permissible for estimating calculations. We have performed estimated calculations for the time and rate of spreading of glass melts at $\sigma = 50 \text{ Pa}$ and conditional spreading $(x-x_0) = 1 \text{ cm}$ (Table).

Table

Time and rate of spreading of glass melts of different viscosity

$\eta, \text{Pa}\cdot\text{s}$	10^{10}	10^8	10^6	10^4	10^3
$V, \text{cm}/\text{sec}$	$1.7 \cdot 10^{-9}$	$1.7 \cdot 10^{-7}$	$1.7 \cdot 10^{-5}$	$1.7 \cdot 10^{-3}$	$1.7 \cdot 10^{-2}$
spreading time	$5.9 \cdot 10^8$	$5.9 \cdot 10^6$	$5.9 \cdot 10^4$	$5.9 \cdot 10^2$	$5.9 \cdot 10$
sec					
hour					
	$16.4 \cdot 10^4$	$16.4 \cdot 10^2$	16.4	0.164	0.0164

The data in Table 1 shows that a drop in the high-viscosity state of the melt spreads very slowly and the spreading time approaches to infinity. Wetting is a required condition for adhesion and sticking of the melt to the substrate. The studying of wetting ability of glass melts by the spreading method has shown that with increasing temperature a decrease of the contact angle is observed. If the adhesion between the melt and the substrate is carried out by molecular forces (physical wetting), the temperature usually has a little effect on the contact angles of wetting [18]. In chemical wetting, the contact angles are very temperature dependent, and this is manifested by the “wetting threshold” – the temperature, upon reaching which there is a sharp change in the contact angle.

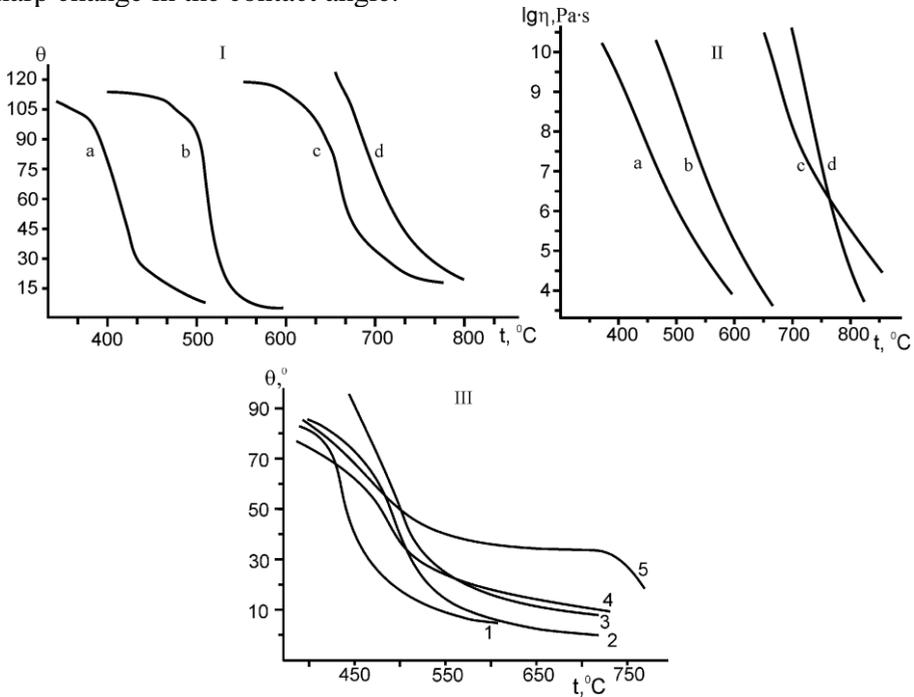


Fig. 2. Dependence of the contact angle (I) and viscosity (II) of oxyfluoride (a, b, c) and oxide (d) glasses on temperature, a) window glass+glass b) 22XC+glass, c) Mn-Zn ferrite+glass, d) alloy X18H10T+silicate glass ($SiO_2-55\%$); (III) dependence of the contact angle of wetting of the original glass (1) and compositions (2,3,4,5) on temperature.

Fig. 2 shows changes of the contact angle and viscosity of fluorine-containing (a, b, c,) and oxide (d) glasses from temperature. A sharp decrease of the contact angle occurs in the temperature range when the viscosity of the glasses changes in the range of $1.1-1.3 \cdot 10^4 Pa \cdot s$. The values of glass viscosities, taking into account the data in Table 1, indicate that the equilibrated contact angles are achieved within 11-13 min, and these values can be used in calculating the work of adhesion, and also characterize the wetting ability of the glass melt. It can be seen from the temperature dependence of the viscosity that the fluoride glasses are shorter, taking into

account the steepness of the $\lg\eta$ - t line and the smaller temperature range of changes in the same viscosities of oxide and oxyfluoride glasses. The introduction of fluorine ions into purely oxide glass increases the oxidizing ability of their melts, and consequently, the corrosiveness in relation to crystalline and amorphous materials. The interaction of the glass melt and the solid phase with the formation of a transition layer is manifested for fluorine-containing glasses by a sharp change in the course of the wetting curves (Fig. 2 a, b, c) in the low-temperature region of soldering. Alkaline earth metal fluorides are comparatively less active than alkali metal fluorides, and the activity of aluminoborate melts increases with the interchange of fluorides in the following series $\text{MgF}_2 < \text{CaF}_2 < \text{SrF}_2 < \text{BaF}_2$. The cohesion force is related to the work of adhesion by the equation [16] $W_a = \int_{x_0}^{\infty} f(x) dx$ (1), where $f(x)$ is a function which determines the decrease of the cohesion force with distance when the system is separated. It is shown that in condensed systems, upon interaction of atoms or ions, the interaction force decreases inversely proportional to the degree of the distance between particles, by the exponent $n \approx 4$ [16]. Therefore, with the minimum possible approach of the phases (X_0) $f(x) = f_a (x_0/x)^n$, where f_a is the cohesion force between the phases at X_0 . After integration of equation (1), we obtain $f_a = W_a (n-1) / x_0$. The work of adhesion of glass melts to ceramics and metals varies in the range of 0.2-0.5 J/m^2 [19] and in the case of chemical interaction, the minimum interphase distance can be estimated to be in order of $\sim 4 \cdot 10^{-10} \text{ m}$. The calculation of adhesion force, gives values in order of $(2.0-4.0) 10^9 \text{ Pa}$, which is close to the theoretical strength of materials. The chemical interaction of two materials should be understood not only as cases of the formation of new phases at the interface, but also the formation of a chemical bond between the interacting phases without the formation of new glassy or crystalline phases.

Studies of the fusibility and glass formation diagrams of aluminoborate systems $\text{MeB}_2\text{O}_4\text{-Al}_2\text{O}_3\text{-MeO/MeF}_2$ (Me-Mg, Ca, Sr, Ba), phase transformations during crystallization of glasses and the regularities of changes in thermal expansion and electrical characteristics of glass crystals from composition have shown that they are promising for obtaining sitalls with low values of TCLE and dielectric properties [20]. It can be seen from the presented curves (Fig. 3a) that the closer the composition of the glass of the binary system to the composition of the ternary crystalline borate of the composition $\text{MeAl}_2\text{B}_2\text{O}_7$ (where Me is Mg, Ca, Sr, Ba), the lower the TCLE values of the sitalls (the content of MeF_2 and TiO_2 in initial glasses is 5%). X-ray phase analysis of crystallization products of glasses of hypoeutectic composition of the $\text{MgB}_2\text{O}_4\text{-Al}_2\text{O}_3$ system showed the presence of $\text{Mg}_2\text{B}_2\text{O}_5$ and MgB_4O_7 . Aluminoborate by composition of MgAlBO_4 is released simultaneously with the above mentioned borates when the content of Al_2O_3 is more than 25 *mol.%*. The ternary compound $\beta\text{-CaAl}_2\text{B}_2\text{O}_7$ ($\alpha =$

$16.7 \cdot 10^{-7} K^{-1}$) in the crystallization products of glasses of the $CaB_2O_4-Al_2O_3$ system, along with $\alpha-CaB_2O_4$ and $Ca_2B_2O_5$, is formed with the introduction of Al_2O_3 more than 25 mol%. The release of $SrAl_2B_2O_7$ ($\alpha=5.5 \cdot 10^{-7} K^{-1}$) and $BaAl_2B_2O_7$ ($\alpha=14.3 \cdot 10^{-7} K^{-1}$) is recorded, the content of Al_2O_3 is 35 and 40 mol.%, respectively [20].

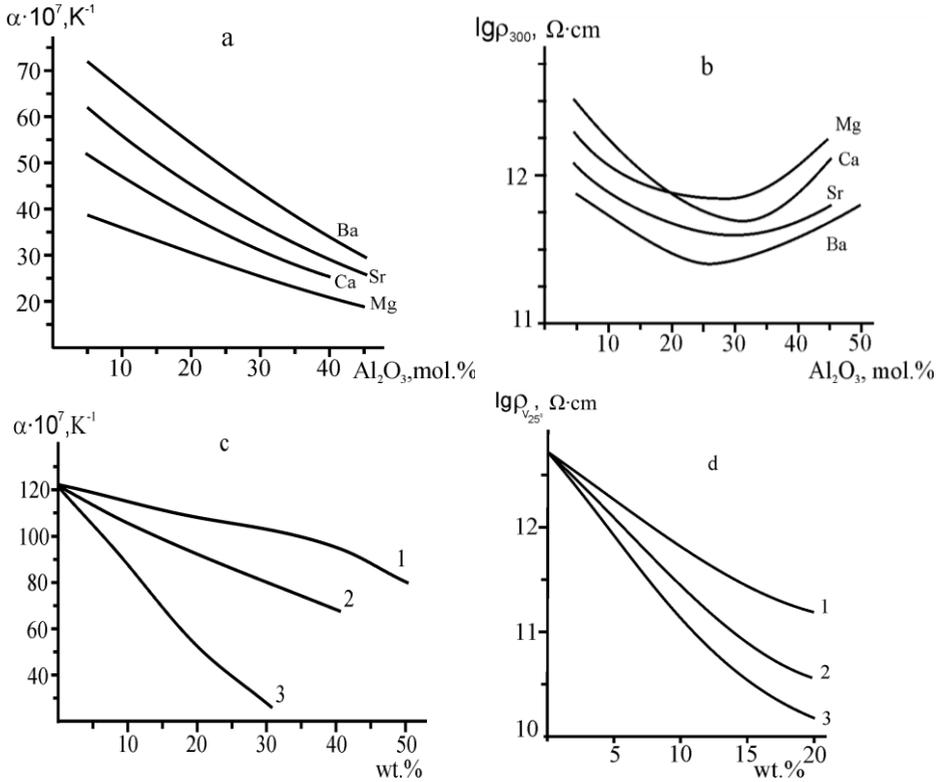


Fig. 3. Dependences of TCLE (in the range 20-300°C) (a) and resistivity $\lg \rho_{300}$ (b) of sitalized glasses of the system of $MeB_2O_4-Al_2O_3$ (Mg, Ca, Sr, B) from composition. Influence of filler concentration on TCLE (c) and resistivity $\lg \rho$ (g) of compositions: 1-PbTiO₃, 2-ZrSiO₄, 3- LiAlSiO₄; the duration of heat treatment at 800°C is 30 min.

When the glass contains less than 40 mol.% Al_2O_3 , crystals of $3BaO \cdot 2Al_2O_3 \cdot 2B_2O_3$ and $5BaO \cdot 2Al_2O_3$ are precipitated, the total TCLE of them is higher than the TCLE of $BaAl_2B_2O_7$, which is released during crystallization of glasses containing more than 40 mol.% Al_2O_3 . The closeness of the TCLE values of crystallized glasses of stoichiometric compositions is due to the isostructurality of crystalline aluminoborates with the general formula $MeAl_2B_2O_7$. In the crystal structure of aluminoborates, the determining ones are chains of trigonal borate and tetragonal aluminate groups, in which AlO_4 tetrahedrons are connected by vertices and each with an isolated BO_3 triangle. According to [21], the low thermal expansion of aluminum borates and sitalls based on them is associated with anomalous

contraction of one of the crystal lattice axes and the simultaneous rotation of BO_3 groups upon heating. In the structure of glass-crystalline material, aluminoborate chains form columns connected by atoms of alkaline earth elements. Thus, the significant asymmetry in the structure of the crystal lattice of $\text{MeAl}_2\text{B}_2\text{O}_7$ (where Me – Ca, Sr, Ba) and MgAlBO_4 causes low values of thermal expansion of the synthesized sitalls in a wide temperature range. Glasses and sitalls of aluminoborate systems containing only alkaline earth oxides and fluorides are distinguished by unusually high electrical resistance (Fig. 3 b), even at high temperatures ($\rho_{600} = 10^{8.5}-10^9 \Omega \cdot \text{cm}$) with anomalously low dielectric constant ($3.5 < \varepsilon < 5.4$) [22]. By controlling the crystallization processes of alkaline-earth aluminoborate glasses (stoichiometric and non-stoichiometric compositions containing fluorides), glass-crystalline materials with TCLE $(5.0 \div 48.0) \cdot 10^{-7} \text{ K}^{-1}$ were obtained. Both groups of materials have high values of microhardness 6500-7500 MH/m^2 , low dielectric characteristics ($\varepsilon = 5 \div 7$, $\text{tg} = \delta = 4.5 \div 15 \cdot 10^{-4}$) and low cooking temperature (1400-1500°C), differing from all known glass ceramics with low values of thermal expansion [20].

Glass composite materials are a mixture of low-melting glass and ceramic filler powders that together have undergone heat treatment and have a low or negative TCLE. By changing the ratio of components, can vary the value of thermal expansion; synthesis compositions with high electrical and mechanical parameters.

The features of the behavior of the heterogeneous media were studied, such as composite materials based on fluorine-containing aluminoborate glasses and crystalline materials: refractory fillers zircon ZrSiO_4 , β -eucryptite $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ and lead titanate PbTiO_3 were used. The filler should practically not enter into chemical interaction with glass, but should form a heterogeneous system with phase boundaries. In general, the appearance of a new phase gives the system a number of valuable properties, expanding the scope of both glasses and compositions based on them. When choosing glasses that serve as matrices in compositions, the main attention is paid to the resistance of glasses to crystallization: glasses of magnesium aluminoborate system, containing up to 50% ΣAlF_3 , MgF_2 , BaF_2 and resistant to crystallization for 60-80 *min.* in a gradient temperature field, were studied. The compositions were prepared by dry mixing of powders (specific surface $1600 \times 200 \text{ cm}^2/\text{g}$) of glass and filler. Among the fillers used, $\beta \text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ has the highest absolute value of negative TCLE ($-130 \cdot 10^{-7} \text{ K}^{-1}$) compared to PbTiO_3 and ZrSiO_4 (-10 and $-37 \cdot 10^{-7} \text{ K}^{-1}$, respectively). The widespread use of PbTiO_3 in the production of glass compositions with low TCLE is associated with the good dielectric properties of PbTiO_3 . In the study of the wetting of the initial glass (Fig. 2, in curve 1) and compositions (Fig. 2, in curves 2, 3, 4), almost linear decrease of the contact angle (θ) with increasing temperature was found, and the

appearance of a “wetting threshold” gives full reason to believe that the mechanism of adhesion and wetting of glass and substrate (22XC) occurs similarly to chemical interaction [23, 24]. It was revealed that an increase of the content of MgO, MgF₂ and AlF₃ in the glass shifts the onset of wetting of the composition to the high-temperature levels. The temperature dependence of the wetting angle of the crystallizing compositions has a different character. In the area of beginning of the exothermic effect of crystallization of the composition (according to the DTA curves), the course of the temperature curve changes sharply and stabilizes at a certain value of the contact angle (Fig. 2, in curve 5), until the precipitated crystals melt. Fig. 3.c presents the results of the effect of the concentration of fillers on the TCLE. It is seen that the required TCLE value can be achieved at different concentrations of the added fillers, and β Li₂O·Al₂O₃·2SiO₂ has a more significant effect on the thermal expansion of the composites. However, at high filler concentrations, the spreading of the composition is significantly reduced and, accordingly, the sintering temperature increases. Compositions based on alkali-free glasses have both low-melting properties and high dielectric properties. Analyzing the obtained values of electrical resistivity from the type and concentration of the filler, the following can be noted: with an increase of all types of fillers, the electrical resistance of the composition decreases, while the compositions with ZrSiO₄ have lower electrical conductivity values. The synthesized compositions are distinguished by low melting point and relatively high microhardness values of 5500-6000 H/m², low dielectric characteristics (ϵ =12-16, tg δ =18-22·10⁻⁴).

Thus, studies of the fusing and glass formation diagrams of fluorine-containing aluminoborate systems, phase transformations during the crystallization of glasses and the regularities of changes in thermal expansion and electrical and mechanical characteristics of glass-crystalline materials from the composition, have shown their promising prospects for obtaining sitalls with low TCLE values and high mechanical and dielectric properties. The possibility of using fluorine-containing aluminoborate fusible glasses in the form of a glass-crystalline material and as a binder in the glass compositions for obtaining low-temperature co-fired ceramic materials for electronics is shown.

**ՕՔՄԻՖՏՈՐԻԴԱՅԻՆ ԱՊԱԿԻՆԵՐԸ ՈՐՊԵՍ ՆԻՄՔ ԲԱԶՄԱՇԵՐՏ
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ՍՏԱՅՄԱՆ ՆԱՄԱՐ**

Ա. Կ. ԿՈՍՏԱՆՅԱՆ և Ն. Բ. ԿՆՅԱԶՅԱՆ

Նոր տեխնիկական ապակիների, դրանց հիմքով ապակեկերամիկական և կոմպոզիտային նյութերի բազայի ընդլայնման համար մտած է միշտ ակտուալ նոր ապակեգոյաց-

նող Համակարգերի ուսումնասիրությունը, որոնք Համատեղում են Հարաբերական դյուրահալուելիությունը և սինթեզված նյութերի բարձր էլեկտրամեկուսիչ բնութագրերը:

Աշխատանքի նպատակը Հանդիսանում է $MeB_2O_4-Al_2O_3-(SiO_2)-MeO/MeF_2$ (Me- Mg, Ca, Sr, Ba) Համակարգերի ապակեդոյացման և ապակիների Հատկությունների ուսումնասիրությունը, դրանց կիրառման Հնարավորության բացահայտումը որպես ապակեբյուրեղային նյութ, և որպես կապակցող “ապակի+կերամիկա” կոմպոզիտի բաղադրությունում ստանալու ցածրՋերմաստիճանային Համատեղ եռակալված կերամիկական նյութ էլեկտրոնիկայի Համար: Հետազոտվել են ապակեդոյացման առանձնահատկությունները, ապակիների և դրանց ուղղորդված բյուրեղացմամբ, ապակու և բյուրեղի խառնուրդների եռակալմամբ սինթեզված ապակեկերամիկական նյութերի Ֆիզիկաքիմիական Հատկությունների փոփոխության օրինաչափությունները: Դիտարկված են ապակու Հալուելի և բյուրեղային լցանյութերի փոխազդեցություն, թրջման և ազհեզիայի պրոցեսների ընդհանուր Հարցերը և դրանց ազդեցությունը Համատեղ եռակալված կոմպոզիտների էլեկտրական և Ջերմաֆիզիկական Հատկությունների վրա: Սինթեզված ապակեբյուրեղային նյութերի Հատկությունների և կառուցվածքի Համալիր ուսումնասիրությունների Հիման վրա մշակված են բարձր Ջերմամեխանիկական և դիէլեկտրիկ Հատկությունների զուգակցմամբ նոր կոմպոզիտներ ցածրՋերմաստիճանային Համատեղ եռակալված կերամիկայի Համար (Low Temperature Cofired Ceramic, LTCC):

ОКСИФТОРИДНЫЕ СТЕКЛА КАК ОСНОВА ДЛЯ ПОЛУЧЕНИЯ МНОГОСЛОЙНЫХ СООБОЖЖЕННЫХ СТЕКЛОКЕРАМИЧЕСКИХ МАТЕРИАЛОВ

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Для расширения базы новых технических стекол, стеклокерамических и композиционных материалов на их основе, остается всегда актуально исследование новых стеклообразующих систем, сочетающих относительную легкоплавкость и высокие диэлектрические характеристики.

Целью данной работы является исследование стеклообразования и свойств стекол в системах $MeB_2O_4-Al_2O_3-(SiO_2)-MeO/MeF_2$ (Me- Mg, Ca, Sr, Ba), выявление возможности их применения как в виде стеклокристаллического материала, и как связующее в составах композиций “стекло + керамика” для получения низкотемпературных сообжигаемых керамических материалов для электроники. Исследованы особенности стеклообразования и закономерности изменения физико-химических свойств стекол и стеклокерамических материалов, полученных направленной кристаллизацией стекол и стеклокерамических композиций, синтезированных спеканием смеси стекла и кристалла. Рассмотрены общие вопросы процессов смачивания, адгезии и взаимодействия расплавов стекол с кристаллическими наполнителями и их влияние на электрические и теплофизические параметры сообжиговых композитов. На основе комплекса исследований свойств и структуры синтезированных стеклокристаллических материалов синтезированы новые композиции, сочетающие высокие механические и диэлектрические характеристики, для низкотемпературной совместно обожжённой керамики (Low Temperature Cofired Ceramic, LTCC).

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