Development of AlN ceramic composites for multilayer ceramic devices

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Abstract

Mechanical and electrical properties of AlN ceramics are dependent of phase composition and sintering temperature. TiO_2 and TiH_2 additives were chosen as the structure and properties modifiers and HfC – as conductive phase. AlN ceramics was considered as dielectric and conductive layers of functionally graded materials. Our investigations showed that AlN-1.5-2% TiO_2 ceramic composites is a prominent dielectric with required properties and in combination with 11–17% HfC it serves as effective ceramic heater.

Broadband dielectric spectroscopy was used for the nondestructive testing of microstructure: dispersion frequency gives information about the effective thickness of a conductive channel; the slope of $\sigma(\omega)$ dependence gives distinction between "lattice" and "carrier" responses corresponding to "intrinsic", which is irreducible, and "extrinsic" processes due to some impurities or injected carriers.

Keywords: aluminum nitride, hot pressing, dielectric response, ceramic substrates, functionally graded materials.

1. Introduction

Microminiaturization of electro technical devices leads to the development of the functionally graded materials (multilayer ceramic devices) - monolithic ceramic bodies with conductive and dielectric layers made by appropriate tapes and sintered together in one step [1]. They can serve as Multi-Chip Modules (MCM-C) (especially HTCC) or composite heating systems (Gradient, Ukraine [2], Fig. 1, KYOCERA Corporation, Japan [3],). Al_2O_3 [4 - 7] and Si_3N_4 [8, 9] are the most commonly produced materials for high temperature dielectric matrix, as well as AlN [10, 11, 12, 13], which has higher thermal conductivity (320 W/m·K vs. 40 W/m·K for Al_2O_3 and 125 W/m·K for β - Si_3N_4).

To improve mechanical and electrical properties of AlN dielectric substrates large cations doping may be applied [14] (Fig. 2). For example, titanium cations may be added in the form of TiO_2 , TiH_2 , etc. Titanium oxide increases relative density, reduces dielectric permittivity and losses [15]. Under dissociation of TiO_2 O^{2-} ions lead to the grain elongation and formation of plate-like morphology (i.e. the formation of polytypes in AlN). Thus they increase toughness of the material [16]. Titanium hydride also reveals a beneficial effect on mechanical and thermal properties of AlN: as TiH_2 dissociates at 600–800°C [17], H^+ cations toughen the structure due to its refinement and formation of solid solution of hydrogen in aluminium nitride [18]. Ti^{2+} ions may increase thermal conductivity of composites [19]. But the effect of such toughening additives on electrical properties of aluminium nitride ceramics was not observed or observed only fragmentary.

Fig. 1. Microstructure of functionally graded material which consists of dielectric (Si_3N_4 -based) (dark) and conductive (Si_3N_4 -13.5 vol.% ZrC) (light) layers obtained by one step hot-pressing [1]

1. ábra Egylépcsős melegsajtóval előállított dielektromos (Si_3N_4 -bázisú, az ábrán sötétebb tónusú) és vezetőréteget tartalmazó (Si_3N_4 -13,5 vol% ZrC, az ábrán világosabb tónusú) funkcionális gradiens anyag mikro szerkezete

For active resistive layer formation different refractory compounds are chosen: TiN [20], MoSi_2 [21], TaN [22], Mo [23], Ni [5]. HfC [24] is a promising additive for high temperature operation. If dielectric matrix of the material is an active element it can produce thermal energy up to 10–30% more. Properties of resistive layer under the influence of various technological factors can vary both in a positive and

in a negative way. Commercially viable thermoelectric heaters should possess a set of optimal parameters of resistive layer, such as: the sign and value of the resistance temperature coefficient, resistance reproducibility, maximal surface temperature at minimal surface density of the heat load.

Fig. 2. Effect of dopants on the complex impedance and dielectric properties of aluminium nitride according to [14]

2. ábra A dőpóló anyag hatása az alumínium-nitrid komplex impedanciájára és dielektromos tulajdonságaira [14] szerint

The aim of present work is the complex investigation of electrical properties of AlN ceramics with addition of modifying (TiO₂, TiH₂) and conductive phases (HfC) for the application as substrate material for MCM and functionally graded materials for ceramic heaters.

2. Materials and methods

Technically pure AlN powder (95 vol.%) was used for preparation of the pure AlN ceramics (samples AlN) and AlN composites (AlN with various additives: 0.5-4 vol.% TiO₂ (samples 0.5/2/3/4TO), 0.5-3 vol.% TiH₂ (0.5/1/1.5/2/3TH)) (sources: AlN, HfC – Chemical reagents factory *Donetsk-Reagent*, Ukraine; TiO₂, TiH₂ – *Nikolaev* alumina refinery, Ukraine). The powder was ground to 1 μm particle size in a planetary mill for 3 h.

The samples were prepressed in the form of pellets with diameter of 18 mm and thickness of 1 mm. Hot pressing was done by applying pressure of 30 MPa, for 20 min at temperatures between 1700°C and 1900°C increased with 50°C steps.

Active resistive composites were obtained from AlN-2 vol.% TiO₂ dielectric matrix with the addition of 11-17 vol.% HfC (samples 2TO-11/13/15/17HC). Samples were hot pressed at 1970 °C for 25 min under 18 MPa. Resulting dimensions of the samples were 50×8×6 mm.

Relative density was determined as the ratio of bulk and theoretical density. The first one was obtained by Archimedes method, the second was estimated using mixtures rule.

Electrical resistance of the insulator was measured by teraohmmeter. For conductive samples voltmeter-ammeter method was used. Electric properties of dielectric samples were measured at indirect heating from 20°C up to 350°C with the rate of 4±1°C placing the measurement cell into a furnace. Heating of conductive samples was made at direct conditions.

For a.c. measurements of dielectric samples the bridge method was used in low-frequency range (10² – 10⁵ Hz). Capacitance and loss tangent values were obtained by direct observation. Real and imaginary parts of dielectric permittivity as well as real part of a.c. conductivity were calculated. In radio-frequency region (10⁴ – 10⁷ Hz) the resonance method was used.

Concentration dependence of electrical conductivity was approximated using effective medium equation (McLachlan's equation) [25]:

$$\theta_i \frac{\sigma_i^{1/s} - \sigma_m^{1/s}}{\sigma_i^{1/s} + (\frac{1}{\theta_{crit}} - 1)\sigma_m^{1/s}} + \theta_c \frac{\sigma_c^{1/t} - \sigma_m^{1/t}}{\sigma_c^{1/t} + (\frac{1}{\theta_{crit}} - 1)\sigma_m^{1/t}} = 0, \quad (1)$$

where σ_p , θ_p , σ_c , θ_c - conductivity and volume content of insulator and conductive phases respectively; θ_{crit} - critical volume content of conductive phase at which charge carriers can freely move from contact to contact (percolation threshold); t , s - parameters which characterize morphology of inclusion particles, the "shape" factor [26]. A set of s and t values was given in [25].

3. Results and discussion

3.1 Dielectric composites

The highest density was achieved in AlN samples at 1800°C (99.9%). Addition of titanium oxide increased the temperature of maximal densification on 50°C.

Fig. 3. Effect of sintering temperature and TiO₂ addition on relative density (a) and conductivity (20°C) (b) of AlN ceramics [27]

3. ábra A szinterelő hőmérséklet és a TiO₂ adagolás hatása az AlN kerámiák látszólagos sűrűségére (a) és vezetőképességére (20°C) [27]

Fig. 3 shows that the presence of TiO₂ lowers the density of AlN-TiO₂ composites at sintering temperatures below 1800°C. At the same time, at sintering temperatures of 1850-1900°C relative density of AlN-0.5-2 vol.% TiO₂ composites was equal to that of pure AlN (99.9 %) and decreased with increasing the additive percentage in composites with more than 3 vol.% of TiO₂ (< 99.7 %) (Fig. 3.a).

It can be assumed that maximum density of the low doped samples is explained by the formation of fusible eutectic $\alpha\text{-Al}_2\text{O}_3\cdot\text{TiO}_2 + \text{Al}_2\text{O}_3$ with a melting point of 1840±10 °C which is confirmed by the results of Kume [15]. The presence of aluminium oxide is attributed to the interaction between aluminium nitride and water under milling.

Minimal d.c. conductivity for AlN samples without additives was observed at $T_{sint} = 1900^\circ\text{C}$ (Fig. 3.b). TiO_2 addition lowers the temperature of minimal conductivity on 50°C despite of the additive percentage. Increase of TiO_2 amount from 0.5 to 4 vol.% increased conductivity of the composites from $7 \cdot 10^{-13}$ up to $1 \cdot 10^{-10} \text{ } 1/\Omega \cdot \text{m}$ due to TiN formation in AlN ceramics as a result of the reaction between TiO_2 and AlN at temperatures $>1600^\circ\text{C}$.

It can be noticed that despite of Kume's results [12] (Fig. 4), addition of TiO_2 in amount of >1.5 vol.% increases dielectric loss tangent. Thus, it can be assumed that at first addition of titanium oxide improves $\tan \delta$ due to the low loss tangent of TiO_2 ($< 10^{-3}$) but then after in-situ formation of TiN complexes an opposite effect can be observed.

Dielectric permittivity of AlN composites with TiO_2 and TiH_2 addition decreases with the temperature (up to optimal sintering temperature) and increases at increasing of amount of the additive (Fig. 5).

Fig. 4. Effect of TiO_2 addition on loss tangent and relative density of AlN ceramics [27]
4. ábra A TiO_2 adagolás hatása az AlN kerámiák tangens veszteségére és relatív sűrűségére [27]

Fig. 5 indicates that ϵ' and $\tan \delta$ decreased over all frequency range. A threshold decline of permittivity and maximum of loss tangent at 10^5 - 10^6 Hz were observed. Frequency dispersion of ϵ' and $\tan \delta$ respond to space-charge polarization (at low frequencies) and hopping polarization (at radio frequencies).

The first one usually “turns off” at lower frequencies (10^{-3} - 10^3 Hz at 300 K). But in the case of the present studies this disabling was observed at higher frequency ($f_d = 2.5 \cdot 10^5$ Hz).

Ceramics and polycrystalline materials are usually multiphase systems. The difference of the concentration of the charge carriers of these phases causes polarization at the boundaries which is usually considered as Maxwell-Wagner's (M-W). The model of it can be described by a conductive layer with constant value of electric conductivity σ . In this case the system is characterized by uniform electric field so all the charges are located only on the interfaces and space charge is neglected. According to Trukhan [28] who described such system to be uniform (heterogeneous) dielectric without leakage currents (but with losses), both flat conductive layers and conductive spherical particles surrounded by dielectric medium, ϵ' ($\epsilon' = \epsilon$) decreases monotonically with frequency and ϵ'' has its maximum at the dispersion region. Dispersion frequency can increase with increasing the dielectric contribution (geometrical enlargement or decrease of permittivity). It asymptotically approaches to Maxwell-Wagner's dispersion frequency when concentration of charge carriers rises. As the variation of conductor parameters in heterogeneous systems almost always exists, dispersion is less sharp than it follows from the theory of Maxwell-Wagner.

If the heterogeneous system is assumed as flat conductive layers (with a width of d) surrounded by a dielectric medium with low charge concentration, then the effective thickness of conducting channel d can be estimated on the basis of the equation for frequency dispersion [34]:

$$\omega_d = 2\pi f_d = \frac{12D}{d^2} \quad (2)$$

where D is the diffusion coefficient for the electron in the medium considered, which can be calculated from Einstein's equation:

$$De = \mu kT \quad (3)$$

Fig. 5. Frequency dependences of dielectric permittivity and loss tangent of pure AlN, AlN- TiO_2 (a) [27] and AlN- TiH_2 (b) ceramics obtained with different additives and sintering temperatures
5. ábra Az adalékok hatása AlN kerámiák dielektromos állapotjának és tangens veszteségének frekvencia-függőségére: (a) AlN és AlN- TiO_2 [27]; (b) AlN- TiH_2

If charge mobility μ in AlN is assumed to be equal to $14 \text{ cm}^2/\text{V}\cdot\text{sec}$ (at 290 K), it gives the value of $D = 0.35 \text{ cm}^2/\text{sec}$.

Thus from (2) the value of $d = 16 \text{ }\mu\text{m}$ can be obtained. All the samples regardless of the amount and type of the additives had the same frequency of dispersion and subsequently an effective thickness of conductive channel. In the authors opinion, it is a typical situation for the materials below the percolation threshold.

The mechanism of charge transfer in amorphous materials is primarily hopping. Subsequently a.c. conductivity is the sum of leakage and bias conductivity: $\sigma(\omega) = \sigma_0 + \omega\epsilon\epsilon_0 t g\delta$, where σ_0 – d.c. conductivity, ω – angular frequency, ϵ – relative permittivity of the material, ϵ_0 – the electric constant, $\epsilon_0 = 8.85 \cdot 10^{-12} \text{ F/m}$, $t g\delta$ – loss tangent. This equation can be expressed as $\sigma(\omega)\omega^n$. In all the previous works [29, 30] where a number of n values was given it was believed that $n \leq 1$.

Although in contrast to electrons, ions move much smaller, nearest-neighbor distances, neither the magnitude of a.c. conductivity, its activation energy nor its frequency dependence can be taken as guides to the nature of the dominant carrier responsible for polarization [29]. However, it is known that aluminum nitride has a wurtzite structure and the covalence bond degree $\approx 60\%$.

So the frequency dependence of a.c. conductivity can be considered within Jonscher's universal power law. The slope of it in logarithm coordinates results an exponent which values can be found in the range $0.5 < n < 0.9$ are closely associated with hopping electrons, $n \approx 1$ are to be associated with the "lattice" response. The distinction between "lattice" and "carrier" responses corresponding to "intrinsic", that is irreducible, and "extrinsic" processes due to some impurities or injected carriers, may prove to be useful tools in the assessment of dielectric materials [29].

Four plots with different slopes can be distinguished on the frequency dependence of active part of admittance: at low- (10^3 – 10^5 Hz , 10^5 Hz) and radio-frequencies (10^6 Hz , $3 \cdot 10^6$ – 10^7 Hz). The second and the third plots have the same slope regardless of the type or amount of the additive and sintering temperature: ≈ 1.1 (for the second) and 0.8 (with TiO_2) – 0.9 (other additives) (for the third one) which reveal dielectric response of AlN grain.

Fig. 6. Temperature dependence of dielectric loss factor of AlN-TiO₂ ceramics obtained at different sintering temperatures

6. ábra Az eltérő hőmérsékleten szinterelt AlN-TiO₂ kerámiák dielektromos vesztesége a hőmérséklet függvényében

In radio-frequency range the value of n of AlN-TiO₂ composites increases from 0.5 to 0.8-0.9 at increase of TiO₂ concentration regardless of sintering temperature. In AlN-TiH₂ composites increase of TiH₂ amount increases n from 0.5 to 0.9-1. At higher sintering temperatures (1850 – $1950 \text{ }^\circ\text{C}$) $n = 0.4$ – 0.5 irrespective of titanium hydrate concentration.

The present studies have demonstrated that n could be higher than unity in contrast to the most common opinion that it is always less than 1. Thus obtained results require further more deeply theoretical understanding.

Dielectric loss factor did not change with the temperature below 150°C and increased with it above (Fig. 6) which indicates conduction losses. Deviation from optimal sintering temperature increases ϵ'' that is associated with the formation of structure defects.

3.2 Active resistive composites

All AlN-TiO₂-HfC composites had high density, 97.5–99.5%.

As it can be seen from the percolation curve (Fig. 7), resistivity of the composites decreases with increasing concentration of conductive additive HfC. At the lowest HfC content (11%) the resistivity is equal to $0.15 \text{ }\Omega\cdot\text{cm}$. Such low value shows that all the studied concentrations are beyond the percolation threshold.

Metallographic analysis of composites showed (Fig. 7) that conductive clusters are formed in a shape of longitudinally elongated structure under the influence of magnetic field.

Modeling of percolation curve gives the values of percolation threshold $\theta_{crit} = 9.9\%$ and coefficient $t = 1.35$. Besides, SIAMS analysis showed that the ratio of conductive phase was $\approx 7.9\%$ (for 2TO-11HC samples).

According to [25] t characterizes the shape of inclusion particles and it is associated with "demagnetization or depolarization" coefficients L_c and L_i of conductive and insulator phase via equation:

$$t = \frac{1}{1 - L_c - L_i} \quad (4)$$

Assuming $L_c = L_i$ one can obtain $L_c = 0.13$ which according to [25] indicate the formation of disk-shaped particles. Comparing these results with Fig. 7 authors believe that 3D morphology of conductive particles is elongated in the third direction. The fact that actual ratio of conductive phase is lower than expected confirms authors' assumption.

Fig. 7. Concentration dependence of resistivity of AlN-TiO₂-HfC composites and microstructure of 2TO-11HC samples

7. ábra AlN-TiO₂-HfC kompozitok elektromos ellenállásának koncentráció-függősége és a 2TO-11HC minták mikro-szerkezete

Temperature dependence of electric resistivity is linear (Fig. 8). Steady positive temperature coefficient of resistance (Fig. 8) for all the studied concentrations of HfC in a wide temperature range makes AlN-HfC ceramic heaters the contenders to the

analogues used today [3]. Besides, ceramic gradient materials provide higher thermal shock and crack resistance because of similarity of thermal expansion coefficient of the components ($5.6 \cdot 10^{-6}$ and $4.6 \cdot 10^{-6} \text{ K}^{-1}$ for HfC and AlN respectively).

Fig. 8. Temperature dependence of electric resistivity and temperature coefficient of resistance of AlN-TiO₂-HfC composites

8. ábra AlN-TiO₂-HfC kompozitok elektromos ellenállásának hőmérséklet-függősége és az ellenállás hőmérséklet együtthatója

Dependence of the surface temperature on the applied power density (Fig. 9) showed that all the composites beyond percolation threshold have the same characteristics despite of the conductive phase content.

Fig. 9. Dependence of the temperature (the difference between surface temperature and the temperature of environment) on the applied power density of AlN-TiO₂-HfC composites

9. ábra AlN-TiO₂-HfC kompozitok relatív hőmérséklet-függősége (a környezeti és a felületi hőmérséklet különbsége) az alkalmazott energiasűrűség függvényében

4. Conclusions

AlN-1.5-2%TiO₂ ceramics showed good electrical properties (low porosity (0.1%), dielectric permeability (9.7) and dielectric loss tangent ($1.3 \cdot 10^{-3}$)) and can serve as ceramic dielectric substrates and dielectric matrix for functionally graded materials. Addition of 11-17% HfC allows obtaining heating elements with required characteristics.

It was shown that addition of small amount of TiO₂ (up to 1.5-2%) increases density and reduces dielectric loss of the composites. But further increase of the additive content has the opposite effect. Deviation from the optimal sintering temperature leads to the formation of structure defects and increases dielectric loss.

Broadband dielectric spectroscopy was used for the nondestructive testing of microstructure: dispersion frequency gives information about the effective thickness of a conductive channel; the slope of $\sigma(\omega)$ dependence gives distinction between "lattice" and "carrier" responses corresponding to "intrinsic", which is irreducible, and "extrinsic" processes due to some impurities or injected carriers.

References

- [1] Brodnikovska, I. V. – Soltis, M. V. – Kirilenko, K. V. – Zvorskii, I. V. – Petrovskii, V. Ya.: Effect of the particle size of conductive inclusions on the structurization and resistivity of Si₃N₄-ZrC ceramics, *Powder Metall. Met. Ceram.*, Vol. 51 (2012) 307-315.
<http://dx.doi.org/10.1007/s11106-012-9433-2>
- [2] Petrovsky, V.: Electrical response on microstructure evolution of multicomponent ceramic matrix materials, *J. Mater. Sci. Eng.*, Vol. 4, № 2 (2010) 39-51.
- [3] <http://americas.kyocera.com/kicc/pdf/Kyocera%20Ceramic%20Heaters.pdf>
- [4] Isobe, T. – Daimon, K. – Sato, T. – Matsubara, T. – Hikichi, Y. – Ota, T.: Spark plasma sintering technique for reaction sintering of Al₂O₃/Ni nanocomposite and its mechanical properties, *Ceram. Int.*, 34 (2008) 213-217.
<http://dx.doi.org/10.1016/j.ceramint.2006.08.017>
- [5] Mclachlan, D. S. – Cai, Kefeng – Sauti, G.: AC and dc conductivity-based microstructural characterization, *Int. J. Refract. Met. H.*, 19 (2001) 437-445.
[http://dx.doi.org/10.1016/S0263-4368\(01\)00024-5](http://dx.doi.org/10.1016/S0263-4368(01)00024-5)
- [6] Yang, H. – Shang, F. – Gao, L.: Microstructure and mechanical properties of gas pressure sintered Al₂O₃/TiCN composite, *Ceram. Int.*, 33 (2007) 1521-1524.
<http://dx.doi.org/10.1016/j.ceramint.2006.07.001>
- [7] Chinellatto, A. S. A. – Contardi, O. A. – Pallone, E. M. S. A. – Tomasi, R.: Production of Alumina Matrix Nanocomposites with Inclusions of TiC and TiB₂ via Reactive Milling, *Key Eng. Mater.*, Vols. 189-191 (2001) 208-215.
<http://dx.doi.org/10.4028/www.scientific.net/KEM.189-191.208>
- [8] Yokoyama, H. – Obata, S. – Kato, N. – Hotta, T. – Abe, H. – Naito, M. – Hirano, S.: Preparation of Three Dimensionally Electroconductive Pattern of Si₃N₄-TiN system by Ink Jet Printing, *J. Ceram. Soc. Jpn.*, Suppl. 112-1, PacRim 5 Special Issue, 112 [5] (2004) 144-S148.
https://www.jstage.jst.go.jp/article/jcersjsuppl/112/0/112_0_S144/_pdf
- [9] Zivkovic, L. – Nikolic, Z. – Boskovic, S. – Miljkovic, M.: Microstructural characterization and computer simulation of conductivity in Si₃N₄-TiN composites, *J. Alloys Compd.*, 373 (2004) 231-236.
<http://dx.doi.org/10.1016/j.jallcom.2003.10.036>
- [10] Krnel, K. – Sciti, D. – Landi, E. – Bellosi, A.: Surface modification and oxidation kinetics of hot-pressed AlN-SiC-MoSi₂ electroconductive ceramic composite, *Appl. Surf. Sci.*, 210 (2003) 274-285.
[http://dx.doi.org/10.1016/S0169-4332\(03\)00155-7](http://dx.doi.org/10.1016/S0169-4332(03)00155-7)
- [11] Kai, A. – Hirata, H. – Miki, T.: Effects of TiH₂ Coating and Insertion of Ti and Cu Foils, *J. Ceram. Soc. Jpn.*, Suppl. 112-1, PacRim5 Special Issue, 112 [5] (2004) 117-118.
https://www.jstage.jst.go.jp/article/jcersjsuppl/112/0/112_0_S117/_pdf
- [12] Kume, S. – Yasuoka, M. – Omura, N. – Watari, K.: Effect of Additives on Dielectric Loss of AlN Ceramics, *Key Eng. Mater.*, Vols. 317-318 (2006) 845-848.
<http://dx.doi.org/10.4028/www.scientific.net/KEM.317-318.845>
- [13] Kume, S. – Yasuoka, M. – Watari, K.: Effect of Lanthanum Oxide Addition on Dielectric Loss and Microstructure of AlN Ceramics, *Key Eng. Mater.*, Vol. 320 (2006) 197-200.
<http://dx.doi.org/10.4028/www.scientific.net/KEM.320.197>
- [14] Jang, S. A. – Choi, G. M.: Effect of Dopants on the Complex Impedance and Dielectric Properties of Aluminium Nitride, *J. Am. Ceram. Soc.*, 75 [11] (1992) 3145-3148.
<http://dx.doi.org/10.1111/j.1151-2916.1992.tb04402.x>
- [15] Kume, S. – Yasuoka, M. – Omura, N. – Watari, K.: Effect of Additives on Dielectric Loss of AlN Ceramics, *Key Eng. Mater.*, 317-318 (2006) 845-848.
<http://dx.doi.org/10.4028/www.scientific.net/KEM.317-318.845>
- [16] Fesenko, I. P. – Kuzenkova, M. O. – Oleynik, G. S.: Reinforced n-AlN-ceramics, *Functional Gradient Materials and Surface Layers Prepared by Fine Particles Technology, Science Series II. Mathematics, Physics and Chemistry*, Kluwer Academic Publishers, Dordrecht/Boston/London, 16 (2001) 257-264.
- [17] Freedman, M. R. – Kiser, J. D. – Herbell, T. P.: Factors influencing the ball milling of Si₃N₄ in water, *Ceram. Eng. Sci. Proc.*, 6 [7/8] (1985) 1124-1134.
- [18] Tkachenko, Y. G. – Morozova, R. A. – Yurchenko, D. Z. – Shevchenko, O. A. – Morozov, I. A. – Satanin, S. V.: Effects of chemicothermal treatment of aluminum nitride powders on the structure and properties of the resulting

- hot-pressed ceramics, *Powder Metall. Met. Ceram.*, 34 (1995) 69-73.
<http://dx.doi.org/10.1007/BF00559854>
- [19] Brodnikovska, I. V. – Vorona, Yu. V. – Petrovskiy, V. Ya.: Receiving of high-temperature dielectrics and heat-spreading substrates on the basis of silicon nitride, *Ceramics: science and life*, 3 (17) (2012) 14-29 (in Russian).
- [20] Monteverde, F. – Medri, V. – Bellosi, A.: Microstructure of hot-pressed Ti(C,N)-based cermets, *J. Eur. Ceram. Soc.*, 22 (2002) 2587-2593.
[http://dx.doi.org/10.1016/S0955-2219\(02\)00120-6](http://dx.doi.org/10.1016/S0955-2219(02)00120-6)
- [21] Köbel, S. – Plüschke, J. – Vogt, U. – Graule, T. J.: MoSi₂-Al₂O₃ electroconductive ceramic composites, *Ceram. Int.*, 30 (2004) 2105-2110.
<http://dx.doi.org/10.1016/j.ceramint.2003.11.015>
- [22] Petrovsky, V. Ya. – Rak, Z. S.: Densification, microstructure and properties of electroconductive Si₃N₄-TaN composites. Part II: Electrical and mechanical properties, *J. Eur. Ceram. Soc.*, Vol. 21, Is. 2 (2001) 237-244.
[http://dx.doi.org/10.1016/S0955-2219\(00\)00198-9](http://dx.doi.org/10.1016/S0955-2219(00)00198-9)
- [23] Yang, J. Z. – Huang, Z. H. – Fang, M. H. – Liu, Y. G. – Huang, J. T. – Hu, J. H.: Preparation and mechanical properties of Fe/Mo-Sialon ceramic composites, *Scripta Mater.*, Vol. 61, Is. 6, (2009) 632-635.
<http://dx.doi.org/10.1016/j.scriptamat.2009.05.042>
- [24] Savino, R. – De Stefano Fumo, M. – Silvestroni, L. – Sciti, D.: Arc-jet testing on HfB₂ and HfC-based ultra-high temperature ceramic materials, *J. Eur. Ceram. Soc.*, 28 (2008) 1899-1907.
<http://dx.doi.org/10.1016/j.jeurceramsoc.2007.11.021>
- [25] McLachlan, D. S. – Blaszkiewicz, M. – Newnham, R. E.: Electrical resistivity of composites, *J. Am. Ceram. Soc.*, Vol. 73, Is. 8 (1990) 2187-2203.
<http://dx.doi.org/10.1111/j.1151-2916.1990.tb07576.x>
- [26] Runyan, J. – Gerhardt, R. A.: Electrical properties of boron nitride matrix composites: I. Analysis of McLachlan equation and modeling of the conductivity of boron nitride-boron carbide and boron nitride-silicon carbide composites, *J. Am. Ceram. Soc.*, Vol. 84, Is. 7 (2001) 1490-1496.
<http://dx.doi.org/10.1111/j.1151-2916.2001.tb00866.x>
- [28] Trukhan, E. M.: Dispersion of dielectric permittivity of heterogeneous systems, *Solid State Physics*, 4 [12] (1962) 3496-3511 (in Russian).
- [29] Joscher, A. K.: The "universal" dielectric response, *Nature*, 267 (1977) 673-679.
<http://dx.doi.org/10.1038/267673a0>
- [30] Brodnikovska, I. V. – Petrovskiy, V. Ya.: Non-destructive monitoring of Si₃N₄ ceramic composites: I. Investigation of phase composition in Si₃N₄-Al₂O₃-TiH₂, Si₃N₄-Al₂O₃-TiO₂, Si₃N₄-Al₂O₃-ZrH₂ composites, obtained with different sintering temperature, *Ceramics: science and life*, 1 (15) / 2 (16) (2012) 39-53 (in Ukrainian).

Ref.:

Brodnikovska, Iryna V. – Deriy, Andriy I. – Petrovsky, Vitaly Ya.:
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<http://dx.doi.org/10.14382/epitoanyag-jsbcm.2014.12>

AIN kerámia kompozit fejlesztése rétegelt kerámia alkatrészekhez

Az AlN kerámia alkatrészek mechanikai és villamos tulajdonságai jelentős mértékben függ a fázis-összetételtől és a szinterelési hőmérséklettől. A HfC mint vezető réteg mellé a szerzők az anyagszerkezet és a mechanikai tulajdonságok módosításához a TiO₂ és TiH₂ adalékanyagokat használták. Magát az AlN kerámiát, mint a dielektromos és vezető rétegek szétválasztására szolgáló funkcionális anyagot alkalmazták. Az elvégzett vizsgálatok azt mutatták, hogy az (1,5-2)% TiO₂ tartalmú AlN kerámia kompozit kiemelkedő dielektromos tulajdonságokkal rendelkezik, és mintegy (11-17)% HfC hozzáadásával kiváló, hatékony kerámia fűtőelem gyártható belőle. A szerzők a mikroszerkezet roncsolásmentes vizsgálatához szélessávú dielektromos spektroszkópot használtak. A diszperziós frekvencia információt adott a vezetőképes csatornák tényleges vastagságáról; a σ(ω) függvény meredeksége alapján megkülönböztethetők a „rács” és a „szállító” alkotók, ami az adott anyagra jellemző „belső” megváltozhatatlan tulajdonság.

Kulcsszavak: alumínium-nitrid kerámia, szinterelés, dielektromos tulajdonság, funkcionális anyagok

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