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PREDGOVOR

Ubrzani napredak nauke, tehnologije i industrije dovodi do poboljšanja kvaliteta ljudskog života, ali i do stvaranja novih rizičnih situacija. Čovečanstvo je suočeno sa rizicima kakvih u ranijoj ljudskoj istoriji nije bilo. Globalno zagrevanje je tipičan primer. Jedan od glavnih problema vezanih za nove rizične situacije jeste – pitanje odgovornosti. Vlade država u svetu ne smeju teret odgovornosti prepustiti isključivo naučnicima i ekspertima, ali takođe ne smeju same odlučivati i preuzimati (ne)odgovornost. Trebalo bi da se konsultuju sa ekspertima i da dobro procene kada i kakve mere treba preduzimati. Potrebna je jaka politička inicijativa da bi se počeli rešavati ozbiljni ekološki problemi kao što je globalno zagrevanje, ali i lokalno zagađenje životne sredine. Politički dogovori na svetskom nivou koji su do sada postignuti u okviru Kjoto protokola, nedovoljni su za zaustavljanje ovog fenomena. Čiste tehnologije - tehnologije koje su dizajnirane da obezbeđuju superiorne performanse za nižu cenu dok istovremeno kreiraju manji gubitak energije od konvencionalnih ponuda - imaju velike šanse da budu motorna snaga koja će obezbediti ekonomski rast.

Nauka, naravno, pre svih uočava probleme opstanka planete i života na njoj. Ona takođe pokušava da ih reši i uspeva onoliko koliko je to realno moguće, imajući u vidu političke, socijalne, ekonomske i tehnološke faktore. Može se konstatovati da su praktično svi prioriteti posvećeni očuvanju života na Zemlji. Nauka i razvoj tehnike i tehnologije mogu tome doprineti u više segmenata:

– *obnovljivi izvori energije;*
– *energetska efikasnost;*
– *smanjenje količine otpada;*
– *smanjenje štetnosti otpada;*
– *reciklaža;*
– *prečišćavanje zemlje, vode i vazduha;*
– *neutralizacija preostalog otpada.*

Bitan faktor za donošenje političkih odluka je i javno mnjenje. Zato je jako važno podizanje opšte svesti i što šira edukacija stanovništva o nephodnosti prelaska na obnovljive, ekološki prihvatljive izvore energije, što je jedan od dugoročnih ciljeva ove Konferencije.

Ovaj međunarodni skup po deveti put organizuje Društvo za obnovljive izvore električne energije (DOIEE) Saveza mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS), uz suorganizaciju Instituta za arhitekturu i urbanizam Srbije (IAUS).

U Beogradu, oktobra 2021.

ELEKTRIČNA SVOJSTVA IZOTERMSKI SINTEROVANE KERAMIKE NA BAZI KORDIERITA KAO FUNKCIJA VREMENA SINTEROVANJA I AKTIVACIJE

ELECTRICAL PROPERTIES OF ISOTHERMALLY SINTERED CORDIERITE-BASED CERAMICS AS FUNCTION OF SINTERING AND ACTIVATION TIME

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Mehaniča aktivacija je uobičajeno korišćen i relativno brz i jeftin postupak za pripremu uzoraka pre procesa sinterovanja. Kordijerit je stehiometrijska smeša tri različita oksida ($2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$). To je veoma atraktivan, široko korišćen visokotemperaturni keramički materijal. Mehanička aktivacija početnih smeša sa 5.00 mas. % TiO_2 izvedena je u visokoenergetskom mlinu sa kuglama tokom 10-80 min. Primenjeni pritisak presovanja pre procesa sinterovanja bio je 2 t/cm2, na osnovu nedavnog istraživanja. Proces sinterovanja je izvršen na 1350 °C tokom 2h i 4h u vazdušnoj atmosferi. Rendgenska difrakcija je korišćena za analizu faznog sastava neaktiviranih uzoraka, uzoraka aktiviranih 80 minuta i sinterovanih 2 i 4 sata, respektivno. Ovaj rad istražuje uticaj produženog vremena sinterovanja na električna svojstva proizvoda.

Ključne reči: *mehanička aktivacija; XRD; električna svojstva; kordijerit*

Mechanical activation is a commonly used and relatively fast and inexpensive procedure for sample preparation before the sintering process. Cordierite is a stoichiometric mixture of three different oxides ($2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$). It is a very attractive, widely used high-temperature ceramic material. The mechanical activation of the starting mixtures with 5.00 mass % TiO_2 was performed in a high energy ball mill during 10-80 min. The applied compaction pressure before the sintering process was 2 t/cm^2, based on our recent investigation. The sintering process was performed at 1350 °C for 2h and 4h in air atmosphere. X-ray diffraction was used to analyze the phase composition of non- activated and 80 min activated samples, sintered for 2 and 4h, respectively. This paper investigates the influence of prolonged sintering time on the product electrical properties.

Keywords*: mechanical activation; XRD; electrical properties; cordierite*

1 Introduction

Mechanical activation is widely used and relatively inexpensive procedure for sintering process sample preparation. Cordierite, $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$, is a very actual high-temperature ceramic material, due to its characteristics, and the experiments showed very good answer on mechanical activation. This material is widely used in various fields, from substrates for micro-electronic packaging industry to cookware, heat exchangers, and glazes for floor tiles. Low temperature thermal expansion coefficient ($20 \cdot 10^{-7}$/ °C) and low relative dielectric constant (~5), these ceramics makes well known material due to their good thermo-mechanical, chemical and dielectric properties [1,2]. They can be applicable as materials that are exposed to sudden temperature changes [3 -7] and also as a semiconducting bearers [8,9]. The temperature range of cordierite sintering is very narrow (1300-1400 °C).

The experiments showed a significant influence of mechanical activation, as well as compaction pressure on starting mixtures (kaolin, quartz, magnesium oxide) on lowering of sintering temperature [10]. Mechanically activated components increased energy due to induced crystal defects compared

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to non-activated ones. During mechanochemical treatment, several processes occur: attrition of starting material, crystal lattice destruction, various defects formation, etc. All mentioned processes increase the chance that during heating, processes could be observed at lower temperatures than usual [11-18]. Mechanical activation have great influence on final product, and it is important to investigate the possible effect on the final electrical characteristics, so it is very important to approach and understand changes that get introduced into the system during mechanical activation.

In this paper, the authors used starting conditions and study the influence of sintering time on phase composition and electrical properties of sintered samples.

2 Experimental procedure

Mixtures of $Mg(OH)_2$, Al_2O_3, SiO_2 and TiO_2 (all p.a. purity) were used in these experiments. The cordierite ceramics starting mixture, $MgO+Al_2O_3+SiO_2$ in the 2:2:5 ratio, with the addition of 5.00 mass % TiO_2, were mechanically activated by grinding in a high-energy planetary ball mill. ZrO_2 vessels and balls were used with the powder to balls mass ratio of 1:40. The milling process was performed in air atmosphere for 10, 20, 40 and 80 minutes. The samples were denoted as K-0, K-10, K-20, K-40 and K-80, according to the milling time.

The pressure used in our experiments was 2 t/cm^2 (approximately 200 MPa). The pressure was performed in a double-sided tool 6 mm in diameter (Hydraulic press RING 14, VEB THURINGER). The compacts were sintered isothermally at 1350 °C, in air atmosphere for 2h and 4h, with heating rate of 10 °C/min.

The X-ray powder diffraction patterns after milling and sintering were obtained using Philips PW-1050 diffractometer with λCu-K$_\alpha$ radiation and a step/time scan mode of 0.05 °/1s. The morphology of the obtained powders and sintered samples were characterized by scanning electron microscopy (JEOL JSM-6390 LV). The powders were crushed and covered with gold in order to perform these measurements.

3 Results and Discussion

Mechanically activated samples of cordierite with the addition of 5 mass % TiO_2 were sintered for 2 and 4 hours at 1350 °C. XRD patterns of samples non-activated and activated 80 min sintered at 1350 °C for a) 2h and b) 4h is shown in Figures 1 and 2.

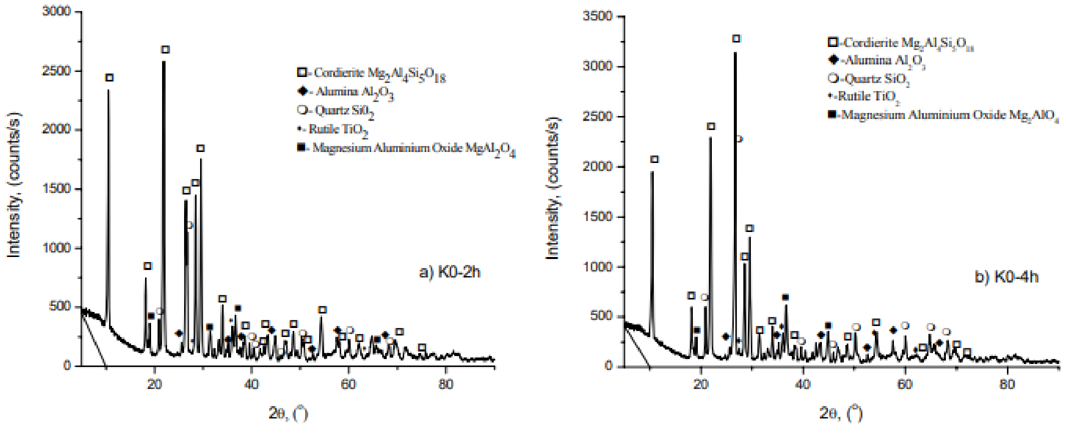

Figure 1. XRD patterns of non-activated samples sintered at 1350 °C for a) 2h and b) 4h

XRD analysis of non-activated samples sintered 2 and 4 hours shows a presence of cordierite formation as well as the remains of the starting oxides. Corund (Al_2O_3), quarts (SiO_2) and $MgAl_2O_4$ and TiO_2 rutile were detected. Comparing the diffraction patterns of non-activated samples, sintered 2 and 4 hours, it can be seen that the sample sintered 4 h have higher amounts of cordierite (66 % compared with 60 % cordierite sintered for 2 hours). The remains of the starting oxides are reduced with the prolonged sintering of the starting material.

Diffraction patterns which are mechanically activated 80 minutes (Figure 2) had significantly greater responses compared to non- activated sintered samples. The sample which was sintered for 2 hours showed practically insignificant traces of the starting oxides corundum (2.4 %) and quartz (0.9 %) and (95.4 %) cordierite phase. The sample sintered for 4 hours has no remaining traces of the starting oxides (except rutile TiO_2 content of 2 % additives whose presence was expected). Cordierite is present in an amount of 98 %, which can be considered a fully completed reaction during the sintering process.

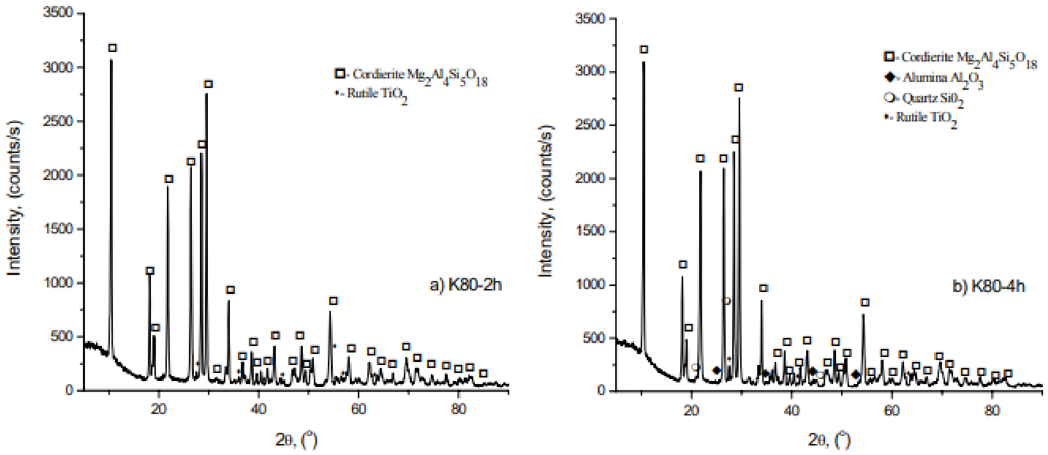

Figure 2. XRD patterns of samples activated 80 min sintered at 1350 °C for a) 2h and b) 4h

Table 1 presents the results of measured capacitance. Electrical properties of the obtained materials were monitored as a function of time of mechanical activation and prolonged sintering time. From these data the value of the dielectric constant was calculated. Electrical measurements were in great accordance with results given previously in the paper regarding XRD patterns. It is obvious that the milling and sintering time have influence on the capacitance and dielectric constant values. Two areas are visible: the first one for samples activated 0 – 20 minutes, and the second for samples activated 20 – 80 min. Both the capacitance and dielectric constant rapidly increase with the first 20 minutes of activation, whereby more significant changes were in the sample sintered for 2 hours. After 20 minutes of mechanical activation changes in capacitance and dielectric constant are smaller. Data value for the dielectric constant of the sintered samples for 2 and 4 hours range from 3.74 to 4.97, as expected.

Table 1. Electrical properties of cordierite after sintering at 1350 °C for a) 2h and b) 4 h as a function of milling time (0 – 80 min)

a)

2h	C	ε_r
0	0.71	3.7418
10	0.88	4.6468
20	0.88	4.6734
40	0.80	4.3363
80	0.83	4.6462

b)

4h	C	ε_r
0	0.77	4.0973
10	0.82	4.3248
20	0.84	4.5167
40	0.92	4.9741
80	0.82	4.5992

4 Conclusions

Investigation results shows that sintering time, as well as mechanical activation, has influence on the final characteristics of the sintered material. The results that justify prolonged sintering time showed that at the same sintering temperature, samples activated 80 minutes have a higher percentage of reacted starting material compared to samples that have not been activated. For samples that were sintered 4 hours and 80 minutes activated starting components were not found. Cordierite ceramics was obtained in an amount of 98%. The remaining 2% is TiO_2 rutile, which was added to the starting mixture as an additive.

Electrical investigation shows the influence of mechanical activation time and sintering time on values of capacitance and dielectric constant. Both capacitance and dielectric constant rapidly increase with first 20 minutes of mechanical activation. Data value for the dielectric constant of the sintered samples 2 and 4 hours range from 3.74 to 4.97, which is in accordance with literature data.

5 Acknowledgement

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6 References

[1] A. I. Kingon, R. F. Davis, *Engineer Materials Handbook*, Vol. 2. ”Ceramics” edited by S. J. Schneider, Jr., ASM International Metals Park, OH, 1991.
[2] N. Obradovic, N. Djordjevic, S. Filipovic, N. Nikolic, D. Kosanovic, M. Mitric, S. Markovic, V. Pavlovic, Influence of Mechanochemical Activation on the Sintering of Cordierite Ceramics in the Presence of Bi_2O_3 as a Functional Additive, *Powder Technology, 218* (2012), pp. 157-161.
[3] V. J. Powers, C.H. Drummond, *Ceramic Engineering and Science Proceedings, 7* (1986), pp. 969.
[4] I. Wadsworth, R. Stevens, The Influence of Whisker Dimensions on the Mechanical Properties of Cordierite/SiC Composites, *Journal of the European Ceramic Society, 9* (1992), pp. 153-163.
[5] M. Pinero, M. Atik, J. Zarzycki, *Journal of Non-Crystalline Solids, 147-148* (1992), pp. 1523.
[6] D. Kervadec, M. Coster, J.L. Chermant, *Materials Research Bulletin, 27* (1992), 8, pp. 967-974.
[7] N. Clausen, G. Petzow, *Journal of Physics, 47* (1986) pp. 693.
[8] R. R. Tumala, Ceramic and Glass Ceramic Packaging in the 1990's, *Journal of the American Ceramic Society, 74* (1991), 5, pp. 895-908.
[9] S. H. Knickerbocker, A. H.Kumar, L. W. Herron, Cordierite glass-ceramics for multilayer *ceramic* packaging, *American Ceramic Society Bulletin, 72* (1993), 1, pp. 90-95.
[10] N. Djordjevic, N. Obradovic, S. Filipovic, J. Zivojinovic, M. Mitric, S. Markovic, Influence of Mechanical Activation on the Constituents of the MgO-Al_2O_3-SiO_2-TiO_2 System, *Tehnika – Novi materijali, 21* (2012), 3, pp. 329-333.
[11] N. Đorđević, M.M. Ristić, Lj. Pavlović, M. Lazić, J. Stojanović, Proceedings *TEOTES, IV konferencija "Teorija i tehnologija sinterovanja"* (2001).
[12] J. S. Reed, *Introduction to the Principles of Ceramic Processing*, Wiley, New York, USA, 1988.
[13] G. L. Messing, C. J. Markhoff, L. G. McCoy, Characterization of *ceramic* powder compaction, *Journal of the American Ceramic Society, 61* (1982), 8, pp. 857.
[14] I. Shapiro, *Adv. Powder Metall. Part. Mater.*, 3 (1994), pp. 41.
[15] J. K. Beddow, *Particulate Science and Technology*, Chemical Publishing Co., Inc. New York, USA, 1980.
[16] R. M. German, *Particle Packing Characteristics*, Metal Powder Industries Federation, Prinston, New Jersey, 1989.
[17] R. Panelli, F. A. Filho, A study of a new phenomenological compacting equation, *Powder Technology, 114* (2001), 1, pp. 255-261.
[18] N. Obradovic, S. Stevanovic, M. Mitric, M. V. Nikolic, M. M. Ristic, *Science of Sintering, 39* (2007), 3, pp. 241-248.