In-situ Formation and Densification of MgAl$_2$O$_4$–Y$_3$Al$_5$O$_{12}$ and MgAl$_2$O$_4$–MgNb$_2$O$_6$ Ceramics via a Single-stage SRS Process

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Abstract:

MgAl$_2$O$_4$ (MA)–Y$_3$Al$_5$O$_{12}$ (YAG) and MA-MgNb$_2$O$_6$ (MN) ceramics with high density were successfully fabricated via a single-stage solid-state reaction sintering (SRS) process at 1580 °C for 4 h. The effect of Y$_2$O$_3$ or Nb$_2$O$_5$ additions from 2.5 wt% to 7.5 wt% on the phase compositions, microstructures, shrinkage ratio, apparent porosity, bulk density and cold compressive strength of MA–YAG and MA–MN ceramics has been investigated. It was found that MgO and Y$_2$O$_3$ reacted with Al$_2$O$_3$ to form MA and YAG during sintering while Nb$_2$O$_5$ reacted with MgO to form MN. YAG and MA grains in the MA–YAG ceramics exist as granular shape, and their average grain size is about 1 μm and 5 μm, respectively. YAG grains distribute on the intergranular space of MA particles. Polygonal MA particles can be observed in the MA–MN ceramics, and MN grains distribute on the intergranular space of MA particles as well as on MA particles. Rod-like MN grains can be formed in the MA–MN ceramics by addition of 7.5 wt% Nb$_2$O$_5$. The diameter shrinkage ratio, volume shrinkage ratio, bulk density and cold compressive strength of MA–YAG and MA–MN ceramics are greatly improved by doping Y$_2$O$_3$ and Nb$_2$O$_5$, respectively.

Keywords: Oxide ceramics; MgAl$_2$O$_4$; Y$_2$O$_3$; Nb$_2$O$_5$; Reaction sintering; Densification; Strength.

1. Introduction

Magnesium aluminate (MgAl$_2$O$_4$, MA) spinel possesses numerous outstanding properties such as attractive transmittance in the range of 0.25–5.0 μm wavelength, good chemical inertness, corrosion and thermal shock resistance, low thermal expansion coefficient (~9×10$^{-6}$ °C$^{-1}$ between 30 and 1400 °C) as well as high flexural strength (180 MPa), hardness (16.1 GPa) and melting point(2135 °C) [1,2]. This type of material has become an attractive candidate material in the manufacturing of transparent ceramics for window and armor applications, porous catalyst supports, humidity sensors, photo catalyst materials, dentistry

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materials, electronic ceramics and refractory materials for the cement and metallurgical industries [3,4].

There are a number of sintering methods published in literatures have been proved to successfully synthesize MA spinel ceramic such as microwave sintering [5], hot pressing sintering [6], high pressure sintering [7], spark plasma sintering [8], microwave assisted with solid-state reaction sintering [9], reaction sintering assisted with high-energy ball milling process [10], and solid-state reaction sintering (SRS) [11].

Among above methods, the SRS process has long been the most popular one for the synthesis of MA spinel due to its simple operation and easy access of raw materials [10-15]. It is of great difficulty to obtain MA ceramic with high density via single-stage SRS process because the formation of spinel usually accompanies a volume expansion of about 8% during the reaction between MgO and Al2O3 [12]. Using a two-stage SRS process is a promising and usual choice for solving this problem. The formation of MA spinel is completed at a lower temperature at the first stage, and then a sintering densification process is conducted at the second stage. However, similar to other preparation processes mentioned above, two-stage SRS process suffers from expensive production cost and complexity.

In order to improve the sintering densification of MA spinel ceramics, a number of oxides and chlorides have been chosen as additives [16-26]. Some additives such as TiO2, Cr2O3, ZrO2, SnO2 and Y2O3 can also improve post-sintering properties such as modulus of rupture, fracture toughness, hardness, strength and thermal shock resistance of MA ceramic. Skarkar et al. [16] reported that TiO2 can improve the sintering densification of MA ceramic at 1550 °C, but has little improvement on the cold modulus of rupture of different compositions MA ceramics sintered at 1550, 1600 and 1650 °C, respectively. Kim et al. [17] found that additions of SiO2 and CaCO3 can enhance the densification of MA ceramic due to the formation of glassy phases in grain boundary region, and TiO2 remarkably improves the densification because of the formation of TiAl2O5 in intra- and inter-gains. Sarkar et al. [18] found that Cr2O3 can promote the densification for alumina rich MA spinel ceramic sintered at 1550 °C, and introducing 1.0 wt% Cr2O3 benefits to restrict the strength degradation after thermal shock for the stoichiometric MA spinel ceramic. Ceylantekin et al. [19] reported that ZrO2 additive can improve the thermo-mechanical properties of MgO-MA ceramics and reduce the strength loss, which leads to longer service life for industrial applications. Ma et al. [20] found that Sm2O3 additive reacted with Al2O3 raw material to form SmAlO4, which greatly improves the shrinkage ratio, bulk density and cold compressive strength of MA ceramic. Tripathi et al. [21] reported that Dy2O3 additive prevents the exaggerated grain growth and benefits the densification of MA spinel ceramic. Tian et al. [22] reported that Nd2O3, La2O3 and CeO2 additives favor the densification of MA ceramic, and the MA ceramic with relative density of 92% can be fabricated when 3 wt% Nd2O3 was added and sintered at 1650 °C for 3 h. Ugur et al. [23] reported that introducing a proper amount of SnO2 improves the microstructures and mechanical properties including strength, modulus of elasticity and fracture toughness of MA-MgO ceramics. Pošarac et al. [24] found that Y2O3 additive favors the densification and thermal shock resistance of MA ceramic. Ganesh et al. [25] found that AlCl3 additive can enhance the spinel formation, and improve the sintering densification of MA ceramic. Mohammadi et al. [26] reported that MgCl2 additive has a great effect on the densification of MA ceramic and particle size of spinel.

However, there are limited reports on the spinel formation and sintering densification of MA ceramics with rare earths additions so far [20-22,24]. In this paper, Y2O3 and Nb2O5 were chosen as additives and respectively added to the mixture powders of calcined MgO and commercial Al2O3 to fabricate stoichiometric MA–Y3Al5O12 (YAG) and MA–MgNb2O6 (MN) ceramics via the single-stage SRS method. The effects of additions of Y2O3 and Nb2O5 in range between 2.5 wt%–7.5 wt% have been investigated by studying the phase compositions, microstructures, shrinkage ratio, bulk density and cold compressive strength of the sintered ceramics.
2. Experimental procedure

2.1. Starting materials

Table I lists the starting materials used for the fabrication of MA–YAG and MA–MN ceramics.

<table>
<thead>
<tr>
<th>Starting materials</th>
<th>Chemical compositions (wt%)</th>
<th>Particle size (μm)</th>
<th>Production places</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MgO</td>
<td>Al₂O₃</td>
<td>Y₂O₃</td>
</tr>
<tr>
<td>Calcined MgO</td>
<td>99</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Commercial Al₂O₃</td>
<td>99</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Chemical reagent Y₂O₃</td>
<td>99.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical reagent Nb₂O₅</td>
<td>99.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2. Preparation of samples

The powders of calcined MgO and commercial Al₂O₃ were weighted according to a MgO:Al₂O₃ mole ratio of 1:1. Y₂O₃ and Nb₂O₅ were chosen as additives to form Y₃Al₅O₁₂ (YAG) and MgNb₂O₆ (MN) via an in-situ reaction between Y₂O₃ and Al₂O₃, Nb₂O₅ and MgO, respectively. The addition amounts of these two additives were both designed as 2.5 wt%, 5.0 wt% and 7.5 wt%. The powders containing above raw materials belonging to two systems (system I including MgO+Al₂O₃+Y₂O₃, system II including MgO+Al₂O₃+Nb₂O₅) were fully milled for 3 h in a planetary ball mill with alcohol as the medium. The milled mixture powders including systems I and II were fully dried at 120 °C, and then pressed at 200 MPa to form MA–YAG (system I) and MA–MN (system II) ceramics samples with dimension of 15 mm in diameter and 12 mm in height. All the formed samples were placed in a high temperature resistance furnace and sintered at 1580 °C for 4 h.

2.3. Characterization of samples

The phase compositions of as-formed MA–YAG and MA–MN ceramics samples were characterized by X-ray diffraction (XRD, CuKα radiation, 30 kV and 30 mA). The microstructures and element distributions of as-prepared MA–YAG and MA–MN samples were examined by scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS).

The diameter shrinkage ratio, volume shrinkage ratio and bulk density of MA–YAG and MA–MN samples were also studied. The diameter shrinkage ratio and volume shrinkage ratio were calculated according to Eqs. (1) and (2), and the bulk density were measured in water under vacuuming condition using Archimedes’ principle, and were calculated by Eq. (3) [27].
\[ \Delta D = \frac{D_0 - D_1}{D_0} \times 100\% \]  

(1)

\[ \Delta V = \frac{D_0^2 H_0 - D_1^2 H_1}{D_0^2 H_0} \times 100\% \]  

(2)

\[ D_b = \frac{m_d}{m_1 - m_3} \]  

(3)

where \( \Delta D \) and \( \Delta V \) represent the diameter shrinkage ratio and volume shrinkage ratio of the sintered samples (%), \( D_b \) represents the bulk density of the sintered samples (g·cm\(^{-3}\)), \( D_0 \) and \( H_0 \) represent the diameter and height of the samples before sintering (mm), \( D_1 \) and \( H_1 \) represent the diameter and height of the samples after sintering (mm), \( m_1 \) represents the mass of a dried sample in air (g), \( m_3 \) represents the mass of the sample with free bubbles on the surface (g), and \( d \) represents the density of water (1.0 g·cm\(^{-3}\)).

The cold compressive strengths of MA–YAG and MA–MN ceramics were measured using a CMT5105 type universal tester at the loading rate of 0.5 mm·min\(^{-1}\). The sample size was \( \phi 15 \text{ mm} \times 12 \text{ mm} \). The cold compressive strength (CS) was calculated by Eq. (4) [20].

\[ CS = \frac{P}{A} \]  

(4)

where CS, P and A represent the cold compressive strength (MPa), maximum load of sample damage (N) and sample compressive area (mm\(^2\)), respectively.

3. Results and discussion

3.1. Phase evolutions

Figs. 1 and 2 show XRD diffraction patterns of as-formed MA–YAG and MA–MN ceramics with various amounts of Y\(_2\)O\(_3\) or Nb\(_2\)O\(_5\) additions sintered at 1580 °C for 4 h. It can be seen that two kinds of new phases, Y\(_3\)Al\(_5\)O\(_{12}\) (Fig. 1) and MgNb\(_2\)O\(_6\) (Fig. 2) form in the MA–YAG and MA–MN samples, respectively, which indicates that there were chemical reactions occurring between Y\(_2\)O\(_3\) and Al\(_2\)O\(_3\) as well as Nb\(_2\)O\(_5\) and MgO during the sintering process. The diffraction intensities of Y\(_3\)Al\(_5\)O\(_{12}\) and MgNb\(_2\)O\(_6\) increase (Fig. 1a–c and Fig. 2a–c) with increasing the addition amounts of Y\(_2\)O\(_3\) or Nb\(_2\)O\(_5\) from 2.5 wt% to 7.5 wt%. The XRD patterns also show that the peaks of MgO and Al\(_2\)O\(_3\) phases disappeared after sintering, which means that MgO and Al\(_2\)O\(_3\) were fully consumed to completely form MgAl\(_2\)O\(_4\) during the sintering. In all the MA–YAG and MA–MN samples with Y\(_2\)O\(_3\) or Nb\(_2\)O\(_5\) additions, the intensity of MA is almost constant, and MA is always the main crystalline phase.

Fig. 1. XRD patterns of the MgAl\(_2\)O\(_4\)–Y\(_3\)Al\(_5\)O\(_{12}\) ceramics with various amounts of Y\(_2\)O\(_3\) sintered at 1580 °C for 4 h.
Fig. 2. XRD patterns of the MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics with various amounts of Nb$_2$O$_5$ sintered at 1580 °C for 4 h.

Addition amounts of Nb$_2$O$_5$

(c) 7.5wt%  s-MgAl$_2$O$_4$  n-MgNb$_2$O$_6$

(b) 5.0wt%  s-MgAl$_2$O$_4$  n-MgNb$_2$O$_6$

(a) 2.5wt%  s-MgAl$_2$O$_4$  n-MgNb$_2$O$_6$

10 20 30 40 50 60 70
Intensity (a.u.)

Fig. 2. XRD patterns of the MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics with various amounts of Nb$_2$O$_5$ sintered at 1580 °C for 4 h.

The chemical reactions between MgO and Al$_2$O$_3$, Y$_2$O$_3$ and Al$_2$O$_3$ as well as MgO and Nb$_2$O$_5$ to synthesize MgAl$_2$O$_4$, Y$_3$Al$_5$O$_{12}$ and MgNb$_2$O$_6$ are shown in Eqs. (5) – (7). The expression between standard Gibbs free energy ($\Delta G^\circ$) and temperature ($T$, K) for reaction (5) is as below [33].

\[
\begin{align*}
\text{MgO(s) + Al}_2\text{O}_3(s) &= \text{MgAl}_2\text{O}_4(s) \quad (5) \\
\Delta G^\circ_2 (\text{J} \cdot \text{mol}^{-1}) &= -35600 - 2.097 (\text{K}) \\
3\text{Y}_2\text{O}_3(s) + 5\text{Al}_2\text{O}_3(s) &= 2\text{Y}_3\text{Al}_5\text{O}_{12}(s) \quad (6) \\
\text{MgO(s) + Nb}_2\text{O}_5(s, l) &= \text{MgNb}_2\text{O}_6(s) \quad (7)
\end{align*}
\]

In this study, the sintering temperature of the MA–YAG and MA–MN ceramics was set as 1580 °C ($T=1853 \text{ K}$), therefore $\Delta G^\circ$ is calculated as $-39472.77 \text{ J} \cdot \text{mol}^{-1}$. It reveals that the thermodynamic requirement for synthesizing MgAl$_2$O$_4$ from MgO and Al$_2$O$_3$ is fully satisfied.

3.2. Microstructures and element distributions

Fig. 3 shows SEM images of as-fabricated MA–YAG ceramics with 2.5 wt%–7.5 wt% Y$_2$O$_3$ additions sintered at 1580 °C for 4 h. It can be clearly seen that the microstructures of fabricated MA-YAG consist of coarse granular particles, fine spherical particles, and remarkable porosities. SEM-EDS analysis, shown in Fig. 4, indicates that the coarse granular particles are MgAl$_2$O$_4$ (MA) particles with the average grain size around 5 μm, and fine spherical particles are Y$_3$Al$_5$O$_{12}$ (YAG) particles with the average grain size around 1 μm. Combined with XRD patterns shown in Fig. 1, the formation of Y$_3$Al$_5$O$_{12}$ (YAG) particles can be concluded is due to high temperature chemical reaction between Y$_2$O$_3$ and Al$_2$O$_3$. It should be noted that the Mg element shown in Fig. 4 comes from MA particles due to fine YAG particle size. During EDS analysis, the spot size of electron beam may greater than 1 μm in dimension, which is greater than the YAG particles size (1 μm approximately), leading to the detection of Mg signal in the surrounded larger MA particles. The amount of YAG particles increases with increasing the addition amounts of Y$_2$O$_3$ ranging from 2.5 wt% to 7.5 wt% (Fig. 3a–c), and YAG particles mainly distribute in the intergranular spaces of MA particles.
Fig. 3. SEM images of the MgAl$_2$O$_4$–Y$_3$Al$_2$O$_{12}$ ceramics with additions of (a) 2.5wt%, (b) 5.0wt% and (c) 7.5wt% Y$_2$O$_3$ sintered at 1580 °C for 4 h.

Fig. 4. EDS spectrums of zones A, B and C shown in Fig. 3 (a) zone A, (b) zone B and (c) zone C.
Figs. 5 show SEM images of as-formed MA–MN ceramics with 2.5 wt% – 7.5 wt% Nb$_2$O$_5$ additions sintered at 1580 °C for 4 h. It can be observed that the microstructures of MA–MN ceramics with different Nb$_2$O$_5$ additions all consist of large MA grains (dark gray phases), fine spherical grains growing on the MA grains surfaces and small rod-like grains in the intergranular spaces (bright phases). However, there is no obvious porosity existing in the microstructures of MA–MN ceramics. SEM-EDS analysis results shown in Fig. 6 reveal that the fine spherical grains and rod-like grains have the same chemical compositions and the chemical formula is considered as MgNb$_2$O$_6$ with combination of XRD results shown in Fig. 2. The length of rod-like MgNb$_2$O$_6$ grains can be as long as 10 µm.

![SEM images of the MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics](image)

**Fig. 5.** SEM images of the MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics with additions of (a) 2.5 wt%, (b) 5.0 wt% and (c) 7.5 wt% Nb$_2$O$_5$ sintered at 1580 °C for 4 h.
3.3. Sintering properties

Fig. 7 shows diameter shrinkage ratio and volume shrinkage ratio of as-fabricated MA–YAG and MA–MN ceramics sintered at 1580 °C for 4 h. It is clearly observed that the samples added with 2.5 wt% – 7.5 wt% Y$_2$O$_3$ or Nb$_2$O$_5$ all have high shrinkage ratios. For the MA–YAG samples (Fig. 7a), with increasing the addition amounts of Y$_2$O$_3$ from 2.5 wt% to 7.5 wt%, the diameter shrinkage ratio and volume shrinkage ratio gradually decrease until 5 wt% and then slightly increase. When 2.5 wt% Y$_2$O$_3$ was added, the diameter shrinkage ratio and volume shrinkage ratio of sample achieve their maximum values of 9.63 % and 25.67 %, respectively. For the MA–MN samples with additions of Nb$_2$O$_5$ from 2.5 wt% to 7.5 wt% (Fig. 7b), the diameter shrinkage ratio and volume shrinkage ratio remarkably increase until 5 wt% and then slightly decrease, and they achieve their maximum values when 5.0 wt% Nb$_2$O$_5$ was doped, and they are 12.33 % and 32.19 %, which are higher than those of the Y$_2$O$_3$-doped samples (Fig. 7a). It also can be seen from Figs. 7a and b that for the samples with additions of 2.5 wt% – 7.5 wt% Y$_2$O$_3$ or Nb$_2$O$_5$, the minimum values of diameter shrinkage ratio and volume shrinkage ratio are still high. It indicates that introducing proper amounts of Y$_2$O$_3$ or Nb$_2$O$_5$ favor the sintering densification of MA–YAG and MA–MN ceramics.

![Fig. 7](image-url)

**Fig. 7.** Change curves of shrinkage ratios of MgAl$_2$O$_4$–Y$_3$Al$_5$O$_12$ and MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics sintered at 1580 °C for 4 h versus addition amounts of (a) Y$_2$O$_3$ and (b) Nb$_2$O$_5$. 

Fig. 6. EDS spectrums of zones A, B, C and C’ shown in Fig. 5 (a) zone A, (b) zone B, (c) zone C and (c’) zone C’.
Fig. 8 shows change curves of bulk density as-fabricated MA–YAG and MA–MN ceramics sintered at 1580 °C for 4 h. It can be clearly seen that the bulk density of samples slightly decreases with increasing the addition amounts of Y$_2$O$_3$, and when 2.5 wt% Y$_2$O$_3$ was added, the density gets its maximum value of 2.85 g cm$^{-3}$. For the Nb$_2$O$_5$-doped samples, the density increases from 2.79 to 3.14 g cm$^{-3}$ with increasing the amounts of Nb$_2$O$_5$ from 2.5 to 5.0 wt%. When 7.5 wt% Nb$_2$O$_5$ was added, then density decreases to 3.02 g cm$^{-3}$. Moreover, the maximum density of the Nb$_2$O$_5$-doped sample is about 0.1 times higher than that of the Y$_2$O$_3$-doped sample. To some extent they formed $Y_3$Al$_5$O$_{12}$ and MgNb$_2$O$_6$ particles occupy the grain boundaries (Figs. 3 and 5), inhibiting the grain growth of MA, and thereby further improve the density of MA–YAG and MA–MN ceramics.

![Graph showing change in bulk density](image)

**Fig. 8.** Change curves of bulk density of MgAl$_2$O$_4$–$Y_3$Al$_5$O$_{12}$ and MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics sintered at 1580 °C for 4 h versus addition amounts of Y$_2$O$_3$ and Nb$_2$O$_5$.

### 3.4. Cold compressive strength

Fig. 9 shows change curves of cold compressive strength of as-fabricated MA–YAG and MA–MN ceramics sintered at 1580 °C for 4 h. It can be clearly observed that the strength values of the samples by additions of 2.5 wt% – 7.5 wt% Y$_2$O$_3$ are all higher than Nb$_2$O$_5$-doped samples, and the maximum strength is 253.2 MPa at the addition of 5.0 wt% Y$_2$O$_3$. For the Nb$_2$O$_5$-doped samples, the strength increases from 115.70 to 157.9 MPa when increasing the amounts of Nb$_2$O$_5$ from 2.5 wt% to 5.0 wt%. However, the strength decreases to 147.1 MPa when the addition amount of Nb$_2$O$_5$ was further increased to 7.5 wt%. Moreover, the maximum strength of the Y$_2$O$_3$-doped sample is about 0.6 times higher than that of the Nb$_2$O$_5$-doped sample, and it is also higher than that of the MA-SmAlO$_3$ ceramics added with 7.5 wt% Sm$_2$O$_3$ and sintered at 1580 °C for 4 h [20].
Fig. 9. Change curves of cold compressive strength of MgAl$_2$O$_4$–Y$_3$Al$_5$O$_{12}$ and MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics sintered at 1580 °C for 4 h versus addition amounts of Y$_2$O$_3$ and Nb$_2$O$_5$.

During the preparation processes of MA–YAG and MA–MN ceramics, Y$_3$Al$_5$O$_{12}$ and MgNb$_2$O$_6$ can be formed from Y$_2$O$_3$ and Al$_2$O$_3$ as well as Nb$_2$O$_5$ and MgO (Figs. 1 and 2). They possibly play a part role in increasing the cold compressive strength of the ceramics. In our future work, it will be necessary to perform detailed research and characterization to fully understand the mechanism on how to increase the strength due to the additions of Y$_2$O$_3$ or Nb$_2$O$_5$.

It can be concluded from Figs. 7–9 that proper addition amounts of Y$_2$O$_3$ or Nb$_2$O$_5$ are both favorable for improving the diameter shrinkage ratio, volume shrinkage ratio, bulk density and cold compressive strength of MA–YAG and MA–MN ceramics.

4. Conclusions

1. MgAl$_2$O$_4$–Y$_3$Al$_5$O$_{12}$ and MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics with high density were successfully fabricated at 1580 °C for 4 h via the single-stage reaction sintering process.

2. MgAl$_2$O$_4$ and Y$_3$Al$_5$O$_{12}$ particles in the MgAl$_2$O$_4$–Y$_3$Al$_5$O$_{12}$ ceramics exist as granular shape, and their average grain size is about 1 μm and 5 μm, respectively. Y$_3$Al$_5$O$_{12}$ is formed due to the reaction between Y$_2$O$_3$ and Al$_2$O$_3$, and they distribute on the intergranular space of MgAl$_2$O$_4$ particles.

3. Polygonal MA particles can be observed in the MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics. MgO reacted with Nb$_2$O$_5$ to form MgNb$_2$O$_6$, and they are mainly present in the intergranular space of MgAl$_2$O$_4$ particles as well as on MgAl$_2$O$_4$ particles. When 7.5 wt% Nb$_2$O$_5$ was added, rod-like MgNb$_2$O$_6$ grains can be formed in the MA–MN ceramics.

4. The sintering properties and post-sintering properties of MgAl$_2$O$_4$–Y$_3$Al$_5$O$_{12}$ and MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics are greatly improved by introducing proper amounts of Y$_2$O$_3$ or Nb$_2$O$_5$. The MgAl$_2$O$_4$–Y$_3$Al$_5$O$_{12}$ ceramics with addition of 2.5 wt% Y$_2$O$_3$ achieve the maximum values in diameter shrinkage ratio, volume shrinkage ratio and bulk density, 9.63 %, 25.67 %, 2.85 g cm$^{-3}$ and 209.4 MPa, respectively, and the maximum cold compressive strength is 253.2 MPa when 5.0 wt% Y$_2$O$_3$ was doped. The MgAl$_2$O$_4$–MgNb$_2$O$_6$ ceramics by
addition of 5.0 wt% Nb$_2$O$_5$ get their maximum diameter shrinkage ratio, volume shrinkage ratio, bulk density and compressive strength, 12.33 %, 32.19 %, 3.14 gcm$^{-3}$ and 157.9 MPa.

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5. References


Садржај: Керамике MgAl₂O₄ (MA)–Y₃Al₅O₁₂ (YAG) и MA-MgNb₂O₆ (MN) велике густине су успешно синтетисане током једноставног синтеровања у чврстој фази на 1580 °C током 4 h. Испитивани су ефекти додатка Y₂O₃ или Nb₂O₅ од 2.5 wt% до 7.5 wt% на фазни састав, микроструктуру, скупљање, порозност, густину и отпорност на притисак керамика MA–YAG и MA–MN. Утврђено је да MgO и Y₂O₃ реагују са Al₂O₃ да би формирали MA и YAG током синтеровања, док Nb₂O₅ реагује са MgO да би формирао MN. Зрна YAG и MA у MA–YAG керамичи поседују грануларни облик, а просечна величина зрна је око 1 μm и 5 μm, истим редом. YAG зрна се распоређују на унутрашњу границу зрна MA. Полигоналне честице MA су уочљиве у MA–MN керамичи, и зрна MN се такође распоређују на унутрашњу границу зрна MA. Шипкаста зrna MN могу да се формирају у MA–MN керамичи са додатком 7.5 wt% Nb₂O₅. Скупљање, густина и отпорност на притисак керамика MA–YAG и MA–MN су значајно побољшане додатком Y₂O₃ и Nb₂O₅, истим редом.

Кључне речи: оксидна керамика; MgAl₂O₄, Y₂O₃; Nb₂O₅; реакциона синтеровање; денсификација; чврстоћа.

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