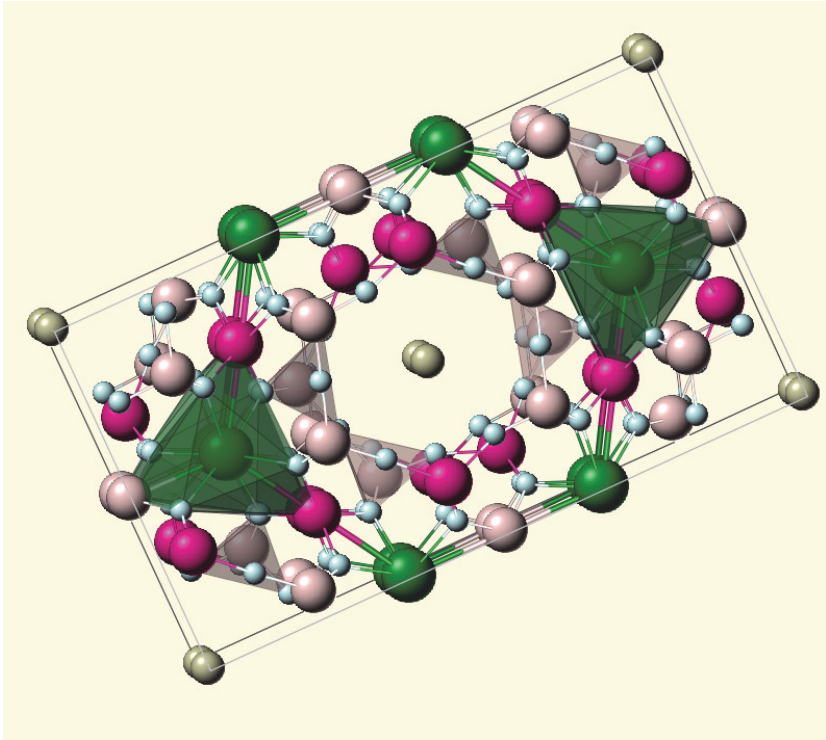


Dr. Nina N. Obradović

Synthesis of Cordierite-Based Ceramics

-Monograph-



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Preface

For about fourteen years, the author has been deeply involved in the research related to the sintering of various materials and during the last six years devoted to the sintering of cordierite-based ceramics. The objective of this monograph is to present the accumulated experience in one volume, which can serve as a basis for the future research in the field as well as a reference for practitioners.

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Belgrade, July 2016.

Author



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1. Introduction

Advanced ceramic materials include a large number of new materials, which are very different by their nature. These materials are the result of the demands of modern technologies for operation at high temperatures and pressures. Modern ceramic materials, opposite to classical ones, are materials with a clearly defined composition and structure, with optimal mechanical, thermal, chemical, and electrical properties, suitable for a specific purpose in accordance with the requirements of modern technologies.

Cordierite-based ceramics, with the basic chemical composition of $\text{MgO-Al}_2\text{O}_3\text{-SiO}_2$, are widely used in various fields, from substrates for micro-electronic packaging industry to cookware, heat exchangers, glazes for floor tiles, etc. Owing to their low-temperature thermal expansion coefficient and low relative dielectric constant, these ceramic materials are also well-known by their good thermo-mechanical, chemical, and dielectric properties. Therefore, they can be applicable as materials exposed to sudden temperature changes and also as semiconductor carriers.

In this monograph, modern principles of the synthesis of cordierite-based ceramics are discussed. They start from the analysis of single, binary, and ternary systems, followed by properties of cordierite-based ceramics, principles of mechanochemistry and mechanical activation as a method for powder preparation, sintering as a method of obtaining the ceramics, possible processes for obtaining cordierite-based ceramics, and finally, presents the author's latest results, which are thoroughly commented. At the end, a short overview is given and some future trends are discussed, as well.

2. Phases in MgO-Al₂O₃-SiO₂ system

2.1. Magnesium oxide (MgO) phase

Magnesium oxide is commonly obtained by metal oxidation or by heating of oxide compounds, such as magnesium hydroxide or magnesium carbonate [1]. Caustic MgO, which is used for obtaining of magnesium cement and ordinary cement, is obtained after annealing at 800–900 °C. An oxide is produced after heating at 1600–1700 °C, to be used for the manufacturing of refractory bricks [2]. Sintered MgO in the form of a fine powder is added to most oxide ceramics, which are used in electronics, because it has good thermal conductivity and is an extremely good electrical insulator. MgO itself accelerates and controls crystal growth and the process of sintering. Magnesium oxide has a cubic crystal structure of sodium chloride, and possesses an ionic bond. The molecular weight of MgO is 40.304 gmol⁻¹, with the theoretical density of 3.6 gm⁻³. Its melting temperature is 2830 °C.

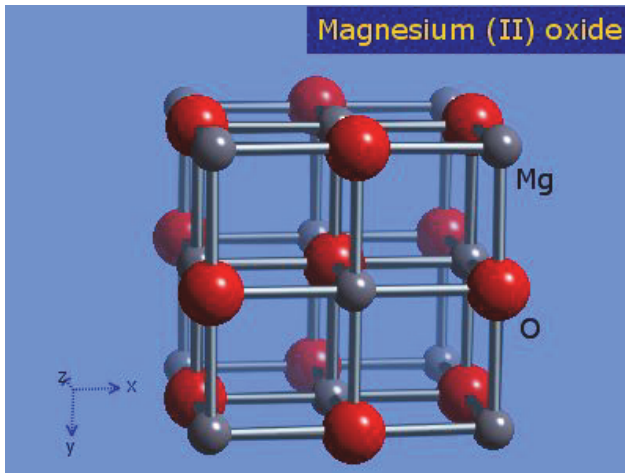


Figure 1. Crystal structure of MgO [3].

2.2. Aluminum oxide (Al₂O₃) phase

Aluminum oxide is a chemical compound of aluminum and oxygen with the chemical formula Al₂O₃. It is the most common occurrence of several aluminum oxides, and specifically identified as aluminum (III) oxide [4]. It is commonly called alumina. It occurs naturally in its crystalline polymorphic phase α -Al₂O₃ as the mineral corundum, varieties of which form the precious

gemstones ruby and sapphire. Al_2O_3 is an electrical insulator, but it has a relatively high thermal conductivity ($30 \text{ Wm}^{-1}\text{K}^{-1}$) for a ceramic material. Aluminum oxide is insoluble in water. In its most commonly occurring crystalline form, called corundum or α -aluminum oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools. The molecular weight of Al_2O_3 is $101.961 \text{ gmol}^{-1}$, with the theoretical density of 4.0 gcm^{-3} . Its melting temperature is $2054 \text{ }^\circ\text{C}$.

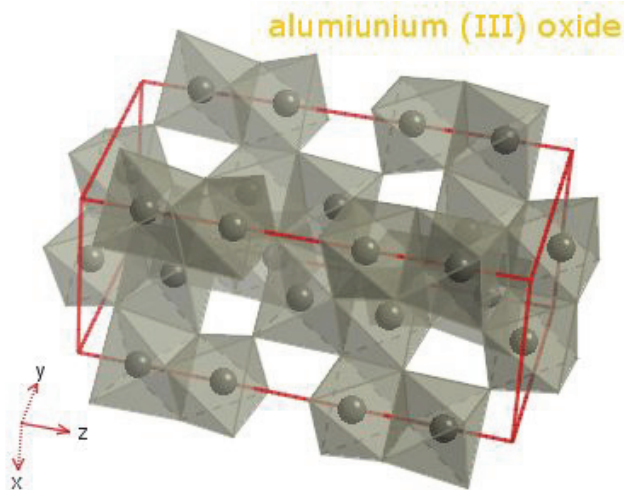


Figure 2. Crystal structure of Al_2O_3 [3].

2.3. Silicon dioxide (SiO_2) phase

Silicon dioxide, also known as silica, is a chemical compound that is an oxide of silicon with the chemical formula SiO_2 . Silica is most commonly found in the nature as quartz, as well as in various living organisms [5]. In many parts of the world, silica is the major constituent of sand. Silica is one of the most complex and most abundant families of materials, existing both as several minerals and being produced synthetically. Notable examples include fused quartz, crystal, fumed silica, silica gel, and aerogels. Applications range from structural materials to microelectronics and components used in the food industry. Silicon dioxide is mostly obtained by mining and purification of quartz. Quartz comprises more than 10 % by mass of the Earth's crust. This product is suitable for many purposes, while for others chemical processing it is required to make a purer or otherwise more suitable (e.g., more reactive or fine-grained) product. The molecular weight of SiO_2 is 60.084 gmol^{-1} , with the theoretical density of 2.533 gcm^{-3} . Its melting temperature is $1710 \text{ }^\circ\text{C}$ (via transformations starting at $867 \text{ }^\circ\text{C}$ to different silica forms).

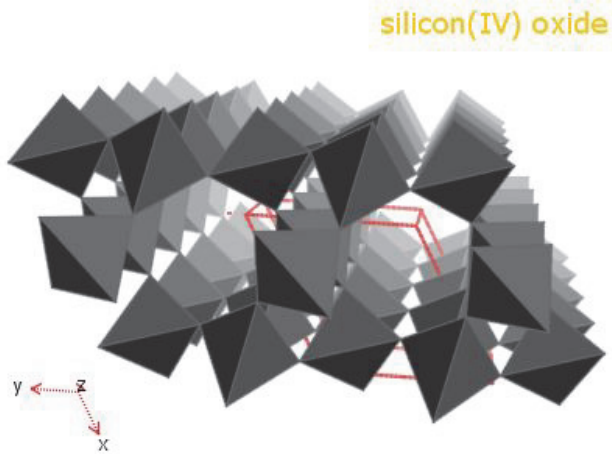


Figure 3. Crystal structure of SiO₂ [3].

Quartz is characterized by a complex polymorphism. Its modifications are α - and β -quartz, α -, β -, and γ -tridymite, and α - and β -cristobalite. Basic modifications could be generally divided into two categories: the first category modifications (quartz, tridymite, and cristobalite) and the second category modifications (α -, β -, and γ -). FCM transformations from one into another modification are very slow, and usage of mineralizators is necessary for its acceleration. SCM transformations from one into another modification are very fast along with negligible changes within the crystal lattice.

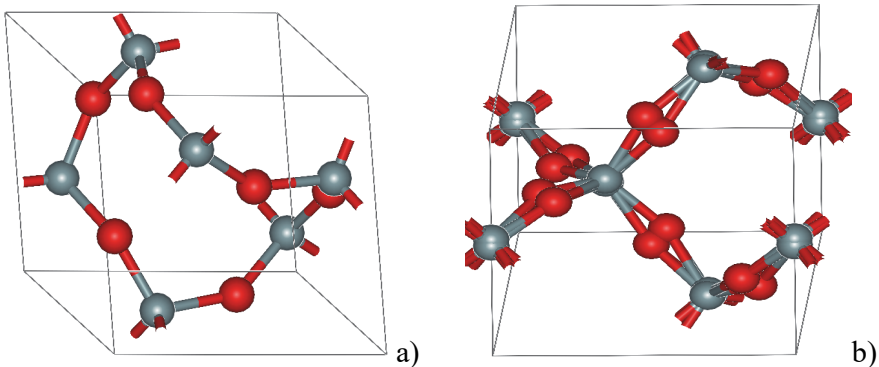


Figure 4. Crystal structures of (a) α -quartz, and (b) β -quartz [5].

The modification of β -quartz is stable at lower temperatures, while α -quartz exists at higher temperatures. The transition temperature from β - to α - is 573 °C. The modification of α -quartz possesses rhombohedral crystal symmetry, with a density of 2.648 gcm⁻³; β -quartz possesses hexagonal crystal