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Thermal plasma synthesis of SiC nano-powders/nano-fibers

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Abstract

Thermal plasma synthesis of nano-powders/nano-fibers is a relatively new technology with great potential for future application in industries. The paper presents the effects of molar ratio on synthesis of SiC by thermal plasma technology. The experimental results show that SiC can be synthesized by thermal plasma technology. The average size of SiC powders is less than 100 nm and SiC fiber-like microstructure were observed.

Keywords: A. Carbides; A. Nanostructures; B. Chemical synthesis

1. Introduction

Silicon carbide is one of the most important non-oxide ceramic materials which are produced on a large scale in the form of powders, molded shapes and thin film [1,2]. It has wide industrial application due to its excellent mechanical properties, high thermal and electrical conductivity, excellent chemical oxidation resistance, and it has potential application as a functional ceramic or a high temperature semiconductor. The main synthesis method of SiC is a carbothermic reduction known as the Acheson process. The general reaction [2] is:

$$SiO_2 + 3C \rightarrow SiC + 2CO(g) \quad (1)$$

A conventional method for the synthesis of pure SiC powders involves many steps and is an energy-intensive process. Further, the SiC particle size is relatively coarse [3]. It is well known that materials with fine microstructures exhibit markedly improved properties without change in their physical appearance. These characteristics include improved strength, stiffness, wear resistance, fatigue resistance and lower ductility and toughness. A great variety of alternate methods like sol–gel [4], plasma [5], laser [6] and microwave [3] have been reported in the literature for the synthesis of fine SiC powders. Nanoscale SiC fibers have important potential applications in nanoelectronics, field emission devices and nanocomposites [7], therefore, efforts have been made by many research groups to fabricate SiC nano-fibers by methods like carbon nano-tubes (as the template) confined reactions [8,9], catalyst assisted chemical vapor deposition (CVD) via the vapor–liquid–solid (VLS) mechanism [10] and template/catalyst-free processes [11]. These methods involve multi-steps and have the difficulty in establishing commercial viability.

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Among the advantages of thermal plasma processing (TPP) techniques in the synthesis of powders are high enthalpies to vaporize all reactants to monatomic gaseous state and to enhance the reaction kinetics by several orders of magnitude, and a clean reaction atmosphere which is required to process high-purity products. Owing to the impurity-free environment and the rapid quenching that is achievable in a plasma reactor, plasma-processing technique ensures synthesis of clean and ultrafine metal, ceramic or composite powders. This is a very suitable method to synthesize refractory materials, such as carbides and nitrides, which are commonly used in high temperature applications. In the thermal plasma processing of nano-powders, the high enthalpy of thermal plasma is used to generate high-density vapor-phase precursors which are then quenched rapidly for synthesis of nano-powders. Due to shock quenching, the supersaturation of vapor species enhances the driving force for particle nucleation to lead to the production of ultrafine particles (down to nanoscale size) by homogeneous nucleation. Several investigations [5,12–15] on the thermal plasma synthesis of metals, ceramics, or composites in the recent past have confirmed that thermal plasma synthesis is one of the most promising methods for producing nano-powders that have high potential in the aerospace industry.

The paper reports the effects of molar ratio on synthesis of SiC nano-powders. The experimental results confirmed that SiC can be synthesized by thermal plasma technology. SEM and TEM observations show that the product is the mixture of nano-powders and fiber-like structure.

2. Experimental setup

The experimental setup of plasma unit includes water cooling system, plasma generating system, thermal plasma reactor, particle feeder system and data acquisition system. The reactor utilizes a non-transferred PT-50C plasma torch (with a maximum power of 45 kW).

Fig. 1 shows the photograph and a schematic diagram of the thermal plasma reactor, which consists of three zones: (i) the combustion/synthesis/reaction zone, (ii) the quenching zone and (iii) the collection zone. Outer shell of the reactor is made of 316 L stainless steel. A graphite tube is used for lining inside the reactor and is insulated with several layers of alumina felt placed between the graphite tube and the inner wall of the water-cooled reactor. The quenching chamber consists of two cone-shape water-cooled copper quenching tubes. Two cone-shaped copper tubes cool the outgoing gas to temperatures in the range of 100–160 °C. The collection chamber has a cloth filter to collect product powders at the exit. The experimental procedure was described in detail in one earlier publication [13].

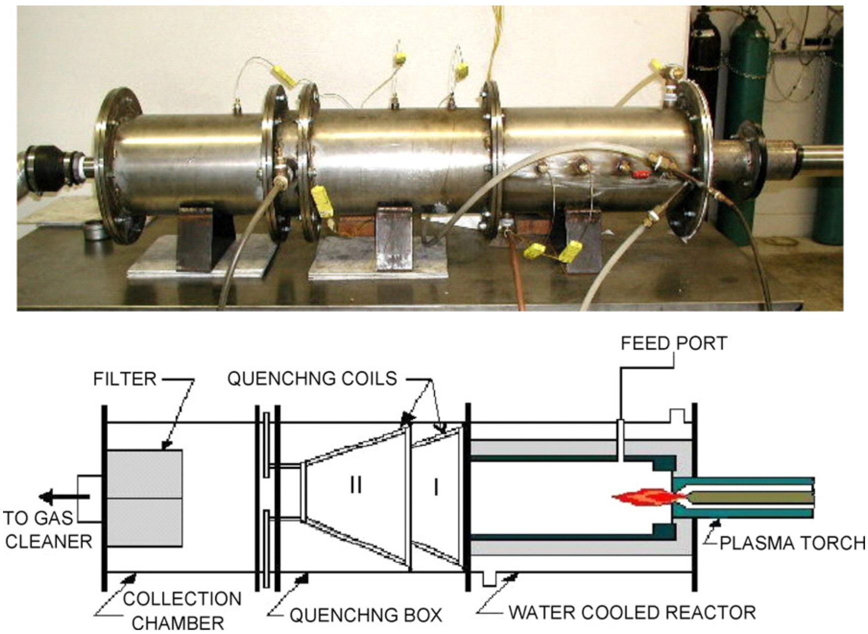

Fig. 1. The photograph and a schematic of the thermal plasma reactor [16].