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Original Research Paper

Influence of carbon precursors on thermal plasma assisted synthesis of SiC nanoparticles

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ABSTRACT

Nanosized SiC was synthesized by solid state method using silicon and carbon powders followed by non-transferred arc thermal plasma processing. X-ray diffraction (XRD) analysis revealed that activated carbon has highest reactivity while graphite has lowest activity in the crystallization of SiC through solid state method. The reactivity was dependent on surface area of carbon source and activated carbon with highest surface area (590.18 $m^2 g^{-1}$) showed highest reactivity, whereas graphite with least surface area (15.69 $m^2 g^{-1}$) showed lowest reactivity. The free silicon content was decreased with increasing reaction time as well as carbon mole ratio. Scanning electron microscope (SEM) study showed that the shape and size of synthesized SiC depends on the shape and size of carbon source. SiC nanoparticles within 500 nm were formed for carbon black while bigger particles (~5 μm) were formed for activated carbon and graphite. Plasma processing of these solid–solid synthesized SiC resulted into the formation of well dispersed, ultrafine SiC nanoparticles (30–40 nm) without any structural modification. Thermal plasma processing resulted into the increase in crystallite size of SiC.

1. Introduction

Silicon carbide (SiC) is one of the most important non-oxide ceramic materials. The phenomenal properties of SiC such as high temperature hardness, wear resistance, low thermal expansion coefficient, high thermal conductivity, strong corrosion resistance, high stability in aggressive environment, and chemical inertness makes it applicable in various field such as turbine blades, diesel engine parts, and nuclear reactor materials [1,2]. Recently, nanosized SiC has been widely investigated to examine their mechanical, physical, and chemical properties that are different from those in bulk forms and often useful [3–6]. For example, nanopowders primarily due to the higher specific surface areas and surface activities can provide the low-temperature sinterability of nanosized SiC in the consolidation processing and the improvement of mechanical properties by making it possible to reach high densities. Therefore, many researchers focusing on the synthesis of nanosized SiC particles. The majority of SiC is produced by the Acheson process, which is based on carbothermal reduction [7]. In addition many methods could be used to produce SiC powders, such as sol–gel methods, gas-phase reaction method and self propagation high-temperature synthesis (SHS) [8–11]. These processes have their merits and limitations over the others such as cost of precursors they use or the lower reaction temperature and the higher purity of the obtained product. Most of these methods optimized to synthesize nanosized SiC particles. However, it is important to note that the properties of nanoparticles can be effectively used by controlling the crystallinity, surface properties, the homogeneity of crystallite size and chemical composition. For example, a high sintering temperature of 1850 °C causes the grain growth of SiC, leading to the lower mechanical properties [12]. Therefore, it is important to develop a process for synthesis of nanosized SiC with high crystallinity, uniform particle size distribution, homogeneity of crystallite size, chemical composition and high thermal stability towards grain growth. Recently, a thermal plasma processing technique has been developed for the preparation of nanosized SiC powders [13–17]. A thermal plasma process is an excellent process for the preparation of high quality ceramic nanopowders due to its unique characteristics such as high temperature to vaporize all reactants, high chemical activity and rapid quenching to form fine powders, a clean reaction atmosphere that yields high-purity products [17]. Therefore, it is considered as one of

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the most promising methods for industrial applications of producing nanosized powders.

In this study, nanosized SiC is synthesized by solid state method followed by thermal plasma processing. Furthermore, our aim in this study is to develop a cost-effective process for mass production of SiC, to increase the production quantity and to reduce the process cost. For production of SiC from the elementary powders, the major process cost comes from the silicon powder, because carbon powder is not expensive. Moreover, the smaller the particles size of the high-purity powder, the higher the price. Therefore, in this study waste silicon powders produced from grinding process of silicon lump at Neoplant Co Ltd. Company are used to synthesize SiC nanoparticles to determine whether cheaper and larger silicon powders could be used to produce SiC and to reduce the process cost. Furthermore, carbon was shown to substantially influence the rate of reaction, morphology and size of the synthesized SiC [18]. Therefore, the effect carbon sources (carbon black, activated carbon and graphite powder) as the starting materials on the synthesis of SiC are also investigated.

2. Experimental

2.1. Sample preparation

The SiC was synthesized by using Si powders (99.5%; Neoplant Co. LTD.) and three different types of carbon source i.e. carbon black (Vulcon XC-72R), activated carbon (Sigma–Aldrich) and graphite (High purity chemicals).

In a typical procedure different mole ratio of Si and carbon (1/1, 1/1.5, 1/2) were mixed together by using ball mill for 12 h. The mixed powder was placed in a vertical tube furnace and heated at 1200 °C for 2–10 h with 5 °C min^{-1} heating rate in the presence of argon gas (1 L min^{-1}). After completion of the reaction the obtained powder was grinded in agate mortar for further characterization.

2.2. Plasma processing of synthesized SiC powders

Plasma processing was carried out by non-transferred arc thermal plasma reactor as reported in our previous work [13].

2.3. Sample characterization

The crystallographic structures of the solid samples were determined using a XRD (D/Max 2005 Rigaku). Particle size and morphology was investigated by SEM (JSM-5900, JEOL) and transmission electron microscopy (TEM-JEM-2010, JEOL). The surface area was analyzed by Brunauer–Emmett–Teller (BET) surface area analyzer (TriStar, Micromeritics).

3. Results and discussion

Fig. 1 shows the XRD pattern of SiC synthesized by carbon black using different Si/C mole ratio for different reaction time. Fig. 1a is the XRD pattern of SiC synthesized by 1/1 mole ratio of Si/C. From figure, it is clear that pure SiC is not formed and large amount of free silicon remained unreacted even though the reaction is carried out for 10 h. However, the decrease in intensity of Si peak with increasing reaction time indicates that more silicon is converted into SiC. When Si/C mole ratio is increased to 1/1.5 even then pure SiC is not formed when reaction is carried for 2 h. However, with increasing reaction time pure SiC is formed (Fig. 1b). Similar is the case, when 1/2 mole ratio of Si/C is used (Fig. 1c). These results show that complete conversion of Si powder to SiC is achieved only when Si/C mole ratio is higher than one. It means higher mole of carbon compared to silicon is required in solid–solid synthesis of

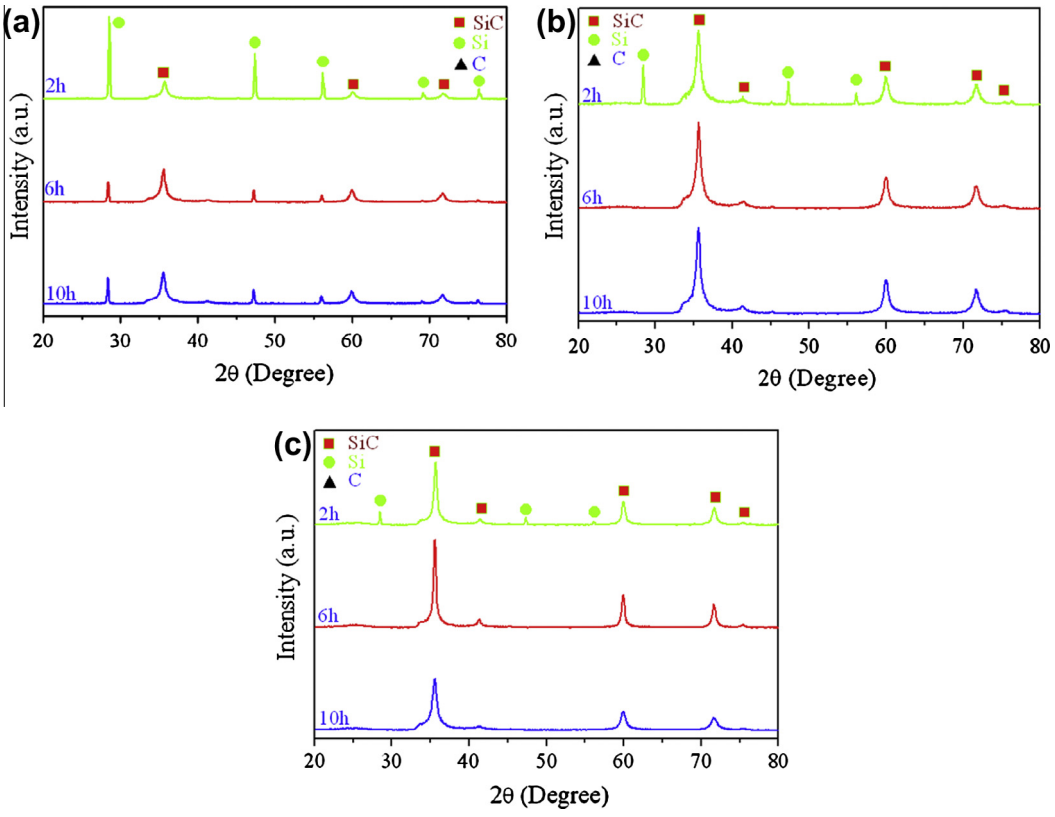

Fig. 1. XRD profiles of SiC synthesized from carbon black (a) Si/C; 1/1, (b) Si/C; 1/1.5 and (c) Si/C; 1:2.