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Comprehensive investigations on the influence of gun current of plasma spraying on the properties of silicon carbide films

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Abstract

Polycrystalline silicon carbide films have been prepared by the gas tunnel type plasma spraying method (GTPS). The effect of gun current on microstructure and mechanical properties was investigated. Scanning electron microscopy, X-ray diffraction, energy dispersive spectroscopy, nanoindentation and abrasive wear were used to characterize the structure, thickness, composition and the mechanical properties of SiC films. Microstructural studies revealed that the formation of cubic silicon carbide (C-SiC) at higher gun currents from 120 to 140 A. The SiC films have good-adhesion, dense, smooth and compact morphology. Hardness of SiC films strongly improved from 23 to 31.5 GPa as the gun current increased from 0 to 140 A. SiC films formed at higher gun current exhibits better wear resistance than that deposited at low gun current, mainly due to SiC films become more hard and more dense. The crystalline cubic silicon carbide films with good morphology and mechanical properties have been obtained from the GTPS method, which makes it a suitable material for high-temperature thermoelectric and mechanical applications.

Keywords: Silicon carbide; Thermoelectric materials; Microstructure; Hardness; Abrasive wear; Gas tunnel type plasma spraying

1. Introduction

Cubic silicon carbide (C-SiC) is receiving great interest chiefly as a wide band-gap semiconductor for high-temperature electronic and optical applications owning to its thermal stability and high resistance to radiation damage. Recently, researchers have been pursuing SiC as a material for high-temperature microsensors and microactutors applications [1]. The high-temperature capability of SiC combined with its excellent mechanical properties, thermal dissipative characteristics, chemical inertness and optical transparency makes SiC an exceptional choice as a material for high-temperature microelectromechanical (MEM) devices. Most properties of cubic-SiC are consequences of both the very strong covalent bonding between silicon and carbon atoms and the tetrahedral coordination (sp^3-bonding). It exists in several polymorphs that have similar atomic arrangements in plane perpendicular to the symmetry axis but differ from each other in the stacking sequence [2,3]. Mostly, the simplest and most stable structure is the cubic phase (isomorphic to diamond), which is considered to be especially suitable for high-temperature engineering applications. Material properties, like high hardness, low friction and low wear versus metals are essential for this purpose. Although, diamond like carbon is fulfill these requirements but they have limited applications as their microstructure, hence tribological and mechanical properties are strongly changed at high temperature. Doping DLCs with elements such as silicon (up to 30 at.%) should extend their applications to high-temperature environments ($T > 675$ K) [4]. However, there are three major requirements for potential applications: first, the adhesion should be strong and durable because it will be the first limitation to long lasting employment; second, the temperature during film deposition should not be too high in order to prevent detrimental modifications of the bulk substrate properties due to structural changes or excessive chemical reactions in the interface region and third, it is necessary to be of low cost to be viable in most applications.

A variety of techniques are used to grow single and polycrystalline forms of SiC thin films, including atmospheric pressure chemical vapor deposition (APCVD), sputtering, metal–organic CVD, atomic layer epitaxy, molecular beam epitaxy, and pulsed laser deposition (PLD). Each technique has its own merits and limitations. Most of the above methods used for growing of SiC coatings based on chemical vapor deposition. The main

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drawbacks of CVD are slow, relatively expensive, contamination of the films and need for high temperature (>1000 °C), which is an important limitation even for electronic device fabrication [5–9]. Recently, it has been demonstrated that cubic-SiC coating can be grown at lower temperatures (750–800 °C) by means of plasma processes and ion beam techniques [10,11]. Although such method is very promising for producing thin and adherent SiC films of uniform composition, but their thickness (~80 nm) is insufficient for many practical applications.

High power gas tunnel type plasma spraying (GTPS) has been developed [12,13] and is used to achieve efficient melting and good quality films. GTPS has been successfully commercialized in a large scale in preparation of advanced ceramics, like zirconia and alumina, due to its simplicity, inexpensive and low temperature features [14–16]. In our recent investigation [17,18], we have synthesized 2–10 μm thick α-SiC films through GTPS. In the previous work, in an attempt to improve the properties of deposited SiC films we have changed some parameters for instance the vortex current, carrier flow rate and plasma gas composition.

In this study, we studied the effect of gun current of plasma spraying on microstructure and mechanical properties of SiC films prepared by GTPS. The microstructure features of SiC were analyzed using scanning electron microscopy (SEM) with an energy dispersive electron spectroscopy (EDS) and X-ray diffraction (XRD). While, mechanical properties were determined by measuring the microhardness and abrasion wear resistance.

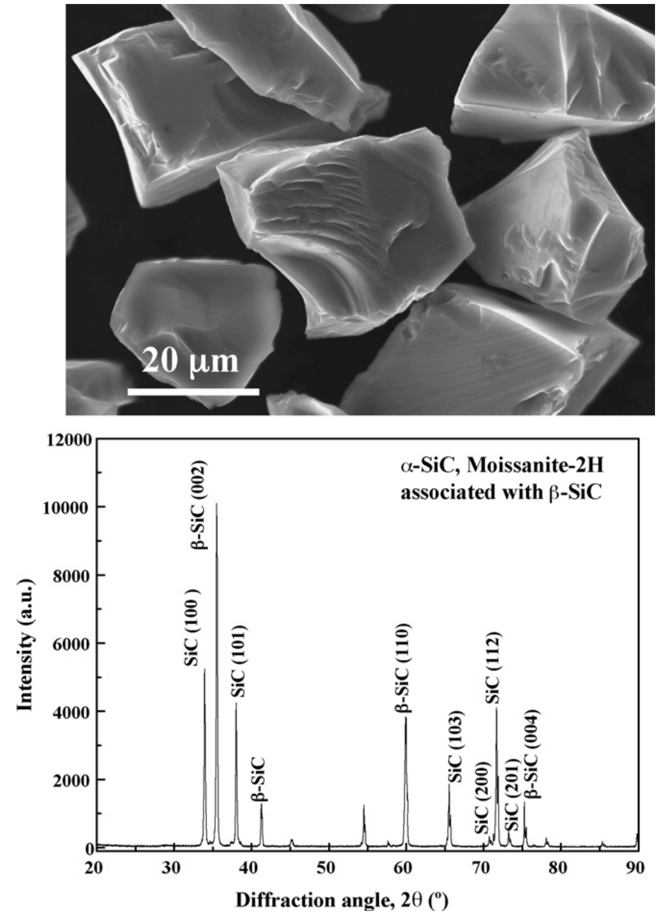

Fig. 1. SEM micrograph and XRD diffraction pattern of feedstock SiC powder.

2. Experimental procedure

2.1. Preparation of SiC films

High purity SiC powder, moissanite-2H, of particle size 20–45 μm was atmospherically plasma sprayed (APS) by using gas tunnel type plasma jet. The morphology and phase structure of the powders are shown in Fig. 1. The chemical composition and purity of the used SiC powder are given in Table 1. The used substrate material is AISI 304 stainless steel with dimensions (50 mm × 50 mm × 3 mm). Before spraying deposition, the substrate was grit blasted using alumina powders to clean and roughen the surface to improve the film adhesion.

SiC films were synthesized using gas tunnel type plasma spray torch that has been previously described [17]. The torch composed of two anodes and one cathode and two power source. The external nozzle diameter is 20 mm and the internal one is 8 mm. The flame diameter is almost 20 mm to melt the majority of the injected powder with high efficiency. SiC powder was internally feed inside the plasma flame stream to get maximum flame temperature because SiC powder has high melting point ≈ 2700 °C. The spraying deposition of silicon carbide was performed under various gun current and the spraying parameters were listed in Table 2.

The deposition efficiency of the spray process and the characteristics of deposited films are strongly influenced by the properties of the starting powders. Powders flowability and sprayability are among the most important parameters. Flowability is a measure of the spraying gun and through the nozzle. Sprayability is strictly correlated to the kinetic and thermal behavior of the single powder granules: too large particles may require too high dwell times within the plasma to attain a uniform temperature and be efficiently molten; small, light particles, on

Table 1
The chemical composition and the purity of the silicon carbide powder

α-SiC (moissanite-2H)	Weight percentage (%)
SiC purity	>97
C	28–30
Si	67–69.5
O	2–2.6

Table 2
Spraying parameters used for the preparation of SiC films

Gun current (A)	0, 80, 100, 120, 140
Dc plasma vortex current (A)	450
Primary gas flow rate, Q (Ar) (l/min)	150
Carrier gas (argon) (l/min)	10
Powder feed rate, w (g/min)	5
Spraying distance, L (mm)	50
Spraying time, t (s)	20
Nozzle diameter (mm)	20
Traverse rate (mm/s)	Nil