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Improvement of nanoparticle filtration efficiency through synthesis of SiC whisker on graphite felt by the VS CVD mechanism

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ABSTRACT

This study examines the synthesis of SiC whisker on graphite felt through the non-catalytic VS CVD (Vapor Solid Chemical Vaporized Deposition) mechanism in order to investigate its potential as a filter to replace the conventional DPF (Diesel Particulate Filer). Since the CVD process is conducted mostly in high temperature exceeding 1000 °C, many restrictions exist in selecting the substrate. Graphite felt is a filter form of non-woven fabric. The graphite felt was selected as a suitable substrate material for this study based on the VS CVD mechanism due to its relatively low cost, high heat resistance, and high flexibility. The appropriate SiC whisker structure of the nanoscale was grown on the graphite felt that exhibited the fore-mentioned characteristics. This enhanced the filtration performance of the bare graphite felt filter more than two times without compromising the gas permeability. Additionally, thermal oxidation resistance was elevated by at least 200 °C more than the bare graphite felt, thereby indicating the transfer of a part of the desirable chemical properties of the SiC.

1. Introduction

Automobiles play important roles in human movement and industrial development. Automobiles are powered by the engine module. Diesel engines are widely used because of their mechanical durability and fuel efficiency. However, the exhaust gases of a diesel engine include COx, also referred to as the carbon oxide compound. This is a major cause of air pollution in recent years. COx is composed of particles with very small sizes ranging from several tens to several hundred nanometers. These particles exist as suspensions in the atmosphere, and they accumulate in the respiratory organs leading to many serious diseases.

In order to regulate diesel vehicle exhaust gases in the EU (European Union), environmental regulations are continuously strengthening from EURO 1 (in 1992) to EURO 6 (in 2013). Additional mounting of DPF on diesel engines is required to meet EURO 6. However, it induces low fuel efficiency and poses a significant burden on manufacturing costs. Additionally, a ceramic honeycomb filter is typically used as a DPF to increase durability against harsh environmental exposures including high temperature, high pressure, and the chemical surrounding the engine system. Nonetheless, this involves a fundamental problem of the trade-off relationship between pore size and gas permeability, structurally.

This study investigates the synthesis of SiC whisker on graphite felt for a next generation filter, to explore the possibilities of a new material and structure. The new filter is expected to improve the various above-mentioned problems of the ceramic DPF currently used in diesel engine. It is also anticipated to simultaneously achieve cost reduction, as using graphite felt as a substrate is relatively inexpensive. In particular, SiC has wide range of applications due to its excellent mechanical and chemical properties, high strength, oxidation resistance, and high-temperature stability [1,2]. Several studies examined SiC as a candidate material for various applications including semiconductor equipment, nuclear reactors, and space aircrafts. Therefore, the application of SiC to the DPF filter SiC holds tremendous potential.

The VLS CVD (Vapor Liquid Solid Chemical Vaporized Deposition) process using metallic catalysts was widely used to synthesize SiC whiskers [3,4]. However, this study adopts a VS CVD Method without a catalyst [5]. In the VS CVD Mechanism, the growth aspect of SiC film or whisker is determined by various deposition conditions, including gas input ratio, temperature, pressure, and total gas flow rate. It is possible to maintain the high mechanical properties of the inherent SiC because of the freedom from the contamination of metal impurities. Thus, well-distributed high-density whisker growth can be induced even inside the substrate through deep penetration of the source gas [6–8].

This discussion indicated that SiC whisker growth on graphite felt is highly suitable for trapping nanoscale particles through the changes in various deposition conditions. Several tests were performed in order to verify its suitability as a high-performance filter.

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Table 1
Deposition conditions for SiC whisker synthesis.

Dilute gas species	Input gas ratio (α)	Pressure (Torr)	Temperature (°C)	Deposition time (min)	Gas flow rate (sccm)	
					MTS	H_2
H_2	2.5–25	1–4	1100, 1200	10–60	40	140–1040

Table 2
Diameter and length range of the whisker grown on graphite felt as deposition time increases (T_{dep} = 1100 °C, α = 40).

Section	Deposition time			
	10 min	20 min	30 min	60 min
Diameter (nm)	90–130	180–210	380–450	480–620
Length (μm)	1.3–1.8	1.5–2.1	2.6–4.3	3.4–4.8

2. Experimental details

2.1. Synthesis of SiC whisker on graphite felt

SiC whiskers were synthesized on a graphite felt substrate consisting of fibers in diameter of 10–30 μm (Grade WDF, National carbon co. Inc., USA) through the VS CVD mechanism by using a horizontal hot-wall furnace. The substrate was cut into samples of size of 15 (W) × 15 (L) × 3 mm (H). The samples were deposited after cleaning with methyl alcohol and DI water.

The chemical reaction of the SiC synthesis was as described in previous studies [2,9–11]. Methyltrichlorosilane (CH_3SiCl_3, MTS, Acros Organics Co., U.S.A) was used as a source, and high-purity hydrogen (H_2) was used as a carrier and diluent gas.

2.2. Morphology characterization

The SiC whiskers were deposited on the graphite felt substrate by varying the deposition conditions of temperature, time, and input gas ratio. The diameters and lengths of whiskers grown on each specimen were measured to observe their growth morphology through SEM (FESEM, JOEL JSM-7001F) microanalysis.

The concept of line density was also introduced from a previous study [12].

The deposition was conducted under the conditions detailed in Table 1. Input gas ratio, α, is defined as the ratio of the total H_2 gas to the MTS source gas (α = H_2/MTS).

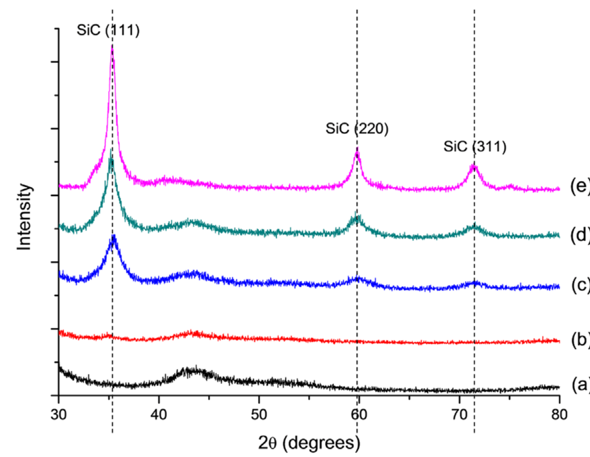

Fig. 2. X-ray diffraction of SiC whisker grown on the carbon felt with increases in the deposition times (T_{dep} = 1100 °C, α = 40): (a) bare carbon felt substrate, (b) 10 min, (c) 20 min, (d) 30 min, and (e) 60 min.

Based on the SEM measurements, the whisker growth model was selected as it was expected to perform better than the other models as a filter application.

The components and X-ray diffraction patterns of the deposited whisker were analyzed by EDX (OCTANE PLUS, AMETEK) and a

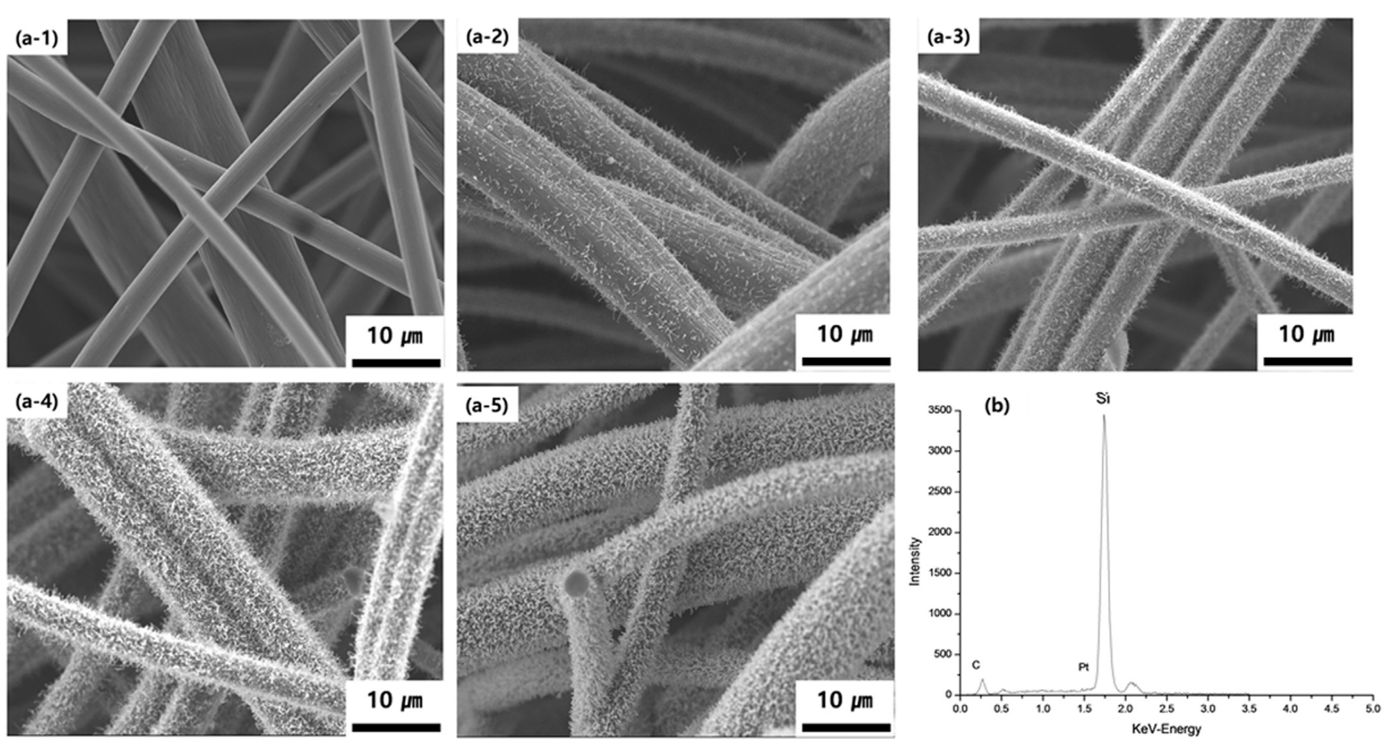

Fig. 1. Morphology of SiC whiskers grown on carbon fibers for various deposition times: (a-1) bare carbon felt, (a-2) 10 min, (a-3) 20 min, (a-4) 30 min, (a-5) 60 min, and component analysis in 60 min deposition time with EDX: (b).