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Development of the geometry of carbon microcoils from carbon nanofilaments

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ABSTRACT

Carbon coils were deposited on a SiO_2 substrate using C_2H_2/H_2 as the source gases and SF_6 as the additive gas using a thermal chemical vapor deposition system. The formation of carbon microcoils was investigated during the deposition of the carbon coils. During the early stage of the reaction, carbon nanofilaments were formed on a specific point on the sample. Further deposition reaction increased the density of carbon nanofilaments. At this step, some of the carbon nanofilaments were observed to have a twin formation, namely, two similar shaped carbon nanofilaments attached to each other. The twin carbon nanofilaments transformed into nanosized wave-like carbon coils with increasing length. After further deposition time, the formation of double helix-type geometry of microsized carbon coils was observed, originating from the nanosized wave-like carbon coils. Based on the investigation of the point of transformation from carbon nanocoils into carbon microcoils, the detailed development of the double helix-type carbon microcoils is proposed and discussed.

1. Introduction

The unique geometry of carbon coils has attracted interest as potential materials for applications in nano/micro mechanics or electronics [1–3]. Recently, a reproducible method for the synthesis of carbon microcoils was achieved by injecting sulfur during the catalytic pyrolysis of acetylene [4]. Sulfur, as an impurity, was generally incorporated in the form of hydrogen sulfide (H_2S), carbon disulfide (CS_2), and thiophene (C_4H_4S) [5–7]. Catalytic chemical vapor deposition (CCVD) process using thermal CVD and a metal catalyst is potentially useful for the preparation of carbon coils because of its relatively low cost and functionality. However, because of the low yield of carbon coils, the CCVD process alone is not suitable for the commercial production of carbon coils. Therefore, there is a need to explore CCVD techniques that are more efficient and reliable. Previously we demonstrated a modified CCVD technique with a flow injection time modulation technique of source gases (C_2H_2/H_2) or an additive gas (SF_6) [8–10]. By using this technique, we could achieve an enhancement in the carbon coil production yield as well as control the geometry of carbon coils.

The growth of the carbon coils, in particular the microsized double helix-type carbon coils synthesized by the addition of sulfur, seemed to follow a quasi-vapor liquid solid (VLS) mechanism [11]. Meanwhile the state of the initial stage during the formation of the carbon coils appeared to play a primary role in determining their geometry. Chen and Motojima reported the growth patterns and the development of morphologies for a reaction time ranging from 5 to 120 min [12]. Furthermore, the development of the carbon coils at the start of the process, namely the preheating stage of the reactor, was reported in our previous work [13]. Despite this body of work, a more detailed and critical investigation is still required to fully understand the formation mechanism of the microsized carbon coils with a double helix-type geometry.

In this work, the development of carbon microcoils was investigated with a focus on the transformation point from carbon nanofilaments into the double helix-type carbon microcoils. SF_6 was chosen as the sulfur-incorporating chemical species because it is a relatively safe material and the fluorine may enhance the nucleation sites of the carbon coils [14]. The reaction process was terminated at an early stage of the process, namely after 1 and 5 min of deposition time and the morphologies of the sample surfaces were investigated in detail. Based on these results, the mechanism of development of the microsized carbon coils from the carbon nanofilaments is proposed and discussed.

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Table 1
Experimental conditions for the deposition of the carbon coils.

Reaction processes	Samples	C_2H_2 flow rate (sccm)	H_2 flow rate (sccm)	SF_6 flow rate (sccm)	Substrate temp (K)	Total pressure (kPa)	Carbon coils deposition time (min)
I	A	15	35	35	1023.15	13.3	1.0
II	B	15	35	35	1023.15	13.3	5.0

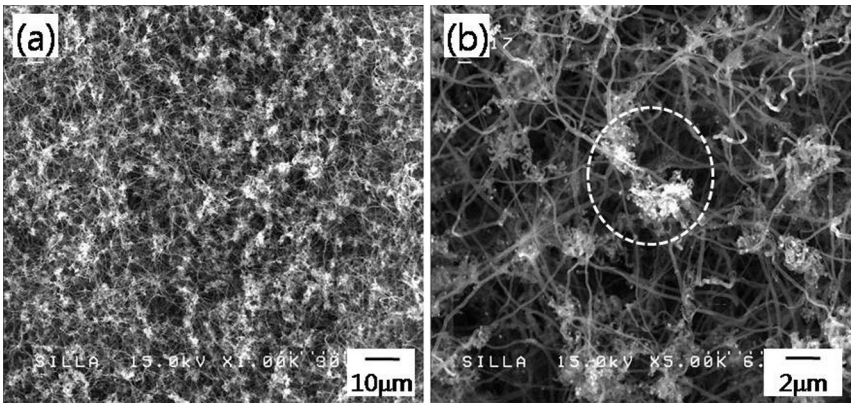

Fig. 1. FESEM images for sample A showing (a) the formation of the carbon nanofilaments on the whole surface area of sample A, and (b) the magnified (5k) image of (a). The area inside of the dotted circle in (b) shows the lumps as well as linear carbon nanofilaments.

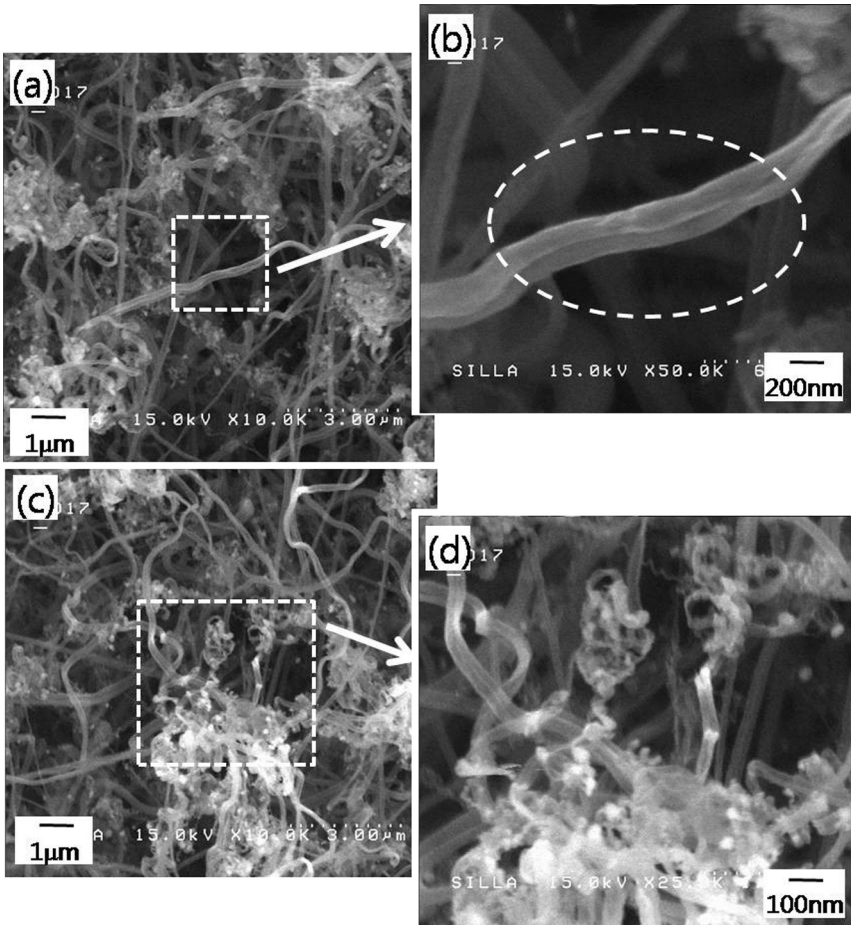

Fig. 2. (a) Magnified (10k) surface image for linear carbon nanofilaments shown in Fig. 1, (b) High (50k) magnification image of the area in the dotted square in (a), (c) Magnified (10k) surface image around the area with lump in (a), and (d) High (25k) magnification image of the area in dotted square in (c).