Effect of substrates on the geometries of as-grown carbon coils

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Abstract: Carbon coils could be synthesized using C_2H_2/H_2 as source gases and SF_6 as an incorporated additive gas under thermal chemical vapor deposition system. The substrate with oxygen incorporation and the substrate without oxygen incorporation were employed to elucidate the effect of substrate on the formation of carbon coils. The characteristics (formation densities, morphologies, and geometries) of the deposited carbon coils on the substrate were investigated. In case of Si substrate, the microsized carbon coils were dominant on the substrate surface. While, in case of oxygen incorporated substrate, the nanosized carbon coils were prevail on the substrate surface. The cause for the different geometry formation of carbon coils according to the different substrates was discussed in association with the different thermal expansion coefficient values between the substrate with oxygen incorporation and the substrate without oxygen incorporation.

1. Introduction

Due to their unique geometry and the chirality, carbon coils have been attracted as the high potential materials for nanoengineering [1-4]. Furthermore, carbon coils was supposed to have unique electrical and optical properties that could be used in nanoelectronics [5-8].

For the practical application of carbon coils, however, it is essential to achieve the large quantity production of carbon coils because carbon coils have been usually found as the low-content by products for the synthesis of multiwalled carbon nanotubes in microwave plasma-enhanced chemical vapor deposition (MW-PECVD) or in thermal chemical vapor deposition (TCVD) [9,10]. Recently, catalytic chemical vapor deposition (CCVD) method has been noticed to enhance the production yield of carbon coils because of its relative inexpensive and applicable feature. Besides the system parameters for CCVD such as the reaction temperature and the gas flow rate, the used metal catalyst, the incorporated additives, and the supported substrate are the important factors for the large quantity production of carbon coils. For the metal catalyst, iron family (Fe, Co, Ni), especially Ni, were known as an effective catalyst for the formation of carbon coils [11, 12]. For the incorporated additives, meanwhile, a trace of the sulfur-related species was regarded as the promising additives for the formation of carbon coils [13]. Supporting substrates seemed to be one of the significant parameters for the formation of carbon coils because the characteristics of the metal catalyst would be affected by the nature of supporting substrate. Consequently, the substrate-influenced metal catalyst could affect the geometry of the as-grown carbon coils. In this respect, the research for the substrate effect on the characteristics of as-grown carbon coils is considered as a primary step for the carbon coils synthesis reaction. It is suggested that turning of carbon morphology can not only take place by changing the CVD conditions (carbon precursor, reaction temperature and time, gas flow rates etc.) but also by appropriately modifying the supporting substrate, the catalyst and the interaction between them. Despite these efforts, further investigation for the effect of the substrate on the formation of carbon coils is still required.

In this work, different substrates were employed to elucidate the effect of substrate on the formation of carbon coils. Based on these results, the cause for this different geometry formation of carbon coils according to the different substrates was discussed.

2. Results and Discussion

For substrate, p-type Si (100) substrates were used. For the oxide substrate, SiO_2 layered Si substrate and Al_2O_3 substrates were employed. A 0.1 mg Ni powder (99.7 %) was evaporated for 1 min to form Ni catalyst layer on the substrate using thermal evaporator. The estimated Ni catalyst layer on the substrate was about 100 nm. For carbon coils deposition, thermal CVD system was employed. C_2H_2 and H_2 were used as source gases. SF_6, as an incorporated additive gas, was injected into the reactor during the initia reaction stage. The flow rate for C_2H_2, H_2, and SF_6 were fixed at 15, 35, and 35 standard cm^3 per minute (sccm), respectively. Detailed morphologies of carbon coils-deposited substrates were investigated using field emission scanning electron microscopy (FESEM, Hitach 4500).

After finishing the deposition reaction (90 min), in case of Si substrate the well-developed microsized carbon coils were mostly observed on the surface of the substrate. The length of the microsized carbon coils is more than ten micrometers. The diameters of the microsized carbon coils are in the range from a few tens nanometers to a few micrometers. In case of SiO_2 substrate, however, the nanosized carbon coils were dominant on the surface of the substrate. Occasionally, the microsized carbon coils were protruded among a lot of the nanosized carbon coils. Several nanosized carbon coils were attached along the side of th emicrosized carbon coils. These results confirm that Si substrate favors the microsized type for the main geometry of as-grown carbon coils.

The different thermal expansion coefficient between the Ni catalyst layer and the different substrates was proposed as the main cause for the geometry change of carbon coils according to the different substrates (Si or SiO_2). The higher difference of thermal expansion coefficient between the metal layer and the substrate may induce the higher stress between them. Consequently, the metal layer will be more easily peeled off and eventually will be broken into very tiny nanosized pieces and scattered in surrounding area. Basically, the mechanism of carbon coils growth was based on the metal size and shape. So, the peeled-off tiny nanosized Ni pieces could be the seed of the nanosized carbon coils. Consequently, the as-grown nanosized carbon coils from the nanosized Ni pieces would depositon the whole surface of the substrate. This is the reason why the density of the nanosized carbon coils from SiO_2 substrate is higher than that from Si substrate.

3. Conclusions

By oxygen incorporation in the substrate, the geometry of carbon coils was changed from th emicrosized type to the nanosized one even under the same experimental condition. The difference of thermal expansion coefficient values between Ni catalyst layer and the substrates was believed to be a main cause for this geometry change.

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